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FOREWORD

The Trans-KARST 2004 conference intends to offer a forum to discuss basic and applied research findings and methodologies which can contribute to the management and development of karst areas. It will help strengthen interest in the preservation of geodiversity, biodiversity and cultural diversity and stimulate communication between researchers, practitioners and policy makers working in karst landscapes. Moreover, it intends to explore ways to integrate natural and social sciences approaches in the management of karst systems.

We have the pleasure to offer you hereby the proceedings of the conference. It contains the extended abstracts of the papers and posters which are presented at the conference. They are in alphabetic order.

We hope you will enjoy the reading and look forward to stimulating discussions.

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STABILIZATION OF KAOLINITIC SOIL FROM VIETNAM FOR CONSTRUCTION PURPOSES BY USING MINERAL POLYMERISATION TECHNIQUE

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Keywords: polymerization, kaolinite, Vietnam, alkalis, aluminosilicates, stabilization.

Mineral Polymerisation Technique (MiP) is a process with which minerals such as clay could be hardened and transformed into useful construction materials (Ingles, 1970) through chemical polymerisation reactions. These mineral polymers are produced at atmospheric pressure and low temperature by using minimal energy input. In this process aluminosilicate kaolinite reacts with alkali at low temperatures and polycondenses into hydroxysodalite, which is a stable and hard material (Patfoort and Wastiels, 1989).

The objective of this paper is to evaluate the quality and suitability of kaolinitic soils from Vietnam for construction purposes, using the mentioned technique. These construction materials should be characterized by their low cost, using low energy resources and using a small amount of alkaline compounds. The primary characteristics of the samples, e.g. chemical composition and clay mineralogy, had been described by the report of Research institute of geology and mineral resource (RIGMR) in Vietnam (Ly ba Tien, 1997; Nguyen Dinh Hop, 1989; Nguyen Ngoc Lien, 1974). Besides that, some descriptions and analyses were carried out in the laboratory in the VUB (Vrije Universiteit Brussel). The specimens were tested under varying conditions, in order to check their physical and mechanical properties, stability and durability. The quality of the specimens is evaluated according to their compression strength (Phan Duc Le, 2000; Nguyen My Linh, 2000).

There are several kaolin deposit locations in the north of Vietnam, which were investigated by the Research institute of geology and mineral resource (RIGMR). The deposit areas are characterised by a tropical monsoon climate. Rainfall is abundant, with annual rainfall exceeding 1000 mm almost everywhere. Rainfall is infrequent and light during the remainder of the year.

For the practical work, soil samples were brought from the Khanh Kaolin mine, which is located in Huu Khanh - Phuc An Village, Tan Phuong- Tam Thanh District, Vinh Phu Province (Coordinate: 21°11’48” Latitude 105°17’ Longitude). The area of the Huu Khanh mine includes many low hills. The slope of the sides varies from 20-25° and there is strong erosion on the top of the hill.

All specimens were made from the following four components: Sodium hydroxide, Water, Kaolintic clay from Vietnam, and fine sand. An alkali solution is an essential source of Sodium ions. These ions attack the lattice of the Kaolinite, such that ion exchange occurs with the hydrogen ions on the broken edges of the clay.

The effect of this ion exchange is repulsion between the large radius Na^+ ions that move the clay particles apart, which has been seen as dispersion in the soil. Actually, the silica in the kaolinite and soil are both being attacked. Sodium silicate and sodium aluminate are produced from this reaction (Gemerts and Mishre, 1989). Sodium hydroxide should be used in small amounts to avoid or at least limit residual alkali in the material and for economical reasons. The medium of the reaction is water, which is used to prepare a sodium hydroxide solution. Afterwards, the solution is added to the mixture of clay and sand. The amount of water influences both the strength of the network that bonds the grains and the workability of the kaolinitic clay from Vietnam. This clay (Huu Khanh kaolin) is the source of aluminosilicate, which is essential for this reaction. The filler in these

Table 1: Specimens composition – (HK)

ID	T (^oC)	R (μm)	Specimens composition; ratios & percentages							
			Clay		Sand		NaOH		Water	
HK1	80	425	100	29.6	200	59.4	15	4.4	22	6.5
HK2	80	425	100	29.5	200	59.0	15	4.4	24	7.1
HK3	80	425	100	29.4	200	58.6	15	4.4	26	7.6
HK4	80	425	100	29.1	200	58.3	15	4.4	28	8.2
HK5	80	425	100	28.9	200	57.9	15	4.4	30	8.8
HK6	80	425	100	28.8	200	57.6	15	4.4	32	9.2
HK7	80	425	100	28.5	200	57.3	15	4.4	34	9.8
HK8	80	425	100	33.9	150	50.85	19	6.44	26	8.11
HK9	80	425	100	31.25	175	54.69	19	5.94	26	8.12
HK10	80	425	100	28.99	200	57.97	19	5.51	26	7.53
HK11	80	425	100	27.03	225	60.81	19	5.13	26	7.03
HK12	80	425	100	44.6	100	44.6	10	4.5	14	6.3
HK13	80	425	100	44.8	100	44.8	11	4.9	12	5.4
HK14	80	425	100	29.5	200	59	13	3.83	26	7.67
HK15	80	425	100	29.15	200	58.31	17	4.96	26	7.58

experiments is fine sand, which has a large effect on the physical stability of the material.

Sixteen series were made from clay (Huu Khanh kaolin), sand, water and NaOH. Each series contained 10 specimens. Table 1 shows the composition and information about these series; T is the curing temperature and R is the maximum aggregate size of the clay after crushing. The NaOH solution was prepared by adding water to the NaOH crystals in a plastic bottle. As these solutions increase in temperature considerably due to the exothermic reaction, the bottles were closed to avoid evaporation of water and were allowed to cool down at room temperature. The sands and soil were mixed first before the NaOH solution was added. Mixing was executed in a planetary mixer (Hobart) and started at speed 1 (~107 revolutions/minute) for 2 minutes and then on speed 2 (~198 revolutions/minute) for 10 minutes. During time intervals, the results of the mixing were inspected, to check whether the mixture was too dry or if any material was stuck to the rotating arm or at the edges and bottom of the bowl. The specimens were moulded immediately after mixing, in order to avoid rapid dehydration, which causes the decrease of workability of the mixture. From each mixture, samples of about 50 gram were weighed and moulded manually in a steel mould at a pressure of 15 MPa. The specimens were cylindrical with a height of about 50 mm and a diameter of about 25 mm. After moulding, each specimen was numbered and weighted. The specimens were cured by placing them for 24 hours in an oven at a temperature of 80^{o}C (open moulded). Afterwards, the specimens were removed from the oven and were allowed to cool down under laboratory conditions. Finally, the specimens were weighed and their dimensions were measured.

To evaluate the specimens' stability under different conditions and their durability, they were treated variously .Of each series, 3 of the specimens were dried in an oven at 40°C for at least 7 days, (this treatment will be referred to as S1) and 3 specimens were immersed in plastic containers filled with demineralised water for at least 7 days (S2). 3 specimens underwent five cycles of drying and wetting. In other words, the specimens were immersed-for approximately one day and then dried in an oven at a temperature of 40°C for one day. This was repeated five times. The specimens were tested immediately after they were immersed for the fifth time (S3). One specimen from each series was immersed partially in water to check efflorescence.

For a better understanding of the geotechnical properties of the samples and for optimization of the sand/clay/water/NaOH ratios, which should be used in the fabrication of specimens, the clay samples were tested on water content, plasticity limit, particle size distribution and loss on ignition. Loss on ignition between 500-650 ^{o}C is around 10.4%. This indicates that the kaolinite content is around 75%. The plasticity limit of the soil is 27.9 %. The particle size of the clay samples (HK) is of silty to clay size. More than 70.11% of the particles have size less than 62 micron.

Compression tests were performed on specimens from each series, HK3, HK14, HK15 and HK16 (Table 1), which were exposed to different conditions: drying, wetting, and cyclic wetting -drying. Fig. 1 shows the compression strength versus the percentage of Sodium hydroxide, which was used in manufacturing of the specimens.

The compressive strength of dried specimens (S1), immersed specimens (S2) and cyclic wet specimens (S3) increased with increasing amount of sodium hydroxide. Cyclic wet specimens (S3) and immersed specimens (S2) showed more or less the same compressive strength. This indicates that the material is stable under wetting drying process. The minimum compression strength of the specimens (S2 and S3) is acceptable. The average loss of strength due to immersion and cycling process of dried specimens is around 57%. The maximum compressive strength under dried, immersing and cycling conditions is 34.00N/mm2, 16.17N/mm2 and 12.78 N/mm2 respectively. These values were obtained by using 4.4% of Sodium hydroxide from the total composition of the specimens (Nguyen Ngoc Lien, 1974; Phan Duc Le, 2000).

Figure 2 shows the variation of the compressive strength of specimens HK1 to HK7, with water content. Increasing the water content from 7.1% to 7.6%, which is close to the plasticity limit of the clay, increased the average compressive strength of the dried specimens with 19%. The average loss of strength after immersion and cycling processes is 54.3% (Nguyen Ngoc Lien, 1974; Phan Duc Le, 2000).

The optimum value of the sand content, Fig. 3, is found to be around 54.69 % (fraction Clay/Sand is 1.75). Maximum compression strength - 44.91MPa - is obtained for the dry specimens. Immersed and cyclic specimens show less strength: 12.95MPa and 16.82MPa respectively.

The density of the specimens after curing varies from 1.93 g/cm^3 to 2.01 g/cm^3. It was observed that the density increased with increasing sodium hydroxide content or by using water close to the plasticity limit of the clay.

The final results show that Clay from Huu Khanh kaolin mine satisfies the criteria to be used as precursors of low-priced, stable, reliable and high quality construction materials, with maximum compressive strengths of 12.78MPa and 34.00MPa, tested under wet and dried conditions, respectively, by using 4.4% NaOH. The optimum water content for high quality construction materials, used for the studied samples, was found to be close to the plasticity limit. Besides that, the sand/clay ratio should be optimized, as the mechanical and physical properties of the material depend largely on this ratio.

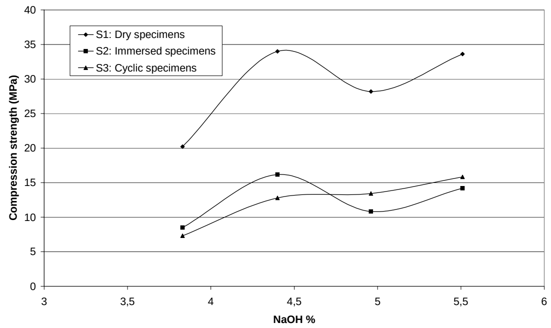

Fig. 1: Compressive strength as a function of percentage NaOH

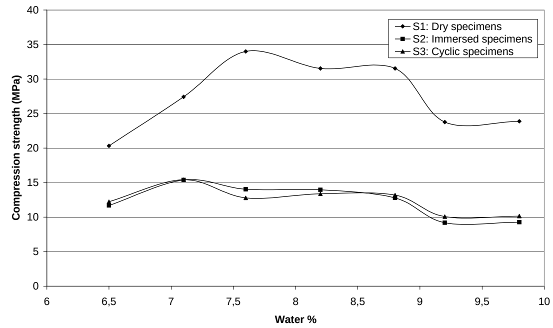

Fig. 2: Variation of compressive strength with water content

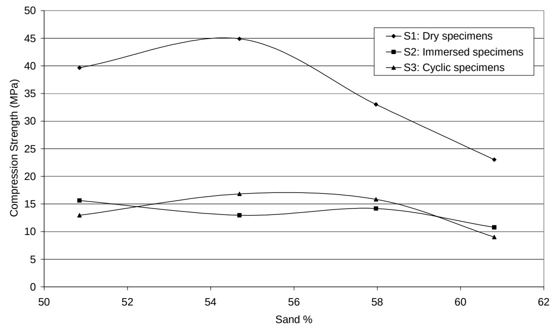

Fig. 3: Variation of compressive strength with sand content

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SUSTAINABILITY OF GUNUNG SEWU KARST SYSTEM: THE MANAGEMENT OF HUMAN BEHAVIOUR AND PHYSICAL ENVIRONMENT

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Abstract. An undergoing analysis indicates that the perception of the environmental degradation problem in Gunung Sewu Karst in Java, Indonesia is influenced more by social, economic and cultural factors, than by the extent of the problem. Indeed, karst management in Indonesia involves social-political issues that may be equally or even more important than the physical factors in terms of environmental management. On the other hand, to aim at sustainability, the characteristics of the karst environment system, its capacity and quality, must be ascertained to assess its capacity to meet the long-term necessities of human beings. These suggest that a thorough understanding of the structure and characteristics of karst environmental systems, which involves both physical landscape and human behaviour are a prerequisite for karst environmental planning and management. This integration of both natural and social sciences should provide insights into the critical linkages and dynamic tendencies of the karst system. However, much of the quantitative work in karst is statistical thus fail to capture the complexity and dynamics of ecological interactions (Jeffers, 1978) such as Gunung Sewu Karst system that involves many interacting subsystems, *i.e.*, land, water, soil, food production, demography, economy and social-culture. A more promising way seems to be the holistic, integrated approach, based on system-oriented analysis. The approach concentrates on the interactions and feedback mechanisms between the different subsystems with cause-effect linkages rather than focusing on each subsystem in isolation. This way, the causal relationships that are responsible for changes in the structure and dynamics of the karst system will be understood and important consideration for developing policies. System approach to Gunung Sewu sustainability suggest that any meaningful understanding, explanation and evaluation of the farmers' decision-making procedures require a sound knowledge of their cultural, physical, social and economic environments.

Keywords: Gunung Sewu, sustainability, social system, human behaviour, resources scarcity.

1 Sustainability in karst regions

The establishment and management of natural areas is one of the most important ways of ensuring that the world's natural resources are conserved so that they can better meet the material and cultural needs of mankind now and in the future. In any natural area, policies must be designed to achieve both goals of sustainability, *i.e.*, to increase welfare of the people and to maintain natural resources. Thus wise development based on the sustainable principle must consider two important conditions:

- Development must be able to give significant benefits to the people living in the areas. This involves the problem of human ecology.
- Development must create a biophysical environment, which is able to continuously support the lives of the people. This involves the conservation of essential ecological processes.

Until recently, both internationally and nationally, discussions on karst sustainability have focused on the maintenance of its physical state and human impacts. This is shown by various recent bibliographies of global karst research (Kranjc, 2001, 2002; Urushibara-Yoshino, 2000), which show that global study of karst has concentrated on the ecocentric aspects of karst processes, of which little can be applied to karst management in the tropics. However, the First International Conference on Sustainable Development in Karst Regions in 2001 followed by this Trans-Karst conference suggests that karst has become a major interest in the challenge of development and that there is an increasing need to integrate both social and natural sciences. Those exploiting the resources must be taken into consideration in order to balance/rehabilitate nature and maintain its integrity. In any system, man is the consumer, who actively utilizes the resources and can therefore actively participate in its management.

Local people have a major stake in managing resources. They are the actual users and managers of the environment in which they live. Research by Ghimire (1994) suggests that very often efforts to reduce environmental destruction in protected areas fail because there is a total lack of control over resources by the local people. This highlights the fact that the management of natural resources must consider social systems. This paper discusses the significance of social systems in Gunung Sewu Karst management. Gunung Sewu Karst in Java, Indonesia, offers an opportunity to study the intensification and sustainability of village agriculture under the pressure of demographic change, social and economic development. A fundamental issue facing Gunung Sewu is whether the present village farming systems will be able to meet, in a sustainable manner, the subsistence and cash requirements of the rural population.

1.1 Karst management constraints in Indonesia

Gunung Sewu Karst management in Indonesia faces constraints both naturally and socially. Firstly, it is difficult to delimit boundaries on the karst surface that are compatible with the maintenance of the quality of underground water, because of the nature of existing subterranean drainage. Secondly, there is a vast farming system on the land on which a large number of farmers depends for survival. Thirdly, the farmers own most of the land, and with the inherent cultural belief that "*tempat kulo lahir ya tempat kulo mati*" (Javanese for "the place I grew up is the place where I should die") would make it almost impossible to persuade them to leave their land / migrate to other places. The people are very dependent on the land for their survival. Resource utilization in the area depends upon the resources that are found in the area, and the necessity to live in the area is influenced by the physico-socio-cultural environment which affects the existing farming system.

According to De Haes *et al.* (*in* Kuik and Verbruggen, 1991) in environmental policy, the concept of sustainability concerns sustainable relationships between society and environment, that it will be achieved when there is a certain stability or balance in the relationships. Sustainability cannot be defined or measured without relating it to standards of quality of life for society as well as for the environment. As underlined by leading academics and planners, there is an innate relationship between social, economical, political and environmental management strategies (Biswas *et al*., 1990; Urich, 1995).

As of 2000, Indonesia gave direct authority to its regencies to develop their areas through the *Presidential Decree No. 5/2001 on Regional Authorities*. Regional government is under the jurisdiction of the Ministry for Internal Affairs. However, under Section 4 of the Constitution, it is stated that any area categorized as a conservation area is still the responsibility of Central Government. Although currently there exists only one national law regulating the guidelines for karst management (*i.e*., *Ministry of Energy and Minerals Resources Decree No. 1456 K/20/NEM/2000*), it focuses from a mining point of view only, yet to be effective karst management needs multiple perspectives as currently various governmental departments are taking interest in karst.

However, the overlapping authorities have made the management of karst in Indonesia more complex than necessary. For example, if the land is to be established as a conservation area, it will be under the responsibility of the Ministry of Forestry that is also responsible for the development of forest trees/production timbers such as teaks and acacia. If most of the residents are farmers, the development of the area should be the responsibility of the Ministry of Agriculture. In addition, the development of scenic areas is the responsibility of the Ministry of Culture and Tourism. On the other hand, the potential and management of karst has been for some time a concern of the State Ministry for Environment, which in 1999 published a book on "Karsts in Indonesia".

1.2 Gunung Sewu Farming System

Gunung Sewu was once considered as a very poor region, where for many years the karst area has been associated with lack of accessible water supplies, dry surface land, underdeveloped villages, and poverty, as Fryer and Jackson (*in* Nibbering, 1991;46) put it, "… *nor is any area as poverty stricken or as depressing to the visitor as the karst like Gunung Sewu, southeast of Yogyakarta; yet even this desolate expanse in which even drinking water is often in scarce supply in the dry season, is thickly populated by the standard of the Outer Islands".* Although it seems at first that the karst area of Gunung Sewu is not suitable for agriculture, employment and income opportunities in the area are largely limited to agricultural sector.

Farmers in Gunung Sewu live in an environment where there is a dramatic seasonal change of climate from a wet to a prolonged dry season. During the dry season, which can last up to 8 months, with an average precipitation of less than 60 mm for 3-4 months, there is practically no running surface water and very limited access to karst water due to very deep underground rivers (can be hundreds of metres deep). This permits almost no cropping for nearly half a year. Rice, as the main staple, can only be grown once, *i.e*., during the rainy season. The environment thus determines key features of their farming system, which is dry field/rainfed.

The Gunung Sewu farmers fear a serious drop in yields, especially of rice, if they were to try a new farming system. Their primary goal is survival through satisfying their basic needs. For small, resource-poor rural households with such a goal, the social-economic circumstances are generally more important considerations in designing effective conservation methods than the constraints imposed by the physical environment (physical risk of erosion). This again reinforces the part that conservation efforts should be design with local social-economical consideration in mind.

This paper is part of a dissertation writing as a result of research on three Districts in Gunung Sewu, *i.e*., Rongkop, Tepus and Ponjong. The subsystems under study, which will be discussed below are developed based on direct interviews with 324 households and field observations.

2 System approach to Gunung Sewu karst sustainability

With the complexity of an ecological process that involves numerous feedback links between social, biological and physical subsystems interacting together, it is not possible to sustain one part without some trade offs from the others. For this purpose, it is necessary to merge all the subsystems that make up the human life support systems, to look at their interplay and to decide how to make the whole system sustainable. Therefore, the solution that responds to resources utilization seems to be a deep understanding of the internal relations of the various interacting parameters within Gunung Sewu karst system. These would include analyzing both the biophysical and socio-cultural factors involve.

The system dynamic approach that is employed here attempts to conceptualize and operationalize Gunung Sewu Karst development processes in a more holistic manner than previous attempts. This is realized through the integration of a series of independent karst subsystems observed that are deemed to operate systematically.

In this research, Gunung Sewu Karst is seen as a system comprising of a set of subsystems interacting with each other through physical conditions and socio-economic and functioning as one unit. These subsystems have relationships such that a change in one of the sub-systems will induce and affect the rest of the system, possibly putting it into disequilibria.

Each sub-system directly affects food production system, thus food production system is the most influenced, although in turn food production in the area have the least direct influence on other subsystems, *i.e*., only to demography and ground cover. While culture and land are the most influential subsystem within Gunung Sewu present land use system in that they influence every other subsystem. Villagers in Gunung Sewu are generally farmers whose attitudes and actions are still abide by their conventional norms, culture and traditions that are inherited from one generation to the next. These occur not only in their social life but also shown in their behaviour towards the environment, culturally, physically and socially, as will be discussed below.

2.1 Farmers adaptations to resources scarcity

Harry Allen (archaeologists, Auckland University: pers. com) said that the age of the present Gunung Sewu settlements is somewhere around 200 years. According to Boedhihartono (anthropologist, Indonesian University: pers. com) the present Gunung Sewu people originated from refugees who were pressured from fertile wet rice field areas and migrated to the more marginal area of Gunung Sewu because of certain reasons such as demographic explosions. Nibbering (1991) through a deep cross sectional study over historical changes in Gunung Sewu also concluded that Gunung Sewu is a consequence of demographic explosion and mismanaged economy.

In Gunung Sewu, the problem of over population leads to farmland extension by the clearing of forest and cutting trees for shelter and fuelwood. The result of such impacts is apparent in four resources of Gunung Sewu: vegetation, soil, water and land such that the availability of all of these resources is limited and thus forms the determining factors for sustaining the area. The decreasing carrying capacity of the land shows how human interventions have produced a greater impact on the availability of the Gunung Sewu resources and is the reasons for adverse environmental changes. These changes were greatly advanced by the geological fragility of the karst environment. The environmental impacts that occurred were inevitable in order to ensure the survival of the human population in an already fragile area with lack of technology.

Cultural responses to resources scarcities

The struggle to survive in Gunung Sewu, encourages farmers to turn to neighbours and has developed a social working foundation amongst them. These have formed their two philosophies of life (known as *the Javanese ethics*) that determine how an individual should behave among his society. The first principle is called "the principle of conflict avoidance" (*rukun*), which stated that in every situation, a person should act in such a way as not to cause conflicts. The second principle is called "the principle of respect" (*hormat*) emphasizing that a person should show some respect towards his/her opposite speaker according to rank and status. These working foundations have been embedded since childhood and have been passed down for generations within the Gunung Sewu community, thus can be regarded as social values. These values have permitted the people to survive on their land. Society and nature are no doubt form essential parts of their lives as farmers. In this kind of traditional subsistence-farming society, sustainable development should be approached from these values. Especially in such a difficult area where nature hardly provides them with enough water and staple food - two most basic essential things in life to survive - the role of society and nature are evident.

2.2 Physical responses to resources scarcity

Responses to sol infertility

Agrosilvopasture - Subsistence farmers are severely affected by on-farm soil erosion owing to its severe impacts on crop productivity. Any effort to cultivate crops means speeding the rate of soil erosion and exposing the danger of crop failure. In such an adverse physical condition like Gunung Sewu, where intensive crop cultivation is prohibited, the farmers have adopted certain type of farming integrating arable farming with forestry and livestock. This combination of farming, forestry and livestock is commonly known as *Agrosilvopasture*.

Trees, especially teaks, and livestock serve as "***natural banks***" as trees are grown and livestock are kept as reserves for marginal years when not enough food is produced, and are sold in time of emergency, such as for education fee or urgent family matters, etc. It is more efficient to plant trees on hillsides due to the economical return within few years as well as lack of maintenance as they grow naturally. Grasses are grown under trees on sloping hills and both have function to support soil, thus improving soil quality. Some crops are also grown under trees. Once the crops were harvested, the leftovers / crop residues are use as livestock feed, for example, skin of maize for cows. Livestock also feed on the grasses. In turn, their dung is used as manure for crops and trees. Livestock in Gunung Sewu are cattle, goat and chicken. They are not kept for the dairy products, or for their meat, as the farmers never drink milk and their diet is totally devoid of dairy products. Beef, goats and chicken are only consumed during feasts or sacred communal meals.

Household waste management - Farmers' activities to improve soil quality also start from around the house. The quality of life in the villages does not allow the farmers to have amenities, thus the household wastes never compose of cans or plastics. Food is wrapped using teak or banana leaves, therefore the wastes are degradable. Household wastes are either covered in the ground and decomposed naturally (become compost) or are burnt. Unlike in China, where the farmers set fire to vegetation on slope and let the ash be washed down onto farmland in dolines (Yuan, 1997), in Gunung Sewu, household wastes are burnt in home garden, then the ash are brought to field to be use as green fertilizer. There are no post-harvest wastes, as they are use as animal feed. This way, household wastes are very useful as source of organic fertilizer for the crops and trees.

Response to diminishing arable land

Opportunities for fulfilment of basic needs, access to off-farm sources of income and available labour determine the actual use of land. A farmer with few options is forced to produce staple crops on every available piece of land.

Home garden – It is the cultivated land on the site where the house is built (Soemarwoto and Conway, 1992). In Gunung Sewu, it provides both subsistence and commercial products where the farmers prefer to plants fruits in combination with crops. Being close to the house, it receives plenty of attention and is a ready source of vegetables, medicinal herbs, livestock feed and firewood.

Use of limestone pockets – The farmers make use of limestone pockets to plant crops on the hillsides. Some of the soils that are washed by runoff downhill are captured in these pockets. Therefore on bare rocks, crops can still grow.

Responses to water scarcity

Fallow period - It would seem at first that land is left barren as a response to diminishing land area. On the contrary, in Gunung Sewu where arable land is scarce and other productivity resources are also scarce, land is fallowed for 2-3 months. Between the time of cassava harvest (June) and start of the rain (September) there is basically no activity in the fields, because fields need to be cleared for rice plantation. Since rice is for subsistence, it is crucial not to miss rice planting during the start of the rainy season. If rain comes early as observed in 1998, then there will be no fallow as the farmers must plant rice before the start of rainy season, or else they won't have any harvest. Therefore, fallow period in Gunung Sewu is regarded as a response to the scarcity of water rather than a response to land scarcity. This supports Nibbering's (1991;249) hypothesis that, "*The scarcity of water has been an overriding factor in causing people to keep population numbers at a low level through a balance between immigration and emigration. The fact that farmers still fallow their land seems to support this hypothesis*". If water (*i.e.*, irrigation) were available, there would be no fallow periods, as the farmers would use the opportunity to grow food instead of doing off-farm work.

Plants selection - The vital role of water is emphasized by the exact correspondence of rice cultivation with the wet season and of its absence during the dry season. When there is water deficit, no crops are planted, *i.e.*, between June - August. In subsistence farming, the logic of production is not optimization of returns but the logic of survival applies – safety first (Scott, 1976). Therefore, multispecies crops are planted. Other crops will guarantee a certain level of production, thus they are mixed with rice. Different crops are resistant to different environmental stresses, and this assumption makes it likely that at least one of the crops in the mixture will perform well.

Traditional means of water conservation - Most of the households have built rainwater tanks to catch rainwater during rainy seasons. Water is so crucial that farmers give great attention to conserve it. Several caves with accessible underground water are sacred. Karst ponds are cemented so that water will not leak out and every year they perform a traditional ceremony ("*bersih desa*" – village purification) where they would clean areas near the ponds, plant trees especially fig trees and put fenced around it or wrap it with yellow cloth to show that they are sacred. They believe that this is a way so that they will be supplied with enough water and to praise God for the good things in life with the hope of having better luck for future harvest.

2.3 Social responses to resources scarcities

Seasonal migration - During slack season (June - August, it is much more economical for the males to go to cities looking for off-farm jobs while females work in the field, harvesting the cassava and cleaning the land, before the start of the rain.

Consumption pattern - Around the 1960's, cassava seems to be the preferred food, however as time went by, although there was little change in the composition of food crops, there were changes in food consumption patterns. With the development of agriculture such as high yielding rice varieties, fertilizers and irrigation in certain areas, food consumption in Gunung Sewu currently consists mainly of rice although cassava is still eaten by most of the older generation as an additional food to rice.

Education - The attainment and effect of formal education has shifted the social and cultural obligations in Gunung Sewu. In effect, modern education becomes a passport to the modern life and is thought to be the only way to escape poverty and hopelessness in the area. The prestige and exposure to mass media influences the willingness of younger generation to attain a higher level of education. In other places in the world, particular activities like ploughing fields, construction of terraces which mostly require male labour, has led some authors (Hudson, 1980; Lado, 1988; Thapa and Weber, 1991) to believe that the sizes of household, in general, and of the male labour force, in particular, become crucial factors determining the adoption and application of soil management and conservation measures. However, in Gunung Sewu, size of the household does not matter because only the parents work in the field. This phenomena, where children are either in school or searching for off-farm activities, is also happening across other villages outside Gunungkidul within Java (Collier *et al*., 1996) and outside the country as well, such as in Maridi District in Southern Sudan (Lado, 1988).

Family size - Due to the cultural respect toward higher officials, not only the children go to school for at least 9 years (government ordered) but the people also follow the family planning programme. This is a population reduction programme carried out by the government as means to reduce population pressure in Gunung Sewu. As a result, out of the 324 households that were interviewed, on average most of farmers have 1 - 3 children, where 2 are the most.

3 Conclusions

The present land use system in Gunung Sewu portrays food production system, in that every effort is aim toward food production. Therefore food production system is the key to understanding social attitudes and decision-making processes by the farmers, since farmers will not take any risks that can jeopardize the availability of food. Risks will only be taken after subsistence demands are met.

Land influenced every subsystem within the whole Gunung Sewu land use system. For the local people who are very dependent on nature, land provides them with food and settlement. Surprisingly, social cultural aspects especially attitudes and perception of farmers, do show their significance in resource management. The farmers' behaviours toward conservation efforts are obviously affected by their traditional beliefs. This puts emphasis on the importance of culture in resource management.

As more and more of the environment becomes man-made and as the inadvertent side effects of environmental alterations appear with increasing frequency and intensity, the need to understand the social and behavioural variables involved will assume ever greater importance. Any meaningful understanding, explanation and evaluation of the farmers' decision-making procedures require a sound knowledge of their cultural, physical, social and economic environments. These values have become the guidance for motivating or supporting the attitudes and behaviour towards things around them. Their beliefs will enhance their service, preserve and sustain their existence. Thus the argument for the rehabilitation of Gunung Sewu karst is not only on managing the physical dimensions that cause the fragility of karst, but it is also on the management of human behaviour.

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PALAEOENVIRONMENTS IN SEMI-ARID NORTHEASTERN BRAZIL INFERRED FROM HIGH PRECISION MASS SPECTROMETRIC 230TH SPELEOTHEM AND TRAVERTINE AGES AND THE DYNAMICS OF SOUTH AMERICAN RAINFORESTS

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Keywords: Amazonian rainforest, Atlantic rainforest, speleothems, travertines, palaeoenvironments.

1 Introduction

Understanding past environmental changes in tropical rainforests is extremely important in order to assess the response of such environments to present and future climatic changes and to understand the causes and the present patterns of biodiversity.

Earlier hypothesis on the origin of biodiversity have stressed the role of past climatic changes in promoting speciation. According to the "refuge hypothesis" (Haffer, 1982), dry periods could have led to forest fragmentation, isolating more humid forested zones (called refuges) within an environment largely dominated by savannas. The refuge hypothesis does not assign timescales for rainforest fragmentation, although recent studies have suggested that speciation could have occurred over timescales of millions of years (Knapp and Mallet, 2003). Although the focus of heavy criticism (Colinvaux, *et al.*, 2000), the refuge hypothesis has generated a large amount of research. In general, pollen studies (Colinvaux *et al.*, 1996, Haberle and Maslin, 1999) tend to support a continuous forest cover throughout late Quaternary climatic shifts, although large variations in rainfall have also been demonstrated by other pollen and isotopic studies (van der Hammen and Absy, 1994; Maslin and Burns, 2000).

Amazon and Atlantic rainforests are the two major forested zones in South America. Amazon rainforest, the largest rainforest in the world, comprise a total original area of 4.1 million km^2 and is renowned for hosting the large biodiversity in the world (30% of all the world's known plant and animal species). Atlantic rainforest, also a biodiversity hotspot, occurs along the coast and has been subjected to heavy deforestation since European arrival. Nowadays only c. 7% of its original forested area of 1.3 million km^2 remains. These two rainforests are separated by drought-prone semi-arid north-eastern (NE) Brazil. Our study does not address the refuge hypothesis directly although it sheds new light on the dynamics of forest expansion in the past as well as indicates alternative ways of promoting speciation. It has long been hypothesized, due to botanical (Mori, 1989; Andrade-Lima, 1982) and faunistic (Costa, 2003) similarities, that the Amazon and Atlantic rainforests were once linked in the past. Although numerous connecting routes have been postulated (Bigarella *et al.*, 1975; Por, 1992; De Oliveira *et al.*, 1999), the timing of forest expansion and their possible recurrence have remained elusive.

The study area lies in the driest portion of NE Brazil "dry corridor", close to the village of Laje dos Negros, northern state of Bahia. Mean annual precipitation is around 480 mm and potential evapotranspiration is in excess of 1,400 mm/year. Present vegetation comprises a low arbustive scrubland known locally as caatinga. The area contains a well-developed underground karst (Auler and Smart, 2003) with abundant secondary calcite precipitates, both underground (speleothems) and on the surface (travertines).

Here we examine shifts in the boundaries of both Amazon and Atlantic rainforest through systematic analysis of past pluvial (and thus forested) periods in NE Brazil. ^{230}Th analyses of calcite speleothems and surface travertines were used to constrain wetter than present intervals. Palaeobotanical analyses of fossil flora embedded in dated travertine allowed plant identification and floristic reconstruction.

2 Past pluvial periods

Fifty-four ^{230}Th ages of growth phases in 11 speleothems and fifty-five travertines samples were obtained with thermal ionisation and inductively coupled plasma mass spectroscopic techniques. Because of the net deficit between rainfall and evapotranspiration there is no speleothem or travertine deposition at present. Thus, any ages unequivocally indicates wetter than present conditions.

Top and bottom ages of speleothems indicate that NE Brazil pluvial phases were short and widely spaced. Because there is an infiltration threshold to be overcome in order to generate speleothems, the speleothem record should be interpreted in terms of pluvial maxima. Major speleothem growth phases occur at 14,800 – 15,900, c. 39,000, c. 48,200, c. 60,200, c. 73,000, c. 86,500, c. 110,000, c. 136,000, c. 179,000 and c. 207,500 yr B.P. These growth intervals coincide precisely with Heinrich events and stadials in the Northern Hemisphere. Travertine data complements the speleothem record, including times not wet enough to generate speleothems. Younger Dryas and Last Glacial Maximum ages are represented, as well as very old (0.9 Ma) ages based on initial δ^{234}U of younger nearby travertines. The last phase of travertine deposition in several sites yielded concordant ages around 11,700 yr B.P., indicating that NE Brazil became too dry to promote calcite precipitation after that. Travertine ages, besides indicating moister conditions, help constrain the age of the abundant botanical fossil remains embedded in the calcite matrix.

Further ^{230}Th and radiocarbon analyses were performed respectively in calcite samples associated with fossil bones of vertebrates and in fossil bat guano, attempting to bracket the age of fossil emplacement and help reconstruct NE Brazil palaeoenvironments.

3 Forest expansion and ecological changes

Travertines present abundant botanical fossil remains, including well-preserved trunk, root and leaf casts. Ongoing systematic leaf identification has allowed the description of 45 morphological types. Although present caatinga vegetation shows predominance of coriaceous leaves, the large majority of fossil leaves are membraneous (less than 5% of coriaceous leaves in most sites). Fossil leaf area larger than caatinga species suggests low luminosity and thus closed forested conditions. Brochidodromous venation (common in the Atlantic rainforest but nearly absent in the caatinga) comprises a significant portion of the deposits. Furthermore, the absence of Melastomataceae in the analysed samples suggests a stabilised forest ecosystem (Rizzini, 1997).

Overall, the palaeoflora of the travertine deposits indicate a mesophilic semi-deciduous forest typical of more humid environments, nowadays found only in isolated relict forested zones known as brejos. The assemblage of fossil plant species suggests the expansion, during the wet phases of the Quaternary, of a dense forest that replaced, or mixed with, the caatinga vegetation. Due to the widespread occurrence of travertine deposits with similar palaeobotanical association in NE Brazil, forest expansion appears to have been a regional phenomenon, providing a possible connection route between the Atlantic and Amazon rainforests.

Fossil mammal remains have also been frequently found within caves in NE Brazil sometimes covered with a thin veneer or calcite. Although ^{230}Th analyses have been performed in several calcite coatings, assigning precise ages to the fossils themselves is difficult due to the unknown time lag between fossil death at the surface, emplacement into the cave and later calcite precipitation. Furthermore, the fossil emplacement mechanism causes bias in the fossil record and thus cave fossil assemblages rarely mirror fauna at the surface. Due to these limitations it is risky to interpret palaeoenvironments based solely on the mode of living of cave fossil assemblages. Nevertheless, former habitats of individual species can yield useful information on past environmental conditions, although many fossilised remains in NE Brazil belong to ecologically versatile species, such as *Puma* (living Jaguar) and *Mazama* (living deer).

Habitats of some of the fossil species probably differed markedly from the now semi-arid and vegetation-poor scenery of NE Brazil. Fossils of llama and extinct bear probably indicate a cooler environment because closest living relatives now live in much colder environments. Because all living monkeys in the New World are arboreal, the two fossil species of giant monkeys (Hartwig and Cartelle, 1996; Cartelle and Hartwig, 1996) are likely to suggest a more forested environment. Local caves are nearly devoid of bat colonies at present, although there is massive guano and fossil bat bone accumulations. Some of the twenty species identified by Czaplewski and Cartelle (1998) now occur only in rainforest biomes, suggesting a moister and more forested environment at time of bat occupation. Three radiocarbon analyses on bat remains have yielded calibrated ages of c. 20,000, c. 23,000 and > 44,000 yr B.P. Overall, vertebrate fossil species data conforms to palaeobotanical data, suggesting past episodes of moister and more forested environments.

4 Final considerations

Dry NE Brazil, bridged in between the Amazon and the Atlantic rainforests, is regarded as a major impediment for the present migration of floral and faunal specimens between both rainforests. Numerous studies, however, have pointed out at similarities between Atlantic and Amazon fauna and flora. Caatinga vegetation shows some intriguing similarities with Amazonia vegetation (Prado and Gibbs, 1993) and late Pleistocene pollen data from a NE Brazil site contains taxa nowadays restricted to the Amazonian and Atlantic rainforests (De Oliveira *et al.*, 1999). Our study has constrained the timing of several Pleistocene pluvial periods associated with forest expansion in NE Brazil. These more humid intervals have caused significant boundary shifts in South America's major rainforest, creating forested routes through NE Brazil. Such periodic forested links were responsible for promoting major biotic interchange, favouring faunal and floral species migration and speciation.

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COLLISION OF INTERESTS IN LAND USE, WATER MANAGEMENT AND ENVIRONMENTAL PROTECTION IN KARST AREAS

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Keywords: karst, land use, groundwater and environmental protection, decision support system.

In many European countries karstic areas are essential for public water supply. These areas are at the same time highly sensitive and valuable natural environments. Conversely, exploitation pressure on these areas is increasing. This mainly relates to fields such as tourism, settlement, transport infrastructure, forestry and pasture management. Due to their heterogeneously distributed consequences in both space and over time, these sometimes competing land-use activities entail unplanned disparities. Unfortunately clean water resources are becoming scarce, therefore protection measures for pollution prevention and remediation should be taken into consideration more seriously and more rigorously executed. Sustainable development of karstic areas means a maximum use of the environment with simultaneous conservation of natural resources. This is difficult to achieve in practice. It requires an exceptional knowledge of natural resources and skill and knowledge of physical planners who have to optimise effects of human activities.

Governmental authorities are forced by law to take decisions within the framework of European, national and regional directives in the fields of spatial planning and groundwater and environmental protection. These tasks can be supported by a decision-support system (DSS), which integrates data from various sources and helps to make decision processes more effective and transparent.

Basic work for such a DSS has been done in the transnational and interdisciplinary project KATER, involving co-operation between institutions from Austria, Croatia, Italy and Slovenia. The project was supported by the Interreg IIc programme, including metadata definition, metadata system, cartographic tools and GIS tools. The direct integration of these tools and information in the decision process will be implemented in the next years in the frame of KATER II project, supported by Interreg IIIb programme. With the help of an inventory all existing data about land-use, existing and potential polluters, soil and aquifer characteristics and, as far as possible, time-series of water and substance fluxes shall be recorded for selected pilot areas. These areas were chosen to reflect a range of land-use types and different national settings. Land-uses considered include summer and winter tourism, settlements, transport, forestry, agriculture and pasture management. Legal frameworks and socio-economic aspects with emphasis on land-use activities shall also be implemented in the DSS. At the catchment level the DSS has to embrace the land management of point and non-point pollution sources. Also, complex relationships between social and techno-economic variables must be taken into account in order to understand how people behave and to help them decide.

EFFECT OF KARST ON VEGETATION. CASE STUDY OF KHANSAR AREA

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Abstract. The objective of this research was to investigate the karst of Khansar with regard to its vegetation. At first, the study area was selected in a way to have both carbonate and bicarbonate formations. Field studies were carried out to determine the vegetation parameters. In addition to field surveys, aerial photographs were used for vegetation mapping. In the next step, geological and vegetation maps were overlain to compare calcic and non-calcic formations and their present vegetation. The results showed that calcic formations are different from other formations by their topographic expression. This typically includes uplands with steep slopes. In the study area, most springs were distributed on calcic formations. The combination of steep slopes, rockiness and available water resources results in a different vegetation on karstic land compared to adjacent non-karstic land.

Keywords: calcic formation, Iran, karst, Khansar, vegetation.

1 Introduction

The study area is located in Esfahan province and geographically lies between 50° 15' 25" to 50° 24' 30" eastern longitude and 33° 10' 30" to 33° 25' 30" northern latitude. The total area of this region is estimated 18600 ha. Due to karstic topography, study area is considered as a part of Zagros. The elevation is ranging from 1855 to 3144 m. Climate of area can be classified as cold steppe to semi desert (based on Gussan classification). The majority of precipitation occurs in winter. Because of geological formations (carbonate and sandstone) and the kind of climate, different types of soil can be seen in study area. In Khansar, soils are calcareous with clayey texture. There is no pH problem due to soil leaching. Soils are alluvial and contain due to erosion much gravel. Soil depth increases from uplands to plains. In the northern part, the amount of precipitation is less and soils are immature (Entisol), without evolution, alluvium and gravel. Their texture is fine and bulky. Towards the plains the texture changes from fine to heavy. The following soils have been determined in the area:

- Regosols: these soils belong to young and azonal soils without different horizon.
- Litosols differ from azonal soils that their soil profile is faulty. These soils are observed in declivitous terrain with low fertility.
- Alluvial soils are occurring in every kind of climate. These soils are not affected by local environment. Their properties depend on the nature of the sediments.
- Calcic Regosols, Calcaric Regosols, which differ by their lime content.

2 Research methodology

At first, study area was selected in a way to have both kinds of carbonate and bicarbonate formations. 1:250,000 and 1: 100,000 geological maps were to determine the boundary of study area. This area was oblong with length and width of 30 and 6 km, respectively.

Field studies were carried out to determine the vegetation condition. In addition to field surveys, aerial photographs were used to vegetation mapping. In the last stage, geological and vegetation maps were overlain to compare calcic and non-calcic formations and their vegetation.

3 Results

The general condition of each vegetation type is represented by 5 types, totalling 13,000 ha in the study area. 4600 and 400 ha of study area is covered by farmlands and rocks, respectively. These 5 types are:

1. Astragalus-Agropyron type: With an area of 1138 ha, is located in southwestern of

study area, next to Khansar. Slope is >50%, elevation ranges from 2200 to 3200 m, climate is cold steppe. Annual mean precipitation is 450 mm. Snow is the dominant form of precipitation. Soil is Lithosol to Calcic Regosol, therefore the condition is ideal for occurrence of different *Astragalus* and *Agropyron* species like *Ag. tricophorum* and *Ag. intermedium*. Following species are growing together with As. and Ag.: *Ferula ovinia, Ferula gummosa, Feritillaria imperials, Gypsophila virgata, Serratula latifolia, Bromus tomentellus, Astragalus adscendens, Artemisia aucheri, Centaurea virgata, Scariola orientalis, Eremorus sp., Ferula sp., Eryngium billardieri, Echinops sp., Thymus kotchyanus, Cachrys ferulaceae, Stipa barbata*, Annual grasses.

2. Cachry-Cousinia type: With 63 ha this zone is located in south western end of the study area. Slope is >5%, elevation is between 3100 to 3600 m, climate is cold semi steppe. Annual precipitation is 400 mm. This type can be observed in eroded uplands with outcropping rocks. Soil depth is very limited and is comprised of calcic stones from Lithosols soils group. *Prangus asperula, Cousinia multiloba, Astragalus adscendens, Astragalus sp., Agropyron tricophorum, Agropyron intermedium, Cirsium bracteosum, Ferula ovina, Ferula gammosa, Stipa barbata, Stachys sp.., Ajuga sp., Fritilaria imperialis* occur in this type.

3. *Phlomis persica-Centaurea gaubae* type: This type is distinguished on eastern hills near Khansar, its area is 388 ha, gravel slope is 15-30%, minimum and maximum elevation is 2300 and 2500 m. *Phlomis persica-Centurea gaubae* type occurs in semi steppe with cold semi steppe climate. Annual average precipitation is 350 mm. Plants are growing on medium eroded hills with shallow soils from regosols and calcic regosols groups. Following species inventoried with *Ph. Persica-Ce. gaubae* are: *Scariola orientalis, Cirsium bracteosum, Agropyron trichophorum, Cousinia sp., Astragalus adscendens*, Annual grasses.

4. *Centaurea gaubae- Scariola orientalis* type: This type is located in the northeast of Khansar and the southwest of Golpayegan. The general habitat features of Ce. gaubae- Sc. orientalis type are as follows: area: 3575ha, slope: 15-30%, elevation: 1900-2700 m, climate: cold steppe or semi desert, mean annual precipitation: 250-350 mm. This type is seen in high mountainous regions with medium erosion and shallow soils. Predominantly, Ce. gaubae- Sc. orientalis type occurrs on high hills with calcic regosol soils. Other species in this type are: *Phlomis olivieri, Astragalus sp., Gunidelia tournefortii, Sophora alopercroides, Eremurus sp.*, Annual grasses, *Cousinia sp., Stipa barbata, Psathyrostachys fragilis*.

5. *Scariola orientalis- Cousinia sp*. type: This type is distributed from southeast of Golpayegan to central parts of the study area and covers about 5450 ha. It starts from 1750 m and continues to 2500 m. Other conditions in this type are as follows: slope: <30%, climate: semi desert, average annual precipitation: 240-350 mm. *Sc. orientalis*- Co. sp. type is usually seen on hill slopes, plateaux, top benches, gravelly alluvial fans and plains with lithosol to calcic regosol groups. Following plants are growing together with *Scariola orientalis* and *Cousinia sp*: *Gypsophila virgata, Noea mucronata, Euphorbia sp., Peganum harmala, Artemisia sieberi, Astragalus sp., Hertia angustifolia, Carthamus sp., Alhaji camelorum, Acanthophyllum sp., Launea sp., Eryngium billardieri*.

4 Discussion and conclusion

There are considerable calcic formations in the south and southwestern parts of Khansar. Also, some other calcic formations are distributed in the northern parts. In view of topography, calcic sands (carbonate) areas include uplands with sharp slopes. Few farmlands can be seen in these areas. In the study area, all outcrops are located on calcic areas, while there is no outcrop on non-calcic parts. Soil of calcic formation is mainly entisol. This is partly due to steep slopes on calcic sands, which affect soil maturity processes and diminish zonation. Most springs are located in karstic regions or neighbouring to them. Because of these factors (immature soil, water resources, sharp slopes and rock outcrops), karstic vegetation differs from non-karstic areas. As-Ag and Pr-Co types are frequently found on calcic areas in southern parts of the survey area, and northern calcic parts are covered mainly with As-Ag and Sc-Co types. In the northern section of the study area, adjacent to farmlands which have caused disturbance in calcic soils, *Scariola orientalis*, as an invader species, has captured most of area.

There are some species such as *Fritellaria veureri, Fritellaria imperialis, Tulipa biebersteinna, Tulipa stalil, Tulipa Montana, and Astragalus sp*. which only occur in calcic parts. These species belong to As-Ag and Pr-Co types and show the differences between calcic and adjacent non-calcic areas. One can conclude that the mentioned species are calcareous, and their occurrence in northern parts of study areas is related to existence of calcic formations.

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SUSTAINABLE DEVELOPMENT OF SHOW CAVES AND PROTECTION OF A COMMON HERITAGE

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Abstract. Show caves meet all the criteria of a top choice tourist attraction. As such, they are not immune for environmental deterioration from the foreseeable growth of tourism. As a common heritage, their protection calls for a management that must be both rigorous and above short-term economic interest so that they will forever remain showcases of excellence that will create, within the public, an awareness to the need to respect this fragile and irreplaceable immemorial geotope.

Keywords: karst, ecotourism, cave management, Digne Declaration.

1 Introduction

In terms of evolution, this new millennium does not offer easy solutions to the many challenges imposed upon us to make ecological choices of paramount importance for the future of our planet. Air, water, wildlife or caves, every component of the Earth's balance is, nowadays, more or less under threat. While pessimists will declare themselves powerless, we can still «think globally and act locally», i.e. by taking modest actions on our own scale and with our own capacities to promote a change in attitude towards preserving the natural underground environment, and by keeping alive the notion, put forward by Gandhi in 1963, that «by respecting it, we will ensure its viability and protect its beauty for the generations to come».

Moreover, the underground ecosystem in general, and caves in particular, as a common heritage whose preservation has been recognized by and explicitly stated in the International Declaration of the Rights of the Memory of the Earth (Digne, France, June 13, 1991), have a specificity that can no longer exist without being protected by specific and binding legislation.

2 Scientific management and protection – tourist congestion management

2.1 Points of reference

In the face of its rapid growth - with a three-fold increase predicted between now and 2020 - tourism is considered a high priority by financial institutions. Consequently, this has become a major concern for many international organisations. For instance, various work programs on tourism are being developed by UNESCO's Commission on Sustainable Development (starting with its seventh session), as well as under the Convention on Biodiversity; a universal code of tourism ethics has been adopted on October 1, 1999 by the World Tourism Organization; and finally, in 1998, the year 2002 has been proclaimed International Eco-Tourism Year by the UNO.

The associations set up by those active in the field aware of the sensitivity and fragility of the karstic environment have created special think-tanks for the protection of these ecosystems.

The International Union of Speleology (UIS) has a *Department for the Protection of the Karst and Caves*, and the bodies responsible for the show caves have joined hands to form the *International Show Caves Association*. At the Postojna meeting, they decided to pool their knowledge and know-how, joining forces in the aim of leading a dynamic policy for the durable and rigorous management of the underground realm.

It would thus be appropriate for each and every country to have a commission specifically responsible for protecting its caves and karstic areas. This commission should also deal proactively with two significant components of underground tourism - show caves and tour-operators - so that this outstanding environment is exploited in a sustainable way from a tourism point of view. These commissions should also in a near future develop strategies to become dynamic and efficient lobby groups.

It is emphasized that the major feature of interest for the most popular tourist destinations is undoubtedly the «*natural environment*», and that the *«natural beauty»* is the prime criterion of interest for the tourist. The *«historic significance»* of a site remains, after landscape and natural beauty, the second factor of choice for most Europeans.

Is it not a fact that all the afore-mentioned criteria are met by the essential components of caves? The underground environment in general and the show caves in particular, do not remain unaffected by this passion for tourism. Their wardens are thus faced with various problems related both to this huge expansion of tourism activity and to the visitors' interest in those sites whose capacity, however, has been restricted by Mother Nature herself!

The foregoing makes it obvious that, faced with solely economic challenges that could easily have unscrupulous operators fail to respect, in their management, this irreplaceable age-old heritage that has nevertheless been entrusted to them, protecting and preserving show caves has become an urgent need. For the benefit of mankind, their ownership title should not give them a blank cheque allowing them to debase at will this common heritage for vile profit.

2.2 Ecotourism on the way of durable development.

In principle, ecotourism is an example of a renewable resource. Following the idea formulated by the Global Organisation of Tourism, its principal objective is the exploration of the natural environment, with a solid education bias as an added value. This type of 'green tourism' should aim to make all inhabitants, visitors and managers to become aware of the need to protect the caves, our natural wealth.

However, this new type of tourism has considerable impact on the caves. Since they are not extensible, what are the limits to set for their exploitation? Should a daily, monthly or annual maximum limit be set to the number of visitors to the caves? Is there a 'golden number' beyond which the tourist exploitation of the caves would cease to be viable in the long-term? Only rigorous scientific monitoring of the ambient air can begin to provide answers to such questions.

Caves have to be considered as real and authentic showcases of an extremely fragile and more than vulnerable underground environment. Their quality is, and must remain forever, pristine.

This showcase concept is already fully justified in the case of Belgium. Over-visiting resulted from «underground tourism» in «wild» systems organized since 1990 by tour operators for adventure-seeking consumers in search of new experiences. Various caves have had to be closed to avoid their utter destruction and to protect and preserve their scientific interest (biological, geological, morphological, hydrogeological, cristallographical, etc.) or their value as underground landscapes.

This is the reason why, as President of the Protection Department with the International Union of Speleology, I have been actively promoting the idea of an «International Show Caves Year ». This idea is relevant in that, by opening these underground jewels to the general public, the ordinary citizen would be able, when visiting one of these outstanding sites, to better understand why some of them have to remain closed: for the same reasons why there is a need to protect the «natural reserves» ecosystem and balance. Once these motivations are fully understood, they will foster over the longer term a greater respect for the beauty and integrity of these ancient common heritages.

For their part, the wardens of caves open to visitors have an obligation to strictly and intelligently manage these heritage properties, both by maintaining their accessibility and by avoiding any over-visiting. They need to be assisted by a parallel team of scientists, speleologists and environmentalists who have to review the impact of construction plans and of the usage patterns on their work tools with a view to recommend best practices and actions to preserve both the karst geotope and ecosystem of the cave.

Indeed, any kind of work done in a cave to make it accessible to visitors is liable to cause irreversible damage to the underground environment. For instance, topographic tampering (new galleries, artificial lakes, new entrance or exit openings, stairwells, footbridges, etc.) can, with time, make a cave «biologically dead» or cause the drying out of concretions.

This irreparable and ever-lasting tampering makes it impossible to restore the cave to its original condition. Not only are these add-ons devoid of any aesthetic value, very often they deeply alter the underground climate and hamper those chemical exchanges between the underground chambers and the outside that represent a delicate, cave-specific balance.

From a biological point of view, the consequence of these modifications is the loss of certain cave-dwelling wildlife habitats, such as puddles, wet zones and cracks, or the shrinking or packing of walls or clay soils.

Another, often overlooked, attack is the result of a temperature increase in show caves. This temperature increase is particularly significant closer to the ceiling and is due to both the visitors' body heat and the radiating heat produced by the various lighting sources installed in the cave. This is the cause of a drying out of ceilings or walls with the associated risk of delamation and falling rocks, as well as a slowing down or halting of concretion-forming processes. It also modifies the living conditions of bats dwelling in the vaults' crevices.

Moreover, the combined effect of this temperature increase, the presence of artificial lights, and the spores and seeds brought in by visitors, is the introduction and growth of a chlorophyllous vegetation in the show caves such as moss or ferns, also called Lamp flora. One still remembers the «green plague», the proliferation of algae and mould that forced the closing of the caves at Lascaux. Both the caves and their prehistoric paintings had to undergo a long rehabilitation process but, unfortunately, certain damages could not be repaired.

There are yet other kinds of disruptions. From the surface down, any change in the run-off water regime (surface or seepage) due to drainage or a drastic change in the vegetation cover (clear-cut logging, land clearing for pastures, excess use of fertilizers and pesticides, creation of parking lots and other recreational facilities, etc.) has an impact on the chemical balance of concretion-forming and on the cave-dwelling organisms.

Generally speaking, mass tourism in a cave ecosystem generates profound changes with long-lasting consequences. Exogenous carbon dioxide and water vapour (from breathing and perspiring) and temperature increase are both disruptive in an otherwise particularly stable physical environment. Moreover, noise, refuse, graffiti and concretion destruction also disrupt the underground ecosystem, often damaging a site forever.

For all these reasons, the scientific management (associated with an impact assessment prior to any kind of work and environmental follow-up studies) of show caves is both urgent and indispensable, if this natural collective heritage is to be maintained in a condition as close as possible to what it was originally. Automatic air quality control and parallel scientific committees are partial solutions.

Although this would be very demanding in terms of cost-effectiveness, it would be beneficial to have, in each show cave, an automatic system to monitor the various air quality parameters that would allow a better control over the flow of visitors against negative impacts on the underground environment and concretions. With such a system, a show cave warden would become aware of the damaging impact of promotional activities such as torchlight visits offered, albeit only twice a year, in an underground site otherwise abandoned for over 40 years!

The idea of a parallel scientific committee to manage each show cave is slowly taking hold. Existing committees are unfortunately too often made up of scientists remunerated by the operator, and the operator will rarely strictly follow their advice. Ideally, a representative of the authorities in charge of protecting heritage sites, and another representing the associations of stakeholders, should also sit on these committees, and their selection should not involve the operators themselves.

Consequently, show cave operators will have to come to accept the idea of being judged by their real commitment to the sustainable preservation of the outstanding environment they exploit that is to say by the quality of their stewardship in promoting a common natural heritage.

Show caves are commercial operations and as such, they must indeed come to a common denominator so that tourism and heritage protection come together to generate both pleasure and emotion among visitors.

Wild and show caves have to be protected not only because they look enchanting during the light-shows but also because they provide science with a laboratory-like environment where climate evolution and global climate changes can be directly felt.

3 Communicating with visitors

My second and much more practical point deals with communication. Every show cave has to have a mandate to inform (about the visit) and educate (about the cave-forming processes and the vulnerability and extreme susceptibility to pollution of a karstic environment). This will heighten the visitors' awareness to the need to respect, and not tamper with, the cave environment, which is also to the operator's advantage.

In my mind, an appropriate educational approach should be a «forced»passage, before entering the cave, in front of a few information boards enhanced by an intelligent selection of locally shot pictures which would be explained and later commented by the guide at an appropriate moment during the visit. Such an «awareness space» could be jointly designed by ISCA (International Show Cave Association) and UIS, ideally along a standardized template, to be an educational summary of the specificity of the karst environment, a kind of periscope intended to give the visitor a series of dynamic decoding keys in preparation for the visit itself.

Smoking and eating should without hesitation be prohibited, and this should be strictly enforced throughout the visit. With clear indications, this should be easily accepted. «Clients» have to be reminded that they are not in a kind of museum where pictures of age-old landscapes are exhibited, but rather in the very heart of a living and fragile environment, within an ecosystem highly vulnerable to man's presence. Visiting a prestigious site such as a decorated or concretion-rich cave is a privilege that must be earned!

In terms of heritage education, show caves aim at awing the visitor while having him reflect upon their ancient past, their present condition and their preservation for the generations to come. The impact of the mechanical «delivery» of the explanations given by an often poorly trained, albeit well-intentioned, «guide» is thus particularly important.

Awareness and education efforts are not the sole responsibility of the show cave operators: schools have also a role to play. Such were the conclusions of the various international teacher training seminars held since 1997 in the area of geotope protection. For instance, the GRECEL program initiated under the auspices of the European Commission's Comenius Project, calls for the development of teaching methods and educational tools to train teachers and give them the qualifications they will need to educate the public and promote awareness in environmental matters. However, show cave operator should make it a matter of pride to hire only guides whose qualifications will prevent them from making asinine comments. These various fields of qualification could be consolidated in a primer prepared for them under the aegis of ISCA and UIS. With the existing information and communication technology, these could even be the subject of an on-line examination leading to an *ISCA Guide's Licence*. A visit conducted by such a licensed guide would then be tantamount to a true seal of quality.

Having visited numerous caves, I have come to yet another conclusion. On top of the conspicuous absence of educational information signs, the visitor will see almost everywhere the same self-explanatory directions, which leads me to believe that about half of the visiting public do not understand, and thus do not obey, those cautionary directions.

Show cave operators should consequently reflect upon a way to clearly convey their messages and directions to visitors by using standardized pictograms rather than words. For instance, instead of having a sign with the words «do not touch», «ne pas toucher», «non tocare», «niet aanraken», «nedotykat se», etc., as well as in those languages such as Russian, Japanese, or Greek that I cannot reproduce here with my word processing program, would it not be wiser to copy instead the international road sign system by posting a red circle with the image of a finger pointing to a dripping «macaroni» crossed by a white bar?

Isn't this a simple, clear and universal means of communication? This principle could, I believe, be applied to a variety of other messages.

4 Conclusions

Underground tourism can be sustainable only by preserving the caves ecological integrity and environment. As was put by Manfred Pils, Secretary General of the International Association of the Friends of Nature, «the expansion of tourism will eventually be its very demise». How true!

Could you envision what would become of those show caves, with their finite space and volume, after an unscrupulous widening of pathways to allow for a three-fold increase in the number of visitors as is forecasted and the sorry state of concretions due to a substantial increase in the ambient temperature and these ubiquitous lights? The direct consequence of all this is that show caves would no longer meet the very criteria of choice which engage the public in travelling to come and admire their fascinating age-old landscapes.

Protecting, preserving and respecting the natural heritage and its various geotopes such as caves must be effected through education at all levels.

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Eds. O. Batelaan, M. Dusar, J. Masschelein, Vu Thanh Tam, Tran Tan Van, Nguyen Xuan Khien

LAND USE OF KARSTIC AREAS IN BELGIUM. CARTOGRAPHY AND DELIMITATION OF KARSTIC HAZARD

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Abstract. Karstic regions are of great interest and value but they are also vulnerable to pollution and destruction. Therefore a long-term management of those areas must take in account specific requirements for nature and groundwater protection, in order to conserve the economic and scientific value associated with this environment.

It is also vital to consider and evaluate the effect of limestone dissolution (karstification) on infrastructures and buildings as well as quarry exploitation. The management of karstic hazards is, since 1997, included in the land use legislation in Wallonia (southern region of Belgium). The aim of this law is to restrict and regulate land use in areas of intense karstic activity to avoid future accidents and risks and, in certain cases, to protect remarkable natural sites under the treat of economic development. In order to apply this legislation, based on the principle of caution, a precise map of the karstic hazard areas must be drawn, based on bibliographic data, successive karstic inventories, hydrogeological context, aerial and satellite pictures, but also on field observation and regular visits to see how the sites evolve.

The Ministry for land use and environmental resources of Wallonia has charged the Walloon Committee for Protection and Study of Underground Sites (Commission Wallonne d'Etude et de Protection des Sites Souterrains), in partnership with the Universities of Mons and Liege, to define those areas of karst hazard and to draw these maps, taking in account the 5000 known karstic sites distributed over +/- 4000 km² of limestone. After 4 years of work, the Walloon Government is now in possession of a completed map of karstic hazard areas. Each of the 393 risk areas has been defined on a 1/10.000 map, and regrouped in a GIS to improve their practical application when it comes to land use planning. Furthermore, this study proposes for each of the 393 areas specific guidelines and restrictions to the development of infrastructure, urbanization and the protection of underground waters and to more specific protection options for remarkable underground sites.

Communes, architects, housing estates, notaries, public and private companies must consult these maps before any new infrastructure project. The risk assessment followed for this study proposes 2 gradations (high and moderate hazard). In general, for areas of the first group the authors recommend the suspension of all further urbanization. In areas of moderate risks, geophysical investigations are required to make sure of the stability of foundations before allowing new buildings.

Keywords: geological hazards, land use planning, risk map.

1 Introduction

The presence of karst and morphologically active features can cause soil instability and impose special care and caution when it comes to urbanization of the affected areas. Karst can cause harm to constructions and people as well as to public infrastructure generating heavy costs for the community.

Certain human activities (quarrying, infrastructure works, doline filling, solid and liquid waste disposal on karst, and cave over exploitation) can cause irreversible modification and degradation to remarkable karstic sites. The impacts and long term effects of those activities on vulnerable natural sites and areas must be more taken in account when it comes to land use planning and regulation.

The Walloon Government is conscious of the intrinsic vulnerability and specificity of karstic areas and therefore has included since 1997 karstic hazard as a specific constrain to urbanization and land use management in the

Land Use Legislation (Code Wallon pour l'Aménagement du Territoire, de l'Urbanisme et du Patrimoine - CWATUP).

In order to locate hazardous karstic areas and to define the intensity of the risk linked with limestone dissolution for land use, the Walloon Government has charged a team of scientists to investigate, map describe and evaluate all karstic constraint areas in Wallonia. This study, which was recently completed, had different objectives:

- to determine the perimeters in which the present density and activity of karstic features should constrain land use in general and urbanization in particular
- to prevent harm to people and goods caused by sinkholes and the lack of specific prevention and rules in areas where those features can occur;
- to protect remarkable karstic sites and natural heritage from degradation caused by human activity, especially building (extension of quarries, road building, collective equipments…).

2 Authors and geographical framework of this survey

This study was conducted by the following research centres:

- the University of Liège (laboratoire de géomorphologie et de télédétection);
- the Faculty of Mons (FPMs - Service de géologie fondamentale et appliquée);
- the Walloon Commission for subterranean studies and conservation (CWEPSS).

The Atlas of Karstic Phenomena (Atlas du Karst Wallon - CWEPSS, 1992-1997), has been used as a prime source of information and data for this study. This atlas is a very complete cartographic and descriptive inventory of all karstic sites of Wallonia. It groups in a geo-referenced database over 5000 karstic features as well as 250 underground rivers.

The surface of carbonate rocks, possibly affected by karstic dissolution, attains 4500 km² in Wallonia, representing almost 30% of the entire territory of the Region. This encompasses mainly limestone as well as chalk and other carbonate rocks that can be dissolved by acidic water. In some areas the limestone can covered by 10 to 50m of unconsolidated rocks but this does not prevent the effect of karstification and sinkhole formation. In total for Wallonia, 393 areas of karstic risk areas have been defined and mapped:

- 126 zones of high hazard
- 266 zones of moderate hazard
- 1 vast zone of low risk covering the area around Tournai (west part of Wallonia).

3 Assessment of karstic constraints

In Wallonia only carbonate rocks can be naturally affected by dissolution. Therefore all caves and karstic features are situated in the limestone areas of the region.

The dissolution processes affecting the limestone are at the origin of underground features (caves, rivers, endokarst, concretions…) as well as typical surface morphology and sites (dolines, sinkholes, resurgences, polje…). Most of these features can induce risks and karstic hazards for construction and land use

Some karstic sites have a more direct impact on risk and land use restriction policy:

Dolines are the most common form of karstic sites directly visible on the surface. The depressions can have different geomorphologic origins but are always caused by intense limestone dissolution. Their distribution can be linked with the distribution and density of joints and faults, but also with the presence of caves (collapse of roof) or with underground rivers causing the removal of rocks. Depressions can appear abruptly at the surface (like in the case of sinkholes), or enlarge progressively. At a geological scale these features are very dynamic and for land use purposes it is important to model their evolution to see how and where they will affect some karstic areas.

Underground rivers and water absorbing sinkholes induce a specific constraint on land use. As it has been shown over time, they progressively draw back all the way to the boundary between limestone and non-karstic rocks. This means that the depression in which the surface water is collected will progressively affect different areas of land and modify the profile of the dale. This can cause floods and reactivate certain sinkholes.

Pollution of aquifers and karstic networks: In Wallonia karstic aquifer supply up to 75% of drinking water. They represent important reserves but their management must take in account their very high vulnerability. This vulnerability is due to the high permeability (large fissure type porosity) responsible for the important transmissivity observed in those aquifers allowing the fast and long distance spreading of pollution and harmful substances. This vulnerability to pollution is one important aspect to be taken in account when it comes to deliver permits for urbanization on limestone and karst. Strict rules must be imposed about management and cleaning of wastewater for new housings. Even if these areas do not always present high human density they must be priorities when it comes to the management and development of a sound and efficient sewer network.

4 Methodology and mapping

To draw the maps of hazardous karstic areas, all useful information, historical observations and previous studies on karst have to be gathered and georeferenced in order to merge and cross them spatially. The following sources of data have been used in particular:

- the Walloon atlas of karst (AKWA) produced and regularly upgraded by the CWEPSS;
- the files and records of the Geological Survey of Belgium;
- ancient and actual geological maps as well as topographical one (on which some ancient depressions can be spotted);
- air photographs from different periods (to try and see how the position and extension of some karstic feature might have changed over the years);
- speleological literature and thesis in geology, hydrology and geomorphology dealing with some of the studied areas.

Once all this information is gathered, compared, analyzed and compiled, numerous field trips in areas presenting a potential karstic risk take place to evaluate this risk (and its severity) and define the extension of the affected zone and see how active the karstic system appears.

The «final product» is a digital map of karstic constraints that must help the government and local authorities to define future land use policies and deliver on a more local scale the urbanization permits.

Gradation of karstic risks and constraints

Based on localization of the karstic features, on their size, density, dynamics and presence of elements which may cause their «reactivation», different classes of constraints are defined on the map.

The karstic sites themselves (black symbols on the map). Each site is mapped with a symbol representing the nature of the feature (cave, insurgence, sinkhole, resurgence…) and a label linking to the descriptive database. The diameter of the symbol has been chosen to represent 30 meters at the 1/10.000 scale of the map. It is forbidden to construct directly on the site in this 30m range.

Zones of high karstic hazard (red polygons on the map). After field survey they are defined taking in account:

- presence of numerous closed sites with coalescent distribution (30m diameters defining a larger area). This is the case of some «fields of depressions»;
- areas in which new and active karstic sites have been observed, confirming the rate of dynamics and the possible extension of the karst affected area in one specific direction;
- areas presenting hydrological conditions favourable to the development of new karstic sites or possible problems of flooding (dry dales represented by an axis);
- presence of endokarst which may cause major sinkholes, especially in areas where the aquifer is over exploited (Tournai area).

Zones of moderate karstic hazard (orange polygons on the map). In those areas karstic features are less obvious, generally of smaller size and not very active. This leads to define in those polygons weaker restrictions when it comes to land use. In certain cases moderate zones have been drawn around the high karstic hazard zones as a «security buffer».

5 Conclusions

Potentially everywhere on limestone subcrop, karst features can develop, sometimes without any clear preliminary sign at the surface. The dissolution process involved in karstification is often rapid and can induce fast evolution and modification in size, extension or localization of karstic sites.

Therefore areas known for their karst dynamic have been particularly surveyed in this study, in order to establish an updated map and to foresee their possible evolution in time and space.

In areas defined as zones of karstic hazard, the nature of the soil and karst dynamics make land use and urbanization a risky business, that should not be allowed without initial investigation (geophysics) to confirm soil stability, especially for the foundations of collective equipment and infrastructure.

This study has established, on scientific basis with intense field checking, areas of karst hazards and has estimated the seriousness of this risk. It is now the responsibility of the government and local authorities in charge of land use planning to take those recommendations into account.

The safe practice principles that are behind this survey must help avoiding future accidents to people and property but also contribute to protect and conserve karst areas and their vulnerability.

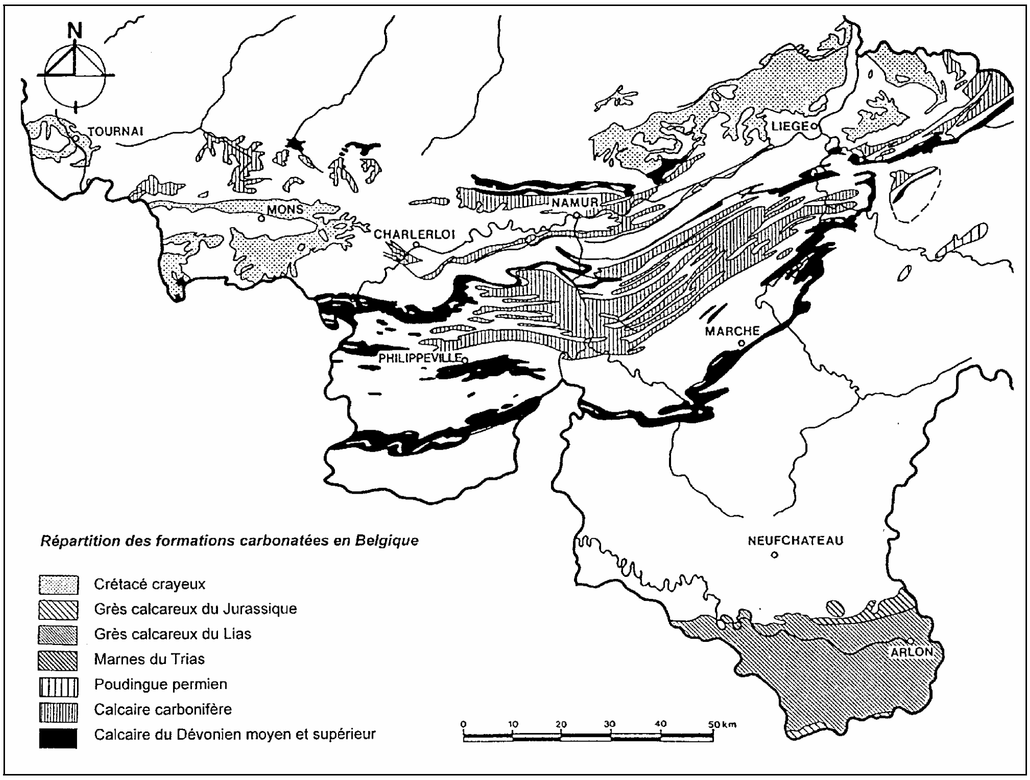
The authorities have now the difficult job to arbitrate between land use permit demands with their impact on economical growth and the safe practice and sustainable development of their region taking into account the geological specificity of karst.

The lost river of Botinfosse (Liege District) – Picture S. Delaby – February 2003.

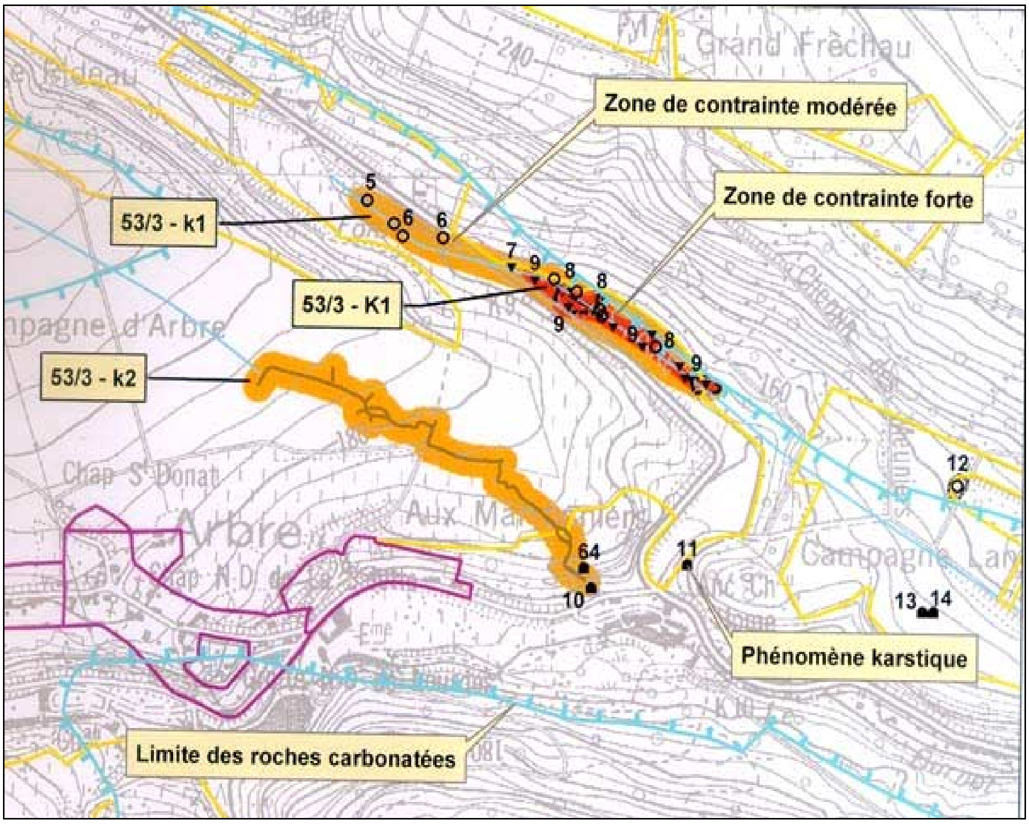
Auges Sinkhole (Profondeville) being used as an wastewater outlet for a new residential quarter. The polluted water is directly poured over naked and fissured limestone (Photo G. Thys – December 2003).

Sinkhole opened under a road and linked with an underground river. Commune of Namur / Ghesquière. Picture G. Michel (May, 2002).

Vast sinkhole (15m deep) that has suddenly appeared in a field in 2001, south of Liege (Amostrenne – Picture Van Dijck).



Distribution of carbonate rocks prone to karstification. Legend from top to bottom, also from young to old: Cretaceous chalk, Jurassic (Bajocian) calcarenites, Jurassic (Liassic) calcareous sandstones, Triassic marl, Permian limestone conglomerate, Lower Carboniferous limestones, Upper and Middle Devonian limestones.



Map extract of Bioul (Namur District) on which different hazardous karstic areas have been defined affecting an agricultural area. On this area the urbanization pressure is quite high (Faculté Polytechnique de Mons – Th. Martin June 2003).

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EVALUATION OF KARSTIC WATER QUALITIES IN THE NAM LA AND SUOI MUOI CATCHMENTS

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Karstic groundwater and surface waters are extremely vulnerable to pollution. For karstic water resources management, it is therefore of utmost importance to monitor water qualities, such that appropriate protection of water resources can be set up. Surface waters and karstic groundwater springs in the Nam La and Suoi Muoi catchment (Vietnam) were sampled in 1999 and 2000 during several field campaigns. These samples were analysed for standard parameters and for bacteriological content. Hydrochemical analysis, based on different indices, graphing, statistical analyses and calculation of saturation indices, explain the water qualities in relation to the regional geology. The bacteriological water analyses show for some springs poor qualities due to faecal coliforms. Observed qualities are explained as a result of the vulnerability caused by karst features. It is argued that the mapping of these features should form the basis for development of water resources systems that will have acceptable water qualities. It is shown that the results of the hydrochemical analysis can contribute to the research into karstic flow systems.

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IMPACT OF CLIMATE VARIABILITY ON THE REGIME OF KARSTIC SPRINGS FOR DIFFERENT GEOLOGICAL CONDITIONS IN BULGARIA

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Karstic springs are important source for water supply in many regions of Bulgaria. They are in different degrees vulnerable to drought. Basic features of the springflow regime are characterised as a result of geological structure and tectonic peculiarities of karstic massifs. The impact of climate variability on spring discharge is assessed for different regions in Bulgaria.

CHARACTERIZATION OF FUNCTIONING GAR-CAGIRE KARSTIC SYSTEMS (PYRENEAN MOUNTAINS) BY GEOMORPHOLOGIC ANALYSIS

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Keywords: karstic aquifer, geomorphology, functioning, polyphasic evolution.

The mount of Gar Cagire, situated to the south of Saint Gaudens in the Pyrenean Mountains (France) is characterized by a complex geology. Several large carbonate aquifers of several hundreds of meters in thickness occur in this area. The carbonates of the lower aquifers are sometimes metamorphosed whereas the superior aquifers are separated by semi permeable marls.

The tectonic style determines a set of shapes, such as continuous circulation oriented by synclinal tectonic forms, or interruption of circulation by differential uplift of tectonic blocks in which the caves are carved. Geology permits to propose a first separation of different aquifer systems.

To understand the present activity of these aquifers, an analysis of shapes (fluviatile, karstic and fluvio-glacial) has been achieved in order to trace the complex and polyphasic geomorphological history of these mountains.

The hydrodynamical data (by autocorrelation and spectral analysis) provide evidence for the existence of a well developed karst with complex working, characterized notably by the composite shape of the unit hydrogram. These observations have brought forward the existence of a paleokarst whose state is twofold, either sealed or very karstified. This survey shows that the most prominent characteristic of the structure and the working of the aquifers within these massifs stems from a polyphasic evolution during the Quaternary.

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MODELLING GROUNDWATER FLOW AND SOLUTE TRANSPORT IN KARSTIC SYSTEMS: FROM DREAMS TO THE REALITY – HOW CAN MODELS HELP FOR GROUNDWATER VULNERABILITY ASSESSMENT ?

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Simulation (modelling) of groundwater flow and transport, using various numerical methods, and taking into account as far as possible the spatial variability of the hydrodynamic and hydrodispersive properties of karstic aquifers is certainly not an easy exercice. Many groups of models can be used. 'REV based models' with single, double, triple continuum approaches can be applied as well for solving flow problems (groundwater quantity) as for transport problems (groundwater quality), but many issues are still challenging: parameterisation and scale of application, calibration/validation issues, sensitivity, applicability. It is the same for 'discrete approaches', which require even more information for solving parameterisation and scale issues, for 'stochastic approaches', theoretically providing the uncertainty of your results in function of the uncertainty of your data, and even for 'fractals techniques' all these issues remain. 'Black-box models' are lighter to handle but are not anymore 'physically consistent'. The prediction results with such mathematical tools cannot be relied on when predictive computations are performed with aquifer stresses (i.e. recharge, pumping, boundary conditions) that will possibly lie out of the calibration range.

The choice of an adequate tool for analysing and simulating karst aquifer behaviour will depend strongly on the kind of problem to be solved: a steady-state flow problem will be considerably more simple to simulate than a transient transport problem with transient groundwater flow conditions. Unfortunately, in practice this last problem is in most cases more realistic than the former one. Another overwhelming factor is the scale of the study: local modelling simulations need more detailed data and probably a more discrete approach in the way of describing the spatial variability than in regional models.

Despite all these limitations, simplified physically consistent groundwater and transport models can help for groundwater vulnerability assessment. Numerical models are useful as tools for consistently interpreting, the results of field measurements and experiments. Calibration of numerical models using these measurements will allow to optimise the use of this information for validating (to some extent) the vulnerability assessment. They can be considered as useful intermediate tools between field measurements and vulnerability assessments. After calibration, one can perform sensitivity analysis to check how results can vary in different stressed scenarios ('what if' simulations) or to consider the uncertainty of the parameters used. Results of this analysis allow the validation of the assumptions in the adopted vulnerability assessment technique.

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STAKEHOLDER REACTION TO THE PROPOSED ESTABLISHMENT OF THE COCKPIT COUNTRY NATIONAL PARK, JAMAICA.

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1 Introduction

Jamaica's Cockpit Country is the spectacular humid tropical "type example" of what Ford and Williams (1989) describe as the "egg-box" style of polygonal karst. Centered on Trelawny Parish, in northwestern Jamaica, the Cockpit Country covers about 450km^2. The cockpits, which dominate the landscape, are steep-sided, more-or-less enclosed lobate depressions, some over 100m deep and 1km in diameter, surrounded by residual hills or ridges, and are so named because they resemble the arenas formerly used for cock fighting (Day and Chenoweth, 2004)

Most of the Cockpit Country is developed in Eocene carbonates of the White Limestone Formation, although some of the southern area is developed on older rocks of the Yellow Limestone group. The White Limestones are in general extremely pure, but the cockpits contain bauxite deposits that are probably derived from Miocene volcanic ash (Comer, 1974). Regional drainage is largely autogenic and northward, although there are some allogenic inputs on the southern boundary. On the northern periphery underground drainage emerges at a series of springs, which feed rivers draining to the north coast (Day, 1985). Cave systems are numerous and varied; some of the larger, such as the Windsor Great Cave, have significant bat populations and have been commercially exploited for guano (Fincham, 1997).

The Cockpit Country vegetation includes a range from wet to dry limestone forest in which there is considerably floristic diversity and an extraordinary number of endemic species (Proctor, 1986; Kelly *et al*., 1988; World Wildlife Fund, 2003). The Cockpit Country fauna is also significant, including threatened bats, snakes, frogs, and all but one of Jamaica's 28 endemic bird species. Human influences have to date been limited by inaccessibility and lack of surface water, although there exists an extensive trail system and many peripheral cockpits have been used for agriculture. In the 1700s escaped slaves known as the Maroons used the Cockpit Country as a base for guerrilla actives against the British army (Eyre, 1980; Day, 2004). Treaties gave the Maroons a degree of autonomy that they have maintained ever since.

Since 1950 much of the Cockpit Country has been designated as a 223km^2 Forest Reserve, although there has been little enforcement of conservation directives. The immediate vicinity has a population of some 10,000 people and is exploited for bauxite mining and agriculture (Barker and Miller, 1995). Less than six percent of Jamaican forests remain intact, and deforestation rates nationally are among the world's highest (World Wildlife Fund, 2003). In the Forest Reserve illegal logging, farming, hunting and trapping for the pet trade are particular problems (Miller, 1998), but the area is recognized as a critical area for plant diversity and endemism (Davis *et al*., 1997). Local deforestation has been estimated at about three percent annually (Eyre, 1989). The Cockpit Country has been proposed as a U.N. Natural World Heritage site (Eyre, 1995), and there are currently plans to inscribe it as a national park (Chenoweth *et al*., 2001).

2 Jamaican karst: Conservation and protected areas

Less than 550km^2 of Jamaica's 7500km^2 karstlands, or about seven percent, is conserved within six protected areas (Kueny and Day, 1998). The Cockpit Country is the largest and most significant of these, although its current status is tenuous; others include the Blue and John Crow Mountains National Park and several smaller forest reserves. In the

Caribbean context, the Cockpit Country remains perhaps the most significant karst landscape to be spared from exploitation and degradation.

Protected area management in Jamaica is "…governed by a standard regulatory and policy framework, but implemented through a variety of governmental and non-governmental agencies and inter-agency arrangements." (Geoghegan and Renard, 2002: 18). The Policy for Jamaica's National System of Protected Areas (Natural Resources Conservation Authority, 1997) recommends local community involvement in protected areas management, but the delegation of management responsibility has not generally been successful (Caribbean Natural Resources Institute, 2001), with the participants representing only a narrow spectrum of local interests, and the organizations hampered by technical and financial constraints and by the absence of a comprehensive legal and regulatory framework (Geoghegan and Renard, 2002).

Jamaica's Country Environmental Profile (Field and Troy, 1998) identified considerable threats to national long-term ecological sustainability, and promoted the establishment in 1991 of the Natural Resources Conservation Authority and the initiation in 1990 of the USAID Protected Area Resource Conservation (PARK) project to create a sustainable national protected areas system (McDonald, 1996). The proposed Cockpit Country National Park is one component of the PARK Project, and was recommended as a protected area by the Jamaica Conservation and Development Trust in 1992 (JCDT, 1992).

3 Conservation and traditional uses of the Cockpit Country

The Cockpit Country was designated as a 223km^2 forest reserve in 1950, and has long been under consideration as a national park. Issues of conservation and development have been discussed throughout the second half of the twentieth century (e.g. Cotterell, 1979; Thorsell, 1981) but little concrete action has occurred and the forest has generally been regarded with ambivalence by both government and local residents. Proposals to establish a national park were initiated in the 1990s under the auspices of the PARK Project and at the behest of the Jamaica Conservation and Development Trust (JCDT 1992). The area has also been mooted as a UN Natural World Heritage site (Eyre, 1995), although it is coming under increasing pressure from encroaching agricultural and other activities (Barker and Miller, 1995; Barker, 1998; Miller, 1998; JCDT, 2003).

Both rational use and despoliation of the Cockpit Country have to date been limited by the restricted access, by the rugged terrain itself and by the lack of surface water. During colonial times, slaves were permitted to grow crops in marginal areas adjacent to plantations, and this legacy has persisted on the margins of the Cockpit Country. In particular, the flatter areas on hilltops or within cockpits have been used for the cultivation of yams, with more extensive flat areas being used for bananas, selected tree crops and the grazing of livestock. Less accessible areas have been used for marijuana cultivation. Agricultural encroachment is of increasing concern, particularly around peripheral population centers such as Troy (Miller, 1998).

4 The national park proposal and stakeholder reaction

Preliminary funding (Ja$7.36m) for a Cockpit Country conservation project, potentially involving establishment of a national park, which was initiated under the USAID PARK Project in 1990, has been obtained by the Jamaican government from the World Bank (World Bank, 1999; Jamaica Gleaner, 2000), and this has rekindled controversy over the area's future status and use.

Awareness of the issue was also elevated by a controversial government plan, now modified, to route a new highway (Highway 2000, from Kingston to Montego Bay) through the area. Opposition to this project from environmental groups and the Maroon community resulted in a proposed rerouting of the road around the Cockpit Country, but the issue of potentially improved access remains contentious. Stakeholder reaction to the national park proposals, perhaps understandably given the general milieu, has been very mixed, with a range from unequivocal support to outright opposition.

International reaction has been generally positive, except from industrial concerns as noted below. International NGOs have been particularly enthusiastic, and the Nature Conservancy has taken a leading role in advocacy and in developing a conservation strategy under the auspices of USAID's Parks-in-Peril Program (TNC, 2003). The Windsor Research Centre (WRC) has played a pivotal role in this regard (WRC, 2003), developing a site conservation plan in collaboration with the Jamaican Forestry Department and the Southern Trelawny Environmental Agency (STEA).

There exists within Jamaica a "ground swell" in support of environmental action (McDonald, 1996) and national conservation organizations have generally been unambiguously supportive of the national park proposal. The Jamaica Conservation and Development Trust has highlighted the need for equitable and sustainable use of the area (JCDT, 2003) and the Environmental Foundation of Jamaica has endorsed the plan, developing a Spinal Forest Project, with the goal of re-establishing intact forest cover throughout Jamaica's mountain core (including the Cockpit Country) and also providing financial support to the Southern Trelawny Environmental Agency. Birdlife Jamaica, an international partner of Birdlife International, has also been extensively involved in Cockpit Country conservation, conducting an Important Bird Area (IBA) study in the Cockpit Country and supporting further protection of the area.

The attitude of local residents has been ambivalent, with considerable support but also reluctance, suspicion, and even fervent opposition. Although they have not been quantified by objective surveys, attitudes within individual communities and towns appear varied, with no clear distinctions between urban and rural residents. Some individuals clearly see potential economic and infrastructural benefits from establishment of the park, but others are concerned about prohibition of traditional forest uses, about increasing official intrusion, about loss of traditional ways of life, and about the role of "outsiders". Community meetings have been held in local towns, but with little consensus. This is not surprising, given the heterogeneity of local communities and both the national and regional experience of participatory planning and management of protected areas (CANARI, 2001; Geoghegan and Renard, 2002). Just as protected areas planning proceeds slowly, and not always with consensus, at the level of national government, so local communities also need to resolve complex issues of inclusion and empowerment. In this context, Geoghegan and Renard (2002) identify four key points: (1) community stakeholder diversity must be recognized, (2) appropriate institutions must be involved in participatory management, (3) priorities must be determined through transparent negotiation, and (4) local involvement must provide appreciable benefits.

Much of the local reaction to national park establishment is founded upon incomplete knowledge of future conditions, regulations and usage. An attitude of "leave well alone" pervades certain sectors of the local community, and this is generally understandable, indeed perhaps laudable. Likewise, potential benefits are also poorly documented, and individuals are generally uncertain about what advantages might accrue from park establishment and the attendant activities. Opposition stems in part from those previously, currently or potentially involved in illicit activities, such as timber extraction, hunting or taking of wildlife, who recognise that enhanced enforcement of existing or new regulations will adversely affect their clandestine activities. In general, there is considerable uncertainty about potential benefits and detriments, and how these will impact individuals and organizations. This reflects prior experience, in that "There is much evidence that Caribbean protected areas, especially those with high levels of management, produce significant economic benefits. However, there is also evidence that benefits are not equitably shared…" (Geoghegan and Renard, 2002).

Prominent among the local residents are the Maroon communities of Accompong and elsewhere, whose attitudes are similarly antithetic. The Maroons remain wary of external intervention, and maintain land tenure probity over much of the Cockpit Country. Their opposition or sanction represents a pivotal component in the establishment and operation of the park, and this is increasingly recognised by other stakeholders. The Accompong Maroon community was influential in the decision to re-route the proposed Kingston-Montego Bay highway, and is also involved in discussions about a possible Maroon Theme Park, which would showcase their history and lifestyle (Jamaica Gleaner, 2003).

Opposition to the national park also derives from business concerns, especially the logging, quarrying and bauxite mining industries, which object to the likely proscription of their economic activities. Bauxite mining, associated largely with North America conglomerates, is Jamaica's second largest industry, accounting for about 20% of earnings. Major bauxite reserves are located within the Cockpit Country, but their extraction is patently incompatible with the national park's conservation imperatives (National Environment and Planning Agency, 2003).

Other commercial sectors envision economic benefits from park establishment. For example, the tourism sector stands to gain from increased visitor numbers, although it is unclear at what scale this might occur. The likely focus is on low-impact ecotourism, such as that presently offered by Cockpit Country Adventure Tours, an enterprise located in Albert Town and initiated by the Southern Trelawny Environmental Agency, but individuals have ventured a variety of scenarios, including an incredible proposal for a cable-car system across the Cockpit Country (Jamaica Gleaner, 1999).

Finally, but crucially, the attitude of the national government appears equivocal, with various agencies voicing differing degrees of support for or caution towards the national park proposal.

These agency alignments generally reflect their areas of responsibility, for example, the National Resources Conservation Authority lists declaration of a Cockpit Country protected area in its Environmental Strategy, and the Forestry Department endorses protection of existing forest reserves in its 2001 Forest Policy (Forestry Department, 2001).

One encouraging recent development is a series of symposia on environmental and planning laws being conducted by the National Environment and Planning Agency (NEPA). This series, supported by The Environmental Foundation of Jamaica (EFJ) and USAID and hosted in 2003 by the Jamaica Institute of Environmental Professionals (JIEP), is designed to increase awareness of environmental jurisdiction among the legal profession, potentially leading to increased environmental protection.

Although several government agencies are supportive, there has yet been no unequivocal official government commitment to making the national park a reality. Likewise, there has to date been no official move to seek World Heritage status for the Cockpit Country, which would enhance its reputation and contribute towards its future conservation. Despite the "ground swell' of support, the future of the Cockpit Country still hangs in the balance.

5 Conclusions

Establishment of the Cockpit Country National Park is not going to be a simple matter, and requires extended transparent negotiation between the diverse stakeholders. Although a national protected areas policy is in place, the Jamaican national government has set out no clear agenda for protection of the Cockpit Country, yet needs to take a leading role in establishing legal boundaries, developing management policy, and enforcing appropriate regulations. Industrial and commercial concerns also need to be addressed, with potential economic benefits of park establishment being determined, and clear indication being given of what activities are to be prohibited or permitted, with accompanying rationale based on sound scientific parameters.

Local communities must be involved in the planning process, yet their views are clearly diverse, and may not readily be reconciled. Gaining the support of the Maroon community is critical, but is unlikely to be easy, given their wariness and sense of autonomy. Local stakeholders need to be convinced of the long-term environmental and economic benefits of park establishment, and local NGOs, environmental and otherwise, can contribute to this. These groups, with appropriate guidance from international NGOs, such as the Nature Conservancy and IUCN, have an important role to play in encouraging timely and transparent negotiation and reconciling diverse concerns, and their involvement will be pivotal in bringing together government and community representatives to make the park a viable reality.

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HOT ISSUES IN KARST CONSERVATION: THE BIODIVERSITY OF HON CHONG HILLS (SOUTHERN VIETNAM), WITH EMPHASIS ON INVERTEBRATE ENDEMISM

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Keywords: karst ecosystem, cave fauna, endangered species, limestone quarry, protection.

The karst of Hon Chong - Kompong Trach, located in the south-west of the Mekong basin, straddle the border between Vietnam and Cambodia. It consists of a number of small, strongly karstified hills, and features a dramatic landscape with peculiar vegetation that is unknown in other parts of southern Vietnam or Cambodia. Many caves of high aesthetical value are present. Several of them contain important archeological remains and historical relics of the war of liberation. Surprisingly, an impact assessment released in 1995, prior to the building of a large cement plant north of Hon Chong, hardly mentioned these significant aspects of the environment except for the Mo So cave in Nui Bai Voi. Nor did this study stated having found anything particular or endemic regarding karst animal biodiversity in the region. As a consequence international funding was granted to the cement plant project in order to foster short-term local development because all environmental features were assumed to be insignificant.

The claim that such an isolated and ancient karst ecosystem possessed an unremarkable biodiversity was however suspect, especially as a unique vegetation type had already been described from the area. A team of biologists was brought together to assess this aspect in more detail. Here we summarize the most significant findings made since 1993, with an emphasis on invertebrates. Numerous species new to science and currently endemic to the Hon Chong-Kien Luong hills were discovered in caves and soils of the area and more are yet to be found. Even new genera and supra-generic taxa of beetles and springtails were collected, making the Hon Chong-Kien Luong hills the richest hot-spot of endemism for deep soil fauna known in the tropics.

Limestone quarrying represents an immediate and far reaching threat to this ecosystem and its unique biodiversity. By the time limestone exploitation contract is completed, less than 3 sq km in several separate limestone blocks will be left in the Vietnamese portion of the karst, making of the Hon Chong-Kien Luong hills the most threatened karst ecosystem of the world. Extinction, on the basis of our present knowledge, would be likely for several endemic species. Placed in a broader perspective, the Hon Chong-Kien Luong karst drama raises vital issues concerning priorities in conservation policy as well as questions of the best methods to be used to mitigate ecosystem destruction generated by quarrying.

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A WORLD-CLASS NATURAL AND CULTURAL HERITAGE: THE KARST OF SOUTHERN SULAWESI

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Keywords: biodiversity, caves, archaeology, cave fauna, Indonesia.

This communication summarizes the natural and archaeological values of the southern Sulawesi karsts in a regional and world context, and points to their vulnerability in the face of current socio-economical development.

The southern regions of Sulawesi (Sulawesi Selatan and Sulawesi Tenggara) have a great diversity of karstic landscapes. They include large coral limestone islands like Muna, steep karst slopes covered with pristine forest up to 2800 m altitude in Mt Mekongga, typical kuppenkarst in Bone-Watampone, and one of the world finest examples of cone karst in Maros. This last area is also unique by its long corridors, associated to basaltic dykes, which "cut" the karst landscape. At a finer grain, the Maros karst has the largest and best decorated cave-systems of Indonesia (the SKT system includes a 12.5 km and a 9.7 km long caves), clean and beautiful underground rivers, and mega-shafts only comparable in size with those of Papua Niugini (Lubang Leaputte, -263m). Deep blue holes and a huge karst lake are remarkable karst features of Muna Island, while the Mekongga Mountain is completely unexplored.

The Maros karst is one of the richest and oldest center of human occupation in Southeast Asia. A high density of prehistoric caves with archaeological remains exist in some areas, including rock art painting, specially near Bantimurung and Lealleang in the Maros karst. Data are lacking for most other karsts of the region, though signs of ancient occupation have been found in the Cani karst, and paintings of disputed age exist in Muna.

Biodiversity of this karst is outstanding as well. The Maros karst, studied by Indonesian and French biospeologists since 1985, is by far the richest hot-spot of cave biodiversity known in the tropics, while Muna, more recently investigated, is emerging as the richest in Southeast Asia for anchialin fauna. Nearly 40 obligate subterranean taxa have been recorded so far from 50 documented caves, most of them in the Maros karst and a few in Bone and Muna (while nothing is known from the Mekkonga Mountain). Highly cave-adapted endemic species have been and continue to be discovered and described, as well as phyletically isolated endemic troglobites. Terrestrial habitats host troglomorphic scorpion, spiders, woodlice, springtails, cockroaches and beetles. Cave fish, flatworms, Hymenosomatid crabs, Atyid shrimps, Cirolanid and Anthurid isopods, Bogidiellid Amphipods, and water beetles make up the bulk of stygobites. The origin of such an exceptional biological richness is difficult to understand, as non-subterranean invertebrates of the region remain poorly known. The large size of the karst, its position at the foot of high volcanic peaks, large connections of the karst voids with the water-table and in a recent past with sea waters may explain this high biodiversity.

This natural heritage unmatched in Southeast Asia has come under serious threat during the last decade, because of growing human pressure, and opening of several big quarries. The fast increase in population density around the karst brought many disturbances, first of all illegal forest logging, while in other parts (Mekongga), logging company are very active. The recent quarries that scratch the limestone north of Maros are bringing a rapid depreciation of landscape value, but touristic potential, only very locally exploited, is still huge, and would be the best insurance against further degradation.

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CAVERS, KARST ENVIRONMENT AND NATURAL PARKS: THE EXAMPLE OF THE GYPSUM KARST AREA OF BOLOGNA (NORTHERN ITALY)

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Keywords: gypsum karst, karst environment protection, Italy.

South of Bologna (Emilia Romagna region, Northern Italy) crops out a tract of the Gessoso-solfifera Formation, the major evaporitic formation of the Mediterranean, deposited during the Messinian salinity crisis (6.0-5.5 My B.P.). The whole depositional sequence is around 200m thick, and is subdivided in 16 evaporitic beds from some metres up to 35m thick, interbedded with euxinic marly clay from some decimetres up to 1.5m thick. The rock is a selenitic gypsum, with V-shape twin crystals up to 50cm.

Messinian gypsum crops out in a narrow strip parallel to the axis of the Apennines, the mountain chain that is the backbone of the Italian peninsula, creating a particular geomorphological unit. It is present both in Emilia (West of the region) and Romagna (East), with different features in the two sectors. In Emilia the evaporitic formation has been involved in the translation of allochtonous nappes with NE vergence. These polyphased movements caused this formation to outcrop near the border between the Apennines and the Po river valley, and are responsible for the dismemberment in some blocks, disconnecting the original depositional linearity. The major outcrops are located in the areas around Reggio Emilia and Bologna cities. The Gessoso-solfifera Fm. crops out in Romagna for a wide tract, to form a long ridge named Vena del Gesso. The gypsum formation lies with stratigraphic conformity atop the Marnoso Arenacea Fm., in a generally autochthonous geologic context. Its geographic position is therefore 10–15 km inside of the Apenninic borderline and coincides considerably with the location of its original depositional basin (Fig. 1).

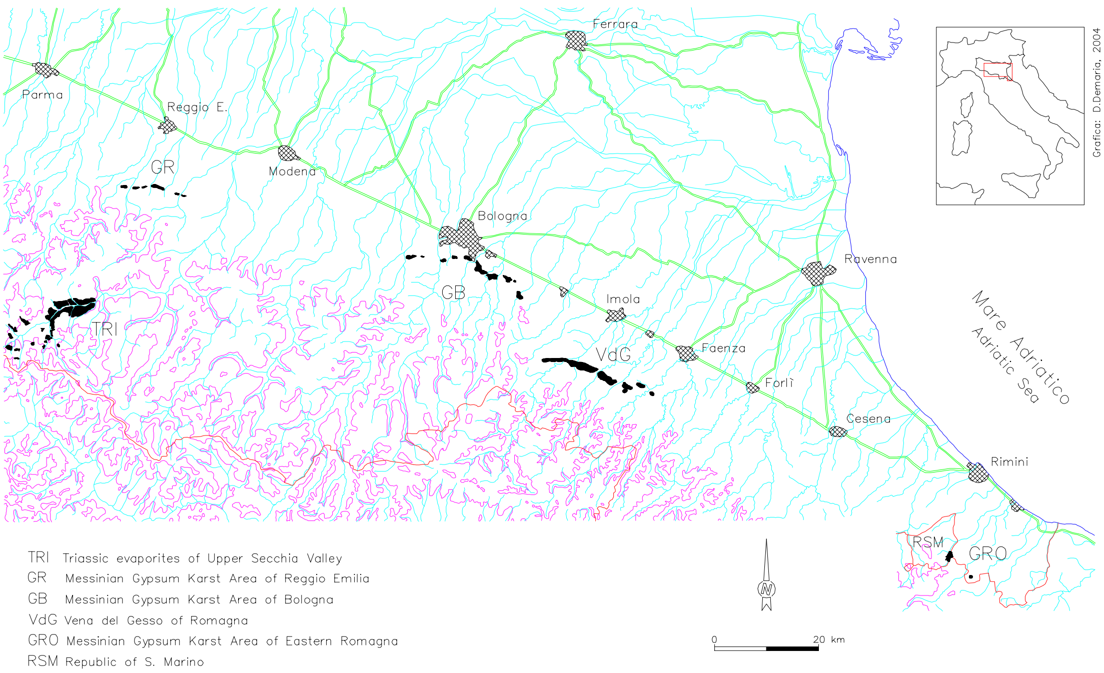

Fig. 1: Study area

Table 1: Protected caves

Cave	Year of protection	Use and notes
Calindri	1964	Only caving, environmental monitoring, Bronze Age site
Pisoliti	1972	Only caving
Novella	1972	Underground Laboratory, environmental monitoring
Buoi	1974	Only caving, environmental monitoring
Bosco	1977	Only caving
Pelagalli	1979	Only caving
Belvedere	1992	Only caving
Spipola	1994	Caving trips for non-speleologists, environm. monitoring
Prete Santo	1997	Only caving, environmental monitoring
Coralupi	2001	Only caving, environmental monitoring

The largest karst areas of Emilia are located in the hills near Bologna, at an altitude between 70 and 360m a.s.l., where the average rainfall is 700 mm/yr. The karst landscape presents the classic morphologies with dolines and blind valleys, and other peculiar landforms such as gypsum bubbles or tumulus and candle-like pinnacles.

In spite of its small surface (a total of only 5 square km), the area has over 200 caves and the longest gypsum karst system in the European Union (the Acquafredda karst system, with a total length of 11.2km and 118m deep). Other important caves are: Gortani Cave (2.0km of length), Gaibola Cave (1,350m), Calindri Cave (1,968m), Farneto Cave (1,014m, an important archaeological site of the Bronze Age declared National Monument), Pelagalli Cave (553m) and Novella Cave (930m).

The Gessi Bolognesi Regional Natural Park was created in 1988 to protect the major gypsum outcrops in the neighbourhood of the city of Bologna; it is in operation since 1990. This is the first example in Italy of a natural park devoted to the protection of the peculiar karst phenomena in evaporitic rocks, furthermore located close to an inhabited area of more 500,000 persons. The course to found this Natural Park was 25 year long and very complicated, but was always stimulated by the local caving clubs. In fact, the first attempts to preserve the karst phenomena in this area date back to the 1960’s, beginning with the closure of some of the most important caves by the cavers.

Today there are ten protected caves (Table 1), one of which is used for caving trips and environmental education for non-speleologists (Spipola Cave) and another one is used as an underground laboratory for the research in biospeleology and in speleogenesis (Novella Cave).

The profitable relation between the Management Agency of the Natural Park and the caving clubs allows better protection of the karst area and the caves. Specific rules are agreed upon the caving activity, and the management of the protected caves is controlled by the cavers, as is the environmental monitoring of the major karst systems of the area, which is carried out by microclimatic control stations inside the caves. For example, in 2001 the Coralupi Cave has been protected with a specific Action of a LIFE project of the European Union for the conservation of the natural ecosystems. In this specific case, our Action is devoted to the preservation of the underground ecosystem and protection of the bats.

The Spipola Cave has a total length of 4.0km and is the central part of the

Acquafredda karst system. The first tract of this cave (about 500m) is used for caving trips for non-speleologists and shows all the characteristic cave morphologies of the local gypsum karst. The trips are guided by young members of a co-operative society who provide cave-helmets equipped with carbide lamps to the visitors and explain the peculiar aspects of the gypsum caves, with special emphasis on the speleogenetic mechanisms and the importance of the caves for the biodiversity. The average is about 1,300 visitors/year, with a ratio of 60% for students of primary and secondary schools. The aim of these cave trips is first of all educational.

In fact the Spipola Cave is not a classic showcave: no fixed structures and no electric lights are used inside the cave. The only artificial pathways are some stairs with the steps cut in the gypsum rock that date back to the 1935, when a first attempt of touristization was made by the founders of the Caving Club of Bologna. The sub-horizontal development of the branches of the karst system allows an easy and quick trip through the cave, creating an ideal condition for the people: a lot are children and frequently only 8 years old. In this case the approach of the guides is of course different according to the age of the visitors. The low number of annual visitors is further explained by the interruption of the cave trips during some times of the year, for example when the bats reside in their nursery.

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DYNAMICS OF CO2 IN THE LASCAUX CAVE: STUDY BY MEANS OF TIME SERIES ANALYSIS

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Keywords: karst, cave, Lascaux, time series, CO_2.

1 Introduction

The cave of Lascaux (Dordogne, France) is a place known all around the world for its paintings and engravings. In 1963, priority was given to the conservation of the site; the cave was closed to the public to become a natural laboratory for understanding of the parameters involved in cave conservation. From a hydrogeological point of view, it is also an experimental site to study the complex functioning of the infiltration zone (epikarst zone) of karst aquifer system (Lastennet, 1999). The cave is just located under the epikarstic aquifer and in the upper part of a paleo-karstic system now partially filled with sand and clay, which can interfere in CO_2 diffusion and distribution processes. Since 1966, numerous and various sensors have been set into and around the Lascaux cave to know the underground flow conditions, climatic conditions and fluctuation of the carbon dioxide gas.

The following study aimed at describing relationship between the complex behaviour of the CO_2 and atmospheric pressure, discharge and/or rainfall in this karst system by means of time series analysis.

2 Geological setting and cave geometry characteristics

The site of Lascaux is located on the left bank of the Vézère River in the north-eastern part of the Aquitain basin. It is into the top part of Coniacian limestone that developed an upper karst system giving now the famous prehistoric site. This system extends downwards into a lower karst system of which only the first level is accessible from the cave.

The cave of Lascaux is known as a downward system with an upper entrance. The cave is composed of three different zones. In the continuity of the entrance an axial zone of 60 meters length (Great hall of the Bulls and the painted gallery), on the right a gallery of 150 meters, from Latteral passage to the chamber of felines with in the middle the "Puits des Sorciers" which gives an access to the last zone called "salles ensablées" and to the lower karst system. The Lascaux cave is a very small system whose volume is estimated between 1900 to 2100 m^3 (Vouvé, 1975). The lower karst system which is only partially accessible would be estimated to 30 000 m^3 (Vouvé, 1968).

3 Measurements into the cave

Many sensors have been distributed in order to monitor external parameters (air temperature, atmospheric pressure, rainfall…) and internal parameters (wall and air temperature, partial pressure of water, carbon dioxide rate, discharge …). Moreover, a system of regulating the atmosphere in order to reduce the condensation process onto mural paintings and a mechanical ventilation system to decrease CO_2 concentration are set into the Lascaux cave. Four parameters are used in this study: rainfall, atmospheric pressure, CO_2 concentration and discharge. For CO_2, we focus on two sensors location: the "Galerie Mondmilch" (Mondmilch gallery) and the "Puits du Sorcier" (the Shaft of the Dead Man). These different time series were recorded for 25 years with an average lag time of one day. Since 1996, the average lag time is of 10 minutes. These long time series are suitable for a time series analysis in time and frequency domain. Each time series is regarded as a realisation of a stochastic process. Autocorrelation, cross-correlation, density of variance, gain and coherence functions are

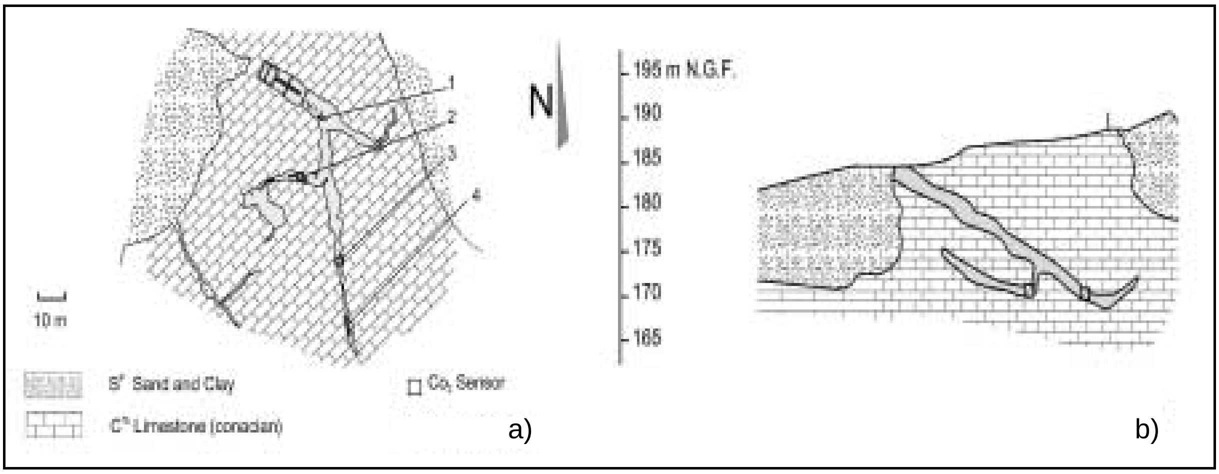

Fig. 1: a) Geomorphologic map (Vouvé 1975) 1- Salle des taureaux – Great hall of the bull, 2- Puits du sorcier –Shaft of the dead man, 3- Galerie mondmilsh – Mondmilsh gallery, 4- Cabinet des félins – Chambers of felines. b) Schematic section along the cave of Lascaux showing CO_2 sensors depth location.

then used to provide knowledge about the behaviour of the CO_2 in the Lascaux cave.

4 Data analysis

Both CO_2 sensors are located at the same depth (Fig. 1b) and on average, when the mechanical ventilation is turned off, the CO_2 is between 1 to 1.5% into the "Galerie mondmilch" and between 4 to 5% into the "Puits des Sorciers". Various measurements of $\delta^{13}C$ into the Lascaux cave for these two different locations show that the CO_2 is produced from the biogenic activity ($\delta^{13}C \approx$ -21.5 –22.3 $^{0}/_{00\ PDB}$). However time series of CO_2 recorded in Lascaux cave exhibit different behaviours as illustrated in Fig. 2. First, it must be compared the atmospheric pressure into the "Puits des Sorciers" and the atmospheric pressure outside the cave. The cross-correlation between these two times series is excellent (>0.95) and any delay can be supposed (delay <10 minutes). The atmospheric pressure in the Lascaux cave follows the outside one and the propagation of a pressure perturbation into the cave of Lascaux is without delay. Figure 2 shows sections of atmospheric pressure and CO_2 time

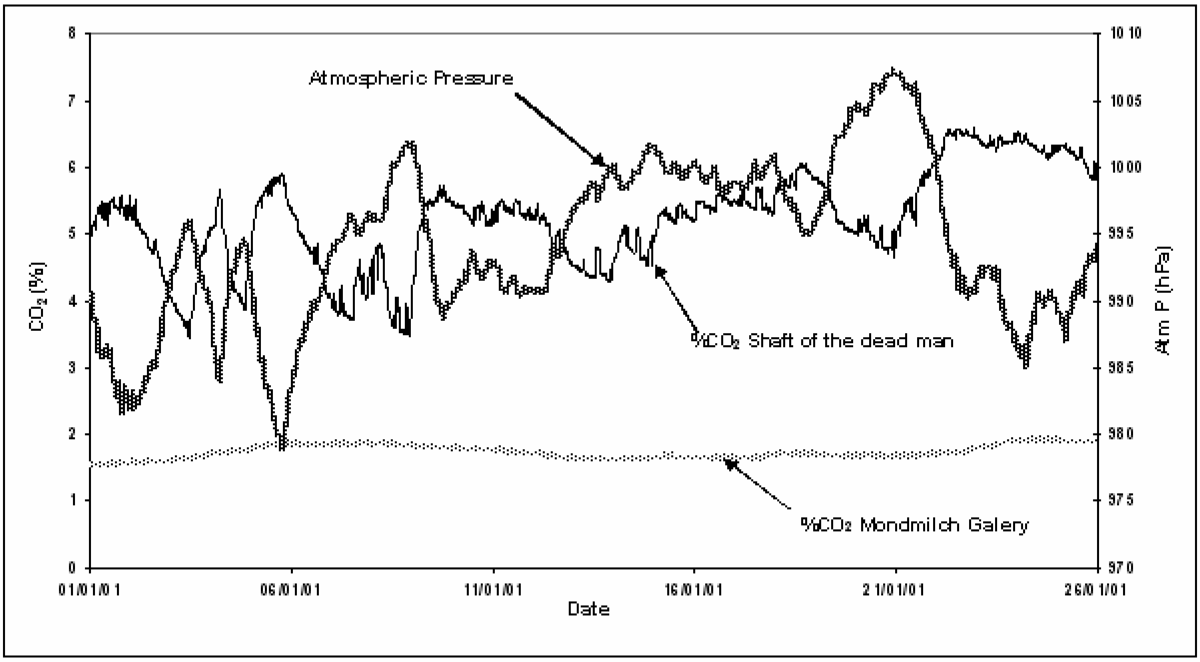

Fig. 2: Example of carbon dioxide gas pressure time series recorded into the Shaft of the Dead Man and the Mondmilsh gallery and atmospheric pressure.

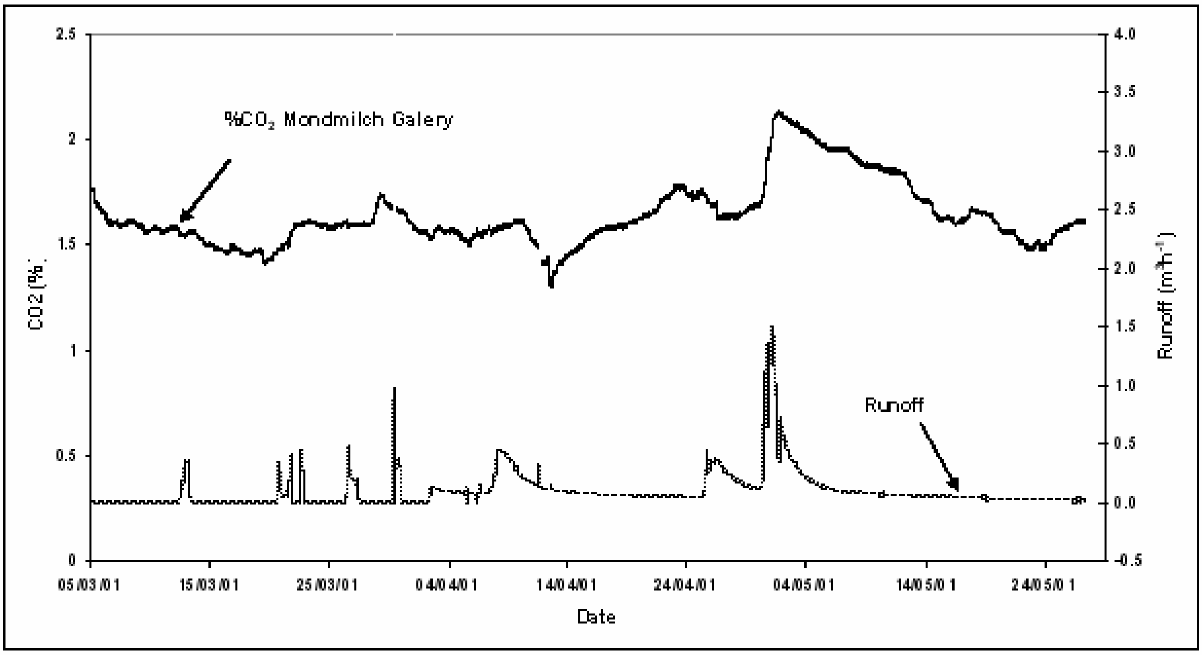

Fig. 3: Carbon dioxide gas pressure into the Mondmilch gallery and outflow rates during a same period extending from 03/05/2001 to 05/27/2001.

series collected during one month in 2001 into the "Puits des sorciers". As expected the cross correlation function gives a negative value of about -0.7 for the cross correlation at lag 0. Moreover cross-spectral density and the function of coherence confirm the linear behaviour between these two times series when a statistical tool as the entropy of a curve is used to detect stationary zones into a times series (Denis and Cremoux, 2002). It can be written the following relationship:

$$\frac{dCO_2(\%)}{dPatm(hPa)} = -0.12 \text{ for Patm<995 hPa and}$$

$$-0.075 \text{ for } 995<\text{Patm}<1008 \text{ hPa}$$

This model can be applied to the whole CO_2 time series in order to remove the effect of atmospheric pressure on CO_2 variations. This new time series is now considered as an output whereas rainfall and discharge are regarded as input. The CO_2 time series exhibits seasonal behaviour but second order variation of CO_2 cannot be explained from rainfall or discharge data. Fluctuation of CO_2 concentration into the "Puits des sorciers", when biogenic activity is low, is only controlled by atmospheric pressure.

Unlike of the carbon dioxide gas pressure recorded into the "Puits des sorciers", the CO2 concentration recorded into the "Galerie mondmilch" are not influenced by atmospheric pressure (Fig. 2). This time series does not need any correction and can be used directly in a time series analysis with discharge as input data (Fig. 3). Cross correlation analysis gives, with a time-lag of 16 hours, a maximum value of 0.40 for the coefficient of correlation. Even if this value stays suitable (13140 samples) factors other than runoff enter the relationship between the two variables, showing non-linear response in epikarstic system.

5 Conclusions

Time series analysis highlights the complex behaviour of CO_2 in a cave and show, for the cave of Lascaux, two different behaviours for the carbon dioxide. Results show the significant role of the atmospheric pressure in the variation of the CO_2 concentration into the "Puits du Sorcier". The sensor is located closest to the lower paleo-karst system which volume has been estimated to 30 000 m^3 under the cave of Lascaux (Vouvé, 1968). This zone might be regarded as a confined reservoir with a high partial pressure of carbon dioxide, whose "Puits des sorciers would be one of the outlets. Another source of carbon dioxide might be the sand and clay formation located all around the cave. The origin of carbon dioxide is organic but more field experiments are required to understand the source of this gas. For the Mondmilch gallery but also for the Great Hall of the Bulls, the variation of carbon dioxide gas pressure seems to be more influenced by the runoff, which shows the influence of the flow transfer into an epikarst system on the dynamic of the CO_2 in a cave.

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INTEGRATED MANAGEMENT OF NATURAL RESOURCES: THE ROLE OF FRAMING AND REFRAMING

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Keywords: natural resources management, framing, multi-stakeholder interaction, ambiguity, negotiation.

"The problem is that there are too many meanings, not too few. The problem faced by the sensemaker is one of equivocality, not one of uncertainty. The problem is confusion, not ignorance."
(Weick, 1995:27).

1 Introduction

In our current world people experience confusion as a consequence of the apparent unpredictability of events in the natural and socio-economic environment. Ecological systems appear very complex, their sustainability seems endangered and they are interrelated among each other and with social and political systems. The public generally expects scientific experts to procure predictability and politicians to assure order in these chaotic systems. These conditions resemble what Emery and Trist (1965; Trist, 1983) described already almost 40 years ago as “turbulent fields”, which are characterized by unpredictable, interdependent and quick changes. They argued that negotiated orders between all actors are most adequate to respond to such circumstances. However different actors may hold very different frames defining what really is at stake. This implies a shift in attention from solving clearly delineated problems to continuous negotiating and tuning between different actors, expertise domains and decision centres. The contribution of experts does not consist then in giving the illusion to the public of a total certainty, control and predictability, but in supporting a joint learning and negotiation process among different social actors to deal adequately with the uncertainties, and in feeding this process with relevant information. While modelling tools may have an important function in providing information, behavioural simulations may play an important function to stimulate multi-actor learning and negotiation processes.

2 Uncertainty, ambiguity and framing

According to Karl Weick (1995) ambiguity is caused by too many interpretation possibilities of a situation, while uncertainty is caused by a lack of information to give any reasonable interpretation. Uncertainty refers to situations in which the problem solvers consider the structure of a problem - including the set of relevant variables - as given, but are dissatisfied with the present knowledge of the values of the parameters (Van Looy, 2000). In uncertain situations it is still rather clearly defined which aspects or parameters are unknown, and gathering more information of the same kind can often solve the uncertainty. In other words, it is clear which frame to apply, but not (yet) how it should be filled in. In ambiguous situations, however, what is at stake is not the value of certain parameters but the structure of a problem – i.e. what the relevant parameters are – or even which problems should be tackled. What is ambiguous is the meaning of a situation and which frame should be applied to make sense of it. While uncertainty can be located at the boundary between knowing and what is yet unknown within a certain frame, ambiguity can be located at the boundaries between different frames of knowledge or different kinds of knowing

The concept of equivocality captures perhaps best the kind of ambiguity created by the existence of two or more equally plausible interpretation possibilities. Weick (1995: 95) suggests this term because "although the word *ambiguity* also means the presence of two or more interpretations, it can also mean something quite different, namely, a lack of clarity, which … makes it quite similar to uncertainty". We will continue to use the term ambiguity, in its meaning of equivocality.

The integrated management of natural resources is increasingly faced with indeterminacy and uncertainty. At the same time, integrated management means taking into account the interdependencies between different uses and users and thus involving different stakeholders in a collaborative decision-making process, each with their own perspectives, interests and priorities.

Frame differences can occur in various forms and at different levels. Frame differences can occur between different scientific disciplines, like the social and natural sciences. Different levels of government involved act within different electoral, scale and responsibility frames. The environment may also mean very different things for actors like water using industries, farmers, tourist agencies or development NGO's. Apart from these more institutionalized stakeholders, loosely organized and sometimes transient stakeholders can emerge, for example a group of inhabitants of a frequently flooded region or a protest group against the construction of a dam.

An interactive approach to framing (Drake and Donohue, 1996; Gray and Donnellon, 1990; Putnam and Holmer, 1992), concept draws the attention to the concrete interactions where actors bring in their conceptions of problems and possible solutions, and how they affect each other's concepts in and through a developing relationship. In such an approach issue are primarily understood as sensemaking devices used for interacting and communicating with others. This differentiates our frame concept from an alternative concept of frames as mental schemata (see Benford and Snow, 2001). As Dewulf, Craps and Dercon (in press) showed, the frames that stakeholders use to make sense of situations are both a reaction and an anticipation to a specific problem domain and to specific other stakeholders.

3 Dealing with multiple frames: uncertainty and ambiguity in decision-making processes

In a participative decision-making process where multiple stakeholders are involved, these different frames meet each other. This creates a situation of ambiguity where multiple frames or perspectives are present at the same time. When different stakeholders try to make sense of the situation from their point of view, they will understand the situation differently, prioritize different problems, include or exclude different issues and favour different kinds of solutions.

Putting the definition of the situation at issue, which is often ambiguous or interpretable in various ways that all seem valid simultaneously, constitutes a trigger for new sensemaking by social construction and negotiation. This has important managerial consequences, because in ambiguous situations information has to be dealt with differently. Since this ambiguity is the result of the different frames that different stakeholders bring with them, ambiguity cannot be reduced in a straightforward way. Adding more and more information is likely to increase ambiguity instead of reducing it. What is needed then is more and more varied cues and mechanisms that "enable debate, clarification, and enactment more than simply provide large amounts of data" (Daft and Lengel, 1986, cited in Weick, 1995:99), in order to create meaning through discussion and joint interpretation. Rich personal media of communication such as meetings and direct contact become more important than poorer impersonal media such as formal information systems and special reports (Weick, 1995: 99).

Social learning, negotiation and conflict management strategies become more important when dealing with ambiguous situations, because the relation between different stakeholders and their frames is at stake. A process called reframing has been identified as a possible way of tuning and connecting different frames. It involves a redefinition of the common problem domain and the frames of stakeholders that makes possible a compatibility or integration between them. Ambiguity is then not only to be considered as problematic and negative, it is also an opportunity for change. It may produce a shock among the involved actors that motivates them to engage in joint sensemaking. Paradoxically, research indicates that reframing may even need ambiguity (Van Looy, 200; Baervoets, 2000; Dewulf, Craps and Dercon, in press). When the relevant differences are voiced and explored within a constructive relationship between stakeholders, the resulting confusion offers possibilities for re-structuring the issue on different sides and thus making connections between the different frames involved. In this sense also, transitions and innovations need ambiguity in order to happen but at the same this ambiguity has to be kept manageable.

4 Conclusion

In our analysis, we tried to illustrate a way of conceiving uncertainty and ambiguity as properties of an interaction and communication process between multiple stakeholders involved in natural resources management in which the meaning of a common problem domain is negotiated through the way the different stakeholders frame the issues. Different languages and formulations produce very different versions of what is the case and what should be done and dealing with this ambiguity is crucial for any form of integrated management. Dealing with these frame differences in a reciprocal way requires a mutual acknowledgement of frames and inputs and their connection into a reflective conversation where the different parties and their issues can feel included. Some or all parties will have to revise, enlarge or reframe the way they relate to the issues and to each other, in order to create a vocabulary that can support mutual understanding and common action, which is crucial for reaching an effective collaborative management of natural resources.

Scientific and technical expert actors, whose frames of knowledge have high status, tend to take their frames for granted. By not taking into account the social consequences of their ideas, they may wrongly assume that their frame will eliminate the ambiguity out of a complex situation. Often experts do not like to be involved in negotiation processes, belonging for them to the realm of the social and personal interests, of which they consider themselves exempted. Therefore, they leap directly to uncertainty reduction, while ambiguity among different frames still has to be dealt with, and new frames have to be created which are meaningful for all the actors. New meanings are not generated as a result of one or another diagnostic or accounting procedure, they are negotiated in direct, personal, emotionally laden interactions, in which persons and groups feel involved. Experience, insight and skills in communication and negotiation processes to deal with ambiguity in multiparty settings is then to be considered a major requirement for all, including scientific experts, policy makers, administrators and specific interest groups representatives, to reach integrated, adaptive and sustainable management of complex (natural) environments.

Behavioural simulations of multi-stakeholder situations offer possibilities for learning about ambiguity, for dealing with ambiguity and for researching ambiguity. For learning purposes, behavioural simulations can create ambiguous situations for the participants to experience. This is accomplished by assigning them different groups and diverging interests to represent and foreseeing moments of interaction between (representatives of) the different groups. For intervention purposes, behavioural simulations can be used to engage different stakeholders to interact within fictitious or quasi-real contexts, where they can learn to deal with their mutual framing differences. For research purposes, behavioural simulations can be seen as simulated or miniature social systems that can be used for obtaining observational data on how ambiguity and differences in framing are dealt with.

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CAVE DATABASE DEVELOPMENT, SPATIAL ANALYSIS AND 3D VISUALIZATION WITH GIS CASE STUDY IN SON LA (VIETNAM)

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Keywords: Son La karst, cave, database management, spatial analysis, 3D analysis, 3D visualization, web-based visualization, VRML.

In the Son La karst region, caves developed in the carbonate rocks are aged from Paleozoic to Mesosoic. The data from caving expeditions unveiled specific underground worlds, having various landscapes with complex and irregular topography. This research discusses the development of a GIS-based cave database, the analysis of the spatial relationship between cave development and tectonic activity and the construction of a three-dimensional (3D) model of the caves. Results from analyses make it possible to get a better understanding on karst formation and groundwater movement.

The cave data model contains cave objects (such as cave passages and cave station) and its attributes, which efficiently represents the real world caves. The spatial database of caves containing the cave objects was developed with the help of ArcView GIS, CaveTools and COMPASS software. The tabular database consisting of measurements that have been collected at cave surveys was developed with MS Access 2000. Dynamic link between the spatial and tabular databases in the GIS application was made through ODBC, a programming interface that enables applications to access data in database management systems that use Structured Query Language (SQL) as data access standard.

As a result, the GIS-based database makes it possible to fully represent the 3D nature of the caves allowing spatial analysis and 3D analysis.

Many researches confirm the critical importance of fractures in controlling the groundwater movement and cave development in carbonate rocks of Paleozoic and Mesozoic age. Different spatial analyses, prior to the features formed by tectonic activities, were examined to reveal the relationship between the development of caves and the tectonic structures in the karst area of Son La. ArcView Spatial Analyst and COMPASS were used for performing spatial analysis.

The results of analyses confirmed that the development of caves was closely controlled by the tectonic activities. Even though the influence of geological structure on cave development is variable, so that it is not possible to provide a set of simple rules governing the influence of faults and fractures on cave development.

In carbonate rocks that do not have primary intergranular voids, fractures, joints and fissures are essential for initiation of downward percolation of water. After a recharge/discharge system is established, permeability of the carbonate rocks will increase with time, water gains access to the carbonate unit and moves through the most permeable unit. The movement will gradually enlarge the fractures with time to form caves. Tilted and folded strata induce additional constraints on groundwater flow directions. In tiled open carbonate rocks, groundwater will initially flow in a down-dip direction. The groundwater may flow parallel to the bedding as well as along fractures that cross the beds. Other factors should always be considered including topography and hydrologic setting. Once a recharge/discharge system is established through channels controlled by fracture patterns, topography and/or hydrologic setting will play the most important role in the formation of caves.

Underground caves are truly three-dimensional with a complicated spatial distribution and a great variety of features. It is difficult to use conventional surveying data and representation methods to reconstruct realistic 3-D caves. The GIS cave database, using ArcView 3D analysis to develop a 3D cave model as a tool for studying the cave geometry result in a quick, intuitive and transparent result.

The topography, fault map and river network were successfully integrated with the cave data in a 3D environment. The incorporation helps us to visually study the relation between cave development and the other controlling factors: topography, tectonic activities and hydrological regime. This process supports the understanding of the structure and patterns of a cave.

As the WWW is an increasingly important medium for GIS applications, a VRML model of the caves has been utilized for web-based, 3-D visualization. The VRML has already shown a capacity to design highly realistic and dynamic worlds with respect to visualization and exploration.

The limitation of this model is that the Web users can only use the end VRML documents and can expect little or no processing of 3D data across the Internet. The dynamic creation of complex VRML documents enable further query and enhanced visualization techniques. Adding 3D GIS operations to VRLM will be the next step towards improved visualisation over internet.

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GEOPARKS IN THE MOUNTAIN KARST OF VIETNAM, ITS POTENTIAL CONTRIBUTION TO LANDSCAPE CONSERVATION AND SUSTAINABLE LAND USE

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Keywords: geodiversity, geoconservation, geotourism, landscape.

1 Preamble

Oriental city gardens intend to bring nature in the cities for good health and progress of intellectual faculties. The Chinese term for landscape, "shan shui" means "mountains and water" and no garden is without rocks or pool. Rocks are placed in groupings that suggest rugged cliffs and soaring peaks. Most prized are the strangely shaped standing Taihu stones, composed of corroded, karstified limestone (Keswick, 2003). Symbolic miniature karst landscapes are omnipresent in gardens and testify of the great reverence for the gentle forces of nature that model the enchanting karstic scenery. Karst ecosystems in Vietnam which have been hospitable for traditional lifestyles but have so far resisted demographic pressure and industrial development are still quite well preserved but also under severe threats. The spiritual and physical links between Taihu garden stones and tower karst may contribute to better understanding of the values of the karst, respect of nature and willingness to its protection.

2 Why geoconservation is needed

A growing, world-wide concern for the preservation of a green and healthy environment, accompanied by the emergence of quality of life requirements and a quick rise of the leisure economy, have gradually led to the vision of landscapes, biodiversity and geological sites as important components of the natural heritage. Corollary, the number of protected monuments and sites, both cultural and natural, is ever growing, including no longer only the truly exceptional but also the more vernacular. Although the vulnerability of the natural environment is mainly addressed by measures to preserve biodiversity, the geological foundation of the living ecosystems is increasingly considered as an integral part of this heritage.

Geosites are landscape components, which illustrate the history of the earth and provide evidence of past life, ecosystems, environments and climate. They are keys to forms (bedrock, soils, geomorphological landforms) and processes (biological, hydrological, atmospheric, encompassing both active, or ongoing, and passive, or fossil, processes), necessary for understanding complex relationships in the system Earth and landscape evolution. Geosites form the striking examples of *geodiversity*.

For each geosite a practical, site-specific conservation management strategy needs to be developed and implemented. This strategy involves documenting the importance of the site, planning and implementing practical conservation and protection measures, site monitoring and site enhancement (Ellis *et al*., 1996). Whereas some sites are of exceptional international importance which justify their nomination among UNESCO's World Heritage Sites (e.g. Ha Long Bay), most sites are important for understanding local, national or regional geology or geological processes.

Geoconservation aims at conservation of geodiversity for its intrinsic, ecological and (geo)heritage values, whereas *geotourism* can be defined as the provision of interpretative and service facilities to enable tourists to acquire knowledge and understanding of the geology and geomorphology of a site beyond the level of mere aesthetic appreciation (Gray, 2003).

Effective preservation strongly depends on raising awareness and education of the citizens, following the chain from knowledge over appreciation to protection. Local citizens take pride in 'harmonious' scenery where nature and culture both have contributed to create stable landscapes with high aesthetic values, while tourists equally appreciate these values (English Heritage, 2000). Karst landforms, which characteristically combine positive and negative topography, yielding ever changing vistas, correspond to this aesthetic ideal. Karst therefore represents the perfect setting for experiencing the processes that model the earth and sustain life.

Karstic features range from single geosites (e.g. a swallow hole), to geosite groups (e.g. a blind valley) to geosite landscapes (e.g. contiguous limestone exposure areas). Protection measures should aim at the maintenance of the physical integrity of the sites, the natural function of hydrographic systems and the identity and dynamics of the karst landscape.

3 UNESCO's Geopark concept

An international group of experts assembled at the 30th session of the IGCP Scientific Board held in February 2002, Paris, recommended to establish a 'Global Network of National Geological parks (Geoparks) seeking UNESCO's assistance' in order to promote the three goals of conserving a healthy environment, educating in Earth Sciences at large, and fostering sustainable local economic development. In May 2002 the draft Operational Guidelines for application were released.

Geoparks thus are territories where "the geological heritage of the earth is safeguarded in combination with a sustainable development strategy".

Geoparks must consist of territories with clearly defined boundaries and acreage for true territorial economic development. Basic choices have to be made, to aim at protection of nature and/or of development of the local economy. Starting a geopark or nature park project generally gives rise to a large consultation of local authorities and stakeholders (Patzak, 2000).

Creation of Geoparks, according to the UNESCO definition and principles, is complementary to other nature protection initiatives and avoids duplication of efforts and conflicts of interest with nature protection agencies, already well established in the country. Geoparks closely correspond to category V. *Protected Landscape/Seascape* of the *International Union for Conservation of Nature* (IUCN) or the *National* or *Regional Nature Parks*, established in many European countries (Normand, 2004).

China quickly established 44 national geoparks (Zhao and Zhao, 2003), whilst in the European Union, out of regional geoparks and nature parks, a network of European Geoparks ™ was created, actually comprising the Réserve Géologique de Haute-Provence (France), Geopark Vulkaneifel (Germany), the Petrified Forest of Lesvos (Greece), Maestrazgo Cultural Park (Spain).

4 Mountain karst in Vietnam, problem statement

According to the *Comprehensive Poverty Reduction and Growth Strategy* (CPRGS), poverty remains widespread, especially in rural, mountainous, remote and isolated areas, in areas with unfavourable conditions for making a living, and in areas where ethnic minorities live. Natural resources have not been exploited effectively, economically and sustainably, with continued environmental and sanitation degradation (natural forest reduction, improper mineral exploitation, soil erosion and degradation, water shortage and pollution, bio-diversity decline etc.). Not surprisingly, the poorest regions are also the major karst regions of Vietnam.

Agriculture in the mountain karst areas is economically uneconomic, except for specialised crops, and thus will not be able to contribute to poverty reduction at a scale even remotely comparable to the rapid growth of prosperity in the plains. Alternative ways of job creation are necessary among which tourism and forest management seem to be the most likely.

Karst regions are, moreover, very fragile and vulnerable to natural disasters (flashflood, mudflow, inundation, rockfall, landslide etc.) and technological problems (water loss and leakage from reservoirs, foundation problems, water shortage and pollution etc.). Furthermore, not only karst regions are vulnerable to disasters locally. In many cases, their degradation is the cause of other types of disasters, such as floods, siltation, riverbank and coastal erosion etc., even more severe and at a larger scale, in the densely populated downstream floodplains and coastal regions.

5 Potential targets for Geopark development

Fortunately, karst has some unique features that, if well understood and appropriately used, could contribute to poverty reduction in karst regions. They might not be able to improve much an agriculture-based economy, but they could offer alternative way(s) for a balanced development and conservation. So what are these unique features?

Cave system and underground water. Karst regions may not have surface water but they usually have plenty of water underground. Although it is located not everywhere underground, there are appropriate and effective methods for the exploration and use of this water.

Bio-diversity and conservation. Rugged, remote, scarcely populated, many karst regions of Vietnam remain among the world richest bio-diversity areas. Most of Vietnam's national parks (e.g. Cuc Phuong, Phong Nha-Ke Bang), nature reserves (e.g. Vu Quang, Na Hang-Ba Be, Pu Luong etc.) are located in karst regions. Karst regions offer a very good opportunity, and at the same time, challenge, for a balanced development and conservation.

Good soils. Soils on karst are stable and rich in nutrients and have long supported subsistence farming, but are gradually removed by erosion, leaving vast tracts of lands as bare rock. While at some places these soils will support new cash crops, reforestation and forest management is a more viable option on the rugged land and should be included in sustainable land use.

Landscape and tourism. Karst regions are known for so many beautiful, breath-taking landscapes. They have been and are offering vast (mostly untapped), tourist potential, including outdoor sports as hiking, caving, mountain climbing, rafting, horseriding etc. Many famous tourist areas of Vietnam are karst, e.g. Ha Long Bay, Cuc Phuong, Phong Nha-Ke Bang, Na Hang-Ba Be etc., some of which have become world nature heritages.

Diversified ethnic cultures. Karst mountainous regions are home to ethnic minority peoples with their unique cultures. Along with all the natural features described above, social and cultural identities and traditional way of living bring a lot of surprises and interests to tourists.

All these unique features are, in many cases, not to be taken for granted. They must be thoroughly investigated before any practical recommendation can be made and any development activity implemented. Karst underground water, for example, must be explored before any decision upon drilling or pumping. Different types of karst soil must be studied before recommending the most suitable type of crop. The landscapes, the caves, the access to them etc. must be evaluated well in advance before any tourist investment etc. Thus, field research is a coherent part of conservation, and conservation will equal development for karst regions.

An area which could fit the definitions of a geopark is the karst range where 2 protected areas already have been established, namely Cuc Phuong which is the first national park of Vietnam and Pu Luong, a very recently established nature reserve. A «corridor» (proposed to become the Ngoc Son reserve) between Cuc Phuong and Pu Luong will strengthen the existing protected areas and will improve the stakeholders' capacity to manage the wider karst ecosystem. The existing legal and institutional framework for "Special-Use Forests" in Vietnam and planned policy are in accordance with IUCN management plans and sufficient to accommodate the Geopark concept.

6 Guidelines for development: visitor management and education

World wide, tourism is one of the fastest growing economical sectors with a high added value. Regions of outstanding natural beauty experience a large growth of eco-tourism as well. Tourism and recreation has become a priority activity in the majority of nature parks worldwide, whatever their legal status. Often it is the same natural value that attracts the visitors, that suffers the most from these very visitors. Dealing with this tourist pressure requires investment on infrastructure such as visitor centers, information points, shelters for wildlife watching, signposting, selective mobility and money for professional guiding services ("rangers"). Local inhabitants, living along the tourist trails, can be trained to tell about making a living in a semi-natural environment, thus supporting authenticity and historical background to the geopark. All of the above is necessary to assure sound ecological management of the geo-heritage. Tourist management and nature conservation have to enforced and reconciled, in combination with preservation of the biosphere and the cultural legacy, maintenance of the ecosystem and geomorphological integrity, and allowing some economic exploitation of the natural resources. "Visitor Payback" schemes have to be developed, enabling sound management of the resources, generating stable income. An additional benefit from eco-tourism may also be the acceptance of restrictive protection measures and increased awareness concerning the need for investments in nature and landscape. Regular evaluation of the geopark's performance, typology of its visitors and assessment of its management practices is necessary to guarantee customers satisfaction, conservation of a healthy geo-bio-cultural heritage and effective sustainability (Eckhardt and Weber, 2003).

6 Conclusion

The Geopark concept, established with the assistance of UNESCO, aims at promoting the conservation of a healthy environment and geodiversity, education in Earth Sciences and sustainable local economic development. Geoparks are complementary in scale and scope to other measures for protection and conservation and can be based on the legal instruments established in most nations for the conservation of monuments and sites and for the protection of ecosystems in danger.

Although operational examples come from the European Union and China, it is suggested that application of the geopark concept to the mountain karst areas in Vietnam may be the best way to guarantee preservation of the unique karst landscape, offering at the same time sustainable development and an acceptable share of the national growth of standards of life to its inhabitants.

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BRITISH CAVE EXPLORATION IN SOUTH EAST ASIA

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Andy Eavis will report on the work his team from Britain have been doing in South East Asia for almost thirty years. They started work in Papua New Guinea in 1975 with what was probably the biggest caving expedition of all time when a team of 24 – most of them young people aged less than 30 years of age – spent six months in the field.

Since then the team has worked in many other areas of South East Asia, discovering some of the largest caves, cave chambers and cave passages in the world in places such as Mulu (Sarawak, Malaysia). They have completed several highly adventurous sporting forays to Irian Jaya, the Indonesian part of the island of New Guinea, and water resources projects in other places, particularly Gunong Sewu on the Indonesian island of Java.

More recently, they have concentrated on China and since the parting of The Bamboo Curtain in the early 1980s, they have completed over 20 expeditions. Most of these trips to China have been made in conjunction with the Guilin Karst Research Institute, originally with Yuan Daxian but more recently with Professor Zhu Xuewen.

The highly illustrated lecture will show the work of the past two decades during which time at least 500 kilometres of cave passage have been explored in China - much of it on a gigantic scale with long caves, large caves and very deep shafts abounding.

Explorations have centered on South-East China, particularly the Provinces of Guangxi and Sichuan with visits also to Hunan, Yunan and Guizhou Provinces among others. There has always been close cooperation with the Chinese, enabling very prolific field work. Nowadays, under the auspices of the China Caves Project and a Western-led Chinese offspring called Hong Meigui, the team fields up to five expeditions a year.

The pace of exploration has “hotted up” and in the last few years, hundreds of kilometres of passage have been surveyed and several of the deepest shafts in the world explored.

Although the exploration work in China continues, other countries in South East Asia have also come under the spotlight, including Thailand and Myanmar and recent work in these countries will also be presented. Going into the future, it is very possible that length, depth and size records will all be beaten in caves in South East Asia.

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INTERDEPENDENCIES AND DYNAMICS OF LAND, FOREST AND WATER RIGHTS – THE CASE OF A KARST REGION IN NORTHWESTERN THAILAND

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Keywords: resource rights, tenure security, legal pluralism, resource management, conflict resolution, Thailand.

1 Introduction

The karst regions of the northwestern Thai highlands are the homeland of different ethnic minority groups. Their traditional agricultural systems, dominated by swidden agriculture, are blamed by the authorities as being unsustainable and the main culprit for forest destruction and land degradation. In the name of conservation the Thai government strongly adheres to the principle of state control of forest areas and has designated a large share of the mountain regions as protected areas, such as national parks, wildlife sanctuaries, and watershed conservation zones guided by a 'forest without people' paradigm (e.g., Ganjanapan, 1997). Traditional tenure regimes and resource management of the upland communities have generally been disregarded. This resulted in a high degree of insecurity of forest, land and water rights and has created a multitude of conflicts between government agencies and communities, upstream and downstream communities and between farmers within a community (Ganjanapan, 1998; Rerkasem, 2003).

Rights on land, water and forest have often been analyzed in an isolated manner. Few studies have focused on the interrelations between the rights of these resources. This paper investigates the control, use and property rights of land, water and forest and the interdependencies between these rights in a comprehensive approach.

2 Study area and methodology

The study area is located in the northwestern mountainous region of Thailand in Pang Ma Pha District, Mae Hong Son Province. It is characterized by limestone mountains with high ridges, steep sloping land and narrow valleys along rivers. The altitude in the area ranges from 500 to 1300 m asl. The mountains are dominated by dry mixed deciduous forest and small patches of evergreen hill forest. Water resources are determined by the karst characteristics; due to high percolation surface water is hardly available for irrigation and household consumption during dry seasons, causing severe water shortages.

Three ethnic minority villages were selected to analyze the use, tenure, and management of natural resources. The Shan village **Mae Lana** is located in the valley of the Mae Lana River at 800 m asl. The ancestors of the inhabitants migrated from Burma more than 200 years ago and could occupy the fertile valley bottoms which are suitable for paddy rice cultivation, which is the main agricultural activity today. Since the irrigated area is not sufficient for sustaining food security, the villagers also cultivate upland crops such as rice and maize and, to a small extent, fruit trees.

The Black Lahu people of **Ja Bo** migrated into the area more than 30 years ago and had to settle on less fertile marginal slopes. The village is located on a mountain ridge at an altitude of 950 m asl surrounded by limestone rocks. The village **Bor Krai** is located at an altitude of 750 m asl. It was founded by families from Ja Bo 26 years ago as, with increasing population, land resources in Ja Bo became scarce. Main agricultural activities in the Lahu villages are cultivation of upland rice, maize and vegetables like cucumber and pumpkin. In addition, the people are engaged in pig and cattle raising, which provides most of the cash income, and the collection of non-timber forest products.

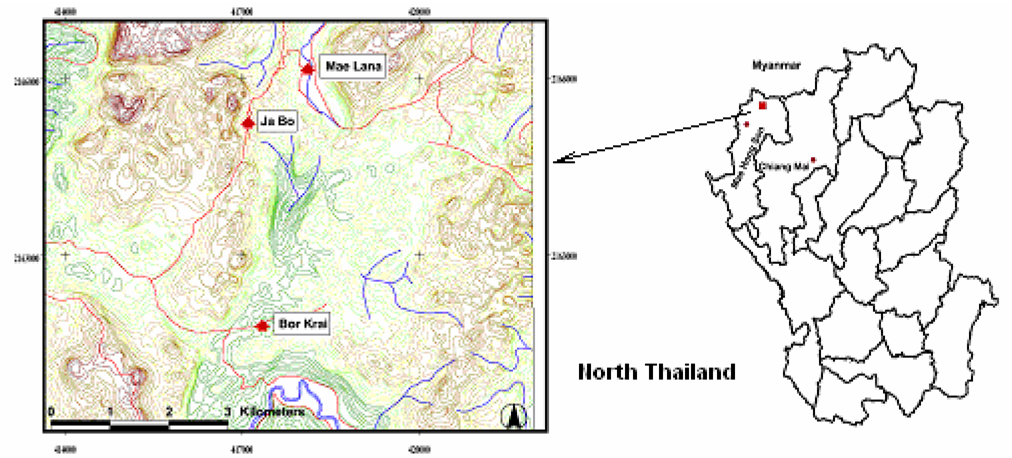

Fig 1: Location of the study villages

The research is based on qualitative and quantitative surveys conducted from 2003 to 2004. Different stakeholders and their role in the control and use of land, water and forest resources are identified. Information on the use and management of natural resources at the community level was obtained from semi-structured interviews with key persons such as village headmen, local committees, and individuals responsible for water management. Interviews with representatives of government agencies gave insight into government policies and their transformations at the local level.

3 Results

The study area is characterized by a co-existence of different tenure regimes as regards the use of and rights over natural resources. On the one hand, ethnic minorities regulate resource use and management by customary laws and norms. Statutory laws, on the other hand, generally concern only the protection and conservation of land, water and forest and widely ignore traditional tenure system. The different interpretation and implementation of the laws and regulations result in a complex tenure system of natural resources which has been described as legal pluralism (e.g., Meinzen-Dick and Pradhan, 2002).

3.1 Interdependence of water and forest

Water shortage in the dry season and floods during raining season are increasingly problems in Thailand. For both problems, deforestation is believed to be the main culprit. This is one argument of the authorities for the forest-for water policies and thus the state control of forest areas. The government rejects existing protection and conservation measures of uplands farmers and ascribes only devastating attitudes to them.

Since decades the villagers of **Bor Krai** have protected several old trees around a water source by customary regulations, even at times when the water was not yet used by the people. According to key informants the major reason for the protection was that villagers feared the quantity of water would decrease without trees. After the sources were connected to a water conveyance system to use the water for household consumption, the protected area was extended. The villagers designated an area of 64 ha as conservation forest which implies prohibition of cutting of trees and hunting to protect the essential source of water supply. In times of water shortage the shaman, together with other villagers, would hold a ceremony at this source which serves to ensure the abundance of water. Similarly in **Ja Bo**, one of the eight water sources, located in a small cave, is considered as sacred and is mainly used for ceremonial purposes. The area around the water source is strictly protected and nobody is allowed to cut trees.

3.2 Interdependence of land and forest

The strict implementation of forest laws since 3 years, which prohibit cutting of newly grown forest, had a tremendous impact on the land use and agricultural practices in the study area. Strategies to overcome this situation differ between the villages.

The two Black Lahu communities **Ja Bo** and **Bor Krai** are located in the Pai Wildlife Sanctuary which implies that all settlement and agricultural activities are illegal. Although the villages are tolerated by the authorities, no land titles are issued and the regulations strongly restrict the scope for action of farmers in their way of life. The traditional system in both Lahu villages was swidden cultivation with a cultivation period of 2 years followed by 7-8 years of fallow. The expansion of this system, related to the population increase, was limited by the lack of suitable land. The Thai-German Highland Development Program (TG-HDP), active in the village from 1983 to 1998, applied participatory land use planning methods to determine the boundaries of agricultural land as well as conservation and use forests. After the project phased out, the Royal Forest Department (RFD) increased the pressure on local communities by declaring long fallows as permanent forest. As a consequence, farmers were in danger of losing considerable parts of their cultivation area (Puginier, 2002). In response, the farmers have reduced the fallow duration to 1-3 years resulting in decreasing yields and increasing weed problems. In short fallow periods the regeneration of the soil is insufficient and, as less burning material is accumulated, fires do not destroy weed seeds efficiently. To overcome these problems the farmers are increasingly forced to use herbicides. A shift to a more intensified system with wet-rice cultivation is constrained by the agroecological conditions of the karst region with limitation in water availability and steep slopes. In addition, wet-rice cultivation is considered illegal by forest authorities because farmers would claim permanent ownership rights for paddy fields.

Farmers of **Mae Lana** are facing the same difficulties on their upland fields since these belong to conservation forest which implies restrictions for the cultivation of annual crops on sloping land. The strategy of the farmer to ensure land tenure rights is different from the Lahu villages. A group of farmers started to cultivate fruit trees because cultivation of perennial crops is widely accepted by the forest authorities as a sustainable land use practice, thus providing a relatively high tenure security (cf. Turkelboom, et. al., 1995, Neef, 2001). However, this system requires high investments and a functioning marketing system. In addition, it may lead to conflicts through the more intensive use of scarce water resources for irrigation, especially during dry seasons.

3.3 Interdependence of land and water

Water management systems in the study villages are complex and strongly reflect local social structures and cultural norms. In the Shan village **Mae Lana**, around 50% of the households own land suitable for wet-rice cultivation and possess registered land use rights. These villagers are mainly descendants of the first settlers. Other households cultivate upland rainfed fields without any legal land rights or depend on leasing contracts in a sharecropping arrangement under which they have to give 50 % of the harvest to the landowner. The irrigation of the rice is managed through a traditional communal system called *muang-fai*, where from a weir (*fai*) in the river the water is distributed via canals (*muang*) to the fields. Thus, land and water rights are closely intertwined as only farmers, whether owners or sharecroppers, with fields along the canals can get access to irrigation water from this system. Different government agencies have tried to improve the *muang-fai* system by installing modern conveyance systems which interfere with customary water management systems and often lack transparency and coordination. Although these ‘improvements’ have not yielded the expected results of reliable water supply and equitable allocation, most water projects in the village have been discontinued.

Given the geo-ecological and climatic environment a secure and reliable water source for household supply is crucial for the villages in the study area. The exchange of water sources between the villages **Ja Bo** and **Mae Lana** demonstrates a high degree of flexibility and pragmatism to ensure this supply and to prevent and resolve resource conflicts. 25 years ago, Ja Bo was located in a valley with reliable waters sources. Following a malaria epidemic associated with the previous location, the residential area of the village was moved to a higher altitude, today, all water sources are located on a lower altitude than the village. Hence, use of these sources would require investments in pumps and water conveyance systems which villagers could not afford. One water source of Mae Lana was located at a higher altitude which allowed water conveyance to Ja Bo by gravity flow. After negotiations it was agreed that Ja Bo is allowed to use the water source of Mae Lana. In exchange, Mae Lana is allowed to use water from a source in the area of Ja Bo to meet the increasing demand of household water. Several farmers in both villages agreed to abandon their irrigated fields next to the respective water source and to provide household water for the other village. This indicates that the welfare of the community is regarded as being of much higher value than benefits of individual farmers.

4 Conclusions and policy implications

Control, use and property rights of land, water and forest show a strong interrelation and are part of a complex tenure system. In this complexity local communities have established own strategies, mostly interlinked with traditions and norms, to protect the natural resources on which they depend. The villagers also demonstrate inventiveness and flexibility by overcoming geo-ecological constrains and finding arrangements within and between communities to ensure access to natural resources and their benefit streams. National policies face difficulties to achieve the aim of protecting natural resources due to lack of coordination, transparency, and participation of local stakeholders. To comply with the official legal system, farmers are forced to change to agricultural practices which are not necessarily more sustainable.

We conclude that any interventions in the tenure system should be based on a carefully assessment of existing customary rights on natural resources. Innovative co-management arrangements for land, water and forest resources, which share the management between government agencies and local communities by making use of their respective comparative advantages, are necessary. The acknowledgement and fair assessment of local forms of managing resources would be a first step to support the capacity of community-based institutions for resource conservation and conflict resolution.

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CAVE-ADAPTED PLANTHOPPERS OF THE CHILLAGOE TOWER KARST (AUSTRALIA)

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The evolutionary forces driving the process of cave-adaptation are still controversially discussed. The relict hypothesis (Barr, 1968) regards cave-adaptation as a consequence of declining climatic conditions on the surface, though that populations could only survive in underground habitats, while those remaining on the surface become extinct. This hypothesis is challenged by the assumption that cave-adaptation is an active process, driven by the exploitation of a novel food resource (e.g. roots). Here, extinction of surface populations is not a prerequisite for the evolution of troglobitic taxa (adaptive shift hypothesis *sensu* Howarth, 1987).

The planthoppers genus *Solonaima* (Auchenorrhyncha: Fulgoromorpha: Cixiidae) is an excellent model for testing these hypotheses. This monophyletic taxon is endemic to eastern Australia (Queensland) and it includes epigean as well as cavernicolous species.

In *Solonaima,* both scenarios are conceivable:

Cave-adaptation may have been driven by the exploitation of a novel food resource: in the habitat of cavernicolous *Solonaima* species roots are abundant. In this case, the different evolutionary lineages which have invaded caves would be of different phylogenetic ages.

Cave-adaptation may have been fostered by the desertification of Australia during the Miocene. This scenario might be supported by the fact that all epigean *Solonaima* species occur in rain forests along or east of the Great Divide, while the cave-dwelling species are restricted to more arid areas west of the Great Divide. With climatic change being the driving force for cave-adaptation, the evolutionary lineages adapted to a permanent life underground would be roughly the same phylogenetic age.

In the present study we aim to approach the question whether cave-adaptation in *Solonaima* is due to adaptive shift(s) or evolved in response to climatic change by reconstructing the phylogeny of *Solonaima* and by correlating divergence events with evolutionary time.

THE SINTACS METHOD TO EVALUATE THE VULNERABILITY TO CONTAMINATION MAP FOR THE KARST AREA OF MT. COVRIA (AVASINIS, FRIULI, ITALY)

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Keywords: hydrogeology, vulnerability map, karst aquifer.

In the last few tens of years in Italy the depletion of the traditional drinkable water sources induced to search for new aquifers, most of which are located within karst formations. But karst aquifers are very complex to be studied due to their intrinsic dishomogeneity and therefore their pollution hazard may result very high and difficult to be correctly defined.

In the last 30 years several vulnerability maps have been printed around the world by using different evaluation methods. Among them, the SINTACS method proved to be the best to describe vulnerability conditions in karst environments because of its adaptability to the dramatic dishomogeneity of those aquifers.

The Mt Covria (Friuli, Italy) hosts important karst aquifers feeding some springs tapped for civil water supply. The aim of the present research was to prepare a map of the intrinsic and integrated vulnerability to contamination of the whole area using the point count system model SINTACS.

The studied area (about 10 km^2) hosts two different hydro-structures where carbonate sedimentary bodies prevail. A Cretaceous paleo-fault, reactivated during Alpine orogenesis, acts as impervious boundary between these two hydrostructures within an overfold. Due to overthrusts they overlie a geological structure with on top aquiclude formations and underlie a monoclinal structure, which, even if partially permeable via fractures, proved to supply no contribution to the recharge of these hydrostructures.

Within these two aquifers karst processes were active since lower Pleistocene and groundwater is actually hosted in dispersed, unhierarchized, drains (*young karst*), while the epikarst is characterized by partially hierarchized, but still interdependent, drains (*rather developed karst*).

Surface and deep morphology, lithology, geological and hydrogeological settings were utilised to define the seven SINTACS-DEU3H parameters (Depth to ground water, Effective infiltration action, Unsaturated zone attenuation capacity, Soil/ overburden attenuation capacity, Hydrogeologic characteristics of the aquifer, Hydraulic conductivity range of the aquifer, Hydrologic role of the topographic slope).

In the present paper the specific methodology to prepare the seven SINTACS thematic maps and the criteria applied to define their relative weights to settle up the intrinsic vulnerability map in karst environment are shortly described. Finally the integrated vulnerability map for the Mt. Covria karst area was obtained by overlaying the intrinsic vulnerability map upon that of the potential and actual sources of contamination.

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PARTICIPATION OF HMONG FARMERS IN AGRICULTURAL RESEARCH IN UPLAND NORTHERN VIETNAM

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Keywords: participation, agricultural research, Hmong, qualitative interviewing, visualization.

1 Introduction

Fostering the participation of local stakeholders in agricultural research is one of the objectives of The Uplands Program[1] and aims at producing relevant and locally adapted innovations while increasing local stakeholders' agency and status. At the same time, analyzing the potential and constraints of participatory research is a *research topic* in itself. This paper derives from research conducted by the author as part of The Uplands Program since 2002. The author's research focuses on practices and prospects of participation in agricultural research, both within the structures of The Uplands Program and other relevant research organizations. Participation is conceptualized here as the involvement of local stakeholders in the production and use of knowledge. The integration of local knowledge into scientific activity is discussed using a theoretical framework based on Niels Röling's distinction between three domains of knowledge; namely instrumental, economic and interactive (Röling, 2003).

The Hmong constitute a medium-sized group in the ethnic mosaic of northern rural Vietnam, the total number of Hmong in Vietnam being around 700,000 (ADB, 2002: 6). In Son La province, one of The Upland Program's research sites, the Hmong are the third biggest ethnic group and make up some 12 per cent of the total population. To date, however, most research has focused on the situation of the local Black Thai majority (cf. Sikor, 1999, 2002; Luibrand, 2001). Current literature on Vietnam's Hmong people remains scant. Interpretations based on ethnicity thus have to rely heavily on field work and can only be combined with historical sources (e.g. Abadie, 2001 [1924]), general literature on the Hmong (e.g. Quincy, 1995) or Hmong in other countries such as Thailand (e.g. Cooper, 1984).

The Hmong continue to be spatially isolated and marginalized by language barriers and negative stereotyping as compared to the local Thai and Kinh people, who are more integrated into wider Vietnamese society. It is therefore instructive to look at a marginal ethnic group such as the Hmong, while reflecting on the scope for participation in agricultural research, because general problems appear in sharper contrast.

2 The local setting

Four Hmong villages (Chi Day, Bo Kieng, Hang Hoc, Co Say) in Chieng Hac commune, Yen Chau district, Son La are the locality of the empirical investigations presented here. Villagers date Chi Day's founding to around 100 years ago; the remaining three villages are satellites and were established from the 1970s onwards. The establishment of the new villages was also politically supported by the state's provision of fruit trees and the allegedly unfulfilled promise of cash rewards for resettlement.

Today, the founding village appears to be the poorest and most disadvantaged. Access to Chi Day is most difficult, as the government's road works are yet to reach the village and hence provide a wider output channel for cash crops, especially maize sales. Due to extremely

[1] The Uplands Program is a Vietnamese-Thai-German collaborative research program into sustainable land use and rural development in mountainous regions of mainland Southeast Asia and funded by the Deutsche Forschungsgemeinschaft (SFB 564, University of Hohenheim). For an introduction to the themes, organizational set-up and scope of The Uplands Program, see: http://www.troz.uni-hohenheim.de/research/SFBeinstieg.

Table 1: Number of households and founding dates of the four villages

	No. of households	Founding year
Chi Day	21	~1900
Bo Kieng	27	1970
Hang Hoc	24	1988
Co Say	15	1994

stony fields, land preparation has to be done mechanically in Chi Day, whereas draft buffaloes are used in the other villages' fields.

Revenues from maize sales are the single most important factor for cash income in all the villages. When asked to name the richest of the four villages, Co Say villagers named Hang Hoc for the following reasons. In Hang Hoc

- the sale price of maize is highest
- farmers have less work transporting the maize
- farmers do not have to invest in an access road because the village was established next to an already existing road

High-yielding hybrid maize varieties are used by all farmers and most of the harvest is sold, whereas land races of white maize are cultivated for human home consumption and animal fodder. A map of Bo Kieng displaying the current use of land, which was drawn by villagers on top of an aerial picture from 1999, suggests that the cropped area was expanded between 1999 and 2003 by more than 100 per cent. This means that over the last five or so years, Hmong farmers could increase their income by expanding cropping area *and* raising productivity through the newly available high-yielding, hybrid maize varieties. A prosperous farmer today harvests up to 25 tons of maize per year, corresponding roughly to 25 million VND (about 1,600 US$). Hence, market integration and household income has increased, especially through the cultivation and sale of hybrid maize, also resulting in a dramatic growth of the upland area under cultivation. Besides providing cash income, however, current forms of upland cultivation also contribute to the increasing pressure on natural resources. It is unlikely that this high level of income from maize can be sustained over a longer period of permanent cultivation, because nutrient depletion of soils is caused by permanent cultivation and loss of topsoil, which in turn leads to decreasing yields (Wezel *et al*., 2002). Nevertheless, farmers and local traders strongly count on maize to improve their livelihoods. Local maize traders have lent between 35 (Chi Day; ~ 2,300 US$) and 120 million VND (Bo Kieng, Co Say; ~7,900 US$) for road construction to the three villages. In return, the traders/investors receive the monopoly for maize sales, besides the repayment of the credit. Government-financed road works are currently enlarging the access roads to the villages. The importance villagers attribute to roads as output channels for maize is underlined by their decision to invest privately instead of waiting for state-funded road works.

3 Reconstruction of a mapping session

The methods used and the context in which fieldwork is embedded will be outlined, followed by the description of one mapping exercise. This provides the scope for a methodological discussion against the background of a concrete data collection activity.

Field work in the four Hmong villages was initiated in the summer of 2003. The methods used were research conversations and semi-structured interviews with individual respondents, three mappings with small groups of respondents and walks on the village territory together with villagers/respondents. Participant observation covered everyday life, one wedding ceremony and one meeting of village leaders from 13 villages.

The field work highlighted in this paper constituted an early, exploratory phase of interdisciplinary cooperation. It was conducted by two male German junior researchers, both Ph.D. students in agricultural sciences at the university of Hohenheim, but with different disciplinary backgrounds. Communication with villagers took place in Vietnamese language and was facilitated by a female Vietnamese translator (Vietnamese-English).This three person research team set out to explore local land use patterns with a focus on pasture management, over eight consecutive days spent in Bo Kieng and Chi Day.

In order to gain an overview of Chi Day's land use including pastures, we invited a group of villagers to draw a map of their village territory. Four villagers drew the village map freehand and answered questions from the researchers.

Before the mapping exercise could take place the research team and their host had to wait an hour and a half for all the respondents to arrive. The casual conversation during the wait were valuable, however, as the researchers learned about relations between the Black Thai and Hmong peoples, current affairs in the village and the backgrounds of those involved in the mapping.

The mapping exercise itself took two hours. After some initial hesitation and insecurity, the respondents accomplished the task of drawing a village map without major difficulties.

4 Methodological discussion of the mapping

Field work was done during the harvest season and cost a considerable amount of time because respondents were very busy and the road was repeatedly blocked by broken down trucks which were supposed to be transporting the maize harvest. The costs (esp. respondents' opportunity costs of time) of data collection thus vary seasonally and field work should not, wherever possible, be carried out during the busiest times in the agricultural year.

On a superficial level, witnessing the production of the map and asking questions during the process offered insights into the local perception of the village area and its surrounding lands. The main elements of this local perception, as expressed in the map, are 1) administrative borders (village and commune), 2) roads and footpaths, 3) houses, 4) crop and pasture land, 5) mountain peaks and valleys, 6) the village's well and water pipe.

<u>Mapping process:</u> A rather long time is required to build up the map, but once this is achieved, rather complex circumstances can be addressed and explained by respondents with relative ease and precision. For example, more than an hour of preparatory map drawing was necessary before being able to discuss the historical dimension of land use. With the current situation displayed on the map, historic trends could then easily be explained by the villagers: the significant extension of cropped land was mainly due to an increase of area under maize.

<u>Reliability:</u> The outcomes of such a mapping exercise should not be considered anything more than unverified data and hypotheses which need further verification and cross-checking. In order to improve the reliability of the data derived from such mappings, they must be embedded in a larger portfolio of methods. In our case, a walk to the pasture with one of the respondents the day before had given us the opportunity to directly see the village's surroundings and the pasture and question our guide on site. Only through these first hand impressions were we able to relate the model (map) to the local reality (village territory). Triangulation by means of adding observation and interview data to that generated by a visualized interview such as the mapping exercise is of paramount importance.

<u>Group dynamics in the respondent group:</u> The interaction between respondents during the mapping exercise can provide hints or verify hypotheses concerning social relations between respondents, and hence yield data on another level than the map itself. As Mosse (2001: 19) noted, public group exercises involving villagers and outsiders are "events […] producing a rather peculiar type of knowledge, strongly shaped by local relations of power, authority and gender".

In the case of the mapping, two respondents vied with each other to lead the process. On the one hand, the former teacher put himself to the fore by playing on his literacy and eloquence. On the other, the wealthy village policeman sought to stay in control by repeatedly taking back the pen in order to do the drawing and explain. Social issues outside of the focal interest that nonetheless influence the outcome of the process - that is, the data obtained - can be observed during such group exercises.

<u>Those not involved:</u> Finally, gender must be mentioned as a major factor in determining who does and does not engage in interaction with researchers. Women's voices are virtually non-existent in what the author could collect of villagers' pronouncements. Besides the language barrier, this is also due to the patriarchal structure of Hmong society (cf. Cooper, 1984: 138) and the denial of Hmong women's right to express themselves publicly. Women-only group interviews or individual interviews with selected women (marked differences exist concerning the degree of openness and ability to express oneself in

Vietnamese) could be used to tackle this 'blind spot'.

5 Discussion of results

The involvement of Hmong farmers in research is discussed in what follows; some specificities related to ethnicity are summarized in order to distinguish how local knowledge enters the research process and the scope for scientific activity to benefit the local community.

The case of the Hmong: Comparing the Hmong to the Black Thai shows that well-known arguments concerning the limits of participation fit the case of the Hmong very well. As the local ethnic majority, the Black Thai who live centrally on the valley floor and often hold positions in the local administration are well integrated into Vietnamese society. Hurdles to participation of Hmong are that 1) researchers face increased travel costs (time, material, risks) simply to get to the remote Hmong villages, mostly on dirt roads, 2) communication is especially difficult due to language barriers. While Hmong men usually have sufficient command of Vietnamese, women and elderly persons often do not speak enough Vietnamese to act as interview respondents and 3) Hmong rank low in the ethnic hierarchy found in Kinh researchers' and Black Thai people's discourses, where Hmong culture is generally perceived as being 'very different'. Considering that dialogue is based on recognition of and respect for the other, this combination of low status (including negative self-stereotyping by Hmong themselves) and perceived cultural distance is a major obstacle for true dialogue –a precondition for participatory research– between (Vietnamese) researchers and research subjects (Friederichsen, 2004). 4) Finally, low levels of formal education and low literacy rates limit the scope for including farmers in formal data recording.

Local knowledge in the research process: Making a distinction between three domains of knowledge (instrumental, economic, interactive; cf. Röling, 2003) applies well to scientific practice, which is organized into disciplines. Instrumental knowledge refers to enhancing people's means of controlling nature for human purposes (natural sciences). Economic knowledge helps people to gain advantage and optimize utility (economics). Interactive knowledge enables people to reach negotiated agreement and concerted action (social and cognitive sciences). Local knowledge is better understood as a non-disciplinary and needs-oriented process which lacks systematic refflection about the bases of the production of knowledge (cf. Neubert and Macamo, 2004). The challenge to research (organized around disciplines) constituted by the complex nature of local action will be illustrated using the maize and investment complex.

The villagers' investments into roads to facilitate the marketing of maize demonstrate how the (academic) domains of knowledge are intertwined in practice. At the instrumental level, villagers and traders recognized that more production of high-yielding maize was feasible with the given resources (soil, water, labor). From an economic perspective, given its market price and the available upland area, maize is a highly attractive crop for Hmong farmers. Therefore, villagers engaged in concerted action to mobilize their own money and find investors to realize higher gains from maize as quickly as possible.

The field work described above only refers to the research projects of one natural science and one social science researcher, and a topic such as road construction clearly falls outside the mandate of agricultural research. A multitude of disciplinary research projects (e.g. agronomy, soil science, economics, social science) would be necessary to address such a complex whole.

Hence, many concessions have to be made concerning the selective nature (according to discipline and research questions) of the inclusion of local knowledge into research.

Which members of the local population can be expected to benefit from the research? As has been indicated, large parts of the village population hardly get to interact with researchers. Therefore, exposure to researchers' external ideas and social learning through direct interaction with researchers is usually limited to men in rather powerful positions. This predicament of research tending to reinforce existing power structures can also be illustrated with the example of pasture improvement. Assuming that 1) the research yields a suggestion on how to improve the pasture and that 2) the innovation is adopted, only a few rather wealthy villagers would profit directly because few households have large ruminants in Chi Day.

6 Conclusions

The mapping exercise appears to be an efficient tool in gaining information about local conceptions of the village and its surroundings, specifically land use. However, such mapping exercises must be used in conjunction with other methods to ensure reliable data. Complex group dynamics within both respondent and researcher groups need to be taken into consideration. This requires moderation skills, sensitivity for group dynamics and researchers' willingness to get involved with 'messy' qualitative data.

Leaving the ivory tower of 'detached science' and involving non-researchers in the process of producing scientific knowledge means embarking on a journey which becomes more contingent and complex the further we go and the higher the heterogeneity of those involved becomes. Again, agricultural researchers need to develop skills in flexible and locally adapted, yet rigorous procedures of qualitative data analysis. Only then can the increased involvement of local stakeholders be expected to yield scientific knowledge.

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SOME OBSERVATIONS ON THE SIGNIFICANCE OF LIMESTONE KARST ECOSYSTEMS IN VIETNAM FOR BAT CONSERVATION WITH AN OUTLINE OF REQUIREMENTS FOR SUCCESSFUL SITE-BASED CONSERVATION MANAGEMENT

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Keywords: Vietnam, limestone, karst, bats, conservation, management.

With over 100 bat species, Vietnam hosts a significant proportion of the world's bat diversity (nearly 10%), including several globally threatened and near-threatened species. While the high diversity of vertebrates found in Vietnam has been variously attributed to a number of factors, it is suggested here that the extensive areas of limestone karst found in northern parts of the country provide highly important habitat sustaining bat populations within these regions. This is a consequence of the extensive networks of caves and other subterranean passageways that typically characterise these areas, which provide ideal roosting sites. Although knowledge regarding the biogeography and status of Vietnamese bats remains limited, review of the current data available suggests that limestone karst habitat also provides an important refuge for the majority of globally threatened species presently known to occur in the country. The recent discovery of two previously undescribed bat species from limestone karst areas in Vietnam further underlines the potential importance of these ecosystems for vertebrate conservation. As a consequence of their significance for bat populations, it is further suggested here that limestone karst ecosystems in Vietnam may also be significant from an economic perspective. Bats as a group have long been recognised to perform important ecological functions in plant pollination, seed dispersal and insect consumption. While evidence from independent studies carried out around the world indicates that these services can assume major economic significance at local and regional scales, as a whole, their monetary value remains little quantified. This is true with respect to not only the Vietnamese bat fauna, but that of the greater mainland south-east Asia region. These considerations suggest that adoption of precautionary approaches in management of limestone karst areas in Vietnam for the benefit of their associated bat populations is highly desirable not only from conservation but economic standpoints. In the interests of promoting development of such approaches, generic threats confronting bats in northern Vietnam are briefly discussed and an outline of requirements for successful site based-conservation management of bat populations in limestone karst ecosystems is given.

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COMMUNITY-BASED KARST AND CAVE MANAGEMENT IN THE RAJAH SIKATUNA PROTECTED LANDSCAPE AND SURROUNDING BARANGAYS, SIERRA BULLONES, BOHOL, PHILIPPINES

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1 Introduction

This paper describes the efforts of the Soil and Water Conservation Foundation, a Philippine non-governmental organization, to develop a community-based karst and cave management programme at the barangay (village) level in the Philippines. The focus is on fourteen barangay of the karst hills of the municipality of Sierra Bullones on the island of Bohol, Central Visayas. All the barangay are situated either in the Wahig-Inabanga Protected Watershed or the Rajah Sikatuna Protected Landscape (RSPL).

Activities undertaken include barangay resident karst and cave resources education, mapping of cave resources including history and use, formulation of preliminary cave management guidelines, cave classification and the mainstreaming of resource protection through the writing and implementation of barangay resolutions and ordinances. The paper details the activities undertaken and outcomes under in the areas of cave and karst management and their outcomes. Additional short and long term activities and expected outcomes conclude the paper.

2 Project Site

Project area is located in the northeast part of Rajah Sikatuna Protected Landscape and adjacent barangays within the municipality of Sierra Bullones. All 14 barangays are situated in the uplands of the municipality. Barangay elevations vary from 300 to 700 meters above mean sea level. Accessibility to the area is via limestone surfaced roads and is rather difficult especially during the rainy season. The most common means of transportation are modified motorcycles that are strong enough to carry up to 5 individuals and a few passenger buses.

The area's vegetation is rather good. It consists of second growth forest. The continued forest expansion can eventually establish a corridor along the ridgelines that form the Wahig-Inabanga and the Rajah Sikatuna Protected Landscape. Barangays, especially those located within low lying areas of the town, are dominated by rice paddies and coconuts fed by good water sources coming from karst area gravity springs.

Caves located above the 500 meter elevation are mostly vertical and dry. Depths range from 12 meters to 29 meters. All of the vertical caves have no sideway extension at their lowest levels. They are usually boulder strewn at the bottom. Other caves have water in them with short to extended passages. The general orientation of cave systems points in two directions. One is directly towards the Rajah Sikatuna and the other towards the Wahig-Inabanga watershed.

3 Cave and karst management: methods and activities

Resident karst and cave resources education began with the notification of the barangay captains of the barangays chosen for inclusion in the karst conservation program. This included informing the captains of the project's activities and procedures. Local initiatives needed to support the project were detailed so that the outcomes could be sustained at the conclusion of the project. The barangay captains of the affected villages were brought together for the consultation. They all agreed to the program and the captains agreed to inform their respective barangay councils

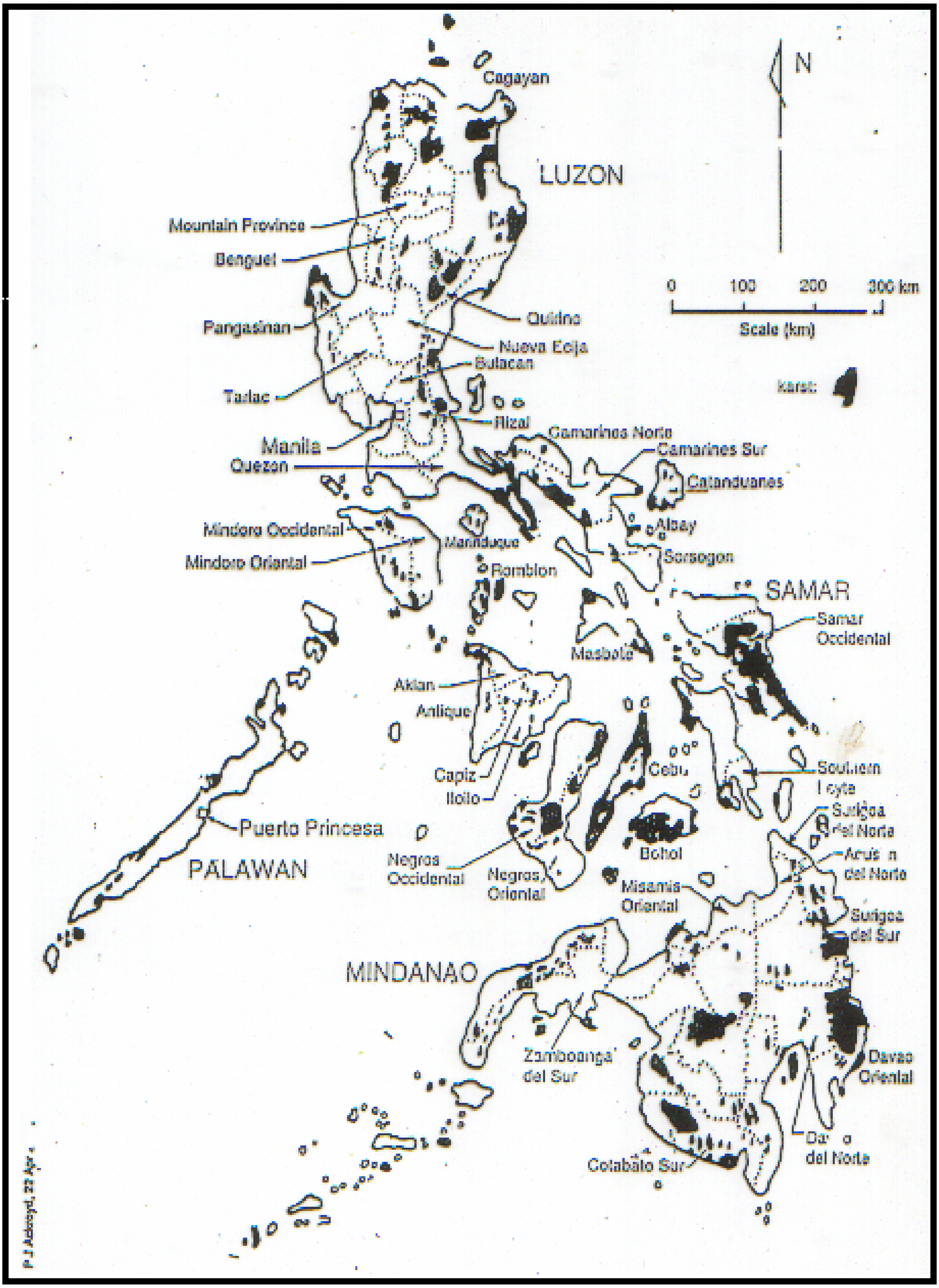

Fig. 1: Karst map of the Philippines, Bohol near the Center

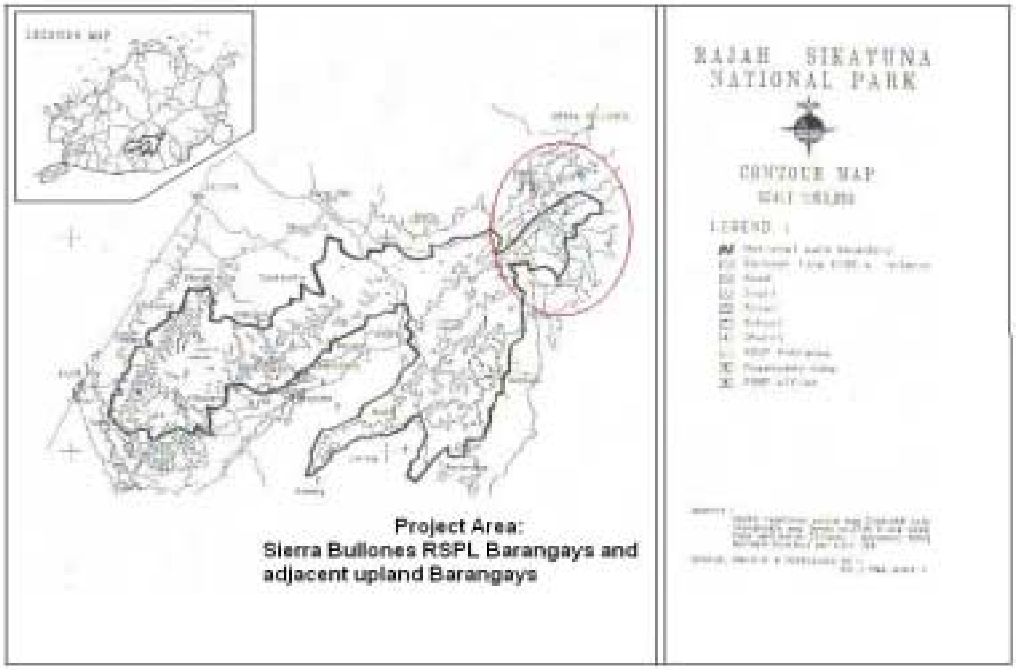

Fig. 2: Location of Sierra Bullones at north end of RSPL

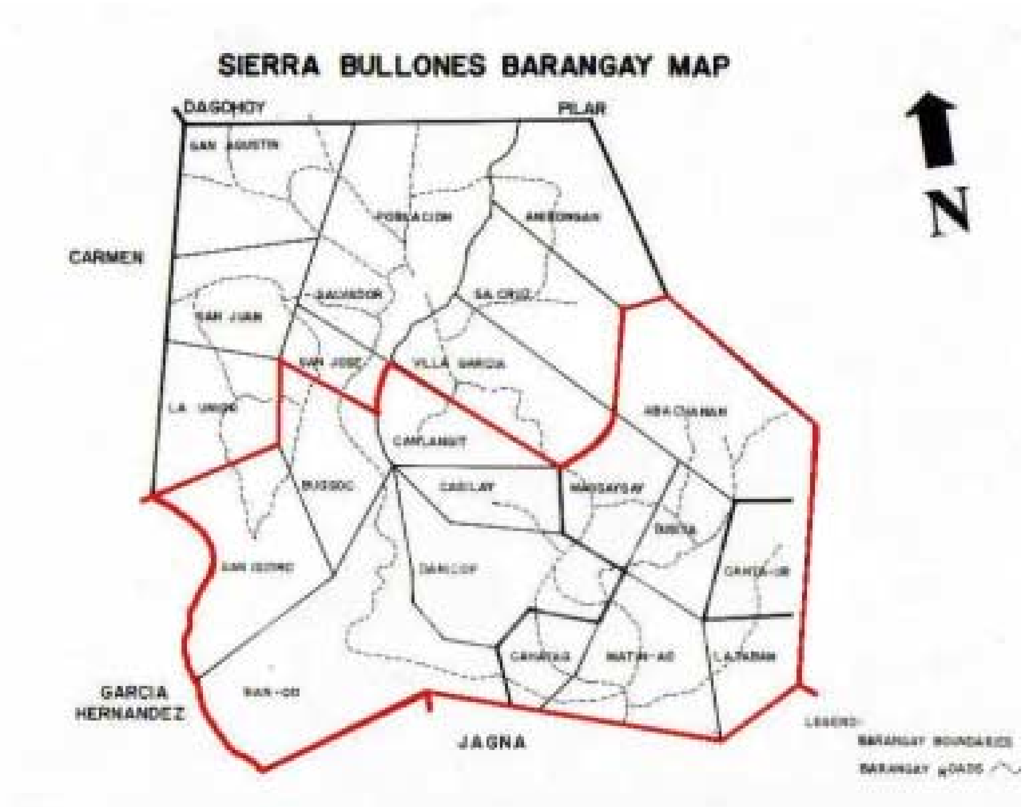

Fig. 3: Study area barangays marked in red

and constituents. Residents from the villages were selected to participate in data collection. The candidates were trained in responsible and safe caving including exploration and management. The training was designed to enhance indigenous knowledge in cave exploration and to promote better attitudes and understanding of local caves.

Cave exploration and mapping was a primary concern of the project. Exploration focused on the methodological aspects relevant to the future management of the protected landscape and protected watershed's caves. Data collected included cave descriptions, surveys and whenever possible, the inclusion of surface karst features associated with the caves and land cover in the vicinity of each mapped cave. So far a total of 58 caves have been mapped in the fourteen barangays.

Cave surveys were limited to accessible passageways of each cave (i.e. no excavations were conducted to extend cave passages). Description of the systems varied based on the type and quantity of cave resources, cave speleothems, guano deposits, cave swiftlet nests and bat populations. Other fauna of interest were eels, fishes, invertebrates and evidence or examples of wild pigs, snakes and other organisms.

3.1 Outcomes

Preliminary cave management guidelines and cave classification activities were initiated by the holding of workshops to draft cave management guidelines. Two participants represented each barangay. Each cave was described and carefully discussed including information on resources and history of exploitation prior to any decision being made on the cave's classification within the evolving schema. Eight management strategies and cave policies evolved.

Tourism – general cave policies

- Vandalism is prohibited inside and outside the cave.
- Urinating inside the cave is not allowed.
- Spitting is not allowed inside the cave.
- Throwing of any garbage in any part of the cave is prohibited.
- Eating and smoking is not allowed inside the cave.
- Bringing and drinking any alcoholic liquids is banned inside the cave.
- Children under ten years of age are not allowed to enter the cave.
- Taking (removing) of any resources in the cave as souvenirs is prohibited.
- Using lamps that emit smoke is not advisable in the cave.
- Malicious acts are not allowed inside the cave.

Tourism – wild caving

- Observe proper sanitation when inside the cave especially avoid the improper disposal of materials that contain chemicals.
- Children under ten years old are not allowed inside the caves.
- People with ailments (heart ailments, others) are discouraged from entering the cave.
- Refrain from using lamps that emit excessive smoke.
- Vandalism is not allowed inside the caves.
- The number of visitors should be limited (to what the cave can safely handle).

Resource use – bats

- Avoid making loud and unnecessary noise inside the cave.
- Removal of bats from the cave is not allowed.
- Bats are not to be teased or otherwise disturbed.

Resource use – swifts

- Extraction of swift's nests from the cave must be controlled. The removal should be scheduled, no more frequently than once every three months or longer if upon further study it is warranted.
- All caves with swifts must be provided with a gateway/door (to prevent unauthorized persons from entering the cave).

Resource Use – Guano

- Extraction of guano from the caves should be on a yearly basis and the volume limited.
- Prior to allowing groups/persons to extract guano from the caves, the barangay should secure a permit from the Protected Area Management Board authorizing them to initiate the activity.
- Only local residents are allowed to haul guano from the caves. Some visitors may be allowed if the law permits them to do so.

Resource use – cave formations

- Vandalism is not allowed on cave formations (such as writing, marking).
- Destroying or extraction of cave formations such as stalagmites, stalactites, candlesticks, etc. for souvenir materials or other purposes is prohibited.
- Using lamps that smoke excessively is not advisable. The visitor should use electric lights (flashlights) or headlamps.

Resource use – water

- Cave visitors should avoid passing through running water if possible as this could be a source of drinking water for local residents.
- When inside the cave, people must avoid using substances (shampoo, soap, etc) that contain chemicals as this may contaminate the water.
- Caves that supply fresh water are the main source of water for local residents and must be protected with gates.
- Throwing of any garbage material inside/along/near the cave or inside it is prohibited.

Scientific value caves

- There is a need to conduct research on rare species observed in caves.
- Only persons with permits are allowed to enter the cave.
- Cave visitors/explorers should not be permitted to enter caves that need further study and observations.
- People/groups who want to conduct research on caves must initially secure a permit from the Protected Area Management Board and from the Barangay.

Mainstreaming of the management imperatives noted above is occurring through a process of barangay resolution reformulation and more rigorous policing of ordinances. The process of protection is presently being integrated into the activities of the local, barangay forest protection committees. This is a critical first step towards the institutionalization of the cave management and conservation program initiated in the barangay. All the above regulations and ordinances are harmonized with the National Cave Management Act. The overall training program was well received by the community.

4 Surface and subsurface biodiversity methods and activities

Biodiversity conservation was a fundamental component of the study as without quality baseline data future change could lack attribution to changes in cave management regimes. Activities included the establishment of two kilometer biodiversity monitoring transects, flora and fauna surveys and efforts to develop a biodiversity conservation and ecotourism framework for the barangay and municipality. The following were the main findings so far from the on-going biodiversity component of the study and include initial management recommendations.

4.1 Outcomes

Effects of Sedimentation: The loss of natural vegetation due to deforestation appears to have caused sedimentation to increase. Erosion from deforested areas, specifically those that have sinkholes, has caused transport of eroded materials to the cave system, oftentimes clogging subterranean waterways. At least a portion of the sedimentation also appears to originate from road construction on slopes above the cave systems. Observations have indicated the greater the sedimentation in the cave the more species are introduced from the outside. Some of these species appear to be adapting to the cave environment. To protect the original inhabitants and protect waterways the sedimentation must be reduced.

Cave Swifts: The declining populations due to over harvesting nests, killing of young birds in the nest, disturbance due to use of torches in the cave, diminishing the food sources by forest clearing, guano collection and treasure hunting must stop.

The nesting periods must be determined and this time protected by limited access to the swift caves. Artificial housing outside the caves may be tried. If this is found successful then collection of nests would be easier and less harmful to the cave system.

An IEC (information, education, communication) program should be started to teach local residents about the importance of swift species, not only as a producer of high value nests but also as a biological control for insects.

A final measure may involve the gating of the caves while providing for access for the birds.

Bats: Many of the same problems affecting swifts also affect bats. These include the cave disturbance by visitors to collect guano, look for treasures, hunting bats, and removal of cave structures. The use of torches that smoke also disturb the bats. The declining population in some areas is owed to hunting, especially of fruit bats.

The diminished population reduces the effective biological control these mammals provide. This in turn affects the size of insect populations that pray on crops as well as humans and livestock. The guano supply, a potential source of phosphorous fertilizer is reduced.

To increase the populations cave environmental conditions should remain as constant as possible. Potential activities are gating of caves while allowing entrance and exits of bats, regulating cave use, prohibiting open torches and prohibiting hunting in any form. Fruit bat tree roosts also need protection to provide stability for population growth.

An IEC program about the importance of bats has already started. Survey of bat species and their requirements should be continued by the government even in locations outside designated protected areas. So far a total of 20 bat species have been identified in six out of the fourteen barangays. These are in the Rajah Sikatuna Protected Landscape.

Eels: This overlooked organism that was once abundant in the rivers of Bohol plays an important part in keeping the cave waterways open. Their burrowing habits open passages that would normally be clogged by sediments in the caves.

The immediate formulation and implementation of no hunting ordinances should occur at the barangay level. The open areas above the caves should be allowed to regenerate through assisted natural regeneration and be protected from fire during the dry season. This, in turn, will allow the mixed forest to regenerate above the caves slowing the sedimentation rate. Monocultures of exotic species should not be planted above caves.

In some cases, there should be limited access to caves where eels are found. The river systems associated with water coming from the caves should also be protected, as the eels are migratory. Only protecting the caves will not solve the problem of declining eel populations.

Again, an IEC program should be started to inform local residents about eels and their importance in the cave ecosystem as well as a potential food source.

Fishes: These organisms are generally imported into the caves explored so far. They should be left alone as they are part of the cave ecosystem.

Invertebrates: They are part of the cave ecosystem as are the fishes, bats and other larger species. Do not disturb.

Wild pigs, snakes and other organisms: These are generally found at the entrance to the caves and seldom will go further than twenty or thirty meters into the cave. Do not disturb and do not hunt as they all have functions in the forest and cave ecosystems.

Vegetation: Recent initial tree surveys along biodiversity monitoring transects indicate 254 species. A special fern and fern allies inventory at the beginning of 2004 listed 173 species in RSPL and adjacent barangays. It is estimated that 150 of these can be found in the 14 barangays of Sierra Bullones. There is also a need to increase the native vegetation in the karst areas by eventually replacing the exotic monoculture planted trees used in former government reforestation projects over the past forty years. All further reforestation projects should only involve the use of indigenous species.

5 Future solutions

The following are steps that can be taken in the near future as a follow-up to the present research effort to ensure the sustainable management of the caves in the six barangay in Sierra Bullones.

Guideline refinement

Work on refining the guidelines and then translate these into barangay ordinances.

Expansion of the survey

There are funds for expansion of the survey both in Sierra Bullones and other barangay in the protected landscape. These funds come from the European Community to Soil and Water Conservation Foundation for Protected Area Management Board strengthening. The start made in Sierra Bullones should lead to establishment of the process in the other protected area barangays. The general outcome should be overall cave management guidelines for the protected area as well as those outside the reserve.

The following are more long term activities and identified priority areas that will have provincial and national significance.

Barangay ordinances

The management of the caves is the overall issue at present. In 1999 the initial six barangays drafted preliminary management guidelines. This effort preceded the formulation of the cave management plan in the Rajah Sikatuna Protected Landscape.

Implementation of the guidelines took effect but resulted in no convictions of violators due to the non-sanction of the management guidelines for caves by the RSPL Protected Area Management Board.

Currently the barangay, as a local government unit, can act by adopting the policies and guidelines. The formal barangay and municipal ordinances can be based on the provisions of the National Cave Management Act. The barangay can integrate implementation and enforcement of the guidelines into the functions of the forest protection committees already established.

Guano and swift nest production

Planning of projected interests in the use of cave resources should also be considered especially the use of guano and swift nests. Recent agricultural practices have adopted the use of organic fertilizers. The use of guano has to be re-introduced for use by farmers.

The market for swift's nests has abruptly increased in the last five years, yet there is a shortfall in supply. No one has shown any interest in culturing this bird species.

The barangay should consider the idea of adopting nest production for three reasons. First, to be able to meet the demand and enhance the revenues of the barangay, second, management of the resource for sustainable use, and third, controlling the unnecessary cave visits that may disrupt the isolation of the birds and damage the cave features in the process.

Adventure Eco-tourism

There is an increasing demand for adventure tours. Caving is a major activity. The protected landscape has a variety of wild caves in the area. As information begins to spread, adventurers will soon be asking for locations. It will be detrimental to the caves if tourists cannot be controlled.

As pointed out in one of the recent RSPL Protected Area Management Board meetings, all tourism activities in the RSPL area should be community based. Since the local residents of the six barangay have initially organized themselves into different groups to function when visitors are present, they should now start concentrating on the management side of the caves for eco-tourism. Work on integrating the same orientation and activities in the eight barangays outside the RSPL need to be facilitated.

Department of environment and natural resources involvement

Involve the Protected Area Superintendent in the cave mapping program. Unfortunately the Protected Areas Superintendent was not available for the initial mapping since his new appointment had not yet been fully processed. However he has expressed interest in the activity. His involvement can help the project spread the activity to other parts of the protected area and perhaps to karst areas outside the protected area. Final steps in the cave classification approval also require the guidance of the DENR as mandated under the Philippine cave act.

6 Conclusions

There have emerged priority areas for further development as noted above. Each reflects the important and evolving intersection between local government and larger political units. The local government units are gaining confidence in their new found autonomy in resource management. In this situation local legislation is more advanced than national and provincial legislation and thus represents a real grassroots movement that could influence and potentially accelerate national policy making for cave and karst landscape management. The lessons learned over the next few years in moving forward with barangay ordinances, guano and swift nest production and the rapidly expanding pressure to exploit cases for eco-tourism will through the networks being grown at provincial and national level feed through and influence other policy makers.

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RECENT UNITED NATIONS EFFORTS FOR THE GLOBAL STUDY AND PROTECTION OF KARST RESOURCES

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1 Introduction

A key element for the future success of karst resource protection is international communication, including the sharing of ideas, experiences and resources. The United Nations through the United Nations Educational, Scientific and Cultural Organization (UNESCO) exists to promote international co-operation among its 190 Member States in the fields of education, science, culture and communication. In the last several decades several UNESCO programmes have made contributions to study and protection of karst resources in a variety of ways: designation of globally significant karst areas to support enhanced protection (Man in the Biosphere Programme and World Heritage Committee), enhanced communication and cooperation between scientists around the world working with common interests and goals (International Geological Correlation Programme (IGCP)) and support of international karst scientific conferences (United Nations Environment Programme). These efforts have in turn been supported by affiliated organizations, in particular the World Commission on Protected Areas Task Force on Caves and Karst of IUCN--The World Conservation Union, the International Association of Hydrogeologists, the International Union of Speleology, and the International Geographical Union. World Bank scientists have also contributed to evaluation of globally significant resources and strategies for their protection.

The purpose of this presentation is to describe major aspects of the current status of efforts of karst study and environmental protection efforts by the United Nations and supporting groups, to highlight a successful Chinese-American collaboration in karst research in southwest China that has resulted from communication initiated in the previous and current UNESCO IGCP karst projects, and to describe a new, proposed IGCP project, the *International Cooperative Study of Karst Water Resources.*

2 Enhanced protection of globally significant areas

Among its goals, UNESCO seeks to encourage the identification, protection and preservation of features or regions that offer cultural and natural heritage designated to be of outstanding value to humanity. In this effort, in 1972 UNESCO adopted the *Convention Concerning the Protection of the World Cultural and Natural Heritage*. According to the convention, cultural heritage refers to “monuments, groups of buildings and properties with historical, aesthetic, archaeological, scientific, ethnological or anthropological value,” and natural heritage refers to “outstanding physical, biological and geological formations, habitats of threatened species of animals and plants and areas with scientific, conservation or aesthetic value”.

By signing the *World Heritage Convention*, participating countries, designated as *States Parties*, pledge to protect the whole of their national heritage, whether or not it is recognized as being World Heritage value. It is the State Parties' responsibility to provide adequate protection and management for their inscribed sites. This is aided, particularly in countries with emerging economies, by access to the *World Heritage Fund*, which annually amounts to about three million US dollars.

While it is clear that there are still many undesignated areas that could potentially qualify for World Heritage status, as of July

2004 788 properties had been inscribed on the World Heritage List with 611 cultural, 154 natural and 23 mixed properties in 134 of the total of 177 States Parties. Of these, ten have been designated on the basis of outstanding karst resources (Table 1). In addition, there are currently 25 natural heritage areas inscribed for other reasons but which have significant cave and karst resources, and nine cultural World Heritage sites that contain cave and karst features.

3 International communication between environmental scientists

Perhaps the clearest results in terms of international scientific advancement in the understanding of karst resources, a prerequisite to conserving them, has been through the achievements of three projects carried out under the auspices of IGCP including 1) Project 299 “Geology, Climate, Hydrology and Karst Formation” (1990-1994), 2) Project 379 “Karst Processes and the Global Carbon Cycle” (1995-1999), and 3) Project 448 “Karst Geology and Relevant Ecosystems” (2000-2004).

We illustrate here, by way of example, a very fruitful cooperation between scientists and students in China and the United States that has directly resulted from IGCP activities. Over eight years collaboration between China’s Institute of Karst Geology and Western Kentucky University has led to an increased level of research productivity and understanding of karst processes following numerous research trips in both directions and other communication. This work has allowed participants on both sides to develop a higher sophistication in the understanding of karst behaviour resulting from the sharing of experiences with regard to varied types of karst systems, and technical information in karst monitoring, hydrochemistry, and Geographic Information Systems. A current collaborative effort, led by the Chinese scientists, seeks to make karst groundwater significantly more accessible to more than 50,000 residents of poor, mostly Miao Minority Nationality towns on the Guizhou Plateau of western Hunan Province, with additional benefits of flood control and power generation.

With the end of IGCP Project in 2004, we propose successor IGCP project, the *International Cooperative Study of Karst Water Resources.* The main purpose of the proposed project is to encourage international cooperation to increase understanding of karst water resources with regard to both ecological and human health concerns, and to promote the sharing of ideas, experiences and resources in developing solutions to karst water resource challenges. There are four major areas of emphasis for the project:

1. Relation of hydrology to the function and health of karst ecosystems: Ecosystems in karst regions are fundamentally influenced by the distribution of water in the surface and subsurface, in turn resulting from the details of local hydrogeology and geomorphology. In many cave environments, for example, aquatic environments can support a rich diversity of organisms, and surface karst ecosystems are commonly influenced by scarcity of water in that environment.

2. Water supply in karst regions: This topic has taken on very timely significance with the recognition (Ford and Williams, 1989) that as many as 25% of the world’s population obtains drinking water supplies from karst aquifers. At the same time, karst areas often offer difficult challenges in water supply both with the quantity and quality of water sources. In many case karst waters are not easily accessible from the surface landscape. Karst waters are also in many cases extremely vulnerable to contamination from urban, agricultural, and other types of land uses that introduce contaminants to the subsurface that travel quickly through karst aquifers with little attenuation to pollute water sources.

3. Water-related environmental problems in karst regions: In addition to problems with the supply of water, there are other very significant environmental problems that occur in karst regions associated with the movement of water through these systems. These include, for example, sinkhole flooding, land subsidence, and sinkhole collapse than can disrupt urban development and create not only severe economic problems, but in some cases have led to loss of life. There are some karst regions where a combination of natural conditions and human events has created very severe environmental problems. Of the 80 million people who live in the karst region that spreads throughout eight provinces of southwest China, for example, eight million

Table 1: World Heritage Sites inscribed specifically for cave and karst features as of 2004 (Sources: Wong et al., 2001; World Heritage website < http://whc.unesco.org/>)

World Heritage Site	State Party	Year
Plitvice Lakes National Park	Croatia	1979/2000
Mammoth Cave National Park	USA	1981
Skocjan Caves	Slovenia	1986
Ha Long Bay	Vietnam	1994/2000
Carlsbad Caverns National Park	USA	1995
Caves of Aggtelek and Slovak Karst	Hungary/Slovakia	1995/2000
Desembarco del Granma National Park and System of Marine Terraces of Cabo Cruz	Cuba	1999
Puerto-Princesa Subterranean National Park	Philippines	1999
Gunung Mulu	Malaysia	2000
Phong Nha - Ke Bang National Park	Vietnam	2003

live below the poverty level, and in many areas these problems have been made worse by rock desertification resulting from deforestation of the region's peak cluster karst.

4. Aqueous geochemistry of karst aquifer/ landscape systems: The fundamental nature of karst systems, and each of the environmental issues that are characteristic of them, are associated with the dissolution of soluble bedrock, primarily limestone, in the carbonic acid solutions of natural waters. Important questions are yet to be fully answered with regard to the behaviour, descriptions, and rates of these processes. These include both fundamental and applied questions that address the quantitative, thermodynamics and kinetics-based relationships that describe the processes that create karst landscapes in the first place, as well as, for example, applied problems addressing how water/rock interactions in carbonate rock regions are impacting the global carbon cycle.

Such international collaborations can indeed have significant scientific, logistical, financial, and even cultural challenges, but the benefits can be tremendous. United Nations Programs such as IGCP help to provide a framework with which to overcome these challenges.

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THE ROLE OF CAVE EXPLORATION AND SURVEY IN THE PROTECTION OF THE WORLD'S LONGEST CAVE SYSTEM: MAMMOTH CAVE, KENTUCKY USA

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The Mammoth Cave System is the most extensive known cave in the world, and exploration and survey continue there. With a currently surveyed length of more than 560 km, and an additional 250+ km of surveyed passages in nearby caves, there is geologically reasonable evidence to suggest that Mammoth Cave may some day exceed 1,000 km in length. The regional, national, and global significance of the karst area there has been codified with the designations of the area as a US National Park, and through UNESCO programmes, a World Heritage Site and International Biosphere Reserve based on the remarkable karst development and high level of biodiversity.

One of the challenges of studying and protecting the karst resources in and around Mammoth Cave National Park is that many of them are underground. Since 1957, the Cave Research Foundation (CRF) has been working in conjunction with resource managers and scientists from Mammoth Cave National Park to conduct about ten expeditions a year in a continuing effort to explore, survey, inventory, and document Mammoth Cave and nearby caves, and no end of the project is in sight. Not only does this work identify locations and geometry of the passages themselves, but it documents the biological, mineralogical, cultural, archeological, and paleontological resources that they contain. The maps produced by the efforts are also an important resource for scientists who study the cave, its water, and how the cave relates to the surface landscape. We know now for example, in large part by cave survey, that the upstream ends of several of the cave's most significant underground rivers extend far beyond the park boundaries to agricultural land, industrial sites, and transportation corridors with detrimental impacts to the cave's water quality and aquatic ecology. The maps also provide critical resources for scientists in several other ways--base maps to plot the features they study, as well as "roadmaps" to find their way around (and back out of) this enormously complex labyrinth. A currently evolving task involves integration of these surveys into Geographic Information Systems databases.

CRF is also surveying and documenting other nearby significant caves in and near the National Park, including Lee Cave (12+ km), Wilson Cave (6+ km), and Smith Valley Cave (4+ km), as well as a large number of minor ones in the "Small Cave Inventory" program. The foundation has also expanded into, and continues to survey significant caves and karst resources in, other National Parks including Sequoia/Kings Canyon, Carlsbad Caverns, Lava Beds, Ozark Scenic Riverways, and Buffalo National River. In addition to its work with the National Park Service, CRF works with the US Forest Service, the Bureau of Land Management, and other state and federal agencies in understanding and protecting karst resources.

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EVIDENCE OF COMPLEX SPELEOGENESIS AT PHONG NHA, VIETNAM

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The Phong Nha Cave demands a thorough review of its speleogenetic history, but it is timely to review some of the evidence that it has undergone an unusually complex process.

It is clear, that like many large limestone caves, it has undergone solution on various levels by both phreatic and vadose processes and this has been compounded by collapse episodes. The major risings that provide the present sources of both the Chay and Son rivers have been known and recognised as major landscape features of Vietnam for many years.

In 1999, Hans Friedrich and myself discovered a number of large pebbles of haematite on the surface. These had the glossy character that suggested deposition from hydrothermal action. Moreover, we found them adjacent to the immense polje that is probably the most striking, yet almost unrecognised, landscape feature of the plateau. This suggests that the polje and its associated high level caves and deep dolines may have resulted from large-scale hydrothermal action. In turn, this drew our attention to the prevalence of high ceiling domes and cupolas in the caves and these are usually recognised as owing their origin to up-welling hydrothermal action.

On the uppermost level of the plateau there is a major unconformity with a layer of granites and pyritic gneiss. The gneiss is now oxidising to sulphuric acid and this is resulting in a soil of extremely high acidity. The plan of the cave system indicates that major tunnels follow a line parallel to the edge of the gneiss; and raises the question of the extent to which this acid has influenced the cave morphology. The occurrence of fine granitic gravels in the caves also suggests a link to this surface phenomenon.

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IS IT FEASIBLE TO DEVELOP A REPRESENTATIVE SAMPLE OF THE WORLD KARST AREAS?

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Keywords: world heritage, karst, representativeness

Approximately 50 karst sites are inscribed on the register of World Heritage, although in some cases the karst as such was not fully recognised during the nomination and inscription process.

There is now a growing concern to look at new nominations within a representativeness framework. In particular, there is now such a framework for palaeontologic sites and the process of developing a similar framework for geologic sites is now well advanced.

However, the very complexity of karst in itself creates some significant problems as karst values are related to a wide spectrum of disciplinary concerns. Probably only Yuan Daoxian has given significant attention to developing a conceptual classification of karst types.

This paper will identify and analyse the karst values that can be specifically identified within the World Heritage estate and will then assess the feasibility of developing a multiple value system to support the further development of karst recognition and protection strategies.

GUIDELINES FOR THE PARTICIPATION OF LOCAL AND INDIGENOUS PEOPLES IN KARST CONSERVATION AND MANAGEMENT

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Keywords: indigenous people, protected areas, conflict, co-management, religion, subsistence.

In most areas where efforts are made to conserve and manage karst resources, local or indigenous peoples have long histories of beliefs about and uses of those resources. Conservation and management of karst involves many intersections with local interests, posing both challenges and opportunities for all involved. This paper offer s a cross-cultural perspective on some of the most important issues of mutual concern, citing the author's experience with local peoples and karst resources in Madagascar, Egypt, Malaysia, Australia and Central America. This paper argues that while there are no universal common threads in the human experience with caves, there are enough frequently recurring themes that some general guidelines of potential use to karst managers everywhere may be developed. These guidelines are presented here, with the caution that they should be carefully measured by local circumstances.

The principal uses of caves and karst by local and indigenous peoples are for subsistence (or profit) and spiritual purposes. While in some cases these uses may create no environmental or social problems, in most instances there are serious issues that karst managers must consider.

This paper begins with the spiritual dimensions, because they are an ancient and essential part of the human experience with caves, and because they are very significant in Asia. Spirituality is also an appropriate place to begin because it is one of the most intangible and difficult areas of concern for karst managers, and is worthy of special effort in developing guidelines.

Human reverence for caves is very ancient and complex. For some cultures, caves are places of origin. The Lakota of North America and the Inca of South America are among these. In even more cultures, caves are places of return, where one's body and spirit may repose after death.

Caves are also what anthropologists call 'liminal' places between two worlds, offering access between the ordinary and the extraordinary. Many of the modern Maya groups of Central America, for example, regard caves as openings to another world. Some of these portals are regarded as the literal or figurate centers of the world.

As places of origin and return, and as portals and centers, caves are important centers for ritual and pilgrimage. Many indigenous peoples make votive and thanksgiving offerings in caves. In many caves there are active offering tables where people leave objects or sacrifice animals to propitiate the spirits, especially to prevent them from being restless, unhappy or even malevolent. At these same altars people also make votive offerings. There are also thanksgiving offerings, in which the original supplicant returns with more objects to say "in thanks for your granting my original wish, I now offer you this." In Asia, the Penan of Sarawak's Niah cave once made votive offerings on an altar in the cave mouth asking for the protection of bird nest harvesters from injury or death in their hazardous work. Votive and thanksgiving prayers and offerings are also typical of the greater traditions of Buddhism and Hinduism.

Caves and rock shelters are often important repositories of cultural expression, much of it spiritual in nature. Australian Aboriginal rock art preserved in and still created in such protected places depict the Dreamtime creation events of the ancestral beings. Modern Aborigines regularly interact with these pictographs to perpetuate important traditions that are central to their identity.

Finally, caves seem often to be important for the psyche and general well being of many traditional and other peoples.

The worldviews of many indigenous cultures reveal that the dichotomy presented here between spiritual and subsistence aspects of cave use among traditional peoples is an artificial one. Some cultures, notably the Maya of Central America, have long depended upon caves and sinkholes for the water that supported them and their crops. The Maya quest for water and food crops cannot be described as exclusively utilitarian, however. Many Maya still believe that rain deities inhabit caves. Caves are the doorways of the gods' abodes, and from them the gods issue rain to water the life-giving crops of the Maya. Many Maya therefore make offerings and pray for rain and for permission from earth deities to disturb the earth in order to plant maize.

Subsistence and profit are, however, often identifiable quite apart from the spiritual realm. Sometimes caves and related features provide indigenous and local peoples with their most basic needs, including shelter, food and water. One of humankind's oldest abodes or temporary shelters is the cave, and there are several places around the world where troglodytes still dwell. Local peoples derive a surprising abundance of food from caves, including fruit bats, eels and even cormorants.

Of most concern to us are those cases where local people exploit karst resources for both sustenance and profit in excess of the sustainable yields of those resources, and often illegally. The most extreme example comes from East Malaysia, where swiftlet nests are relentlessly over-harvested because they are almost worth their weight in gold. In principle, the harvest of bird's nests could provide a perfect model for sustainable use of a natural resource. Growing demand and greed are, however, keeping a potentially perfect system from working. The system is collapsing, along with the bird populations. This paper argues that simple human greed began to erode and finally led to the collapse of a nest harvesting system that was once sustainable because a single ethnic group endowed with the exclusive right of harvest weakened and lost its grip on the resource.

Another economic problem is that indigenous and local people often believe riches are to be found in caves, leading to senseless "prospecting" and destruction of cave resources, and to damaging impacts on scientific research. A related problem is that local peoples also destroy the archaeological integrity of many sites in their search for saleable artifacts.

Such examples of overuse and destruction of cave resources by indigenous peoples seem disturbing to us. But we need also consider that the economic and other interests of outsiders – including all of us interested in karst management and conservation – often harm or destroy the spiritual and subsistence cave resources of these peoples. Any protection or development of caves and karst is almost certain to impact indigenous and local interests, both spiritual and subsistence. Protected area managers may deliberately or unwittingly restrict or deny vital access to sacred sites. Tourists may destroy speleothems and other spiritual resources. Often in the inter-ethnic competition for economic resources of caves, it is the non-indigenous groups who wrest control away from indigenous groups. Extra-local or non-indigenous exploitation of karst resources also frequently leads to destruction of important economic and spiritual resources of local people. A good example is around Ipoh in West Malaysia, where the quarry industry is a constant threat to the area's important Buddhist and Hindu cave temples.

Caves and other karst features are, in sum, not marginal or useless spaces but highly meaningful and useful places for traditional and local peoples. They are venues for tension and even conflict between traditional groups, between traditional groups and outsiders, and between traditional groups and the people who would protect and manage caves for other purposes. What is needed is accommodation between the local peoples and karst managers. Despite many problems involving indigenous and local peoples, the locals have great potential to assist in the conservation and management of karst resources. Because of their long and intimate association with their homelands, they often possess profound and detailed knowledge of the resources. From detailed ethnographic documentation of local knowledge and identification of issues of overlapping concern between locals and karst managers, the managers can build on local knowledge and institutions to involve local people in surveys, planning, and implementation. The goal should be to achieve a balance whereby legitimate access by local and indigenous peoples is guaranteed, while any negative impacts of that access are reduced or eliminated. Ways may also be found to ensure that local people benefit economically from conservation and management efforts. This paper articulates the following guidelines to reconcile and involve local people with karst conservation and management.

Extensive baseline studies of the cultural and economic importance of karst features to local people should be carried out along with other baseline surveys.

Because local people in many cases have inhabited karst regions over long periods of time, they possess ethnoscientific knowledge of the resources that should also be collected as part of baseline data. Much of their ethnoscience is also sound "science."

Cave social science should be undertaken with the possibility in mind that indigenous rights and access may be the best guarantors of cave and karst conservation.

Cave managers must protect indigenous cultural resources, including pictographs, artefacts, and burials, from damage by tourists and other users. This may require that some caves or portions of caves be permanently closed to visitors, or that visitor access is carefully monitored by trained guides. Indigenous access should be allowed as much as is possible.

Cave ritual should be protected. It may be desirable to allow access to locals and visitors at different times so that locals are not disturbed in prayer and offering.

Indigenous and local peoples should have priority in permissible exploitation of cave resources. Their harvests need to be monitored, regulated and enforced. Other ethnic groups may need to be banned from access to these resources. Inappropriate local uses of caves may need to be eliminated, but in ways that are sympathetic, while alternatives or compensation are made available.

Portions of karst protected area and development project budgets should be allocated from the beginning to target local and indigenous people.

Local and indigenous people should, whenever possible, have priority in employment. They can be hired to assist in bioinventory and mapping. They can be employed as guides, rangers, and watchmen, in construction and maintenance, and in archaeological excavation.

Where feasible and appropriate, karst tourism that highlights or features local perceptions and uses should be developed. Done appropriately, this can help to boost indigenous pride and also increase revenue, and has great educational value for visitors.

Enforcement of cave conservation laws needs to be both consistent (not meted out arbitrarily) and appropriate (with different fines and other penalties applying to different groups violating laws with different intents). Most importantly, enforcement needs to be uncorrupted.

Education and sharing of information is vital for project establishment and ongoing success. Locals need education about a host of issues, from karst hydrology to principles of sustainable harvest to tourist culture and archaeological context. Project managers and employees need to learn what they can from locals about the caves, from basic navigation to sites of special interest and ecological interactions. Formalized partnerships that involve education and sharing of views may be appropriate. Beyond not touching speleothems, tourists need to be educated about cultural dos and don'ts in the caves.

The author appeals to members of the audience and readers of the paper to contribute information on these topics. One goal is to develop a systematic worldwide database of the intersection between local people and karst, in order to develop useful guidelines for karst managers.

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MICROCLIMATIC CHARACTERIZATION OF THE ESCOURAL CAVE (PORTUGAL): CONSERVATION OF A PREHISTORIC ROCK ART CAVE IN A VERY SENSITIVE KARSTIC ENVIRONMENT

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Keywords: karst, cave, rock art, conservation, microclimatology.

1 Introduction

The prehistoric rock art cave of Escoural has been discovered in 1963 during the exploitation of a marble quarry. This cave occupies a major channel from the epikarstic zone of a well developed karstic network. This cave is visited by around 45 people every day (Brunet *et al*., 2002). The goal of this study is to record enough multi-parametric data to appreciate the quality of the conditions of conservation of the cave. The comprehension of the exchange mechanisms between the walls and the air circulations, will be of help to foreseen the influence of various potential disturbances, like an increasing number of visitors. The main point is to avoid conditions favourable to carbonate dissolution or crystallization on the painted or engraved walls. To meet this objective, it will be necessary to limit the transfers at air-rock interfaces and thus to maintain the air parameters in the cavity (temperature, moisture, CO_2) as close as possible to the values ensuring balances, and avoiding processes of condensation or evaporation.

2 Geological setting and cave geometry

The Escoural cave is located in the South of Portugal close to the town of Santiago do Escoural, around 20 km west from Evora. The cave is dug in a small hill made of pure metamorphic limestone. The intense exploitation of marble has considerably reduced the thickness of the ground above the cave which is now less than three meters below the surface. The cave is composed of a main gallery, where most of the rock art is located, connected with 17 large karstic channels (around 1 meter in diameter). A footbridge has been placed in the main gallery to avoid destruction of archaeological remains,

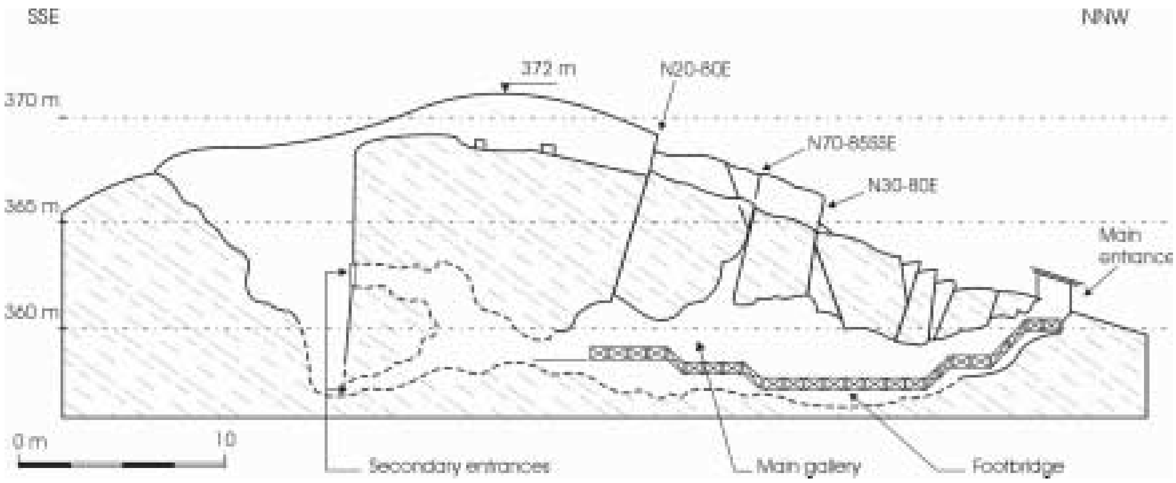

Fig. 1: Schematic geological cross section through the Escoural cave.

which are abundant in the whole cave. The structure of the cave is strongly affected by the intense fracturation of the marble (Fig. 1). The main faults (N20-80E, N70-85SSE and N30-80E) are supposed to play a major role in water circulation and to be the way most infiltration goes through.

3 Data acquisition device

In order to precise the evolution of the climate of the cave, data recording devices have been set up to study the evolution of air temperature (6 probes), wall temperature (6 probes), air velocity, air moisture and air pressure. Outside air temperature, amount of rainfall and atmospheric pressure have also been recorded (Fig. 2). All the atmospheric sensors and probes are connected to a data recorder located into the cave, close to the main entrance.

The data obtained were interpreted in conjunction with geological information (geometry of the marble, geological structure of the region). Detailed observation of the wall (water infiltration zones, major discontinuities, crystallisations) and hydrochemical data from infiltration waters (alkalinity, CO_2 pressure, calcite and dolomite saturation indices) has allowed to characterize the main phenomena taking place in the cave.

4 Results

Since its discovery the cave is in an evolutionary situation due to its very superficial situation (only a few meters below the ground level). Two major phenomena can be of interest for conservation (Brunet and Vouvé, 1996): the condensation of water vapour on the paintings covering the wall of the cave which may occur in spring and autumn during periods of inversion of temperature between the atmosphere of the cave and the exterior, and the circulation of infiltrated waters which may entail the crystallisation of carbonates on the prehistoric paintings. We have calculated that the infiltration waters tend to be oversaturated with respect to calcite and dolomite, which is a main worry for conservation. Crystallizations of carbonate can be observed on many paintings and engravings, these crystallizations are not recent and this phenomenon has probably begun immediately after the realisation of the art work (Fig. 3). The soil above the cave is very thin but it produces enough CO_2 to give a highly corrosive potential to infiltrating waters. These waters are thus able to dissolve carbonates in the very first meters of the ground. As a consequence, calcite crystallisations are mainly located below the main faults which behave has major infiltration zones. Thus, rock art drawn below fault plans are all covered with calcite.

The cave also show intricate air circulation pattern. The daily variation in temperature inside the cave can reach 2°C. These variations are mainly due to a mixing between the warm and humid air of the cave and dry and colder air from outside. This modification relates to the opening of the cave door several times every day during the visits. This change in temperature is strongly prejudicial to rock art conservation because in favourable periods it may entail water evaporation and thus calcite formation on the wall.

Fig. 2: Map of the Escoural cave and location of atmospheric sensors (1, 2, 3, 4, 5, 6: temperature probes; ■: data recorder).

Fig. 3: Calcite crystallisation covering prehistoric drawings (horses).

5 Conclusion

The Escoural cave is one of the few rock art sites in Portugal and its only cave site. Water infiltration is the main threat to the cave conservation. Most of drawings are already covered with calcite particularly under fault planes where water infiltration flows are very active. For the time being, the impact of visitors on the climatology of the cave is still negligible and the main disturbance is caused by the opening of the door cave which induces major perturbations in air temperature and humidity.

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LINEAMENT ANALYSIS FOR THE GROUNDWATER IN KARST FRACTURED ROCKS IN THE SUOIMUOI KARST CATCHMENT

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Keywords: Vietnam, lineaments, karst, remote sensing, groundwater

Abstract. Vast areas of the world consist of hard rocks (basement complexes), where water is restricted to secondary permeability, and thus to the fractures and the weathered zones. Most of such areas have a shortage of water. As the success ratio of drilling in hard rock terrain may be low, and the use of geophysics is often judged as too expensive, the study of lineaments from remote sensed imagery is an attractive alternative. High production areas in hard-rock aquifers are generally associated with conductive fracture zones. An effective method for defining the fracture zone is based on lineament indices, which are extracted from satellite imagery. Together with a detailed structural analysis and understanding of the tectonic evolution of a given area it provides a useful tool for hydrogeologists for studying groundwater in fractured rock and developing water resources. The relationship of lineaments, fractures and groundwater is studied by Mabee *et al.* (1994), Kresic (1995), Sander (1997), Magowe (1999), Krishnamurthy *et al*. (2000). They agree that a high density of lineaments indicate in general the presence of groundwater. Hung *et al*. (2002) suggested that fractured rocks could be analysed by studying lineaments with the help of lineament indices. An application of the proposed methodology, on basis of Landsat ETM images, is given here for the tropical Suoimuoi karst catchment, NW-Vietnam.

1 Introduction

The study area, the Suoi Muoi River catchment, is situated northwest of the city of Son La, between longitude 103°33’ E and 104°00’ E and latitude 21°20’ N and 21°29’ N, covering 284 km² (Fig. 1). The population of the Son La province is 650,000 inhabitants, resulting in an average density of 48 inhabitants/km². Natural hazards, droughts and floods are frequent threats to daily life. The Son La karst area is part of the Son La-Thuan Chau karst highland, a mountain range extending over 300 km in NW-SE direction and with an average width of 10-30 km. The karst landscape is characterized by the absence of permanent surface flow, closed depressions, caves, the existence of large springs, and the presence of sinkholes into which entire streams, like the Suoimuoi River, disappear underground. In the Suoimuoi catchment, the karst landscape occurs mainly in the central part and stretches from northwest to southeast, on average 10 km wide and ranging from 500-850 m high. This area is characterized by a peak cluster morphology (cf. Chinese Fengcong), blind valleys, deep dolines, narrow valleys, chained sharp peaks and many swallow holes exiting underground into caverns. In the middle part of the area, mainly peak forest landscape dominates with residual karst peaks and tower karst, which emerge here and there above the dissolution- erosion valleys (Tuyet, 1998).

The Son La-Thuan Chau karst area consists mainly of two sub-areas. The southwestern parts are composed of karst water-bearing carbonate rocks of Paleozoic age, Banpap (D_2*bp*) and Early Permian-Carboniferous Chienpac (C-P_1*cp*) Formations. The northeastern part is of Middle Triassic age with the Dong Giao Formation (T_2*dg*). In the Suoimuoi catchment, karst occurs in limestones and dolomites of Late Cambrian, Middle Devonian, Carboniferous - Early Permian and Middle Triassic age. These carbonates have a favourable composition, texture, and structure for karstification (Hung, 2001).

Many different tectonic phases and neotectonic movements have intensively affected these rocks. The present Son La karst highland is dissected by NW-SE, SW-NE, sublatitudinal, and submeridional trending faults. The NW-SE fault system resulted from the collision of continental crust in the Precambrian. The region then was affected by NW-SE oriented folding due to Indosinian closure of the Paleotethys, starting in Late Permian and culminating during Middle Triassic. All the deposits were finally uplifted during the Neogene Himalayan collision event (Tri *et al*., 1977; Tri and Tung, 1979; Tien *et al*., 1991). A series of sub-parallel strike-slip faults can be recognized in the Son La fault zones. Furthermore, Son La town is located on the active Tuan Giao-Son La seismic zone where many destructive earthquakes with intensities of up to 6.5 on the Richter scale have been recorded.

The continuous tectonic activity in the Son La region accompanied by strong uplift and associated tilting towards the Da River valley to the east, has resulted in the destruction of the Miocene-Pliocene peneplane surface and the creation of deeply incised valleys. This system modifies the block structures formed by the faulting. The SW-NE fault system is younger than the NW-SE one. These SW-NE transform faults are discontinuous. The width of fractured zone ranges from 800-1200 m (Hop, 1997).

2 Structural deformation

Through brittle deformation, two mechanisms or modes of propagation, shear and extension, generate fractures. Frequently, the shear fractures occur as a conjugate pair and the extension fractures bisect the acute angle in pair. The extension features are oriented parallel to the direction of the maximum

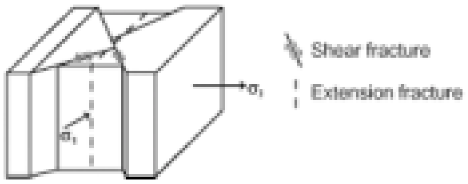

Fig. 2: Stress orientation and corresponding types of fractures

compressive stress (s_1), and perpendicular to the minimum stress (s_3) (Fig. 2). As a result of propagation mode, the apertures of the extension fractures tend to be larger than those of shear fractures. Groundwater flow may be more significant along the extension fractures. Fernandes and Rudolph (2001) concluded that tectonic activities, which result in brittle deformation, generate: 1) shear fractures that remain under compression and are not very transmissive; and 2) more permeable extension structures tend to be associated with wide aperture fractures. The recognition of these extension fractures would be valuable for groundwater resources development. Lineament analysis may be the most effective method to map these types of features.

By understanding the orientation of the stress field that generated the structures in the study area, it is possible to evaluate which lineaments can be associated with mostly shear fractures or conjugated faults and which with extension fractures. Figure 2 depicts the stress field and the general position in space of the shear and extension fractures that are generated by a strike-slip tectonic regime.

Two main types of conjugate fracture patterns are recognized for the Suoimuoi catchment, depicted by the diagrams in Fig. 3 and 4. Hop (1997) supposed that both fracture types (E-W and NW-SE) generated faults (shear fractures) and extensional fractures which affected the rocks from Precambrian up to Middle Triassic. The E-W fracture type is accompanied by shear fractures with a NW-SE and NE-SW direction and extension fractures with a sub-E-W direction. The NW-SE fracture type is accompanied by shear fractures of sub-N-S and sub-EW direction and extension fractures with a NW-SE direction. The correspondence of the NW-SE shear and extension directions and the E-W correspondence of shear and extension directions, make these two directions most favourable for groundwater development. Figure 5 shows the rose diagram for the

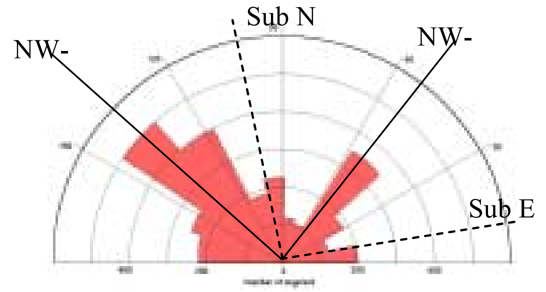

Fig. 3: Rose diagram depicts the distribution of faults on geological map (Hop, 1997)

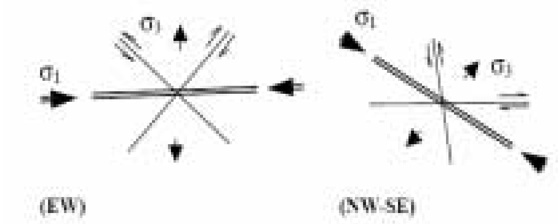

Fig. 4: The orientations of shear and extension fractures

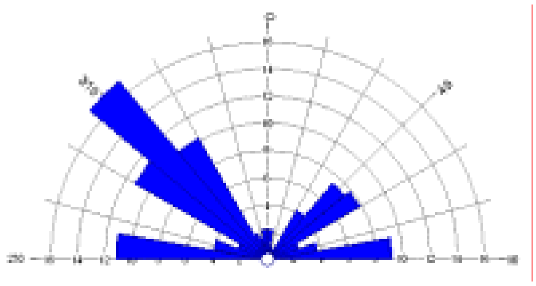

Fig. 5: Rose diagram depicts the distribution of lineaments in Fig. 7

digitally extracted lineaments after correcting. The very high density of NW-SE and NE-SW lineaments in this figure is due to additional lineaments caused by times of tectonic revolution. The densities of the sub-N-S and sub-E-W lineaments are, therefore, relatively reduced.

3 Lineament analysis

Lineaments are extracted from satellite images by edge enhancement functions available in most remote sensing software packages. The module GeoAnalyst, with the Line function of PCI Geomatica software is regarded to be one of the best functions for lineament extraction. However, its result is often still confusing and contains many errors from a geological point of view (Fig. 6). Therefore, a correct image pre-extraction step is critical. Important aspects to consider in the preprocessing are the choice of bands, their spectral characteristics, image transformation or ratio methods and

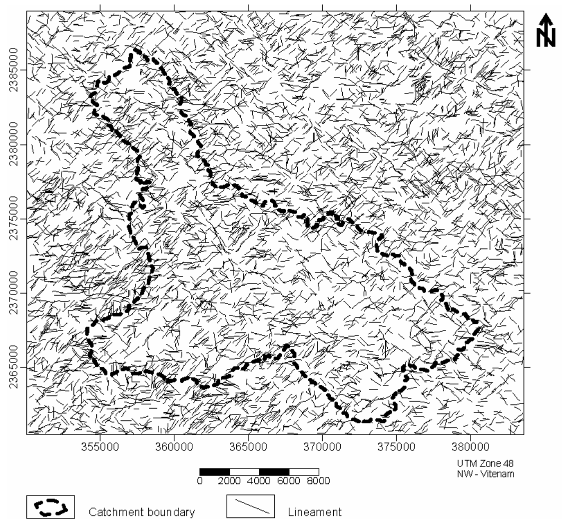

Fig. 6: Lineament map of the Suoimuoi karst catchment resulting from PCI Geomatica extraction, no lineament analysis software was used

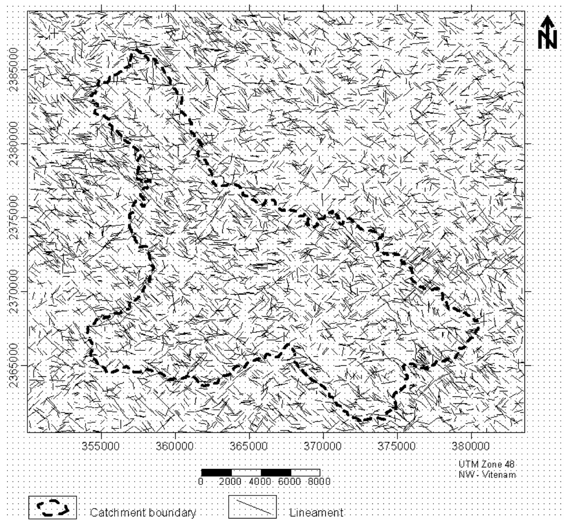

Fig. 7: Map of lineaments, as given in Fig. 1, postprocessed by lineament analysis correction software

identification of zones with hydrological features.

Taking the preprocessing into account will enhance lineament features and make them more appropriate for use in groundwater resources evaluation.

A necessary post-extraction step is the correction and analysis of the lineaments (Fig. 7). In this article this step is performed by Lineament Analysis Software, which was developed by the Department of Remote Sensing and Geomatics of the Research Institute of Geology and Mineral Resources of Vietnam. In this software lineaments are corrected one or more times (removing, connecting…) based on the statistical and geological characteristics and the spatial scale of the lineaments.

Three main kinds of lineament indices for characterising a fracture zone are distinguished 1) Total length of lineaments - X, 2) Total number of lineaments - Y, and 3) Total number of lineament intersections - Z. At small-scale analysis the average length index can replace the above indices. The Lineament Analysis Software further takes into account the spatial distribution of the lineaments and provides tools for mapping and classifying lineaments.

4 Fracture zone characterization

The fracture zone is defined on basis of the density of a lineament index. The critical value of the lineament index for defining a fracture zone boundary can be estimated by field observations of the intensity of rock deformations. The hypothesis is that a higher lineament density index corresponds to a higher rock deformation. Facture zone (F) can be described as a function of the three lineament indices

$$F = f(X, Y, Z)$$

Two simple functions can be used for defining the fracture boundary by trial and error calibration based on the observations

$$F = aX + bY + cZ$$

$$F = X * Y * Z$$

where *a, b, c* are calibration constants. Figure 8 gives the resulting map of the lineament density function F.

In this study the Z value is equal to Z + 1, because in several places the Z value equal to 0 (there are no intersection of lineament).

The relationship between the identified fracture zone and the occurrence of groundwater can further be improved by the results from pumping tests. The resulting lineament index density map can be correlated with the measured transmissivities in order to generate a groundwater transmissivity map.

The lineament software describes the fracture zones by their boundary, relative intensity, direction of lineaments and the conjugate pair of lineaments, which form the fracture zone. Figure 9 shows the distribution of shear, extensional fractures on the boundary of fracture zone. We can predict the groundwater behaviour through that map with the additional information from the topographical characteristics.

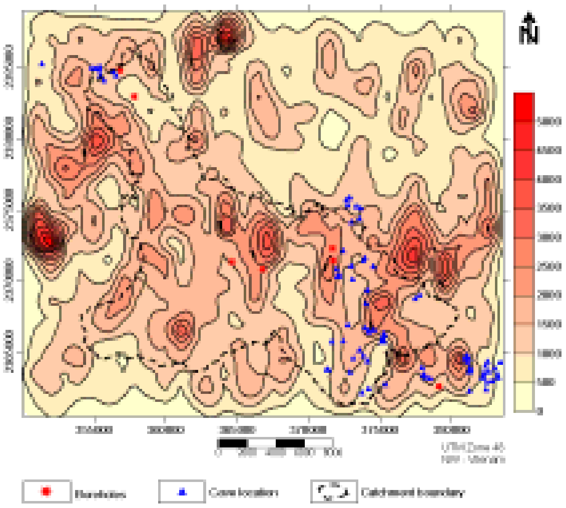

Fig. 8: Map of lineament density function F

Fig. 9: Map of delineated fracture zones

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Eds. O. Batelaan, M. Dusar, J. Masschelein, Vu Thanh Tam, Tran Tan Van, Nguyen Xuan Khien

REMOTE SENSING AND GIS ANALYSIS OF THE LANDCOVER IN TROPICAL KARST SUOIMUOI CATCHMENT IN VIETNAM

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Keywords: remote sensing, GIS, landcover, change detection analysis.

1 Introduction

One of the most effective tools for environmental studies in mountainous areas, especially tropical karst mountainous areas, is remote sensing and GIS. Remote sensing and GIS technologies are scientifically established tools, but are not yet routinely used in environmental analysis, monitoring and impact analysis. The here presented remote sensing and GIS supported environmental analyses consist of methods for image transformation, image fusion, time series, and change detection analysis. In this paper different remote sensing and GIS techniques are applied with the purpose to deduce geological and hydrological information. Landsat multispectral bands were integrated with the high resolution Landsat ETM panchromatic band. Time series and change detection analysis is applied for studying land cover changes.

2 Study area

The study area, the Suoi Muoi River catchment, is situated northwest of the city of Son La, between longitude 103°33’ E and 104°00’ E and latitude 21°20’ N and 21°29’ N, covering 284 km² (Fig. 1). The Son La karst area is part of the Son La-Thuan Chau karst highland, a mountain range extending over 300 km in NW-SE direction and with an average width of 10-30 km. The karst landscape is characterised by the absence of permanent surface flow, closed depressions, caves, the existence of large springs, and the presence of sinkholes into which entire streams, like the Suoimuoi River, disappear underground. In the Suoimuoi catchment, the karst landscape occurs mainly in the central part and stretches from northwest to southeast, averaging 10 km wide and ranging from 500-850 m high. The landscape is characterized by a peak cluster morphology (*cf.* Chinese Fengcong), blind valleys, deep dolines, narrow valleys, chained sharp peaks and many swallow holes exiting underground into caverns. In the middle part of the area, mainly peak forest landscape dominates with residual karst peaks and tower karst, which emerge here and there above the dissolution-erosion valleys (Tuyet, 1998). The climate characteristic of the Suoimuoi catchment is humid subtropical with summer rainfall and a monsoon regime. The major climate characteristics in the research area are summarized in Table 1.

The area is mainly inhabited by ethnic minority groups. The Thai, the major ethnic group, is poorly economically developed and suffers from low living conditions. Regular life threatening conditions as droughts, floods, earthquakes and epidemic diseases occur.

3 Methodology

Image fusion is defined as “The combination of two or more different images to form a new image in a certain algorithm” (Carper *et al.*, 1990). The definition of image combinations and techniques depends on the characteristics a data set should have in order to serve the user. As our purpose is integrating different images from different sensors to facilitate visual interpretations, pixel based fusion provides a useful tool. It can be grouped into two main classes: color related techniques and statistical/numerical techniques. The second group uses statistics about individual channels for correlation analysis. The color related methods deal with the transformation between display-device and perceptual color spaces. The most popular color related technique is based on the intensity – hue – saturation (HIS)

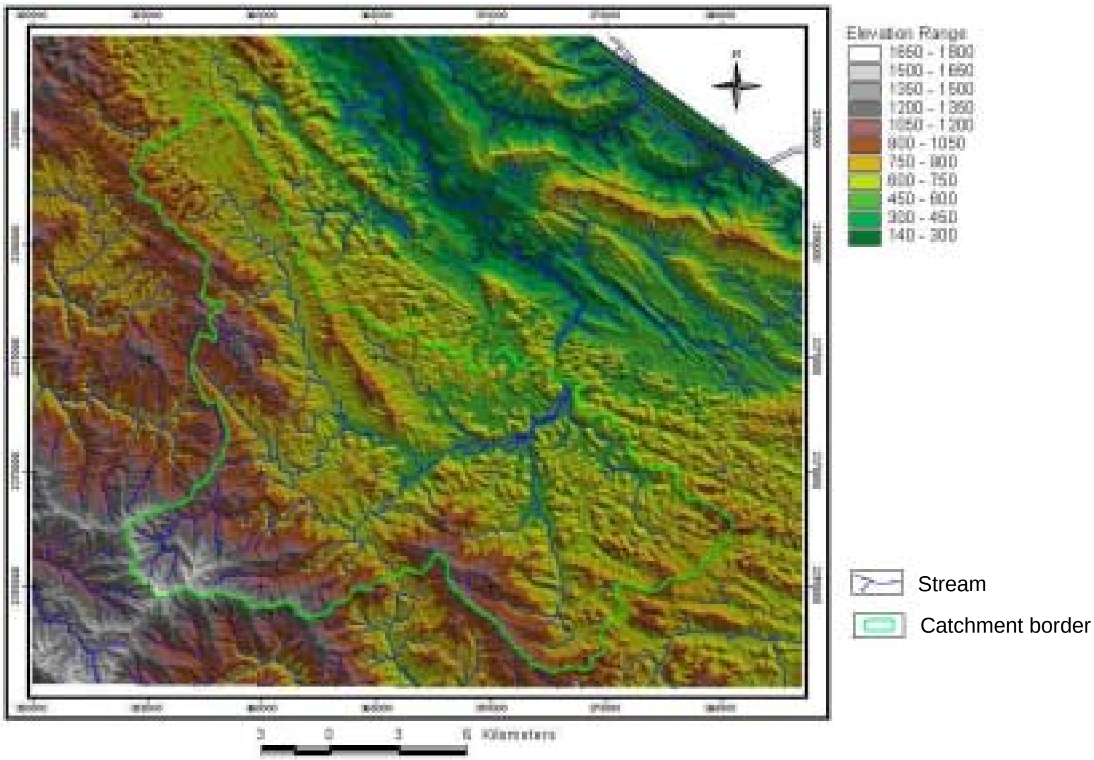

Fig. 1: Suoi Muoi River catchment.

Table 1: Summary of climatic data for the research area.

	Dry season (Oct-Mar)	Wet season (Apr-Sep)	Yearly
Mean temperature (°C)	18.0	24.2	21.1
Mean min. temp. (°C)	12.5	20.7	16.6
Mean max. temp. (°C)	24.7	29.2	27.0
Mean Precipitation (mm)	27.5	230.8	258.3
Evapotranspiration (mm)	104.2	133.8	148.0

transform. This technique transfers the composition in RGB space to the IHS space. The IHS technique can be applied to fuse images from a single sensor, or multisensor data, or image data with ancillary data. Some geoscientists have experimented intensively fusion with the IHS method using geophysical data, geochemical data, thematic data, and data compiled from fieldwork (Harris *et al.*, 1990; Schetselaar, 2000).

Change detection techniques can be roughly grouped into two categories: (1) those detecting binary change/non-change information, such as using image differencing, image ratioing, vegetation index differencing, and principal component analysis (PCA); and (2) those detecting detailed "from-to" change trajectory, such as using the post-classification comparison and hybrid change detection methods.

Vegetation indices (VI) in remote sensing are combinations of reflectance of two or more bands, usually in the visible red band and the near infrared band. The most common vegetation index is the *Normalized difference vegetation index* (NDVI).

$$NDVI = \frac{(R_{nir} - R_{red})}{(R_{nir} + R_{red})}$$

Where: R is the reflectance, (DN) after haze correction, of the red (R_{red}) and the near infrared band (R_{nir}). The NDVI is a ratio ranging in from –1 to +1.

For Landsat MSS sensor, the visible red and the near infrared band correspond to band 5 and band 7, respectively. For Landsat TM sensor the visible red and the near infrared band correspond to band 3 and 4, respectively.

Digital image classification uses the spectral information represented by the digital numbers in one or more spectral bands, and attempts to classify each individual pixel based on this spectral information. The resulting classified image is comprised of a mosaic of pixels, each of which belong to a particular theme, and is essentially a thematic "map" of the original image. There are two common ways of digital image classification: *supervised classification* and *unsupervised classification*.

An *unsupervised classification* method is used here, it is based on the numerical information in the data, which is then matched by the analyst to information classes. The clustering algorithms are used to determine the natural (statistical) groupings or structures in the data. Usually, the analyst specifies how many groups or clusters are to be looked for in the data. In addition to specifying the desired number of classes, the analyst may also specify parameters related to the separation distance among the clusters and the variation within each cluster.

4 Result and discussion

The result of the landuse classification is given in Fig. 2, it represents the result of NDVI classification with additional information from aerialphotos. Main land uses in Suoimuoi from 1973 to 1993 are listed in Table 2. From 1973 to 1993, more than 36% of forest area and nearly 24% of shrub area disappeared (Table 2). The lost area of vegetation cover is totally converted in arable land and bare soil. We notice the incredible speed of the losses in Fig. 2.

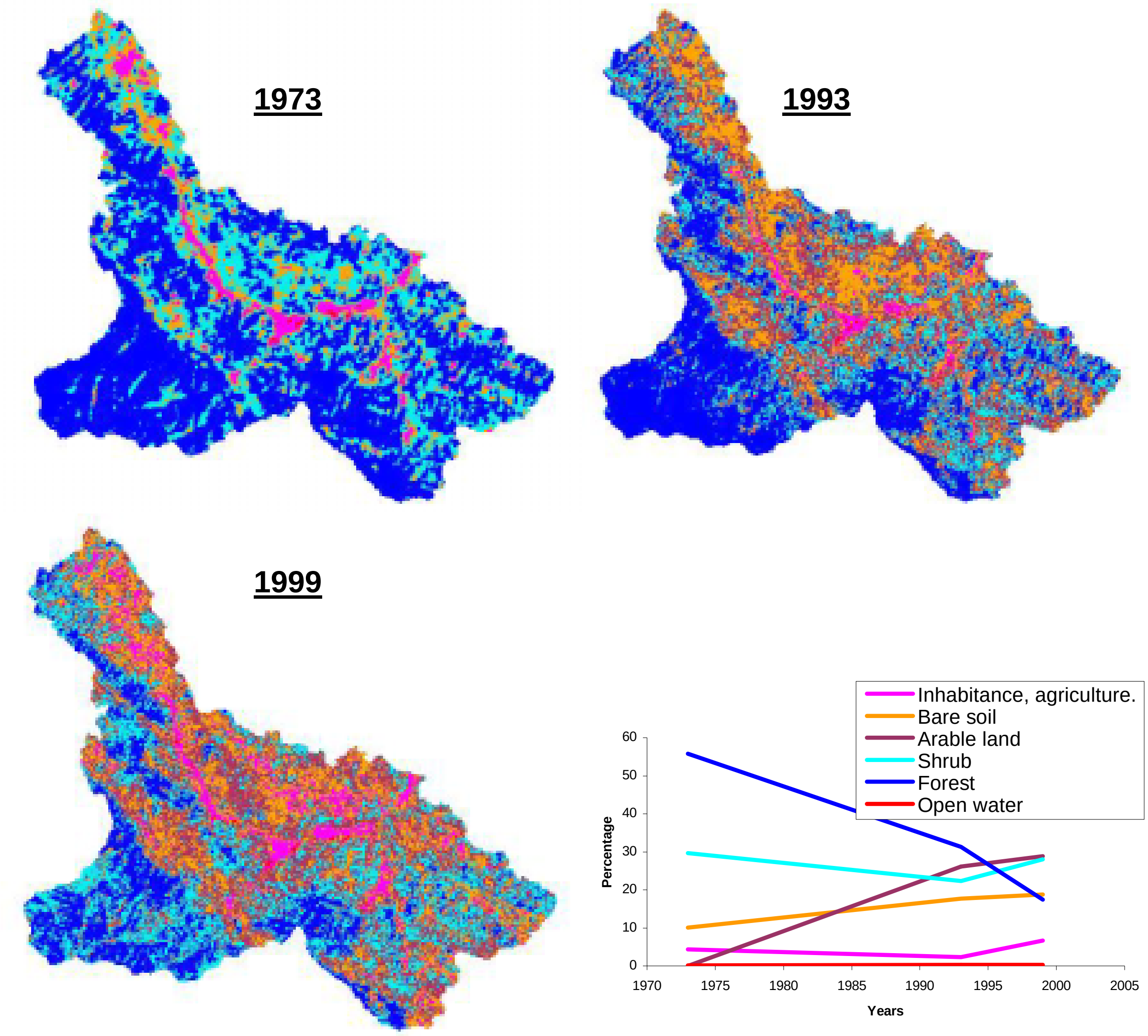

Fig. 2: Landuse map of Suoimuoi catchment in 1973 – 1993 – 1999.

Table 2: Main landuse in Suoimuoi through 1973 – 1993 – 1999.

Description	1973		1993		1999	
	Area	%	Area	%	Area	%
Open water	457200	0.16	648000	0.23	857925	0.30
Inhabitance, agriculture.	12434400	4.38	6633000	2.34	18823950	6.63
Bare soil	28540800	**10.05**	50065200	**17.64**	53157150	**18.73**
Arable land	0	**0.00**	74205900	**26.14**	81762750	**28.80**
Shrub	84078000	**29.62**	63362700	**22.32**	79653600	**28.06**
Forest	158346000	**55.78**	88938000	**31.33**	49614975	**17.48**
Σ	283852800	100.00	283852800	100.00	283852800	100.00

In only 6 years, from 1993 to 1999, the forest area decreased with 44%. The average decrease of forest loss per year in the period 1993-1999 is twice bigger than in the period of 1973-1993. If the same speed of forest loss as during 1993-1999 is maintained than around 2005 almost all the natural forest in Suoimuoi catchment will have disappeared.

5 Conclusion

Using an IHS transformation with a hue invariant in merging high resolution PAN with multi spectral Landsat ETM7 gave the potential of maintaining the spectral balance of the multispectral data set. The integration of Landsat ETM7 band 7-4-1 with high resolution PAN provided complementary information with respect to the discrimination of major geographical feature in detail. With the high-resolution image, both type of features, manmade and natural, are easy to recognize.

This investigation shows that the forest area in the Suoimuoi catchment decreases very fast. The present forest cover is a meagre 17.5% comparing to 55.8% in 1973. The main reason for the deforestation is human activities. The loss of natural forest will cause many natural disasters (flooding, landslide...) in the catchment.

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REMOTE SENSING AND GIS-BASED ANALYSIS OF CAVE DEVELOPMENT IN THE SUOIMUOI CATCHMENT VIETNAM

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Keywords: remote sensing, GIS, karst, cave development, lineament.

1 Introduction

During the last decade, Vietnam experienced a rapid economic growth. Sustainable growth, however, also requires an improvement in the quality of life. Rural water supply and sanitation are, therefore, priority issues for the Vietnamese government and of international donors. Since 1998, the Vietnamese-Belgian research project “Rural development in the mountain karst area of NW Vietnam by sustainable water and land management and social learning: Its condition and facilitation” (Masschelein and Swennen, 1997) aims at increasing knowledge and expertise regarding the assessment and evaluation of karst systems in Son La and Lai Chau provinces (NW Vietnam). The project has gained a lot of information from several speleological expeditions, organized by the Research Institute of Geology and Mineral Resources, Belgian Geological Survey, Belgian-Vietnamese Karst and Cave Association, and the Speleological Association of the University of Leuven (Dusar *et al*., 1994; Coessens *et al*., 1996; Mrose *et al*., 1998; Spekul *et al*., 2000). During three expeditions, 129 caves and 35 km of cave development have been surveyed. The main purpose of the study is to examine the relationship between the development of caves and the tectonic structures in the karst area of Son La.

2 Study area

The study area, the Suoi Muoi River catchment, is situated northwest of the city of Son La, between longitude 103°33’ E and 104°00’ E and latitude 21°20’ N and 21°29’ N, covering 284 km² (Fig. 1). The Son La karst area is part of the Son La-Thuan Chau karst highland, a mountain range extending over 300 km in NW-SE direction and with an average width of 10-30 km. The karst landscapes include the absence of permanent surface flow, closed depressions, caves, the existence of large springs, and the presence of sinkholes into which entire streams, like the Suoimuoi River, disappear underground.

The Son La-ThuanChau karst area consists mainly of two sub-areas. The southwestern parts are composed of karst water-bearing carbonate rocks of Paleozoic age, Banpap (D_2*bp*) and Early Permian-Carboniferous Chienpac (C-P_1*cp*) Formations. The northeastern part is of Middle Triassic age with the DongGiao Formation (T_2*dg*). These carbonates have a favourable composition, texture, and structure for karstification. Many different tectonic phases and neotectonic movements have intensively affected these rocks. The present Son La karst highland is dissected by NW-SE, SW-NE, sublatitudinal, and submeridianal trending faults. The NW-SE fault system resulted from the collision of continental crust in the Precambrian. (Tri *et al*., 1977; Tri and Tung, 1979; Tien *et al*., 1991; Hop *et al.,* 1997). Tam *et al*. (2001) concluded that the karst groundwater aquifers in the Suoimuoi catchment are determined by fractured/fissured media whilst the cavern conduits, although abundantly occurring in the region, act as groundwater galleries and/or conveyers.

3 Methodology

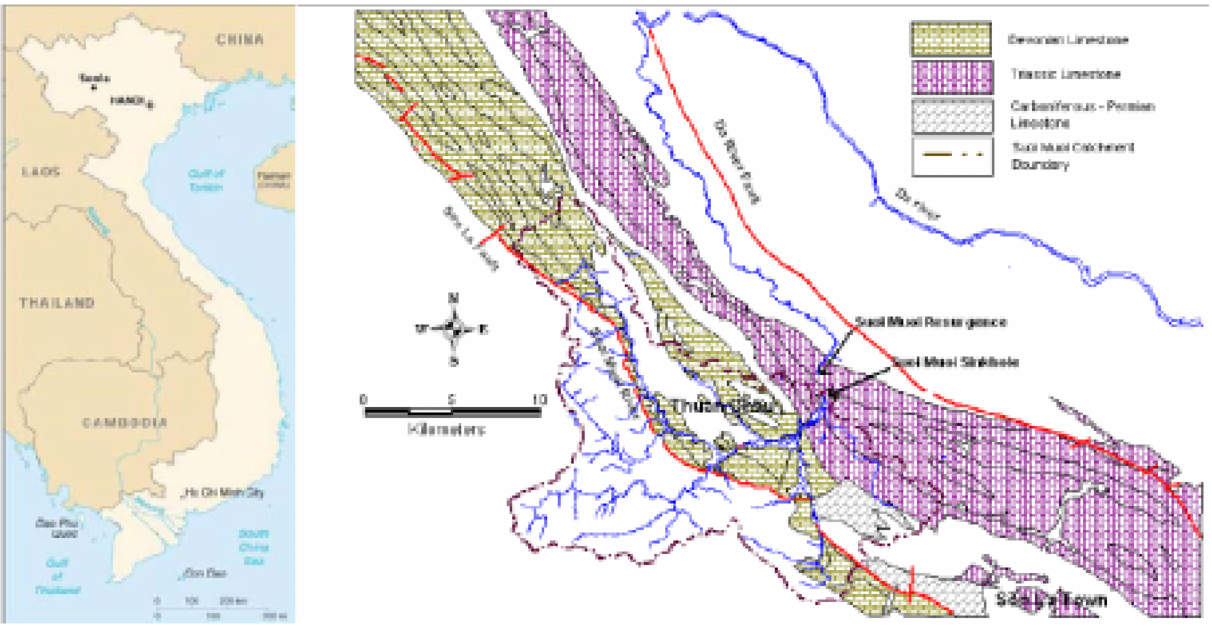

Fig. 1: Map of study area, indicating the Triassic (T_2adg_1 and T_2adg_2), Carboniferous (C_3-P_1bd), Devonian (D_2bp_1, D_2bp_2, D_2bp_3) and Cambrian ($\in_3hr$) karst formations, mapped cave locations and faults in the Suoimuoi catchment, digitized from geological map (Hop et al. 1997)

Integration of remote sensed imagery with ground surveys is a promising method in cave development studies. In this research a methodology was set up in which a variety of remote sensing and GIS techniques support cave analysis in the tropical karst area.

Remote Sensing

The major analysis steps for cave development based on analyzed Landsat ETM and a cave database are given by Hung (2001). Our purpose was to integrate images from different sensors to facilitate visual interpretation. For this purpose, pixel-based statistical/numerical or color related fusion techniques are an appropriate tool. Statistical/numerical fusion uses the statistics of individual image bands for correlation analysis. The color related fusion methods were used here and deal with the transformation between display-device and perceptual color spaces. The technique can be applied to fuse images from a single sensor, or multisensor data, or image data with ancillary data, like geophysical, geochemical, thematic data, and data compiled from fieldwork (Harris *et al.,* 1990; Schetselaar, 2001). In order to study the tectonic fracture zone in Suoimuoi catchment, both visual and digital lineament extraction were applied. The digital extraction used Laplacian and directional filters to enhance the lineaments. Lineaments from these images were extracted by PCI Geomatica software, combined, and further processed by lineament specific software (Hung, 2001).

Structural Deformation

Through brittle deformation, two mechanisms or modes of propagation, shear and extension, generate fractures. Frequently, the shear fractures occur as a conjugate pair and the extension fractures bisect the acute angle in pair. The extension features are oriented parallel to the direction of the maximum compressive stress (δ1), and perpendicular to the minimum stress (δ3) (Fig. 2).

As a result of propagation mode, the apertures of the extension fractures tend to be larger than those of shear fractures. Groundwater flow may be more significant along the extension fractures. Fernandes and Rudolph (2001) concluded that tectonic activities, which result in brittle deformation, generate: 1) shear fractures that remain under compression and are not very transmissive; and 2) more permeable extension structures tend to be associated with wide aperture fractures. The recognition of these extension

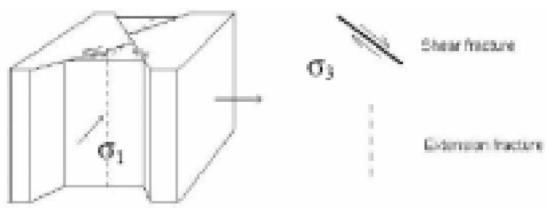

Fig. 2: Stress orientation and corresponding types of fractures.

fractures would be valuable for groundwater resources development. By understanding the orientation of the stress field that generated the structures in the study area, it is possible to evaluate which lineaments can be associated with mostly shear fractures and with extension fractures.

4 Results and discussion

Lineament and fracture zone analysis

In order to define the fracture zone, the map with digitally extracted lineaments was used to calculate the density of lineaments in the Suoimuoi catchment under the hypothesis that a higher density of lineaments indicates a higher intensity of deformation. The most common method is to calculate lineament density as the number of lineaments per unit area (n/km²), or as the number of lineament intersections per unit area (n/km²), or as the total length of lineaments per unit area (m/km²). These lineament density indices are calculated for a raster with a grid cell resolution of 1 km² and can be reclassified into ranges of values and presented as an isopleth map Since the Suoimuoi catchment can be considered as a homogeneous tectonic region, the fracture zone can be defined on basis of the statistical characteristics of the two indices: average length of lineaments and ratio between number of intersections of lineaments and the number of lineaments per km². In zones with a low value of these indices, caves cannot develop. In zones with a very high density, rock stability is too low for cave development. Therefore, the fracture zone is defined as the zone where the two indices have a value between the average plus and minus one standard deviation. Two main types of conjugate fracture patterns are recognized for the Suoimuoi catchment, depicted by the diagrams in Fig. 3.

Hop (1997) supposed that both fracture types (E-W and NW-SE) generated faults (shear fractures) and extensional fractures that affected the rocks from Precambrian up to Middle Triassic. The E-W fracture type is accompanied by shear fractures with a NW-SE and NE-SW direction and extension fractures with a sub-E-W direction. The NW-SE fracture type is accompanied by shear fractures of sub-N-S and sub-EW direction and extension fractures with a NW-SE direction. The correspondence of the NW-SE shear and extension directions and the E-W correspondence of shear and extension directions, make these two directions most favourable for groundwater development.

Cave development study based on lineament analysis

The caves cluster in the southeast and northwest of the catchment. Most of the active caves, which have developed along NW-SE direction, have horizontal passages or very slightly inclined passages, while most of the caves developed along NE-SW direction have inclined passages (Dusar *et al.*, 1994). The inclination of those caves somewhat follows the dipping of carbonate rocks. In those cases, the bedding planes may also provide routes for groundwater movement. However, in such cases movement is often controlled by fracture patterns and hydrological regimes. Figure 4 combines density data for average lineament length, number of lineament intersections, and number of lineaments.

The crosshatched area in Fig. 4 is the most favourable fracture zone for cave development since it is the overlap of the two extracted fracture zones. Most caves are located in the favourable fracture zone. In the central southeast part, some caves do fall outside the favourable fracture zone; however, they have developed on the contact of limestone and non-limestone formations. The favourable fracture zone in Fig. 4 can be used to suggest zones for

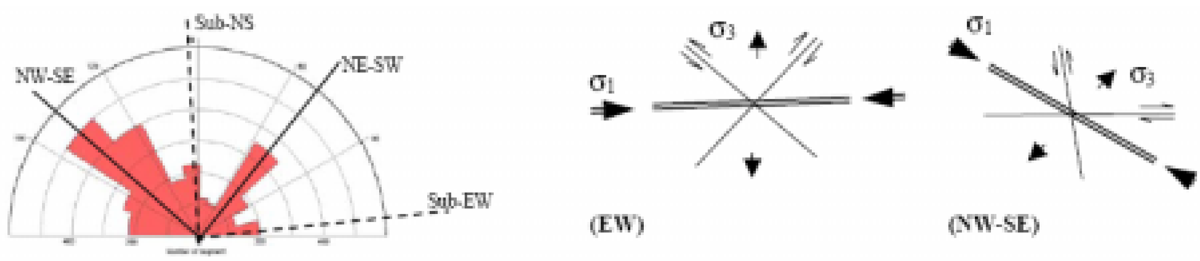

Fig. 3: Rose diagram depicts the distribution of lineaments on geological map (Hop, 1997). Also shown are the orientations of shear and extension fractures.

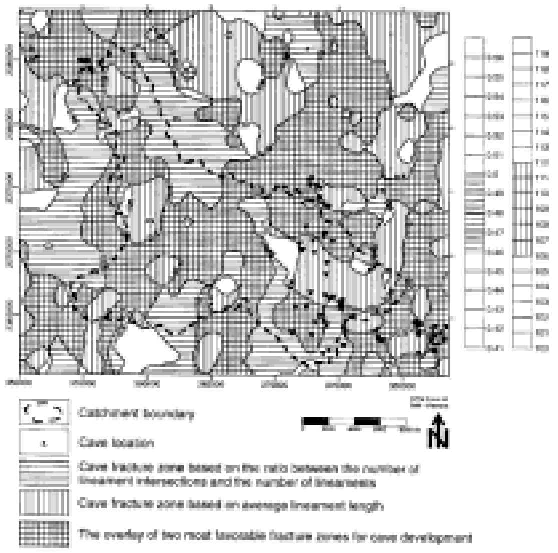

Fig. 4: Overlay of the density map of average lineament length with the density map of the ratio between the number of lineament intersections and number of lineaments. The horizontal and vertical hatched areas are the fracture zones favourable for cave development. Overlain, the crosshatched area is the most favourable fracture zone for cave development.

finding new caves in the Suoimuoi catchment.

5 Conclusions

A methodology has been set up, involving remote sensing and GIS analysis to map, predict and explain the occurrence of caves in a tropical karst region. Based on a geologic analysis, it is concluded that tectonic activity was very strong in the Suoimuoi catchment. The tectonics resulted in a NW-SE dominated fault system. The integration of Landsat 7 ETM imagery with high-resolution panchromatic data provided complementary information with respect to the discrimination of major geologic features and allowed lineament extraction in detail. A favourable fracture zone for cave development is determined through the analysis of the lineaments. The cave correspondence with the fractured zone was very high. Outside the fractured zone caves occurred at the formation contact between limestones and non-limestones. The majority of the caves developed along the major structural NW-SE direction. It is suggested that the favourable fracture zone for cave development can be used to predict cave occurrences.

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REMOTE SENSING AND GIS-BASED ANALYSIS OF SINKHOLE DEVELOPMENT IN THE SUOIMUOI CATCHMENT, VIETNAM

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Keywords: remote sensing, GIS, karst, sinkhole, DEM.

Karst has a distinctive topographic landform resulting from geological weathering and erosional processes. The primary process is the dissolving action of water of soluble bedrock (usually limestone, dolomite, marble and to a lesser extent gypsum). This produces a landscape characterized by features such as epikarst, vertical shafts, sinkholes, sinking streams, springs, complex subsurface drainage systems and caves. A *sinkhole* is a topographically closed karst depression, wider at the rim than its bottom. It is commonly of a circular or elliptical shape with a flat or funnel-shaped bottom.

Integration of remotely sensed imagery with ground surveys through GIS tools is a promising method in sinkhole development exploration. In this research a methodology was set up in which a variety of remote sensing and GIS techniques support sinkhole analysis in the tropical karst area of the Suoimuoi catchment, NW Vietnam. The hue invariant IHS transformation was applied to integrate Landsat multispectral channels with the high resolution Landsat 7 ETM panchromatic channel. The resulting fused image was used, after enhancement, to digitally extract areas with relatively low elevation. These extracted areas were evaluated by a digital elevation model. The distance between sinkholes on one hand and caves and faults on the other hand was investigated as well as the correspondence between sinkhole and fracture zone occurrence.

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INTEGRATION OF REMOTE SENSING AND GEOPHYSICS FOR GEOSTRUCTURAL ANALYSIS OF THE TAM DUONG KARST AREA, VIETNAM

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In geological remote sensing the two application fields which benefit most from information extracted from satellite imagery are lithological and structural mapping. Information from surface mapping is commonly used to postulate the distribution of geological features in the subsurface. Surface geological features may be traceable in bedrock outcroppings (ground surveys), from air photographs (photogeological reconnaissance) and/or from satellite images. In the subsurface, geological features may be perceptible from boreholes, cuttings and/or surface geophysics methods. Geophysics is a scientific discipline involving the measurement of parameters that are diagnostic of the physical properties of the materials at and beneath the earth's surface. Ideally the measured quantities give the user, by way of the physical properties for which the geophysical data are diagnostic, some meaningful understanding of the structure, composition and processes occurring within the earth. This leads to the idea that geophysical data should be integrated with remotely sensed data because the two sources can complement each other. Remotely sensed data can detail features on the earth, while geophysical data can describe these features in the subsurface. In this paper, remotely sensed data (Landsat ETM) and geophysical data (aeromagnetic and gravity) are integrated to establish a geological map, and detail the structural conditions of the Tam Duong area in NW Vietnam. Different techniques are applied for both kinds of data: image transformation, lineament analysis, qualitative interpretation of gravity and magnetic anomalies, interactive analysis and model fitting of geophysical cross-section. The integration of remote sensing and geophysics shows promising in increasing the knowledge of the geological structure of the mountainous karst area of Tam Duong, NW Vietnam. This integration will be the key for further hydrological, cave development, and mining studies.

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THE MANAGEMENT, CONSERVATION AND PROMOTION OF HA LONG BAY – THE WORLD HERITAGE SITE

Ngo Van HUNG
Director of the Ha long Bay Management Department

1 Background of Ha Long Bay

1.1 Geographical location:

Ha Long Bay is located in the Northeast of Viet Nam, belonging to Quang Ninh Province. It is in the coastal area stretching from 106^0 56’ to 107^0 37’ east longitude and 20^0 43’ to 21^0 09’ north latitude covering an area of 1,553 km^2 with 1,969 islands. Ha Long Bay has been recognized twice by UNESCO as a World Heritage Area for its universal aesthetic values and for its geology and geomorphology. The area of 434 sq. km. includes 775 islands of which 411 are named.

1.2. Ha Long Bay’s outstanding global values

a. Aesthetic value: Ha Long Bay is a large archipelago containing Karst landscape eroded by the sea. Ha Long's island system has emerged from the sea. When visiting Ha Long Bay, tourists can view islands with varied shapes that are not found anywhere else in the world. These islands were formed by the processes of orogeny earth movements over hundreds of years and weathered by heavy rain fall.

b. Geomorphologic and geological value: Ha Long Bay is a mature Karst landscape developed during a period of warm, wet, tropical climate. The sequence of stages in the evolution of a Karst landscape over a period of 20 million years requires a combination of several distinct elements including massive thickness of limestone, a hot wet climate and slow overall tectonic uplift. It contains carbonate sediments and the decayed remains of enormous forests of tree ferns with old creature relics and some kinds of extinct flora and fauna fossil.

c. The bio-diversity value: Ha Long Bay is a marine island area containing an abundant bio-diversity with 1,776 species listed by scientists (Table 1).

On the islands, the scientists surveyed, they found seven rare and unique species of flora in Ha Long. They are Ha Long cycad, violet chirita, Ha Long fan palm, woolly chirita, Ha Long balsam, schefflera and yellow slipper orchid.

Table 1: Biodiversity indicators for Ha Long Bay

Creature groups	Kinds	Genders	Family name
Phytoplankton	177	46	31
Zooplankton	56	33	25
Sea weed	90	52	29
Sea grass	1	1	1
Fish	109	86	57
Hard coral	136	44	12
Soft coral	41	27	11
Zoobenthos	219	147	89
Mangrove	15	15	12
Flora	847	/	/
Amphibian	13	/	/
Birds	72	/	/
Total	1.776	/	/

d. The Cultural - Historical value:

Ha Long Bay is a home of ancient Viet people:

- *Soi Nhu Culture:* lasted from 25,000 to 7,000 years ago.
- *Cai Beo Culture:* lasted from 7,000 to 5,000 years ago.
- *Ha Long Culture:* lasted from 5,000 to 2,500 years ago

2 The management and conservation of the World Heritage Ha Long Bay

2.1 Administrative machinery:

In 1995, the Management Department of Ha Long Bay was established by Quang Ninh Provincial People’s Committee (Fig. 1). Its function is the management, conservation and promotion of the values of Ha Long Bay. Its aim is to balance the conservation and exploitation of Ha Long Bay's values if these values are conserved and developed well, they would facilitate in the management.

2.2 Challenges in the management and conservation of Ha Long Bay:

a. Difficulties and challenges in the conservation of Ha Long Bay:

Ha Long Bay is a large area containing a range of outstanding values and potential for socio-economic development. However, in the recent years, rapid economic development without control has resulted in environmental degradation. The reasons are as follows:

- Ha Long Bay is an insular and marine area with a complex terrain.
- The development of socio-economic activities taking place on Ha Long Bay is a great challenge for environmental protection and Heritage conservation.
- Fishing communities who live on Ha Long Bay.
- Activities of marine transportation and ports.
- Activities of tourism, coal mining exploitation, urbanization by extending the boundary of the mainland area.
- Waste from industrial areas.
- Over fishing and aqua culturing of sea-products.
- Local communities' awareness on Heritage conservation is still limited.
- Ha Long Bay Management Department's size is still too small and its management capacity insufficient to meet the heritage conservation's need.
- Heritage management has been inadequate and limited.

b. Under the influences of the above mentioned reasons to the heritage conservation:

- Waste from households of fishing villages who live on the Bay, floating houses and the urban population living around the heritage area all contribute to water pollution.
- Urbanization by extending the boundary of the mainland area and infrastructure construction results in water pollution and to partial sediments in the currents of the Bay, especially at the accesses in front of the

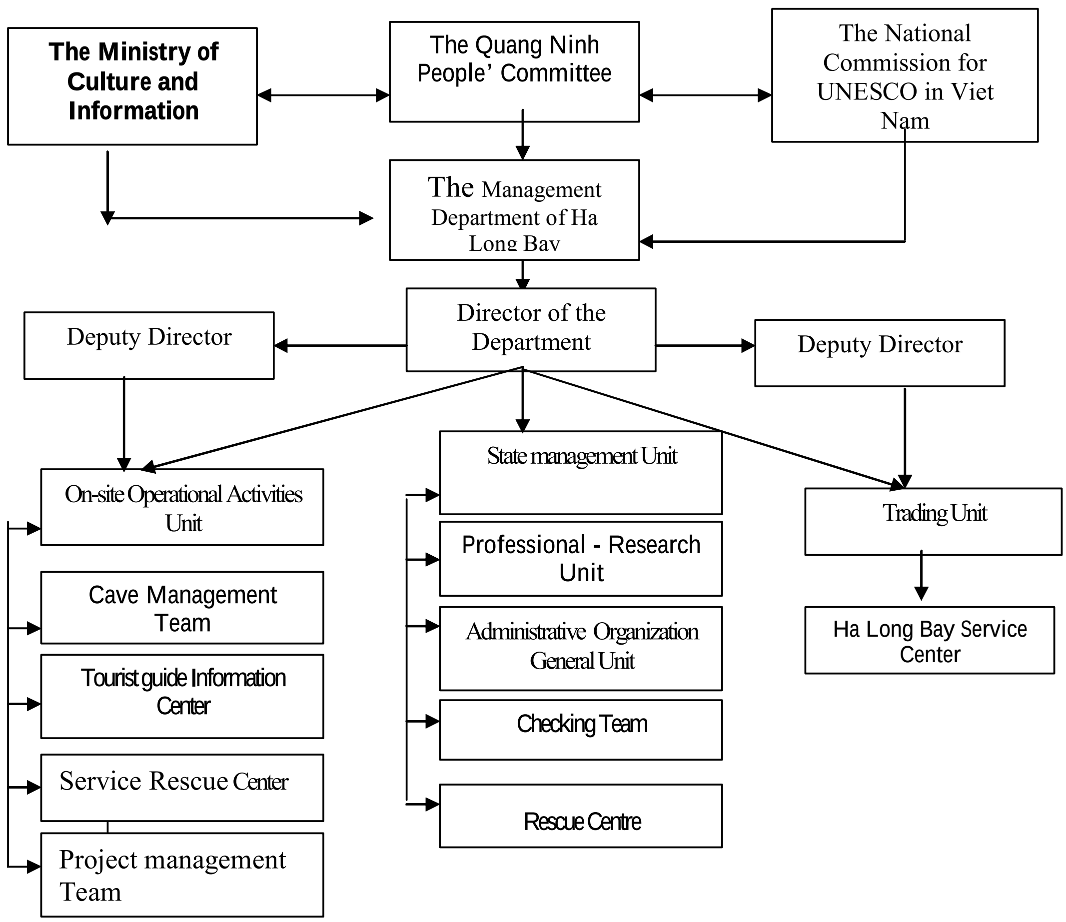

Fig. 1: Organizational chart for Ha Long Bay management department.

entrances to caves.

- The extension of aqua-culture areas in tidal flats results in the reduction of mangrove forests, removing the habitats and food resources of creatures and reducing the bio-diversity of the area.
- Limited knowledge and awareness of fishing communities results in over fishing and environment pollution etc.

3 Measures for the heritage management and conservation

- Monitoring, surveying and studying the heritage's values: The Department has cooperated with the International flora and fauna Organization (FFI), Hai Phong Institute Office (HIO) and Resources and Ecological Institute in identifying and estimating the impacts on natural resources and the potential of socio-economic development to the area.
- Policy, mechanisms, management strategy and controlling activities have been set up on Ha Long Bay: regulations on environment protection for activities occurring on the Bay, especially the management of waste and rubbish, cave resources and fishery exploitation

General plan of Ha Long Bay:

- Boat anchorage, over- night staying points.
- Inhabitant on the Bay, business and service areas.
- Aqua-culture areas.
- Building the Regulations of WH Ha Long Bay management to correct and manage all activities occurring on the Bay.

- Setting up the promotion and community education program on the Heritage's values:

- Cooperating with Education and Training Department and FFI to bring the Heritage curriculums into schools.
- Cooperating with media organizations such as: radio, newspapers, televisions etc. to promote Ha Long Bay's values.

- Tourism potentials must be exploited in accordance with the principle of sustainable development.

- Excursion tours on the Bay are limited to control number of tourists who come to visit the sensitive area impact to ecological environment and Heritage conservation.
- A system of islands, caves, grottoes and plants living on islands is a part of the Heritage. Therefore, the examination and control all acts which damage natural landscape are maintained and strengthened.
- Construction of tourism services on the Bay is designed in harmony with natural landscape ensuring to minimize impacts its environment.
- Only available beautiful caves have been exploited for tourism. However, it must ensure conservation principle and limit any impact to geological and geomorphologic values. Cave development and path making in caves must be controlled and limited.
- Any acts of destruction on the islands or mountains, acts which damage Ha Long Bay's landscape and environment etc are strictly forbidden.

4 Recommendations

- Extending the mutual relationship with other organizations, individuals, and scientists in the study, survey and monitor of Ha Long Bay's values.
- Proposing foreign and domestic organizations and individuals to support on professional skills and working means to survey Ha Long Bay and Heritage capacity training.
- Strengthening promotion and community education to enhance the awareness of Heritage protection.

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BUILDING SUPPORT FOR KARST LANDSCAPE CONSERVATION IN VIETNAM: WORKING WITH LOCAL COMMUNITIES AND NATIONAL VALUES

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Keywords: understanding landscapes, spiritual values, mythology, Chinese garden.

Karst habitats are regarded as important sites for biodiversity conservation. In addition to their unique biological diversity resulting from the particular physical characteristics of karst limestone, their importance in terms of natural resources, in particular water resources, and their remarkable beauty have been noted. Despite general recognition of these values, karst landscapes and their associated ecosystems are under threat of damage and destruction around the world. These threats are particularly acute in Vietnam as rapid economic development puts great pressure on karst area natural resources. Efforts to strengthen interest in the conservation of karst landscapes have tended to focus on values that can be explained in economic terms. Estimations of the economic value of karst areas for their biodiversity, natural resources, hydrological services and tourism have been at the front of efforts to justify their conservation. However, expounding values in economic terms can be a double-edged tool for conservation. If found wanting in economic terms, then opponents of conserving karst landscapes can also base their arguments on economics. For example, replacing biologically rich natural forests with single species commercial forests could be justified in economic terms despite the loss of biodiversity and landscape values as long as economically important water-catchment functions were preserved.

Karst mountains, however, are valued in Vietnam and elsewhere in ways that do not easily translate into economic terms or which can be monitorized. Ancient links to karst limestone exist in religious and cultural symbols that retain their power today. Stories and myths in Vietnam are full of reference to karst mountain, their forests, their beauty and their dangers. Eastern art and philosophy use images of karst mountains in both naturalistic and symbolic ways, and contemporary art forms continue this tradition. The current practice of incorporating karst limestone and water into household decorations and shrines clearly demonstrate the ongoing relationship between karst limestone and Vietnamese culture. These historical and contemporary connections between karst and culture suggest that the definition of ‘landscape’ when applied to karst conservation needs to have a broader definition than generally applied by conservationists. The ‘meaning’ accorded to karst landscapes by different people is critical to their relationship to and understandings of these physical location and their resources. Incorporating these understandings into conservation initiatives for karst landscapes will broaden the basis for building support for conservation and thus strengthen efforts to conserve.

This paper will explore the potential for building support in Vietnam for conserving limestone karst areas by using local and national values of karst linked to Vietnamese culture and traditional values. It will be suggested that greater progress will be made if such values form the basis of efforts to describe the values of karst conservation areas and justify their preservation rather than basing conservation awareness messages on western-based scientific and economic arguments. The paper will provide a general discussion of the role of cultural and spiritual values in current conservation theory and practice and then move on to describe the specific roles that cultural and spiritual values could play in building interest in and support for the conservation of karst areas in Vietnam.

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INVESTIGATION ON KARST WATER RESERVOIRS IN SOUTHERN IRAN: TWO WATERSHEDS IN HORMOZGAN PROVINCE

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Abstract. Hormozgan province is located in the South of Iran. Geological formations with groundwater reservoirs consist of both calcitic or dolomitic carbonates, prone to karstification, and non-carbonate sediments. Hydrogeological research on two watersheds named Shamil and Mehran was based on 22 exploration wells, 3 piezometric wells and 322 springs. Results show that in the Shamil watershed 92% of springs have discharges less than 20 l/sec and in the Mehran watershed 96% of springs have discharges of 10 l/sec. Also, the water quality was identified.

Keywords: carbonates, discharge, dolomite, geology, Mehran, non-carbonate, Shamil.

1 Introduction

The word "Karst" refers to a specific feature in soluble stones morphology and hydrology. Karst has a direct relation with calcitic and dolomitic rocks although, "karstification" processes also occur in gypsum and saline formations. Therefore, we can claim that karstification processes most frequently occur in calcitic formations compared to other rock types.

In Iran, karst is very important because it covers more than 15% of the country and leads to good water resources.

Iran is an arid country receiving only 1/3 of global mean annual rainfall. So, water is of the highest important and finding karst water sources stimulates knowledge of karst formations in different parts of the country. Studies show that mean annual precipitation of Iran is about 400 billion m^3. From this, 90-110 billion m^3 is controlled and harvested while 290-310 billion m^3 is considered wasted through runoff, floods, evaporation or percolating in the ground. Many underground rivers water result from the presence of karstified formations and re-appear as springs. To show the role of karst for water supply in Iran, some examples are given here. About 13-20 million m^3 of water is harvestable each year from calcitic areas around Shiraz. Studies show that there are considerable water resources under karst landforms without perennial surface streams in Jahrom which can improve this area's agriculture. Also, in Bandar Abbas, it is possible to exploit 6 million m^3 of water from sources in carbonatic Geno mountains. Determining karst water resources is thus very important for regional land planning and development plans. We have focused on karst water resources of Hormozgan province with an area of 68472 km^2 in southern Iran (longitude: 52º 31´– 59º 18´ E, latitude: 25º 21´-29º 1´ N). From a total area of 68.472 km^2, 30.000 km^2 is comprised of Quaternary alluvial deposits and the rest is covered by consolidated rocks. There are 59 salt domes (2353 km^2) in Hormozgan province. Average annual precipitation of Hormozgan is 170 mm and its climate is classified is arid. Water deficiency is a very serious problem in the study area. More important than water deficiency is the problem of water contamination. Exploitation of water resources from contaminated formations, especially Hormoz sery saline domes, leads to contamination of underground and ground water sources, and in turn results in limitation of useable water. Since karstic reservoirs are contaminated less in relation to alluvial aquifers, they can be used as main water sources for drinking.

2 Development of calcitic formations in Hormozgan province

Hormozgan is located in the south eastern part of the Zagros Mountains and contains Zagros-Makran zones. Cacitic formations are mainly related to anticlines. Hormozgan calcitic or dolomitic formations, in which karstification processes occur, are as follows:

1. Gury, lower to middle Miocene formation
2. Asmari, Oligocene- Miocene formation
3. Jahrom, Paleocene- Eocene formation
4. Bangestan, upper part of-lower Kertase group
5. Khami, Jurassic-lower Kertase group

These formations cover more than 8000 km^2. In addition, these are some other formations such as Metamorph and Kader and Melanj sedimentary series, which may contain ground water reservoirs.

3 Calcareous sources identification studies

Study of calcitic formations of Hormozgan province started in 1989. Result of studies of two basins including Shamil-Jamash, and Mehran-Coastal strip are discussed.

The study area is located in undulated overthrusted sections of Zagros and is comprised of a continuous series of anticlines and synclines. Water sources of the calcitic rocks in the Shamil-Jamash basin were sampled by 10 discovery wells and 1 piezometric water. Also, water sampling was done in 108 springs. In the Mehran-Coastal strip basin, samples were taken from 12 calcitic discovery wells and 2 piezometric wells and 214 springs. To study the quality of under ground reservoirs water in hard formations, all of water sources were sampled. Some water properties such as EC, T.D.S., S.A.R., and color were investigated. Water types and classes in view point of agriculture and Schuler diagrams were determined, too.

4 Results

Results show that discharge status of springs is as follows: 92%: <20 l/sec, 6%: 20-50 l/sec, and 2% >50 l/sec. These springs are mainly used for agriculture and drinking. EC ranges between 277 and 18426 mmohs/cm. Due to presence of various lithologic layers and tectonic conditions, water quality of calcareous reservoirs in various formations of area is different. Generally, suryes demonstrate that there are considerable calcareous water sources in carbonated stones, especially Gury formation and Bangesatan group, which these sources are able to provide needed water for people who live in this basin.

Studies of Mehran-Coastal strip water sources show that 96% of springs have >10 l/sec discharge, 2.3% 10-20 l/sec, 1.4% 20-50 l/sec, and 0.5% of springs have >50 l/sec discharge. These springs are mostly used for agriculture. EC of these springs ranges between 750-100000 mmohs/cm.

Because of the large surface of the study area, the variability of geologic formations and presence of salt domes resulted in huge variations in water quality of different formations. In the easternmost parts of Hormozgan water quality is very low and not drinkable while in western parts the quality of water is satisfactory. So, one can conclude that development of water reservoirs in the eastern part of the study area is not possible for these reasons, but there are considerable karst springs in its western parts, especially on Asymary-Jahrom formations, that can be used widely for drinking.

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A SYSTEMATIC APPROACH AND PARTNERSHIP IN THE STUDY OF CONTAMINANT SOURCES AND TRANSPORT IN A KARST GROUNDWATER BASIN

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Keywords: karst, contaminant transport, groundwater basin.

1 Introduction

In farming areas underlain by karst, nitrates from waste and fertilizer use, bacteria from livestock waste, and the application of pesticides, cause degradation of groundwater quality. Groundwater pollution affects not only water quality for human use and consumption but can also endanger plant and wildlife. In order to address these problems of contamination of karst aquifers, a systematic approach is required in which the function of the aquifer and its relationship to the recharge area, and the sources of contamination, are considered separately and as integrated parts of a karst groundwater study. The development of effective management practices to preserve water quality, and remediation plans for areas that are already polluted, requires a better understanding of hydrologic flow paths and solute sources is required to determine the impact of contaminants on karst groundwater basins, identification of the actual sources of contaminants and understanding of the processes affecting local contaminant concentrations.

Field research was conducted in the Coldwater Cave groundwater basin in order to determine the impact of agricultural contaminants on the water quality of the basin. The objectives of the study were to identify and delineate the linkages between contaminant sources, groundwater quality, land use and the hydrologic character of the shallow karst groundwater basin and its recharge area. This was accomplished by integrating data from an area karst feature inventory, a series of dye traces, water quality sampling, hydrologic measurements, contaminant source identification and land use analysis.

The study was conducted in partnership with the Hoffman Environmental Research Institute (Western Kentucky University), Upper Iowa River Alliance, Iowa Research Conservation and Development group and the Coldwater Cave Project of the National Speleological Society. The Mammoth Cave Water Quality Lab at Mammoth Cave National Park provided water quality analysis. The USDA-Agricultural Research Service, University of Missouri, at Columbia, Missouri conducted pesticide analysis and the Center for Cave and Karst Studies did dye receptor analysis. The University of Iowa Hygienic Lab conducted a parallel study to determine the source of bacterial contaminants using ribotyping. The partnership and cooperation in the field studies and analysis were invaluable in helping to understand the hydrogeology of the Coldwater Cave groundwater basin and to determine the impact of agricultural contaminants on the water quality of the area.

2 Study area

The Coldwater Cave groundwater basin is located within the agricultural setting of the Corn Belt region of the United States. The study area encompasses 80 km^2 in northeast Winneshiek County, Iowa and southeast Fillmore County, Minnesota. The rock units containing this hydrologic system form the Galena aquifer, which is one of the major agricultural and domestic water sources for most of the region (Hallberg *et al.,* 1983).

The Coldwater Cave groundwater basin is part of the Upper Iowa River watershed in northeast Iowa and southeast Minnesota. The upper Iowa River flows to the Mississippi River located 60 km to the east.

The Coldwater Cave groundwater basin is drained by subterranean conduit flow via the Coldwater Cave System (Kambesis and Bain, 1988). The cave system, which is dendritic in nature, is developed in the Ordovician-aged Dunlieth Formation and has been mapped to 27 kilometers in length with survey work in progress. The groundwater basin underlies the Pine Creek and Cold Water Creek watersheds. Streams from both of the watersheds lose water to the subterranean drainage system. Numerous sinkholes in the study area also contribute water to the groundwater basin. The subterranean stream resurges into Cold Water Creek via Coldwater Spring, which has a discharge rate of 33,500 liters/minute during base flow conditions (Huppert *et al*., 1988). Cold Water Creek flows into the Upper Iowa River located a kilometer to the southeast. The combination of surface and subsurface drainage in the Coldwater Cave drainage basin reflects the complex interaction between the surface and subsurface streams.

3 Cooperative field work

3.1 Karst feature inventory

A detailed karst feature inventory was done to determine where surface water was entering the groundwater system and to locate discharge points where groundwater was coming back to the surface. The karst feature inventory provided dye injection locations and identification of sites for water sampling and dye receptor locations. The inventory was a coordinated effort between researchers at the Hoffman Environmental Research Institute, personnel from the Coldwater Cave Project and contract employees of the Northeast Iowa Research, Conservation and Development group.

3.2 Dye tracing

Dye tracing is the most effective means to identify underground flow routes within a karst groundwater basin, to underground creeks, and to determine how long it takes groundwater to move from sinking streams at the surface to the springs that drain the basin.

A total of 24 sites were used to monitor for dye which required a coordinated effort between the various different partners of the study. Thirteen sites were used within Coldwater Cave and eleven sites were located either at springs or at places on the Upper Iowa River. All sites were not used for all traces. During the qualitative traces, charcoal dye receptors were placed at the springs, in the river and in the cave. During the quantitative trace, water samples were taken from the shaft entrance of Coldwater Cave at hourly intervals for 36 hours. Field assistance for the dye tracing work was provided by the Hoffman Environmental Research Institute, Upper Iowa River Alliance group and the Coldwater Cave Project. Dye receptor analysis for qualitative traces was provided by the Mammoth Cave Water Quality Lab. The Center for Cave and Karst Studies at Western Kentucky University analyzed the water samples for the quantitative traces

3.3 Water quality sampling and analysis

Water sampling was conducted over the course 14 months to determine water quality within the Coldwater Cave groundwater basin. The springs that drain the groundwater basin served as water sampling sites for this study. Water was analyzed for cations, anions, nitrates, pesticides, and fecal coliform levels. In conjunction with water sampling, the study also tracked pH, conductivity, temperature and discharge at the springs. The Mammoth Cave Water Quality Lab provided analysis for cations, anions and nitrates. The USDA-Agricultural Research Service, University of Missouri, at Columbia, Missouri conducted pesticide analysis. Coldwater Cave Project personnel conducted the sampling program and measured discharge and other water parameters for the duration of the sampling period.

3.4 Parallel project

The partners conducting the Coldwater Cave groundwater basin study also provided field assistance to a contaminant source analysis project that was conducted by the Upper Iowa Research, Conservation and Development group, and the University of Iowa Hygienic Lab. Water samples were collected weekly and analyzed for bacteria. Ribotyping was conducted to determine the source of bacteria within the groundwater basin.

4 Field study results

The karst feature inventory and dye tracing data indicate that the karst terrain that characterizes the Coldwater Cave groundwater basin provides multiple direct hydrologic connections from the surface into the aquifer. The results of the quantitative dye trace showed that surface-groundwater connections and the rapid velocities associated with groundwater flow in the Coldwater Cave karst aquifer allow for contaminants to move quickly into and through the groundwater system.

Water quality analysis indicated that levels of atrazine vary seasonally and atrazine metabolites persist in the groundwater year round. Storm events cause significant increases in bacteria levels and that nitrates persist in elevated quantities in the groundwater throughout the year.

Preliminary results from the ribotyping study suggest that high levels of bacteria are coming from cows and human sources. The human sources may be faulty septic systems which are common in the area. Overall, the study showed that contaminants that enter the karst groundwater returns to the surface via springs and those contaminants within the groundwater become part of the surface streams and rivers that are fed by those springs.

5 Synergy and cooperative research

The cooperative effort between the research entities, water quality labs, agencies, and citizens groups is a stellar example of what synergy can accomplish in identifying and helping to solve environmental problems. The field work and lab analysis was provided gratis by all groups involved.

The information gained from this study has been used for educational purposes in the Northeast Iowa area, for seminars and workshops on karst and karst related issues, and to work toward improving the groundwater quality in northeast Iowa.

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USE OF SUBTERRANEAN FIELD STUDIES AS A BASELINE FOR KARST RESEARCH AND RESOURCE MANAGEMENT. CASE STUDY: LECHUGUILLA CAVE, NEW MEXICO

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Keywords: survey, inventory, cave management, cave research.

1 Introduction

In order to effectively manage a natural resource, it is important to know its geographic extent, orientation, morphology and its relationship to the surface topography. Understanding the nature of a natural feature and its components is critical to successfully protecting it. Baseline cave surveys, cave and karst resource inventories, documented observations, and photography can provide a large body of information that is critical for resource management. The same information is important for initiating questions that lead to scientific research that is also valuable for a fuller understanding of the natural resource in question.

Lechuguilla Cave, which is located within Carlsbad Caverns National Park in New Mexico (USA), is managed by the National Park Service (NPS) of the U.S. Department of the Interior. Due in large part to the stewardship of NPS and the foresight of the American caving community, science and conservation have always been a part of the exploration and survey efforts in Lechuguilla Cave. Survey and documentation of cave features and observations has resulted in a large body of baseline information about the cave that has proved valuable for resource management and for initiating studies in geology, cave microbiology, microclimatology, mineralogy, geomicro-biology and geochemistry.

Prior to the mid-eighties, Lechuguilla Cave was known as one of the guano caves within the Guadalupe Mountains of New Mexico. A series of digging efforts that culminated in 1986 allowed access to the rest of the cave and exploration and survey revealed the true potential of the cave system. Many miles of cave passages have been discovered and mapped that were significant not only in extent and depth, but also because of their geologic, biologic and hydrologic resources. Lechuguilla Cave is currently the deepest limestone cavern in the United States at 489 m and is the third longest cave in the States at 180 km.

2 Cave surveys, resource inventories and photo-documentation

For most land features, visualization of the shape, form and orientation of the feature is an important part of its geomorphic study. Maps, satellite imagery, aerial photography and LANDSAT images are important tools in geomorphic studies. They augment the visualization of a feature both in a local and regional context. Caves and their associated subterranean features cannot be so easily visualized because they are hidden from the "view" of most surface image recording technologies. Visualization of a cave can only occur when the feature has been mapped. Field methods in cave exploration and mapping involve simple but effective survey techniques. Station to station survey is a process that involves recording distances, azimuth, inclination and passage dimensions at each station and generating in-field plots of the cave passages in plan, profile and cross sectional view. These data are used to determine cave passage morphology, passage orientation and extent, and general layout of the cave. Georeferencing the survey data with a topographic map or a digital elevation model shows the relationship between cave passages and surface topography.

In addition to location information and dimension data, field documentation also includes generating detailed in-cave sketches. This is the crux of the field documentation process where cave features and other resources are drawn to scale and tied to specific survey stations. From these data can be generated detailed descriptions of passage characteristics and features. This method provides a graphical resource inventory of cave features. More detailed inventories can be conducted during the actual survey process or can be accomplished on subsequent resource inventory visits.

A picture is worth a thousand words, thus photography is another important facet of cave passage and feature documentation. Photodocumentation can accompany the in-cave survey or can be conducted during dedicated resource inventories. Cave photography is more difficult than standard photography because of the complete lack of natural light and the logistics and difficulty of the in-cave environment. It is often more effective to conduct the photodocumentation process separately from the survey and inventory phase.

3 Base line maps and databases

The data collected from cave survey are translated into base maps that become the basis for future explorations and mapping objectives. These maps, along with the detailed observations from field notes and from extensive photodocumetation, provide the context where research questions are posed and serve to instigate scientific investigations.

The graphic and dedicated resource inventories can be compiled into searchable databases. GIS software can map the resource inventories onto georeferenced base maps. The resulting maps are extremely useful for resource management and protection. They are also valuable in terms of providing base line and background information for karst and cave research.

4 Lechuguilla Cave – A case study

Historically, cave and karst related scientific investigations follow cave exploration and survey. In Lechuguilla Cave, they proceeded in parallel. The first and most obvious investigation that was based on the location and descriptive data was the basic geology of the cave. Early on in the exploration and survey it was determined that the cave spanned the Permian-aged Artesia group and into the massive and breccia members of the Capitan Limestone. Good vertical control on the survey line helped determine the relationship of different cave passages within the cave and allowed comparison to passage levels in other area caves in the area.

Gypsum deposits are ubiquitous throughout the cave system. Their locations, extents and descriptions as documented in survey, notes and with photography helped support the research that confirmed sulfuric acid speleogenesis for many of the caves in the Guadalupe Mountains (Jagnow, 1989, Hill, 2000).

In addition to massive gypsum and sulfur deposits, varicolored residues were noted during the cave survey. With permission from the Park Service, small samples of the various residues and some speleothems were collected by survey teams. Analysis of the corrosion residues and from speleothems revealed the surprising result that there is a biologic element that contributes to cave development. The significance of the geomicrobiology interactions is providing insight into the basic mechanism of the dissolution and precipitation by microorganisms (Northup *et al*., 2000). The microbe environment is also being studied by NASA scientists who believe that it may be an analog to similar environments on other planets (Boston, 2000).

Lechuguilla Cave is a photographer's paradise and photographers usually accompany survey teams. One of the early research questions involved the many pools and lakes that had been photodocumented throughout the cave. A water-sampling program was established through the NPS and Lechuguilla Cave Project. Samples were collected in conjunction with survey trips. The studies found that the water chemistry between the different pools varied and was a function of precipitation chemistry, cave bedrock and the many gypsum deposits located throughout the cave (Turin, 2000). Photodocumentation of some of the more unusual speleothems instigated the research that determined that microorganisms may also contribute to certain types of speleothem development.

Resource inventories that were instigated by NPS documented many unusual minerals within Lechuguilla Cave. Caves formed by sulfuric acid-bearing waters contain direct by-products of their origin including gypsum, hydrated halloysite and alunite. Lechuguilla contains many of these minerals. The alunite is important because it contains potassium which gives it the potential to be dated by the K-Ar or $^{40}Ar/^{39}A$ dating methods (Poylak and Provencio, 2000). Poylak *et al.* (1998) used $^{40}AR/^{39}A$ dated alunite to determine that Lechuguilla Cave is at least 5 million years old.

The exploration and survey of Lechuguilla Cave has influenced the modes and methods of cave mapping in the United States. The abundance and delicacy of formations, unusual sediments, and microbiology within the cave have caused both explorers and resource managers to reevaluate human impact on all caves in general and has raised the profile of cave management and karst research.

As a result of the extensive exploration and mapping program and the parallel scientific field work which involved sample collections, detailed resource inventories and extensive photodocumentation, Lechuguilla Cave is one of the best documented examples of cave development in a hypogene environment. Important research in geology, microbiology, microclimatetology, mineralogy, geomicro-biology and geochemistry has been conducted in the cave. Exploration and survey continues in this incredible cave and continues to provide the basis for research and resource management within the system.

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COMPARISON BETWEEN THE KARSTIC AND PSEUDO-KARSTIC SOILS AND THEIR CONSISTENCE

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Abstract. There are two mountain ranges in Iran, Alborz in the north and Zagros in the west. Their lithological composition mainly consists of carbonate rock (with karst land forms) and marls (with pseudo-karst land forms). In the regions characterised by these rocks, different soil types develop with particular vegetation and water quality. In this research, two different zones in Alborz with carbonate rocks (Upper Cretaceous) and marls (Neogene) were selected and their soils studied in view of their physico-chemical properties and evolution. The obtained results reveal that in the karst regions, soils with different stages of development are formed. These soils are correlated to the topographic situation and vegetation type .In conditions of poor vegetation and steep slope, soils are non developed or very thin; in conitions with modest vegetation and low slopes, deep structured soils are formed. The soils of pseudo-karst are mainly non developed and they have not any pedogenetic horizons. Comparisons between the soils of these areas have shown that great differences exist in view of pedogenetic stages, physico-chemical properties and soil consistency.

Keywords: Alborz, Zagros, Upper Cretaceous, karst landforms, pedogenetic horizon, soil consistency.

1 Introduction

Erosive features on Koohe Sorkh mountain, southwest of Semnan, bear many similarities to karst land forms but have a different origin, described as pseudokarst. The bedrock of these land forms are fine grained and evaporitic sediments, producing redbeds. These erosional land forms result from tunnel erosion by drainage systems which are complex on surface, simple underground but connected to the surface. The studied soils on pseudokarst are non-developed soils without pedogenetic horizons.

Southern Alborz mountain zone is passing through the northern part of Semnan city district. River courses are more prominent here. Water erosion and dissolution of carbonates has resulted in many karstic holes. Soils on these karst forms are deep and structured.

The studied area is located in Semnan city with latitude 53° 10′ to 54° 45′ E and longitude 35° 15′ to 35° 50′ N.

2 Materials and methods

This study made use of the following basic information:

- Topography maps scale 1:250000 and 1:50000
- Aerial photos scale 1:55000 and 1:20000
- Geology maps scale 1:100000 and 1:250000
- Satellite data scale 1:100000
- Lithology, geomorphology and pedology studies
- Field observations
- Climate data
- Karst and pseudokarst forms interpretations
- Overlay of field data and primary interpretations.

3 Results

3.1 Geology and lithology

Karst region

Rock types in this region belong to the Triassic, Jurassic and Upper Cretaceous.

- Triassic carbonates are assigned to the Elica formation which includes three parts: fossiliferous limestone, hard dolomite and light gray limestone.
- Upper Jurassic carbonates are assigned to the Lar formation which includes thin beds of limestone with nodules of white chert, thin-bedded limestones.
- Upper Cretaceous carbonates include gray limestone, cherts and white limestones.

Pseudokarst region

Pseudokarst land forms in the studied area are located on the upper red bed formation, which includes evaporatives, chalk, marl and clay which are the predominant lithology. The formation can be sudivided in two parts:

- Lower part (M1), includes gypsum and salt.
- Medium part (M2), includes chalk, gypsum and clay with salt.

These regions belong to rangeland and its dominant species are Peganom spp. and Euphorbia accompanied by Artemisia spp.

3.2 Pedology

Karst region

Although the soils on mountains with high slopes are not very developed and deep, they have pedogenetic horizons.

A control profile was dug on a 35° slope with west exposure. This profile is not deep and gravelly, due to its situation (high dunes), and show a Ac horizon that directly is overlying the limestone bedrock.

According to temperature regime and arid and toric moisture regime, their classification is as following:

- Order: entisol
- Subgroup lithic torriorthents (calcaric lithosols).

Laboratory results

The profile has a sandy loam texture, with lime content 25.5%, soil pH 8, EC about 0.37 ds/m and organic matter content very low. The main character of this profile is as following:

AC: 0-15 cm: Soil color is yellowish brown when it is dry; soil texture is light sandy loam with fine structure. When the soil is dry, it is fragile with high permeability, and it is an alkaline soil. The soil contains gravel and boulders.

Pseudokarst region

The main properties of soil in this part are its dispersed structure with high density, low permeability and low holding capacity. There is neither pedogenetical process nor stratification. Vegetation cover is very scarce and the content of organic matter in the surface layer is very low.

One of the dug control profiles in this region is situated on a steep slope with north facing exposure. Two soil samples were taken from 0-15cm and >15cm.

0-15cm: loam texture, EC about 20.1 ds/m with 6.7 pH, the content of lime is 18%. Bicarbonates are 10 meq/lit. Total amount of anions and cations is approx. 2379 and 3434 respectively with SAR about 16.6.

>15 cm: clay-loam semi heavy texture, pH about 6.16, EC 24.8 ds/m. The content of invisible lime is 30.3% and bicarbonates 12 meq/lit. Anions are 6412 and cations 6448, and SAR is 133.

4 Discussion

Results obtained from karst and pseudokarst soils in two regions showed that the soil in the karst area undergoes pedogenetic evolution and develops stratification. Plants can grow on such soils, which possess suitable permeability and good structure. But karst soils which are located on marls do not undergo evolution and do not develop pedogenetic horizons. Due to contraction and swelling these soils break up and produce diaclases. Therefore, water can pass through these soil layers and finally cause pseudokarst land forms.

The comparison of soils in these regions showed that there are significant differences in soil types, soil formation, soil properties and consistency.

The soil in karst regions has suitable structure and texture properties and also a high consistency. The presence of salts in the pseudokarst regions, which are linked to upper red bed formation, leads to water erosion.

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MONITORING THE DISTRIBUTION AND DIVERSITY OF KARST DEPENDENT BATS USING BAT DETECTORS

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Limestone karst is a critical resource for cave dwelling bats in Myanmar but is under threat from mining interests. Bats constitute over a quarter of Myanmars mammal diversity and yet little is known about their distribution and conservation requirements. Here I discuss research into the use of bat detectors to identify and monitor the diversity and distribution of Myanmars threatened cave roosting bats. I used time expanded recordings of echolocation calls from previously captured bats to quantify our confidence in identifying free flying bats from their echolocation calls. Finally I will discuss the echolocation behaviour of cave dwelling South East Asian bats and provide guidelines for the use of bat detectors in monitoring this biodiversity.

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LAND-USE PLANNING IN A KARST-BIOSPHERE RESERVE ENVIRONMENT

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Keywords: karst, planning, policy, biosphere, landscape, stakeholders.

Significant challenges face planners, businesses, and local governments in coping with changing land-use demands in karst regions. Increased suburban sprawl, growing tourism and related demands for services, air-quality mandates and other regulatory requirements, and water-quality problems are just some of the issues facing planners and policymakers in the U.S. and elsewhere. The Mammoth Cave Area of South Central Kentucky was designated an International Biosphere in order to encourage cooperation between stakeholders, acquire knowledge through research, promote public awareness of karst-related problems, and share data and information between stakeholders and other biosphere reserves. This designation was granted because Mammoth Cave National Park, the local development authority, private businesses, and local government agencies had demonstrated their willingness to consider the results of research in their planning. Yet despite the Biosphere Reserve designation, the Mammoth Cave area is increasingly faced with development schemes that threaten the delicate karst landscape. This paper examines the implications of the Biosphere Reserve designation and its impact on policy and planning in the Mammoth Cave Region. Preliminary results suggest that although the International Biosphere Reserve Program provides a satisfactory framework for the merging of science and policy for the public good, the lack of legislative or enforcement power inhibits the ability of individual biosphere reserves to achieved sustainable development goals.

The International Biosphere Reserve (IBR) system was instituted by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1968 as part of the Man and the Biosphere Program (Fletcher, 1996). One of the main goals of the IBR system is ecosystem management, which focuses on biodiversity preservation in conjunction with sustainable economic development (Brown, 2002). Prevailing ideologies prior to the IBR's creation argued that plant and animal biodiversity could be sustained by protecting small areas inside of larger ecosystems. National parks, wildlife refuges, preserves, and other types of fragmented habitat have resulted from these protection efforts. However, it is becoming increasingly evident to ecologists and environmentalists that all living things and their physical environments are linked together (Cooperrider, 1991). Thus, the IBR program seems to offer just the model needed to achieve ecosystem management goals. In order for a location to receive an IBR designation it must meet certain criteria. First, it must have a legally protected "core" area, which is often a National or State Park or Reserve. Secondly, the core area must be surrounded by a zone or zones that are generally rural, or where human activity is of low intensity. These areas are considered "zones of cooperation and are buffer zones to the core area. Thirdly, adjacent to the buffer zone should be an area of transition, the "interaction zone," where communities work to achieve a level of sustainable development that will help to conserve the natural resources of the core area while being economically beneficial (Fletcher, 1996). This third criterion has become the most problematic in terms of achieving the objectives of IBR designation and is the focus of this research paper.

UNESCO designated the Mammoth Cave Area Biosphere Reserve [MCABR] in 1990. Mammoth Cave National Park forms the legally protected core area (Fig. 1). The Park City and Cave city areas were delineated as the zone of cooperation. The interaction zone extends past Bonnieville to the north, past Glasgow to the east, to Woodbury in the west, and to Bowling Green in the south. This zone encompasses parts of six counties: Barren, Butler, Edmonson, Hart, Metcalfe, and Warren. The most important research and monitoring problems facing the MCABR concern the groundwater hydrology of the area, along with air quality in the entire region. Karst systems are very susceptible to pollution due to the unusually quick movement of water through sinkholes and cracks and crevices in the bedrock. Poor water quality threatens biodiversity in the MCABR, as there are over 200 species of animals that either live in, or use the caves in this region (MCNP 1997). Although the MCABR has achieved outstanding success in research and monitoring, planning agencies and developers are not always willing to act upon the recommendations that come from these activities. As a matter of fact, the biosphere reserve designation is often maligned or ignored. A prime example of this is the planning and development of the Kentucky Trimodal Transpark by the Intermodal Transportation Authority, Inc. (ITA), an agency of the Warren County Fiscal Court and the Bowling Green City Commission. The primary site for this 4000-acre industrial park is about 5 miles northeast of Bowling Green, just inside the MCABR's interaction zone. The ITA claims that the Transpark will attract mainly high-tech and transportation oriented businesses, but it is zoned for both light and heavy industrial use (ITA 2003). Transpark opponents argue that developers have not sufficiently addressed geological and environmental concerns. They question whether or not the members of the ITA have educated themselves or the public about the potential geohazards associated with the fragile karst topography of the area and how the development project will affect the MCABR (Kuehn and May, 2002). These concerns seem to be valid. The only environmental assessment completed for this project argued that the eight miles separating the Transpark from Mammoth Cave National Park are more than adequate. No mention is made of the MCABR or the fact that the Transpark is located in the interaction zone (Wilbur Smith and Associates, 2001).

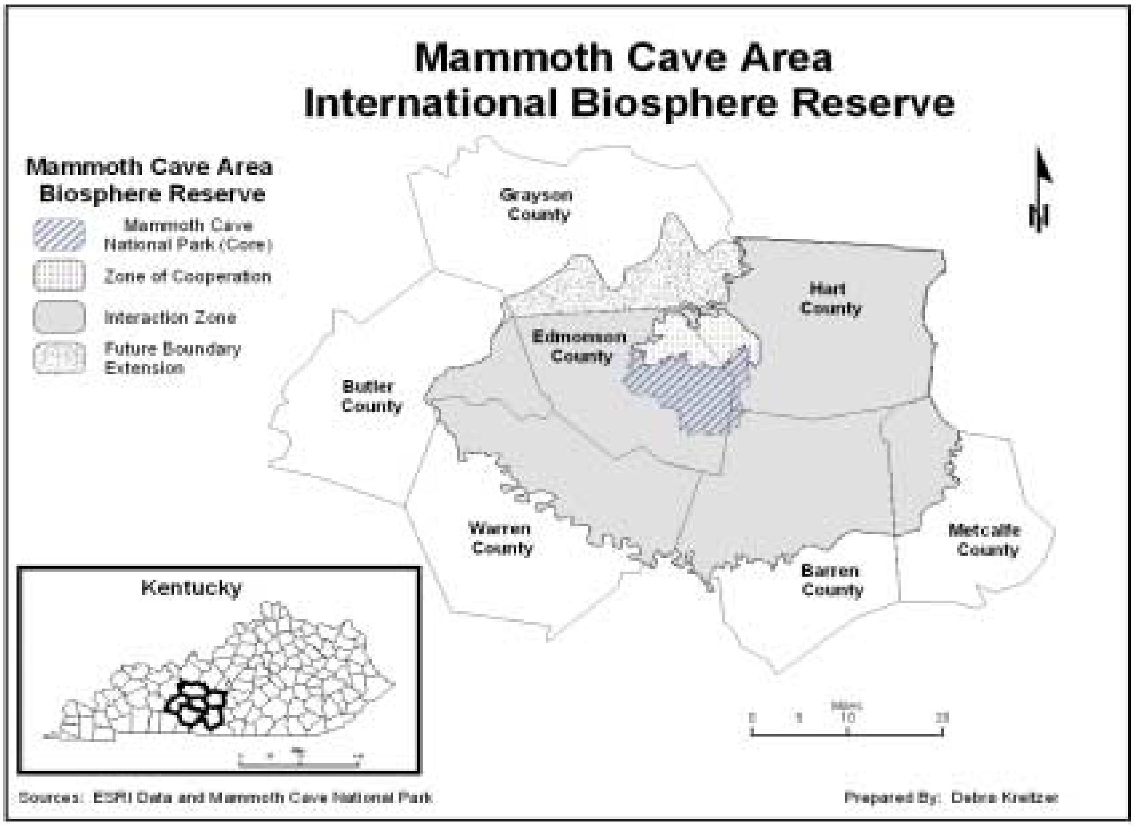

Fig. 1: Mammoth Cave Area International Biosphere Reserve

A critical element of the land-use planning dynamic in karst-biosphere reserve environments, particularly for smaller, more rural regions, is the political-economic pressure to create and develop employment opportunities. Globalization ideologies that encourage communities to link the local to the global in order to participate in the "transformational" forces of the global economy often seduce community leaders into decisions that value short-term job creation over long-term sustainable development policies. Building tax revenues and creating "well-paying" jobs often are the quantitative measures of political-economic success for planners and community leaders, rather than a more qualitative measure of quality of life and environmental sustainability. In Bowling Green, Kentucky, for example, there has never been a meaningful debate within the community about the nature of sustainable development or about the type of community that the majority of citizens envision for the future. Neither has there been any meaningful dialogue between stakeholders, communities, visitors, researchers, and others about the MCABR and its role in the sustainable development of the region (Kreitzer, 1998). Generally, planning and development rhetoric has oscillated between the sublime – a high probability of polluted water flowing uphill across a drainage divide and into the Mammoth Cave drainage basin – to the ridiculous – the new intermodal transpark project will create thousands of jobs and revitalize the entire south-central Kentucky economy. Undisputable empirical evidence to support either of these projected outcomes has yet to materialize!

Unfortunately, the problems associated with the MCABR are indicative of the weakness of the entire IBR program. UNESCO's Man and the Biosphere program includes no enforcement mechanisms (except to withdraw recognition) to ensure that individual IBRs comply with the ecosystem management approach of conservation and development. Another complication is the attitude of U.S. policymakers towards the IBR program. The U.S. withdrew from UNESCO in the mid 1980s over corruption concerns and just recently rejoined. However, these concerns did not extend to participating in the IBR program; on the contrary, the U.S. is home to forty-seven IBRs, more than any other country. The U.S. Man and the Biosphere Program is poised to be a model for sustainable development for other countries participating in the IBR program. Regrettably, the problems plaguing the MCABR are not unusual. Even though the United Nations has no jurisdiction over IBRs in the U.S. (or in any other country), pressure has developed to end participation in the Man and the Biosphere program (Brown, 2002). If opponents have their way, and the U.S. IBR program is eliminated or limited, the ecosystem management approach will suffer serious setbacks. This could be especially problematic for karst areas since it is often difficult to define the boundaries of a karst ecosystem.

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MAGMATIC INTRUSIONS IN THE CONG NUOC CAVE IN THE NORTHWEST OF VIETNAM: PETROGRAPHY AND ITS INFLUENCE ON THE CAVE DEVELOPMENT

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Abstract. In 2001-02 a team of Belgian-Vietnamese speleologists explored the karst in the Tam Duong area (northwest Vietnam). The cave Cong Nuoc reached the depth of 600 m, which makes it actually the deepest cave of Vietnam. In the cave magmatic intrusions were found at different depths. These magmatic rocks are dark and contrast strongly with the light colored Triassic limestones. The thickness of the intrusions varies from a few tens of cm up to 2 m. A petrographical description classified the rock as a medium grained dolerite. It is mainly composed of biotite, augite, mica and a variety of needle like quartz. Calcite is present as thin veins (1 mm) and as small individual crystals in the rock. The dolerite contains many fragments of silicified calcareous rock fragments, in which relics of fossils are recognized. It is striking that the cave develops along these intrusions, as the magmatic rocks are almost insoluble in water. An explanation for this is that the intrusions are related to faults in the massif. Water percolates along these discontinuities, corrodes the limestone and erodes the dolerite. At the surface similar Paleocene magmatic intrusions are known. But in this region it is the first time the intrusions are described in caves. It is important to notice that the 3 dimensional aspect of the intrusions is only found in caves. As the intrusions are linked to faults, and the faults control the cave development, mapping out the intrusions can help to find water in this karstic area.

Keywords: cave, dolerite, magmatic intrusions, speleology, Vietnam.

1 The Cong Nuoc cave

During the speleological expedition from December 2001 to January 2002 a Belgian-Vietnamese team explored the karst zones in the province of Lai Chau (NW Vietnam). It was the sixth joint expedition in NW Vietnam, and carried out in the framework of the VIBEKAP project (*Rural development in the mountain karst area of N.W. Vietnam by sustainable water and land management and social learning: its conditions and facilitation*)-(SPEKUL *et al*., 2004). The exploration of the Cong Nuoc cave (zone Tam Duong) started the year before and reached in 2002 the final depth of -600m (with 1882m of development), which makes it actually the deepest cave in Vietnam (Masschelein, 2002).

Cong Nuoc starts in a large and beautiful porch (20m wide and 20m high) high up in the wild forest near the village Chiêu Sai Pin (about 1h15 walk from the road). The entrance is located near the lithological contact between limestone and sandstone. The cave contains the fantastic 220m deep Josephine pitch (Fig. 1).

Fig. 1: Profile of the Cong Nuoc Cave (depth of 600m) (after Spéléo)

Approximately 600m below the entrance the ancient collector or master cave is reached, which means only about 160m higher than the supposed resurgence at the altitude of 280 msl (Hang Doi), but at a distance of at least 6km. Remarkably the orientation of this master cave is about east-west, where we supposed it to be directed to the northwest. Of course the passage is only explored for a limited distance (about 200m), which does not allow a definite conclusion about water drainage in the area. But it gives anyway an indication of the underground drainage direction.

2 The magmatic intrusions

In the cave at different depths magmatic rocks are found, probably related to the same intrusive event. These dark rocks contrast strongly with the pale limestones. The contact between the dark magmatic rock and the host rock is sharp. At some places a thin orange layer consisting of iron oxides and hydroxides could be found at the contact, but no rim of contact metamorphism in the limestone is detected. The thickness of the intrusions varies from some tens of cm to more than two meters (Lagrou, 2002). The magmatic rocks are found at three distinctive levels:

(1) At the top of the first large pitch (P30) at -30m from the entrance. Sill intrusion (parallel to the stratification of the limestone)

(2) At the bottom of the first pitch after the Josephin pitch (P220) at -320m. Dyke intrusion (cuts across the structure of the limestone) with an orientation: strike 255°, dip 30°N – clearly related to the fault plane.

(3) At the bivouac chamber at -420m of the entrance: a horizontal sill forms the roof of in a large room (5mx20m).

2.1 Petrography of the dolerite

A petrographical description classified the rock as a medium grained dolerite (basic intrusive rock). It is mainly composed of the minerals biotite, augite, mica and a variety of needle like quartz. The mica is abundant and olivine is absent. Biotite and augite often reveal alterations. Calcite is present as thin veins and as small individual crystals in the rock. The calcite veins have a width of about 1mm and 2 sets of directions are observed. The dolerite contains many fragments of silicified calcareous rock fragments. In these calcareous rock fragments relics of fossils are recognized (most probably bryozoans and ostracodes, R. Dreesen, personal communication).

Xenoliths (foreign inclusions in the igneous rock) found in the dolerite consist quartzitic rocks**,** most probably representing river pebbles from the underlying conglomerate (Fig. 4). These pebbles were incorporated in the rock at the moment the magma penetrated the sedimentary rock sequence.

2.2 Data on dating the intrusion

The limestone belongs to the Dong Giao Formation, Middle Triassic in age. The limestones of the Dong Giao Formation are very karst sensitive in this area (Dusar *et al*., 1994). Magmatic intrusions are known in the area and are of Paleocene in age. But in this region it is the first time the intrusions are described in caves.

Fig. 2: Right: the dolerite intrusion contrasts strongly with the light colored limestone. Left: the cave develops along the intrusion.

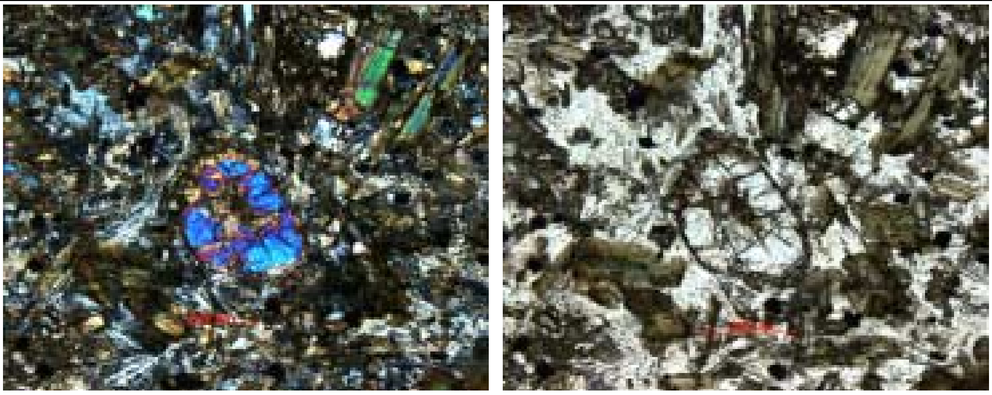

Fig. 3: Micrographs of the doloritic rock in thin section. Notice the augite crystal in the middle, biotite at the upper right corner (field of view 1x1mm, left picture is taken with crossed polars).

3 Influence on cave development

It is striking that the cave develops along the intrusions (Fig. 2), as the magmatic rocks are almost insoluble in water. An explanation for this is that the intrusions are related to faults in the massif. Water percolates along these discontinuities, corrodes the limestone and erodes the dolerite. As the intrusions are linked to faults, and the faults control the cave development, mapping out the intrusions can help to find water in this karstic area. As surface water is very limited in the karst, detailed geological mapping is recommended in the search for water.

It is also important to notice that caves are particularly suited to study the 3 dimensional aspect of the intrusions' morphology (its geometry) as much 'outcrop' data are available. At the surface the area is dominated by wild forest, making outcrops in this dense vegetation scare.

In fact, this preliminary study of the intrusions in caves in the area is carried out during the cave exploration. We recommend to study the geometry of the intrusions in more detail by measuring the directions of the sills and dykes.

Fig. 4: The xenolith found in the dolerite intrusion consists of a quartzitic rock.

4 Acknowledgements

The speleo colleagues of the Belgian-Vietnamese expedition, more specifically T.D. Ke (RIGMR), J. Masschelein (BVKCA) and K. Mandonx (SPEKUL, the underground photographer), are thanked for the joint exploration of this fantastic sporting and superbly shaped active cave with his spectacular black dolerite intrusions. J. Mareels (KU Leuven) and R. Dreesen (Vito) helped with the petrography of the igneous rock and the remarks of M. Dusar improved this article.

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Eds. O. Batelaan, M. Dusar, J. Masschelein, Vu Thanh Tam, Tran Tan Van, Nguyen Xuan Khien

INTRODUCTION TO CUC PHUONG NATIONAL PARK

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1 The history of Cuc Phuong National Park

On 7th July 1962, in recognition of the scientific value of the natural diversity of fauna and flora at Cuc Phuong forest, the Prime Minister made the decision (number 72/TTg) to establish the Cuc Phuong National Park (formerly known as the Cuc Phuong Reserve Forest). The park was established with the initial purpose of preserving and managing the existing natural habitat and to develop the park into a site for research into fauna, flora and tropical sylviculture.

On the 8th January 1966 the Park Management Board was established (decision number 18/QDLN) under the former Vietnam Forestry Department. The park is now under the Ministry of Rural and Agricultural Development. The main responsibilities of the Park Management Board are;

- management and protection
- research and tourism
- education for both domestic and foreign visitors.

2 Physical characteristics

Location

Cuc Phuong National Park is located approximately 120 km South-West of Hanoi, close to the rice fields of the Red River Delta. It is approximately 70 km from the sea.

Cuc Phuong National Park covers an area of 22,200 ha, located from $20^0$14' to $20^0$24' N and $105^0$29' to $105^0$44' E. 51.1% of Cuc Phuong National Park lies within Ninh Binh province, 24.6% lies within Hoa Binh province and 22.5% lies within Thanh Hoa city. The following 4 districts and 14 communes are located either within the park or in close proximity to it’s perimeter: Cuc Phuong, Ky Phu, Van Phuong and Yen Quang of Nho Quan district; Thach Lam, Thanh Yen, Thanh My of Thach Thanh district; Lac Thinh, Yen Lac, Phu Lai, Yen Tri and Ngoc Luong of Yen Thuy district; Yen Nghiep and An Nghia of Lac Son district.

Geographical and topographical structures

Cuc Phuong National Park is located at the end of a limestone mountain range that runs to the sea in a Northwest to Southeast direction. The park sits in a small narrow valley between 2 parallel limestone mountain ranges. The main road of the park runs along the middle of the valley. Between the limestone mountains, running in the same direction, are lower soil hills that are divided by gradually sloping passes. Together they create a relatively large and long valley with an average height, in the valley, of 200 -350m above sea level.

Cuc Phuong National Park is, on average, 300 to 400 meters above sea level. It is slightly higher in the Northwest than in the Southeast. The Cuc Phuong mountain range stands like an island surrounded by fields. There are narrow fields to the north of the park, along road no.12, and also to the West, along the Buoi River. To the Southwest are the lower rice fields of Nho Quan.

The geological base of Cuc Phuong is limestone, from the Triassic period, mixed with Shiste, Argalit, Aleurolit and Gneis.

The layer base at Cuc Phuong is comprised of the layer of Redsins on the limestone, the layer of Feranits on the hills, and the layer of Margalit - Feralit or yellow Feralit on the velleys.

Climate and hydrology

The climate of Cuc Phuong is tropical monsoon. The temperature varies from 16.6^{0}C to 24.7^{0}C with an average of 20.6^{0}C. The highest recorded temperature was 39^{0}C on 05/071979 and 09/08/1979 and the lowest recorded temperature was 0.7^{0}C on 18/01/1967.

The annual average rainfall in Cuc Phuong is 2157.2 mm with the majority of this occurring in areas of high elevation and dense forest cover. In the buffer zone the average rainfall is approximately 1799.5 mm, in areas of light forest cover the average rainfall is 2058mm and in dense forest the average is 2396.7.

Weather is divided into two seasons. The rainy season is from May to November with an average temperature of 23 ^{0}C and rainfall of 1922.9mm (representing 89.1% of the total annual rainfall). The dry season is from December to April with an average temperature of 15 ^{0}C and rainfall of 224.3 ^{0}Cmm (representing 10.9% of the total annual rainfall).

Because the topography of Cuc Phuong is karst, there is very little flowing water in the park. The two permanent sources of water are the Buoi and Ngang Rivers in the Northwest of the park. Most other bodies of water only exist in the rainy seasons and when the rain ceases, the water flows into sinkholes and underground streams. Generally flooded areas will drain within 1-2 days of flooding.

3 Nature resources

Flora

Forest covers 20,473ha of Cuc Phuong National Park, representing 92.2% of the total 22, 200ha of the park. The vegetation is evergreen tropical forest, and is divided into 3 categories:

- The forests in the valley and piedmont areas contain 5 canopy layers; 3 of these layers are woody, 1 is shrub and 1 is ground vegetation
- The forest on the sides of the mountains contains 3 layers: the emergent canopy layer; the canopy layer and the lower canopy layer.
- The forest on the top of mountains contains 2 layers: the higher layer and the lower layer.

The Cuc Phuong flora is a point of convergence of 3 immigration flows:

- The Humid Tropical current involves Malayan – Indonesia factors.
- The North West current bring temperate factors from Yunnan, Quizho, and the Himalayan sub-mountain Temperate Zones
- The West – South West current brings Indian - Malaysian factors from arid area of India and Myanmar.

Cuc Phuong has many diverse plant species. A total of 1983 species (equivalent with 24.6% of plant species totality of Vietnam) belong to 915 genus (equivalent with 43.6% of plant genus totality of Vietnam) and 229 families (equivalent with 68.9% of plant family totality of Vietnam) of 7 phyla have been recorded in the park.

Fauna

The fauna of Cuc Phuong is very diverse. According to results of the previous inventories (1970 to date), Cuc Phuong has 119 species of mammal, 67 species of reptile, 43 species of amphibian, 65 species of fish and thousands of insect. In comparison with the rest of Vietnam this data shows that Cuc Phuong, while only occupying 0.07 % of the total area, has 30.9% of the entire number of vertebrates in the country. Cuc Phuong is a point of special diversity of fauna in Vietnam, however 60 of the species in the park are recorded in the Red Data Book of Vietnam (published in 2000). This includes the Delacour's langur (*Trachypithecus francoisi delarcouri*) which is endemic to Cuc Phoung and is the official symbol of Cuc Phuong National Park.

4 Others resources and caves.

Cuc Phuong, with its Karst terrain, has many beautiful caves including: Trang Khuyet (Crested Moon), Vui Xuan (Merry Spring) and Pho Ma Giang (Descended King's Son In-Law). The caves are not only beautiful but are also historically and culturally important. Since 1966-1976 there have been many archeologists visit to research and excavate these caves, during this time they found that:

- In Dong Nguoi Xua (Cave of Prehistoric Man) 3 ancient graves were discovered and excavated finding many human and mammal bones, simple tools, earthen wares and snail and other mollusc shells. According to scientists, prehistoric man lived here approximately 7500 years ago during the Hoa Binh – Bac Son cultural age.
- In Con Moong Cave (Mammal Cave) 4 ancient graves were discovered and many polished stone tools were found. Three of these graves were from the Son Vi cultural age (10,500-12,500 years ago) and the remaining one belongs to the Hoa Binh cultural age.

In 2000, a fossil of an ancient vertebrate animal was discovered in a limestone area of Cuc Phuong National Park. The fossil was examined by scientists from Hanoi Museum of Geology and experts from Colorado University, Kent State and the Geological Society of the United States of America. The fossil was identified as a species of Placodonts (Placodontia). The fossil bones are exposed in a thick bed of limestone in the Middle Triassic Dong Giao Formation.

5 Conservation and international cooperation activities

In addition to research into biodiversity, the base of conservation work, Cuc Phoung National Park is committed to supporting in-situ and ex-situ research and conservation programs and to working with international organizations that have shown concern for Vietnam's protected areas.

Plant Conservation

The Cuc Phuong botanical gardens were established with the purpose of maintaining the genetic source of plants which are of value to both Cuc Phuong and Vietnam. On this 180ha site are 366 species of plants including: 210 wooden plant species native to Cuc Phuong, 85 wooden plant species native to other regions of Vietnam, 5 introduced species, 20 edible fruit species, 15 bamboo species, 15 areca palm species and 16 taros species. 80% of plants in the botanical gardens are growing well and some have produced fruit. The Cuc Phuong National Park is one of the 3 Vietnamese botanical gardens first recognized as an International Botanic Garden and, in the future, will provide native species for Vietnam's re-plantation programmes.

Sika Deer (Cervus nippon) and Sambar Deer (Cervus unicolor) Conservation Programme:

Both the Sika and Sambar Deer were once native to Cuc Phuong but have not been present for a long time. This programme aims to release both species back into the park. There have been 8 individuals released to date and the program currently has 95 individuals living in semi-wild conditions in the botanical gardens. These animals are healthy and breeding well and some of them will be released back to nature in the future.

Endangered Primate Conservation Programme

In a partnership between Cuc Phuong National Park and the Frankfurt Zoological Society - The Republic Federation of Germany, the Cuc Phuong Endangered Primate Conservation Project, a rescue centre for endangered primates, was established in 1993. It currently has 132 individuals, including 16 species and sub-species of endangered primates, in captivity in the centre. Six of these species are not found in captivity anywhere else in the world. At present, 9 species, including Langurs and Gibbons, are breeding well. For these species it is exceptional result.

Turtle Conservation Centre

The aim of this programme is to protect terrestrial and fresh water turtles and tortoises in Vietnam, particularly those which have been confiscated from illegal traders by the Provincial Forest Protection Department. At present, nearly 800 individuals, of 17 species, are being kept in captivity at the Turtle Conservation Centre. Nine of these species are breeding successfully and approximately 200 hatchlings are born annually. In recent years the TCC, together with Provincial Forest Protection Departments and Cuc Phuong National Park, has released hundreds individuals back to their natural home.

Other animal conservation programmes

There are many rare and important animals facing extinction. The Cuc Phuong National Park has had success carrying out conservation programmes for other animals such as: Owston's Palm Civet (*Chrotogale owstoni*), Hymalayan Porcupine (Acanthion subcristatum), Brushed-tail Porcupine (*Atherurus macrourus*) and Silvered Pheasant (*Lophura nycthemera*). These animals are bred not only for the purposes of genetic preservation but also because they are a financially valuable species (except the civits) that can generate income. The successful of this programme will be the basic factors for development the programme in the near future.

Looking back, the management of Cuc Phoung National Park are proud of how the park has developed and how it has accomplished conservation tasks on behalf of the Government.

The most important thing to come from all the conservation work and success is for other National Parks and Nature Reserves in Vietnam to learn from the experience of Cuc Phuong National Park. Cuc Phuong has the capacity to share a lot of knowledge that has beeen accumulated over more than 40 years.

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GEOCHEMICAL CHARACTERIZATION OF COMPLEX MULTI-LAYER KARSTIC SYSTEMS. SPRINGS OF PÉRIGUEUX, FRANCE.

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Keywords: karst aquifer, multi-layer, vulnerability, mixed waters, geochemistry, PCA.

1 Introduction

The springs of Périgueux, (Moulineaux spring and Toulon spring) – Dordogne, South-Western France – constitute one of the main water resource of this area. In spite of a good chemical quality (HCO_3^--Ca^{2+} waters), these springs remain very vulnerable from the bacteriological and turbidity point of view. One observes in the same way a regular increase in the nitrate content since 15 years. These big flows springs (average discharge: Moulineaux = 1 $m^3.s^{-1}$ and Toulon = 0.5 $m^3.s^{-1}$) were first studied in the 1970's (Von Stempel, 1972) and then in the 1996's in order to redefine the protection area around the springs in accordance with the new French law on water resources protection. The risks of pollution induced by a new motorway near the spring's site, has led the authorities to re-specify the limits of the catchment's area and, as a preventive measure, to search for a resource of substitution.

2 Location and geological settings

The recharge area of the springs is located in the North-Eastern part of the Aquitaine sedimentary basin mainly in the upper Cretaceous carbonated sediments and probably in the middle and upper Jurassic limestone. The extension of the limits of these systems is poorly known laterally (from 50 to 200 km^2) but also in depth. Very few dye tracings have been carried out because of a lack of well identified water losses. The water balance is difficult to establish because the flows are badly controlled. The structural study carried out in the sector has shown the existence of an anticline structure of NW-SE direction, as well as associated faults, below the Toulon spring. This structure resulting from the formation of the Pyrenees (in the South of the Aquitaine Basin) during the Tertiary, allows the upward circulation of groundwater by two main vertical karstic conduits (Abyme spring and Cluseau spring which are both Vauclusian type springs). The Toulon spring drains the North-eastern part of the area whereas that of Moulineaux drains the Southern part.

Toulon and Moulineaux springs emerge respectively from Turonian and Santonian limestone. Only the hydrogeological context of Toulon is represented (Fig. 1).This fact naturally led to the assumption that these springs were the regional discharge of the Turonian aquifer and of the Coniacian-Santonian aquifer. Data from new drillings associated with a space and temporal geochemical study show the participation for each major spring of a deeper groundwater resource. These springs would in fact be the discharge of multi-layer systems because of both local structural context and paleogeography of the area.

3 Methodology and results

By using a classical geochemical data processing (Lastennet, 1994; Lastennet *et al.*, 1997 and 1999) from 1978 to 2000, by multidimensional statistics (PCA) and by interpreting data with samples from new drilled boreholes (Table 1), the end members involved in the mixing have been identified. Thus, the participation of deep groundwater has been demonstrated. In the case of the Toulon karstic system (Fig. 2A and 2B), the aquifers of the middle and upper Jurassic take part in the flow of the spring. These waters are discriminated by their magnesium content resulting from interactions with dolomite, which is present in abundance in Jurassic sediments. At a multi-annual scale, results

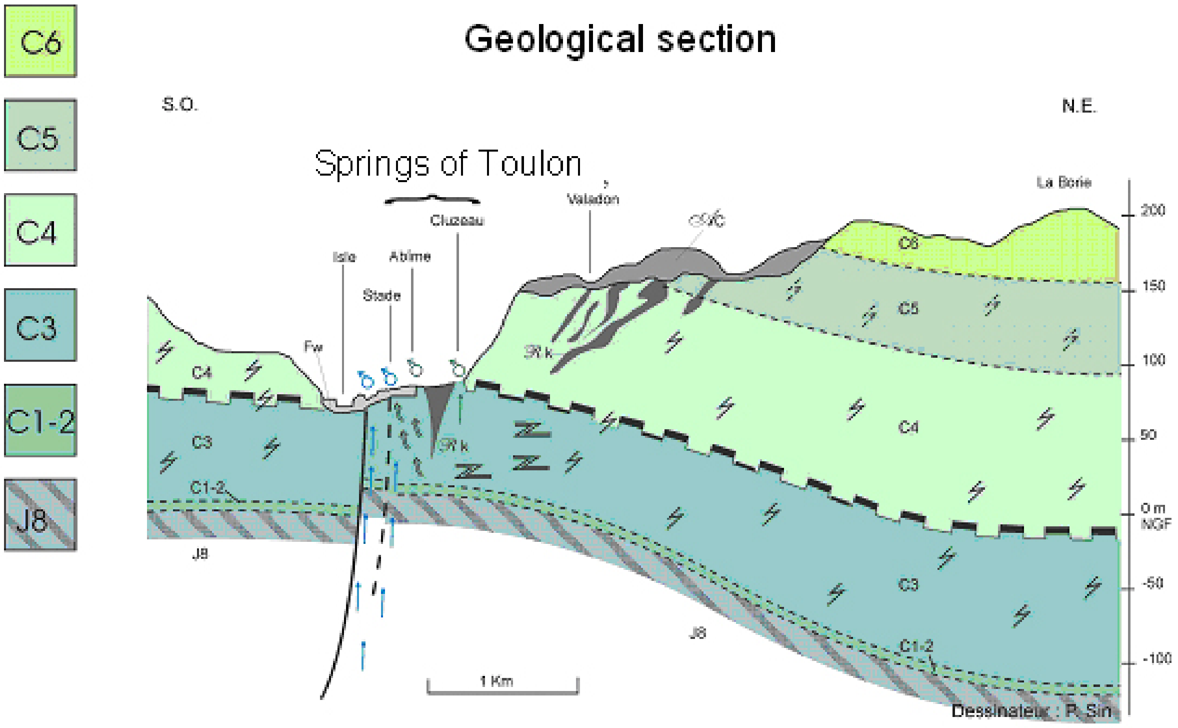

Fig. 1: Geological section and schematic flows into the karstic system of Toulon at Périgueux

Table 1: Geochemical characteristics of the karstic springs of Périgueux and the Jurassic closest boreholes (CT: Total Coliform; ST: Total Streptococcacea)

	T	Turbidity	pH	Cond.	HCO3	Cl	SO4	NO3	Ca	Mg	Na	K	Fe	SiO2	Isc	Isd	pCO2	CT	ST
Site	°C	NTU		mS/cm	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l			atm %	n/100ml	n/100ml
MOULINEAUX karst Mean (1978-2000)	**13,30**	**3,16**	**7,40**	**420**	**267**	**11,13**	**6,39**	**10,56**	**89**	**3,69**	**6,04**	**0,99**	**0,21**	**16,75**	**0,15**	**-0,94**	**0,99**	**163**	**23**
TOULON karst Mean (1978-2000)	**13,79**	**2,46**	**7,31**	**508**	**334**	**11,54**	**9,89**	**11,08**	**104**	**7,82**	**6,23**	**1,19**	**0,12**	**14,62**	**0,20**	**-0,57**	**1,57**		**72**
Chancelade borehole (Jurassic middle and sup) 06/08/1999	**20,00**	**0,20**	**7,50**	**430**	**278**	**12,90**	**9,30**	**5,20**	**65**	**21,10**	**9,10**	**1,20**	**<0.05**	**17,40**	**0,22**	**0,24**	**0,79**	**15**	**0**
St Laurent-sur-Manoire borehole (Middle and upper Jurassic) 05/08/1998	**18,60**	**0,60**	**7,20**	**500**	**313**	**13,70**	**4,80**	**4,80**	**88**	**16,10**	**6,10**	**0,90**	**<0.05**	**14,90**	**0,08**	**-0,3**	**1,74**	**100**	**0**
Château Lévêque (1) borehole (Middle Jurassic) 22/03/2001	**18,60**	**1,40**	**7,30**	**520**	**333**	**20,60**	**8,00**	**5,40**	**96**	**17,10**	**6,50**	**<1**	**0,10**	**17,60**	**0,23**	**-0**	**1,46**	**30**	**4**
Château Lévêque (2) borehole (Middle and upper Jurassic) 19/06/2000		**0,90**	**7,30**	**465**	**336**	**11,30**	**9,20**	**10,10**	**101**	**13,40**	**5,20**	**1,00**	**<0.05**	**14,10**	**0,25**	**-0,1**	**1,46**	**50**	**20**

clearly show the evolution of each component in the mixture.

These proportions vary according to the hydrodynamic of the whole system and thus according to hydraulic potential of each aquifer taking part in the flow. During low waters of summer, the participation of the Jurassic aquifers is predominant (the magnesium is high). Conversely the Cretaceous aquifers mainly contribute to the flow during high waters because of their fast recharge during winter and spring (nitrates, pCO2, Cl, HCO3, Ca).

The spring of Moulineaux (Fig. 3A and 3B), considered for a long time as the main discharge of the Santonian-Coniacian aquifer (Von Stempel, 1972), shows a mixing between two end members which tends to indicate the participation of the Turonian aquifer to the flow. During summer, groundwater from this formation are clearly confined and their quality is then excellent. During winter and spring, the

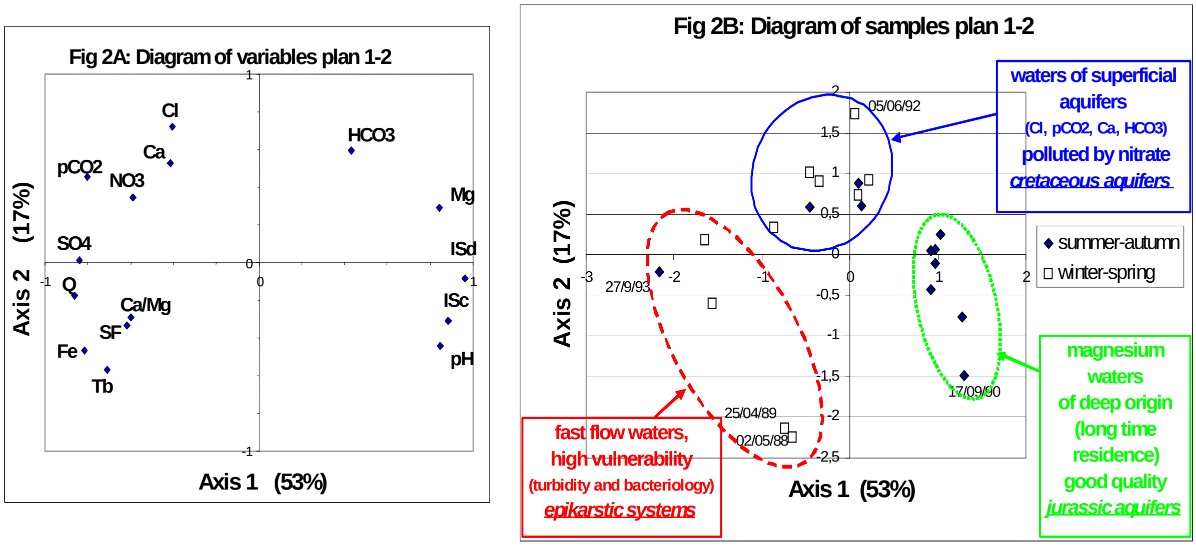

Fig. 2: PCA on the karst system of Toulon (1987-1998). Diagram of variables (Fig. 2A) and diagram of samples (Fig. 2B).

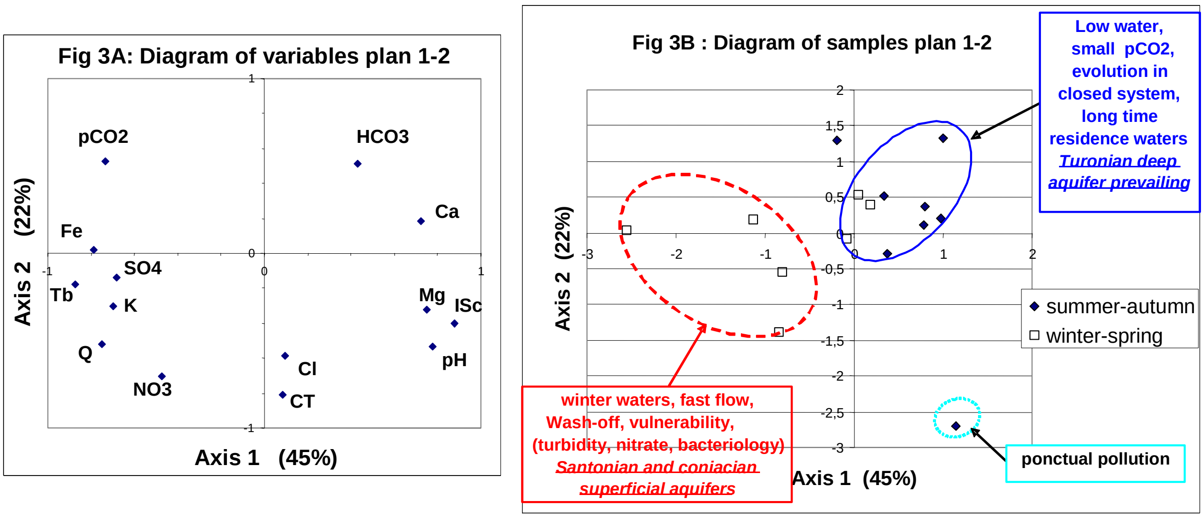

Fig. 3: PCA on the karst system of Moulineaux (1992-2000). Diagram of variables (Fig. 3A) and diagram of samples (Fig. 3B).

water quality is mainly influenced by the participation of superficial and more vulnerable waters. Periods of rains cause brutal increases in turbidity associated with bacteriological germs (coliform bacteria, streptococcaceae) which can prevent waters from meeting drinking standards. This is a major worry for water supply managers.

4 Conclusion

The new approach of the karstic systems of Périgueux presented in this paper, should allow to better apprehend the multi-layer hydrogeological systems and to better protect this exceptional water resource. The results from this study highlight the complexity of relationships between different groundwater stories into a carbonate multi-layer. The geological history (structures, sedimentology), the periods of karstification (upper jurassic, upper Turonian) then clogging (Eocène – sidérolithique-, quaternary), base level fluctuations, have a major influence on the regional hydrogeological behaviour. In this area “Dordogne” there are many vertical karstic wells, as a result of fluctuating sea levels, crossing the different jurassic and cretaceous aquifers and giving these mixed waters.

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PROTECTION OF THERMAL KARST CAVES IN A LARGE CITY (BUDAPEST, HUNGARY)

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Keywords: thermal karst, thermal springs, mixture corrosion, cave protection.

The Hungarian capital Budapest lies on the banks of the Danube (Duna) river and has nearly two million inhabitants. The city was either built on the narrow young terrace of the river and the surrounding lowland, or on the hillsides of the mid-mountainous region, extending down to the riverside. These mounts are built of carbonate rocks, partly by Triassic limestone and dolomite, partly by Tertiary limestone and marl. At some places, younger clay deposits cover the slopes of the mounts.

In the geohistoric past, warm waters had sprung forth in several phases and at several places. Due to the uplift of the mountain and downcutting of the Danube, springs have dried in several cases. In the area of Rose Hill (Rozsadomb), these form today accessible cave passages. Dissolution in Pleistocene times has led to the formation of 60 caves (among them 6 large caves, each several km long) and even more cave indications known today. The known length of the cave passages already exceeds 35 km. In foundation pits for new buildings, new cave indications are observed and speleological exploration of known caves also results in new discoveries every year.

In Budapest, not only the protection of caves as natural phenomena (often decorated with wonderful crystals) is important but – in close connection herewith – also that of thermal wells. Though the caves can be regarded as paleokarst, their relation with the younger, active spring passages is obvious. Among the cave passages filled with warm water, the Molnar Janos cave is already 3 km long as a result of new discoveries in 2003.

Dissolution of the caves is due to mixture corrosion. This process takes place some metres below the existing karst water level. Its main components are the different headwaters of a large water cycle which starts as infiltration water in the karst, then passes underneath the Pest plain covered with impermeable clays, and finally returns to the surface along a fault line after a residence time of 1000 to 10.000 years. Here, near the surface, the headwaters which traversed variable pathways and reached different depths (thus having different temperature and chemical composition) mix with each other and with the cold karst water filling continuously the cracks of the rocks below the karst water table. In addition, direct infiltration from the surface occurs which means a greater risk for the calcite, aragonite, gypsum and barite crystals of the Jozsef Hill cave (Jozsef-hegyi-barlang), the Szemlö hill cave (Szemlö-hegyi-barlang) and the Pal valley cave (Pal-völgyi-barlang).

The greatest risk is the big city environment itself. Although the area of cave occurrence corresponds to the most expensive real estates of the city, often with beautiful panoramic views, there are still deficiencies in the canalisation and some old (already 100 years old in the vicinity of the springs of today) conduits leak at several places.

Budapest is a city of spas. Several medicinal baths and hospitals were established, based on the thermal springs of today. Their protection is an economic interest of the first rank. Additional risk factors are buildings and roads with firm pavements that withhold direct infiltration. Thus, above known cave passages building of new houses was already prohibited 17 years ago. This protection is now extended to their immediate vicinity.

Unfortunately, unpredictable damage also exists today. Because of economic reasons, it has not been possible to cease the salting of the roads during frost and snowfall periods in wintertime. Furthermore, vibrations caused by motor vehicle traffic can also damage the caves, breaking even the conduits.

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INNOVATION AS A PROCESS OF NETWORK BUILDING, SOCIAL LEARNING AND NEGOTIATION. IMPLICATIONS FOR TRANSDISCIPLINARY RESEARCH COLLABORATION.

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This paper reflects on the role that natural and social scientists may play in innovation processes towards sustainable rural resource management. First, the paper discusses several conceptual shifts with regard to the understanding of innovations and innovation processes. Subsequently, it is argued that the processes that need to be supported communicatively in the context of deliberate efforts to stimulate innovation are network building, social learning and conflict management at multiple levels. Thirdly, the paper discusses the implications of this mode of thinking for setting up viable transdisciplinary research collaboration efforts, and for the role of scientists therein. A variety of newly emerging roles and tasks are identified and discussed. Special attention will be paid to arriving at a relevant and coherent set of natural and social science questions for collaborative research. To this end the paper discusses a specific methodical approach for making a socio-technical problem analysis, aimed at integrating and explicating insights from social scientists, natural scientists and societal stakeholders.

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A PRELIMINARY STUDY ON THE DRIVING FACTORS ON KARST ROCK DESERTIFICATION. CASE STUDIES OF YUNNAN PROVINCE, CHINA

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Rock desertification has been one of the most serious environmental problems in karst terrains of Yunuan province, China. Numerous studies have suggested that population pressure and malpractices in land-use played a great role in the processes of rock desertification. Can the rock desertification be processed under natural conditions? The study in Xichou and Laoping counties, Yunnan province has found that:

1. There are one or two clay interlayers, 1-1.5cm thick in the speleothems, which could be dated back to 7000-8000ys, and it could be interpreted as the underground representation of surface karst desertification.
2. The degrees of land degradation, in some extent, have well correlations with the karst evolution stages, e.g. it is increasing from karst high land, fengcong – shallow depression, karst deep gorge to karst deep depression.
3. In addition, the analysis of social-economic data has shown that some indexes correlate with rock desertification, which could represent somehow the degree of human impact on the land, such as land-cultivated rate..
4. RRA and PRA surveys have realized that the political policy and the change of economic model do have imposed a great impact on the karst environment. Accordingly, It can be concluded that nowadays' rock desertification is the result of extreme human activities against a background of physical geographical conditions. Under natural conditions, desertification could also be caused by changes in climate and local water environment. Some approaches and suggestions of treatment are discussed.

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FLOOD PREDICTION IN THE KARSTIC SUOIMUOI CATCHMENT, VIETNAM

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Abstract. The major obstacles to modelling flood processes in karstic areas are a lack of understanding and model representations of the distinctive features and processes associated with runoff generation in those regions and a lack of field data. In this study, a distributed flood modelling approach, WetSpa, was performed by modifying model representations of some of the predominant features and processes of the karstic Suoimuoi catchment with complex-terrain and mixed land use in the northwest Vietnam. The model was calibrated based on 15 months of hourly hydrometeorological data, topography, land use and soil types in GIS format, and used to continuously simulate both baseflow and fast-responding overland, conduit and channel flows during stormflow periods. Considerable variability in simulation accuracy was found among storm events and within the catchment. The simulation results showed that the model represents reasonably well stormflows generated by rainfall events in the study catchment, and the potential of using distributed flood simulation for estimating future flood conditions under changing land use conditions. It is argued therefore that the WetSpa approach is suitable for application in karstic areas under human and natural pressure.

Keywords: flood prediction, WetSpa, GIS, karstic Suoimuoi catchment.

1 Introduction

The Suoimuoi River catchment is situated in the mountainous Da River basin in the Northwest Vietnam. It covers an area of 273 km^2 with the Suoimuoi sinkhole as the catchment outlet. The catchment is confined by two regional deep fault systems trending in NW-SE direction, the Son La Fault on the east and the Da River Fault on the west. A range of non-limestone and limestone rocks of different formations are exposed within the catchment as shown in Fig. 1. There is almost no surface water drainage in the karst area. Instead, closed depressions exist here and there with cave systems developed in the bottom or in the rock walls (Tam, 2003). The karst aquifers receive water, mainly by the regional groundwater flow, with additional important in-situ recharge by rainfall, surface water and exotic water from higher-lying non-karstic areas. The movement of karst groundwater is closely controlled by these tectonic conditions. The groundwater is mainly stored in fractures, crushed zones and caves. Along the river course, there exist a number of karst springs/resurgences and sinkholes in which the interaction between karst groundwater and surface runoff occurs (Tam *et al*., 2001).

The Suoimuoi catchment is characterized by a humid subtropical climate and influenced by the monsoon regime prevailing in Northern Vietnam. Two distinct seasons can be observed in the area: the dry winter lasting from November to April and the extensive rainfall summer from May to October. The yearly mean temperature is 21.1°C, the mean annual precipitation is 1450 mm of which about 85%

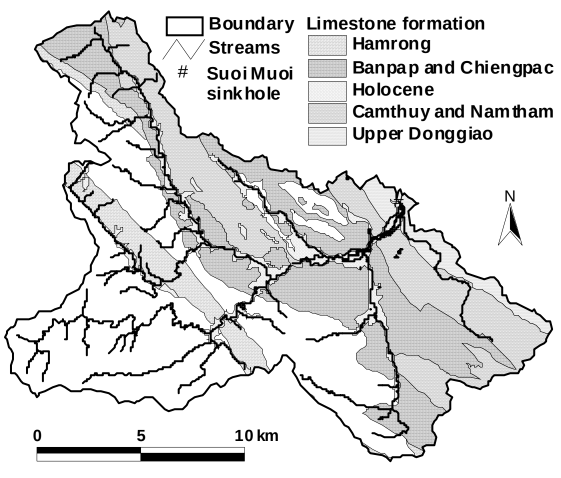

Fig. 1: Distribution of karst limestone in the Suoimuoi catchment

falls during the rainy season in summer. According to Tam (2003), the total discharge of the Suoimuoi River tributaries located in the non-limestone area west of the Sonla fault contributes only 7-10% to the total river discharge measured at the Suoimuoi sinkhole. However, their discharge contribution can rise up to 25% of the total river discharge during storms due to surface runoff generated from the steep non-limestone rocks.

During the period 2000-2003, an extensive hydrological and geophysical survey was conducted to study the mechanisms of hydrogeological processes in the Suoimuoi catchment. Many sophisticated methods, such as computer modelling, hydrogeological mapping, tracer and pumping test, etc., are performed to analyze complex groundwater systems. However, computer modelling is difficult to realize accounting for turbulent-flow conduits in the karst areas. Even dye tracing, which is usually considered the most convincing tool for delineating groundwater basins in karst, is not physically or economically feasible in some cases, and rarely gives more than an outline of the major conduit flow. Geophysical surveys may help to delineate the local geologic framework and major conduits, but the surveys cannot determine detailed flow patterns and divides in karst areas. However, all these methods provide significant information and analysis in delineating drainage systems and determining hydrological characteristics of the karst aquifer. In this paper, a flood simulation approach for the Suoimuoi catchment using the modified WetSpa hydrological model is presented, for which modelling processes and parameters are adjusted separately for the limestone and non-limestone areas based on 15 months of hourly hydrometeorological data.

2 Methodology

The watershed model approach used in this study is a modification of the WetSpa model, which was originally developed by Wang *et al.* (1997) to study the Water and Energy Transfer between Soil, Plant and Atmosphere, and adapted to flood prediction on hourly basis by De Smedt *et al.* (2000) and Liu *et al.* (2002, 2003). The hydrological processes are simulated in a grid-based schematisation of a river basin including precipitation, interception, depression, surface runoff, infiltration, evapotranspiration, soil moisture storage, interflow, percolation, groundwater storage and discharge. The model uses the spatial information of catchment topography, soil type and land use, and recorded meteorological data to predict river flow hydrographs and spatially distributed hydrological characteristics, such as soil moisture, infiltration rates, groundwater recharge, surface water retention or runoff, etc.

For the non-limestone areas in the Suoimuoi catchment, the WetSpa model is applied, for which the runoff of each grid cell is calculated by a modified rational method

$$V_s = CP(\theta/\theta_s) \tag{1}$$

where V_s is the amount of surface runoff [L], P the net precipitation [L] (rainfall minus interception), θ the soil moisture content [L^3/L^3], θ_s the saturated soil moisture content [L^3/L^3], and C a potential runoff coefficient [-], which is assumed to depend upon slope, soil type and soil cover and interpolated from values collected from literature. Next, the generated runoff is routed to the catchment outlet along its flow path using the method of linear diffusive wave approximation (Liu *et al.*, 2003)

$$U(t) = \frac{1}{\sigma\sqrt{2\pi t^3/t_0^3}} \exp\left[-\frac{(t-t_0)^2}{2\sigma^2 t/t_0}\right] \tag{2}$$

where U(t) [T^{-1}] is the flow path unit response function at time t, t_0 [T] and σ [T] are mean flow time and its standard deviation. The parameters t0 and σ are spatially distributed, so that each flow path has different parameters depending on the length of the flow path and the physical characteristics of the flow path elements. The total direct flow at the catchment outlet is calculated by the convolution integral of all flow path responses subjected to the spatially distributed runoff computed for each grid cell. The infiltrated water into the soil is used for consequent percolation, interflow and evapotranspiration, which are controlled by the moisture content, hydraulic gradient and soil textures. The groundwater flow is simulated using a linear reservoir method on a small subcatchment scale forming the baseflow of river discharge.

The schemes of WetSpa model are not valid in simulating processes of the kastic area in the catchment due to the change of hydrological regime. Water may flow overland from ridge tops, and then enter the ground in upland regions through recharge features and resurgent at springs in low areas. Diffuse infiltration can also take place through the soil or through epikarst. On steep slopes that do not readily develop sinkholes, diffuse infiltration can occur through the soil or into bedrock fissures. Moreover, it is difficult to identify groundwater flow paths and divides in karst aquifers, which arises from the extreme heterogeneity and anisotropy of the karst aquifer, and from changes in groundwater patterns with different stages of flow. For example, groundwater flow paths, divides, and basin boundaries can shift in response to rising groundwater levels during and after major precipitation events. Taking account of the above specific characteristics, the WetSpa model is modified as follows in order to better represent the predominant hydrological features of the karst area in the catchment.

Surface runoff coefficient is set to zero to reflect the condition that almost no surface flow is apparent in the karst areas.

Water that contributes to conduit runoff in the unsaturated zone is estimated taking account of the effects of slope, soil type, land use, moisture content, and is assumed to be a linear function of the expected surface runoff in the WetSpa model, i.e.

$$V_c = \alpha CP(\theta/\theta_s) \tag{3}$$

where V_c is the amount of water that contributes to conduit flow [L], and α [-] is a global parameter within the range 0 – 1 and realized through model optimization.

Routing of conduit flow is accomplished by the method of diffusive wave approximation as described in Eq. 2, but its concentration time and variance are adjusted based on the analysis of observed hydrographs.

The parameter of hydraulic conductivity and other soil features (porosity, pore size distribution index, etc.) are readjusted through model optimization.

Groundwater flow is simulated using a linear reservoir method, for which the flow recession coefficient is obtained from the analysis of observed hydrographs.

Through above modification, the WetSpa model is used to simulate the flow responses to storm events in the karstic Suoimuoi catchment. Specifically, the pattern of individual groundwater flow paths tends to have a strong vertical component in the unsaturated zone and a strong tendency to follow the strike in the saturated zone. Conduits carry high-velocity turbulent flow, and they include caves that are large enough to explore. The statements about preferred flow routes in this study are supported by the mapping of accessible conduits (Hung *et al*., 2002). The total hydrographs at the catchment outlet are obtained by summation of the direct flow, interflow and groundwater flow from the non-limestone areas and the conduit flow and groundwater flow from limestone areas.

3 Application

The measured hydrometeorological data during October 2000 to March 2001 are used to calibrate model parameters in this study. The hourly stream flow into the Suoimuoi sinkhole was captured by an automated water level logger. The recorded hourly series of water level was converted to the flow hydrograph by a well calibrated rating curve that was constructed on the basis of many discharge-water level pairs measured at different stages of the stream flow (Tam, 2003). The resulting hydrographs are used in the baseflow separation and the model validation. Hourly precipitation was monitored by an automated logger located 4 km upstream of the Suoimuoi sinkhole, and was assumed uniformly distributed over the catchment. In addition, the data of potential evapotranspiration and air temperature were collected from a nearby gauging station, which are used as input to the WetSpa model.

Topographical maps at scale 1:50,000 were available and cover the entire Suoimuoi catchment. Based on these maps consisting of a 20m contour level, A DEM with 50m spatial resolution and the surface drainage network with drainage density of 0.66 km/km^2 were created as shown in Fig. 2. The topography of the catchment is characterized by highlands in the upper part and lowlands in the lower part of the catchment. Elevation ranges from 539 to 1815m with an average catchment slope of 33.2%. The major soil types of the catchment are Cambisol (43.7%) distributed in the highland areas and bed rock (22%) distributed in the lowland areas in which mature karst landscapes are characterized. Other soil types are Fluvisol, Luvisol, Leptosol, Travertin, Acrisol and Nitrosol, which are distributed

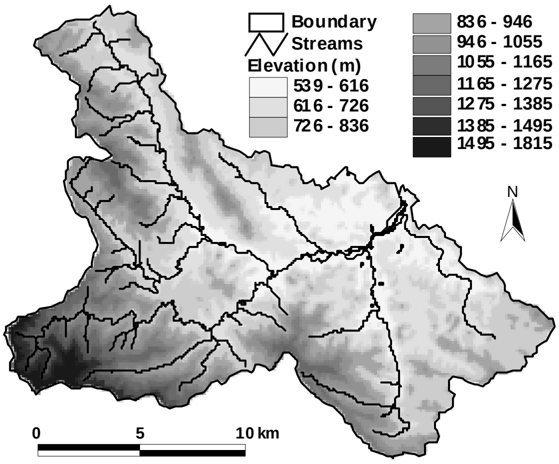

Fig. 2: Topographic map of the Suoimuoi catchment

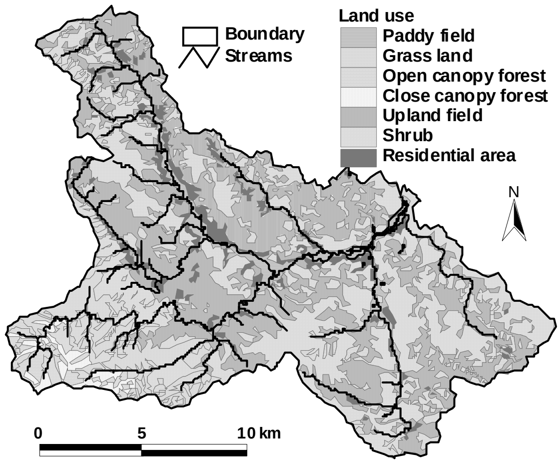

Fig. 3: Land use map of the Suoimuoi catchment

over the catchment. All these soil types were converted to the USGS soil texture classes for use in the WetSpa model (Huong, 2002). The distinguished land use types are: close canopy forest (1.7%), open canopy forest (4.2%), shrub (40.4%), grass land (5.6%), upland fields (38.3%), paddy fields (5.2%), residential area (4.5%) and open water (0.01%) and are distributed as shown in Fig. 3. The above land use categories were further converted to the WetSpa land use types based on vegetation and land use assessment (Huong, 2002).

Model parameters are identified firstly using GIS tools and lookup tables, which relate default model parameters to the base maps, or the combination of base maps. Starting from the 50 by 50 m pixel resolution digital elevation map, hydrologic features including surface slope, flow direction, flow accumulation, flow length, stream network, drainage area and sub-catchments are delineated. The threshold for determining the stream network is set to 50, i.e. the cell is considered to be drained by streams or conduits when the total drained area becomes greater than 0.125 km². The threshold for delineating subcatchments and main streams is set to 1000. Maps of porosity, field capacity, wilting point, residual moisture, saturated hydraulic conductivity and pore size distribution index are obtained from the soil type map. Maps of root depth, Manning's roughness coefficient and interception storage capacity are derived from the land use map. Maps of default runoff coefficient and depression storage capacity are calculated from the slope, soil type and land use class combinations. The residential areas are mainly distributed besides the Suoimuoi river channel as villages or small towns. Due to the grid size, the residential cell is assumed 10% covered by impervious materials (roof, road, etc.), and the rest covered by farmland. The average flow depth is estimated using the power law relationship (Molnar and Ramirez, 1998) with an exceeding probability of a 2-year return period resulting in a minimum overland flow depth of 0.005 m and the channel flow depth of 1.0 m at the catchment outlet. By combining the maps of the average flow depth, the Manning's roughness coefficient and surface slope, average flow velocity in each cell is calculated using Manning's equation, which results in a minimum value of 0.005 m/s for overland flow, and up to 2.5 m/s for some parts of the main river. Next, the celerity and dispersion coefficient at each cell are produced, and the values of concentration time and its standard deviation for each contributing cell are generated as described by Liu *et al.* (2003). With the above information, the unit flow path response functions are calculated from each cell to the sub-basin outlet and from the sub-basin outlet to the basin outlet.

In dealing with the specific problems of karst areas in the Suoimuoi catchment, the WetSpa model is modified, the surface runoff coefficient is set to zero, and the conduit flow and groundwater flow are estimated separately by a conceptual method and a linear reservoir method. The volume of water contributed to the conduit flow in the unsaturated zone is assumed to be a linear function of the surface runoff in the non-limestone areas under the same condition of slope, soil type and land use. Likewise, the concentration time of conduit flow is estimated by the calculated surface flow time multiplied by a correction factor. Using GIS tools and the hydrological modelling extension, the average calculated flow time of the karst areas is computed by integration of the flow time of each grid cell weighed by its percentage of area and flow coefficient. A correction coefficient is then obtained by comparing the value with observed hydrographs at the catchment outlet, and applied to each karst cell in the catchment. Additionally, model parameters in the karst areas, such as the hydraulic conductivity, pore size distribution index, etc., are adjusted during model calibration by multiplying a correction factor for each of them. The groundwater recession constant at the catchment outlet is found from the baseflow separated from the observed hydrographs. This value is around 0.018 day^{-1} according to Tam (2003), and is adjusted for each subcatchment based on its slope, drainage area and geological features.

Model calibration is implemented by comparing the simulated hydrograph with the observed hydrograph. Each of the correction factors and functions involved the use of coefficients is determined using an independent model optimization process (Doherty and Johnston, 2003). The objective function is the sums of squares of the difference between observed and predicted flows at the Suoimuoi sinkhole. The correction factor for estimating the volume of conduit flow is found around 0.15. The concentration time of conduit flow is about 1.5 times the surface runoff, while the hydraulic conductivity is about 2.5 times the default value and the soil pore size distribution index is around 1.0, which leads to a very high percolation to the saturated zone in the karst areas. A graphical comparison between observed and predicted hydrographs during the simulation period is presented in Fig. 4.

It can be seen from the figure that the hydrograph at the Suoimuoi sinkhole is well reproduced by the model. Four statistical evaluation criteria were applied to the 15 months simulation results to assess the model performance. It is found that the WetSpa model reproduces the observed water volume with -3.4% under estimation. The model Nash efficiency for reproducing the river discharges is 69% (Nash and Sutcliffe, 1970). The adapted Nash efficiency for reproducing low flows is 85%, and for high flows 70%, which indicate that the model is suitable for water balance simulation and flood prediction in the karstic Suoimuoi catchment, but the accuracy of peak discharge prediction needs to be improved. The model is also able to simulate the spatial variation of other hydrological characteristics at each time step, including surface runoff, infiltration, actual evapotranspiration, groundwater recharge, etc. This gives the advantage of computer automation and analyzing the effects of

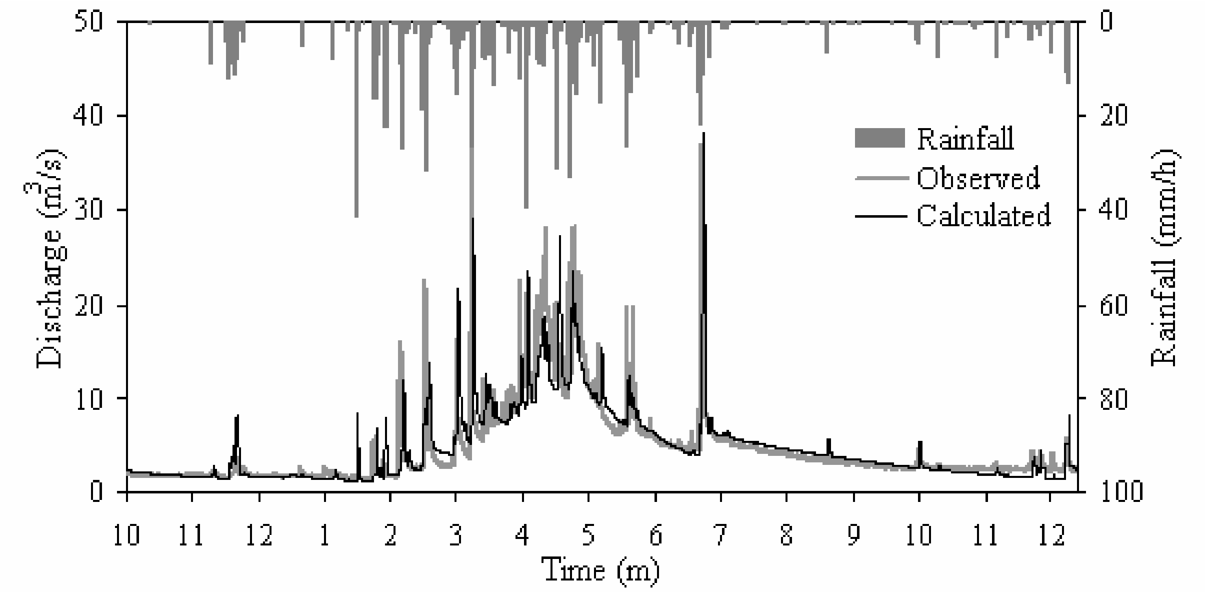

Fig. 4: Observed and calculated flow hydrographs at Logger station during 2000-2001

topography, land use and soil type on the hydrologic behaviour in a river basin.

4 Conclusions

A test of a GIS-based modelling approach for flood prediction in the karstic Suoimuoi catchment was described. The model uses a modified rational method to calculate surface runoff in non-limestone areas and conduit flow in limestone areas based on the spatial characteristics of topography, soil type, land use and moisture condition. Flow into the outlet sinkhole was routed with the linear diffusive wave approximation method, while the concentration time of conduit flow is multiplied by a correction coefficient. Total discharge at the basin outlet was calculated by summing predicted flow from both non-limestone and limestone areas in the catchment. The model was calibrated on a 15-month flow data series collected at the Suoimuoi sinkhole. The results of the calibration show that in general flow hydrographs are well predicted, especially the baseflow at the catchment outlet. However, the predictions of peak discharge for some of the storms are not satisfied indicating the need for improved methods of runoff volume calculation flow routing in karstic catchments.

As described in the paper, the karstic aquifers in the Suoimuoi catchment possess large underground reservoirs of water, but these reservoirs are difficult to exploit because little is known about their hydraulic behaviour. A simple hydrological model, like the WetSpa model used in this study, can provide useful information about the behaviour of such complex flow system. The model explicitly acknowledges the lack of detailed knowledge about the location and size of conduits and other flow paths with fewer data requirements and calibration parameters. In addition, the effects of topography, soil type and land use on potential runoff, recharge and outflow can also be evaluated. Work is continuing on incorporating a more physical-based approach in estimation of runoff volume and flow transport into the model to study the complex hydrological behaviour of the river catchment.

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CONSERVATION OF KARST DEPENDENT BAT DIVERSITY IN MYANMAR AND BEYOND: A DARWIN INITIATIVE APPROACH

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Myanmar's huge variability is reflected in its high biodiversity and contrasted by its lack of institutional capacity to manage this diversity. Although 88 bat species have been recorded there have been no contemporaneous publications on this diversity since WWII. This presentation describes how this situation is being addressed through a Darwin Initiative funded project and considers cave bat conservation in the wider perspective of South East Asia.

THE IMPORTANCE OF CENOTES IN STRUCTURING BAT COMMUNITIES IN YUCATAN, MEXICO

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Cenotes (from the Maya word *dzonot*) are water sink holes formed by the dissolution of limestone. In the Yucatan Peninsula, they are the main water sources for plant and animal communities, including man. Our project is investigating the importance of cenotes for bats. Bat community structure is being compared between forest and pastureland, with and without cenotes. Our hypothesis is that bat community characteristics (species composition, diversity, abundance and dominance) will differ significantly between sites and seasons. Five ground mist nets, one canopy mist net and one harp trap are set at each site. Insectivorous species are also monitored with a Pettersson D980 bat detector and BatSound Pro software (Pettersson Elektronics, Uppsala, Sweden). Community characteristics were analyzed with Species and Richness Software (Pisces Conservation Ltd). During 48 nights we caught 1,739 bats from six families and 24 species grouped into six trophic guilds: aerial insectivore, gleaners, frugivore, nectarivore, sanguivore and carnivore. Phyllostomids were the most abundant with 16 species. Molossidae, Natalidae and Emballonuridae had one species each. *Artibeus jamaicensis* was the most abundant species in all habitats. *Desmodus rotundus* was abundant in the cenote in pastureland but was absent in the cenote in forest. All habitats showed lower bat abundance during the dry season (non-parametric Wilcoxon test). The cenote in pastureland was the most diverse habitat (H'=1.5493) and was significantly different from the others investigated (randomization test at 5% Level). Pastureland was the least diverse. Diversity showed no significant difference between seasons, except in forest without cenote (t=3.65; *d.f.*60.5; $p < 0.05$). Our results demonstrated that cenotes increase bat diversity in the habitats in which they occur. Further analysis of the echolocation calls will increase the number of insectivorous species recorded at the study sites.

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OFFERING A VIRTUAL ROUND TABLE - SOME REFLECTIONS ON A MULTI-STAKEHOLDER COLLABORATIVE LEARNING EXERCISE IN THE CONTEXT OF THE ESTABLISHMENT OF THE NGOC SON NGO LUONG NATURE RESERVE - HOA BINH PROVINCE - VIETNAM

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Limestone Landscape Improving Negotiation for Conservation
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1 Introduction

Complex societal problems are often characterised by diverging interests (social, economical, cultural, and political) of different actors. Problem solving strategies in these cases should for that reason start with the recognition of mutual dependencies (or inter-dependence) between the actors that are involved in the problem at stake. Social sciences, and more particularly educational sciences, organisational psychology, anthropology and sociology can play an important role in finding sustainable solutions. These sciences suggest different methods of conflict resolution such as "collaborative-problem solving", "joint problem solving", "social learning", "interactive policy making", etc. A consistent characteristic of these various approaches is that they advocate an interactive (or participatory) style of problem solving, where shared learning or "social learning" of interdependent stakeholders is the key mechanism for arriving at successful, sustainable solutions.

This paper describes and analyses the actions and research of the Limestone Landscape: Improving Negotiations for Conservations project, hereafter the LLINC project[1/], during the establishment of a new protected area in Northern Vietnam: the Ngoc Son Ngo Luong Nature Reserve.

The Ngoc Son Ngo Luong area constitutes a part of the Cuc Phuong – Pu Luong landscape. The Cuc Phuong Pu Luong area is a karst area where two protected areas already have been established, namely Cuc Phuong National Park and Pu Luong Nature Reserve. To better protect the entire karst range and its wildlife, Hoa Binh provincial authorities proposed in 2002 to establish a new protected area, which should function as a corridor between Cuc Phuong National Park and Pu Luong Nature Reserve. This protected area, called the Ngoc Son Ngo Luong Nature Reserve, would cover approximately 190 km^2, comprising six communes, namely Nam Son, Bac Son and Ngo Luong in Tan Lac district, and Tu Do, Ngoc Lau and Ngoc Son in Lac Son district belonging to Hoa Binh province. In this area, about 76 % is classified as forestland.

Almost eleven thousand people live in the area under study. The majority of the inhabitants belong to the Muong ethnic group. Traditionally, the Muong economy is based on a system of subsistence agriculture where paddy rice dominates. Today, a second crop of paddy rice is cultivated where irrigation is available. Animal husbandry is also a main source of income for the households. There is a lack of off-farm activities, due to the remote location of these mountain communes. The local population has traditionally a strong relation with the forest. The income from forest products is estimated at 10 to 15 percent of the total income. The majority of the activities in the forest are of a collecting type; i.e. firewood, bamboo shoots, mushrooms, and medicinal plants are collected. More than 80

[1/] The LLINC project comprises researchers from the Institute of Anthropology (IA) and the Research Institute on Geology and Mineral Resources (RIGMR) in Hanoi, the Universities of Leuven and Brussels in Belgium and is financed by the Flemish Interuniversity Council Belgium (VLIR).

per cent of the surveyed households in Ngoc Son and Ngo Luong also collect timber for house construction (LLINC, 2004).

The LLINC project in partnership with the Forest Inventory and Planning Sub Institute in the North-West Region (FIPI-NW) was responsible for the implementation of the feasibility study. The aim of this feasibility study was to assess the feasibility of establishing a new nature reserve in the Ngoc Son Ngo Luong area. This is achieved through an evaluation of the biological, geological and socio-economic values of the area, an assessment of the conflicting pressures on the area, and an analysis of the perceptions and expectations of the different stakeholders relating to the forests and future nature reserve

The goal of the social science group of the LLINC project during the feasibility study was double. In the first place, LLINC observed and analysed the process of establishment, trying to develop more knowledge about the practice of learning and negotiation processes during the creation of a new protected area. In this respect, LLINC identified the convergences and divergences in the perceptions and expectations of the different stakeholders, thereby drawing attention to the potential conflicts in the area. In the second place, LLINC tried to the influence decision-making process by providing information relating to the social-economic characteristics of the area and the perceptions and expectations of all the stakeholders involved to both authorities and local people. Through meetings and discussions with the different stakeholders LLINC offered a virtual round table to them, giving them the opportunity to get to know and understand each other's position and reflect their own position and ideas.

2 The tasks of LLINC in the feasibility study

The LLINC project shared together with FIPI-NW the responsibility for the implementation of the feasibility study of the proposed Ngoc Son Ngo Luong Nature Reserve. Such collaboration constitutes a strategic renewal as in the past only one single institution, namely FIPI had the responsibility for the organization of this activity. FIPI-NW is a governmental organization directed by foresters, very strongly guided by the "grand state" tradition, whereby the engineering rationality is the central element of the activities and the technical dimension is dominating the social dimension. Without publicly confronting this technicist approach, the strategy proposed by LLINC had from the very beginning been out of line with the one developed by FIPI-NW.

Indeed, one of the main tasks of the LLINC project in the feasibility study LLINC was to identify convergence and divergence both in terms of physical borders as in terms of understandings, perceptions and expectations of the different stakeholders. LLINC project tried to answer the three following questions in particular:

(a) Which type of protected area is most suitable for the region: Nature Reserve, Species/Habitat Conservation Area or Landscape Conservation Area? Are there other possibilities next to a protected area to protect the landscape and to ensure the corridor between Cuc Phuong National Park and Pu Luong Nature Reserve?

(b) Where could be the different borders of the protected area (strict protection zone, eco-rehabilitation zone, service-administration zone)? What are the different possibilities?

(c) How can the needs and expectations of the different stakeholders, especially the local people be taken into account?

Next to identifying convergence and divergence of perceptions and expectations and pointing out different alternatives for the area, the LLINC project also aimed at improving the understanding and nourishing the negotiation between the different stakeholders during the creation process by offering the different stakeholders a virtual round table.

3 The methodology, a virtual round table

LLINC distinguished three different groups of stakeholders which were all expected to play a role or be implied in the future nature reserve.

(a) **Central Level.** Hoa Binh People's Committee (PC-HB), Hoa Binh Forest Protection Department (FPD-HB Forest Protection Department (FDP),); Forest Inventory and Planning Sub-Institute in the north-west region (FIPI-NW), LLINC project, Pu Luong – Cuc Phuong

Limestone Landscape Conservation Project (Pu Luong – Cuc Phuong LCP) of Fauna and Flora International (FFI);

(b) **Intermediary Level.** Tan Lac and Lac Son People's Committee (PC-Tan Lac, PC-Lac Son) and Forest Protection Department (FPD-Tan Lac, FDP Lac Son), local authorities of the concerned communes (PC communes, Communist Party of Vietnam);

(c) **Local Level.** Chief of the villages, local population.

Rather than bringing actors together around a 'real' round table in view of establishing a negotiation process, the project decided that in this case the concept and related practices of a 'virtual' round table was preferable so as to organize the negotiations at a distance, whereby the project had the function of an information vehicle and a proposal and reception platform.

Originally, the LLINC project planned to conduct three cycles of information collection and feedback, an initial round, a first round and a second round. In a first instance, information relating to the understandings, perceptions and expectations of the different stakeholders would be collected through meetings and interviews. Consequently, this information would be analyzed. In the second place, this information was to be presented to all different stakeholders. The goal of this was to place a (structured) mirror in front of the different actors. The mirror would provoke reflection on their thoughts, position and behaviour. This reflection might urge the different stakeholders to change their position or even their perception. The mirror could bring about discussion in the villages, and among the different stakeholders. In these discussions people were expected to learn again from each other (social learning). The idea was that a regular feedback to all the stakeholders, creating reflexive knowledge and provoking discussions, will stimulate and nourish the establishment process of the Ngoc Son Ngo Luong Nature Reserve.

In reality however, this planning was not implemented as such. The first round of data collection was for instance followed by a round in which feedback and data-collection took place simultaneously. In practice, it seemed very difficult to conduct a one-way process of data collection or information feedback, especially at the local level. When the LLINC researchers asked questions, people asked questions too, and when the LLINC researchers provided feedback, people reacted.

During the initial round, in the period October-November 2003 data were collected concerning the understandings and perceptions relating to forests and forest management and to the Ngoc Son Ngo Luong Nature Reserve. Concretely, LLINC has conducted about 150 semi-structured interviews at all three levels.

The first round consisted of a series of feedback meetings with each of the stakeholders in December 2003. During these meetings the LLINC researchers presented information relating to the other stakeholders' understandings, perceptions and expectations. The reaction of the stakeholders to this feedback document and/or meeting was recorded on tape and detailed notes were taken. About 40 feedback meetings were organised during December 2003, all on a collective basis.

The goal of the third field survey (February 2004), which took place in the second round, was thus to obtain more detailed information relating to the expectations about the boundaries, regulations, management and type of protected area. A series of questionnaires was conducted among the stakeholders involved. In total, LLINC has conducted about one hundred structured interviews.

A seminar in March 2004 closed the process conducted by the social science component of the LLINC project in the framework of the feasibility study. This seminar aimed in the first place at providing feedback relating to the information collected among the different stakeholders. In the second place, the LLINC project intended to provoke a debate around the different options to conserve the environment in a sustainable way and to create the corridor between Cuc Phuong National Park and Pu Luong Nature Reserve.

4 Identifying convergence and divergence in perceptions and expectations

Using the information collected during the process described above, the social science part of the LLINC project identified convergence and divergence of understandings, perceptions and expectations, including perceptions on forests and (forest) boundaries, understandings relating to the plan of Hoa Binh provincial authorities to create a nature reserve (did they know about this plan?, how did they get to know the plan?, what do they know exactly about the plan), perceptions on what a nature reserve is, and expectations relating to the establishment, regulation and management of the nature reserve.

Perception on forests and (forest) boundaries

The central and intermediary stakeholders perceive forest boundaries as clear fixed borderlines, while the local people perceive boundaries more in terms of contrasts in landscape elements (e.g. slope versus valley) and land use (e.g. forest versus bare land). As a consequence, the local perception of boundaries is often vague and not permanent. The central level and district level stakeholders perceive the forest in terms of management goals, while the local people and the commune authorities perceive the forest in terms of physical features.

Plan to create the Ngoc Son Ngo Luong nature reserve

During the first LLINC survey in October 2003, LLINC has noticed a disjunction in the information flow between the district and the commune level. Of the six communes concerned, there were two communes, which were not aware of the plans of Hoa Binh province to create a new nature reserve.

One needs to underline that all stakeholders involved approve of any action that aims at protecting the environment in general and the forest in particular. But one needs to acknowledge that the information which the local authorities and certainly the villagers have at their disposal is diffuse, fragmented and heterogeneous, even to the point that about one fourth of the villagers has absolutely no knowledge about the plan of the province of Hoa Binh to create a new protected area. The local stakeholders approve of the idea to protect the environment, and therefore they also automatically approve the idea to create a nature reserve even though they have no clear idea of what a nature reserve is and what it implies.

Defining a Nature Reserve

On the central level, the most accurate definitions of a nature reserve and more in general a protected area are given by on the one hand specialized agencies of the state (FPD-FIPI-NW) and on the other hand by the two projects Pu Luong – Cuc Phuong LCP and LLINC. From the moment we go down to the district level, the definitions become very general and broad. The definitions stay similarly quite general and broad on the commune and the local level. Only FPD at district level mentions that a nature reserve is actually a type of a Special-Use Forest.

Establishment of a Nature Reserve

The different stakeholders have different ideas and opinions about how ideally a nature reserve or in general a protected area should be established. In particular, the opinions relating to the situation of the settlement zones and the villages in the future nature reserve show a high diversity. The majority of the stakeholders believe that settlement zones will be included in the nature reserve. Indeed, they distinguish two zones, the villagers will therefore be included in the regeneration zone (if one takes the administrative borders as the borders of the nature reserve). For them, the strict protection zone has to be free of all habitation and agricultural cultivation. This vision is in contradiction to the ideas of the commune authorities. Two thirds of the staff member at commune level and 83 per cent of the interviewed villagers wish that the settlement zones are not included in the nature reserve no matter which zone.

Concerning the boundaries of the nature reserve, generally, all stakeholders would like that the nature reserve has clear and precise boundaries. Beyond this, the opinions diverge greatly. The first topic on which the opinions diverge is the criteria that should be taken into account when one draws the boundaries of the nature reserve. The second topic on which the opinions diverge is the question of who has to be in charge of demarcating the boundaries of the nature reserve. All the levels agree that the design of the boundaries should be a collective decision involving the political authorities and the technical services of the Government. Finally, the participation of the local people in the demarcation of the boundaries is strongly advocated. Everybody at district level and at village level, and three fourth of the interviewees at commune level is positive about this. The major reason for this expressed by all stakeholders, is that the local population knows the environment and the realities on the field. A second reason, seldom cited, is that the boundaries should be adapted to the life of the villagers, i.e. the boundaries should take into account their constraints and needs.

Management and Regulation of a Nature Reserve

Relating to the regulation and management of the future protected area, in the first place, we have to underline that for all stakeholders, without any exception, the regulation has at least to include two elements: a detailed description of the activities which are allowed and forbidden inside the nature reserve and the penalties in case of offences.

Relating to the activities allowed and forbidden inside the nature reserve, one can observe a clear divergence between the position of the people responsible at province and district level (FPD) on one hand and those of the commune authorities and villagers on the other hand.

In general, the people responsible at province and district level underline the necessity of a formal prohibition of every collection, hunting and exploitation activity of natural and forest resources inside the nature reserve. The expectations are different on the commune and village level. Three activities are identified which should be allowed, following decreasing order of importance: the collection of firewood, the collection of NTFP, and the cutting of trees for house construction. The local authorities, the villagers and certain staff member members of the FPD brought up the existence of local arrangements (commune-district) which will allow the local population to continue to exploit the timber for construction in the future, even if these arrangements are not wished for by the staff members of the FPD. Next to these three activities, the large majority of the local stakeholders support a prohibition of all other activities listed in the questionnaires (hunting, cultivation of land, construction of a house inside the nature reserve, catching of ruminants and other collection and exploitations activities with commercial purposes).

Concerning the participation of local people, the large majority of the stakeholders wishes a participation of the local authorities and population, without which the effectiveness of the protection of the nature reserve cannot be guaranteed. The only remaining question is whether the local actors are considered as real partners or simply as executors of the legal and technical provisions. According to PC-HB, FPD-HB and FIPI the local people are essential in the implementation of protection guidelines, but it is not necessary for them to participate in the management board. The more we descend to the local level, the more the need to integrate the local people and authorities in the nature protection is put forward. According to the staff member of PC-Tan Lac and PC-Lac Son the commune authorities should play a central role in the management of the nature reserve, and this under the supervision of FPD. However, according to the district and commune authorities, taking into account the opinion of the local people does not necessarily imply that the local people should be directly involved in the creation process. According to the commune authorities, both the commune authorities and the villagers are the ones who will directly ensure protection of the environment. Therefore, these stakeholders should get a position in the Management Board. The ideas of the local people are more or less similar to the ideas of the commune authorities: the Management Board should include all stakeholders ranging from the provincial to the local level.

5 Discussion and Conclusions

The paper concludes with an analysis of LLINC's actions both in terms of process; (i.e. has LLINC introduced more participation and negotiation in the establishment process?; could the role of LLINC be referred to as a facilitation role?, and did the different stakeholders change their perspectives and behaviour during the process?); and in terms of outputs; i.e. what would be the most optimal way to protect the area and how could the needs and capacities of the local people be taken into account in the future regulation and management structure?

The LLINC project aimed at stimulating and nourishing the collaboration during the feasibility study process for the establishment of the Ngoc Son Ngo Luong Nature Reserve.

Looking back, we conclude that although no explicit negotiation was provoked during the seminar in Hoa Binh in March 2004, 'implicit negotiation' has been going on throughout the whole process. The different stakeholders listened to each other's points of view, presented and clarified by the LLINC researchers, and kept these ideas in mind. Following the dimensions of Gray (1996) we could say that LLINC has succeeded at least to include 1) Appreciative planning (i.e. stakeholders understand each other's intentions and have gained a broader comprehension of the problem than they had in the beginning) and 2) Dialogue into the establishment process (i.e. may or may not produce agreements, but if they do, they only serve as a recommendation to another body: there should be generation of integrative ideas for resolution and ongoing interaction among the players once the dialogue is concluded). Throughout the process of collecting information and providing feedback, the LLINC project has brought the different stakeholders together, and given them an occasion to think about each other's ideas and understandings. Throughout the process, the different stakeholders have built a better understanding of each other's needs and capacities, contributing to a better co-operation.

FIPI-NW for instance, inspired by the ideas of LLINC and FFI, adopted in the end a more landscape-oriented approach, while in the beginning they were emphasising the importance of protecting the forests and following the administrative boundaries. Their final report (FIPI, 2004) mentions a regulation for the collection of firewood and timber harvesting an expansion of the agricultural area and the role of the local people in the implementation of the forest protection measures. Many participants at the Hoa Binh seminar considered the seminar a success, as they were enthusiastic about the new methodology and approach LLINC was following. Especially the local authorities and the local people claimed to have learned a lot during the process.

During the process, the LLINC project took up the role of facilitator, trying to improve the collaboration between the stakeholders through information exchange and the creation of a negotiation opportunity (Hoa Binh seminar). But LLINC was more than a facilitator. Indeed, a facilitator should have no judgement and no authority to make or impose a decision (Shuman, 1996). Yet, LLINC, even though it had no authority to make a decision, did have an own opinion and a vision. Therefore, LLINC was considered during the whole process as a stakeholder. In particular, LLINC has always tried to include more participation, more negotiation into the process, next to keeping an open mind relating the 'nature' of the protection of the area. Thus LLINC did and will certainly influence the final contents of the management and investment plan for the area.

While analysing the understandings, perceptions and expectations of the different stakeholders, the LLINC project identified potential tensions and conflicts. Unfortunately, there has never been a real discussion about the 'form' on how the environment should be protected. The LLINC project had suggested eight alternatives in its feasibility study, but only the Nature Reserve was withheld at the Hoa Binh seminar.

Based on the Vietnamese law and on international experiences, LLINC had suggested at the seminar eight options to protect the environment in the area (LLINC, 2004): Nature Reserve, National Park, Species and Habitat Conservation Area, Landscape Conservation Area, UNESCO Man and Biosphere Reserve, designation of a local forest reserve, allocation of Land Use Certificates (RBC), or the allocation of Forest Protection Contracts. In the last version of the FIPI-NW feasibility study (FIPI, 2004), so-called plan 4 is proposed as a solution on the short term, a nature reserve comprising the six communes and a part of Tan My to ensure the link with Cuc Phuong National Park. According to LLINC, on the long-term, a Culture-Historic-Environment Area (Landscape Conservation Area) could be considered for the whole karts region. In such a type of protected area, the local population could play a more active role, not only limited to an executive role but also comprising a decisive role in the establishment and management of the protected area.

As at the moment it has been decided that the area will become a nature reserve, the only choice parameters that are left are the boundaries and the type of management. LLINC has offered already its assistance in delineating the boundaries and drafting the rules and regulations of the nature reserve based on its former research on divergence and convergence of perceptions and expectations.

Relating to the further research activities of the LLINC project, LLINC will continue its process-based research. Inspired by the recent criticisms concerning the quality of the participatory approaches (Lavigne *et al.*, 2001; Cooke and Kothari, 2001), which were mainly based on post-evaluations once the conservation area was established or the development project was finished, LLINC will continue to put forward the participation and negotiation process itself as the central object of study, based on the belief that participation is more a process than an outcome.

Future research could include among others, a stakeholder analysis (identification and classification in relation to role and legitimacy, (Himmelman, 1996), classification in relation to power and interest (Eden, 1996) and stakeholder influence mapping (Fin, 1996). The analysis could also focus on the ideas that the different stakeholders have about negotiation and participation following the scales of Huxham (1996). There might be an evolution in their ideas?

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INFERRING THE HYDROGEOCHEMICAL FUNCTIONING OF KARST AQUIFERS BY SEPARATING THE DISTRIBUTION OF ELECTRICAL CONDUCTIVITY CURVES AT KARSTIC SPRINGS

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Keywords: karst, electrical conductivity, DFC separation, hydrogeochemical functioning.

The study presented deals with the analysis of the hydrogeochemical functioning (e.g., structure and transport properties) of karstic aquifers based on the method of the distributions of electric conductivity frequency (DCF). This method, developed by Bakalowicz (1979) and utilized by several authors (Plagnes, 1997; Maqsoud, 1996) is here refined so as to separate the various types of water appearing at a karstic spring. In its initial form, the DCF already allowed a qualitative insight of the hydrogeochemical functioning of karstic aquifers. The decomposition of DCF curves developed here allows a more quantitative approach since water types can be separated from the global distribution curve since the hydrogeochemical signature of the various compartments of a karstic hydrosystem can be identified (infiltrating zone, conduit-flow system, annex-to-drain systems). These hydrogeochemical signatures can be then compared:

1. in terms of percentage of contribution to the global DFC curve area;
2. in terms of spreading (coefficient of variation or standard deviation) which provides new features for the interpretation of the global functioning of the system.

The new parameters extracted from the decomposition can be also used for the comparison of systems within the framework of multivariate analyses, for example.

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MIOCENE SYNRIFT PALEOKARST AND ASSOCIATED SULPHUR DEPOSIT AND THEIR EMPHASIS ON OIL EXPLORATION, GEMSA AREA, RED SEA, EGYPT

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Keywords: sedimentology, paleosol, economic geology.

Two paleokarst profiles developed within the Miocene sediments of Gemsa area, Red Sea, Egypt. These two-karst systems are separated by erosion surface. The lower is Endo-paleokarst of Upper Miocene, developed mainly in the Miocene gypsum, anhydrite and carbonate of Gemsa Formation, Red Sea. The upper superficial paleokarst is subsequently developed on the overlying carbonate rocks. The erosional contact between the recognized paleokarst surfaces is dominated by rhizocretional horizon consists of argillaceous debris and residual organic materials accumulated pedogenetically on the surface and converted onto kaolinite.

The lower paleokarst is resulted from ascending hot spring water that accommodated the fracture system prevailing during synrift activity of the Red Sea, and may be associated with the processes of oil migration during release of the associated water under relatively phreatic conditions. The upper superficial karst profile is related mainly to a humid paleoclimate of the Quaternary age.

Hydrogeologic and geologic data show that abundant cavities detected in the vicinity of sulfur deposits can be formed by thermal karstification, which is one of the most important processes controlling the formation and redistribution of the sulfur deposits in Gemsa area. The infrequent presence of silicification is a rather good indication for thermal karstification.

A new karst model for the formation of sulfur deposits is suggested. It agrees with the hydrogeological features of the Miocene sequence and its tectonic instability and the numerous intervening unconformity surfaces with the biogeochemical mechanisms of sulfur origin in moderate temperature diagenetic environments. The occasional presence of sulphur and associated nodules of secondary nodules of carbonate is rather good indication for biogenic alteration by migrated oil water. The concluded model could be used as case study for oil prospect ion in similar areas in the world.

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THE JEITA CAVE RESOURCE DEVELOPMENT – LEBANON: IMPACTS AND ASSESSMENT

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Keywords: tourism, groundwater, speleology, karst.

The Jeita Cave is the most famous cave of Lebanon and probably of the Middle-East. It consists of some 9 kilometers of surveyed - more or less lateral - underground passages, hosting an underground river with an average discharge rate of 2.3m^3/s. First discovered and documented in 1836, this cave has played an important role in impacting not only the community of inhabitants living in its close vicinity, but almost the whole population of Lebanon. This contribution aims to shed some lights on the development of the Jeita karstic resources – including drinking water and show-cave – in the past century and its impact on the Lebanese society.

Near the end of the 19th century, the Jeita springs, which are the outlets of the cave underground river and a hydrogeological drain of the huge Jurassic aquifer of Mount Lebanon, attracted scientists and engineers, who managed by the beginning of the 20th century to convey the Jeita cave waters to the city of Beirut – capital of Lebanon. Today, the Jeita waters feed about a million inhabitants. Since the late 1950s, a part of this cave was transformed into a show-cave. The Lower Gallery (i.e. the Thompson Cavern and the Dark Lake) was opened to the public by the end of 1957. One year later, the Upper Gallery was discovered through a heroic climb of more than 60 m, performed by pioneering Lebanese cavers who owe the establishment of organized speleological activities to the early exploration of the Jeita caverns. In January 1969, the Upper Gallery was opened to the public. Subsequently, the Jeita Cave became the real attraction of the Lebanese tourism and a national symbol (e.g. post-stamps and money tickets featuring scenes of the cave and its river were issued). Following the beginning of the 1970s, the Lebanese strife started, and the show-cave project was sadly aborted. Both tunnels leading to the Lower and Upper Galleries were used to store munitions, the outside buildings for military purposes, and the cave interior for torture. In 1995, almost 5 years after the cease of the Lebanese war, the show cave with its two galleries was re-opened to the public. The Lower Gallery is visited by means of boats running on rechargeable electrical power for a distance of 400m. The Upper Gallery lies more than 60 m right above this lake with an average distance of 800m. Since its re-opening, the show-cave receives around 280,000 visitors per year (according to the statistics of the managing company). It provides around 50 full-time job positions, mainly occupied by residents of the surrounding localities.

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INTEGRATING ENVIRONMENTAL EDUCATION INTO KARST MANAGEMENT IN VIETNAM

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Environmental education is considered an integral tool in the management of the natural environment. International environmental conventions and meetings regularly call for increased education to reduce the degradation of environments and promote more sustainable management. There are significant karst environments in Vietnam and as the field of karst management grows it is important to look at the way environmental education is being integrated into karst management.

This paper gives a short background to the history and applications of environmental education on a global scale, highlighting a timeline of the development of the concept. Although no clear definition has universal acceptance, much of the Tbilisi declaration highlights concepts that can be seen as guiding principles, such as the categories for environmental education: awareness, knowledge, skills, attitudes and participation. The role, use and need for integrating environmental education into karst management is then specifically discussed.

A general overview on the ways in which environmental education is being integrated into karst management in Vietnam is highlighted with a focus on the coastal karst of Halong Bay and mountain karst of Cuc Phuong Pu Luong, where most materials have been developed. The paper is also supported by a display of karst education materials that show the practical integration of environmental education into karst management in Vietnam. These materials show how environmental education materials are focused on audiences and themes, and includes specific audience focuses of: tourists, schools and policy makers.

There are typically limited resources available for the development of environmental materials for natural resource management. To date this can also be seen in Vietnam, however as the field of karst management is still quite small on a global scale many of the practitioners know each. As such there is the opportunity to overcome this limiting factor by strategic sharing of more generic karst education materials.

The paper concludes by looking at recommendations for and potential ways in which environmental education can be better integrated into karst management in Vietnam. Some of the recommendations include: links to cultural heritage – for example at Cat Ba there are stories of the ‘Green Pyramids’ at Halong there is the story of the ‘Descending Dragon’; poster and educational materials to highlight geology and biodiversity of karst areas; the potential for a documentary on karst areas of Vietnam; guide training to expand caves education from existing cultural emphasis to include more geological and biological information; and generally increasing levels of knowledge within karst areas will help to develop better management.

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THE HYDROCHEMICAL CHARACTERISTICS OF THE SHALLOW CHALK KARST AQUIFER IN FARAFRA OASIS, WESTERN DESERT, EGYPT

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The Groundwater resources for the Farafra Oasis are developed from two main aquifers, one is the deep sandstone aquifer while the other is the shallow chalk karst aquifer, the latter is the most important as it conveys water to the numerous springs scattered in the floor of the oasis. The flow of water is controlled by the prevailing joint systems which also control the location of springs. The hydrochemical characteristics of the shallow aquifer is affected by the lower deep aquifer as it recharge it by leakage through fractures(it is the only source of recharge in this arid region), also the presence of playa deposits around some spring has a great rule in redistribution of cations and anions in water. The water quality of the chalk karst aquifer is high and suitable for irrigation and drinking, and the area away from any sources of intense pollution.

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CONTRIBUTION TO THE KARST HYDROGEOLOGY OF SON LA, VIETNAM BY ARTIFICIAL TRACER EXPERIMENTS

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Abstract. This paper reports on the first tracer tests that were ever carried out in the karstic northwest of Vietnam and performed within the framework of the Vietnamese-Belgian Karst Project. Common salt, fluorescent dyes uranine (fluorescein) and sulforhodamine B were used as tracers. The experimental results have proven the existence of flow paths between injection points and springs in Suoi Muoi and Nam La catchments. Tracer recovery rates are determined and vary from 29 to 96%; the estimated flow velocities vary from 72 to 288 m/h.

Keywords: tracer test, breakthrough curves, Vietnam.

1 Introduction

A tracer experiment is a powerful tool that has many applications in hydrological investigations. Quantitative tracing tests are the most useful types of field methods that can be applied in the investigation of a karst aquifer. The technique is often used to determine recharge areas, general direction of groundwater flow, and groundwater travel times in karst aquifers (Atkinson, 1973; Käss, 1998). Tracer tests have also been applied to assess the vulnerability and determination of wellhead protection zones in karst area (Meus *et al*., 1999; Goldscheider, 2002).

Since early 2000, the Vietnamese-Belgian Karst Project has carried out quantitative tracing tests in the Suoi Muoi and Nam La karst area, NW-Vietnam. These are the first tracer tests performed in this area. The purpose of the research is to map underground conduit systems and to characterize the dynamics of underground water transport. Additionally, the research evaluates and adapts the tracer techniques for application under the local conditions. This paper describes quantitative tracing experiments and determines the tracer recovery rate, hydraulic properties and direction of underground flow paths in this karst area.

2 Study area

The study area is situated in northwest Vietnam in the Son La province, between eastern longitudes 103°35’5’’ and 103°51’33’’ and northern latitudes 21°20’03’’ and 21°33’53’’. It has an altitude between 600 and 1700m. The area has tropical monsoon climate, characterized by two seasons: a hot and rainy summer and a colder and dry winter. The mean annual temperature is 21°C. The mean annual rainfall attains 1413 mm but precipitation is unevenly distributed over the year (Nguyet, 2000).

Two regional faults systems in NW-SE direction, the Da River Fault and Son La Fault, run through the area. The area is built up of carbonate and non-carbonate rocks of different formations (Tuyet, 1998). In the southwest part the non-carbonate rocks consist of quartzite/sericite schists, siltstone and sandstone intercalated with thin-bedded limestone. Thin-bedded siltstone, shales and medium-thick bedded conglomerate, sandstones and conglomerates outcrop in the northeastern part. The carbonate rock, mainly limestone, outcrops in the centre of the test site (Fig 1).

The test site has two main river systems namely Suoi Muoi and Nam La River. In the Suoi Muoi River at an altitude of 646m one of the main tributary sinks in the Ban Lay cave. The Suoi Muoi River end in a blind valley, the Dong Giao limestone formation outcrops here and is cut by the river. Under low water level conditions, the river sinks in the several shallow holes (Tham Han cave) at an altitude of 312m. But under high water conditions the capacity of the shallow holes is insufficient

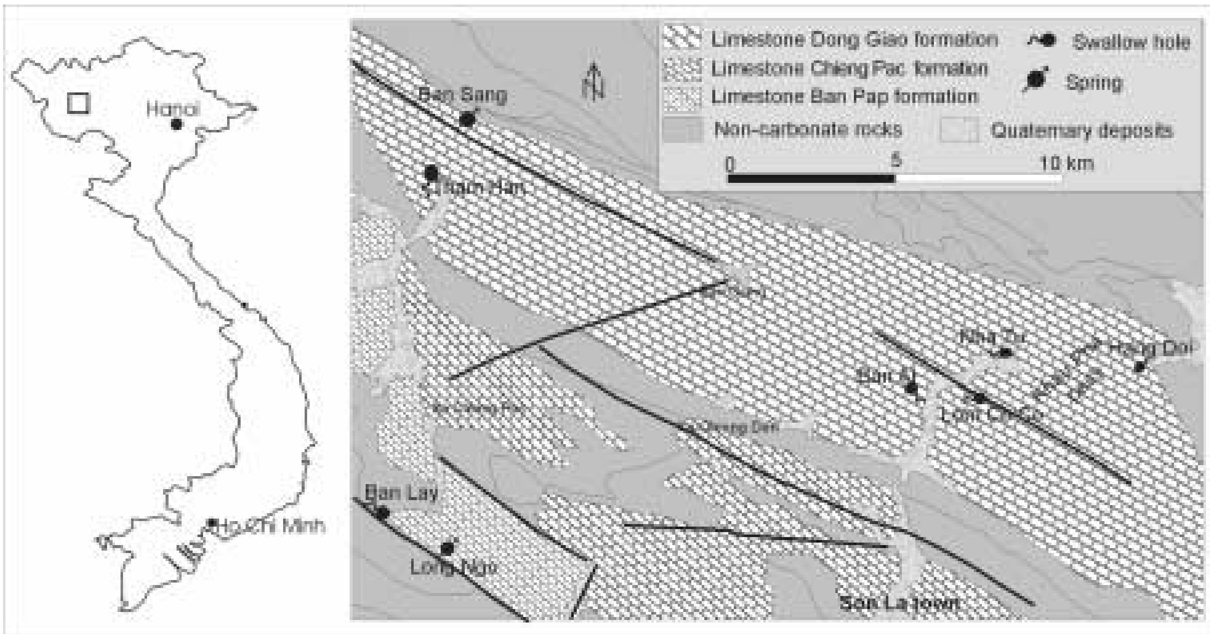

Fig. 1: Location, geology and hydrology of the test site

and the valley completely floods. The Long Ngo spring is located in the limestone of Ban Pap formation about 1.5 km of Ban Lay cave. The Ban Sang spring is situated in the Dong Giao limestone formation at the contact with the non-limestone, about 2 km from the Chieng Ngam village.

The second river system, the Nam La River, has several tributaries coming from the south. This river runs through Son La town towards the Khau Pha pass. The Dong Giao limestone formation outcrops in lowest part of valley. Here the entire river is swallowed in several caverns called Ban Ai, Lom Co Co and Nha Tu. The Hang Doi spring is located about 5 km at the other side of the Khau Pha pass in eastern direction.

3 Tracer experiments

Four tracer tests have been carried out in the

Table 1: Summary of tracer experiments in Suoi Muoi and Nam La karst springs in Son La province, Vietnam

Experiment	Date injection	Injection site	Altitude (m)	Amount of tracer(kg)	Sampling site	Altitude (m)	Linear distance (m)	Discharge (m3/s)
Suoi Muoi (VT1)								
Uranine	22-Feb-00	Two active shallow holes/	546	4.6	Ban Sang spring	312	1950	4.11
Salt		Tham Han cave		200			1900	
Bon Phang (VT2)								
Uranine	04-Oct-00	Ban Lay cave	826	1.4	Long Ngo	646	1500	0.24
Salt				200	spring		1500	
Nam La (VT3)								
Uranine	07-Oct-01	Nha tu cave	566	1.485	Hang Doi	136	4000	6.28
Sulforhodamine B		Ban Ai cave	576	2.1	spring		5500	
Nam La (VT4)								
Uranine	19-Feb-03	Ban Ai cave	576	1.95	Hang Doi	136	5500	not
Sulforhodamine B		Lom Co Co	540	3.639	spring		5000	measuared

Suoi Muoi and Nam La catchment between 2000 and 2003. Table 1 summarizes the experiments.

4 Results and discussion

4.1 Underground flow paths, tracer breakthrough curves and recovery rates

The first experiment has proven the connection between the swallow holes, Tham Han cave, and Ban Sang spring. The connection between the Ban Lay cave and Long Ngo spring is determined in the second experiment. The last tracer test has proven the existence of connection between Nha Tu, Bon Bay swallow holes and Hang Doi spring. Only the experiment in Ban Ai cave has a negative result (Fig.3). The results show that the tracer breakthrough curves are very distinctive for the different tracers (Fig 2). The shape of the curve depends on the character of the tracer, prevailing flow conditions and structure of the karst aquifer.

The obtained tracer recovery rates vary from 29 to 96%. It is clear that all the tests have significant loss of tracer. There are several possible explanations for apparent loss of tracer as well as the major difference in recovery rates between the experiments. It seems obvious that the losses are due to the presence of some, unmonitored spring(s) in the system since the tracer tests were monitored at only one expected outlet. Other possible reasons are: (1) the missing tracer mass is due to too crude estimation of the injected mass; (2) the missing tracer mass was adsorbed by some substances within the system. Naturally, one or more of the causes can prevail at the same time.

Salt and especially dye tracer are affected

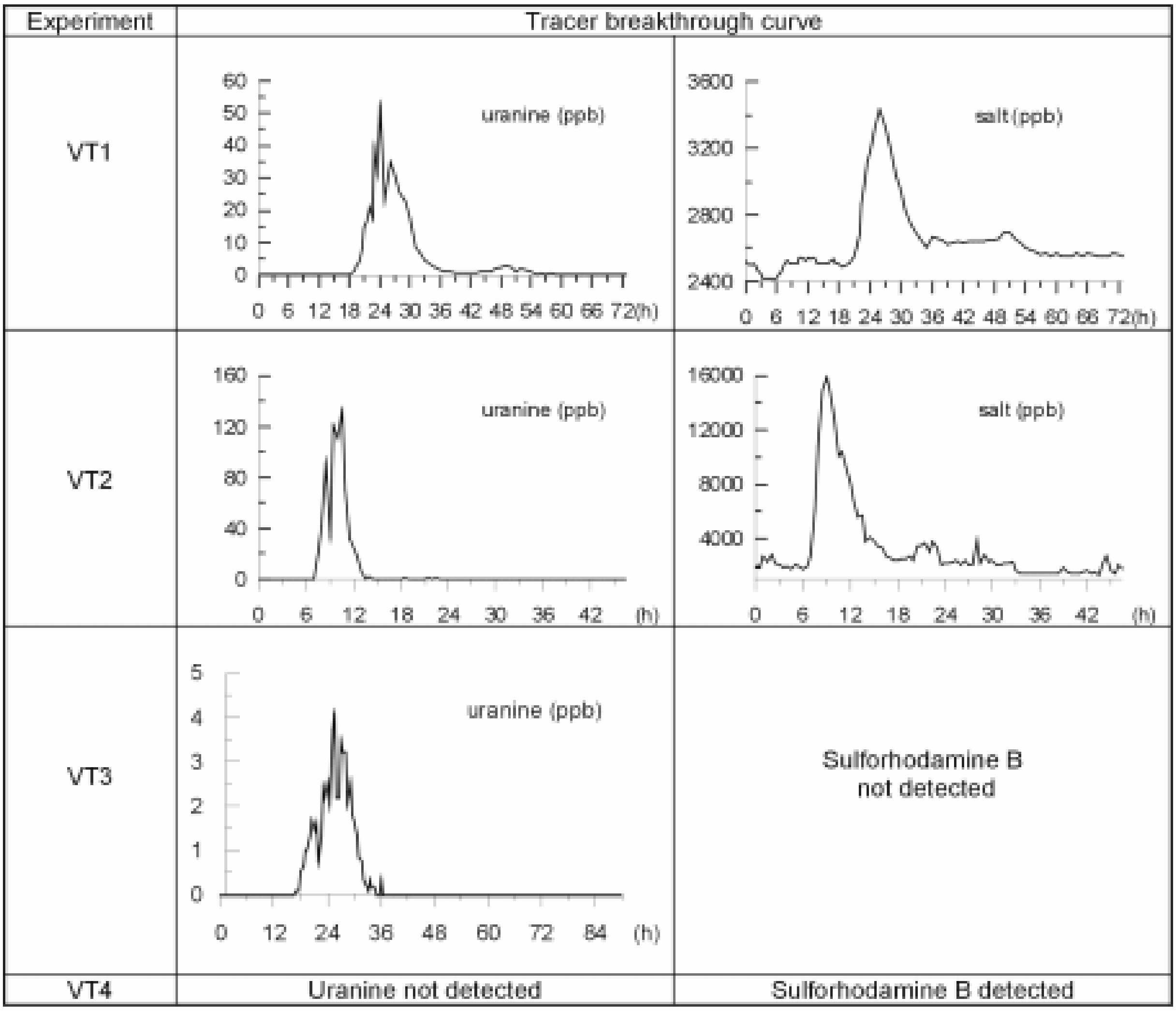

Fig.2: Tracer breakthrough curves in Suoi Muoi, Nam La catchment, NW Vietnam

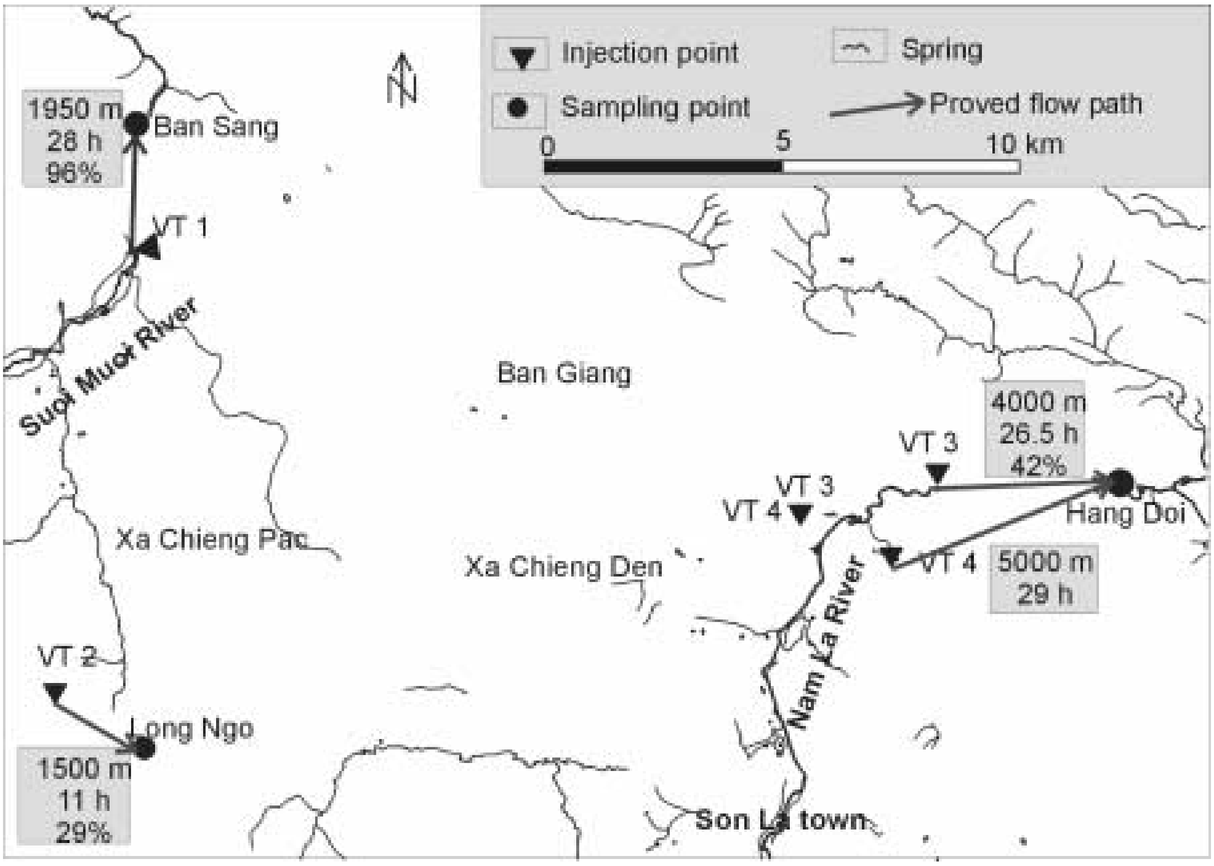

Fig.3: Tracer location and proved groundwater flow paths

by some substances within the system that causes losses in tracer mass. Such losses are due to either adsorption of dye on suspended sediment, karst conduits wall, or suspended organic matter in the system or to the diffusion or flow of some of the tracer from the cave passages into water-filled voids in the surrounding bedrock (Atkinson, 1973). Alternately, cations of salt are subjected to loss due to ion exchange, anions are also subject to a marked sorption in aquifers with organic material (Käss, 1998). Using tracer in a tropical karst region like Son La could strongly be affected by the above causes and the recovered tracer mass would be always lower than the injected mass.

4.2 Hydraulic properties

The estimated groundwater velocities vary from 72 to 288 m/h. Those velocities are rapid even for karst groundwater flow and indicate a low resistance flow path. The Peclet number change from 49 to 832. It indicates that in the Son La karst conduits an advective controlled mass transport prevails.

Suoi Muoi River: The analysis of the tracer-breakthrough curve indicates the existence of two conduits in this area: a main and a tributary karst conduit. Low flow velocities and long longitudinal dispersivities determine the existence of a reservoir in the tributary karst conduit.

Bon Phang: The mean tracer velocity and short-lived breakthrough curve suggest a single karst conduit without major bifurcation in the area. The dye tracer-breakthrough curve has multiple peaks, this could be explained by water flows from the Ban Lay cave passage into the surrounding fractures before it flows back to the karst conduit.

Nam La River: Long longitudinal dispersivity and multiple peaks of the tracer breakthrough curve indicate the existence of storage in the karst conduit. The multiple peaks on a breakthrough curve may indicate intermittent flushing of dye from a hydraulic dead zone.

5 Conclusion

The tracer-breakthrough curves proved the existence of a connection between shallow holes and expected outlets in Suoi Muoi, Bon Phang and Nam La River. The analysis of the recovery rate and tracer-breakthrough curves suggested that there exist two karst conduits in Suoi Muoi River and a single karst conduit in Bon Phang and Nam La case. The information has contributed to drawing a map of groundwater flow systems for the Son La area. The experiments also show that both salt and dye tracers can be successfully applied in this type of area. The results of these tests have contributed to a better understanding of the karst hydrogeology in the Son La area. This technique is one of the quantitative methods that are particularly useful in characterizing karst aquifers in Vietnam.

6 Acknowledgments

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ADAPTATION AND APPLICATION OF THE PAN-EUROPEAN APPROACH TO GROUNDWATER VULNERABILITY MAPPING TO THE SON LA KARST AREA, VIETNAM

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Abstract. A groundwater vulnerability map was prepared for the Son La karst area, Vietnam, using an approach developed by the European COST action 620 on 'vulnerability and risk mapping for the protection of carbonate (karst) areas'. It was necessary to adapt this approach to the local hydrogeological, climatic and economic conditions. The modified (simplified) method is proposed for vulnerability mapping in other Vietnamese karst areas.

Keywords: vulnerability, groundwater, Vietnam.

1 Introduction

In Vietnam, there are a variety of tropical karst landscapes, which cover almost 20 % of the land surface. The karst area in NW Vietnam is 8190 km^2 large and holds important groundwater resources that are crucial for the economic development of the region (Tuyet, 1998).

Karst aquifers are particularly vulnerable to contamination. Due to thin soils and swallow holes, contaminants can easily reach the aquifer, where they are transported rapidly over large distances. Karst groundwater thus needs special protection. However, it is not practical to demand maximum protection for large areas, as the resulting land-use restrictions would not be acceptable. Groundwater vulnerability maps may help to find a balance between groundwater protection and socio-economic aspects.

The European COST Action 620 proposed an approach to vulnerability and risk mapping for the protection of karst aquifers (Zwahlen, 2004). This approach was developed by European scientists having in mind the hydrogeological conditions and data availability in their countries. In order to apply this approach to Vietnamese karst areas, it was necessary to adapt it to the local conditions. This paper outlines the conceptual framework of groundwater vulnerability mapping, and describes how it was adapted and applied to the Son La karst area.

2 The Son La karst area

The test site is the catchment of the Tham Ta Toong spring, which contributes 50 % to the drinking water supply of Son La town, NW Vietnam (Fig.1). The area is 68 km^2 large and 600 to 1700 m high. Karst landforms comprise chains of peak-clusters, dolines, dry valleys and caves. The mean annual precipitation is 1413 mm, with a rainy season in summer, and the mean air temperature is 21 °C (Nguyet, 2000). Late Precambrian to Triassic rocks outcrop in the area, including three limestone formations (Dong Giao, Ban Pap, Chieng Pac), claystone, sandstone, basalt and tuff (Tuyet, 1998). Quaternary deposits cover the valleys.

The limestones are covered by shallow soils and drain underground, while surface flow frequently occurs on non-karst formations. Surface streams often sink underground via swallow holes and caves, some of which were explored within the framework of the Vietnamese-Belgian Karst Project (Dusar *et al.*, 1994). Speleological data suggest connection between the swallow holes and the spring, which has not yet been proved by means of tracer tests.

3 Groundwater vulnerability mapping

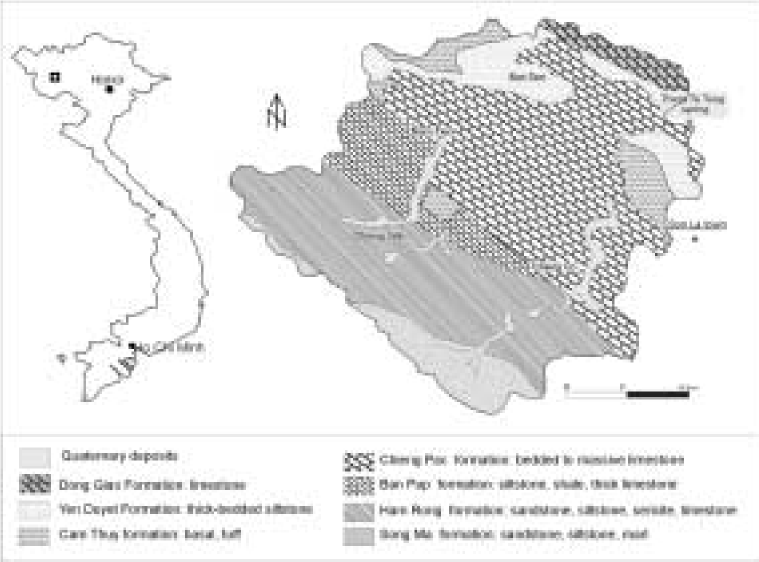

Fig. 1: Location (black rectangle), geology and hydrology of the Son La test site.

3.1 The pan-European approach (COST 620)

The terms ‘vulnerability of groundwater to contamination’ and ‘natural protection against contamination’ can be used alternatively (low protection = high vulnerability). Intrinsic vulnerability takes into account the hydrogeological characteristics of an area, but is independent of the nature of the contaminants; specific vulnerability additionally considers contaminant properties. There are two general approaches to groundwater protection: Resource and source protection. Vulnerability assessment is based on an origin-pathway-target model. The origin is the location of potential contaminant release. The pathway includes the passage from the origin to the target. Resource vulnerability maps take the groundwater surface as the target, and the pathway consists of the passage through the unsaturated zone. For source vulnerability mapping, the well or spring is the target. Two main aspects are to be considered when assessing vulnerability: travel time and attenuation. The pan-European approach to intrinsic vulnerability mapping uses four factors that influence travel time and attenuation: overlying layers (O), flow concentration (C), karst network development (K), and precipitation regime (P) (Fig. 2) (Goldscheider and Popescu, 2004).

The overlying layers consist of four types of layers: topsoil, subsoil, non-karst rock, and unsaturated karst rock. These layers provide some degree of natural protection, dependent on their thickness and properties. Concentration of flow in the catchment of sinking streams may bypass the overlying layers. Groundwater resource vulnerability maps can be created by a combination of the O and C factor. The P factor is relevant when comparing different climatic zones, and the K factor applies for source vulnerability mapping.

3.2 Local adaptation of the method

The modified method of intrinsic resource vulnerability mapping uses two factors: overlying layers (O) and flow concentration (C) (Fig. 3). The assessment scheme for the O factor is simple: A low protective function is

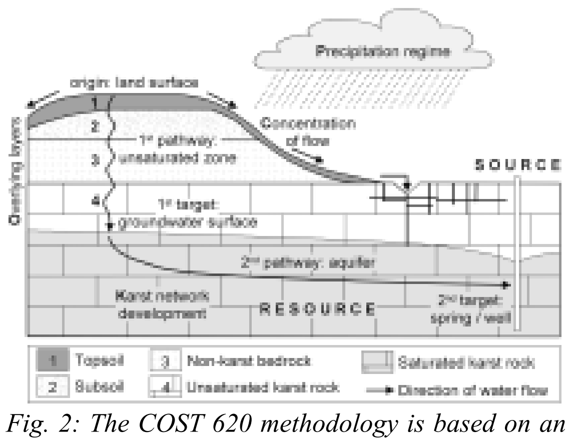

*Fig. 2: The COST 620 methodology is based on an origin-pathway-target model. For resource protection, the groundwater surface is the target. Vulnerability assessment uses up to four factors: **P**recipitation regime, **O**verlying layers, **C**oncentration of flow, **K**arst network development (Goldscheider and Popescu, 2004).*

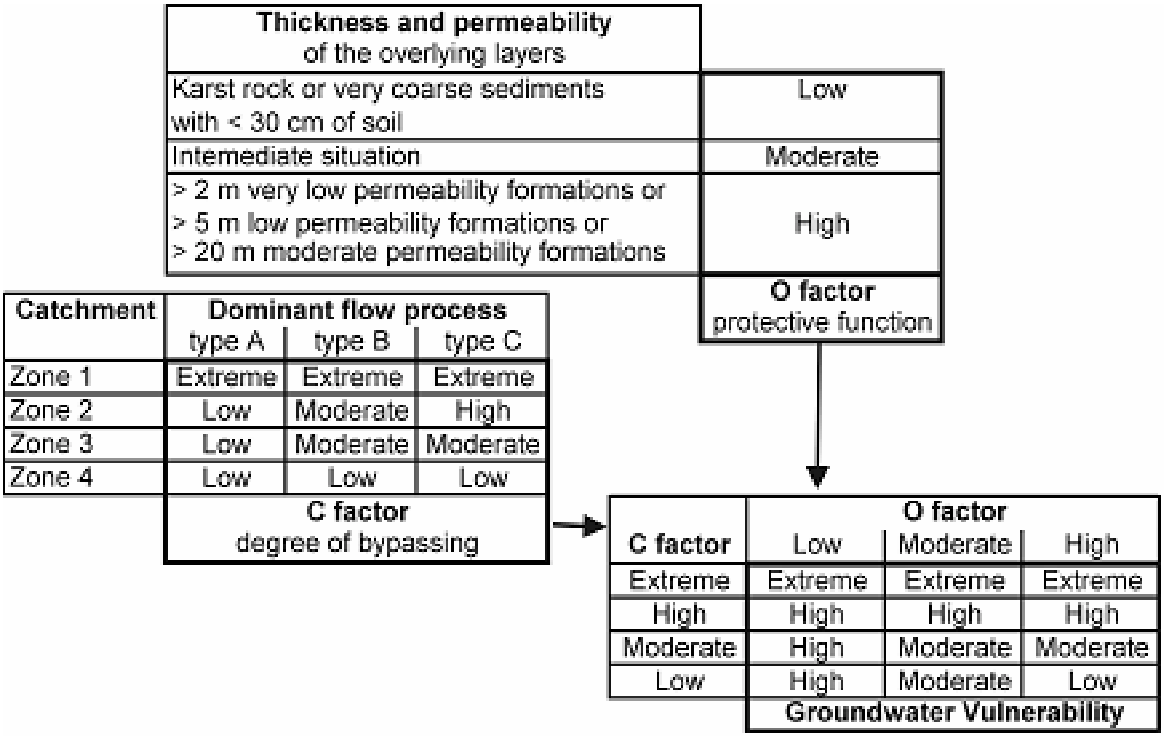

Fig. 3: Proposed simple method of groundwater resource vulnerability mapping for Vietnamese karst areas.

assigned to karst rock covered by less than 30 cm of soil. Sufficiently thick layers of limited permeability provide high natural protection. Moderate protection is assigned to intermediate situations, e.g. 1 m of soil overlying karst.

The C factor expresses the degree to which the overlying layers are bypassed by flow concentration in the catchments of swallow holes. The first step is to determine the dominant flow process (after Goldscheider, 2002):

- Type A: Direct infiltration and percolation takes place on high permeability formations.
- Type B: Intermediate situations.
- Type C: Frequent surface runoff takes place on low permeability formations.

The second step is to determine if this type of flow occurs within the surface catchment of a sinking stream. Four zones can be distinguished (after Goldscheider, 2002):

- Zone 1: Swallow hole, surface stream up to 1 km upstream from the swallow hole, 20 m buffer zones on both sides of the stream.
- Zone 2: The rest of the catchment areas of the sinking stream.
- Zone 3: Areas outside the catchment of sinking streams but inside the karst catchment.
- Zone 4: Areas that drain laterally out of the karst catchment.

The C map is obtained by combining the dominant flow type and the surface catchment map. Combining the O and C maps then allows creating the vulnerability map. Four vulnerability classes are symbolised by colours from red (extreme vulnerability) to blue (low vulnerability).

3.3 Application to the test site

The O factor was determined on the basis of the geological map and field observations, directly using the table in Fig. 3. The C factor was assessed in two steps. First, the dominant flow process was determined using the geological map and field observations. Direct infiltration (A) takes place on limestone formations with shallow soils; frequent surface flow (C) occurs on Quaternary deposits and clayey formations; an intermediate situation (B) was assigned to all other settings. The swallow holes were mapped during fieldwork; their catchments were delineated based on a topographic map.

Overlaying the O and C map then created the vulnerability map (Fig. 4). Only three classes of vulnerability are present in the test site: extreme, high and moderate. Extreme vulnerability is restricted to small zones near sinking streams. High vulnerability is present both on karst limestone (low protection of the

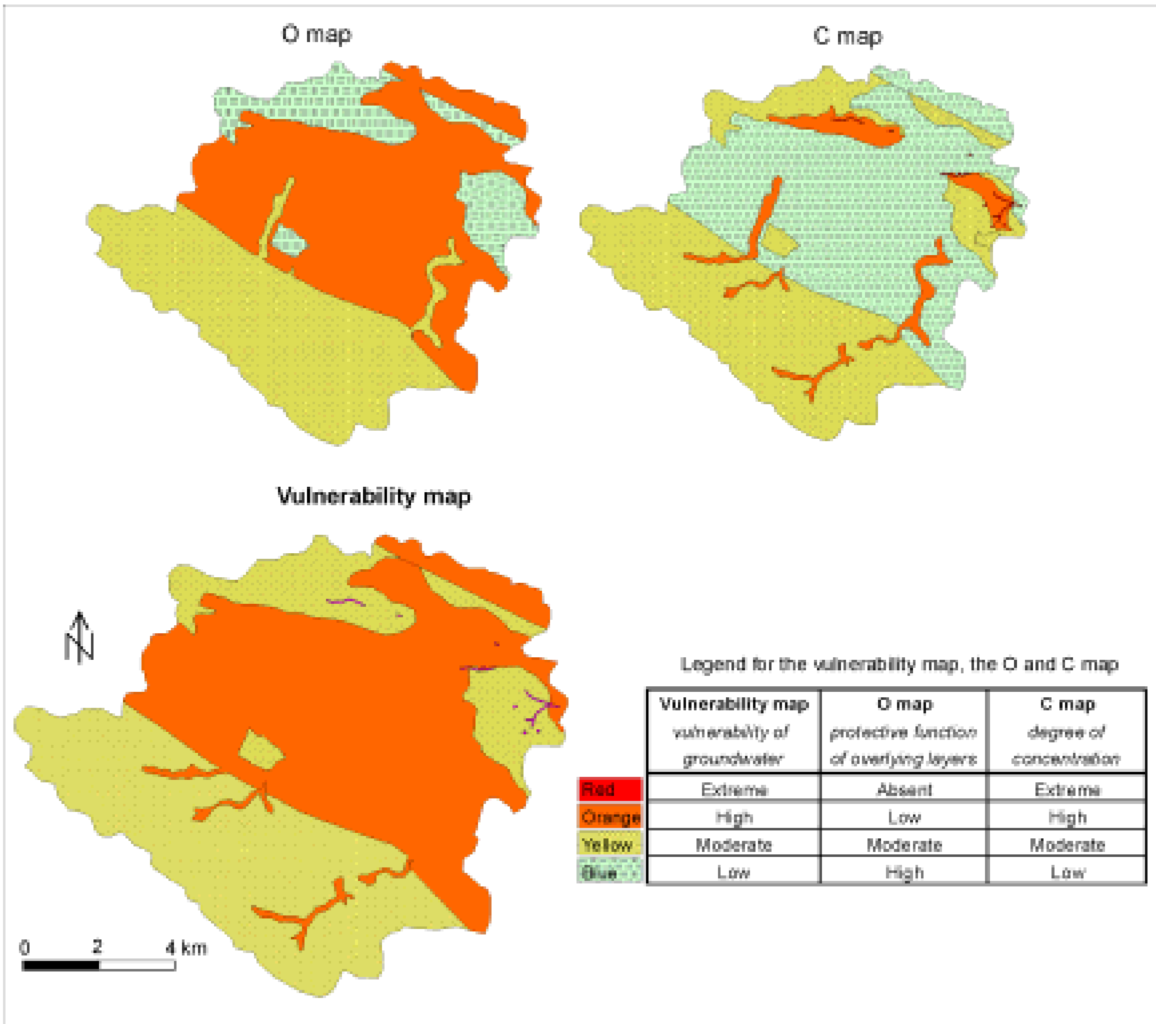

Fig. 4: O map, C map and vulnerability map of the Son La karst area, and legend for the three maps.

overlying layers) and on Quaternary deposit (surface flow near sinking streams). The rest of the area was classified as moderately vulnerability. These results are reasonable in terms of karst hydrogeology, and at the same time applicable, as strict land use restrictions will only be required on relatively small zones.

4 Acknowledgement

We thank the Vietnamese-Belgian Karst Project for supporting geological data and the fieldtrip.

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WOMEN PARTICIPATION TOWARDS ECOTOURISM INDUSTRY IN KARST REGIONS. A CASE STUDY AT GUNUNGKIDUL REGION (INDONESIA)

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Karst represents a unique topology of nature. It creates beautiful scenes of nature such as caves, notched beaches, cones and towers, which possess high tourist potential. In every province of Indonesia, karst occurs with appeal to tourists, particularly at places such as Gunungkidul.

There is a high degree of participation of women in the development of tourism in karst regions. Their participation is based on providing services to tourists visiting the region, by selling food, souvenir, or handycraft, being tour guide etc. These activities are aimed at supporting family income, since they can not depend on land farming. Some characteristics of karst region such as temporary shortage of water supply and unfertilized soil do not make them suitable for dryland farming. The tourist industry may give them opportunities to increase their quality of live by having other income. However, there are also shortcomings as many of local women involved in the karst tourist industry are not well educated or trained. So they do not have the ability to manage and conserve karst features of whole regions. In contrast, the issue of ecotourism has been coerced onto the tourism industry to create a more environmentally responsible tourism. This not only the responsibility of stakeholder but rather for all involving people including women.

The paper discusses on how women participation should be maintained in order to develop the ecotourism industry, especially related to the region's autonomy. The paper will also conclude how to optimize women participation in managing and conserving karst regions by developing an environmentally responsible tourist industry.

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ASSESSING THE CONSERVATION REQUIREMENTS OF KARST DEPENDENT BAT FAUNAS THROUGH FAECAL ANALYSIS

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The global decline in bat abundance has been primarily attributed to habitat loss and roost destruction. Karst dependent bats have permanent roost sites in limestone caves in Myanmar and data on their dietary requirements is important to implement future conservation measures. Faecal analysis is of significant benefit for providing conservation guidelines for future management given the problems of direct observation of prey capture and habitat use in bats. Furthermore it contributes significantly to our understanding of how resources are transferred between the terrestrial and subterranean ecosystems. This study describes the diet of cave roosting bats in Myanmar assessed by faecal analysis and provides suggestions future conservation management.

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DIFFERENCES IN ASSESSMENT OF THE SLOPING LAND IN THE LIMESTONE MOUNTAINS IN NGOC SON-NGO LUONG AREA (NORTHWESTERN VIETNAM) AND THEIR INFLUENCE ON THE ESTABLISHMENT OF A NATURAL RESERVE.

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Abstract. Against the background of a Project to establish the Ngoc Son-Ngo Luong Natural Reserve (NS-NL, Northwestern Vietnam), the use of sloping land for farming in the area is assessed differently according to the different awareness of related parties. The research assumes that there is a basic conflict between the tradition of agricultural cultivation of the sloping land of the local people and the rangers' view to limit the agricultural production within certain areas. This conflict reflects the dilemma between local development and forest protection.

1 Introduction

The assessment of the impacts of terrace field cultivation[1] on forest ecology has always been problematic to the residents of the tropical forest (Bahuchet, 1993: 19, Bahuchet *et al.* 2000: 79). In the Ngoc Son-Ngo Luong area (hereafter NS-NL), the unfavourable geological conditions for wet rice cultivation and the advantages of forest land have resulted in the local people focusing on terrace field cultivation. The existence of a large area of planted forest (FIPI, 2003:11, 12, 16) shows the importance of agricultural activities in the area in the past (LLINC, 2004:28). However, as often blamed as the main cause of forest degradation, terrace field cultivation has been considered as an activity that should be banned.

In the background of a project to establish the NS-NL natural reserve (proposed in 2003), discussions on the use of agricultural land in the future natural reserve seem to have the agreement of related parties, as the project will only mark the limestone mountain areas as restricted area, while agricultural land will be marked as ecological rehabilitation area and each family will be given a larger lot of agricultural land than currently. (FIPI, 2003:22) However, an in-depth study on the use of local agricultural land and observation of the discussions between related parties do not confirm this. On the contrary, the ambiguity in statistics of the terrace field cultivation land in existing data and the observation of the use of agricultural land of households in the project area lead us to the thesis that there still are important differences in related parties' perceptions and assessments. Our research question is: what are the differences in the related parties' assessment of the use of sloping land for terrace field cultivation? Is there a gap in their awareness? And why?

The aim of this article is to show the diversity of awareness (or perspective) relating to the use of sloping land in terrace field cultivation without aiming to criticize or appreciate these points of view. We will limit ourselves to the findings relating to the classification of agricultural land by various local functional agencies in contrast to the perspective of the local population. It consists in the analysis and comparison of the existing local classification system of agricultural land. The data used in the article were gathered during various field trips in which open and semi-structured interviews were conducted with all parties involved.

[1] This term refers to different types of agricultural cultivation using cutting (not digging the roots), then let dry and burn the plants on a plot of tropical forest to cultivate on the ashes (Bahuchet, S. 1997: 18). For Condominas, this term is replaced by the term "*essartage*" with a similar meaning as the word "*swidden*", which includes all the characteristics of this type of agricultural cultivation. (Condominas,G .1997: 231).

2 Ngoc Son-Ngo Luong, the dilemma of conservation and development

The co-existence of steep, out of access limestone mountains which are favourable to the development of forest ecology, and non-limestone land strips that can be used for the cultivation of wet agricultural fields has led to great challenge in conservation and development in the NS-NL mountain area (RIGMR, FIPI, 2004).120 kilometers away from Hanoi, the NS-NL reserve is in the southwest of Hoa Binh province, in Northwestern Vietnam. It is an area of high mountains, including Ngoc Son commune (Tan Lac district) and Ngo Luong commune (Lac Son district). The total acreage of the area is estimated to be 19,000 km^2.

Local residents are mostly from Muong ethnic group. The traditional social structure of the group, in general, is based on family and clan rules, in which the roles of the clan leader and patriarchal head of the family are respected (Cuisinier, 1948). Forest land belongs to the community and the use of forest land belongs to the families that exploit and cultivate that land (Cusinier, 1948). On the contrary, wet rice fields belong to the hamlets, but have long ago been allocated for families to cultivate (Nguyen Tu Chi, 1998).In the mountain valleys, where there are fertile and bigger wet rice fields, household economy is mainly based on rice cultivation. However, terrace field cultivation, hunting and husbandry are supplementary, but vital resources (Nguyen Tu Chi, 1998, Nguyen Ngoc Thanh, 1988)

At our field visit site, agricultural land accounts for 3% to 15%, of which only 15-30% are for wet fields (LLINC: 24). In addition, for many years now, the shortage of water for cultivation has brought the local economy into difficulty. Food security for local people is still a problem that needs to be solved (2003 report of NL People's Committee). The topographical conditions have created difficulties for the development of non-agricultural economy. In general autarkic, subsistence economy still plays a major role. Against the background of the project to establish the NS-NL natural reserve, local officials and people are facing a dilemma of development and conservation (LLINC, 2004)

3 Land management and the diversity of perspectives on the use of agricultural sloping land

Local agricultural land management is under the management system of different government levels and under the professional influence of two sectors: Land Administration (managing land) and Forestry (managing forest and forest land). The cooperation between these functional agencies and the government is mechanic, as under the administrative point of view, those functional agencies are considered part of the government. In addition to the People's Committee as an executive body, the Party organization is in charge of taking decisions, of the organization and inspection of the implementation of local policies. To help the people implement the policies, there are various mass organizations and People's Committees at different levels[1].

Under this administrative system, hamlets of the Muong ethnic group and villages of the Viet group are not the grassroots government management unit. However, all of the agricultural land use activities are conducted at the household level within the hamlets (Land Law, 1993). For the hamlet community, the clan chief plays an important role in counselling and arranging any conflicts arising from land use among different households (Quach Thi Oanh, 2002), while the role of hamlet chief is considered as the bridge between the households and the different levels of government. In term of awareness and of the way in which people perceive the situation, the influence of these two figures is remarkable, not just on the local villagers, but also on the local government officials. So, for dozens of years, land management has involved many agencies, mass organizations and other stakeholders in the dialogue on local land management and use. Against that background, the presence of a project to establish the NS-NL natural reserve, with the participation of international organizations (Fauna and Flora International, and K.U.Leuven, Belgium) and natural science researchers (FIPI, RIGMR) and social science researchers (LLINC – Institute of Ethnology),

[1] Documents on the organization structure and use of land in this article are taken from staff of Justice Division, Lac Son district.

has further diversified the number of stakeholders (LLINC, 2004:5-6)

4 Conceptions of sloping land use for terrace field at the NS-NL area. The differences between the related parties.

To the residents of the river delta, the forest – with disadvantaged living conditions for the people – is the living space of the backward people. In their view, the terrace field cultivation of the highlanders is attached to nomadic farming, cutting and burning down forests, leading to the destruction of forest for cultivation purposes (Condominas, 1993, LLINC 2004:28). With this view in the background, local government always wanted and wants to limit the terrace field cultivation area within the planned area: from 1960 to 1990, the government's settlement program has mobilized 482,000 households, with 1,800,000 people to settle down in the low land areas (Hoang Huu Binh, 2003:37).

In the NS-NL area, although the local tradition considers terrace field cultivation a major production activity, since the 80s and 90s, with the government's policy to close down the forest, households no longer have the freedom to expand their terrace field as before; on the contrary, the terrace fields have been narrowed to bare hills only. However, the need to expand terrace field has always been pressing among the households, local people always try to take full use of bare land, even degraded to expand their cultivation area. According to statistics of the communes, in 1999, Ngoc Lau commune 43 households cleared 12.5 hectares of bare land for cultivation. In 2000, this number increased to 68 households with total acreage of 19.93 hectares. In 2001, an additional 24.9 hectares of sloping land was cleared in the commune. The same situation occurred in other communes. In 2000, nearly 2.8 hectares of land was cleared in Tram hamlet (Ngo Luong commune) (each household cleared additionally an average 0.4 hectares – compared to the allocated 0.5 hectares of agricultural land for each household). In 2002, Khu hamlet (Ngoc Son commune) has 9.5 hectares of land being cleared. At the same time, people in Mon hamlet (Tu Do commune) cleared 5.6 hectare of land (each household cleared an average of 0.5 hectare compared to the allocated 0.3 hectare)[1]. These figures reflect the households' need of land for cultivation, as well as the existence of different types of agricultural cultivation in the local sloping land. So how that fact is reflected in the conceptions and awareness of the related parties?

We start with the view on terrace field land of the General Department of Land Administration, reflected through the model N.01 – TK of the Land Administration (under Decision No. 507/1999/QD/TCDC, signed on 12/10/1999).

In this classification form, the classification of agricultural land is according to the state's plan. Therefore, the name of the type of land is defined according to the type of trees being planted on that land. In this case, terrace field is classified as land for annual plant. "Land for annual trees" includes a) "land for rice and subsidiary crop" b) "terrace field" c) "other annual plants" (form No.01-TK of the Land Administration Division, Tan Lac district, 2003). For better definition, an instructional circular No. 1558/DC-DDBD (dated 13/10/1999) clarified that land for terrace field is the hilly and mountainous (sloping) land for the cultivation of rice or other annual plants. "Land for annual plants" is defined as flat land for the cultivation of annual plants except rice. Therefore, according to the General Department of Land Administration, "terrace field land" includes the mountainous or hilly sides that are used for agricultural exploitation, while agricultural land in the flat area are classified as "land for other annual plants"

But the further away from the central government we, the bigger the difference in knowledge of the classification system. Let's take a look at the actual use of sloping land mapped by the local functional agencies: For the district's Land Administration – Agriculture – Forestry division, the view that terrace field land accounts for a small amount has dominated among the land administration staff as the massive terrace field cultivation has been banned since the 80s. On the map of current land use of Ngo Luong commune in 2003 (drawn by the Land Administration Division of Tan Lac district), terrace field, coded N-56b, only existed as a small dot in the

[1] Result of the author's field trip in October, 2003

map. In the form N-01-TK dated 30/10/2002 of this agency, “terrace field land” (which means hilly and mountainous sloping land, according to the Land Administration) only accounts for 179.7 hectares, while land for “other annual plant” (flat land, according to the Land Administration) increased to 2149.936 hectare. Meanwhile, for the commune land administration staff, the use of sloping land is much more complicated and different. In a report on land use of the communes, we see the word “land for subsidiary crop”, which does not exist in the classification system of the Land Administration sector. We have to note that agricultural cultivation on terrace field, based on burning down the forests and plotting the seeds has been very familiar to the communal land administration staff, as they are the local people, live in the local community, and they themselves practice those customs after their working hours.

By comparing the reports of the communes, we see that 4/6 communes use the word “land for subsidiary crop” to define the land used for annual trees apart from rice in the local agriculture. Meanwhile, only two communes use the word “terrace land” under the TK model of the Land Administration sector.

Therefore, based on this report, we understand that in Ngoc Lau, Bac Son, Ngo Luong, terrace field no longer exist, and the agricultural structure only includes rice field and subsidiary field. Meanwhile, in Ngoc Son and Tu Do, that structure is rice field + terrace field. And finally, in Nam Son, according to the local knowledge, there are only rice field + land for other annual plants (flat land according to the Land Administration sector), and there are neither “terrace field” nor “subsidiary crop” according to the local Land Administration staff. On the contrary, for the RIGMR research staff, the geologists, the situation is different: the area for “terrace field” of Nam Son commune is much bigger than other communes (409.4 hectare compared to 471.4 hectares of the total 5 other communes)[1].

For these researchers, the NS-NL land is classified into 7 different categories. According to the land use criteria, “terrace field land” is recognized as a bigger space, including all lands on the hill sides, mountain sides, valleys and wherever there are thin layer of soil and limited water resources.

For FIPI, the agency in charge of conducting the feasibility study for the project on the establishment of the NS-NL natural reserve, land in the research site are classified according to its chemical and physical composition. Therefore, according to FIPI’s view, local land is classified into 6 categories. Terrace land is understood as sour Ferralitsoils (FIPI, 2003:6). But in their proposal on land use of the NS-NL natural reserve, there are only two types of agricultural land: a) “rice field”; b) “subsidiary land” (FIPI 2003:6).

According to the Forestry sector, only the “productive forest” can be allocated to the households for protection and cultivation of additional agricultural products. According to the province’s forestry agency, most of the forest area in NS-NL area are classified as “protective forest” and therefore can not be assigned to the households as the case of productive forest, and should be under the forestry sector’s management.

But according to the local people, the above mentioned definitions are vague, especially for old people and women. In the traditional perception, local people only classify land as cultivable land (called *tol* – meaning soil hills in local dialects), and non-cultivable land (called *khu* – meaning stone mountains)

Therefore, according to the local people, they can use the hill sides for agricultural cultivation. In the old customs, a black forest, with many small plants, are considered a good plot of land for agricultural purposes. In the past, when the forest covered all the hills, households could clear the land for cultivation. The circle for laying the land fallow is about 10 years. Nowadays, households can only cultivate in certain areas allocated from the assigned forest land (LLINC, 2004), and that circle is shortened. 80% of the interviewed households say the techniques for laying the land fallow have been cut short for intensive cultivation to compensate for the shortage of food due to the limited land acreage and quality (FFI, 2002: 9)

However, the traditional cultivation methods have created a system of diverse and detailed terminology to define the different types of forest for agricultural cultivation being used until nowadays: for the shallow land that can be used for wet rice cultivation,

[1] RIGMR, 2004: 64

people use the word *na* (field); for flat land that can be ploughed but there's no water for subsidiary crop, people use the word *lu,* and for sloping land without water, cannot be ploughed but can be hoed, people use the word *bon* (in Ngo Luong, Bac Son, Nam Son) or *roong* in Ngoc Son, Tu Do, Ngoc Lau. Especially, for the terrace field for rice, people use the word *hoong*[1]. Despite the changes in land relations, people's view on the use of sloping land still bear traditional characteristics: in their conception, hill side can be used for terrace fields and can be transferred to their relatives if needed, and the exact acreage of their land is not so important. By now, to estimate the acreage of a plot of land, local people still base on the weight of the seeds to give an estimation on acreage. The statistics, for them, is just a form of conditioning, while for the management staff, they should be much more correct and simple (FIPI, 2003:22).

5 Conclusion

The diversity of parties related to the management and use of agricultural land in the NS-NL limestone area implies big differences in the assessment of the actual use of sloping land for local terrace field agricultural cultivation. Besides, the unique geological and biological characteristics of the limestone mountain area, as well as the special local socio-economic issues have attracted the participation of other agencies in the project to establish the NS-NL natural reserve. The differences of socio-economic background of the partners of the project have led to the differences in their perception of the issues, based on the views and experiences of the groups to which the partners belong. The study shows that there is a basic difference between the traditional notion of the local people which appreciate the cultivation on sloping land, and of the wishes to limit these activities of the functional agencies. Lying between these two extremes are the confused notions, reflecting the conflicts between the awareness of different groups when they have to choose between the local household economic development and the project's purpose to conserve the nature. The research results also show that there are differences in statistical data and documents on the use of terrace land, not just depending on professional techniques, but also on differences in perception and view. In such a background, a real dialogue between the conservation project and related parties on the use of agricultural land will encounter difficulties due to the differences in awareness and perception. The experiences of natural conservation projects have shown that the use of cultivation area is one of the central socio-economic conflicts[2]. Therefore, the part of social and anthropological research in conservation and development projects is not only academic, but can help to indicate the socio-economic problems to be addressed in the dialogue between different partners.

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EPIKARST – A PROMISING HABITAT

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Abstract. Epikarst is an upper layer within the vadose zone, partially saturated with water and capable of delaying or storing water and contaminants. Owing to the importance of the epikarst as a habitat of high diversity of meiofauna a series of trickle sites in the caves was established. To understand an epikarst as a habitat, its structure and physico-chemistry nature chosen caves were those previously monitored and for which a list of epikarst species is available. Microgeographic distribution was studied due to basic question whether nearby drips are more similar than distant drips and whether drips in one cave are more similar than drips in different caves. Epikarst species are known from few caves since few caves have been studied. An inventory of epikarst fauna for monitoring involved selected four caves in the so-called Postojna-Planina cave system (Slovenia). The system is known as the location of the world's most diverse caves. These are the only caves with 40 or more species. Nevertheless the heterogeneity of distribution of stygobites within the epikarst is even more striking. Diversity in the epikarst may rival or exceed of other karst zones. Special attention was given to the stygobiontic species of copepods (Crustacea), which they were the most abundant of all. Conservation can best be accomplished through habitat protection, which must include protection of the associated surface habitat.

Keywords: caves, epikarst zone, percolation water, Copepoda, Slovenia.

1 Introduction

Interfaces, or ecotones, between terrestrial and aquatic ecosystems have an essential role in the movement of water and materials throughout the landscape. Ecotones are zones where ecological processes are more intense and resources more diversified. They are also zones which react quickly to human influences and changes of environmental variables (Gibert *et al.*, 1997). Three important vertical and horizontal groundwater/surface water ecotones are recognized: soil-karstic aquifer interface, *i.e.*, epikarst, spring and interface between saturated and unsaturated zone in karstic and porous aquifer and stream underflow, *i.e.*, hyporheic zone (Gibert *et al.*, 1990). The main characteristics of these interfaces are their great variety of elasticity, permeability, biodiversity and connectivity.

The purpose of this study is to describe an epikarst fauna from four karst caves, represented by a numerous specimens of Copepoda (Crustacea) and reveal possible environmental factors determining species composition of Copepoda. Epikarst fauna is still poorly known. This lack of research is partly due to inaccessibility of epikarst for direct scientific research.

2 Material and methods

The four caves studied are situated in south and southwest Slovenia. In the caves Postojnska jama, Pivka jama, Črna jama and Planinska jama (*jama* = *cave*) we collected samples once a month. The Postojnska jama cave system is the longest cave system in Slovenia (about 20.000 m of galleries) and is built by the Upper Cretaceous carbonate rocks (Šebela, 1998). All chosen caves are part of it. Caves were chosen to be representative of the region named "Classical Karst" in Slovenia. They were also caves with a known previously monitored epikarst fauna.

Temperature, pH, conductivity and discharge were measured *in situ* by a conductometer (LF 91, WTW) and pH meter (323, WTW). Water samples for analyses, according to "Standard methods" (APHA, 1998), were used for analysing chemical parameters in the samples. The samples were stored in plastic containers and kept at 4 °C prior to analysis. An ion chromatograph (761 Compact IC, Metrohm) was used to analyse the concentrations of major ions. Chloride, nitrite, nitrate, phosphate and sulphate were determined on an anion separation column. Sodium, ammonium, potassium, calcium and magnesium were analysed using a cation separation column.

During the period of one month, the water from trickles was directed through a funnel into plastic containers. On two sides, they have holes covered with a net (mesh size 0.080 mm) to retain animals in the container. The content of the plastic containers was fixed with 4% final solution of formaldehyde at the sampling spot and stored for further processing. In the laboratory we separated the organisms by means of stereomicroscope at 40x magnification and stored them in 70% ethanol. Further processing and identification of the organisms was performed under a compound microscope.

Overall similarity of the epikarst fauna of the different caves was measured using Jacquard’s formula.

Total diversity in a sample, including both observed species and unobserved species, was estimated used two measures (Colwell and Coddington, 1994) – Chao’s method and a Burnham and Overton’s jackknife estimate.

3 Results

A total of 15 taxa were found: Turbellaria, Nematoda, Gastropoda, Oligochaeta, Araneae, Acarina, Ostracoda, Copepoda, Bathynellacea, Isopoda, Amphipoda, Diplopoda, Collembola, Coleoptera, larvae Diptera. The most abundant were the specimens of Copepoda. Among the copepods one cyclopoid copepod, and 14 harpacticoid copepods were found (years 2000 – 2001). Eight harpacticoids are probable new species. Individual caves had between 5 and 11 copepod species and between 4 and 8 stygobionts. Pivka jama had the most species (11) and the most stygobionts had Pivka jama and Črna jama (8).

The total number of estimated epikarst species has to be found with more intense sampling. Except for Planinska jama, where samples are still unworked, estimates of the total number of epikarst species were less than twice than the observed number. A number of assumptions are made in order to use estimates which may or may not be realistic, but it does give an idea of total diversity (Brancelj *et al.*, 2004).

Species overlap among caves is shown along with Jacquard's index. In general overlap was low. The mean value for Jacquard's index was 0.33, and its maximum observed value was only 0.36. The same index for two pairs of caves as Postojnska jama and Črna jama, Postojnska jama and Pivka jama is not surprising since the caves belong to the same cave system. This means also the same geographical and geological situation of the caves and the same influence of external environmental factors.

In the calculations of estimates and overlaps data of Planinska jama are not included since the observations and studies are still going on.

4 Discussion

In Slovenia 43% of the territory consists of carbonate rocks with karst. Slovenia has by far the richest aquatic hypogean fauna in the world. This supports results of fauna of copepods in the epikarst which is unusually rich. The majority of aquatic species found in the percolation water of the Postojnska jama cave system are tiny crustaceans. The high number of species found in the caves with a dominance of stygobiontic species and species which are likely new to science indicate that biodiversity in the epikarst is high. This data at the same time provide an enigmatic situation which governs in the epikarst habitat. Four caves of the same cave system are likely to be an important site of subterranean biodiversity. One is developed as a tourist cave (Postojnska jama) and other three (Pivka jama, Črna jama, Planinska jama) are occasionally show caves.

The simultaneous monitoring of fauna and environmental parameters for a series of trickles, some of them previously monitored, showed that there is extensive heterogeneity in the epikarst fauna, most of which we do not understand. The success of the sampling procedure requires that each step is properly achieved. The selection of sampling sites is as important as the choice of appropriate methods for sampling epikarst fauna. Errors in the selection of sites yield a misleading faunal overlap between epikarst habitats. Epikarst habitats are too diverse and too different for applying a few quantitative sampling methods. Thus, the research was supplemented with the study of microgeographic distribution. The basic question was whether nearby drips are more similar than distant drips and whether drips in one cave are more similar than drips in different caves. Combining the data on hydrogeology and chemistry in the unsaturated karst zone and with a special emphasis on the biodiversity and the ecology of the fauna in the epikarst zone, we have been directed our research into the ecological and microgeographic studies of epikarst fauna, which is carried away by the trickles of percolation water from the epikarst zone. Filed observations and studies are continuously going on.

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CONTAMINANT TRANSPORT IN KARST ENVIRONMENT. INFLUENCE OF AQUIFER HETEROGENEITY AND VARIABILITY OF HYDROLOGICAL CONDITIONS

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Keywords: karst, transport simulation, tracing test, vulnerability mapping, groundwater protection.

Prediction of contaminant transport in karstic systems can be particularly challenging due to aquifers heterogeneity and to the critical influence of hydrological conditions. The presence of zones affected by intense dissolution, such as dolines, coexisting with blocks of lower permeability, account for the spatial variability of aquifers properties. Rapid concentration of flow towards organized conduit networks during rainfall are responsible for strong and rapid variation of discharge rates and flow velocities in both saturated and unsaturated zones. A prevision of contaminant transport is thus only possible by accounting for both the spatial and temporal variability of karst.

The approach presented here aims to simulate, on the basis of field data (geology, pedology, hydrographs, tracing test and infiltration test) the transport of a non-reactive contaminant through the different layers defined in karst system. The simple 1-D "VULK" program is used for simulations. This dual-porosity analytical advective-dispersive model allows transient transport under steady state flow conditions to be calculated. Flow is assumed to be vertical in the unsaturated zone (soil, unconsolidated sediment, non-karstic bedrock, epikarstic zone), and horizontal within the saturated zone. For each layer, thickness, flow velocity, dispersivity, and dilution factor are estimated in order to reproduce breakthrough curves observed during tracing tests. The use of a double porosity approach, implying the estimation of porosities and exchange coefficient proved necessary to reproduce the tailing effect commonly observed on the field.

Several test sites located in the Jura Mountain (Switzerland) have been investigated. Observations and experiments performed at different level within the saturated and unsaturated zone allowed parameters required for the simulation to be calibrated. The influence of recharge type on the result of tracing test proved to be critical and resulting in modification of the parameters used for the simulation. Hydrological condition (high water, low water), characteristics of natural or artificial rain events (intensity, total amount), antecedent humidity conditions, type and rate of pollutant input (diffuse or punctual contamination), had a strong influence on tracer breakthrough. This implies that hydrological condition and pollution scenario must be strictly taken into account for tracing test interpretation and transport simulation. The significant solute storage capacity observed in the vadose zone during field experiments was only taken into account in the dilution factor so far, but an additional approach could be proposed. This would help to reproduce the partial mass of tracer recovered even for non-reactive tracers and the multi-peak breakthrough curves frequently observed during time variable hydrologic conditions.

The results obtained so far provide an interesting insight into the behaviour of karst systems. Simulations calibrated by field experiments can be used to forecast the effect of contamination on karst water quality for a given hydrologic situation. The coupling of the VULK simulation program with a GIS allows transport simulations for the whole catchment of a spring or well to be carried out. It permits the most important breakthrough curve parameters to be evaluated such as transit time, relative concentration and duration of contamination, which are used to define a quantitative vulnerability index. Based on the determination of this index, vulnerability map can be processed, bringing a valuable tool for groundwater protection in karst environment.

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Eds. O. Batelaan, M. Dusar, J. Masschelein, Vu Thanh Tam, Tran Tan Van, Nguyen Xuan Khien

METHOD OF KARST SOCIAL AND ECONOMIC RISK ASSESSMENT ON LARGE TERRITORIES

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The suggested method allows to forecast characteristics and to make corresponding maps of karst collapses intensity (cases/year·km^2, m^2/year·км^2), karst risk of physical and economic losses of territory, buildings and constructions (m^2/year, m^2/year·km^2, $/year, $/year·km^2), and also karst social and individual risk of people death from karst collapses (persons per year, persons/persons year) as within the limits of separate buildings, constructions and small settlements, (at local level) and large territories, adequate to city agglomerations and subjects of the Russian Federation (at regional level).

Such assessment of karst hazard and risk assumes carrying out in all cases of a special complex of researches and the engineering investigations, including operations.

1. Identification of the natural and technological conditions, factors of karst deformation on the basis of collecting and the analysis of all known information on karst deformation in measured and adjacent territories.

2. Spatial analysis with GIS allowed expanding statistical bases of studied hazard, to define karst collapse, its sizes and relationship with geologic structures and geomorphologic elements, tectonic faults, economical objects.

3. Implementation of field researches on key- sites with the purpose of specification or an establishment the percent ratio of the total area of all fixed surface karst forms to the site area (the coefficient of karsting), regularities and the age of karst deformations with using radiocarbon, geologic, geomorphologic, pollen and other methods.

4. Zoning of the affected areas on regional-geological, zonal-climatic and technological factors of development of karst and distribution on this basis the data received in key-sites to all estimated territory.

5. Assessment of karst hazard and risk.

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MULTIDISCIPLINARY RESEARCH AT THE CAVE OF LETTERS, ISRAEL: A MELDING OF PHYSICAL AND SOCIAL SCIENCES

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Keywords: geophysics, geoarchaeology, mapping, archaeological probes, cave.

1 Introduction

Research in 1960-61 by famed Israeli archaeologist Yigael Yadin, in what came to be called the Cave of the Letters (COL), yielded a priceless collection of artefacts including scrolls, pottery, coins and bronze objects. Jewish rebel commanders, and their families, who sought refuge in the cave near the end of the Second Jewish Revolt against the Romans (~135 C.E.) left these objects. An archive of 70 documents in Hebrew, Aramaic, Nabatean and Greek were discovered in the cave. About a dozen letters bore the name of Simeon Ben Koseva, the historical figure known as Bar-Kokhba, leader of the Second Jewish revolt. The Bar-Kokhba letters were mostly military documents that contained plans and orders. Another cache of documents recovered from the cave was the personal archive of Babatha, a young woman from a remote village in the Dead Sea area. The bundle of documents she left chronicles what life was like for a Jewish family at this important time in history.

No research was conducted in the cave between 1961 and 1999, and it was postulated that a substantial amount of new information about this unique period in history remained to be discovered. Research expeditions to the Cave of Letters in July 1999 and July 2000 utilized state-of-the-art technology, as well as traditional geologic, archaeologic and surveying techniques, to add a substantial amount of new information to the existing bases of knowledge about the Second Jewish Revolt, as well as the viability of geophysical research in caves. Because the COL is located in the tectonically active Dead Sea Rift Zone (Fig. 1), and local limestone layers are being wedged apart by the growth of gypsum crystals, the cave floor is covered with roof fall that obscures the underlying archaeological deposits. Ground Penetrating Radar (GPR) was used in the interpretation and reconstruction of living surfaces below the roof fall. Other geophysical analyses included the use of two-dimensional electrical resistivity tomography (ERT) to further image the rebel occupation surfaces, and a gradiometer and a high-resolution transient EM metal detector were used to locate artefacts in and below the rubble. The data necessary to produce new, detailed maps of the cave was also collected, and a series of new maps were created (two of which are presented in Fig. 2 and 3).

Fig. 1: Location of the Cave of Letters

2 Historical background

In 132 C.E. the legendary Shimeon Bar Kokhba led the Second Revolt of the Jews against Roman rule. The First Revolt, which occurred 62 years earlier, ended with the famous resistance at Masada. During the Second Revolt, Bar Kokhba's troops captured Jerusalem, and restored the Jewish state, but

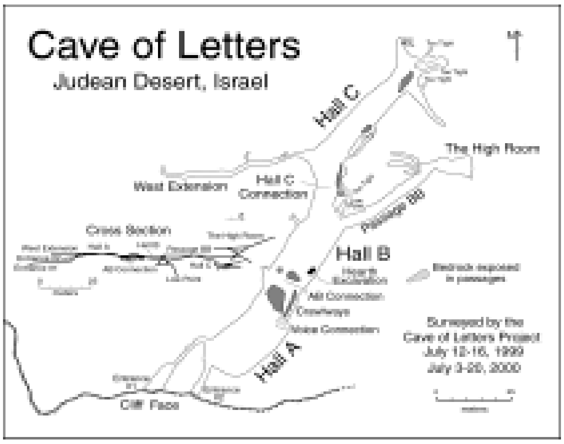

Fig. 2: New base map of the Cave of Letters

they were eventually defeated in 135 C.E. by the Roman general Julius Severus. Events associated with the First Revolt, recorded by Josephus Flavius, are part of the historical record for this period. No such historian existed for the Second Revolt, so for nearly 2,000 years Shimeon Bar Kokhba remained a mythical figure known mostly through Jewish folklore. All of this changed in 1960 when an archaeological expedition headed by Yagael Yadin explored a cave in the Nahal Hever near the village of En Gedi (Aharoni and Rothenberg, 1960; Yadin, 1963).

During Yadin's excavations of 1960-61, Hall "A" yielded a large cache of bronze objects, as well as other assorted artefacts. Excavations in Hall "B" led to the discovery of a fragment of a scroll that contained a rendering of an old psalm. Then, in Hall "C" the expedition discovered a bundle of leather that later proved to be a goat waterskin. Contained inside this package were beads, perfume flasks, cosmetic tools, a hand mirror and a bundle of papyri tied with string. Among the papyri were four wooden slats that were covered with writing, which were later determined to be letters from Shimeon Bar Kokhba to military commanders stationed at En Gedi. The first wooden slat contained the heading "Shimeon Bar Kokhba President over Israel." The goatskin belonged to the wife of Yehonatan bar Be'ayan. When she fled to the cave she had taken it with her as part of her household belongings (Aharoni and Rothenberg, 1960; Yadin, 1963).

3 Methodology

In order to create a new, detailed set of maps for the Cave of Letters, a survey was completed using hand-held survey instruments

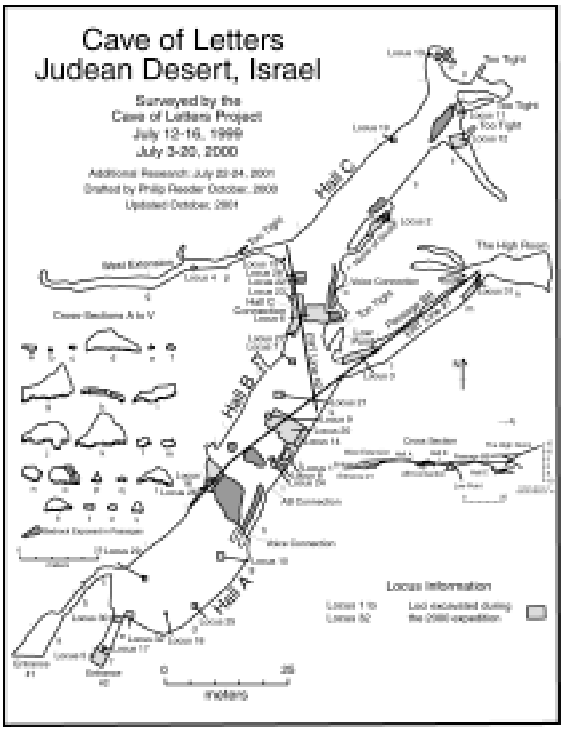

Fig. 3: Map of COL with cross-sections, ERT lines and archaeological locus information.

that included 1) an optical compass, 2) an optical inclinometer and 3) a nylon survey tape. A total of 82 survey stations were established within the cave. Data collected between each station includes azimuth, inclination, and distance. At each survey station a sketch of that segment of cave passage was also produced. The survey data was plotted using the CAVEPLOT computer program, and the plots were exported to Adobe Illustrator for map production. Plan view and cross-sectional maps were produced, as well as maps that depict the locations where geophysical and archaeological analyses were completed (Fig. 2 and 3).

A portable digital pulseEKKO™ 100 and 1000 GPR system was used to obtain the GPR profiles. Four antennae frequencies, 100, 200, 225 and 450 MHz, were tested. To reduce data collection time in the rugged cave environment a backpack transport system was employed. The digital profiles were processed and plotted using pulseEKKO™ software. The application of radar stratigraphic analysis, an approach for interpreting sedimentary environments (Beres and Haeni, 1991; Jol and Smith, 1991), provided the framework to investigate both lateral and vertical geometry of the reflection patterns. After processing, printing and interpreting the GPR profiles while in the cave,

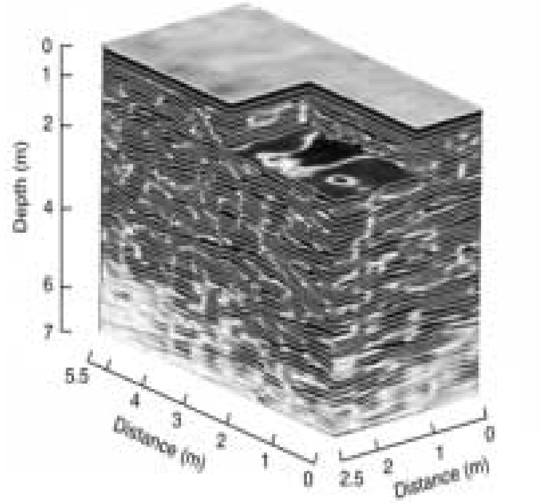

Fig. 4: Three-dimensional GPR cube with Bar Kokhaba floor exposed.

archaeological probes were completed at selected locations using an endoscope, metal detector, and/or traditional archaeological excavation techniques.

The two-dimensional electrical resistivity and tomography (ERT) analysis involved introducing an electrical current into the cave floor with two electrodes, and measuring the voltage drop across the surface with two other electrodes. Because electrical flow disperses throughout the geologic materials that make up the floor of the COL, these measurements provided information about the electrical character of materials below the surface of the cave floor. Profiles were produced by modeling the data from a series of measurements with different depths and locations along a survey line (Reynolds, 1997). In the COL two electrical resistivity and tomography transect lines were established (Fig. 3, 5 and 6). A gradiometer and a high-resolution transient EM metal detector were also used in the COL, with limited success, to locate artefacts in and below the rubble.

4 Results and discussion

Very detailed maps of COL were prepared after the 1999 and 2000 expeditions. Using a base map created with Adobe Illustrator (Fig. 2), additional maps were produced that included 1) a map that depicted the location of roof fall and the topography of the cave floor, 2) a cross-section of the cave, which also became part of many of the other new maps, and 3) detailed cross-sections from 22 different locations in the cave (lettered “a” through “v”).

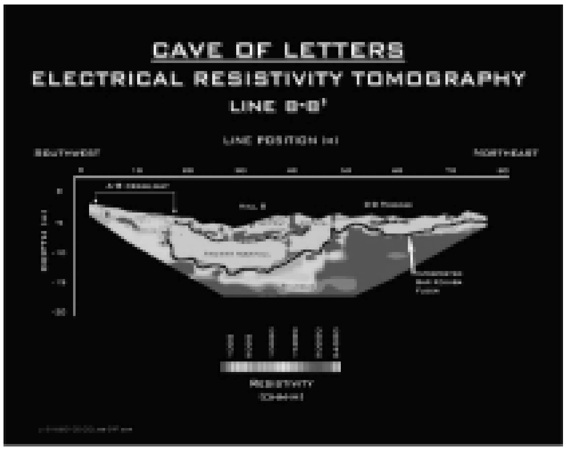

Fig. 5: ERT profile from COL.

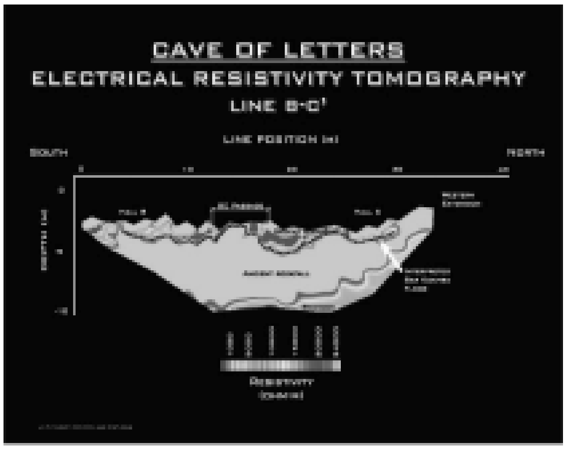

Fig. 6: ERT profile from COL.

An archaeological finds map was produced after the 1999 and 2000 expeditions, and maps were also produced that depict the location of GPR or ERT survey lines. Figure 3 contains many of the map components discussed above. The maps created based upon this research are the most accurate maps ever produced of the Cave of Letters.

As part of the GPR analysis, a three-dimensional data set was collected from a 5.5 m by 2.5 m grid in Hall “B” (Fig. 4). Three-dimensional datasets of this type greatly aid in interpreting the framework of the subsurface materials and provide a more detailed view of the geometry of individual units. This experimental data set enhanced our ability to interpret the three-dimensional geometry of the Bar-Kokhba floor, which appears within the cut out of Fig. 4. The ERT and GPR data corroborated each other regarding the location of the Bar Kokhba living surface, and in some instances ERT more clearly delineated this surface. Figures 5 and 6 are cross-sections produced from the ERT data that clearly indicate not only the location of the Bar Kokhba surface, but the nature of the geologic materials found below the cave floor.

In Fig. 5 and 6, based upon interpretation of the ERT data, the Bar Kokhba living surface has been differentiated. Also indicated are areas of recent rockfall, ancient rockfall, and bedrock. ERT and GPR analysis in the COL were used to indicate optimum zones for endoscope analysis and excavation.

5 Conclusions

This research marks the first successful use of GPR to delineate living surfaces buried in a cave environment. Both GPR and ERT indicated areas below the rubble for endoscopic viewing and archaeological probes. Based on cave surveying, a set of detailed maps were produced, and the length of the cave was determined to be 525 meter, which is 275 meters longer than previous surveys indicated. By utilizing a multidisciplinary approach, and working within the framework of the emerging field of geoarchaeology, unique insights were gained with respect to the use of geophysics in cave research, and that coupling traditional archaeological and geographical methodologies with geophysics can provide a new and unique understanding of the importance of the COL.

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GEOMETRY OF A KARSTIC RESERVOIR IN THE WESTERN-PYRENEES (ARETTE, FRANCE). EXAMPLE OF THE "FONTAINE D'ORBE" SPRING.

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Keywords: karst aquifer, karst structure, geometry, vulnerability, drinking water supply.

1 Introduction

The Fontaine d'Orbe spring is a karstic spring that supplies the rural city of Arette (Southwestern France) with drinking water. The average flow is estimated around 50 $l.s^{-1}$ and the whole catchment area is estimated to be close to 2.4 km². Its principal chemical and physical characteristics are as follows: average electrical conductivity = 285 µS/cm; average temperature = 11.2 °C.

In 2000, an unforeseen organic pollution problem in the water catchment has questioned the origin of the water and has blamed the accuracy of the catchment's area limits definition. At the time, the main problem was that the origin of the pollution was located out of the protection area established until then. Therefore, considering the French government's law on water policy of January 3rd 1992, the spring's protection area must be redefined.

Considering the complexity of this aquifer and the lack of accurate geological data, we have chosen to develop a multidisciplinary approach. It combines geophysical tools (electrical surveys and radar), a structural analysis of the Urgonian limestones, a new detailed geological mapping of the area and dye tracing operations.

2 Geological context

The studied area is situated near the North Pyrenean Fault that is to say at the boundary of the European and Iberian plates and more exactly in the structural unit called the "Chaînons Béarnais". The local geological structures are orientated N 110 and affect Mesozoic formations (Fig. 1). The Orbe spring emerges from the Lower Cretaceous platform limestones (Urgonian sediments). The karstic aquifer is limited by the Albian marls in the North and by large intrusions of Cainozoic ophites (dolerite) in the South. The relations between ophites intrusions and the Cretaceous limestones have recently been the subject of thorough investigations (Desreumaux *et al*., 2002), which question the regional stratigraphy and paleogeography. This original layout found in the whole area of the "Chaînons Béarnais" confers to this aquifer a major interest as drinking water supply in the region. Moreover, fractures' analysis has allowed proposing a diagram of the karstic aquifer's geometrical structure (Rey, 2003). Actually, the Cretaceous limestones are much fractured because of the Pyrenees' unsettled geological history and three groups of fractures (open or not) influence, in a clear way, the cutting of the calcareous landscape: N 30-85 NW; N 150-45 NE; N 100-40 SW. Theses directions of fracture seem to guide the karstic flow to the aquifer's outlet zone, that is to say the Orbe spring.

3 Artificial tracing operations

Many dye tracing (Rey, 2002) carried out with artificial tracers have already established a direct hydraulic link between the Vert River, which crosses over the catchment's area of the Orbe spring, and the outlet zone (Fig. 1). The results have shown that the Vert River takes part in the water supply to the spring up to 5 %, during the summer 2003. These tracing

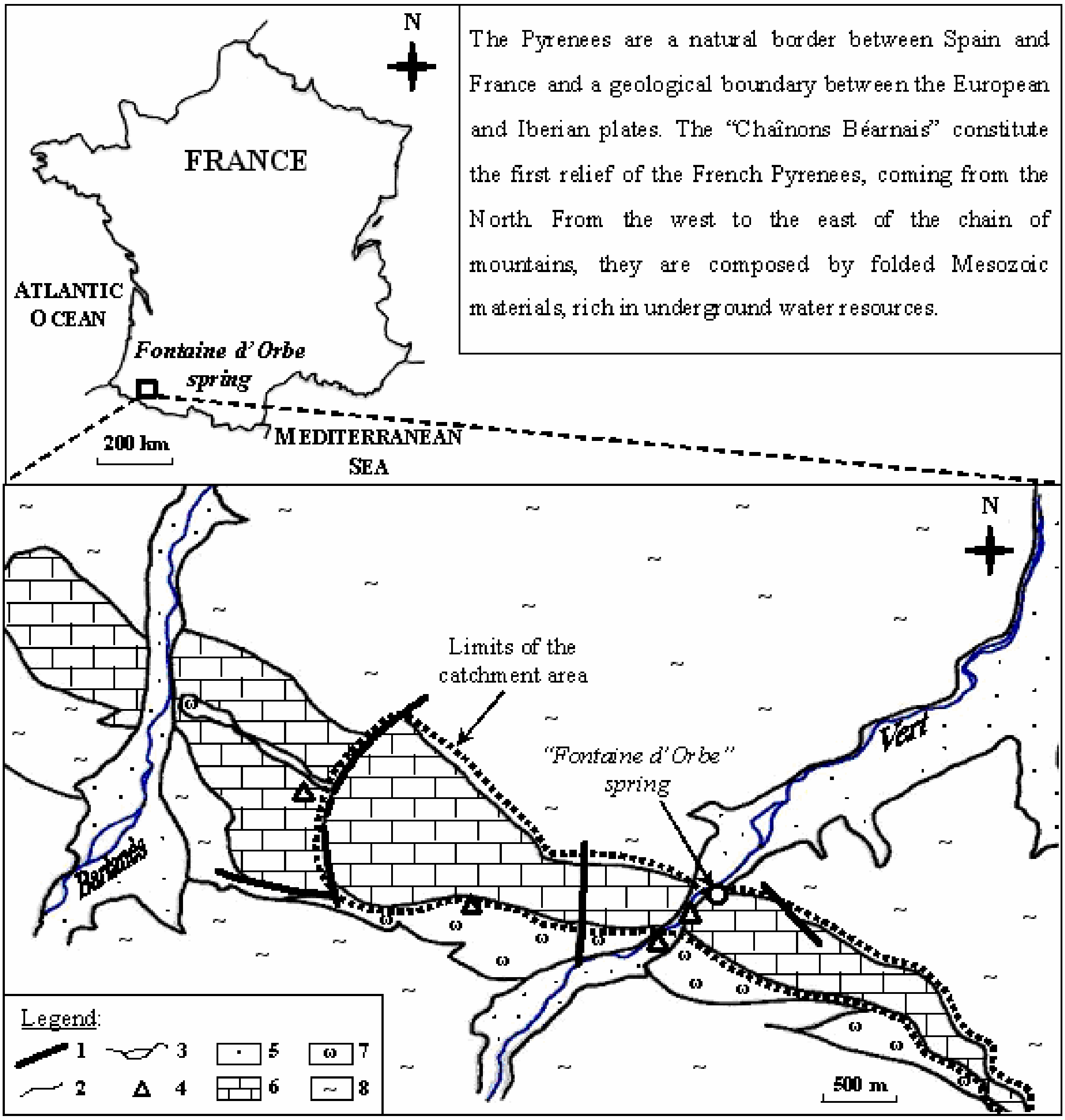

Fig. 1: Simplified geological map of the studied area and localisation of the catchment area's boundary. 1: Major faults; 2: Geological limits; 3: Torrents; 4: Injection point of dye tracings; 5: Quaternary alluvial plain; 6: Urgonian limestones; 7: Cainozoic ophites; 8: Albian marls.

operations have also confirmed us that the water of the torrent infiltrates all along the calcareous formation through a system of open fractures. However, the relatively low percentage of infiltrated water from the river, doesn't question the vulnerability and the quality of the Orbe spring's water.

New tracing operations (Δ symbol on the Fig. 1) realised with fluorescein out of the current defined catchment area, in the west part of the zone (Fig. 1), are proved to be positive as we see on the Fig. 2. These experiments demonstrate that the extension of the karstic system should be more developed that it has been thought. So, the spring's catchment area must be extended again and we

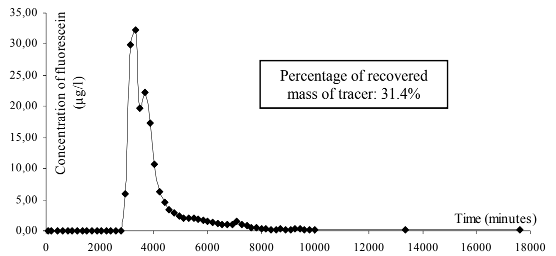

Fig. 2: Results of artificial tracing operation realised on January 16th 2004.

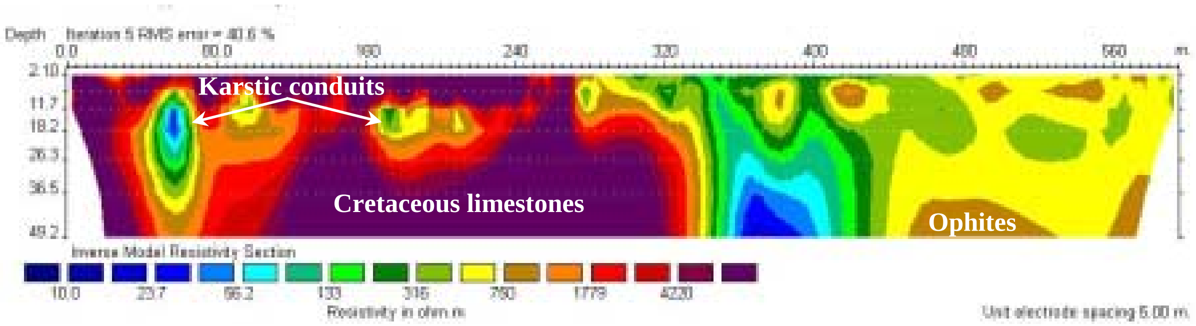

Fig. 3: Electrical resistivity pseudosection, pole-pole array (Loke M.H., 1999), realised across the main geological structure, from the north to south.

can think that the part of the Urgonian formation, to the west of the main fault drawn on the Fig. 1, must be taken into account. Consequently it seems that the potential relation between the two rivers (the Barlanès and the Vert River, see on the Fig. 1) should be analysed, thanks to a new dye tracing.

4 Electrical imaging surveys

The geological data have been completed by the realisation of electrical surveys across the studied zone. The observation of the geological structure linked up with the geophysical results shows that a hydrothermal originated layer exists between the limestones and the ophites (Fig. 3). On the Fig. 3, we can clearly see a blue area which represents a low electrical resistivity due to a clay rich material. All the electrical pseudosections show that this hydrothermal origin formation, appeared during the putting in place of the ophites intrusions, is thicker that we thought and continuous from east to west. This clayey level constitutes a continuous low permeability shield and limits the catchment's area to the South and to the East; the Albian marls play the same role in the North.

Moreover, geophysics' tools and particularly the resistivity sections confirm the existence of a major karstic channel, 10 meters below the spring level, and the sub verticality of the Urgonian layers and of the geological contacts between limestones and ophites (Fig. 3), and between limestones and marls.

5 Conclusions

The multidisciplinary method used for this study has allowed us to grasp the complexity of this hydrogeological system. Thanks to the complementarity of the different disciplines, notably between the geological observations and the results of electrical geophysics, some interpretations have been compared and confirmed with each others. At last, this new survey has permitted to redefine the limits of the catchment's area and then to protect this high quality water resource as efficiently as possible. However, some questions always remain on the origin of the water but in an immediate future isotopic analysis, new artificial dye tracings and new electrical surveys will surely bring us answers to these interrogations.

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VARIABILITY OF SOILS IN A KARST CATCHMENT OF NORTHERN THAILAND

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Keywords: soil, water balance.

Since 2000 "The Uplands Program" is working in the mountainous region of Northern Thailand. Emphasis of "The Uplands Program" is on development and testing of sustainable agricultural production methods, the formulation of development concepts for rural institutions, advancement of methods for research of complex ecosystems and their interaction with the socio-cultural, economical and institutional framework. At the moment one focus of soil related research is on the water balance in a small karst catchment. This is to enable the prediction of water availability due to changing land use.

In the soil map of Thailand (Vijarnsorn and Eswaran, 2002), soils of mountainous regions (slope > 35%) are simply classified as an undifferentiated slope complex. This information is insufficient for establishing a water balance at the catchment scale. Therefore detailed soil mapping was envisaged.

The Bor Krai catchment is situated in the Pang Ma Pha district approximately at 19° northern latitude and 98° eastern longitude (Fig. 1). The elevation ranges around 800 m. a. s. l. . The landscape is characterised by steep, often cone-shaped mountains consisting of mostly massive limestone with karstic depressions in between. Alongside to these steep mountains are some more smooth hills which mainly consist of sand-, silt- and claystone (Fig. 2). These hills are mostly furrowed by the surface runoff. At some

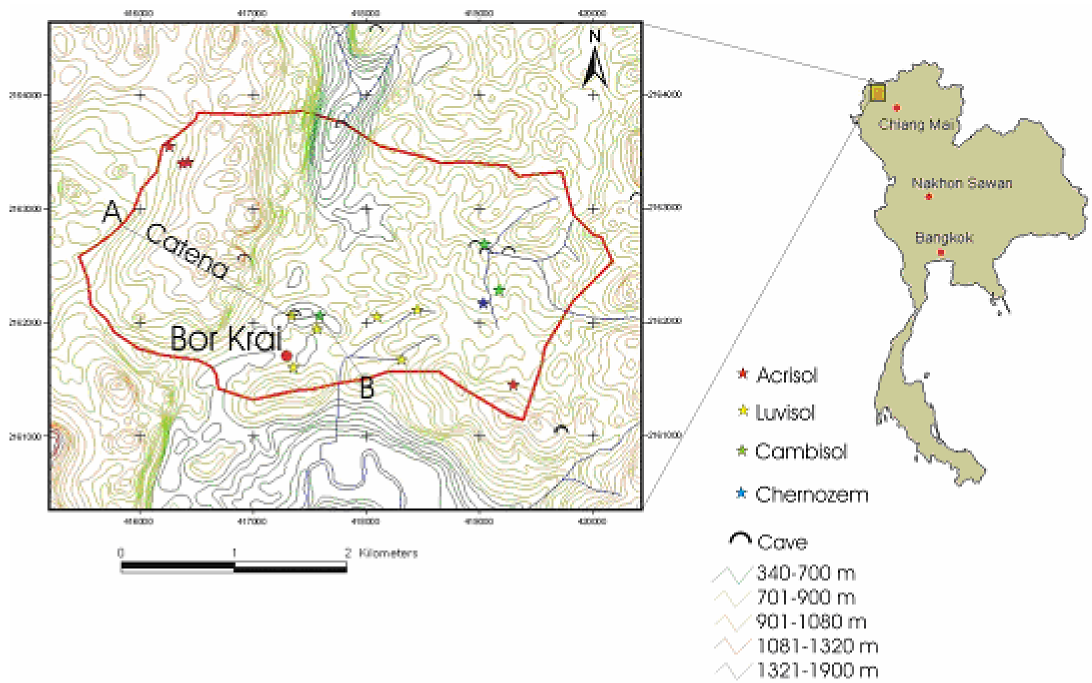

Fig. 1: Location of the research area in Pang Ma Pha district.

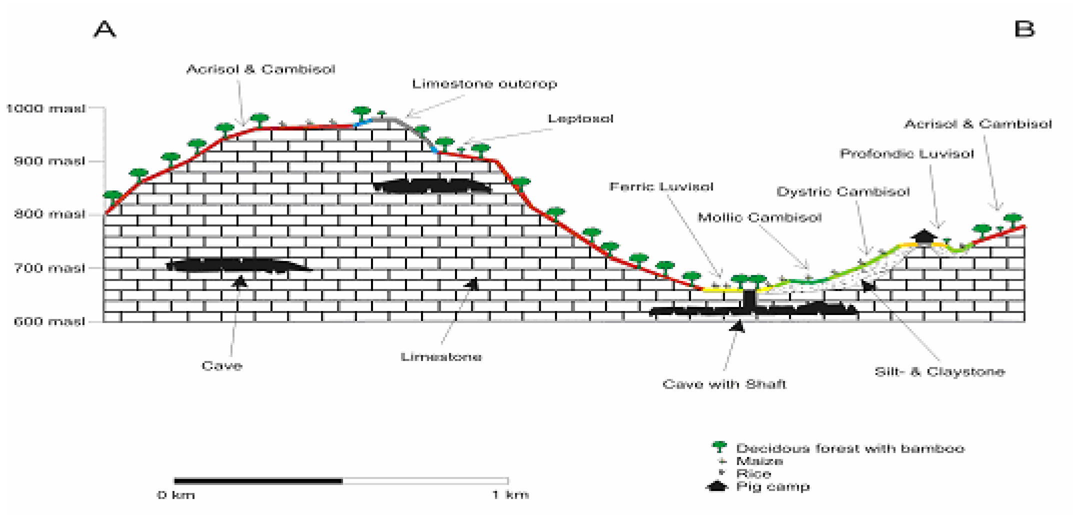

Fig. 2: Catena through the Bor Krai catchment

special places volcanites with different composition occur. In between the claystone the volcanites do not appear in a morphological sense, but in between the mountains of limestone the volcanites build landform depressions. The volcanites should have intruded after the genesis of the limestone and clastic rocks. According to Hahn and Siebenhühner (1982) limestone and clastic rocks were deposited in the Permian age. The limestone facies are from the shallow parts of a marine basin, whereas the clastic sediments were deposited in deeper parts. The clastic rocks are laterally interfingering with the limestone. In some areas some intersections of dolomite in between the limestone occur.

In the part where the limestone is nearly uncovered subsurface discharge is predominant and gave rise to the genesis of the biggest caves of Southeast Asia.

Only where a thicker cover of impermeable rock occurs, a certain surface runoff can be detected. In total the research area belongs to the Salween catchment, a river which flows into the Indian Ocean.

Soil mapping reveals that it is possible to distinguish between soils originating from limestone and such from other materials (clay-, silt-, fine sandstone, vulcanite). According to the WRB classification (FAO, 1998) on limestone and dolomite Humic Acrisols are predominant, additional Umbrihumic Acrisols, Leptic Acrisols, Chromic Cambisols, Mollic Cambisols and Ferric Luvisols were found. In the surrounding of freshwater springs Calcic Chernozems on freshwater limestone were detected. On clastic rocks (sand-, silt-, claystone) Profondic Luvisol prevail, followed by Leptic Luvisols, Leptic Cambisols, Mollic Cambisols, Dystric Luvisols, Endostagnic Luvisols and Ferric Luvisols. Volcanites inhabit Chromic Acrisols and Leptic Cambisols.

Humic- and Umbrihumic Acrisols are widespread on karst plateaus and in larger karst depressions like poljes and dry valleys. They show a high variability of their morphology related to the landscape position and to the present and past anthropogenic uses. These deeply weathered red soils contain mainly gibbsite as clay mineral, with a low cation exchange capacity. They are managed under extensive low input conditions and depend entirely on natural regeneration of plant nutrients through fallow periods. Beside the low cation exchange capacity, phosphorous and potassium deficiencies were identified. In contrast to the chemical soil characteristics, the physical soil characteristics are convenient (Sereke, 2002).

Mollic-, Leptic and Chromic Acrisols mainly occur in soil pockets of limestone outcrops. They are characterized by diffuse horizon transitions, strong micro-aggregates and reddish colour. As a result of those strong micro-aggregates, the infiltration capacity seems to be quite high. In the volcanite zone, the Chromic Acrisols are reddish brown, showing a granular structure in the topsoil, followed by angular blocky to prismatic structure towards the depth. The top of the Argic horizon is characterised by clay skins, whereas the lower part shows many slickenside.

Ferric Luvisols mostly can be found at places being affected by erosion, like slopes or karst depressions which are directly connected to caves or shafts (Fig. 2). At such locations the normally deeply positioned Ferric horizon comes closer to the surface. The Ferric horizons are normally characterised by many reddish hematite mottles. In most cases the hematite mottles increase with the depth.

Profondic Luvisols can be found in the clastic rock unit at places which are less affected by erosion or which show a tendency to accumulate soil material. Such places are wide ridges of hills or lower slopes. These soils are characterized by a big development depth and by an Argic horizon in which the clay content does not decrease by more than 20 percent relative from its maximum within 150 cm from the soil surface.

Mollic Cambisols are described for the bottom of karstic depressions, where the limestone unit is still overlain by the clastic unit. Towards the slope, the Mollic Cambisols pass into Dystric Cambisols. Lab analysis (Table 1 and 2) of Tinoco-Ordónez (2003) show, that the Dystric Cambisols loose potassium, phosphorous, calcium, magnesium, whereas the lower positioned Mollic Cambisol gain all these elements. For the same reason, the cation exchange capacity and the base saturation is in the Mollic Cambisol also higher than in the Dystric Cambisol.

Leptic Luvisols and Cambisols are occurring at exposed relief positions, like ridges and convex slopes or close to the outcrops of limestone.

Stagnic Luvisols are mostly restricted to lower slope positions. These soils shows mottling in such a way that the surfaces of the peds are lighter and paler coloured, and the interior of the peds is enriched with dark coloured iron and manganese oxides.

Leptosols exist only close to limestone outcrops especially in the area of the cone shaped mountains. Mostly Leptosols are building a transition zone of only some centimetres between the limestones and the Acrisols and Cambisols.

In the surrounding of karst springs Calcic Chernozems on freshwater limestone occur. These soils are characterized by a very thick topsoil, many cavities, crumbly structure and carbonate content in all parts. According to Tinoco-Ordónez (2003) the cavities are from

Table 1: Dystric Cambisol - lab analysis of Tinoco-Ordónez (2003)

horizon designation	lower depth (cm)	total nitrogen (%)	total carbon (%)	K(mg/kg)	P(mg/kg)
Ah	20	0,1	1,3	132,1	3
AB	46	0,1	0,5	112,6	0,1
Bw1	90	0,1	0,3	90,1	0
Bw2	120	0,1	0,3	69,9	0
Bw3	160	0,0	0,3	59,2	0
Bw4	>160	0,1	0,2	62,4	0

horizon designation	Ca++ (cmol+/kg)	Mg++(cmol/kg)	K+(cmol/kg)
Ah	4,9	1,9	1
AB	1	1,6	1
Bw1	0,7	1,1	0
Bw2	0,9	1,2	0
Bw3	0,9	1,4	0
Bw4	1,1	1,8	0

horizon designation	CEC-pot (cmol+/kg)	base saturation (%)	Feo/Fed	pH H2O
Ah	21,3	35	0,13	6,2
AB	26,2	12	0,05	5,5
Bw1	26,8	9	0,02	5,2
Bw2	27,8	9	0,02	5,1
Bw3	29,7	9	0,02	4,8
Bw4	32,5	11	0,02	5,1

Table 2: Mollic Cambisol - lab analysis of Tinoco-Ordónez (2003)

horizon designation	lower depth (cm)	total nitrogen (%)	total carbon (%)	K(mg/kg)	P(mg/kg)
Ah	40	0,1	2,3	203,7	39,9
AB	60	0,1	1,6	259,7	5,6
Bw1	80	0,1	1,4	236,7	3,1
Bw2	116	0,1	1,4	183,4	3,5
Bw3	>116	0	1	117,4	9

horizon designation	Ca++ (cmol+/kg)	Mg++(cmol/kg)	K+(cmol/kg)
Ah	13,4	2,1	1
AB	10,7	1,5	1
Bw1	8,9	1,1	1
Bw2	8,8	1,1	1
Bw3	6,9	1	1

horizon designation	CEC-pot (cmol+/kg)	base saturation (%)	Feo/Fed	pH H2O
Ah	33,1	50	0,18	6,5
AB	30,9	43	0,18	6,5
Bw1	27,5	40	0,19	6,5
Bw2	30,2	36	0,25	6,2
Bw3	24,7	34	0,18	6

roots, vertebrates, reptiles and amphibians.

Land use is restricted by water shortage in the dry season, and by steep sloping land. Due to the confinement of nutrients to the topsoil, prevention of soil erosion is essential. Most of the exposed slopes are depleted, whereas most of the depressions are enriched with respect to nutrients. For the Luvisols and Cambisols Tinoco-Ordónez (2003) describes a high number of black coated iron concretions and nodules, usually increasing with depth, indicating lateral water movement and/or stagnant water conditions. Most soils show phosphorous deficiency and also black coated iron concretions.

First analytical results reveal variable physical and chemical soil characteristics in the karst catchment which are worth further investigations. Especially for the estimation of the water balance in the karst catchment the knowledge of the spatial distribution of the characteristics is a pre-requisite.

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SAHASTRADHARA, A KARST TOPOGRAPHIC WONDER, TURNING INTO A TOURISTIC PARADISE IN INDIA

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The action of underground water with its negligible velocity in bringing about the dissolution of carbonate rocks is well exhibited and preserved in the Quaternary Limestone Formations in an area of about 2 km^2 in the northeastern part of the city of Dehradun at Sahastradhara (meaning million streams) in India. The prolonged and widespread solvent action of underground water, reducing the naturally occurring land surface to an extremely irregular topography, made up of an interwoven system of sinks, caverns and solution valleys. The resulting landscape is peculiar in its appearance and extremely irregular in its drainage pattern. The caverns at Sahastradhara lie above the water table. The percolating vadose water containing dissolved $CaCO_3$ gets the first chance of evaporation and reaches the roof of the cavern in the form of droplets. These droplets stick to the roof for a while, get evaporated and, therefore, deposit small granules of $CaCO_3$, which are fixed with and naturally hang from the ceiling towards the floor in the form of stalactites and from the floor towards the ceiling in the form of stalagmites are well preserved in the Sahastradhara caves. The word Sahastradhara draws its name after the trickling of water from million places in the limestone caves. There are six interconnected caverns in the form of caves, each of which is about 500 meter in length. The work is under progress by the Archeological Survey of India to preserve the existing and to explore for new caves in the entire region of about 20 km^2. By the side of these caves, naturally occurring sulfur spring exists. This sulfur spring spa which has many medicinal values such as the ability to eradicate skin diseases together with the adjoining limestone caves draws thousands of national and international tourists every year. The local authorities and the Indian Tourist Development Corporation, Government of India, are promoting the spot as a big attraction center for tourists in the country.

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MANAGING POLLUTION OF WATER RESOURCES IN KARST SYSTEMS

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Industrial, agribusiness, and rural residential development are placing increasing stress on karst aquifers already impacted by traditional agricultural land use. Based on extensive literature searches this paper examines the ways of karst water protection. Successful karst protection depends on a systems approach using correct information and mass education. Educational materials from GOs and NGOs can increase citizen awareness. The karst issues can be brought into primary and secondary school classrooms, as well as to environmental educators at museums, state parks, and soil and water conservation districts. The bench-scale karst groundwater model is a visual tool that demonstrates surface water and groundwater interactions in karst. Numerous presentations and workshops can help planning GOs and NGOs create new standards and ordinances protecting karst watersheds, and to provide technical, managerial, and financial assistance to drinking water providers. The karst aquifers may present special challenges if these waters are especially vulnerable to contamination due to land use with bacteria, nitrate, fluoride, arsenic, heavy metals, pesticide and excess nutrients whose sources and transport into groundwater basin should be determined using isotopic analysis, antibiotic resistance analysis, and general water quality testing, coupled with a detailed evaluation of the extent and land use of the recharge area, and surface and groundwater movement in the basin. A systems approach should be developed in which the function of the aquifer and its relationship to the recharge area, and the sources of contamination, are considered separately and as integrated parts of a karst groundwater study. In particular, a better understanding of hydrologic flow paths and solute sources is required to determine the impact of contaminants on karst groundwater basins, and then remedial measures should be taken.

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ROLE OF WATER DISPERSIBLE SOIL COLLOIDS IN CO-TRANSPORTING HEAVY METALS THROUGH THE UPPER SOIL COLUMN

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Karst areas have specific karstecology system on which the soil quality plays important role in the relationship of the clime-host rock and the greenery. Depending on the organic content and pH value, soluble and complexed heavy metal contaminants of the soil can get into the greenery. For this knowing the state of the soil and contaminant transport is indispensable. A series of intact soil (with high $CaCO_3$ content) column experiments were conducted to assess the role of water dispersible soil colloids, with diverse physicochemical and mineralogical composition, in co-transporting selected heavy metals through the upper column. Another objective of this work was to identify the colloid, soil and solution properties facilitating or hindering salt water intrusion. Water dispersible colloids were of montmorillonitic, mixed, illitic and kaolinitic mineralogy. Colloid suspensions of 200 mg/L were mixed with four standard solutions of 0.1, 1, 10 and 100 mg/l concentrations of Cr, Mn, Fe, Ni, Cu, Zn, Cd and Pb prepared for AAS calibration and sorption study, and introduced into duplicate undisturbed soil columns at constant flux. The effluents were collected and analyzed periodically for metal concentrations. Batch equilibrium isotherm experiments were also conducted to evaluate the metal adsorption capacity of the colloids. Metal transport was enhanced in the presence of colloids by an average of 10- to 25-fold, but the increase was colloid and metal specific. In general, Cd^{2+} is the least strongly retained by the soils than the other toxic cations, and hence can pose a more serious problem of polluting groundwater with its extreme toxicity. Zn, Cu, Pb and Cd were found far more mobile than other four metals. Increasing the metal concentration in the colloid suspension beyond 10 mg/l hindered metal-colloid transport through the columns due to coagulation, flocculation, flow retardation, and pore clogging. Metals are more sorbed on silty loam than on sandy loam because the former has higher organic matter, clay, montmorillonite contents, CEC and surface area. Most of Agra soil is sandy loam, and hence it is advised that all wastes containing heavy metals should be treated before disposal into loamy formations.

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CONTAMINANT IMPACT SIMULATION BY MEANS OF COMPARATIVE TRACER TESTING AND SIMPLE ANALYTICAL MODELLING

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Keywords: specific vulnerability, comparative tracer tests, contaminant transport, modelling, karst.

Karst aquifers are generally recognised being very vulnerable to land surface contamination. This is due to the occurrence of preferential flow paths and the lack of a significant protective cover above the carbonates, both causing short residence time and low hydrodynamic dispersion effects. Certain reactive contaminants may receive additional attenuation by undergoing other physical and chemical processes.

Comparative tracer tests have been carried out in order to better understand the processes that may affect reactive contaminant transport in karst environments. Several tracers with different rock interaction potential have been applied to identify and differentiate attenuation processes that are related to different kinds of substances. Fluorescent dyes, salts and particle tracers were employed as surrogates for real contaminants, such as organic compounds, heavy metals and microorganisms. The experiments showed that the tracer breakthrough at the detection points is strongly related to the nature of the injected substance. It is particularly noteworthy that tracer testing in the unsaturated zone provides interesting results suggesting that the uppermost layers (soil, epikarst) may be crucial for contaminant-specific attenuation as they are often being rich in organic matter and clay minerals. Saturated groundwater flow does not demonstrate significant segregation between nonreactive and reactive tracers. Particle tracing highlights the rapid transport of microbiological contaminants, a phenomenon frequently of concern in karst water management.

Tracer experiments demonstrate the need of groundwater protection and landuse management techniques, which take the particularities of specific contaminations into account. In order to evaluate the vulnerability of a karst water resource to specific types of contamination, a simple analytical transport model has been used, simulating, coupled with nonreactive advective-dispersive flow, the interaction of reactive contaminants with the medium. The above tracing tests from different karst settings were used for model calibration and validation in terms of retardation and degradation processes.

Both tracer tests and modelling tools visualise how the target may be affected by a contamination event in terms of breakthrough curves. Tracer injection scenarios, as well as real contamination scenarios, essentially affect the degree of attenuation in a karst system. This is not only due to hydraulic conditions (flow velocity, water storage), but also due to the variability of contaminant release (release pattern, time frame). To quantify these effects, tracer experiments for different tracer injection scenarios were carried out and simulated by varying the input functions of the model. Simulation results highlight the importance of well defined contamination scenarios in terms of risk assessment.

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HYDROCHEMICAL AND ECONOMIC INDICATORS TO DEFINE RISK INDICES FOR KARST SPRINGS

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Keywords: hydrographs, chemographs, economic value, karst, vulnerability mapping, risk.

The risk of damage to the quality of a groundwater resource can be expressed by linking the magnitude of a potential contamination event (risk intensity) and the consequences if the event actually occurred (risk sensitivity). The risk intensity is, on the one hand, a function of the hazard input at land surface, considered in terms of contaminant concentration, duration and spatial distribution. On the other hand, attenuation processes occur between injection and detection point normally reducing risk intensity. The degree of attenuation, which mainly depends on the geological and hydrological conditions as well as on the contaminant type, may be illustrated on vulnerability maps. Intrinsic vulnerability reflects the reduction in potential risk of a conservative contaminant input unit, while specific vulnerability refers to a particular reactive contaminant type. Vulnerability and risk mapping is particularly promoted in karst areas due to the failing of classical groundwater protection strategies.

Spring hydrographs and chemographs are recognised being a practical tool for describing karst aquifer characteristics. They can thus be regarded as reflecting the global response of a rainfall or contamination event. Organic matter, for instance, is enriched in the uppermost soil layer. Organic matter chemographs can be taken as representing advective-dispersive groundwater flow from soil infiltration to the spring outlet. They are thus suitable for intrinsic vulnerability characterisation of the entire spring catchment. Other chemical compounds may reflect contamination by specific pollutants in the catchment.

The aim of this study is to derive a multi-disciplinary approach by identifying simple parameters for karst spring risk assessment. Indicators of organic matter and nitrate spring response have been used to describe global intrinsic and specific spring vulnerability correlating their concentrations in spring water during low and high water conditions. These indicators should provide a global perspective of the vulnerability of the basin in terms of spring protection. While vulnerability maps provide a tool for intra-basin management, spring vulnerability parameters may be used for inter-basin comparison. In addition, holistic risk assessment, considering risk sensitivity as well, requires information about the costs of spring water quality degradation. Several economic approaches have been tested with regard to groundwater resource evaluation. An economic indicator for spring contamination has been established considering the potential benefit that is derived from the resource. Both issues were quantitatively linked to a final risk index combining the physical parameters of groundwater flow and contaminant transport with the social issue of spring value.

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VARIABLE CONTROLS ON EOGENETIC KARST DEVELOPMENT IN THE MARIANA ISLANDS

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Carbonate islands in the Mariana Arc are tectonically active and composed of late Tertiary and Pleistocene limestones that mantle Eocene volcanic edifices. Eogenetic karst development (i.e. karst formed on carbonate rocks that have not undergone deep-burial diagenesis) observed in the Mariana Islands indicate variable controls (lithologic, chemical, and structural) on island karst development. Original models for island karst development were based on observations on the tectonically quiescent Bahamian Islands and Bermuda, where interfingering of facies and structural deformation is minimal.

Fieldwork in the Mariana Islands (Tinian, Rota, and Aguijan) has identified three distinct classes of caves based on primary controls on dissolution: 1) contact caves, 2) mixing zone caves and 3) fissure caves. Contact caves (stream caves) are lithologically controlled and form at the contact between carbonate and non-carbonate rocks where allogenic recharge is focused. Mixing zone caves form where the mixing of waters of differing chemistry increases dissolution at the margin of the fresh-water lens (flank margin caves) where fresh and saline waters mix and at the top of the lens (water table caves) where vadose and phreatic waters mix. Mixing zone caves develop along distinct horizons defined by the fresh-water lens, and therefore record relative changes in sea-level as the fresh-water lens shifts in response to glacio-eustacy and tectonic uplift. Fissure caves are structurally controlled and form by the preferential flow of water along planes of brittle deformation (faults and fractures) produced by regional tectonism and margin failures. These caves provide fast flow routes for increased recharge and discharge, which distorts the fresh-water lens morphology.

The variations in island karst development imposed by lithologic and freshwater/saltwater mixing were previously predicted by work on other carbonate islands, but the influences of brittle deformation observed in the Marianas provide additional complexity. Individual caves in the study area exhibit distinct primary controls on dissolution, however sites that exhibit variations in lithology, geologic structure and fresh-water lens position in close proximity show the influence of multiple controls on dissolution. The complex nature of the carbonate islands of the Mariana Arc demonstrates well the variations in eogenetic karst development, which is not strictly controlled by the position of the fresh-water lens.

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GENDER PERSPECTIVE IN KARST CONSERVATION OF THE GUNUNGSEWU REGION, CENTRAL JAVA, INDONESIA

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The Gunungsewu Region, Central Java, Indonesia is a dry and barren karst area, always facing water deficiency in the dry season. There are around 250.000 people living in this less productive area. They are in general farmers, poor, and not well educated. Actually the Gunungsewu region has high potential for natural resources, especially minerals and groundwater. But the natural resources exploitations done by the people are commonly not based on environmental management, and finally tends to quickly damage the karst ecosystem. Therefore, counter measures for remediation of the environmental degradation need to be executed. To realize these, it is no desirable to depend solely on government guidance and support, but to seek active support by the local people, based on participation principles. In this concept, the role of all people either men or women has to be equal. This paper discusses on gender equality in the implementation of karst conservation measures in the Gunungsewu region in Central Java.

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LIVING STALACTITES: BIOGENIC DEPOSITS OF SUBAERIAL TUFA

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Keywords: karst, speleothems, microphotographs, petrography, Mariana Islands.

Friable and porous stalactites are often encountered in the entrances of caves (Fig. 1a) and plastered to cliffs in the tropics. Centimeter to meter in scale, their overall shape is somewhat irregular. Crooked, bulbous, and pendant-like forms are common and their growth axis is often deflected from the vertical. In addition to stalactitic features, other analogous morphotypes also occur and include draperies, stalagmites, columns, irregular patches, and bedrock coatings (Fig. 1b). Their outside surfaces feel powdery or earthy and vary from white to gray, purplish, green, brown, or black in color. They are frequently covered by wet, pasty, largely organic coatings, which, in some specimens, are dry and exhibit desiccation cracking and flaking (Fig. 1c). A wide array of biota is associated with these features and includes bacteria, cyanobacteria, algae, mosses, higher plants, and various invertebrates. On the inside, these stalactites are light colored and composed of layered microcrystalline material, sometimes reminiscent of chalk (Fig. 1d). They almost invariably lack sparry calcite characteristic of normal cave stalactites and other speleothems.

These features are sometimes interpreted as remnants of former solution cavities and are thought to arise by decay and diagenesis (micritization) of speleothems that become exposed to outside conditions by breaching and collapse of caves. While this may certainly be true in some cases, the vast majority of these convincingly speleothem-like formations are actually deposits of subaerial calcareous tufa that form in land surface environments. Our analysis of 52 samples of such stalactites from cave entrances, cliffs, sea caves, widened fractures, and bedrock overhangs in the Mariana Islands has revealed ample evidence for deposition in an epigean environment. The deposits are composed of microcrystalline calcite and organic matter, and contain various inclusions (such as eolian particles, microbial structures, plant material, arthropod and insect fragments; and within the littoral realm, foraminiferal tests, diatom frustules, and skeletal grains of marine origin). Most specimens were dripping epikarstic water at the time of collection, and aragonite, indicating active growth, was detected in a few samples.

In thin sections, layering is generally conspicuous, but often irregular, convoluted, and discontinuous, consisting of alternating laminae of microcrystalline calcite and dark material of apparent microbial origin (Fig. 2a). The crystallites, typically a few microns in size, are unsorted and randomly oriented. Equant crystals of calcite are generally absent, and only rarely occur as secondary occlusion of pore space. Microbial material and organic content vary from insignificant to considerable, indicating that precipitation is controlled by both inorganic and organic factors, each of which may dominate the other under different environmental conditions. Inorganic precipitation is driven by CO_2 degassing from dripwater, just like inside caves; but the increased evaporation effects induce rapid deposition of calcite, causing a more random orientation and smaller size of crystals than those comprising normal carbonate speleothems. Biologic influence, such as photosynthetic removal of CO_2 and availability of crystal nucleation sites provided by living organisms, can also drive the precipitation of calcite, resulting in largely biogenic structures. The interplay of inorganic and organic factors can be observed within single specimens, where the best shaded portions of tufaceous stalactites may exhibit little evidence of microorganisms, while other parts are clearly bioconstructional (Fig. 2b).

Among the latter are microfabrics composed entirely of calcified cyanobacterial filaments. These are oriented along consistent axes and consist of hollow tubes surrounded by one to several layers of calcite. In peripheral parts of the deposits, individual cells can be observed emerging from these tubes. The central hole is circular in cross-section, 2-6 μm in diameter. Adjacent to the tube (and cyanobacterial cell) is innermost calcite layer composed of unsorted crystallites less than 2 μm in size. Outer crystals are larger and exhibit regular size and arrangement (Fig. 2c). Most often, they are oriented subparallel to the filament, but can also extend at near 90^{o} angles to the cyanobacterial cells, forming crystal spikes 20-30 μm long (Fig. 2d). The length of individual filaments is difficult to ascertain but is estimated to be several millimeters. Amazingly, certain deposits we investigated contain nothing but such calcified filaments (Fig. 2e). The empty space between them can be empty, as in the case of some highly porous and soft tufa patches plastered onto bedrock; or partially infilled by microcrystalline material, as in many tufaceous stalactites. Such deposits are basically colonies of calcite-armored cyanobacteria, which provide the framework that traps and binds micrite, or provide nucleation sites for its precipitation, so that microcrystalline material gradually fills the empty space between the calcified filaments (Fig. 2f). As such, they are living structures analogues to stromatolites and coral and algal reefs, and the only example of fully subaerial bioherms.

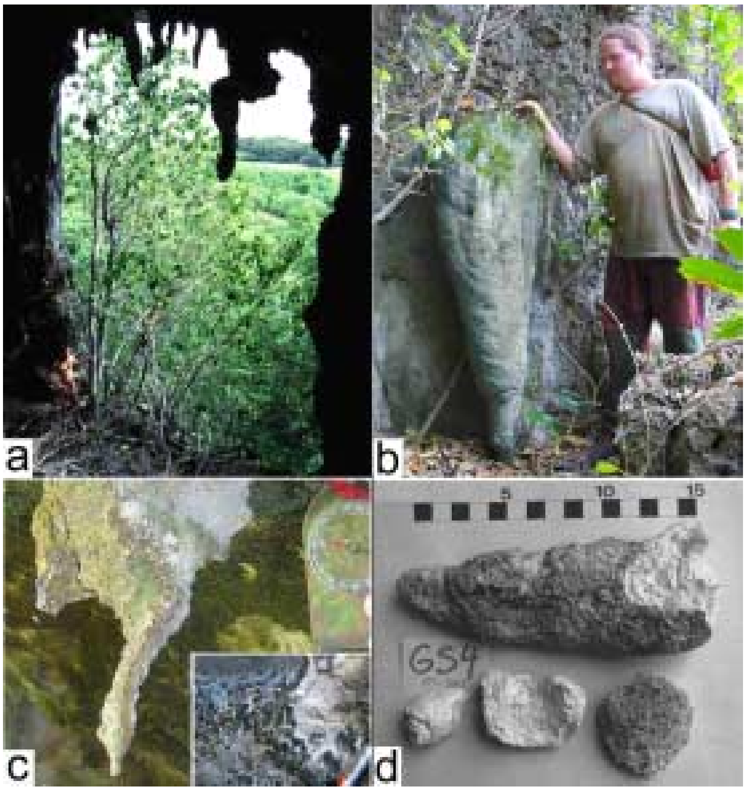

Fig. 1: In situ and hand specimens of tufaceous speleothem-like deposits from cave entrances and cliff faces in the Mariana Islands. a) Stalactites at the entrance of Ritidian View Cave at Ritidian, northern Guam, Mariana Islands. Note the highly irregular shapes. Person for scale. b) A stalagmite-like tufaceous deposit at the base of an inland cliff at Chiget, Tinian, Mariana Islands. Note the smooth coating on the bedrock to the left of the deposit and the sharp contrast with the karren-pitted rock surface elsewhere on the photograph. c) A small irregular stalactite at the underside of a collapsed boulder at Chiget, Tinian, Mariana Islands. It is deflected towards the light. Its left side, facing the light, has a light green coating, while its opposite side is white and uncoated. Compass (10 cm long) for scale. Inset photo shows desiccated and partly destroyed coating on a nearby tufaceous drapery deposit. AA battery for scale. d) A tufaceous stalactite sample from Ritidian cliff line, northern Guam. Note the color contrast between the exposed surfaces (dark) and the interior (light), and the crumbly nature of the deposit. Scale in centimeters.

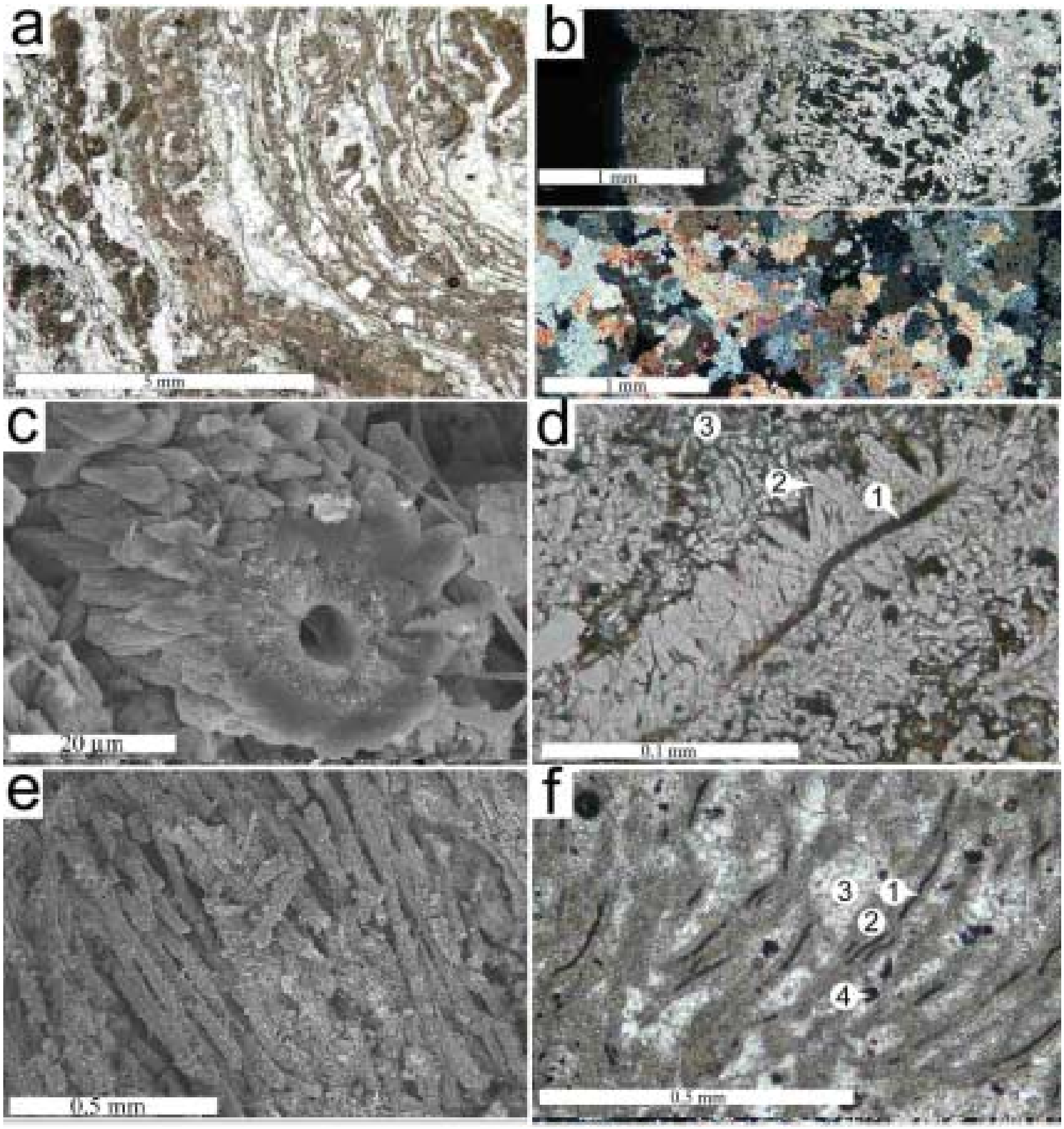

Fig. 2: Micromorphology of tufaceous speleothem-like deposits from cave entrances and cliff faces in the Mariana Islands. a) Plain light thin-section photograph showing layering consisting of alternating and irregular laminae of microcrystalline calcite (light) and organic material (dark). b) Polarized light thin-section photographs of contrasting microfabrics of light-facing (top photograph) and shaded (bottom photograph) parts of a small tufaceous stalactite, less than 5 cm wide. Note the biogenic structures, organic material, absence of laminae and any recognizable crystals, and extremely high porosity in the light-facing side; and crystal development, low porosity, and no evidence of microbial structures in the shaded side. c) SEM micrograph of a calcified filament and its cross-section. Note the extremely small size of crystals adjacent to the central canal and the large size and regular arrangement of crystals forming the periphery. Also note that a small part of the organism is visible in the central hole. d) Plain light thin-section photograph of a calcified filament cell. Note the cyanobacterial cell in the central tube (1), the long spiky crystals attached to it and oriented at approximately 90^o angles (2), and calcite filling the surrounding space (3). e) SEM micrograph of a tufaceous stalactite composed entirely of calcified filamentous cyanobacteria. f) Polarized light thin-section photograph of a microfabric supported by calcified filament framework. Note the cyanobacterial cells (1) and their calcite linings (2), the near complete infilling of voids by microcrystalline calcite (3), and the scattered dark globules of likely bacterial origin (4).

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INTERPRETATION OF A CAVE SYSTEM BASED ON TRACER EXPERIMENT, GEOSTRUCTURE AND CAVE DEVELOPMENT ANALYSIS

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Abstract. This paper presents an interpretation of a cave system, the Khau Muong - Lan Trong conduit, in the National Natural Reservation Zone of Phu Luong in NW Vietnam. Geological and cave surveys are carried out which predict the existence of possible underground connections between the Khau Muong sinkhole and the Lan Trong resurgence. Tracer experiments, using common salt (NaCl) as a tracer, are implemented to verify these connections, which result in a two-peak break-through curve. The two peaks are interpreted as the result of the tracer transport through a cavern conduit system having a sump that act as a hydraulic barrier to postpone the tracer transport process. This interpretation is strongly supported by the analysis on geostructure and cave development, which shows that the conduit system is composed of two passages developed along two respective faults, and the sump is found at the intersection of the two faults.

Keywords: Vietnam, carbonate rocks, tracer experiment.

1 Introduction

Tracer experiments have been applied in karst hydrological study and proved as one of the most effective tool to investigate underground conduits in karst environment. Many essential hydrogeological and hydrodynamic properties of the conduit system under investigation can be obtained by interpretations of break-through curve resulted from tracer experiments. Ideally and theoretically, a tracer experiment shows a single-peaked break-through curve of a skewed “bell” shape which corresponds to the analytical solution of the Fick's equation. However, many tracer experiments also exhibit multi-peaked break-through curve, i.e. a curve composed of a largest peak and a series of precedent and subsequent smaller peaks. The multi-peaked feature can be interpreted as (i) the conduit system is composed of several parallel branches, and the movement through these branches leads to the different arrival times of the tracer creating respective peaks of the break-through curve (ii) the system is of a single conduit composed of several hydraulic resistances (e.g. sumps) which delay the movement of a part of the tracer and thus also creating respective peaks. This study presents a two-peak break-through curve of the tracer curve conducted in an underground cavern conduit system in NW Vietnam. Analysis on the regional geological structure and the conduit development is also carried out, which shows that the conduit system is composed of a sump and conduit passages. This sump, acting as a high hydraulic resistance, traps a part of the injected tracer volume. That results in the two distinct transports of the tracer: the first is a quick movement of the groundwater flow through the conduit, and the second is the subsequent release of the trapped volume of the injected tracer. Thus, two peaks are created in the break-through curve, and the result strongly supports the above-said second interpretation.

2 Geological setting and cave development

The conduit system of Khau Muong - Lan Trong is one of the largest underground cavernous systems recently investigated in the National Park Zone of Cuc Phuong - Phu Luong in NW Vietnam (Ke et. al., 2003). In the study area, the carbonate rocks, aged Middle Triassic (Anizian stage), are of the Dong Giao formation T_{2a} dg (Fig. 1). The

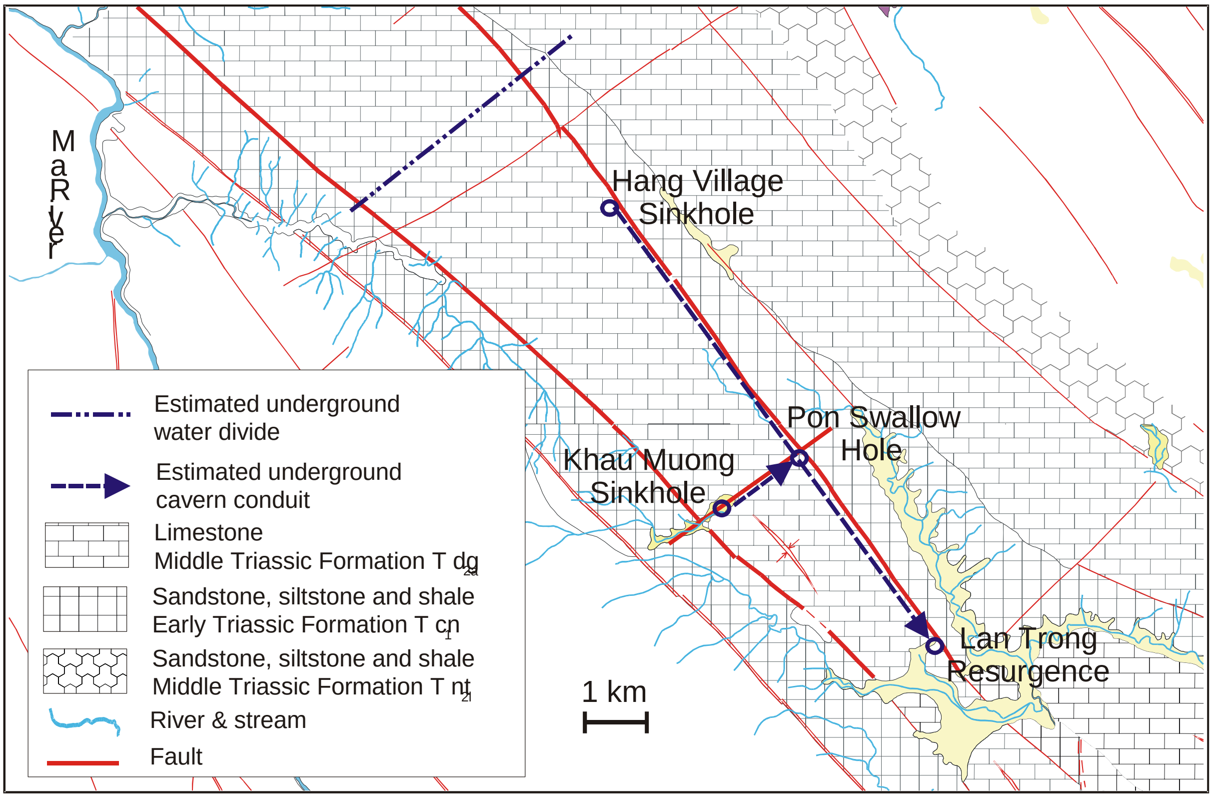

Fig. 1. Geological sketch of the Khau Muong – Lan Trong conduit system.

rocks are moderately-thickly bedded, and are regionally dipping to SE and NW, forming a series of NW-SE striking anticlines and synclines. Furthermore, these formations are intercalated by poorly permeable terrigenous rocks, namely sandstone, siltstone and shale, aged Early and Middle Triassic (Ladinian stage), of the Co Noi formation T_1 cn and the Nam Tham subformation T_{21} nt. Principal faults, which are often deeply seated and act as stratigraphical boundaries, mainly develop in NW-SE and NE-SW directions. Other faults, which are either sub-longitudinally or sub-latitudinally striking, are often younger and formed after the orogeny.

The conduit system develops within the Dong Giao formation. Due to tectonic - neotectonic activities and favourable exogenous factors, the limestones are fractured and especially strongly karstified. Most of the cavern passages develop in the NE-SW direction, along faults and crashed zones, or follows the stratigraphical boundaries stratified the limestones and the impermeable terrigenous formations. The conduit system is composed of several entrances, one of which is the Khau Muong sinkhole, and an exit, the Lan Trong resurgence. The underground basin, which drains to the conduit system, is confined by the impervious terrigenous formation of Co Noi in the NE and SW. In the NW, as the groundwater discharge take place in several springs located along the Ma Tributary, it is assumed that there is an underground water divide existing somewhere between the river and the Hang Village. Assuming the Lan Trong Resurgence as the outlet, the underground basin area of conduit system is therefore estimated at about 50 km^2.

Only a few passages of the conduit system between the Khau Muong Sinkhole, the Pon Swallow Hole and the Lan Trong Resurgence were surveyed with the total surveying length of 1270 m. The cave surveying data shows that the main conduit branch follows the crashed zones of the NW-SE trending fault, starting from the Hang Village and ending at the Lan Trong resurgence. Many cave expeditions were carried out in NW Vietnam (Dusar, 1994; Lagrou, 2001), which show that the caves often exhibit multilevel or multi-step pattern, e.g. they are composed of horizontal passages, each develops at a respective elevation and connects to each other by vertical shafts. Each level corresponds to a change in groundwater discharge point in the geological development history of the region. The lowest level is relatively equal to the local erosional base. Furthermore, it is shown that the vertical cavern shafts often coincide with the intersection location of two faults or fractured zones (see the Queen Cave in Lagrou *et al.*, 2001). The elevation of the Hang Village, Pon Swallow Hole, Khau Muong Sinkhole, and Lan Trong Resurgence is 240 m, 160 m, 480 m, and 145 m a.s.l., respectively. The elevation of the Ma Tributary is the same as the Lan Trong Resurgence and is considered as the local erosional base. Comparing the elevation of Ma Tributary with the Pon swallow hole and the Lan Trong Resurgence, it is assumed that the Pon – Lan Trong cavern passage is relatively horizontal and is located at the local erosional base. As the elevation of the Hang Village elevation is much higher than the Pon – Lan Trong passage, it is estimated that there is at least a jump-down in elevation from the Hang Village level to the local erosional base of the Pon – Lan Trong passage. The jump-down can take place in one or several vertical cavern shafts, which might exist somewhere along the NW-SE trending fault segment between the Hang Village and the Pon Swallow Hole. The passage between the Khau Muong Sinkhole and the Pon Swallow Hole is considered as one of the branches of the system. This passage starts at the Khau Muong Sinkhole and develops along the crashed zone of the NE-SW trending fault towards the Pon Swallow Hole (Fig. 1). This swallow hole is located in a doline, where is also the intersection of the NW-SE trending fault and the SW-NE trending fault. Based on the common cave development pattern discovered in NW Vietnam, it is estimated that somewhere nearby there is a vertical shaft connecting the Khau Muong cave development level to the main conduit level.

A relatively large sump is found a few meters beyond the swallow hole. The groundwater flowing from the Hang Village and the Khau Muong Sinkhole is temporarily ponded in the sump and subsequently drains towards the Lan Trong Resurgence. During extensive rainy periods, the doline is often flooded. A possible explanation for this is the inflow volume of water from the Hang Village and Khau Muong Sinkhole is larger than the conveying capacity of the main conduit segment between the Pon Swallow Hole and the Lan Trong Resurgence. Therefore, it is concluded that the sump acts as a high hydraulic resistance, which delays the water movement from the Hang Village and Khau Muong Sinkhole to the Lan Trong Resurgence.

3 Tracer experiment and break-through curve analysis

During the rainy season of the year 2003, 600 kg of common salt (NaCl) was used as the tracer and injected to the Khau Muong Sinkhole (Tuy *et al.*, 2003). In the Lan Trong Resurgence the tracer sampling was undertaken at the same time as the tracer was

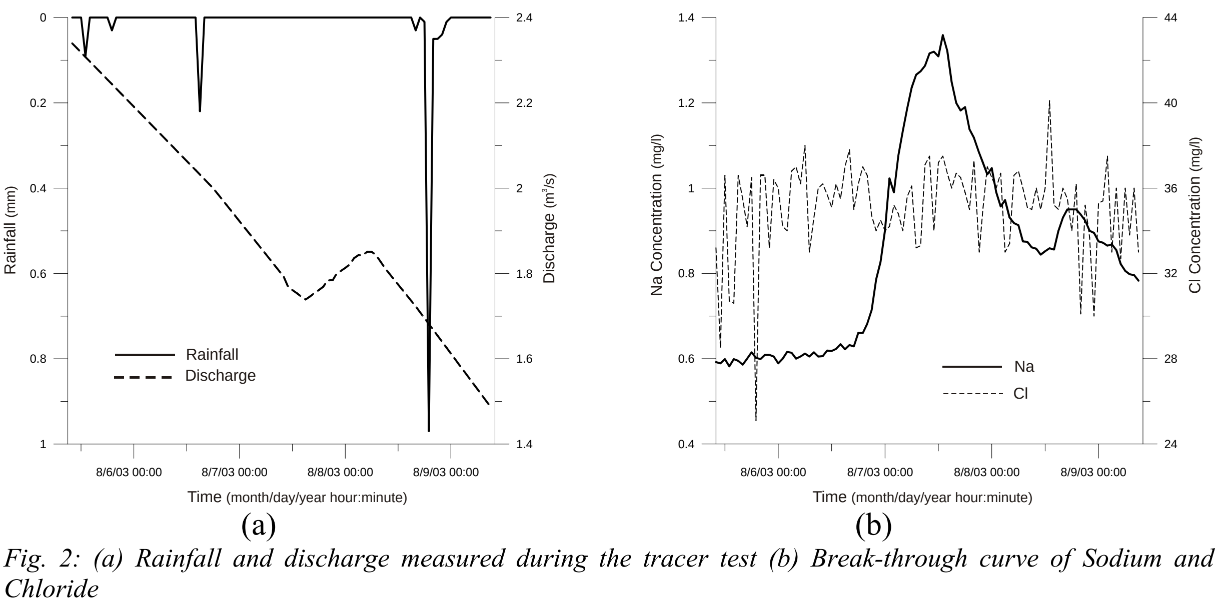

Fig. 2: (a) Rainfall and discharge measured during the tracer test (b) Break-through curve of Sodium and Chloride

injected. Time interval between every sampling is one hour and the sampling lasted for four days. One day before the experiment there was a light rain which caused the resurgence discharge slightly increased. During the sampling campaign, the rainfall and the discharge was monitored by automatic reading devices installed in the Lan Trong Resurgence (Fig. 2a). The samples were analyzed for Sodium and Chloride content by the Atomic Absorption Spectrophotometer (AAS GBC 905 AA) and the standard titration method, respectively. The sensitivity of the AAS is 0.004 mg/l, and the resulting break-through curve of the Sodium is presented in Fig. 2b. Because of poor analytic result of the titration method and maybe also other unknown factors, the break-through curve of the Chloride exhibits too much chaotic variations and no apparent peak (Fig. 2b).

The tracer mass recovery rate, R_m, is estimated as

$$R_m = \frac{M_{out}}{M_{in}} x100\% = \frac{\int_{t_o}^{t_n} C(t)Q(t)dt}{M_{in}} x100\% \qquad (1)$$

where M_{in} is the tracer mass injected in the sinkhole, M_{out} is the tracer mass recovered at the resurgence, t_0 is the fist sampling time, t_n is the last sampling time, and $C(t)$ and $Q(t)$ are the concentration of the tracer and the resurgence discharge at time t. As the background concentration of the Chloride could not be estimated, the estimation of the respective tracer mass recovery is also unable. With regards to the Sodium the background concentration is estimated at 0.589 mg/l and the respective tracer mass recovery rate is 72%. Apparently, the sampling duration is not sufficient to recover the entire mass of injected tracer (Fig. 2b). The cut-off of 28% of the injected tracer mass is assumed to be recoverable if the sampling was continued for a few days more. Therefore, the experiment is considered relatively perfect and the coefficient of tracer sorption to the conduit is almost zero.

The mean tracer residence time $\bar{t}$, defined as

$$\bar{t} = \frac{\int_{t_0}^{t_n} tC(t)Q(t)dt}{\int_{t_0}^{t_n} C(t)Q(t)dt} \qquad (2)$$

gives relevant information on the time required for the centroid of a nonreative pollutant mass spilled in the vicinity of the injected tracer to be discharged. For the Khau Muong – Lan Trong conduit system, the mean tracer residence time is estimated at $\bar{t}$= 47.37 hrs, and the karst conduit volume, defined as

$$V = \int_{t_0}^{\bar{t}} Q(t)dt \qquad (3)$$

is 124770 m^3.

The Péclet number, a measure of the relative contribution of mechanical dispersion and diffusion to solute transport, is estimated at 0.66 for the conduit system under investigation. This value indicates that diffusion/dispersion and advection are in transition and thus approximately equal to each other. This conclusion is also strengthened by relatively low value of mean tracer velocity, $\bar{v}$ ≈ 0.06 m/s, which is estimated by

$$\bar{v} = \frac{\int_{t_0}^{t_n} \frac{1.5x_s}{t} C(t)Q(t)dt}{\int_{t_0}^{t_n} C(t)Q(t)dt} \qquad (4)$$

where x_s is straight-line distance between the Khau Muong Sinkhole, the Pon Swallow Hole and the Lan Trong Resurgence. The coefficient of 1.5 is taken into account as the average sinuosity estimate of the travel distance of the tracer from the sinkhole to the resurgence.

Ideally and theoretically, the tracer break-through curve should have a positive skewed bell shape corresponding to the Fickian one-dimensional transport equation described bellow

$$\frac{\partial C}{\partial t} + v(t)\frac{\partial C}{\partial x} - D_L \frac{\partial^2 C}{\partial x^2} = 0 \qquad (5)$$

where $D_L = \alpha_L$ x $v(t)$ is the longitudinal dispersion, α_L is the longitudinal dispersivity, and x is the distance variable. Equation 5. describes the variation of pollutant concentration in time and space, provided the injection is done immediately (Dirac injection). However, the tracer break-through curve of the Khau Muong – Lan Trong conduit system shows two peaks as though two sources of tracer of were injected, the second injection

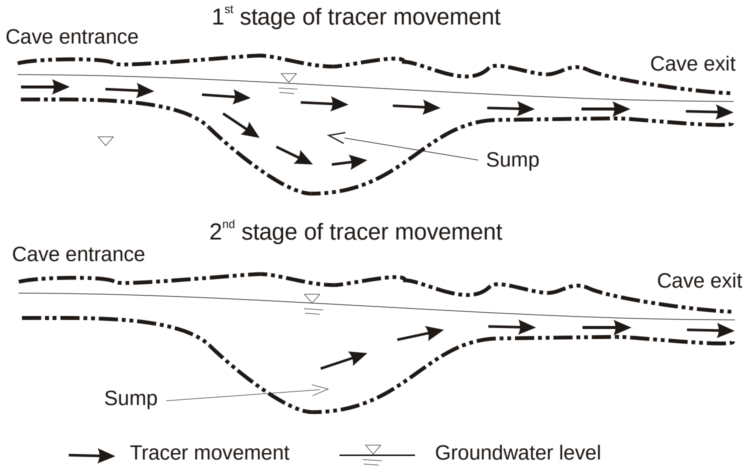

Fig. 3: Schematic illustration of the tracer movement in a conduit system having a sump

comes after the first injection about 35 hrs. As the common salt was certainly injected only in the Khau Muong Sinkhole, the "second injection source" is interpreted as the portion of the salt trapped in the sump. That is, upon the injection the salt starts movement through the conduit system; not entire volume of injected salt move straight and immediately to the resurgence but a certain portion is trapped in the sump when the solution fluid passes there (1st tracer movement stage in Fig. 3) and is subsequently released as the second injection source (2nd tracer movement stage in Fig. 3). The resulting break-through curve likely shows a superimposition of the curve yielded by the injected source and the curve yielded by the trapped source which starts at the above-estimated delay time. However, it is not expected this trapped portion of salt to exhibit a second skewed "bell" peak as described by Eq. 5 since this source is not a true Dirac injection. Instead, the peak shape caused by this source should be flatter than the theoretical shape because the trapped solution is gradually released.

Finally, the duration for the salt to transport from the Pon Swallow Hole to the Lan Trong Resurgence is estimated as the subtraction of the delay time from the mean tracer residence time, which is equal to 12.37 hrs.

4 Conclusions

The analyses on geostructure – cave development and tracer break-through curve show that there exists a sump in the Khau Muong – Lan Trong underground cavern conduit system. This sump is associated with a vertical shaft which appears in the intersection location of two fault system. Furthermore, this sump acts as a high hydraulic resistance to delay the groundwater movement from the Khau Muong Sinkhole to the Lan Trong Resurgence. A portion of the tracer injected in the sinkhole is trapped in the sump as it passes there. This quantity of tracer is subsequently released, forming the second peak of the break-through curve. This study result shows that a multi-peak tracer breakthrough curve is likely an indication of a multi-level cave system.

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INTERPRETATION OF RECOVERY TESTS IN FRACTURED AND KARSTIFIED LIMESTONE IN NORTHWEST VIETNAM

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Keywords: Vietnam, carbonate rocks, pumping test, recovery test.

This paper presents an application of the double-porosity concept and the Cooper-Jacob straight-line approximation in an interpretation and analysis of recovery tests in fractured and karstified limestone in NW Vietnam. Based on the occurrence of two parallel straight lines in semi-log plots of drawdown vs. pumping time and residual drawdown vs. recovery time, a method was developed to calculate hydraulic properties of the fractures and the matrix blocks. Early-time drawdown is related to a water release from fracture storage while late-time drawdown as a consequence of a release from both fractures and matrix blocks. Both media share a conductive property of the fractures. The drawdowns of early- and late times are described by the well-known Theis well flow equation, and under appropriate conditions can be approximated by the Cooper-Jacob approximation, resulting respectively two parallel straight lines. Relevant equations are derived for residual drawdown on the basis of the principle of superposition, which facilitate a curve-matching method to calculate principal aquifer characteristics, such as recovery transmissivity and storativity.

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KARST ON CAYMAN BRAC

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Cayman Brac is a good example of a small oceanic carbonate island that has experienced cycles of submergence and emergence during the Tertiary and Quaternary. It is well karstified at the surface and underground. During three Tertiary cycles, carbonate rocks were deposited – uplifted and karstified - and buried as paleokarst with caymanite fillings. The island was then uplifted with a minor tilt, and Quaternary limestone deposited on its coastal platform. It is girdled by cliffs with a marine notch at +6 m, the Sangamon (125 ka) high sea stand. Phytokarst is well developed on the coastal platform and the interior plateau.

Caves occur all over the island. Most prominent are (i) Notch caves, developed at or 1-2 m above the notch, and (ii) Upper caves, at varying elevations higher in the cliff faces. Notch caves and some upper caves accord to the flank margin model of speleogenesis for small islands, but speleothem dating indicates that many at the Notch are, in fact, >400 ka in age, having developed at a previous high sea stand.

There has been speleothem deposition and dissolution in all caves. Major dissolution and bedrock facetting is attributed to cycles of condensation corrosion, which are modelled from field meteorological and hydrochemical data. “Bellholes”, (a rare, very distinctive negative form in caves) are attributed to microbial activity utilising condensation waters in entrance twilight zones.

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RADICAL CHANGE IN THE ATTITUDE TOWARDS WATER SUPPLY: THE BIRTH OF A "PUBLIC SERVICE"?

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1 Introduction

The aim of the proposed study is to analyse the impact of the realisation of three drinking water supply systems in Bon Phang commune (Tuân Châu district, Son La province, N-W Vietnam). Two of these systems were built in the context of a Vietnamese-Belgian Karst project (VIBEKAP) that ran between 1998-2003[1]. The aim is:

- To analyse the **nature and extent** of transformations that are induced (directly or indirectly) by the realisation of the two drinking water supply systems.
- To **compare the local experience** of water management with the "National Rural Water Supply and Sanitation Strategy" (NRWSS).
- To analyse the **dynamics** of these transformations (the learning process).

2 Water supply in Bon Phang commune

Traditional water supply consists in local people getting water from karst springs and non-karst creeks. The water is not processed or filtered. For the 16 villages of the commune, there are five perennial springs, three temporary springs (June to September) and seven water creeks. During the dry season water quantities significantly decline and in some parts of the commune this results in severe water shortage. The cartography of the water resource and human establishment show that while the villages in a commune follow the geographical setting of the sources, in return in some cases, there is a discrepancy between the arrangement of water points and village unit, i.e. some water points are being used by several villages whereas the other ones by only a part of a village.

Three water supply systems were constructed since 2001:

- A CERWASS/UNICEF large-scale top-down project (2001) serving the Bon Phang central valley (Long Ngo source). A full piped water supply scheme to 280 individual households in nine villages (7 of the central valley and 2 outside).
- Two small-scale water supply systems by VIBEKAP / UNICEF (2001) in Nam Tiên (128 households) and Noong'O villages (61 households) based on a participatory approach. The proposed target villages of Nong'O and Nam Tiên are located in a slope land area, out of the reach of the central valley water scheme. Water supply problems in this area are more stringent than in the valley. The situation in Nong O (Thai village, counting 62 households and 330 inhabitants) does not pose any particular problem: the source has an important and regular flow, which largely satisfies the water requirements of the inhabitants. The only true constraint is that the source is also used to irrigate one hectare of rice plantations located downwards. The water supply network feeds each house. The situation in Nam Tiên village (Kinh village, counting 128 households and 650 inhabitants) is much more complicated. The flow of the source is low and the number of households high. In this case, the feasibility to supply water to all inhabitants depended on two main factors: the feasibility (capacity) to store water; the mode of water distribution between the households. At the end, like in Noong O, the water supply network feeds each house.

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Text Box 1: General design and functioning of private water supply facilities

- The collective backbone of the system consists of one or more large water collecting/pressure regulating tanks, a filter system and large water pipes.
- Individual house connections branch from the main system. Households pay themselves the cost of the individual connections (pipes, water meter and tap): 100.000 VND[1]
- Water is paid for depending on the amounts consumed. The payment arrangements may vary from village to village. The price per water cubic meter initially varied from 200 to 500 VND.

Radical change in the attitude towards water. More important than the purely technical aspects of change are the changes in attitude towards water use and supply:

- Once the systems are in place, access to water is more regulated (limited) than before and users have to pay for water, a resource which until recently was free of charge.
- Users and technical services enter into a new type of contractual relationship, type “public service”.

In order for the new approach to be successful, changes in attitude are required from both users and administrative/technical services. Of course, the introduction of the new approach necessitated a transition period of trial and error, in particular with regard to modes of payment and management. Several questions could be raised which are of interest from an academic as well as a practical perspective: 1). From the technical service point of view users do not pay for water as such, but for the “service”. Do users perceive this in the same way? 2). Which kind of local organisation is able to manage the system? 3) To install this local organisation, to what extent there is real coordination between the different stakeholders? 4) Will it amplify or reduce existing socio-economic differences between households / villages / communes?

3 Evolution of the national policy on rural water supply

3.1 Some preliminary key findings

Dissatisfaction about collective water supply facilities. Until recently, all government-initiated water supply projects implied the construction of collective systems (with public tanks and basins). Technical services as well users cite numerous disadvantages of these collective systems: poor level of investment, maintenance and management leading to rapid degradation of the system and the water quality.

Increasing demand for private water supply facilities. Technical services as well users increasingly favour the realisation of private house connections. Based on experience with a limited number of such facilities already in place (Text Box 2), technical services mention that maintenance of the collective parts of such systems markedly improves, that water is used more economically and that the collection of water consumption fees raises funds that allow proper maintenance/modernization of the system and remuneration of a management committee. Private house connections would furthermore gradually improve hygiene conditions (construction of private bathrooms/latrines).

3.2 The “National Rural Water Supply and Sanitation Strategy” (NRWSS)

The Vietnamese policy on rural drinking water supply is undergoing a profound evolution, spearheaded by the formulation of a “National Rural Water Supply and Sanitation Strategy (NRWSS)”.

Text Box 2: **Principles and guidelines of the National Rural Water Supply and Sanitation Strategy (2000 –2020).**

- Community participation: users are placed at the centre of the strategy.
- Effective information, education and communication (IEC) programmes, integrated at grass roots level, started before the planning or construction of RWSS facilities.
- Demand responsive approach: after being properly informed, users decide on the service level, technology and the management they want for their RWSS facility.
- Users (with the exception of the poor) will pay the majority of the construction costs and all users will pay 100% of the operating costs.
- Effective ownership and management arrangements shall be put in place for all

[1] 1 USD = 15.500 VND; 1 €uro = 19.000 VND

RWSS facilities that are intended to serve more than one household.

- Competitive tendering shall be the basis for future construction.
- Appropriate technologies supporting the development objective shall be promoted.
- Flexibility: NRWSS recognizes the particular need to develop appropriate regional guidelines for mountainous/karstic limestone areas.

3.3 Decentralisation: transfer to users

The responsibilities are decentralized to the provincial level which is supposed to manage and to implement the national strategy. Because of the distance from the provincial centres, the district plays the intermediary role. At commune level, the people's committee is responsible for the coordination and implementation of the RWSS projects in coordination with the users, groups of users, mass organizations (especially the Women's Union). At village level: the village authorities represent a vital link between the people's committee and the users which organize themselves into groups of users. When the users finance the major part of RWSS projects, they are always regarded as owners of the systems (NRWSS, 2000, T 1: 19)[1]. They are fully responsible for the exploitation and management of the systems. Nevertheless, in case the users do not have the necessary expertise, a formal and qualified expert will be made available to protect them. Moreover, concrete regulations are formulated, for instance those on quality of the construction, water quality and type of chemical treatment. And a professional guidebook is put at the disposal of the districts.

4 Participatory process in Bon Phang commune

In the case of the construction of the two water supply systems in Nam Tien and Nong'O a participatory approach was followed. Like in most development projects, the emphasis was given to the active participation of the population in different stages of implementation (through meetings, interviews, participatory video, etc.). From this experience can be learned:

The process of meetings held with different stakeholders involved in groups or in plenary sessions has given rise to intensive exchanges of opinions on the raised problems as well as on the diversity of everyone's proposed solutions. For this, the participatory approach is regarded as a success as it has occasioned real exchanges of information and opinions. But facing the radical change brought about by the construction of a network of drinking water supply serving each household and meeting the project's requirements in organizing the management of the system, it has also shown its limits or more exactly the impossibility to rely exclusively on this approach to solve all encountered problems.

Through a number of questionnaires that have been conducted in Nam Tiên and Noong O villages few months after the construction of water supply systems, the project could verify that the information has circulated nicely and well, given the fact that the met persons understood at least on the one hand, the applied tariffs (price of water cubic meter) based on consumption level and/or the using type (domestic – commercial) and on the other hand, the collected financial resources (remuneration of the members of management board; establishment of a fund for maintenance and repair of the systems). Thus, the concept of "service" seems to be perceived and accepted by the population: they do not pay for the water but for the access to the water supply network and service provided to each household.

A good circulation of information does not mean necessarily the collective decision-making. The review of the ratified principles in successive meetings with the population of Nam Tiên village is a striking evidence of it. The readjustment of water prices as well as the composition of the management board have been approved unilaterally by the local authorities without any prior consultation with the public; this does not go in the direction of a transparent functioning. The general tendency in the three systems under consideration is to confine the role of the management board in a simple mission of technical check/monitoring and collection of funds whereas the power of decision-making and management is seized by the local authorities.

[1] NRWSS (2000). *The strategy report*. Volume 1. NRWSS, Hanoi.

5 Rural water supply: interest and limits of the local management

To the extent that the procedure adopted by the project shows numerous similarities to that defined by the NRWSS and advocated by UNICEF/CERWASS in the "Guidelines for preparing, implementing and operating a community-based clean water and sanitation improvement plan", the still partial results of the study conducted on a number of systems implemented in a karstic area are beyond the strict framework of the studied examples.

5.1 Self-financing and technical choice: "participatory" approach

The focus that structures the NRWSS is to give a very large autonomy to the local level perceived as the level of users in the village and commune. It is specified that the users bear most of the construction costs and all costs incurred by the maintenance and operation of the system. However, construction costs will be partly subsidized for the poorest villages by the national fund established for this purpose. It is indeed hardly possible in a mountainous area and for the poorest communes, i.e. the villages with 50-100 households to afford the costs of up to hundreds of millions VND for the drinking water supply network serving individual households. According to this logic, the appropriation and responsibility taken by the population for the systems are assured especially by the users deciding on the nature of technical arrangements they wish to build up in their own village or their commune after receiving the information (IEC) required for this choice. Then, two questions arise:

If it is considered that the population has to pay most of construction costs, is it a real option for them be concerned for access to quality water meeting standard norms? As a matter of fact, the households of a village are not much likely to accept to partly self-finance the costly infrastructures aimed at ensuring the supply of quality water (filter tank, chemical treatment) as far as the cost of such infrastructure seems to be out of proportion to the improvement that the farmers will experience from these infrastructures. The villagers often express to us this way of thinking: *my father, my mother and my ancestors had been drinking this water and they had never been sick"*, implying "*we do not want this structure if we have to pay for"*.

The intention to make the population "choose" has become the "obsession" of the new strategy. However, if the wish for technical adaptation to local conditions is a desirable orientation that one can only approve, it doesn't mean that the population has the technical expertise of choice. Our experience showed that most of the technical options and alternatives are not and could not be the population's work but that of the experts (engineers, etc.): if people wish to adopt a participatory procedure, it seems that the stake is elsewhere (see the third point).

In brief, one can doubt the fact that the involvement as means to increase the appropriation and responsibility of the population for the systems is the unique and infallible remedy to the encountered problems. Financially, could this much-expected involvement be a form of disengagement from a burden that would preferably rest upon the shoulders of the population?

5.2 Maintenance: capacity of financial and technical management

In following the logic of the above point, the NRWSS designates the "community" and the group of owners as the people fully responsible for the operation of the systems in place: if a financial support could be provided for the construction in the poorest villages, in return, the principle of full responsibility of the population for the maintenance does not suffer any derogation either arrangement. Our experiences show that if the local management by the intermediary of management board or a group of users (NRSWSS) seems to us a key factor of the sustainability of the systems, it is not able to take up this mission alone and at all events. On the one hand, they do not have the technical competence required for ensuring the good functioning of the systems. On the other hand, even if the users regularly pay, the collected money does not allow coping with all breakdowns.

5.3 Local autonomy and public service: seeking a compromise?

As we have already emphasised it, it does not mean that the village or commune level does not constitute a suitable scale for ensuring the management of the systems but it means that this level is not able to satisfactorily manage it alone. The reason for this could be stated as follows: the organizational, technical and financial resources are not all available at local level and could not be fully mobilized and assumed by this level.

Like in health care, power supply and education, there is an economic-scale intervention in here. This is not absolutely profitable nor predictable at village or commune level but it could become profitable and predictable at the scope of a group of communes or a district: an engineer specializing in water supply management could not be remunerated by a single commune nor assigned solely to the service of a commune. The need for establishing a network of competences with their coordination and complementariness plots the contours of what is called "public service".

In our opinion, the relevance of the participatory approach is in the process of devising a "public service". Instead of focusing on technical and financial choices which finally accept only a very few distortions and arrangements, why not to explain these choices for concentrating on the main stake that is the creation of a system based on the principles of mutuality and partnership (multi-collaboration approach). In this setting, it is more correct to talk about negotiation rather than participation, certainly because the negotiation between the stakeholders and the most successful form of participation. Thus, for instance, if the users are asked how much they pay for the supply of a water cubic meter of water, the answer is obviously "the least possible" or even "nothing". In return, the process of negotiation comes back to say: the maintenance and repair of the systems represent a cost that we value at so much; in the price of water to be fixed by you, if you don't take into account this component, you will take the risks and so do we. So, as partners and stakeholders, we have all requirements to be negotiated and adapted in order to come to an acceptable compromise because can not build anything without guarantees: the written commitment of different partners is the last and formal step which sanctions the agreement.

Contrary to the dynamic of growing autonomy, the emergence of a "public service" based on a dynamic of integration to the extent that such service can only work from an organizational, economic and technical viewpoint by establishing a network of competence and creating the relations of interdependency between partners. A step forward in this direction would be the definition of a guiding diagram for local management of the systems, a real book of responsibilities to which, each of the partners would subscribe as prior condition for all construction of water supply system. At the end of negotiation process, the rules and principles would be specified by accepting no arrangement and they will be applied just as they are on the regional and even national territory and what are those which in return can be adapted to local conditions (adaptations defined within the framework of a process of negotiation held at this level). The framework and scope of this balance "central management/local specific management" would be defined and specified according to the wanted involvement by the State. It would be possible, for instance to anticipate the establishment of minimum remuneration of water: application of tariff floor for the whole country, by geographical and cultural zones, etc. It would be also possible to adopt the principle of repayment to the State technical structures (at provincial and district levels) from a portion of monthly collected funds (10-20%) on each network in compensation for what they have to do to make a specialized engineer available in case of breakdown and to take charge of the cost of repairs exceeding the financial affordability of the locality, etc. This logic of interdependency implies, inter alia, that a financial statement for the functioning of drinking water supply is presented periodically not only to the users but also to the higher level structures of management.

6 Conclusion

Within the framework of drinking water supply to the rural population, in our opinion there is no fundamental contradiction between a local management based on certain autonomy and the insertion of local management in a larger framework being the only one that is able to guarantee a legitimate (legal and institutional) existence and sufficient capacity of functioning to ensure the sustainability of the systems. The compared evolution of the functioning of three water supply systems in Bon Phang underlines neatly the fact that the geographic isolation of remote villages and communes in mountain area should not lead decision makers and international donors to choose a fully autonomous policy regarding the functioning and management of collective services meant to meet the elementary needs of the population.

The notion of “public service” rests on the creation of networks of technical and organisational competences and the implementation of financial and human means which are not fully available at the local scale, and which correspond to the mission of the state, which is to work for general interest.

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GEOHYDROLOGICAL CHARACTER, WATER SUPPLY POTENTIAL AND QUALITY OF SOME KARSTIC SPRINGS IN TAMDUONG TOWN

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Abstract. Tamduong is a mountainous town in NW Vietnam, a cultural, political, and economic centre of the Tamduong district, Laichau province. It has a high population density. In future, Tamduong is planned to be the capital of the new Laichau province, furthermore Tamduong also lies on the important tourism route of the NW, therefore totoal water volume that is required to supply for drinking, production, industry, and other activities will considerably increase compared to the present. The searching and assessment of water sources, proposal of measures for reasonable exploitation, use, and protection of water resources are requisite and urgent for Tamduong in the present and future. Our initial results provide the bases to speak about the water richness of the Tamduong karst aquifer which is characterised by the shallow watertable; groundwater even resurges on the surface in some places. Although the water has generally a good quality, some sources, which have been used as drinking water, are contaminated. Besides, deforestation in catchment is alarming and reducing the water reserve of the studied area.

1 Physical geography of Tamduong Town

Tamduong Town lies on a vast karstic polje developed in NE–SW direction. The bottom is at 900m asl and rather flat; there are the conic or tower karst hills. In the northeast are the dissected mountains with deep and narrow valleys and steep slopes, many peaks over 3000m belonging to the Phansipan mountain ranges. In the southwest is the Lungcu–Nungnang mountain range with many peaks of nearly 3000m. The area covers a natural depression slightly tilted in NW–SE direction.

Since Tamduong lies on an area of strong karstification, the surface drainage network is poorly developed because surface streams do not stay long on the surface but quickly go underground through the sinkholes to the underground courses. These underground courses resurge when encountering favourable conditions that produce the high, stable, and permanent discharge springs in the two margins of the Tamduong karstic polje. This is the main water source for supplying drinking water and economic activities of Tamduong town.

The regional climate is evidently divided into two seasons: rainy and dry seasons. Total yearly rainfall is 2670mm (Ly Van Nau, 1991; Climate of Laichau province. *Laichau climate station, Dien Bien Phu*) in which rainy season rainfall is 80-85% of the total yearly volume.

The rainy season lasts from April to October; mean temperature is 18–27^{O}C. Dry season lasts from October till April. In the dry season, precipitation is low, it is cold, mean temperature reduces to 9-17^{O}C; there is a lot of fog and drizzle.

Vegetation cover is sparse, the dense forest almost does not exist due to the extensive deforestation for upslope fields, exploitation of forest products and fire woods; forest only remains in the tops of the high mountains, other areas have scrubs and grass.

In the area, a main route is the road N^{O} 40, this is an important route in the town. In Tamduong a new route to Sinho facilitating the economic circulation for the town is being built; the rest is the inter-commune, inter-village roads, connected with each other by the tracks; travel still meets a lot of difficulties.

The population is dominated by the Thai, Kinh, H'Mong, Dzao, and Hanhi. The Kinh and Thai people normally inhabit along the main roads and live on trade, water rice growing, working in the national offices and the other jobs. Other minority groups often inhabit far from the centre, in remote villages and live principally on the upslope cultivation. Manual exploitation of mineral deposits (slate, sand, limestone…) is performed in some places. National electricity network is already set up in Phongtho town; other areas use small generators. In general living standard is improving; however in the remote villages people are still encounter much hardness.

2 Geohydrology

Tamduong town lies on an anticlinal structure directed NW-SE with a core of Lower Triassic terrigenous rock; its flanks are Donggiao limestone (T_2a*dg*). A strong karstification produces the sinkholes and underground caves with good water storage. The SE flank of the anticline is rather gentle so resurgences are mainly there. The caves in this area are also less deep and there are many horizontal ones. The NW flank gradually becomes steep and natural resurgences are not seen as in the NE flank. According to the cave data (from Belgian-Vietnamese speleological expedition), the caves often develop into the deep vertical shafts. This proves that groundwater level is deep, corresponding to the karstified level. There are many deep caves such as Hang Doi nuoc (-298m), Silengchai (-300m), and Congnuoc (-600m).

Geohydrological character in Tamduong town can be divided based on the existence, movement, and the richness of groundwater as follows:

Porous water: This type is stored in the pores of the Quaternary loose sediments that consist of gravel and cobbles in both margins of the Tamduong karst polje and along Nampe, Namde Rivers. Water is rich and discharge is seasonally varying (such as the resurgence 10110205 in dry season discharge is normally less than 0.1 l/ sec., but in rainy season it becomes rather high, and often runs out on the surface). Water is clear, no color, no smell, with a sweet taste; temperature is 20-21^{O}C, pH 7.5-8. The local people however do not use or rarely use this water since the groundwater level is shallow, permeability and movement of water are good but infiltration is bad so it is easy to be vulnerable by living, industry, and agricultural wastes. The supplying source is mainly rain and surface streams.

Fractured water bearing strata: Water exists in the rock fractures that are generated by tectonics or during the diagenesis, of in the fractures developed along the bedding planes of the sediment layers. The water bearing formation of this type, include Tanlac (T_1o*tl*), Nammu (T_3c*nm*), Suoibang (T_3n-r*sb*) and Yenchau (K_2yc) formations. Those are the terrigenous formations with bedded structure, numerous fractures in the rock. However, only do the near surface fractures as well as the ones along the cataclastic tectonic zones are possible to hold water; at the same time water storage in the strata is also limited. The previous studies did discover hardly any resurgences in these formations. The VIBEKAP studies have discovered some resurgences but with small discharge and only in a type of leakages from the weathering crust. In the resurgence N^{o} 28 that occurs in the shale cataclasistic zone, Q = 0.3 l/s; in resurgence N^{o} 02 that was monitored in November 2002 Q = 0.2 l/s, water is clear, no color, no smell, pH = 7.5, T^{o}= 23 ^{o}C but this resurgence does not exist in the dry season (surveyed in April 2003). It can be said that this strata is very poor; the main supply is rainy water; in the dry season almost no water exist in the strata.

Karst water: Some important karst springs concentrate around the Tamduong town. They are in Donggiao formation (T_2a*dg*) that consists of light grey or sometimes pinkish limestone and clayish limestone. This is a water rich stratum. Discharge of the springs is rather large, from 4-18 l/sec. Water is discharging all year round, is clear, no color, no smell, and sweet taste, pH 7.5-8 (Photo 2).

The karst underground water is mainly supplied by the surface water from denudation areas and rainy water. It directly relates to rainy water because the discharge often increases at heavy and long rains.

3 Characters and environment status of water sources

During geohydrological monitoring from 4 till 15 October 2002, we investigated some important karst springs around the Tamduong town. We have measured and taken samples from these springs.

The ground springs around Tamduong town all resurges from the fracture systems and caves. Discharge is rather large and more specifically the resurgences exist all year round. In rainy season, discharge considerably increases and in dry season, it falls.

Measurements and calculation of discharge of the resurgences show that total discharge of the resurgences is rather large (4230 m^3/day). This total discharge can well meet the demand of water use for Tamduong town if there is a proper planning and use of water.

The resurgences are sampled for the analyses of drinking water criteria with a comparison to the Vietnam's standard for drinking water.

From the analytical results and national criteria of quality for groundwater standard supplied for drinking it is shown that all the resurgences around Tamduong town are within the permitted limit ensuring a healthy supply except the only sample NO 08110211 (Huyen Uy source) is contaminated with Coliform which does not meet the standard of quality. This bacterial contamination is due to that local people dammed the resurgences for their bathing right in the resurgence. Water is not drinkable, it needs to be boiled.

4 A proposal of measures for proper exploitation and protection of water resources

Water for all people and economic activities in Tamduong town is supplied from the karst springs (4230 m^3). These karst springs therefore are very significant to life and living. To ensure their permanent supply and healthy quality, it is needed to have proper measures for protection and use:

- Building of storage tanks around the karst springs
- Cattle are not carelessly bred but must by separate from the springs (Photo 1).
- Do not install waste houses and sewages near the springs.

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HYDROGEOLOGY AND KARST GROUNDWATER QUALITY OF NGOCSON - NGOLUONG REGION

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Abstract. In general, the limestone regions are short in surface water but abundant in groundwater, the reasonable exploitation and use of karst groundwater for the living and other supply activities are considered to be very important. The region is severely short in water in many locations, but very rich in some others. The karst groundwater sources are also seen as very sensitive to the contamination agents due to their impermeable bed of the aquifer. The studied region carries such a hydrological character. From the researches, we present some aspects of the hydrogeology, the richness as well as water quality status.

1 Location

The studied region includes 6 communes belonging to 2 districts of Lacson and Tanlac (Hoabinh province). Those are the Ngoclau, Ngocson and Tudo communes of Lacson district (the Vuban mapsheet, F-48-127-D), and the Bacson, Namson, and Ngoluong of Tanlac district (the Maichau mapsheet, F-48-127-A) of Hoabinh province. It is limited within the coordinates: $20^0$30’48” - $20^0$40’12” N, $105^0$00’79” - $105^0$30’53” E

2 Physical geography of a studied region

This is a region composed of mainly limestone with seriously rugged topography of peak cluster-depression type, altitude increasing from SE to NW from 400m to over 1000m; the slope is often very steep and almost vertical in some places forming the elevated mountains compared to the Hong river deltaic plain in the NW and the Ma river plain in SW. Pinched between the limestone mountain ranges are the non-karst strips very narrowly distributed having a rather mild topography of the denuded hill or hilly series, or the valleys of Namtham (T_2nt_1), Tanlac (T_1tl) formations. This is a place with favourable terrain for settlement and farming of the local inhabitants. Transport system is still difficult but considerably improved; roads to commune centers and villages can be reached by cars or motorcycles; communication and commodity exchange are convenient in general. Climate is divided into two distinct seasons: rainy and dry seasons. Rainy season frequently starts from May to October, and dry season from November to April.

Karstification produces the fractures, caves, and the sinkholes being capable of well draining so surface streams are very limited except some calcareous shale strips of the Namtham formation (T_2nt_1) that is a non-karst formation. Since its outcrop area is not large, the surface streams are often very short and impermanent. They often appear in rainy season and abandoned in rainy season such as in Namson, Bacson, Ngoluong, Tudo, Ngocson and Ngoclau. Surface streams often quickly disappear into the sinkholes supplying the deep karst aquifer.

3 Geostructure

Studied region is a part of the Da river rift structure with 4 main units including:

Conoi formation (T_1 cn)

This formation distributes mainly in the two NE and SW margins of the studied region in Tudo, Ngoluong communes forming the long strips in a NW-SE direction. It consists mainly of small-grained non-carbonate sediments such as shale, sandstone, and siltstone. It is thinly bedded, grey, light grey, and yellowish colored; in some places it is intercalated with calcareous shale, lenses of limestone; total thickness is up to 660-860m. It conformably underlies the Donggiao formation while the boundary is indefinite. The formation has been studied in detail by many authors. (Nguyen Dinh Hop *et al*., 1994; Hoang Ngoc Ky *et al*., 1976) and determined as Early Triassic age according to paleontological and lithological criteria and stratigraphical relations. In respect to the hydrogeology this is a main impermeable stratum of the region.

***Donggiao formation* (T$_2$*adg*)**

The Donggiao formation widely distributes in the studied area forming the immense limestone belts in a NW-SE direction. It is divided into the two sub-formations (T$_2$adg_1) differed from each other by its bedding and clay contents. The lower sub-formation consists of mainly clayish, thinly bedded limestone of 420-500m thick. In upper sub-formation (T$_2$adg_1), limestone is purer, thickly bedded to massif of 500m possibly thick and a sounder karstification. The formation has been set up by Pham Van Quang (in Dovjikov A. E., 1965 as an editor-in-chief) and later supplemented by many others (Dinh Minh Mong *et al*., 1974; Hoang Ngoc Ky *et al*., 1976 etc.). This is a formation mainly composed of limestone of shallow marine facies containing Anisian fossils and conformably relates with the Namtham formation above. Donggiao formation is considered as the main water-borne unit in the studied region.

***Namtham formation* (T$_2$l *nt*)**

The Namtham formation distributes in the center of studied region with the long bands in a NW-SE direction. It is composed of two sub-formations. The lower sub-formation (T$_2$lnt_1) is met in Ngocson - Ngoclau area; thickness reaches 430-660m including shale, calcareous shale, lenses of limestone, siltstone. It is strongly crumpled to micro folds. Similar to Conoi formation, it can be considered as an impermeable unit. The upper sub-formation (T$_2$lnt_2) is mainly composed of siliceous limestone, thickly bedded limestone and intercalated with shale, sericite shale in some places, 170-340m thick. The Namtham formation has been defined as Ladinian age by many researchers according to paleontological, lithological criteria and stratigraphical relations (Nguyen Dinh Hop *et al*., 1994). In the studied region it conformably underlies the Donggiaon formation. Similar to Donggiao limestone this can be seen as a water-borne unit.

Quaternary loose sediments.

These are formed mainly along the small streams with varied thickness of 1 - 15m; origin is mixed from deluvium to proluvium with sand, silt, and some gravel, debris.

The Ngocson - Ngoluong region has a structure of a complicated syncline. The syncline is constituted by Namtham formation (T$_2$l*nt*), the two flanks are Donggiao rocks (T$_2$a*dg*) and edges are the Conoi (T$_1$*cn*) formation; axis prolongs in the NW-SE direction. Near the fault, rocks are disturbed; dip can be over 60^0.

The studied region has NW-SE and NE-SW directed faults in which the NW-SE fault system a dominant such as the faults that divide the Donggiao 2 (T$_2$adg_2) sub-formation from the Namtham 2 sub-formation (T$_2$lnt_2). It extends in NW-SE direction for over studied region; besides this main fault region also has other faults which is also the formation-separating ones but with a small scale.

From analyses in stratigraphy, folding and faulting, some regulatory observations can be drawn for the Ngocson - Ngoluong area as follows:

- Since intercalated occurrence of small-grained terrestrial insoluble stratigraphy, the Conoi formation (T$_1$*cn*), lower sub-formation, Namtham formation (T$_2$l*nt*) with Donggiao (T$_2$a*dg*) limestone, Namtham upper sub-formation (T$_2$lnt_2), the region can form two karst aquifers. In which the main aquifer is in the Donggiao formation, the perched one is the Namtham upper sub-formation.
- Common interceptor is the Conoin formation (T$_1$*cn*)
- Interceptor of the perched karst aquifer is the Namtham upper sub-formation.
- Karst aquifers all have a prolonged structure in NW-SE direction; karst groundwater tends to move from NW to SE.
- Owing to a presence of NW-SE and NE-SW faults, the perched karst aquifer relates to the main karst aquifer. Groundwater in the main karst aquifer will resurge to certain locations at the contacts with the plain of the Ngocson - Ngoluong limestone strips. In which there can be the resurgences with a large and stable discharge all year round.

4 Character of karst springs

The author's direct surveys and speleological explorations to Ngocson - Ngoluong region indicate that the karst drainage network in the region is partially stored in the small fractures, soil cover of the epikarst, and mostly stored

Table 1: The karst springs in Ngocson - Ngoluong region

NO	**Spring**	**Coordinate**	**Altitude (m)**	**Discharge (l/s)**
1	NS 40	X: 185,13.56; Y: 2276.95	880	320
2	NS 39	X: 185,14.96; Y: 2276.78	1000	42
3	NS 41	X: 185,14.19; Y: 2276.27	910	7
4	NS 52	X:185,18.39; Y: 2270.09	810	1.15
5	NS 53	X: 185,15.79; Y: 2274.50	900	2
6	NS 56	X: 185,25.29; Y: 2268.25	680	0.6
7	NS 50	X: 185,17.99; Y: 2271.87	882	0.8
8	NS 62	X: 185,25.58; Y: 2268.09	660	0.5
9	NS 64	X: 185,23.98; Y: 2269.19	745	0.4
10	NS 68	X: 185,17.75; Y: 2275.03	865	3.5
11	TD 03	X: 18530.26; Y: 2260.54	345	2
12	TD 05	X: 18532.14; Y: 2259.38	347	7
13	TD 10	X: 18538.74; Y: 2256.95	220	2.5
14	TD 12	X: 18538.67; Y: 2257.78	420	1050
15	TD 13	X: 18537.89; Y: 2261.93	480	0.15
16	TD 14	X: 18538.02; Y: 2261.75	480	0.05
17	TD 24	X: 18535.14; Y: 2261.47	620	5
18	TD 26	X: 18542.42; Y: 2258.61	460	3
19	TD 27	X: 18541.39; Y: 2259.00	480	7
20	TD 35	X: 18542.00; Y: 2260.37	450	0.4
21	TD 36	X: 18542.92; Y: 2259.89	470	1
22	TD 37	X: 18543.14; Y: 2259.32	500	1.5
23	TD 38	X: 18543.71; Y: 2259.04	470	2
24	TD 39	X: 18539.99; Y:2259.77	485	0.8

and mobiled in the fractures, protocaves and caves. There are the underground rivers in many places such as in Namson and Bacson etc. Karst groundwater resurges to surface in the appropriate locations in the form of springs. After discharge and elevation following types of springs can be seen in the region (Table 1).

1. Springs with large discharge: These springs resurge to the surface from the main karst aquifer (Donggiao limestone, T_2adg). Typical springs are in Mu village (Q > 1.00m3/s) Coigao village (Q = 4.0 l/s), Ngoclau commune house (Q = 7 l/s). Those springs often resurge at a low position on the foot slope. Water runs all year round; discharge is very large in rainy season. Around springs are the travertine terraces, an evidence of long existence of the springs.

2. Springs with average discharge: Most of these karst springs can relate to the perched karst aquifer. Those springs relate to the Namtham (T_2lnt_2) upper sub-formation. This can be seen in the Ngocson, Ngoluong, and Ngoclau areas. Those springs have an average discharge ranging around 0.15 - 2 l/ s and often distribute along the boundary between Namtham 2 (T_2lnt_2) limestone and the Namtham 1 (T_2lnt_1) terrestrial rocks. Around those springs are often observed the travertine terraces justifying their long existence.

3. Springs with a small discharge: Those springs often relate to the perched karst aquifer and often distribute in center of the Ngocson - Ngoluong mountain range as well. They have a high elevation with a very varied discharge; some of them appear to exist in rainy season only. Typical are the springs in Ngoclau and Ngocson; their discharge fluctuates from 0.05

Table 2: Discharge, using status, and exploitation potential of some resurgences.

NO	**Symbol**	**Location**	**Discharge (l/s)**	**Using status**	**Exploitation potential**
1	NS 40	Hohai – Bacson	320	Agriculture	Average and small
2	NS 39	Hohai – Bacson	42	Agriculture	Average and small
3	NS 41	Hohai – Bacson	7	Agriculture	Small
4	NS 52	Bai hamlet	1,15	Agriculture, living	Small
5	NS 53	Xom hamlet- Namson	2	Living	Small
6	NS 56	Luongduoi – Ngoluong	0,6	Living	Small
7	NS 50	Xom Do – Namson	0,8	Living	Small
8	NS 62	Ngoluong Com. House	0,5	Living	Small
9	NS 64	Luongtren –Ngoluong	0,4	Living	Small
11	NS 68	Chieng hamlet – Lungvan	3,5	Living, farming and fishing	Small
12	TD 03	Coigao – Tudo	2	Agriculture, living	Small
13	TD 05	Coigao – Tudo	7	Agriculture, living	Average and small
14	TD 10	Khuong – Tudo	2,5	Living	Small
15	TD 12	Mu hamlet – Tudo	1050	Agriculture, living	Average and small
16	TD 13	Vang hamlet –Ngocson	0,15	Living	Small
17	TD 14	Vang Hamlet – Ngocson	0,05	Living	Small
18	TD 24	Dong village –Ngocson	5	Agriculture, living	Small
19	TD 19	Dien village –Ngocson	3	Living	Small
20	TD 26	Xe 1 village –Ngoclau	3	Living	Small
21	TD 27	Ngoclau Com. House	7	Agriculture, living	Small
22	TD 30	Khop village – Ngoclau	0,1	Living	Small
23	TD 35	Dam village –Ngoclau	0,4	Living	Small
24	TD 36	Bang – Ngoclau	1	Living	Small
25	TD 37	Bang – Ngoclau	1,5	Living	Small

l/ s to 0.1 l/ s. Additionally in the area also exist the leakages with a very small discharge (0.001 l/s) relating to the epikarst or weathering - soil crust on the non-karst areas.

5 Aquifers

Regional hydrogeology is expressed on hydrogeological map of 1/50, 000 scale. According to principle from "International Association of Hydrogeologists UNESCO" the map contain the information such as distribution areas, types of existence, the richness, and physio-chemical properties of the aquifers.

Porous water has a narrow distribution area in the inner-mountain, pre-mountain Quaternary depressions and along river valleys. In the region exists this aquifer but with an irregular distribution in Ngoclau, Ngocson, Tudo, in Bacson with a narrow area, in Namson and Ngoluong it is larger. The aquifer lithology is mainly clay, gravels, and small-grained sand in upper parts and sand, cobbles, gravels in lower parts. Thickness varies depending on the locations ranging from 1m to 15m. This is a rather water-rich stratum. Its richness seasonally changes as it is influenced much by surface and rainy water. In rainy season groundwater level rises after the raise up of river water level. In dry season groundwater clearly decreases. In some localities, people make wells for drinking water as in Ngocson and Ngoclau. This is though a relatively water-rich stratum with a

Table 3: Vietnam's Criteria for potable water quality (From Institute of Epidemic hygiene, 2002)

NO	Criteria	Unit	Maximal limit	Super-vision level
1	PH		6,5-8,5	A
2	Aluminium	mg/l	0,2	B
3	NH_4^+	mg/l	1,5	B
4	Iodine	mg/l	0,01	
5	Arsenic	mg/l	0,01	B
6	Cadimium	mg/l	0,003	C
7	Chloride	mg/l	250	A
8	Lead	mg/l	0,01	B
9	Manganese	mg/l	0,5	A
10	Mercury	mg/l	0,001	B
11	Potasium	mg/l	200	B
12	Nitrate	mg/l	50	A
13	Nitrite	mg/l	3	A
14	Total Fe	mg/l	0,5	A
15	Sulphate	mg/l	250	A
16	Phosphate	mg/l	0,7	A
17	E. coli	Coli/100 ml	0	A

good exploitation capacity, the locals do not use them. In the region only are two wells observed being dug in this stratum that are the wells in Ngocson and Ngoclau with good reserve and quality. Type of water in the stratum is calcium bicarbonate; total mineralisaton M = 20-40 mg/ l.

The relatively poor water-borne stratum in Namtham formation, lower sub-formation (T_2lnt1):

It narrowly distributes of the hill strips in Namson, Bacson, and Ngoluong. The resurgences have a small discharge, some places they only exist in rainy season. In some places there are better resurgences from the limestone and clayish limestone intercalations such as in Ngoluong and Namson. Water resurges in a form of leakage, discharge 0.02 - 0.05 l/ s (in Namson) and 1.5 - 2 l/ s (in Ngoluong). Water is of calcium and calcium-magnesium bicarbonate; low total mineralisation, M = 100 - 300 mg/ l.

Very poor water-bone in Conoi (T_1cn) sediments

The Conoi formation (T_1*cn*) distributes in the narrow bands in NW-SE direction in the fringe of the studied region. In fact it can be seen as an interceptor. Almost no resurgences are observed in this stratum; discharge is also very small and impermanent.

The water-rich strata in Donggiao (T_2adg) and upper Namtham 2 (T_2lnt$_2$) limestone:

Limestone strips of the Donggiao (T_2a*dg*) formation and the Namtham 2 upper sub-formation (T_2l*nt*$_2$) are of water rich; the Namtham 2 stratum specifically is of a perched aquifer because the bottom is the intercepted stratum of the lower Namtham 1 (T_2l*nt*$_1$). As the high karstification many caves and sinkholes etc develop. Surface streams quickly disappear underground supplying to the karst aquifers (e. g in Namson and Bacson there are the streams with discharge of 0.3 - 0.5m3/ s). In contrary in the Tudo, Ngoclau etc communes the perennial karst springs with a very large discharge (0.1 - 1m3/ s or more) are observed for instance in Coigao, Mu, Ri villages (Tudo commune), in Khop (Ngoclau and Ngoluong communes). Depth of the aquifer locally changes and depends much on structure - tectonic features. Caving results indicate that in SE Ngoluong the caves that often develop as deep as more than 100m still do not reach groundwater level (Bat, Gibbon caves in the Bo hamlet - Ngoluong). In SE Namson and Bacson commune and SW Lungvan commune karst groundwater level is at a depth 50m compared to the erosional baselevel (Gold Spot cave in Lungvan; Gold Spot cave in Bai hamlet - Namson, Hayhai cave in Bacson). In contrary in NE Namson and NE Ngoluong communes karst groundwater level locates in a rather shallow position discharging at the local erosional baselevel (Ho cave in Luongtren, Ngoluong commune; Chieng cave in Chieng hamlet, Lungvan commune, Ton cave in Ton hamlet, Namson commune). In Tudo, Ngocson, and Ngoclau commune groundwater level is rather shallow. Resurgences are all at the local erosional baselevel, along the boundary between the non-karst and karst rocks or along the faults. Water is mainly calcium and calcium-magnesium bicarbonate; low total mineralisation, M = 20 - 300 mg/ l

6 Quality and contamination status of some important

Table 4: A comparison of analytical results and permitted limit values of some elements in water in Tudo, Ngoclau, and Ngocson areas

Group	Criteria	Unit	Number of analysed samples	Value of content		Maximal limit of permitted contents	Comment on standard
				Max	Min		
Nitrogen	NH_4^+	mg/l	23	0,005	0,005	1,5	Stan. achieved
	NO_3^-	mg/l	23	3,34	0,005	50	Stan. achieved
	NO_2^-	mg/l	23	0,08	0,005	3	Stan. achieved
Toxic metals	I^-	mg/l	23	9,94	0,01	0,005	23 sam.> stan.
	Cd	mg/l	23	0,003	0,001	0,003	Stan. achieved
	Pb	mg/l	23	0,005	0,0002	0,01	Stan. achieved
	As	mg/l	23	0,0002	0,0002	0,01	Stan. achieved
Other compounds	Cl^-	mg/l	23	1,7	0,07	250	Stan. achieved
	TFe	mg/l	23	0,05	0,006	0,5	Stan. achieved
	SO_4^{-2}	mg/l	23	0,1	0,01	400	Stan. achieved
	PO_4^{-3}	mg/l	23	10,55	0,005	0,7	4 sam. > stan.

Table 5: A comparison of analytical and permitted limit values of some elements in water in Namson, Bacson, and Ngoluong areas

Group	Criteria	Unit	Number of analysed samples	Value of content		Maximal limit of permitted contents	Comment
				Max	Min		
Nitrogen	NH_4^+	mg/l	25	0,005	0,005	1,5	Stan. achieved
	NO_3^-	mg/l	25	3,249	0,005	50	Stan. achieved
	NO_2^-	mg/l	25	0,14	0	3	Stan. achieved
Toxic metals	I^-	mg/l	25	1,27	0,01	0,005	Excess of stan.
	Cd	mg/l	25	0,003	0,001	0,003	Stan. achieved
	Pb	mg/l	25	0,007	0,0002	0,01	Stan. achieved
	As	mg/l	25	0,0002	0,0002	0,01	Stan. achieved
Other compounds	Cl^-	mg/l	25	10,65	0,53	250	Stan. achieved
	TFe	mg/l	25	0,418	0,005	0,5	Stan. achieved
	SO_4^{-2}	mg/l	25	0,01	0,0	400	Stan. achieved
	PO_4^{-3}	mg/l	25	17,37	0,005	0,7	Excess of stan.

groundwater resurgences

The surveys, measurements, and sample analyses from 58 important resurgences near the settlement areas show that, most of the karst groundwater resurgences all come out from the cave and fracture systems. Discharge of some resurgences is relatively large with water all year round such as the ones in Mu and Ri villages. Most of the remaining resurgences have a small discharge, frequently exhausted in dry season such as in Bacson, Namson, Ngocson and Ngoclau. Discharge considerably increases in rainy season. The resurgences are used by the locals for living and agriculture (Table 2).

Water sample analyses show that all the water sources in the region are of tasteless (total mineralisation ranges within M = 20 - 300mg/ l), lying under permitted standards, harmless except some criteria in Iodine and phosphate that are higher than permitted standards (Table 1, 3, 4)

For each type of water, there are 3 limits symbolised as A, B, and C showing supervision levels of elements in water. Limit A shows a very strict supervision level, limit B is rather strict level, and limit C is moderate supervision level. Criteria and levels are used to assess the contamination of water taken from decision of Health Ministry dated of 18th April 2002 (Table 3). Table 4 gives some chemical analytical results for water in Tudo, Ngoclau, and Ngocson areas, Table 5 for the Namson, Bacson, and Ngoluong areas. Most of water samples in 6 communes of Tudo, Ngoclau, Ngocson, Namson, Bacson, and Ngoluong all chemically have the contents not exceeding the permitted limits except some samples with phosphate and iodle contents exceeding the limits such as some samples taken from Tudo, Ngoluong areas. Phosphate content in the samples (sample 04 = 9.162 mg/ l; sample 05 = 10.55 mg/ l; sample 19 = 9.779 mg/ l; sample 57 = 13.11 mg/ l; sample 58 = 11.820 mg/ l; sample 59 = 10.840 mg/ l). For iodine samples (sample 08 = 2.12 mg/ l; sample 38 = 2.33 mg/l; sample 50 = 1.27 mg/ l). The excess over permitted criteria of these two elements is still not appropriately explained that needs time for further study. Criteria of microorganism in particular, because water is still not yet sampled and analysed, there are no results for conclusion. There have been however, the cases plague spreading (red sore eyes) whose cause is presumed to collectively use water source in Mu hamlet.

7 Some preliminary observations of protection and reasonable use of water resource in Ngocson - Ngoluong region

Surface and karst groundwater in the Ngocson - Ngoluong limestone - terrestrial strips is separate from their vicinities in NE and SW because, the whole region is comparatively uplifted. Among them exist a close relationship. Surface water in Bacson, Namson, and Lungvan is presumed to pour to Hung hamlet, and most of which moves to the SE so that together with autogenic sources in Ngocson and Ngoclau pour to Mu village in Tudo commune etc.. Since such a close relation, protection and reasonable use of this resource become very important. For example the exploitation without planning which causes in water pollution in upstream etc can passively impact the downstream in the SE, so:

- It is necessary to have protection measure to the karst groundwater which is very sensitive to contaminants by setting up the hygienic protectional zones for the water sources; cattle should not be chaotically bred, toilets, animal cages, and waste sites are not made near the drinking water sources and the karst sinkholes.
- It is needed to maintain and protect the forest so as to sustain the supply to the water sources as well as to give them a self-protection.
- Prospects for exploitation of karst groundwater in the region to supply to living and other activities are rather high, but since the difficult topography and character of springs are in anywhere in the region so it makes difficulty for water supply; the places with inhabitants there is no water, the places where people do not concentrate, water is abundant.

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Eds. O. Batelaan, M. Dusar, J. Masschelein, Vu Thanh Tam, Tran Tan Van, Nguyen Xuan Khien

BAT STUDIES AT KIM HY PROPOSED NATURE RESERVE, NORTHEASTERN VIETNAM

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Keywords: Northeastern Vietnam, caves, Chiroptera, systematics, distribution, conservation.

Located in Na Ri district, Bac Kan province, Kim Hy Proposed Nature Reserve (22°11'-22°18' N, 105°54'-108°08' E) is covered by the typical limestone forests. Beside its high value of biodiversity, Kim Hy plays an important role in regulating the regional climate.

Recently, detailed surveys on bat fauna were conducted at Kim Hy Proposed Nature Reserve. A total of 20 bat species belonging to 10 genera, 4 families, 2 suborders were recorded: Megachiroptera (Old World Fruit bats *Pteropodidae*: 2 species) and Microchiroptera (Horseshoe bats *Rhinolophidae*: 8 species, Leaf-nosed bats *Rhinonycteridae*: 4 species, Evening bats *Vespertilionidae*: 6 species). Among the species, two were listed in the 2000 Red Data Book of Vietnam at category R (Big-leafed horseshoe bat *Rhinolophus paradoxolophus,* Great evening bat *Ia io*), four in the 2002 IUCN Red List of Threatened Species (Great evening bat *Ia io,* Hairy-faced bat *Myotis annectans,* Thomas's horseshoe bat *Rhinolophus thomasi* at category LR/nt and Big-leafed horseshoe bat *Rhinolophus paradoxolophus* at category VU). It is noticeable that a few species had only one or two caught individuals, such as *Ia io* {2}, *Rhinolophus thomasi* {1}

During the surveys, a number of caves were first found within Kim Hy's primary forest area. Among them, the largest cave, named SAT45, has the most bat species in Vietnam. Unfortunately, the bat species living in this cave have been killed for food by local people.

Finally, many activities of local people, such as bat hunting, gold exploitation, and bee honey collection, have been threatening severely Kim Hy's bat fauna. It is time that these activities are banned, and conservation of bats at Kim Hy Proposed Nature Reserve should be considered as soon as possible. Based on the recorded data, a number of solutions are recommended.

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COLLABORATIVE RESEARCH ON THE CONSERVATION OF KARST ECOSYSTEMS IN MYANMAR

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Abstract. The limestone karst areas with many exceptional physical and biological features form a distinct biome within Myanmar. The varied topography of many karst areas creates a wide range of microhabitats and specific niches for the adaptation of karst species. Thus the karst areas in Myanmar are extremely rich in different kinds of species. Among major groups of karst organisms in the world, almost 1000 species of bats are known to be cave-dwelling species either in limestone or in other rock. About 70 species of insectivores and 3 species of frugivores are known or expected bat species to roost in caves of Myanmar (Vermeulen and Whitten, 1999). Conserving limestone areas with all the conditions for the process of karst formation and with its bat communities intact plays a crucial role in achieving the healthy ecosystems on which human population depend. A series of collaborative studies between Yangon University and Harrison Institute, UK were initiated from 1999 up to date to assess the distribution, status and species richness of karst areas with emphasis on Myanmar bat species. Since then, 10 survey trips were made in Kayin, Mon, Kachin, Shan, Rakhine, Chin States and Ayeyarwady, Mandalay, Sagaing, Bago, and Tanintharyi Divisions and joint research papers published in well recognized international journals. Some of the joint survey trips were conducted under the sponsorship of Darwin Initiative Programme. The most active collaborative works were undertaken by the researchers in Zoology Department, Yangon University and those from Harrison Institute, UK. First International Bat Workshop was conducted in the Zoology Department of Yangon University sponsored by Darwin Initiative Programme and Total FinaElf E & P Myanmar. This paper reviews the limestone karst regions surveyed and bat species recorded throughout the country. The bat species new to the existing fauna of Myanmar are also mentioned. Collaboration between Yangon University and Harrison Institute increase number of scientists associated with wider aspects on biodiversity conservation. Fruitful outcomes of collaborative works are outlined and discussed.

Keywords: Myanmar, bats, collaborative research.

1 Limestone karst regions in Myanmar

There are large tracts of land in South East Asia with spectacular topography, plateaus, gorges, ranges of hills with sharp outcrops ad towering hills rising from either flat river plains or from the sea. These are known as limestone formations – sedimentary rocks that were built up millions of years ago by corals, shells, algae, and other marine organisms. Tectonic movements lifted them above sea level, after a long burial beneath layers of sediment. Erosion first removed the sediment cover and then sculpted the limestone spectacularly into karst landscapes (Vermeulen and Whitten, 1999). One of the South East Asia countries, Myanmar is composed of varied structural and geological units. The country falls naturally into the following four divisions, each of which runs from north to south, through the length of the land according to Chhibber (1934);

1. The Shan plateau on the east,
2. The Central Belt of Myanmar, covering roughly the river basins,
3. The fold ranges of the Western Yoma, the Naga Hills in the north,
4. The narrow coastal strip of Rakhine.

Of these 4 divisions, the Shan Plateau which has an average height of 950 m above sea-level mainly comprises of limestones and its southern continuation through Kayin-Kayah Range into the Tanintharyi Yoma. The limestone of the plateau is known to belong to the Carboniferous to the Lower Triassic period and thus it is much earlier than that of the mountains which occur elsewhere in the country. Its age ranges from about 1,000 million years ago in Mong Long area to about

160 million years ago in Kalaw area (Nyi Nyi, 1967). With the dominance of limestone outcrops in Shan, Kayah, Kayin, Mon States and Tanintharyi Division, Myanmar possesses many limestone karst areas with exceptional physical and biological features extending from the north to the south.

Many species of animal and plant groups are represented in karst regions and a relatively large proportion is recorded to be endemic. In particular, karst areas under humid tropical conditions are home to numerous species with restricted range. This may have probably originated from the extreme and diverse environmental conditions of tropical karst surfaces. Karst organisms which mainly depend on karst habitats such as bats, birds, fish and many invertebrates though of interest, tropical limestone areas are still the least studied by researchers.

Several permanent lakes in limestone areas, or fringing them, are inhabited by unique fish communities with a large number of endemic species (Vermeulen and Whitten, 1999). In Myanmar, 16 of 31 species have been suggested as endemic to Inlay Lake and its affluents, located at about 1000 m elevation in a limestone area of Southern Shan State (Ferraris, Kullander and Fang, 2003). In the check-list of existing bird species in Inlay Wetland Sanctuary was recorded by Forest Department to be more than 200 species of waterbirds and migratory birds including globally rare species, Jerdon's Bushchat (*Saxicola jerdoni,),* Indian skimmer (*Rynchops albicollis*), Sarus Crane (*Grus antigone sharpii*) and Ferruginous duck (*Aythya nyroca*) (Unpublished report).

In line with limestone karst areas, the best known karst feature, caves occur throughout Myanmar, commonly in limestone rock. In Mon State, large caves are common and they are assumed to be more than 40 major caves within the area. Perhaps 21 of these contain antiquities or Buddhist temples (Bates and Tin Nwe, 2001). The caves are often separated from one another by long distances. The great sheet of limestone, which once must have covered the country, has been dissolved or removed and only isolated hills thus remain. Caves in limestone regions are also scattered all over the Shan Highlands. The limestone caves are however known to be more numerous in Southern Shan State than in the Northern Shan because of the presence of different nature of the rocks. Apart from such caves in limestone karst regions, some caves are to be found on the sea coast of Tanintharyi Division.

2 Richness of cave-dwelling Bat species

Since cave dependent bats and caves are closely associated, many bat species inhabit the caves either of limestone or in other types of rock. In the tropics, a single cave may house a dozen or more species. Bat colonies may number hundreds of thousands to millions of individuals. In some regions of East Asia, such colonies are found exclusively in caves. In Myanmar, about 70 species of insectivores and 3 species of frugivores are known or expected bat species to roost in caves (Vermeulen and Whitten, 1999). Thus, conserving limestone areas with all the conditions for the process of karst formation and with its bat communities intact plays a crucial role in achieving the healthy ecosystem on which human population depend.

3 Bat research in Myanmar

Bat research, but based on a series of opportunistic field surveys has been initiated in the late 19th century and more formal programme was undertaken in 1913 till 1945. There has been relatively little research on the bats of Myanmar in the last fifty years. After a long gap, a series of collaborative surveys had initiated jointly with researchers from Yangon University (YU) and Harrison Institute (HI), UK since 1999 to pursue with the systematics of bat species. Extensive joint works were then extended to various fields of bat research apart from systematics after the signing of Memorandum of Understanding (MoU) between YU and HI on 22 June 2000. Since then, the assessment of the status and species richness of karst areas with emphasis on Myanmar bat series are being more undertaken and fruitful outcomes are constantly produced within very short period of joint research.

4 Field survey trips conducted

Field survey trips were conducted by the collaborative partners two or three times annually. To date, ten survey trips were made in majority of the states (Kayin, Mon, Kachin, Shan, Rakhine, Chin) and divisions

(Ayeyarwady, Mandalay, Sagaing, Bago and Tanintharyi) of Myanmar.

In line with the significant achievements of joint studies, collaborative teams of YU and HI obtained the grant from by Darwin Initiative Programme within the period from 2002 to 2005. The grant is to assist Myanmar in its attempts to conserve limestone karst dependent bat species, including globally threatened ones. A total of (13) limestone caves in Kayin State, (8) caves in Mon State and (25) caves in Shan State have been surveyed.

5 Academic outcomes of collaborative research

Of many fruitful outcomes of collaborative research, a notable one is the successful first International Bat Workshop held at Zoology Department, Yangon University from 23 to 27 October 2002. Papers were presented by nine researchers from Myanmar and nine from various nations such as UK, USA, Australia, India, Malaysia, and Portugal at the Workshop. The outcome of this workshop further strengthened the relationship between the researchers of YU and HI. In the year 2002, two PhD candidates from Myanmar were visited HI as Darwin trainees to further their knowledge on bat research. Amongst the Darwin trainees, three candidates completed their PhD degree with the aspects on systematics, wing osteology and wing morphology. Five of Darwin trainees are now in the process of completing their PhD thesis on the aspects of echolocation, ecological and behavioural studies.

Mutual understanding between the collaborative partners provoke other international scientists joined the field survey trips in Myanmar jointly conducted by researchers from YU and HI. Thus, the on-going collaborative researches include not only on bats but also birds, snails, and small mammals. In addition, an expert on canes and palms was also included in the team. This broadens the aspects of biodiversity conservation.

6 Scientific outcomes of collaborative research

Outcomes of the bat research included – 11 species of microbats that could be added to the bat fauna of Myanmar. The notable ones were *Craseonycteris thonglongyai, Rhinolophus malayanus, R. marshalli, R. stheno, R. acuminatus, Myotis chinensis, M. horsfieldii, M. mystacinus, Ia io, Coelops robensonii*, and *Pipistrellus pulveratus* recorded from the limestone karst areas of Kayin, Mon and Shan States.

Of these new records of bats to the country, the bumble-bee bat (or) Kitti's hog-nosed bat (*C. thonglongyai*) was recorded as a unique bat species as it was thought to be endemic to Kanchanaburi, West Thailand. It is also possibly the world's smallest mammal and is listed as globally endangered species in Red List of IUCN (2000). In 2001, a single individual of this species was caught by collaborative team of YU and HI in a limestone cave located on the flood plain of the Gyaing River, Mon State. In 2002, nine caves including the first recorded one were detected by acoustic method.

As well as this significant findings, (135) species of birds were recorded by Inskipp, Inskipp and Buckingham (unpublished report) from the collaborative trip of limestone karst areas (Kayin and Mon States) in 2001. Of these species, 2 are globally threatened: Greater Spotted Eagle, *Aquila clanga* (Vulnerable) and Imperial Eagle, *A. heliaca* (Vulnerable) according to Birdlife International (2001). On the side of flora, YU and HI team, recent surveyed to the limestone areas of Tanintharyi Division during 2003 has produced new records of 3 rare species rattan for Myanmar of the total species of 14 rattan collected. Six species of palms were also recorded from the limestone areas of Tanintharyi Division (unpublished report).

During collaborative work, three scientific papers concerning limestone karst areas of Myanmar and the bat species associated with karst areas were published in well recognized international journals. More than three papers are in preparation.

7 Environmental considerations in limestone karst areas

Preserving limestone karst areas and their biodiversity is a vital role to ensure health of ecosystem on which people depend. In a large number of limestone areas in Myanmar, extensive dense forests still cover the limestone outcrops. One of the best examples is Zwe-ga-bin range, located in Pa-an of Kayin State. There are also many undisturbed steeply scarped solitary limestone hills, long ranges with impressed landscape and caves with immense beauty such as stalagmites and stalactites.

At present, the exploitation of limestone for industrial purposes is observed in Myanmar though it could still not be considered as large scales. However, limestone, being a non-renewable resource, damage caused by its extraction is a primary concern in environmental management. Main potential threats to limestone ecosystem and its biodiversity are the extraction of limestone for the cement industry, paper industry, for use in road and building construction. Frequent use of dynamiting for limestone quarrying will undoubtedly impact not only on loss of the hills, but also for the depletion and extinction of limestone karst dependent organisms. It was noted by locals in Kayin State that the number of bats in the cave has noticeably decreased since the mining operations started for cement production (personal communication).

Selection sites for those development projects and biodiversity assessments should thus be considered as primary concerns in limestone karst areas for impact mitigation. Exploitation of guano deposits, noise disturbance of visitors, strong light illumination used and renovation of the caves for religious purposes, climbing and caving on limestone hills for recreation as well as other intensions are other minor concerns to be raised in the awareness of limestone karsts and its dependent lives.

8 Acknowledgements

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EFFECTS OF DEFORMATION AND KARST IN RESERVOIR ESTABLISHMENT OF TEKEZE HYDROELECTRIC POWER, NORTHERN ETHIOPIA: IMPLICATION TO THE DEGREE OF UNCERTAINTY IN GEOTECHNICAL ROCK MASS CHARACTERIZATION

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Keywords: damsite, rock mechanics, metamorphic limestone.

This paper discusses on the possible effects of karst and deformation on the design of a huge hydroelectric power plant under construction in Tigray, Northern Ethiopia. It explains the degree of uncertainty in the overall of geotechnical characterization of the limestone terrain. It is based on the field observations before and after the compilation of final site investigation report valued for final the design.

As the energy sector in Ethiopia is increasingly exposed to rapid social and economic changes, the Ethiopian Electric Light and Power Authority started a construction of hydroelectric power project in Tekeze valley since January 2003. The access to reliable electricity supply is the privilege of less than 30% of 60 million Ethiopian population. The installed capacity is only about 500MW, mainly hydropower. This project is designed to produce 300MW. It is now constructing access routes to start the main dam and powerhouse construction and is expected to be completed in the coming six-seven years.

The project area coordinates are 1435000mN-1480000mn and 0450000mE-0490000m; the dam site is at 1475220mN and 470750mE and about 150km west of the Ethiopia Rift Valley System. This hydroelectric power project counts on an Arch dam with a catchment area of 30,390 km^2. It will be constructed in a steep gorge of approximately 350m deep, extending over a distance of about 1.5 km. The river follows nearly a straight course through the gorge with annual average flow of 119m^3/s. The reservoir is a sort of channel filling extended to around 70-80 km upstream.

The geology of the area is mainly represented by extensively folded and faulted Upper Precambrian Tambein Group, which includes dolomites, slates, limestone and metavolcanics. Limestone can be basically divided into black and light gray karstic limestone with massive and laminated appearance. In some places, this formation display calcite veins and sills. A shear zone trending NE-SW, with width of 5 Km and more has been recognized upstream of the dam site by means of SPOT satellite imagery.

The dam site is located within the limestone which has a thickness exceeds 400m of stratigraphic column within the gorge. The lithological succession of the gorge is composed of strongly deformed karstic limestone and slates in the northern edge of the above-mentioned NE-SW trending shear zone. The deformation pattern of this shear zone is mainly ductile frame with different sets of fractures giving rise to NE-SW trending stretched monocline overturned folds affected by faulting parallel to the shear zone. The dam will be located in a gorge perpendicularly cross-cutting karstic limestone in the north westernmost monoclinic limb of an overturned anticline. The axial plane of the anticline strikes NE-SW and dips by about 50^{0}NW. Even though, it the karstic limestone has been reported at the dam site, and open joints and thinly lamination with graphite coating have been associated with local fault propagation of the regional ductile reformation, it was not possible to quantify the boundary conditions to modify the rock mass characterization to foresee their effects, which basically introduced high uncertainty.

There is a field observation in the dam site near the heart of the dam anticline, where the bedding is not clear and exhibits a schistosity-like pattern, and where the calcite infilling is clearly associated with a thick sill of micaceous rock. This also reported on petrographic analysis by the occurrence of sparitic to microspartic calcite, with organic material along the schistosity planes, classified as calcareous schist. The effect of such weak-plane intrusion and deformation is not integrated on the adapted rock mass classification, which led to a plain vagueness.

The presence of three systematic joint sets in the dam site is reported. **J1**: with attitude of 75-850/222-242, **J2**: with attitude of 36-560/110-130 and **J3**: sub-horizontal (5-150 to south) with strike of E-W: mostly they are continuous, on both of the river except for local interruption going through the heart of the anticline, and located just downstream of the dam axis, open but spaced, filled in surface with weathered calcite up to more than 500mm in thickness and graphite-coated joints. Jointing of the rock mass is more apparent within the ridges. Generally the effects of these joints in strength assessment are considered except the extent of weathering and the effect of graphite coating (with probable water-graphite interaction facilitating weathering and accelerating alteration). The graphite coatings overall effect with regard to the geotechnical properties of rocks is not well investigated which introduces uncertainty. Besides the presence of systematic patching of bedding planes with graphite in banded facies of limestone has been reported in boreholes and adits. But it has been not considered as endangering the overall stability of the dam. Field observation of this graphite also confirms that they are abundant, continuous, and straight to slight undulating nature, which may extend its effect.

The geomorphology of the gorge appears related to the nature of the karstic limestone, i.e. massive, medium bedded brownish to dark gray limestone (more than 50 m thickness), thinly laminated dark gray karstic limestone (100 m thickness) and bedded light gray karstic limestone (about 70 m thickness). As observed on bed contacts, there seems to occur a penetrative weathering. As the Tekeze River is deeply entrenched within the regional plateau, there is no concern of possible leakage towards adjacent valleys. Therefore, the watertightness of the reservoir is dictated by the local permeability at the dam site. But the presence of joints and karstic limestone in the reservoir and dam site will challenge such general remarks. Besides, failures due to excessive leakage are reported in almost all microdams in limestone terrains of northern Ethiopia and it is common that underground leakage is a major problem of dams located on limestone terrains.

The permeability of the dark gray karstic limestone that constitutes the valley floor and abutment has been estimated by Lugeon tests in boreholes and it is reported that construction of the grout curtain can be executed accordingly. But upstream of the gorge, open joints in the numerous bedding, fractures of the slate with thin beds of limestone probably constitute a seepage path, which may affect the watertightness of the reservoir and induce stability and leakage problems.

It is reported that the karst may provide by-pass through its southwestern peri-anticlinal closure. However, due to the attitude of the overturned dam anticline, and specifically to its axis plunging about 200 SW, the underground percolation path is probably more than 5 km long, i.e. a maximum gradient of about 2%, which is negligible. But the presence of a spring located about 1.5 km downstream at the contact the slate and limestone suggest the probability of presence of cave routes in limestone, which question the watertightness of the dam. Even, it is not well defined the effects (extensive leakage and potential ground stability) of deep joints in right banks due water pressure as the headrace tunnel is designed there.

The bulk density of samples collected in the Tekeze gorge, dam site boreholes and exploration adits is generally comprised between 2.44-2.73 g/cc, with mean value of 2.68 g/cc. As the dry unit weight are slightly higher, with values around 2.8g/cc, porosity being around or less than 1%. This is a range for very dense and compact rocks. And most rock samples USC results are found to show a mean value of 55.2 MPa within a range (42-82.4 MPa) while I_s (50) result between 1.36- and 5.56. The results of the two tests do not strictly correspond with ISRM standard index to UCS and I_s, as I_s values little higher. This condition makes the strength interpretation biased to rely on the existing rock mass characterizing procedures. Moreover, the USC values are rather low compared to the good quality rock. Such lower mechanical resistance of rock should be clearly defined with deformational and weathering history of the rocks to understand the rocks response to the future hydraulic environment.

It has been also reported that the tensile strength ranges between 5 and 24 MPa, with a mean value of about 9 MPa, which is almost typical to limestone rocks. The permeability tests are associated with rock mass classes to design grouting works, but actually the rock class development is not full controlled in the document due to the above-mentioned defects. Besides the presence karstic phenomena and boundary conditions assessment on deformation and stability can make the understanding of geotechnical properties complicated, which needs detail consideration as it introduce high uncertainty.

From the document delivered to the final design of the project, it is possible to learn rock mass characterization rely on the laboratory geotechnical test results and discontinues assessment to feed the routine rock mass characterization classification procedure (RMR). It is known that such classification schemes are providing a guide line outlook and needs a specific modification according to the site conditions which is not done on the Tekeze hydropower project. Moreover, the classification does not have clear rooms to incorporate effects of weathering, karstic and deformation features as it is described in the above sections.

Generally the deformation and karst effect is quite high and difficult to consider with the routine classification schemes for such huge and sensitive projects. Moreover, it should be kept in mind that most of the failures recorded with serious physical and economic consequences are generally related to the fact that actual geological conditions were not fully understood, or more often not considered adequately in the assessment of stability.

BIODIVERSITY IN THE LIMESTONE AREA OF HA TIEN AND KIEN LUONG, KIEN GIANG PROVINCE

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Keywords: karst landscape, Mekong delta, endemicity, conflict conservation – exploitation.

The limestone of Hatien and Kien Luong (Kieng Giang province) is unique for the landscape of the Mekong delta area .It supports a high diversity both for the flora and the fauna. A preliminary survey has shown the presence of 272 species of vascular plants and 155 species of vertebrate. Noteworthy is the presence of 6 mammals with *Presbytis cristata*, 5 reptiles and 6 birds recorded in the Red Book of Vietnam. However, the karst of Kien Giang is now suffering by human impact, especially lime exploitation. It needs an appropriate consideration and management for the conservation.

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AGRICULTURAL SUSTAINABILITY AND HUMAN ECOLOGY IN KARST MOUNTAINS

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Two large karst regions border the mountainous area of North Vietnam: at the north border with China and at the border with Laos. The ecological system of karst is well known by the fragility, which is characterised by drought, floods, soil erosion, rock desertification, low productivity and poverty.

The green revolution of the 70's and 80's was successful in the plains but in regions with more rugged topography this revolution has not happened.

In the past 30 years, the population of the mountains increased faster than in the plains but the food production increased slower than the population.

In the 1950’s the agrarian reform has not happened in the mountains, in the 1960 the collectivisation of agriculture was realised. Rice fields in valleys could not feed the population, therefore the dryland cultivation area increased and deforestation was serious.

In the beginning of 1980’s the Decree No 100 with the introduction of contract between co-operatives and farmers had little influence in the mountains, but the Resolution No 10 in 1988, with the return to the peasant household, boosted the food production. In 1993, the allocation of agricultural and forest land to peasants had a great impact on the intensification of valleys and the conservation of forests.

At that time mountainous agrosystems were in a crisis situation: forest was seriously destroyed and land under shifting cultivation was eroded, people were searching for another way of development. The evolution of agrarian systems began to change towards to a more sustainable ecology: the intensification of lowland cultivation is increasing, the dry rice area in shifting cultivation is reducing, cash crops are developing, the reforestation and the forest conservation get a start.

The intensification technology can be applied only when the land becomes a rare commodity and labour is abundant. This is why the intensification could be realised only at a certain level of population pressure. When the land and the forest are allocated to households, the price of land increased, the intensification of the valleys is taking place and gives surprising results: the mountains become self-sufficient in food production. When the population pressure increased, the resource of agrarian systems was firstly destroyed and these systems were in crisis. But further due to the increase of the cost of land and the decrease of the cost of labour the intensification process increases, the land productivity will be improved and resources will be conserved. These changes will be induced by new adapted institutions and technologies.

Present problems of the uplands are the change of peasant household from subsistence to the commercial farming and the development of the market. These processes need non-market and market institutions.

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PRELIMINARY RESULTS OF A STUDY ON KARST GEOLOGICAL ENVIRONMENT IN THE PU LUONG REGION

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Abstract. In order to protect the environment, stimulate the economic development and improve the life standard for the inhabitants in the karst regions, it is necessary to have a detailed knowledge about the karst geological environment. Risk protection and prevention and reasonable exploitation can then be proposed. To meet those requirements, a study programme on assessment of the karst environment in some key areas of NW Vietnam has been started in which the Pu Luong-Cuc Phuong region is included. With its widely known values in many aspects of aesthetics, landscape, history, culture, biodiversity, geology and geomorphology, the Pu Luong Nature Reserve-Cuc Phuong National Park is already developing as a tourist destination. The Ministry of Agriculture and Rural Development, World Bank and the FUDESCO (from Spain) have agreed on a project for the conservation of biodiversity of the inter-region of Pu Luong- Cucphuong with total budget of 1,111,447 US$.

1 Geographic location

The Pu Luong Nature Reserve covers an area of 654 sq. km belonging to 4 topographical map sheets in a GAUSS projection (coordinate from $20^0$12’ to $20^0$20’ and $20^0$20’ to $20^0$35’ northern latitude; $105^0$30’ to $105^0$45’ and $105^0$00’ to $105^0$15’ eastern longitude).

2 Physical geography

The Pu Luong region is the termination of the Sonla – Mocchau mountain-and-plateau range stretching from NW to the SE margin of the Bacbo plain. Within this limited surface there are different topographic landform ranges: high, average and low mountains, hills, plains alternating with narrow valleys. The highest mountain is the Pu Pha Phong range (extrusive rock) with the Pu Luong peak up to 1587m. This mountain range has very steep flanks dissected by deep and narrow valleys, prolonging in NW-SE direction. The slopes quickly lower down to the Ma river valley in the SW and the Co Lung – Ban Khan Valley in the ENE. The average and low mountains and hills are carved out of mostly terrigenous rocks alternate to build a complex network. The limestone mountain ranges are elongated in a NW-SE direction with the peaks of towers, pointed pyramids, trapezes at an elevation of 1000-1100 to 100-600m asl surrounded by the dolines, sinkholes, troughs, closed and rugged depressions.

The Pu Luong forest remains the primary forest because of the ruggedness and difficulties of these limestone mountain ranges. These characters are softened toward the east and southeast with 100 m high residual hills of limestone intercalated with the troughs in a NW-SE direction. On the valley bottoms there are many vertical sinkholes, basins, dolines and karst depressions surrounded only be escarpments. In the midst of the region there is a large valley which continues to Hoabinh. Along this valley, there is an almost random distribution of schist or limestone hills at an average elevation of 400-500m with a hard laterite weathering crust of uneven thickness.

The Pu Luong has a tropical monsoon humid climate with a rather cold winter without much of rain; a hot and rainy summer. The yearly mean temperature reaches 23.5 to 24^0C. The yearly heat amplitude is 5.5^0C. The winter mean temperature is < 18^0C. Continual blows of strong cold air can decrease temperature to < 10^0C. The summer mean temperature is about 26-28^0C. When the hot and dry weather occurs, the maximum daily temperature can reach 37^oC. The total yearly precipitation is approximately 1500-2000mm. Even in the winter months there are drizzles or small showers. Because of a closure to the sea, it is often wet. The yearly average humidity is 85%. The lowest average humidity is 82-83%. In the time of Laos wind, humidity is only 65-

70%. In winter, the drought time dry time lasts from November to the next January. The daily mean humidity can drop to 60-70% or lower. In Pu Luong there are phenomena of fog, frost, dry wind, hot air. In winter, prevailing wind direction is from NW or NE, in summer it is the east or SE wind. The yearly mean evaporation is about 639mm. The rain regime closely relates to the evaporation, in summer it is higher than that in winter. Storms forms the most important natural hazards causing in strong wind, heavy rains especially prevail in the months of 7, 8 and 9 that can be up to the grade of 11-12. In Pu Luong, there is a river called Cham, a tributary of the Ma River flowing in a NW-SE direction and joining with the Ma River in La Han (Ba Thuoc). Most of the regional surface flow is in accordance with geological structure. In limestone areas, surface flows are rare, often restricted to the underground. The Pu Luong Nature Park has 4 types of forest according to physical conditions: tropical, subtropical, pure needle-leaf on the mountain slope and the karst forest Pu Luong, Especially the precious wooden trees have been extracted a lot, so the layer of high and largely canopied trees is often small and average. When limestone is weathered it will produce the greyish yellow soil with moderate thickness, somewhere it is thin. The weathering is strong. In Phuluong, there are exist the groups: humid feralite on limestone, humid feralite on magmatic rock, feralite on limestone, feralite on magmatic rock and feralite on sedimentary and metamorphic rock.

3 Some geological features of the Pu Luong karst environment

3.1 Stratigraphy

In the area exist following formations: Namco (PR_3-$\in_1$*nc*), Songma ($\in_2$*sm*), Hamrong ($\in_2$*hr*), Banpap (D_2*bp*$_1$), Toctat (D_3*tt*), Bacson (C-P_1*bs*), Camthuy (P_2*ct*), Yenduyet (P_2 *yd*), Conoi (T_1*cn*), Donggiao (T_2a*dg*), Muongtrai (T_2*mt*) and Quaternary.

The Namco formation is distributed in the west of Hoixuan mapsheet with an area of 30 sq. km with only the sediments from its upper part including quartz-sericite shale, quartz-muscovite, chlorite, quartz-mica and quartzite with a thickness of 600m. This formation is unconformably overlain by the Songma formation ($\in_2$*sm*).

The *Songma formation ($\in_2$sm)* is mainly distributed in the west of Hoixuan around the Buky anticline and is prolongated to the south or to the north in Phule area. The formation is mainly composed of sericite siltstone, quartz-sericite shale and sandstone, interbedded by marble, fine-grained limestone, conglomerate, quartzitic sandstone and greenschist. The formation is divided into 3 sub-formations, each of them bearing limestone, marble, recrystallised limestone or calcareous schist as layers or lenses. The thickness changes from 50 to 180m. Lithological analyses all give the calcite content of 85-98%, with micro-grained, crystalloblastic or recrystallised, regular or allomorphic texture.

Conformably laying on the Songma formation are the formations of: Hamrong ($\in_2$*hr*) that consists of fine-grained sandstone, siltstone, sericite schist, limestone, clayish limestone and calcareous schist. These sediments are grouped by the geologists into different strata: Dovjikov (1965) assigned them to D_2e and C-P; Dinh Minh Mong (1976) to Dienlu formation ($\in_3$*dl*) or Langvac ($\in_3$*lv*). Tran Duc Luong and Nguyen Xuan Bao (1980) to Hamrong formation ($\in_3$*hr*). Do Van Chi (1992) identified the Hamrong formation ($\in_3$*hr*) when geologically mapping of the Quanhoa –Vuban sheet at a scale of 1:50,000 and divided it into 2 sub-formations. In the area, the sediments of the formation produce a band in a NW-SE direction from Phule to Nasai ferry and a few occurrences in Lamsa (in SE corner of the Hoixuan mapsheet) in a form of small tectonic blocks. Contents and thickness decrease from lower to the upper parts, from 70-80m in lower parts to lenses or thin layers in the upper part.

The sediments of the Banpap (D_2bp) formation have a rather large distribution and are divided into 3 bands in a NW-SE direction: the first band from Langmuop to Lahan, the second one from Langcoc to Langan and the narrow third one from Luong River to Langphun. Dovjikov (1965), Dinh Minh Mong (1977) grouped these sediments to Motom formation (D_2*mt*). The formation is mainly composed of light grey, white grey limestone. In the lower part it is interbedded with schist, siltstone, thin layering and it presents a more massive structure in the upper part. Total thickness is 550-660m. From Langbut to

Langphun of the Hoixuan mapsheet a set of colorfully striped limestone (a stripe on the map is 2-4 cm wide) extending in a NW-SE direction with a thickness of 80m of grey limestone, thick layering and strongly recrystallised, distributed within a band of terrigenous rock of the Toctat formation (D_3tt). The latter sediments conformably overlie the Banpap sediments and unconformably underlie the mafic extrusive rock of the Camthuy formation (P_2ct).

Limestone of the Bacson formation ($C\text{-}P_1bs$) has a scattered distribution together with the bands of extrusive rock (P_2ct) extending in a NW-SE direction from Phu Pha Phong to Tuong mountain, Xa Lang with an area of about 30 sq. km. Diagenetic colouring divides the formation into many sets with total thickness of about 800m including breccias, clayey limestone, grey to dark grey siliceous limestone in thin layering, thick layered limestone of greyish yellow color, irregularly grained and marbleized limestone or white grey and opaque limestone with thickly layered structure, recrystallized in lines.

In the studied area, the Middle Triassic limestone is present in the Donggiao (T_2adg), Muongtrai (T_2lmt) and Namtham (T_2lnt) formations. In the last two formations limestone is in interbedded layers or lenses within narrow distribution areas. The Donggiao limestone on the contrary largely distributes in the NW Vietnam and in the studied area. This limestone makes up a large band in a NW-SE direction like in Lungcao, Langam, Langphia with a thickness of 1000-1200m (Do Van Chi, 1992). This formation is divided into 2 sub-formations: the lower is layered limestone containing clay, grey to dark grey colored; the upper one is massive limestone with less clay, grey to light grey colored.

3.2 Tectonics

The studied area lies on the NW tectonic region including 2 tectonic zones of Songma (Ma River) and Sonla (Phan Cu Tien, 1988 and Dinh Minh Mong, 1976) with 5 structural stages: Upper Proterozoic –Lower Cambrian ($PR_2\text{-}\in_1$), Lower Paleozoic (Pz_1) Middle Paleozoic (Pz_2) and Upper Paleozoic – Lower Mesozoic ($Pz_3\text{-}Mz_1$) (Do Van Chi, 1992). The faults are diverse; most of them reflect the depth, scale, characters, sequence of the formation and their development directions. They relate to many kinds of mineral resources. The NW-SE system is most common in the area and is the thrust faults with a great depth of 10-15km (Do Van Chi, 1992), the next is the NE-SW system the faults are short with small scale. Besides, there are the sub-latitudinal and sub-longitudinal systems. These systems cause displacements of the NW-SE and NE-SW systems.

3.3 Mineral deposits

Mineral deposits are rather rich in the area. Among the known deposits that meet the industrial requirements and play a most important role on a large scale are limestone quarries for cement, constructions. Besides, deposits of iron, gold, lead are also noted.

3.4 Geomorphology

The karst region of Pu Luong is in the zoned karst unit of “the Song Ma and the Son La”. From the NW to the SE in the Pu Luong area the mountain ranges are aged of Late Cambrian, Carboniferous-Early Permian and Middle Triassic. In which the Hamrong limestone ($\in_3hr$) discontinuously distributes along the Ma river valley. Owing to the discontinuous distribution and tectonised structure the Hamrong limestone often produces residual karst towers. The Banpap limestone (D_2bp) is present in Dienlu and Dongtam etc. making up the band surrounding the Dienlu anticline with an alternation of some hard thin calcareous schist, siliceous schist that is producing the karstic mountain range landscapes. The Bacson limestone ($C\text{-}P_1bs$) is present in Camthuy, Dienlu, Dongtam and Quanhoa etc. making up the karstic mountain ranges embedding the Dienlu anticline or the residual towers on the watershed of the high mountains on terrigenous rocks. The Donggiao limestone (T_2adg) are very common in the area, creating “the Truongson mountain range” being shaped like a plateau extending from Suoi Rut to the seaside with two steep NW and SE flanks prolonging along the faults. On the “plateau” top surface develops the landscape of “tower like mountains with the approximate elevations connecting to the deep valleys, depressions”. This landscape exists on the chains of anticlines-synclines with very steep flanks paralleling in the NW-SE direction. The Camthuy extrusive rock frequently makes up the structural landform that is the highest in the area with common rock falls on the steep slopes (Phuluong range).

Within the distribution zone of the Donggiao limestone also exist the narrow bands of the fine-grained terrigenous rock of the Tanlac formation (T_1tl). They either create the denudation-erosion asymmetrical valley landscape directing in NW-SE intercalated with the limestone mountains or the valleys with the washout-denudation carrying the relics of the fossil river terraces. On the limestone range the surface karst landforms are very developed such as karren, microkarren, dolines, depressions, valleys, karstic poljes, through valleys, crests, tower peak-clusters, pyramids. The most outstanding features are the dolines, closed depressions and deep valleys compared to the peaks of 100-200m high. The more to the southeast the more clearly directed NW-SE the edges and ranges which alternated with the very deep valleys and the closed depressions. In some places residual karst towers remain on the low denudation hilly areas. Some valleys are widened to become karstic poljes.

Fluvial landforms are produced by the Buoi River such as the low and high flood plains. The low flood plains appear in the convex bends or where the riverbed widens. They are composed of pebbles, gravel, sand and clay. The high flood plains continuously distribute in both riversides, in a height of 6-7m, a width of 500-700m. The surface is uneven by the cutting of the tributaries.

In addition to the limestone, there are also many areas of basic and neutral igneous rock, porphyry andesite and basalts. The terrigenous mountains and the limestone mountains are in different elevations (with consequently different climate belts): the tropical belt below 700-800m and the sub-tropical belt of the average elevation over 800m.

3.5 Vegetation

In the Pu Luong Nature Reserve exist 4 types of forest:

- the closed tropical evergreen rainforest on the terrigenous mountains and hills;
- the closed tropical evergreen rainforest on the limestone low mountains;
- the closed sub-tropical evergreen rainforest on the earthen mountains;
- the sub-tropical rainy green forest on the limestone mountains of the high belt.

The number of the present botanic species in Pu Luong that have been preliminarily listed are 552 species (in Kim Hi are 729 species and in Huu Lien are 794 species). It is certain that when being strictly protected, the number of species in Pu Luong will be equal and exceed the other regions since its advantages in geographical location (Cuc Phuong of an area of 22200ha with 1880 species).

3.6 Soils

In Pu Luong, limestone occupies 60% of the area (17662ha). According to the background of soil-producing materials and the high belts of climate, soil is divided into: the humid ferralite soil on limestone, the humid ferralite soil on basic and neutral igneous rock and the ferralite soil on sedimentary and metamorphic rock with fine-grained cohesion. This classification however, is only completely implicated in a small area but not yet meets an overall classification nationwide.

4 Speleology

In the area exist many caves in very different heights including the hanging and the active ones but the investigation is just preliminary. 12 more new caves have been explored.

It is most noted that the Khau Muong and Pon caves are connected and with a length of kilometers but the water level inside the caves is very high with many siphons, the exploration had to be temporarily stopped. This system is also the main drainage system of the Pu Luong area. The caves that have recently been surveyed have common characteristics: multiphase, many stages (in northwest), single-phase (in southeast) and develop in a NW-SE direction that is also the direction of the faults controlling the regional framework. They have a large scale and dimension but often choked by the collapses from the roofs causing in the local inundations in Pu Luong area. Some caves that sufficiently meet the requirements for tourist should be used to serve the Pu Luong cave tour.

5 Conclusion

The impact of the karst environment is influencing the conservation of the geo-ecological system such as rock, soil, water and the fauna and flora system of the Vietnam's nature in general and the regional karst ecosystem in particular. A study of the karst environment will contribute to the elucidation of the nature of one of the most complicated environments. The key karst area of the Pu Luong Nature Reserve is representative for the whole large limestone fields of NW Vietnam. It is a valuable region with respect to landscapes, history, culture, geology, geomorphology and biology… so it has been recognized as a Natural Reserve Protected Area to be strictly protected. The karst environment of this key area is recently heavily vulnerable and hard to be recovered under human impacts which cause many hazardous consequences such as soil loss, water pollution, scarcity of surface water, erosion, floods, droughts, diseases related to karst environment, rapid subsidence and rockfalls. With advantages in natural beauty the regional tourist is urged to investigate the above phenomena so as to contribute to the remediation of the losses and support models for the sustainable development in this karst area.

In order to meet the above needs the project: "*A study, assessment of the karst environment in some key areas of NW Vietnam*" in which the Cuc Phuong-Pu Luong is being designed. The project must synthesize a large amount of data on karst geology-mineral deposits, karst geomorphology-hazards, karst hydrology-speleology, karst soil-landuse etc. and propose new methods for the karst environment study (soil and landuse in the karst environment, water and its potential in the karst environment and cave and tourist potential in the karst environment etc). With an application of modern technologies such as remote sensing, GIS, speleology etc the project will elucidate the status and nature of the karst environment, assess the influences on the karst environment. This is a second project concerning to the karst research in Vietnam and is the first one on the research of karst that is permitted by the Vietnam's Ministry of Industry. It is hoped that the project results will bring new valuable contributions to the karst environment; at the same time it can provide the necessary information to the authorities in directing the sustainable use of karst environment.

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CHARACTERISTICS OF HUMID TROPICAL KARST OF VIETNAM

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Abstract. The exposed karst area of Vietnam approximates 60,000 sq. km which is a link of the tropical karst belt of the globe, closely related with the karst on the Indochina peninsula, Southeast Asia, and humid tropical karst of South China. Vietnam has 4 main karst zones which are Vietbac, NW, North Trungbo, and NE (the Catba – Halong area). Salt rocks are not found on mainland Vietnam; so the only dissolvable rock is limestone. Vietnam meets all the necessary and adequate conditions for karst development such as availability of limestone with a high purity, bedding structure, and experienced many tectonic cycles so rocks are strongly fractured; irregular tectonic uplift, rich in rainfall (1,200 to over 2,000 mm/ year), high humidity, thick vegetation cover, and high temperatures favoring the development of organisms, accelerating chemical interactions, and emitting much CO_2 as feedstock for the karstification. Vietnam's karst developed during a long period and was subjected to strong modification by recent hydrogeochemical surrounding systems. So an adequate system of surface and subsurface karst types is present. The outstanding characters of Vietnam's humid tropical karst are the high diversity in biology, morphology, and landscapes. Very thick vegetation cover makes up the evergreen multi-canopied forests that are scarcely seen in the other karst regions in the world, especially when compared to the classical karst in Slovenia – where are merely bare rocks. Karst of Vietnam denotes a high biodiversity, rich in genera and species with many endemic species. Forest in Phongnha – Kebang contain 2,400 flora species, 1,069 fauna species have been identified; the Cucphuong karst area is only 220 km^2 but 1944 species of Cormobita have been identified from 908 family-branches, 224 families, 86 orders, 15 classes, and there are as many as 541 Chordata and 1,800 butterfly species identified. A combination between topography and ecology has created for the karst in Vietnam the typical karst landscapes such as the peak cluster-depression with the two sub-types; the residual karst (tower) landscape with the two sub-types, and the Halong-type sea karst landscape – an unique scenery of Vietnam – a residual karst landscape on the mainland ingressed by sea and turned over to become islands as forests on the sea surface that are rarely seen elsewhere all over the world.

Keywords: karst ecosystem, karst landforms, karstification, world heritage.

1 Scattering

Vietnam's karst is a partial component, a link of the tropical karst of the earth. Karst of Vietnam closely relates to the humid tropical karst that is well-known in Southeast Asia and particularly closely relates with the humid monsoon tropical karst prevailing in South China.

Total exposed karst area of Vietnam nearly reaches 60,000 km^2 approximating 18% of the total area of the country. Resting on the geo-structure characters, karstified conditions, landforms and landscapes, Vietnam's karst is divided into 4 main zones that are the Vietbac, the NW, the NE, and the North Trungbo, and a small area in Danang.

The Vietbac karst zone is the largest in Vietnam reaching nearly 40,000 sq. km. It continuously relates with the humid tropical karst of South China where the karst area is up to millions square kilometers particularly developing in Guizhou, Guangxi, and Yunnan. The Vietbac karst zone immensely distributes in the provinces of Hagiang, Caobang, Baccan, Langson, Thainguyen, Tuyenquang, Yenbai, and Laocai with the typical residual karst landscape, but also exists the peak cluster-depression in some localities.

The NW karst zone produces the almost continuous strips from Vietnam – China border in Phongtho, Sinho, Tuachua, via Sonla, Hoabinh, Hatay, Ninhbinh to the seacoast of Bacbo gulf with a length of over 400km, and 20km in average width.

The North Trungbo karst zone includes a big limestone block of Phongnha – Kebang that was just recognised by the UNESCO as a world's natural heritage. This block, together with the Khammouan block of the Central Laos produce a large massif with an area of over 20,000 sq. km in the eastern margin of Indo-China peninsula with the ecosystems and landscapes of typical humid tropical karst.

The NE karst zone includes the karst areas of Halong bay recognised by the UNESCO as the world's natural heritage, the karst area surrounding Catba island, and the not very large karst areas in the mainland of the Haiphong and Quangninh provinces. Although the area is not very large, karst there is grouped to a particular zone by its specificities in genesis: it is formed in the interferential areas of the mutual interaction between the continental and ocean processes, the karst therefore has the peculiarities in morphology, landscapes, and ecosystems.

In addition to the above karst zones, owing to geostructure of Vietnam's territory exist also the small karst areas in many places such as Quyhop (Nghean), Nguhanhson (Danang), and Hatien (Kiengiang)… and the presently-formed karst areas in Hoangsa and Truongsa archipelagoes.

2 Conditions for karstification

An overall observation can be drawn: "*Vietnam converges all the necessary and adequate conditions for the karstification*". The main karstified conditions or agents include:

2.1 Availability of high-purity limestone

Presently Vietnam has not discovered the karst on gypsum and salt rocks, but only the karst developed on limestone. Limestone of Vietnam is plentiful aging from Proterozoic to Quaternary.

Besides the above principal formations, limestone is also present in the lenses and interbeds in many sedimentary formations of Paleozoic and Mesozoic. Quaternary limestone in the form of reefs and atolls (Hoangsa and Truongsa archipelagos) and randomly distributes in continental shelf of Vietnam.

All the above limestone has a marine origin, a rather pure composition; lime contents often exceed 95% highly favoring the karstification.

In structure, limestone is thinly-to-averagely-or-massively bedded. In texture, except the recrystallised limestone in the Dadinh formation, the rests have a small-to-fine granular texture, favoring the karstification.

2.2 Folding

Except Quaternary limestone, all the limestone formations in the Vietnam's territory are folded, in which the oldest are Baikalian folding, the Caledonian, the Hercynian cycles and then the Indosinian cycle. Consequently the limestone formations are folded into the folds of various forms and dimensions; there are also some places where limestone has a cuesta structure. Being folded, limestone normally develops to a great depth and frequently fractured creating the channels for water deeply penetrating into the blocks for the karstification.

2.3 Faulting

In many localities influenced by faulting, limestone is fractured, and crashed into powder creating the cataclastic zones of tens of kilometers long. There are many fracture systems of different strikes, properties, and density occurred by the faulting on limestone creating the channels for water deeply penetrating into the blocks for the karstification.

In Vietnam the fissures on limestone also occurred by the earthquakes, specially where immediately suffered from or are influenced by a transmission of earthquakes along the seismo-generated faults such as the Caobang – Tienyen, the Hong (Red) river, the Chay river, the Da river, the Sonla, the Dienbien – Laichau, the Ma river, the Ca river… faults.

2.4 Neotectonic deformations

Many localities are uplifted to over 2,000 m or more, many places are lowered, even submerged under sea level, or buried below the young sediments in hundreds meters. This character determines a building up of different karst landscapes in Vietnam, as well as it defines the attitudes of the hydrological blocks in the specific karst zones or regions.

2.5. Climate for karstification

As already known, the karstification is expressed by a simple formula:

$CaCO_3 + CO_2 + H_2O$ □ $Ca^{2+} + HCO_3^-$.

The formula shows that limestone is despite available, the karstification still is not taken place. At the same time after Cobel J. (1959) the denudation rate or the amount of limestone resolved: X= $4ET/100$ (E is the real water discharge in l/ s; T is $CaCO_3$ content in resolved in water in mg/ l) is proportional to the water volume contributed in the karstification. The karst zones of Vietnam fall in a humid tropical climate with a rather high rainfall.

Due also to a high rainfall, the air humidity is often high (relative humidity is often over 82%). Average annual temperature in the karst regions of Vietnam is 23^0C. The above characters define the humid tropical regime of climate in Vietnam.

2.6 Vegetation cover

The karst regions of Vietnam have a thick vegetation cover, which facilitates the karstification. The results and comparisons of the karstified intensity in the forest and non-forest areas, the wet and dry areas in China continent by Yuan Daoxian (1991) gave a generalisation and comment: the karst denudation rate in the humid tropical zones is much higher than that in the other climate zones.

A thick vegetable cover together with their exchange and decay considerably accelerates the CO_2 content on the soil and air favoring the karstification. On the other hand, the humid tropical conditions are favourable for the micro-organism activities, increasing also CO_2 for the karstification. In a not very far future, the karstology in Vietnam will certainly quantifies the above qualitative observations.

3 Specific character of Vietnam's humid tropical karst

3.1 Existence of a comprehensive system of karst surface and underground landforms

Regardless of the old buried karst under the younger geological formations, on exposed limestone massifs are often observed the surface and underground karst landforms. The surface types include:

Karren and microkarren: Microkarren are 1-2 cm deep, 1-2 cm wide, and tens of centimeters long; the karren are 2 cm to 5-10m deep, more than 2cm to 3-5m wide, and tens of meters possibly long. Between the channels, and scallops are often the sharp edges, but sometimes flat, their bottom often has leaves, roots, and humus. In the state of humid and hot climate, vegetables well grow; many big trees who have the steady roots cramped to the channel bottom. All karren and microkarren surfaces thus, are covered under the forests. This is a specificity of the karst in the humid tropical regions that are not observed in the steppes or deserts.

Dolines are the negative topography with varying sizes; their diameter is from 10m to thousands of meters; depth is from less than 10m to hundreds of meters; the slopes are more or less gentle if having resolution and erosion origin; the slopes are often cover by clay, debris, and there are many sinkholes (small shafts); or the vertical slopes if they are generated from the underground collapses. Most of the dolines have a more or less symmetrical projection. Their density varies very much depending on each limestone massifs.

Closed depressions are the negative closed karst topography with a very multi-shaped projection; the slopes are often the scarps, bottoms are more or less flat covered and maybe completely with clay, humus, and tills. On the bottom may occur the karst resurgences, but frequently the sinkholes. The depth is often tens to hundreds of meters; length reaches many kilometers. The closed depressions by underground collapses often have vertical slopes, their bottoms are all limestone boulders and blocks; typical is the Swallow cave being 120m wide and -150m deep.

Opened depressions: This is a very common negative karst topography; they can be seen to be "*semi-closed*". They can connect to the valleys, blind valleys, and pocket valleys… The opened or semi-closed valleys often have the length greater than the width; the depth is often from tens to hundreds meters; the bottom is flat or rugged; the slopes are mild or vertical; on the bottom there are the sinkholes or resurgences.

Karst valleys: These are the prolonged semi-closed depressions as the erosional valleys on the denuded non-karst areas. The outstanding character in morphology is their prolonged shape; the length is many times greater than width and depth; the slopes are mild or steep; but the bottoms are commonly flat, there are the contemporary or permanent streams on the bottom.

Blind valleys: When a river comes from the denuded highlands to a karst area, it makes the "*blind valley*" on the limestone. Water in the blind valleys through the sinkholes disappears to the deep karst aquifers creating the river-caves. In the blind valleys there are the geomorphologic fluviatile features such as terraces, flood plains, and the karstified features such as the draining caves, vertical scarps, and the blind valley itself. In the blind valleys often appears the flash flood as the Namla valley via Sonla town.

Pocket valleys: These are the valleys on limestones connected to the erosional valleys on the non-karst rocks. The valleys have the big springs surged out to the surface making the surface flows then pouring to the main river outside the karst areas. They valleys often have flat bottoms, vertical flanks. Typical pocket valleys are the Namliep of Namla River, and the Bansang of Nammuoi River…

Through valleys: These are originated by the streams cutting through limestone block. The valleys often have the vertical scarps; they are very deep; there are many rapids and falls on the bottom; most typical is a segment of "*the Da river canyon*" from Hangtom bridge to Namma of over 40 km long; the two flanks are vertical, over 1,000m deep…

Shelter: There are two types of shelters: the ones in the coastal areas of Halong bay, Baitulong bay. The shelters by the mechanical and chemical corrosion of sea water often have big size, sometimes surrounding an island and deeply caved the limestone blocks from 1-2m to tens of meter; they are 4-5m to 9-12m high; the other type can be found in some limestone blocks on the mainland with a smaller size and only commonly occur in the sides contacted with the corrosional plains or the karst valleys. The waterlines get deep to the limestone blocks that are rarely less than 5m; the length rarely reaches 100m. The shelters reflect the static stages of sea level at the erosional base level for the karstification. When the area is uplifted, the base level is lowered, the shelters are raised up. In Manduc (Tanlac) area exist 5 levels of ancient shelters; the highest is 50m from the present plain surface.

Karst ranges, massifs, and towers: These landforms increase a topographical contrast making up the karst peak cluster-depression landscape in which the concave terrains include plenty of the above-described types; and the peaks are very diverse. The peaks can be very sharp or short pyramids, the prolonged ranges, or massifs, or a combination between the ranges and the massifs. Most of the karst ranges, massifs, and towers have the very steep or vertical slopes. In Halong and Baitulong bays the karst landforms are mostly submerged under sea water. A scenery of wading islands of all looks and size on sea surface sculptures here a fantastic charm.

Residual hills: The residual massifs of limestone on the accumulation plains are sometimes called as mogote that are very common in Vietnam in the Hong River and Thanhhoa deltas. Limestone massifs on the plains often have the vertical cliffs, under the cliff are very often seen the corrosional notches.

Karst poljes: The karst poljes of Vietnam present at different elevation. The typical ones are: Tamduong (900m), Chiengla (600m). Many other karst poljes are at not very high altitude encountered in different karst regions of Vietnam. Most of the karst poljes of Vietnam are produced relating to the output activities of karst groundwater and karst hydrological regime.

Corrosional plains: On the karst zones of Vietnam, the corrosional plains are observed with different dimensions and altitude. The low corrosional plains are exemplified as the Manduc – Tanlac of below 50m; the high ones are exemplified as the Mocchau of 1,000m; the Sinho of 1,500m. Many corrosional plains on the karst regions of Vietnam are at an altitude from 300-400m to over 1,000m. Most of them have a large dimension, sometimes reaching hundreds of square kilometers. Their surface is rather flat and there are usually the limestone summits. The common underground karst landforms include:

Vertical shafts: Mostly seen in the peak cluster-depression areas at a high elevation (over 500m). There are the single shafts such as the Swallow cave in Sonla town of -150m deep; it has an oval shape, 80m wide, 120m long; there are many shafts of 10-20m wide, and a depth reaches 200m. The Congnuoc shaft in Lannhithang consists of many pitches connected to each other totally making -600m deep, in which the first one is nearly 20m.

The *single chamber caves* are a multiple morphology and size.

The *multi-chamber caves* include many caves connected to each other by the horizontal or vertical siphons. The chambers are connected to each other to make up a series or the galleries and passages. When the passages are connected by a vertical siphon, a system of multi-stage caves is produced reflecting many cave-forming cycles in the areas typified by the Queen's cave centered on the NW karst zone (Dusar *et al.*, 1994). In a same system there are possibly the two anisotropic stages of the two generations imposed on each other, typical is the Bat cave 1 in Sonla.

Underground river-caves: Underground river-caves are often met on the limestone massifs of Vietnam, especially the massifs on the slopes of high and big mountains of the denudation origin. Allogenic water then comes from the denuded non-karst areas with a considerable volume and together with autogenous rain water to make the underground river-caves in a big scale. The Phongnha system that is 44km long and the Vom system in the Kebang limestone area that is over 31.2 km (unfinished) are the typical ones. On the not very high karst areas such as Kebang, Cucphuong… the underground river-caves are often horizontal, not many waterfalls. In contrary, on the high karst regions such as Mocchau, Thuanchau, Sinho, Lannhithang… the underground river-caves have steep profiles, many cascades, siphons; water violently works or sometimes freely falls making the fierce roars, typical as the Namla and Nammuoi underground rivers in the center of NW karst zone.

Flowstones are extremely diverse in morphology and scale. In the fossil caves are all observed the magical flowstones. The calcite precipitations are often seen in all the caves. It is possible that since the high rainfall and favourable conditions, the cave precipitations in Vietnam often have the big size.

Allogenic speleological deposits: In the caves of Vietnam, very common are the inorganic depositions brought in by the streams outside the karst areas; that are the guano, bird excrements, bodies of other animals that are mainly seen in the fossil caves and normally at less than 300m from the entrances. The deposits by the collapses of the walls and ceilings are also frequently seen in the fossil and active caves.

3.2 Rich, diverse, and highly endemic ecosystems

The climate condition with a high rainfall, humidity, and radiation itself together with the difficult terrains conduct the forming of a thick evergreen forest with the rich and diverse ecosystems of a high endemism for the humid tropical karst of Vietnam. This peculiarity is not present on the karst of other climate regions in the world.

Excluding the karst regions that are being exhausted by the extraction such as Donggiao, Mocchau, Thuanchau, and Dongvan… on the remaining karst areas of Vietnam is all observe the forest. Dang Dong Ha (2002) described the Kebang forest being so thick that sunlight could not get the ground. According to Vo Quy *et al.* (1996) in Cucphuong – Puluong exist the 3 main types of forest. Forest on the bottom of karst valleys with a 5-canopy structure in which the sky canopy includes the big trees of 40-60m high, 5-6m in diameter; the main ecological canopy consists mainly of the trees of 20-35m high producing the principal canopy of the forest; the subordinate canopy is composed of trees of 10-20m high scatteredly distributed; the small tree canopy includes the trees less than 10m high; and the floor is the grass and climbs. The second type is the forest on the valleys slopes of a 3-canopy structure. The upper canopy includes the trees of 15-30m high; the principal canopy includes the trees of 10-15m high; and the floor canopy is composed of the small trees and climbs. The third type is the forest on the top with a 2-canopy structure including the small trees, the lower canopy includes the thorny and climbing plants… In the Phongnha – Kebang, Hagiang, and Bacson karst areas forest has a similar structure to that in Cucphuong area.

Nowadays there have not been an adequate generalisation on the karst ecosystem in Vietnam from different regions, but an overall observation can be drawn is that: The humid tropical karst ecosystem of Vietnam has a high biodiversity and endemism (Do Tuyet, 2001). Only in Cucphuong – Puluong karst area, according to some authors (Le Vu Khoi, 1994; Vo Quy *et al.*, 1996) there are 1944 Cormobita species from 15 phyla, 86 orders, 224 families, and 908 genera.

According to the latest news, the Phongnha – Kebang has 2,400 flora species in which there are the endemic ones (Nhan Dan Newspaper issue N^O 17,730 on Feb. 14. 2004).

Fauna is the same as flora, there have not been the studies and statistically adequate works for the karst of Vietnam. Specifically the Phongnha – Kebang karst area there are 1081 fauna species censored. In Cucphuong – Puluong the researchers (Vo Quy *et al*., 1996; Maxwell, 2000) have listed 541 Chordata species.

The Molluscs has not been thoroughly studied but it is convinced that it is innumerable. Over a length of 200m in Cucphuong 90 Mollusc species have been discovered. It can be considered as a record in density of this animal in Southeast Asia (Maxwell, 2000).

Insect, especially butterfly is so plentiful. Only does the Cucphuong – Puluong karst area have as much as 1,800 butterfly species from 30 orders that have been discovered (Vo Quy *et al*., 1996); density of individuals is very high. Beginning of summer butterflies form the layers on the dry streams and on the tracks.

In the Phongnha – Kebang, 1081 fauna species have been discovered (Nhan Dan Newspaper issue NO 17,730 on February 14, 2004). In which the Chordata specifically has 568 species from 43 orders, 130 families.

Of the fish species there are some endemic ones in the Phongnha – Kebang karst area such as: *Cyprinus centralus, Cyprinus sp.,Chela quangbinhensis, Hemibagrus Vietnamensis.*

The Catba karst area is despite small, only $140km^2$, there are as many as 839 Cormobita species from 495 family-branches, 149 families, and there are 115 Chorada species from 21 orders, 58 families, and 86 genera. Similarly the Babe karst area is only 137 km^2 there are 417 Cormobita species have been listed from 115 families, 274 family-branches, and there are 250 Chordata species from 191 genera, 85 families, and 27 orders.

3.3 Typical karst landscapes

The Chinese scientists (Yuan Daoxian, 1991) used a local term "*Fengcong*" to denote a cluster of closed depression and peak landscape (peak cluster - depression), and "*Fenglin*" to denote the karst peaks on the plains (peak forest plain) while describing the humid tropical karst landscapes in their south country. With humid tropical karst of Vietnam, we observed three main types of landscapes that are the peak cluster – depression, the residual karst (tower karst), and the Halong-type landscape. Each type is subsequently divided into the sub-types.

Peak cluster – depression landscape: This is the the most common, best-known, and typical landscape for the limestone massifs on the mainland of Vietnam. It assembles the karst outstood topographical features such as the pyramids, the conic massifs and ranges with the lowered features such as the dolines, the closed depressions, and valleys. Altitude of this landscape varies from 300-500m to over 2,000m. Depending on the characteristics of the raised and lowered features, it is divided into some sub-types as:

- The peak cluster – depression: This is common with the dolines, closed, and semi-closed depressions. Their highlight is that the bottom is uneven, often outcropping limestone bedrock or incompletely covered with a thin crust of clay, humus, and stones; and there are many caves and sinkholes; there is usually the thick evergreen forest. On the plan, the depressions are more or less symmetrical, or sometimes distorted. Among the depressions are the raised topography in the form of high towers, short towers, cones, and massifs; relative elevation is from less than 100m to 1000m compared to the valley bottom... Slopes of the raised features can be the escarpments, the slopes outcropping the bedrock of limestone, or sometimes less steep or mild; they can be covered incompletely with the thin crust of clay, humus, and boulders; vegetable cover has 2 to 3 canopied layers. Various types of karren present on the slopes. This karst landscape is viewed in the center of Phongnha – Kebang massifs, in Hagiang, Bacson, Sinho, and Tuachua. The landscape usually relates to the Devonian, Carboniferous-Permian limestone with a great total thickness, thickly or massively structured, truncated, folded and block-uplifted in Neotectonic stage. In this landscape, surface drainage system is almost absent meanwhile the vertical shafts, deep pitches, and canyons are so common. The deepest caves in Vietnam such as Congnuoc (-600m), Silengchai (-290m) in Langnhithang, Tachinh (-402m) in Tuachua and many others of deeper than -300m which have just been discovered in Hagiang are of this type.
- The range peak – valleys: the low topography includes the closed depressions, semi-closed depression, and the valleys of all

types (of which are the blind, the pocket, and the through valleys). On the valleys there are possibly the streams or only acting in the rainy season, and possibly the drained caves or the resurgences. Under the valleys are often the underground river-caves such as the Namla underground system of 6km long, the Nammuoi system of 4km long, the Phongnha system of over 40km long, and the Vom system of more than 30km long… In which there are the immense chambers; underground rivers are streaming there… Both sides of the valleys or the midst of the two valleys are the raised and prolonged karst topography. Most of the cases the ranges are rugged by the occurrence of the small funnels and depressions. Surface of the peaks often exposes the micro-relief of karren, microkarren as well as the forest of 1 or 2 canopies often blankets the features. Slopes of the ranges expose the bedrocks of in some places covered by a little clay, humus; there exists the forest of 3 canopies. The slopes variably inclined from 20-30^0 to 60-70^0, or vertical in some localities. The height difference between the valley bottom and the peaks can reach over 1,000m as the cases observed along the Da river Canyon (Do Tuyet *et al.*, 1998).

Usually in the big massifs such as Kebang, Mocchau, Thuanchau, Lannhithang, Bacson, and Hagiang… one can observe the co-existence of the two sub-types denoted above.

1. Residual karst, generally named tower karst landscapes: This is the landscape that Ford and Williams (1989) spoke to be innumerous residual hills of limestone relatively emerged on a lower surface. Depending on the genetic nature of the lower relief, the karst landscape can be subdivided as follows:

• *The Residual karst landscape on the corrosional plains and karst poljes:* Corrosional plains and karst poljes often possess a rather flat terrain; there are the sinkholes, caves, underground hydrological networks; there are possibly the karst springs; limestone can outcrop on the surface or covered with the reddish brown clay, being the weathering products of limestone, or covered with aluvia in some places. The typical corrosional plains are Mocchau, Sinho, Maichau, Caophong… and the beautiful kart polje are Tamduong, Chiengla… The residual hills emerged on the plain surface are diverse in morphology and size; they are from some tens to 200-300m high; the slopes are mostly 20-60^0 steep; bedrock exposes; on the foot slopes there can be the tills and blocks of limestone. Because corrosional plains and karst poljes are long favourable for settlement and agricultural production so the forest there has been entirely destroyed; there can be grass and scrubs on limestone hills. This sub-type presents in many localities in the NW, Vietbac, and Phongnha – Kebang.

• *The karst tower landscape on the accumulation plain:* This is very common on the humid tropical karst belt. In Cuba it is spoken to be *Mogate* (Watson, 1989); in China it is spoken as *Fenglin* (Yuan Daoxian, 1991). This is a landscape of innumerable residual karst hills on the accumulation plains. The residual hills are conic, tabular; or the short towers and columns, and maybe also the domes swollen up on the plain surface. The towers are characterised by that surrounding slopes are normally vertical; in many places there are the watermarks inscribed as deeply as 1-2m or more to the blocks. Height of the hills rarely exceeds 300m. Most of the cases the forest cover has been destroyed; there is maybe a scarcity of the scrubs; there are sometimes the river-caves getting through the hills. Terrain surface has the microkarren, and karren. The plains are normally very flat; there are the strata of young alluvial or deltaic sediments. These are the prosperous inhabited localities of Vietnam. This landscape is typified in Haiphong, the SW margin of the Bacbo delta (Hatay, Hanam, Ninhbinh), and the Thanhhoa plain.

2. The Halong-type landscape: It can be stated that Prof. Le Duc An (1972), a geomorphologist has been the first person who mentioned the term "*Halong-type karst*" to denote a karst appearing at a conjunction between sea and mainland. Recently he and colleagues (Tran Van Tri, Le Duc An *et al.*, 2003) more adequately described this in an article "*the world's heritage of Halong bay – its distinctive geological values*" after the karst landscape of Halong bay was itself recognised by the UNESCO as a world's natural heritage. The Halong-type karst is created on the Carboniferous – Lower Permian limestone of the Bacson formation (C-P$_1$*bs*) having 1,000m in thickness, thinly-to-thickly bedded structure, monoclinal or slightly rippled folding, a high pureness of lime, and slowly uplifting in the Neotectonic stage. The karstified duration lasts very long, from Late Permian through Mesozoic and turned out to be the relics, the modified by the present karstification. The above authors assumed that at right prior to Late Pleistocene a matured karst that had been produced on the mainland, was set up that Williams T. (1998) thought to be created in a "*stage of forming the new plains*". This is a fenglin karst or the tower karst landscape with a innumerable limestone tower and conic hills emerging on the corrosional plains and karst poljes, and on even the closed, semi-closed valleys. Since the end of Late Pleistocene (11,000 years BP) sea water began invading this karst zone. Till 7,000 – 4,000 years BP sea water was highest, Halong bay has been officially formed. 3,000 – 2,000 years BP, sea still ingressed, the bay has been enlarged and then narrowed. 1,000 years BP and present time the bay is trended to be open again. Mechanic and chemical actions as well as the sedimentation considerably modify the karst here and create a type of landscape by the mixed interactions of the sea and continent, or more precisely the continental karst has been invaded by the sea and modified by the its actions in Late Quaternary and present time. That is the nature of Halong-type karst landscape.

The Halong area is 1,553 km^2 having 1,969 islands of all size, in which the small islands (100ha to 10ha and less) take 91.5% of the total; the area ratio between island and water is 1/9 and here can be considered as the isling forest. The islands are from some tens of meters to 220m high. In some big islands such as Hangtrai (461.3ha) exist karst depressions and dolines, but almost all the islands are lonely on the sea surface. A specific feature of the Halong karst is the very appearance of isles floating on water surface whose surrounds are the vertical cliffs. Feet of the cliffs, by the mechanical and chemical corrosion of the sea are dug to make the notches of 3-5m deep or more at the heights of 2.0 – 2.5m, 7 – 8m, and 9 – 12m.. To the shelters of many places there are the shells firmly adhered. The difference of Halong-type karst is the cave development, mostly the horizontal caves; the chambers are thousands of square meters; many ones connected to each other to make the complicated systems. In the caves there are plenty of calcite precipitations forming the stalagmites, stalactites, draperies, and columns… of the big size reflecting the periods with the favourable conditions for karstification happened in Halong. The floor topography of Halong was comparatively flat because the karst had approached a maturity forming the corrosional plains and karst poljes, then thanks to the accumulation and corrosion of the sea, it is becoming flatter. Because of long-time consumption of wood, forest on the Halong karst has been either entirely destroyed or only scattered with remaining small trees and scrubs.

4 Thinking about a proper use of karst resources

The karst environment is very fragile, susceptible to be destroyed, very sensitive to human impacts, and once destroyed it is almost impossible to recover. Rather than wryly describing the unsatisfactory impact of ongoing human land use on the karst and feeling unhappy about what is being lost, an action plan for better land use is proposed, based on the principles of sustainable development.

4.1 Selection of proper settlement areas

Good settlement areas must have sufficient water for household use and agriculture, sufficient land with flat or comparatively flat topography for agricultural production, roads already existing or possible to be opened to facilitate mobility, transport of goods and liaison to the vicinity. In karst environment those areas are often the large negative landforms such as karst poljes, corrosional plains, pocket valleys, and blind valleys. Particularly in the blind valleys the houses and other constructions should be arranged higher than the historical flood levels and warning systems for flash floods should be installed. Of course such places have been historically selected for creating settlements, becoming important townships and villages today such as the Tanlac, Yenthuy, Maichau, Mocchau, Maison, Sinho, and Tamduong…. Nowadays overpopulation should be avoided. Between the villages and natural forests there should be regulated buffer zones to avoid gradual loss of natural forests. Some towns should be shrunk, but others could be enlarged like Sinho and Tamduong.

4.2 Good organisation of agriculture in the negative landforms

Those are the karst poljes, corrosional plains, closed valleys, blind valleys, and pocket valleys where cultivation of aquatic rice, industrial trees, drought-resistant trees, or husbandry breeding can be carried out at an intensive scale. In these, either surface water is available, or groundwater is not very deep, easy to be extracted; the terrain is flat; soil free from erosion. However, it is necessary to prohibit destroying forest for cultivation land on the slopes to avoid desertification effects on the karst.

4.3 Reasonable management, exploitation, and protection of forest

Forest is very rich and diverse. Protection and maintenance of forest and wild nature is a priority because forest on karst will not recover once destroyed. The exploitation should be reasonably planned assuring that biodiversity and biomass will not be decreased resulting in a reduction of fauna and flora species listed in the red book of Vietnam.

4.4 Extraction of karst-related mineral resources

Limestone and dolomite are the primary mineral resources for the cement industry and road and construction materials, ornamental stones and secondary industrial minerals for many applications. Their predictive reserve is considered as "unlimited" (about 5175 billion tons). Limestone is randomly quarried at many roadsides and heavily quarried near the populous spots and the SW margin of Bacbo delta (Ninhbinh, Hatay, Hoabinh and Phutho) and in Sonla town. Such a concentration of exploitations is damaging the karst landscape. The overall lively image of the NW Vietnam karst is lost forever in these areas. Extraction sites should be selected based on scientific assessment of the resource and where their scenic impact is minimal.

Similarly, apatite mining is losing the natural scenery in Tamduong, Laocai. The manual and semi-mechanised mining of placer gold and gemstone which are sometimes concentrated in active underground karst systems causes pollution and utter disruption of the sediment although this type of small-scale and often semi-legal mining does not affect the overall scenery of the karst environment. All exploitation activities should be carefully planned and motivated by sustaining the karst ecosystems.

4.5 Early investment for the exploitation of tourism

There are currently tours such as Hanoi – Bichdong which helps visitors enjoy the residual karst scenery of "*a Halong Bay on land*" in Ninhbinh; Hanoi – Cucphuong is a excursing and research tour to a typical tropical karst ecosystem; Hanoi – Maichau for visitors to visit and enjoy the karst landscape and compare the customs and farming practices of a part of Bacbo delta having an aquatic rice cultivation with the mountainous peasants and the Thai – Muong cultural villages; Hanoi – Mocchau – Dienbien – Sapa – Babe lake is an overall long-day excursion tour that offers an opportunity to enjoy the karst landscapes, peoples, practices, and farming level in the NW; Hanoi – Kimboi is a disease-treatment tour by the Kimboi hot spring on the karst of Donggiao formation. Besides, there are plenty of spontaneous tourist spots in localities integrating the scenic enjoyment with worshipping for spiritual world since long ages for which the Thay Pagoda, Huong Pagoda are typical.

In the coming time it is needed to invest, enhance, and sustainably exploit these tourist routes. In addition, sporting, adventure and research tours to the caves in Mocchau, Sonla town, Tuangiao, Tuachua, and Lannhithang areas can be initiated. In those localities many majestic caves have been discovered with lively speleothems and travertine formations, ever thrilling the foreign researchers and explorers who came from Belgium, Australia, Spain, France, Italy and China. It should be stressed that the caves with their internal formations are invaluable properties which are unable to recycle. So it is necessary at the earliest stage to plan and protect, either restrict use or allow visits, like the Chinese did with the Dragon cave, the Australian did with Jenolan caves, or the American did with the Mammoth cave.

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GEOLOGICAL STRUCTURAL CONTROL OF KARST WATER IN TAM DUONG AREA, LAI CHAU PROVINCE, VIETNAM

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Abstract. On the basis of available geological data, the authors try to characterize the main geostructural features of the Tam Duong area (Lai Chau province, Vietnam) in an attempt to understand the karst water resources of the area.

Keywords: geology, stratigraphy, tectonics.

1 Location

Tam Duong and its adjacent area are located at the NW end of a geological structure named by most geologists as "Da River Rift", which itself stretches more than 400 km in the NW-SE direction from the Sino-Vietnamese border to the Tonkin Bay and further. To the NE the structure borders with the Phan Si Pang anticlinorium and the Tu Le volcanic super-imposed depression. To the SW it borders with the Ma River anticlinorium. Acting as the border between these structures are deep-seated faults which are believed to cut down till the Earth's mantle.

Da River Rift was formed when the continental crust of the region had already consolidated, followed by a relatively quiet period during Upper Paleozoic before thinning and extension occurred along faults of NW-SE direction. These deep-seated faults cut through the Mohorowices and served as the conduits for the melted magma to come up. At the same time, various sediments had formed under marine conditions. They consist of a series of vertically alternating formations, starting from high titanium alkaline tholeite basalt, alkaline olivine basalt, komatiite basalt, trachite basalt, picrite diabase etc., unconformably overlying the pre-rift basement. These were then overlain by fine-grained terrigeneous formation consisting of sandstone, siltstone, claystone and the latter in their turn, by carbonate-terrigeneous and pure carbonate rocks. Overlying these carbonate rocks are fine-grained terrigeneous formation consisting of deep sea grey, blackish grey claystone and argillite which have formed during the deepest subsidence of the rift. The total thickness of rift formations at the central part of Da River rift may reach up to 8000 m.

Da River rift closed down when tectonic conditions changed, with extension weakened and replaced by compression, sea narrowed down before completely disappearing. Earlier formed geological formations were subjected then to folding and faulting during after Carnian or right before Norian (Dovjikov *et al.*, 1965). Regional compression took place more strongly during Himalayan or Miocene epoch (Tapponier, 1982).

After rift formation, localized depressions appeared in the region with Norian-Rhetian coal bearing molasse accumulation, Cretaceous red coloured, coarse-grained continental formation and Quaternary loose sediments, which gently overly rift and pre-rift formations. Faulting and magmatic activities occurred strongly again during Middle-Late Mesozoic and Kainozoic epochs. In particular, neotectonic block uplift of more than 4000 m in Phan Si Pang to the northeast also uplifted and deformed the area, making its structures very complicated.

2 Structural stages

The study area is composed of 3 stages i.e. pre-rift basement, rift and post-rift stages, each in its turn, consists of one or several sub-stages of corresponding structural complexes.

2.1 Basement stage

Pre-rift basement formations do not exist within the narrow area of interest. However, close to its NE border, Bui Phu My *et al.* (1978) have described 2 pre-rift formations. The lower Lung Po (PR_{1-2} *lp*) formation consists of metasediments with garnet-bearing granite, amphibole-rich granitic gneiss, intercalating in the upper part with migmatized schist, interbeds of quartzite, amphibolite, amphibolite schist and marble lenses. The total thickness of the formation is about 1000 m. The rocks strike in the NW-SE direction, dipping complicatedly to the SW. It is unable to determine the lower boundary of the formation while in the uppermost part the formation is seen conformably underlying the Sinh Quyen formation ($PR_{1\text{-}2}$ *sq*). However, the Sinh Quyen formation crops out only on the northeastern foot of the Phan Si Pang range whereas on its southwestern foot which directly borders with the Tam Duong area one can only see the Ban Diet formation (C_3 *bd*) directly overlying the eroded surface of the Lung Po formation.

The Ban Diet formation (C_3 *bd*) starts with black schist, fine-grained quartzite with interbeds of basalt, dark grey dirty limestone, changing upward to thin-bedded, light grey silicious schist, reaching in total about 500 m. According to Phan Cu Tien *et al*. (1977), the Ban Diet formation conformably overlies the Da Mai formation (C_1 *dm*) while unconformably underlies the Cam Thuy formation (P_2 *ct*). The rocks strike in the NW-SE direction, dipping 40-50^0 to the SW.

On the other hand, the entire study area as well as its adjacent areas to the NW, SE and SW is covered only with rift formation so any thought of pre-rift formations there is just interpretation.

2.2 Rift stage

This stage consists of several sub-stages, starting with:

a. Early Triasssic volcanic sub-stage

This sub-stage consists of rocks of the Vien Nam formation (T_1 *vn*) (Phan Cu Tien, 1977) i.e. basalt, plagioclase basalt, high titanium alkaline tholeitic basalt, alkaline olivine basalt, komatiite basalt, picrite diabase, changing upward to porphyry basalt, trachite, porphyry trachite, rhyotrachite, agglomerate, agglomerate tuff, felsite tuff, totalling 1150 m. The eruption took place under continental, sub-continental conditions, with products unconformably overlying pre-rift formations and conformably underlying the Tan Lac formation. In the study area, the rocks of this sub-stage form a continuous belt on the right bank of Nam So River, from Ta Leng to Then Sin and further in the NW-SE direction to the Sino-Vietnamese border. Our own study also found a small area covered by the rocks of this sub-stage around Nung Nang not described by To Thu *et al*. (1999). This implies the Nung Nang area has been uplifted to form a local anticline.

b. Olenikian fine-grained terrigeneous sub-stage

This sub-stage consists of rocks of the Tan Lac (T_1o *tl*) formation (Phan Cu Tien *et al*., 1977) which is equivalent to the upper part of the Co Noi (T_1 *cn*) formation (Dovjikov and Bui Phu My, 1965). The formation contains sandstone, tuffogeneous sandstone, siltstone, claystone, with interbeds of calcareous sandstone, claystone, limestone lenses etc., thinly bedded from less than 1 mm to 1-2 cm. The rocks are grey, pinkish grey, some places light grey, very often seen with polished bedding surfaces. The total thickness is up to 950 m. The formation was formed under deep see conditions with typical Olenikian fossils (To Thu *et al*., 1999; Phan Cu Tien *et al*., 1977). It conformably overlies the Vien Nam formation and underlies the Dong Giao formation (T_{2a} *dg*).

In the study area, this sub-stage crops out widely in Sung Phai, Lan Nhi Thang in the form of a big lens (the Tam Duong anticline), 10 km in length and as long as 2 km in width at its central part. To the SE of Suoi Thau village, shale of the formation was seen dipping 10-45^0 changing gradually its strike to form the SE end of the anticline. Rocks of the formation were also seen at Tam Duong Dat, at the foot of the SW slope of the Phan Si Pang range, at the foot of the NE slope of the Lung Cu range (Tan Phu Nhieu village), and around Nung Nang village.

c. Anisian carbonate sub-stage

This sub-stage is composed of rocks of the Dong Giao formation (T_{2a} *dg*) (Jamoida and Pham Van Quang, 1965). In the study area, this formation very widely develops, covering as much as 170 km^2, forming a continuous belt from Lan Nhi Thang karst plateau through Tam Duong, Nung Nang, Ban Giang, Dong Pao and Y Ho in the NW-SE direction. In addition, a small area of limestone of the formation crops out near Binh Lu. Study by To Thu *et al*. (1999) and by us show the formation is divided into 2 sub-formations. The lower sub-formation contains grey, bluish grey calcareous shale, marl, thin-bedded limestone.

The upper sub-formation contains fine-to-medium-grained, clean, thin (5-10 cm) to thick (40-50 cm) bedded, even massive limestone, with colour changing upwardly from dark to light grey, totaling 1150 m. The limestone strikes constantly in the NW-SE direction, changing its dip and dip angle from place to place. Containing typical Anisian fossils, the formation has formed under marine conditions, conformably overlying the Tan Lac formation and underlying the Nam Tham one, which is not seen in the study area.

d. Carnian fine-grained terrigeneous sub-stage

This sub-stage is composed of fine-grained terrigeneous rocks of the Nam Mu formation (T_{3c} *nm*) under deep-sea conditions (Dovjikov and Bui Phu My, 1965). The rocks include very thin-bedded (usually less than 1 mm) slate, argillite, with interbeds of siltstone and fine-grained sandstone of black, dark-to-brown grey colours, totaling up to 1500 m. Containing Carnian fossils, the formation conformably overlies the Muong Trai formation (T_2l *mt*), which does not develop in the study area and unconformably underlies the Suoi Bang formation (T_3 n-r *sb*). In the study area rocks of the formation were seen in small areas East of Ban Hon, SW of Na Khan, Phat villages and along Nam Mu river NW of Ban Dich village.

In brief, the study area is basically made of the rift stage with the 4 sub-stages described above. Deserving special attention is the widely distributed Anisian carbonate sub-stage.

2.3 Post-rift stage

This stage is made of 3 sub-stages.

a. Norian-Rhetian sub-stage

This stage is composed of coal-bearing molasses of the Suoi Bang (T_3 n-r *sb*) formation (Dovjikov and Nguyen Tuong Tri, 1965). According to Bui Phu My *et al*. (1978) this formation can be divided into 2 sub-formations. The lower sub-formation includes gritstone, sandstone, siltstone, claystone and coaly shale totalling 1100 m. The upper sub-formation contains siltstone, sandstone, shale of dark-to-light grey colours, totalling 800 m. Containing Norian-Rhetian fossils, this formation unconformably overlies rocks of older formations and in its turn is underlain by younger formations. In the study area, this sub-stage was only found around the Ban Hon village.

b. Late Cretaceous-Paleogene sub-stage

This sub-stage consists of coarse-grained, red coloured continental rocks of the Yen Chau formation (K_2 *yc*) (Nguyen Xuan Bao, 1960). The rocks were formed under plate collision conditions, which resulted in highly dissected mountainous relief. Debris of different origin e.g. proluvial, proluvial-alluvial, alluvial and lacustrine etc., was accumulated in intra-mountainous depressions, resulting typically in coarse-bedded (1-2 to 5-10 m thick) conglomerate, gritstone, sandstone of oblique texture and poor roundness. The rock grainsize varies from less than 1 cm to 15-20 cm, sometimes up to 40-50 cm while its mineral composition greatly varies, with a lot of rock types that form the catchment, including calcareous gravels. The middle and upper parts of the formation also contain interbeds of fine-grained rocks like sandstone, siltstone and shale. The total thickness of the formation, according to Bui Phu My *et al*. (1978) reaches up to 1500 m. Many fresh water fossils of Late Cretaceous age have been found. The Yen Chau formation unconformably overlies older rocks and in its turn, underlies younger rocks.

In the study area, the above-described sub-stage forms the Lung Cu-Nung Nang range, stretching more than 30 km from SW of Cang Ty village to SW of Ma Sa Phin village. The area of interest is located just at the foot of the NE slope of this range.

Also belonging to this post-rift sub-stage are Paleogene magmatic intrusive and dyke (minete) rocks of Pu Tra (E *pt*) formation, Pu Sam Cap ($\varepsilon\xi$-$\varepsilon\gamma$ E *pc*) and Phong Tho (λ E *pt*) complexes.

The Pu Tra volcanogenic formation (E *pt*) includes alkaline effusive rocks of neck facies, with boulders and breccias (1-2 cm to 80 cm) of volcanic lavas (violet, purple coloured trachyte, trachyte porphyry, syenite porphyry, leuxitophyr) and interbeds of purple conglomerate, sandstone and siltstone, totalling in thickness, according to Bui Phu My *et al*. (1978), up to 400 m. In the study area, this formation exists in a complicated conical form SW of Ma Sa Phin. Ancient calderas 100 m in depth can still be found at the centre of the cone at the altitude of 2200 m MSL. Numerous boulders of purple trachyte, 1-2 m up to 10-15 m in size, can be found at the foot of the E, NE slopes of this cone.

The Pu Sam Cap (εξ-εγ E *pc*) intrusive complex develops in the study area with 2 small massifs, one to the East of Tam Duong Dat and the other to the West of Dong Pao. This alkaline complex is composed of ash grey, coarse to very coarse crystalline syenite, quartz syenite and granosyenite, with such dark minerals as aegirine, augite, calcite, riebeckite etc. The complex is often seen penetrating granitic rocks of the Y Yen Sun and Phu Sa Phin complexes (which do not crop out in the study area). Isotopic dating by Izok E. and Le Dinh Huu (1965) gave the complex an age of 53-56 m.a.

The Phong Tho (λ E *pt*) Paleogene dyke complex, described commonly by geologists as minete, is kind of vein rock of grey to dark grey colours. The rock texture is porphyric with idiomorphic crystals of biotite, hornblend, pyroxene while the fine-grained matrix contains amphibole, pyroxene, alkaline feldspar, feldspathoid and biotite. Minete dykes are often seen penetrating the Dong Giao limestone, ranging in width from 10 cm to 50-80 cm, sometimes 1.5 m, and tens of metres in length. On the ground surface, the rock is easily weathered to reddish brown soil. At depth, however, the rock is still very fresh, as seen, for example, at Cong Nuoc cave (- 600 m) (Lagrou, this volume).

c. Quaternary post-rift sub-stage

This sub-stage includes Quaternary formations of different origins. Examples are Quaternary accumulations along the Nam Mu River and its tributaries as well as along the Nam So River. The accumulations usually form sandbar and floodplain, and to a lesser extent, the first terrace, containing boulders, cobbles, grits, sand and clay, ranging in thickness from 1-2 m to 5-10 m. Of relatively wide distribution of such formations is the lowland area near Binh Lu while small floodplains sporadically develop along the Nam So River, where the river widens it channel.

Proluvial accumulations, meanwhile, relatively widely develop from Ta Leng to Binh Lu, in the form of a nearly continuous belt along the foot of the SW slope of the Phan Si Pang range. Such accumulations contain poorly graded boulders (1 m to 5-10 m in size), cobbles, breccias, grits, sand and clay, ranging in thickness from 1-2 m to 30-40 m. Their cementation often results from lateritization, giving a reddish brown colour and a supposed age of Late Pleistocene.

Gravitational accumulations (diluvium) are often seen at the foot of the NE slope of the Lung Cu-Nung Nang range as a result of rock fall and other mass wasting movements from the Yen Chau formation. They include a mess of boulders, cobbles, breccias and grits, ranging in size from tens of centimeters to 10-15 m and in thickness from 5-10 cm to 30-50 m.

3 Folding characteristics

Post-rift formations are usually less affected by folding activities than their pre-rift and rift counterparts. Bui Phu My *et al.* (1978) described folds in this area as forming the so-called “Lan Nhi Thang anticline”, which stretches in the NW-SE direction, with terrigeneous rocks of the Tan Lac formation (T_1o *tl*) exposed at the core and limestone of the Dong Giao formation (T_{2a} *dg*) at its two flanks. Our studies have helped describe this fold in more detail, in that it is a big anticline, complicated by higher order folds. The folds are in general, inclined to the NE, with the SW flank steep and overturned and the NE flank gentler while the fold axis gradually plunges to the SE.

The core of the anticline crops out in an ellipsoid form, up to 2 km in width and stretching for more than 10 km from Lan Nhi Thang to Suoi Thau village. The exposed rocks are wholly of the Tan Lac formation (T_{1o} *tl*). To the SE of Suoi Thau village one can find relic limestone massifs of the Dong Giao formation (T_{2a} *dg*) seemingly “sitting” on top of shale of the Tan Lac formation, where the latter show a curving strike, changing dip from SW via SE to NE, and dip angle from 10-15^0 to 40-45^0. At Hong Thu Man on the SW flank and Sung Phai on the NE flank of the fold one can find rocks of the Tan Lac formation all dipping 30-45^0 to the NE. This implies the fold is overturned with its axial surface inclined to the NE.

From the center of the Tam Duong town we have mapped a series of 3 high order anticlines. The first anticline crops out 300 m to the SW of the Huyen Uy spring, and is seen again East of Lao Ti Phung village. At these outcrops one can see the Dong Giao limestone dipping 40-50^0 to the NE and 50-70^0 to the SW. The second anticline crops out at the foot of Seo Phin Mountain (South of Nam Long village), where the Dong Giao limestone dips symmetrically to the NE and SW. This anticline is found again at Lao Ti Phung village. The third anticline also stretches in the NW-SE direction and is exposed at Nung Nang village where one can find effusive rocks of the Vien Nam formation (T_1 *vn*) underlying shale of the Tan Lac formation (T_1o *tl*), which in its turn, underlying, at the fold flanks, limestone of the Dong Giao formation (T_2a *dg*). In between these high order anticlines are 3 corresponding synclines of the same order.

Observations show that subjected to strongest erosion is the axial part of the Tam Duong anticline near Lan Nhi Thang and Suoi Thau villages where the relief is commonly higher than 1000 m asl, with a summit of 1457 m. Down to Nam Loong and Tam Duong town, the roof of the Tan Lac formation is also uplifted but not yet wholly exposed on the ground surface. This results in the karst aquifer in the Dong Giao limestone in a very shallow position around Tam Duong town. On the other hand, from Tam Duong town, the fold axis plunges gradually to the SE and sharply to the NW. Following that trend, the karst aquifer also sharply deepens in the NW direction from Tam Duong town via Gia Khau, Ma Quai Thang toward Lan Nhi Thang and gradually lowers down to the SE. With the high order anticline cropping out at Nung Nang village at relatively high altitude (around 1300 m), with relatively impervious rocks of the Vien Nam (T_1 *vn*) and Tan Lac (T_1o *tl*) formations at its core, one tends to conclude that the underground watershed of this karst aquifer runs through Nung Nang village, wherefrom the karst water flows toward Tam Duong town, Nam Loong village and further to the SE.

In the area where rocks of the Nam Mu formation develop we have mapped a relatively symmetric syncline, which stretches in the NW-SE direction through the Pa Pe pass. Composed of black slate, its SW flank dips 70-75^0 to the SW whereas its NE flank dips 60-70^0 to the NE.

Research by many authors (Dovjikov *et al.*, 1965; Bui Phu My *et al.*, 1978; To Thu *et al.*, 1996 etc.) confirms the Yen Chau formation (K_2 *yc*) is less subject to folding, i.e. gently inclined to the SW at 15-30^0. The Quaternary sediments, on the other hand, are not yet subject to any folding activity.

4 Faulting characteristics

While surveying and mapping the 1/200,000 Lao Cai-Kim Binh geological map sheet, Bui Phu My *et al.* (1978) defined a deep-seated fault, the so-called Phan Si Pang fault that separates the two Phan Si Pang and Da River tectonic zones. The fault stretches in the NW-SE direction from Nam Coum via Then Sin, Binh Lu and continues to the SE. In general, the fault can be traced along the foot of the SW slope of the Phan Si Pang range. It is believed to go down to the upper mantle and have served as the conduit for the magma to erupt out to form the Vien Nam formation. As located wholly within the Da River zone, the study area is thus not in the direct vicinity of the fault. On the other hand, being strongly compressed, along with foldings, a number of faults, mainly in the NW-SE direction, also develop in the area. They are believed to be shallow, intra-formation faults, or at most, they could go down to the crystalline basement or the Conrad surface only, i.e. not down to the mantle. Of these faults, the Nam So fault expresses itself quite clearly on the ground surface, serving as the NE tectonic boundary of the Dong Giao limestone. The fault runs through Ban Hon village to Dong Pao, dipping to the NE and acting as a thrust fault.

From SW of Si Leng Chai to Hong Thu Man there is another fault of the same NW-SE direction. This is an intra-formation fault that cuts only within the Dong Giao formation. The fault trace can be seen clearly on the present relief. The fault dips about 40^0 to the NE, complicating the Tam Duong anticline.

In addition, in the study area, one can still observe several other faults that run along the Nam Dich and Nam Mu rivers. Being intra-formation faults, they all stretch in the NW-SE direction and dip to the NE.

In general, all the NW-SE faults found in the study area are not deep-seated. Dipping to the NE, they are thrust faults in nature.

Apart from the NW-SE faults described above, traces of NE-SW faults can also be found in the study area. One of these faults is the Dong Pao-Binh Lu fault. Being relatively young, it displaced other NW-SE faults to form such localized depressions as found in Binh Lu, and forced different sections of some present day rivers to follow the NE-SW direction.

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GEOHAZARDS IN THE KARST REGIONS OF VIETNAM

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Abstract. Vietnam has nearly 60,000km^2 of exposed karst, taking nearly 20% of the total country's area. Karst of Vietnam has a high biodiversity and a great potential of bauxite, phosphorite, gemstone, plentiful groundwater, and the special values in agro-forestry, tourism, and national defence. Civilians on karst become more and more populous. The use of karst for many purposes is speeding up making the karst environmental system that is inherently sensitive to human impacts, easy to be destroyed and impossible to recover once destroyed necessary to get more soundly aware of the geohazards on the karst to restrict the loss by the unconscious or purposed actions, contribute to a sustainable protection and development of the karst environment in Vietnam. The frequent geohazards on the karst are flash floods, waterlog, long inundations, drought, contamination of groundwater, loss of forest and soil, rock desertification, excessive and negative consumptions of the karst resources. Geoharzards and the prevention, mitigation of loss will be discussed in the article.

1 Overview

It is commonly conceived that any phenomena occurring in nature as well as any geological states by human that cause in or threaten the loss of properties and life of people are geohazards. In Vietnam, karst occupies nearly 60,000 sq. km approximating 18% of the whole country's area; it bears many mineral deposits such as phosphorite, bauxite, gemstone, gold, tin, groundwater, forest resources with a dense biomass, a high biodiversity and endemicity. Limestone yielding karst is itself an indispensable material for cement industry, road pavement, construction as well as many other industries. A rapid population growth of Vietnam as well as the increasingly rapid economic exploitation has been much causing in the risks conducting the more and more severe damages of karst environment of this country. The studies of geohazards on karst, therefore are really urgent.

Karst of Vietnam is not only large but also diverse in landscape. In which there are the typical landscapes such as the peak cluster – depression, the residual or tower karst, and the karst island or the Halong-type landscapes. In each type of landscape or each karst type, again occur the specific hazards. For example on the peak cluster – depression landscape the first hazards to say about is waterlog and flash flood on the blind valleys, continual inundation in the karst depressions and poljes, severe drought, loss of soil and forest, and desertification. In the residual karst landscape where are the populous localities, the contamination of the karst springs, the sinkholing, and collapses of the underground spaces, phenomenon of destroying the cave and excessive exploitation of karst resources. On the karst island landscape, the phenomenon of destroying caves, flowstones, and environmental pollution. Among many types of hazards on the karst regions of Vietnam, we focus on a presentation of some major types and alarms targeting to mitigate the loss and a sustainable development of environment.

2 Flash floods and waterlogs

On the karst regions, waterlog and flash floods only happen in the range peak – valley landscape i.e. a sub-type of the peak cluster – depression landscape. At the same time, waterlog and flash floods only occur on the karst with special positions, normally on the slope or foot of the denuded mountain ranges or plateaux that composed of the non-karst rocks. Then flood water is from the allogenic drainage networks collecting water from the denuded highlands and concentrates at the blind valleys of the karst areas. The place of flood is the bottom and the lower parts (including riverbed and flood plains) of the blind valleys.

It is probably the most typical waterlog on the karst of Vietnam that can be said is the one on the Namla and Nammuoi blind valleys. Both valleys locate on the NE flank of the

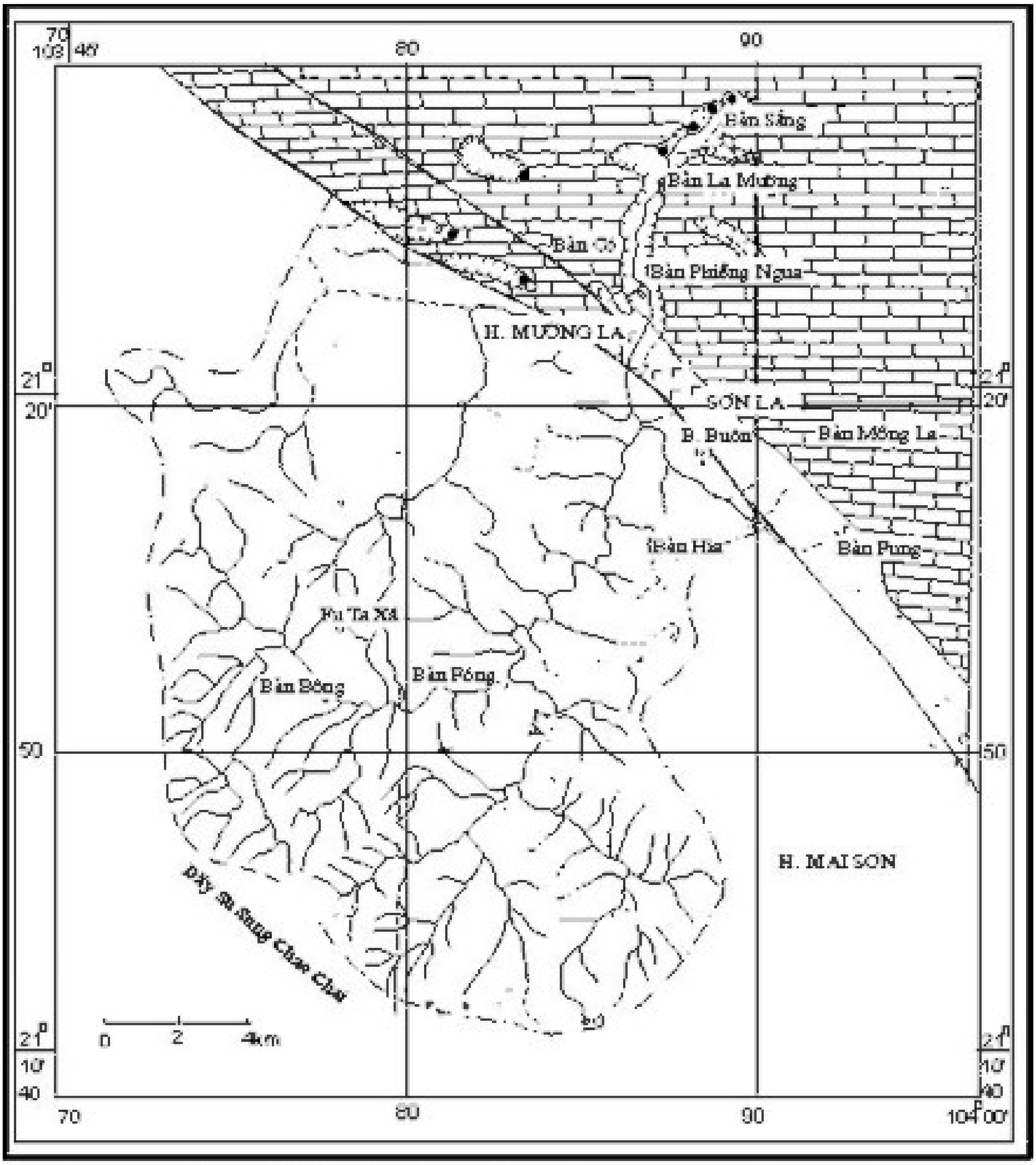

Fig : The Namla blind valley that is formed by water coming from non-karst area to the karst area then completely disappearing to underground systems

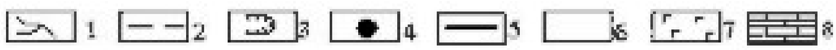

Fig.1: 1. Surface streams; 2. Watershed; 3. Blind valley; 4. Sinkhole; 5. Geologic fault; 6. Non-karst rocks; 7. Volcanic rocks; 8. Limestone

Sung Sung Chao Chai – a watershed mountain range between the Da and Ma rivers (Fig. 1). Limestone area of both valleys is only around 20% meanwhile 80% remaining area of the basin is the denuded high topography on terrestrial rocks and sericite, quarzite, amphibolite; terrain is dissected; the slope is great (28-35^0). The basin has a funnel shape; the flows rapidly branch making surface water rapidly concentrate to the main stream then flows to the karst parts. On the Namla blind valleys from Mong village to Phienghay of 10km long, there are some karst springs and several tributary valleys that are usually dry but at the rains they are ready to make floods.

Human activities in the region conducting more waterlog potentials are that the very forest cover has been razed; the slope surface has been ploughed for farming; besides the people still made many ponds and lakes for fishing and aquatic poultries. Structure of the basin and economic activities are themselves the cause so that when it long and heavily rains since a tropical low pressure with a precipitation as high as 200-300mm per 1 or 2 days waterlog will be generated. A waterlog on the Namla blind valleys on July 27, 1991 had robbed the life of tens people, ruined infrastructures, destroyed everything on its sweep even a rocky hill in Phienghay then formed the Bombay lake.

Thus waterlog on Namla blind valley was resulted from the mutual interactions of heavy and long-last rain, the funnel shape of the basin; high slope and the ploughing on the slope, destroying the forest cover, many water-stored constructions on the dry streams… Man can not stop the rains, can not change the basin structure and inclination of the slopes, but he can certainly stop the flood when he is decisive to restore the upstream forest so as to regulate the floods at the big rains, as well as he can build the upstream lakes that are big enough to block the floods. In order to limit and mitigate the loss by the floods, it is first to be planned; building the houses and constructions on the sweeping way is not allowed; organising the monitors and early alarm of possible floods to people, settling away from the floods to ensure a safety of life and properties of the civilians.

Besides the above exemplary waterlog, on the blind valleys of the NW waterlog also happens in some blind valleys in Vietbac and Phongnha – Kebang.

3 Inundations

In general on the karst regions, surface water is rare, but in certain geomorphologic features, in a certain time, it is fairly abundant, even can make inundation harming the economy and living activities of inhabitants. Inundation in Bombay – Phienghay, in Namla blind valley, in Phe village of the Nammuoi blind valley, in Chiengla karst polje, in the closed karst depression of Noonglua… can be given here as the typical examples. All these location belong to the NW. Inundation in the Phongnha – Kebang and Vietbac karst zones has not been studied in detail.

Inundation of the Bombay – Phienghay area on Namla blind valley had a basic cause that allogenic water from surface streams on Su Sung Chao Chai denuded highland was collected in the rainy season to the Namla blind valley. Water sank into depth via many draining caves such as Lamuong, Phaily, Phailuong, Bombay, Phienghay but most of which were choked by mud, leaves, logs, and roots with living wastes. Water that came in was too much, capacity of the draining caves was limited, as result the extra water caused in serious inundation in the cave entrances. In which the Bombay lake had an area of nearly 100ha, more than 25m deep, and lasted during all rainy season entirely flooding the farming areas of the local people.

The inundation in Phe village of the Nammuoi blind valley also has a same cause as that in the Namla blind valley. Since the basins of Nammuoi and Namla are very steep so, it is only 24-32 h after big rain in the upstream, the flood will occur at the downstream. In order to limit the flooding duration, the only measure is to dredge and clean the cave entrances to improve their draining capacity.

A type of flood whose cause can be different from that in the Phe and Bombay villages is the case in the Chiengla karst polje – an important economic and population spot of the Thuanchau district, Sonla province. In rainy season, the karst polje largely becomes a big lake of 1-2 to 4m deep and surrounded by the limestone ranges, massifs and mountains with vertical flanks. Duration is often from 2 to 3 months. Farming is absolutely impossible. Travel must use the rafts or boats. The Chiengla karst polje has a distinguished karst hydrological regime. Of which there are some karst resurgences in the NW side, after resurging water forms the surface flows on the plain. Then, from surface inlets water continues disappearing underground through some holes in the NE side. Because the draining capacity of the caves is limited, the excessive water due to the difference between the input and output volumes that is the cause of flood there. Our explorations show that, all the draining caves here have the entrances that are almost closed so their capacity is very limited. In order to control the flood phenomenon on the Chiengla karst polje, cleaning and removal of the draining caves are the only proper medium needed to carry out. Besides, selection of suitable crops and cattle compatible to the flood regime should also be taken into account so as to restrict the loss by the floods.

The Noonglua flooding area (NW Ai village – 5 km from Sonla town) has an absolutely different cause from the above mentions. Noonglua is a closed karst depression; the bottom is relatively flat and there are many vertical sinkholes as deep as –100m surrounded by the high terrain. The caves though are so deep, in reality Noonglua is a part of the perched karst aquifer. Fluctuation of karst groundwater table can be 130m. Consequently in dry season, ground water is lowest; only do the deepest caves of the lower part of the aquifers have water; the vertical caves and the Noonglua valley bottom are completely dry. When rainy season comes, water level is raised; all the underground spaces of the aquifer are filled up with water, in that time the Noonglua depression is flooded as deep as 20m. After rain, height of the perched karst aquifer gradually decreases the Noonglua lake is accordingly lowered. Since the causes as mentioned above, there are really no ways to prevent a characteristic phenomenon as the case of Noonglua lake. It is luckily possible to only select proper crops at the time when the lake is not flooded.

4 Droughts

In a nature, because a double-space structure that is composed of the surface and underground features, they link together via a dense fissure system and caves… so in principle surface water is not present on the karst highlands. There, at the rains, water follows the fissures, the vertical and oblique caves quickly going deep to make the underground hydrological network. That is why also on the karst highlands (peak cluster - depression) can not exist the surface drainage networks as those on the non-karst area. Almost volume of water although through the fissures and caves comes to the depth, there is still a small volume kept in the shallow stratum (epikarst); this water enable the karst surface to be moist to a certain extent and help vegetables survive and alive. When vegetables grow, their roots and the products from them themselves produce a shallow water-borne stratum adding to the water in the epikarst. As result the forest cover on karst is once destroyed is synonymous with the acceleration of severe drought.

For the karst highland of the peak cluster – depression landscape, drought is radical, or an inevitable phenomenon of nature. The best is not to live on those areas, and if reluctantly, seeking for drinking water should often be directed in the epikarst and the perched karst hydrological bodies defined by geostructure; the catching and storing tools must be made otherwise.

5 Pollution of karst aquifers

Groundwater in Quaternary sediments, in weathering crust o various bedrocks, in the tectonic fractured zones, in the pores of the sedimentary and volcanic rocks… is yielded by a medium of permeability. Since the permeability, the toxic substance and microbes are firstly kept on the upper strata, water becomes clean when reaching the deep aquifers. Water on karst is absolutely contrary. Since surface water immediately follows the cracks and caves to the depth without any filtering process, a direct circulation between surface and groundwater is established; contents and properties of the ground and surface water are very less different. Consequently once the surface source is polluted by the living wastes, hospital rubbish, industrial sewage, pesticide and fertilizers… the karst aquifers are immediately vulnerable and polluted.

On the karst, the only source of water for living is the karst aquifers themselves in the caves and cracks. It comes out in the resurgences and seepages that the locals directly use as the drinking and production medium. In some localities, karst water can be tapped by drilling as in Cucphuong, Donggiao, Bimson, and Hanam. Feeding the karst aquifers are the autogenic rainy water or sometimes the allogenic sources from surface denuded highlands. Conservation and protection of both reserve and quality of the feeding sources to the karst aquifers must be thoroughly aware and practised by each individuals and organizations who are set on the karst. Our studies (Do Tuyet *et al.*, 1998) show that all the karst water sources in Sonla town area are polluted with microbes. We have also promptly recommended the authorities and people of Tamduong town to stop piling the living and hospital rubbish to the karst dolines in west Namloong despite it is as far from town center as 5 km (Do Tuyet *et al*., 2003). Previously the unrefined sewage from Sonla sugar factory resulted in such a pollution that the karst aquifer in as far as 10 km from Maison could not be used.

The activities conducting a vulnerability of quality and reserve of the karst aquifers are all from man, he therefore must be conscious to limit it; on other hand, authority has to be concerned applying so powerful and effective sanctions as pollution of the karst aquifer can be controlled.

6 Underground collapse

On most of the karst areas of Vietnam is although observed the bare limestone, in some places in Vietbac karst zone, west Quangtri, in Phunhung, Phiengpy of Tuangiao, in Mocchau plateau, Maison of Sonla, in vicinities of Tamduong of Laichau… limestone is observed underlying the not very thick crust of reddish brown clay which is the autogenic residual product of the karstification. In those places surface subsidences are common. In Phunhung, Phiengpy many active sinkholes are encountered. There are the dolines of 40-60m in diameter, 10-20m in depth; the slopes are $30\text{-}50^0$, there are some parts of vertical scarps of 3-5m high and 4-8m long; slopes and bottoms all have the reddish brown clay. The sinkholes halt in dry season but strongly activate in rainy season. The dolines are formed in the reddish brown clay of as deep as 30m, at an altitude of 550 meanwhile the Nammuc river bed is considered as the local erosional baselevel at only 200m asl. Phunhung locates on the watershed area between the Ma River in the west and Nammuc River – a tributary of the Da River in the east. This means that the subsidences are on the covering crust above the karst aquifer in the depth.

The sinkholes in Phunhung, Tuangiao develop mainly on the geomorphologic features as corrosional plains (the Phunhung corrosional plain). In Mocchau, Maison, Nasan, and many other areas of the corrosional plains here are also covered with a not very thick crust of reddish brown clay where many sinking dolines are encountered. The dolines have a diameter of 5-10m to 30m, depth of 5-30m. Bottom of the dolines are usually the draining caves or pitches. A difference from those in Phunhung, Phiengpy is that the walls and bottoms have very little clay; limestone immediately crops out to the surface whose reason is the topography itself being incompletely covered by a very thin crust of reddish brown clay.

In the Tamduong town, both the sinkholes that are completely in the reddish brown clay and the one with the bare rock on slopes and bottom are present. The dolines are 10-15m deep and 15-20m in diameter. The Tamduong area develops on the karst polje. The results of speleological explorations in Lannhithang, Tamduong town and the vicinities show that the caves well develop there, many cave chambers of big size, many limestone blocs that are almost empty by a long and intensive karstification. Just in Tamduong town, the karst aquifer is rather shallow; many segments of underground river-caves have been found; the river is below the limestone layers covered with the reddish brown clay. The phenomenon of collapse of the underground spaces can happen at any time.

Collapses and subsidence of the karst underground spaces is apparently a dangerous and disadvantageous phenomenon to the constructions and economy. The builders therefore must be learned of a nature and potential of collapses and subsidences and have the prevention ensuring a safety to the constructions.

7 Leakage and water loss of reservoirs

As already known, the karst specifically has a double-space structure. The underground space is established by the cracks, protocaves, caves, galleries, conduits, and siphons… Karst water is stored in the cracks, and caves; Bottom of aquifers coincides with a basement or the karstified limit. Water of surface reservoirs likes the hanging pockets of water that is always inclined to move down to the karst aquifer below, or to the position where is not karstified yet.

In China, despite people have carried out a very basic study from a detailed geo-engineering mapping applying the classical and modern methods such as geophysics, drilling, excavations, hydrological bumping tests, remote sensing analyses, normal and isotopic tracer experiments, hydrogeo-chemistry… before building of each construction on the karst; in practice it is revealed that the wish is rarely reached. In Guangxi, there are consequently 644 reservoirs on karst occurring water loss; in Yunnan province there are as many as 41% of the constructions that have the problems (Yuan Daoxian, 1991). This reveals that a water loss of the reservoirs on karst is always a problem of concerns to be resolved ensuring a safety to the constructions. In Vietnam almost the small and average scale reservoirs on karst have the problem. Typical is the Tralon in Maison district, Sonla province that never has the water volume as designed because a considerable amount of water leaks through the fractures and caves (Do Tuyet *et al.*, 1998). In Phonglai (Thuanchau) there is a small lake, before enforcement it still had have water, but after hardening the floor to hope having more water; it had been contrary that just after letting the lake filling with water, a high water column broke away the floor making all water disappear.

Thacba lake is a large hydroelectric reservoir in Vietnam built on the karst. Because waterlevel coincides with the erosional baselevel, as well as the karst aquifer, so in nature it is not a perched lake but the water-collect lake, the lake did not lose water by the karst.

Sonla lake is the largest hydroelectric reservoir that will be built in a coming time. Previously designers have been purposed to dam the Da River at Pavinh with an average water level at 265m (asl), high tide level is 272m. After accomplishment, a large lake will appear on the mountains; a part of the reservoir bottom and its SW bank are limestone; Also, the lake has a large karstic window of 3km long from Muongtrai village to Men village belonging to the NW side of the Pytoong limestone block. The differentiation of the water level between the NW side of the block and its SE side in the downstream is 50m. A length from this side to another is 5,000m. The studies indicate that the karstified depth of the Pytoong block can reach 190m. From 190m upwards, caves are very well developed. There are many caves with the big rooms. Both fossil and active river-caves have been found in this 450m-thick and NW-SE stricken limestone block. Potential of water loss through the Pytoong block can therefore be spoken to be comparatively realistic (Do Tuyet *et al.*, 1997; 2001). The Vietnam's Assembly and Government however have decided the reservoir's height not exceeding 215m and the issue of its water loss through the Muongtrai karstic window has not been taken into consideration.

8 Desertification

The primary humid tropical karst regions of Vietnam are inherently where there is a thick vegetable cover with a very big biomass, high biodiversity, and often have the thin layer of soil and decayed plants. On bottom of the dolines, closed depressions, and valleys the clay and soil layer is often thicker. That is a vital ideal environment reflecting an environment full of light, heat, and humidity. Environment however has been more and more violated under the increasingly economic activities; vegetables have been devastated; the soil cover is thus quickly lost; limestone bedrock is barer and barer; drought is more and more severe; flood and inundation are more and more serious. A lively landscape owned by the karst is gradually replaced by the mourning scenarios alienated from the life, or the deserted landscape.

Many localities in the world are at a danger of this drama. In Guizhou of China for instance, bordering on the Vietbac karst zone of Vietnam within 5 years from 1974 to 1979, $642km^2$ of a total $3312km^2$ have become deserted. Average speed of soil loss is 6.5cm/ year on the slope > 45^0; 4.5cm/ year on the slope $36\text{-}45^0$; 3.5cm/ year on the slope $26\text{-}35^0$ (Yuan Daoxian, 1991).

In Vietnam there are no detailed works on soil loss of the karst so far; but the karst regions where are violently tapped such as Hagiang, Tuachua, Sinho, Lannhithang, Thuanchau, Maison, Maichau, Ngoluong, and Donggiao… the deserted speed will certainly not much different from that in Guizhou of China.

Desertification started with cutting trees and deforesting, drying then burning for the field lands. Slope surface is not only unprotected but also being ploughed and dug to seed rice, corn, and manioc… At the rain, especially tropical showers with a high precipitation, soil is liquefied and stimulated by mechanic action of rain drops; and slope is frequently great so it is quickly drifted away. The coverage is lost; limestone bedrock is step be step exposed to the surface as far as it is all the bare rock. Rocky desertification appears. For the karst environment, the rocky desertification is of an extreme danger. Because, as already spoken the karst environment is very fragile, easy to be broken down, and impossible to recover once broken (Do Tuyet, 2001). This involves in a reality that for the plants alive and grown up the good soil has to be availed. But limestone soil is very difficult to yield. Yuan Daoxian (1991) wrote that it was needed 500,000 to 800,000 years for a soil layer of 1m thick on the humid tropical conditions in South China. And according to Ford D and William P (1989), respective figure must often be 200,000 – 300,000 years. For the other geo-environments such as alluvia plains, denuded hills, or coastal swamps… it is quite possible for men to regenerate an ecosystem if it was once offended. But, despite how much money and labors are invested, the blankets of forest on a bare limestone will not be able to be grown again. So how painful it is when looking at the hills of all bare rock stood out on the plain surface in Thanhhoa, Ninhbinh, Hatay, Haiphong, and Quangninh where had been once vegetated. A migrating compaign in the 1960s of the former century made the forest on the karst areas of Vanho, Mocchau, Maison, or Nasan that had been once very dense become lost and replaced by a deserted landscape. Very many karst regions in Vietnam are crying out for a help to stop the rock phenomenon. It comes from human. Human is obligated and only human can afford to block away the disasters.

9 Excessive extraction of karst resources

Since the quick economic growth in the recent years, the karst resources are at a state of excessive extraction. This is massively expressed in some respects as follows:

- Mining limestone for cement production, construction and road materials; Only within the last 10 years, cement productivity of Vietnam has increased from more than 2 million to 25 million tons. Major material for cement is limestone. Many residual limestone hills in Trangkinh suddenly vanish due to the mining of limestone for the two large cement factories of Hoangthach and Haiphong. Similarly the karst towers in Hoangmai area have been out of sight since the mining for road pavement and for the Nghison cement plant. Especially the limestone areas of Hanam and Ninhbinh are being horribly mined for the cement plants in Kienkhe, Dabut, Donggiao, Bimson, and for construction materials. The mining is normally from outside to the inside of the massifs creating a smearing landscape. The green of vegetations on the tropical karst is dotted with numerous yellowish white mining spots. Hoping that in future, limestone mining ought to be reasonably planned and the mining techniques should be proper so that the landscapes will not be broken.
- The locals take flowstones in the caves for ornamentation, making the false mountains, and for sale. The areas of Luongson, Kimbang, and Donggiao and many other locations in limestone regions, for a benefit, many local civilians have been going to the caves searching for the beautiful flowstones to sell for money that forever deprive beauty of the caves. In order to prevent the phenomenon, the people have to be taught and brought up with learnings; and authorities of all levels should issue as powerful sanctions and punishments as such habits can be deterred.
- In many beautiful caves, especially the ones which have been chosen as worshipping such as Huongson, Giakhanh… the believers have been accustomed to burn incenses causing most of the flowstone to be dirty that their natural colors can not be regained. To preserve a possessive beauty of the caves as done in the civilised nations, the phenomenon should be off; authorities are not indifferent to the reality but steel power should be applied at a need so as to direct the communities.
- Ornamentation is too motley with a lot of false colors not reflecting the nature of the caves as the touring companies did like in the Thiencung (God's palace) cave in Halong, Phongnha in Quangbinh. The false light also creates a change of cave ecosystem, especially the algae species. Beauty of caves, in our mind, is the soul of a deep nature, a treasure to thousands of descending generations. Being drawn by ephemeral profits could make the bad changes even of all nature, and harm our

life. Our slogan is that: "*When you eat a fruit don't chop the tree down*".

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AN APPROACH TO EVALUATE THE REGIONAL VULNERABILITY OF WATER TAPPINGS FROM KARST AQUIFERS IN HAUTE-NORMANDIE (FRANCE): A COUPLED GIS / HYDROLOGICAL TIME-SERIES ANALYSIS

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Keywords: karst, vulnerability, GIS, hydrological time-series, turbidity.

The main water resource in Haute-Normandie (France) is groundwater, which is derived from the chalk aquifer. Moreover, the karstic nature of this aquifer implies strong connexions between groundwater and the surface. This feature induces frequent interruptions of water supply at water tappings (either springs or wells).

This study is composed of two approaches:

1. A hydrological approach which consists of a 30 well-bore and springs reactivity survey, each corresponding watershed being more or less connected with the surface. Turbidity, temperature and electrical conductivity were measured in situ by means of Ysi datasonds according to a 15 min time-step. Geochemical, microbiological and particle size distribution analyses are performed punctually, consecutive to rain events. Signal processing and analyses are used for time-series analyses. The aim of the hydrological approach is the assessment of the karstification degree of the various hydrosystems.

2. A morphostructural approach which consists of the knowledge of geological and morphostructural parameters in the studied area: land use, geomorphological parameters (DEM), superficial layers thickness and their spatial distribution, chalk lithology, tectonics). The morphological and geological parameters will be mapped by means of GIS.

The first stage will provide the degree of karstification for each site thanks to hydrological data. A karstification map of the zone studied will be realized by means of interpolation between the various points, according to the various groundwater basins.

The second stage consists of the comparison of the hydrological data, recorded at each water tapping, with the morphostructural and geological context using multivariate analyses so as to check the existence of relationships between karstification and geology.

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KARST WATER MANAGEMENT IN DONG VAN AND MEO VAC DISTRICTS, HA GIANG PROVINCE, VIETNAM. CONTRIBUTION OF GEOLOGICAL AND SPELEOLOGICAL INVESTIGATIONS

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Abstract. Nearly 50% of the area of Dong Van and Meo Vac districts of Ha Giang province is occupied by limestone, with typical peak clusters and intra-mountain blind depressions. The topography is strongly dissected with deep river gorges and steep slopes, subjected to severe erosional and denudational processes and rarely covered with topsoil layer. The whole area is predominantly at 1300-1500 m, even up to 1700 m m.s.l. The Dong Van and Meo Vac district centers are at app. 900-1000 m. At the same time, the local erosional base, e.g. the Nho Que River and Nhiem River, is only at 400-500 m and 250-300 m m.s.l. respectively. Under such conditions surface flows are very scarce and surface water resources are very limited. Surface streams in the area are mostly very short, becoming dry very soon after the rainy season. Most of them disappear at some cave entrances or sinkholes. Also under such high hydraulic gradient the usual groundwater table practically does not exist. Results of the recently conducted investigations on karst geology and speleology provide important insights into the structural characteristics and extent of karstification, which may play a decisive role in governing the hydrology of the studied area. On that basis, the authors would like to recommend some solutions for local water supply.

1 Location and tectonic settings

Ha Giang is the northernmost province of Vietnam and Dong Van and Meo Vac are also the northernmost districts of the province. Severe climatic conditions (annual rainfall averages only 1600 mm, concentrated moreover in only 3-4 months during summer), rugged topography and difficult access etc. have ranked these two districts among the most difficult locations in terms of clean water supply for both living and production of this ethnically diverse province.

According to the regional structural framework and available geological data, Ha Giang province belongs to the Northern Bac Bo geological region. The region is the southernmost part of the activated Sino-Vietnamese platform, with deeply sunken Pre-Sinian crystalline basement. Its thick and strongly deformed Sinian-Paleozoic-Early Triassic cover contains a series of small depositional disruptions and discontinuities at the end of Early Cambrian, Early Ordovician, Silurian, Devonian and beginning of Late Permian periods. In particular, the so-called “Phu Ngu aulacogene” was formed during Ordovician period, which expanded later into the so-called “Gam River Silurian basin” filled with terrigenous-carbonate sediments and alkaline-acidic effusive rocks. During the Mesozoic-Cenozoic activation-orogenic epochs the “Hien River” and “An Chau” super-imposed depressions were formed with shallow marine terrigenous and acidic effusive rocks of Triassic ages. They were followed by coal-bearing. Late Triassic graben-like depressions, which since Jurassic period evolved into continental basins, intra-mountainous depressions with reddish Cretaceous rocks and lignite-bearing Neogene sediments. Subjected to tectonic movements throughout the Phanerozoic epoch, the region’s structural plan reflects clear block feature with many uplifted blocks e.g. horst-like Ma River, Fansipan and Red River anticlinoria, dome-like Chay River, Ha Lang blocks and arc-like Coc Xo and Bac Son blocks ([1], [2]).

2 Stratigraphy

Also according to available and recently edited geological data, many rock types of different periods, from Late Cambrian to recent ages, crop out in the studied area. Of particular interest are the following formations:

- *Song Cau formation (D_1 sc):* About 650 m in thickness, the formation begins with a layer of basal conglomerate, which unconformably overlies Ordovician rocks, followed mainly with dark brown schist, interbedded with sandstone, siltstone and calcareous shale;
- *Mia Le formation (D_1 ml):* About 700 m thick, it overlies conformably the Song Cau formation and consists mainly of schist with interbeds of sandstone, siltstone, calcareous shale and limestone lenses;
- *Na Quan (D_{1-2} nq) and Khao Loc (D_{1-2} kl) formations:* These equivalent formations develop at the NE and SW edges of the studied area. Being 500-700 m thick and conformably overlying the Mia Le formation, they contain mostly quartz-sericite schist, calcareous shale and siliceous limestone;
- *Toc Tat formation (D_3 tt):* Approximately 200 m in thickness, overlying conformably Na Quan and Khao Loc formations and forming small, wavy folds, it consists mainly of thin-bedded siliceous limestone, calcareous shale with interbeds of coaly shale.

These Devonian sediments usually go together, forming a NW-SE belt at the NE edge, along the right bank of Nho Que River. Another wider belt, also stretching NW-SE, crops out at the SW, in the area of Yen Minh and Quan Ba districts.

- *Bac Son formation (C-P bs):* Consisting mainly of moderately-to-thick-bedded, even massive limestone, 1000-1200 m in thickness, the formation crops out in the central part of the studied area, occupying nearly 50% of the area of Dong Van and Meo Vac districts. Being quite gently-bedded, the rock forms large-sized folds and unconformably overlies Devonian formations;
- *Dong Dang formation (P_2 dd):* About 200 m thick and consisting of bauxite, coaly shale, siliceous limestone, this formation rests on the eroded surface of Bac Son formation;
- *Hong Ngai formation (T_1 hn):* This formation conformably overlies Dong Dang rocks with about 350 m of mainly sandstone, siltstone, schist, limestone and calcareous shale.

Rocks of these two formations also go together, forming 2 narrow belts following the two NW-SE faults that run through the central and SW parts of the studied area.

- *Song Hien formation (T_1 sh):* The formation is divided into 2 sub-formations:
- *Lower sub-formation (T_1 sh_1):* About 600 m thick and usually separated from older rocks by tectonic borders, the lower sub-formation consists mainly of calcareous shale, sandstone and siltstone, which are interbedded at many locations with basaltic effusive rocks;
- *Upper sub-formation (T_1 sh_2):* About 500 m thick, this upper part consists of tuffogenous sandstone, siltstone and shale;
- *Na Khuat formation (T_2 nk):* Up to 1000 m in thickness, this formation shows a gradual transition from the underlying Song Hien formation, with mainly sandstone, siltstone and a little limestone and calcareous shale at the lower part.

The Song Hien and Na Khuat formations also often go together, unconformably overlying the Bac Son limestone and forming a wide belt along the big, NW-SE faults at the south and SW part of the studied area. Right at the Dong Van district center is a narrow belt of the lower part of Song Hien formation, which stretches along a NW-SE fault, showing a tectonic contact with the limestone of Bac Son formation.

- *Quaternary loose sediments:* These sediments bear fluvial and fluvio-proluvial characteristics, consisting of gravel, pebble, silt, clay and forming terraces and floodplains along streams, rivers and within intra-mountainous valleys. They are just a few, sometimes up to tens meters in thickness.

3 Aquifers and aquitards

In terms of water bearing characteristics of the above described formations, one may distinguish the following aquifers and aquitards:

The Devonian aquitard, consisting of the Song Cau, Mia Le, Na Quan and Khao Loc and Toc Tat formations. The limestones contained in these formations are usually clayey, siliceous, interbedded with coaly shale and deformed into small, wavy folds, thus regarded as not so favourable for karstification. Along the right bank of Nho Que River, the Devonian limestone is seen plunging to the SW, without any considerable water exsurgent points. Comparing its water bearing capacity with that of the Carboniferous-Permian limestone of Bac Son formation, one may group all Devonian rocks into one aquitard that underlies other strata;

- The Carboniferous-Permian aquifer, with limestone of Bac Son formation;
- The Permian-Triassic aquitard, with sediments of Dong Dang, Hong Ngai, Song Hien and Na Khuat formations;
- The uppermost horizon of Quaternary loose sediments.

Of particular interest and the only important water resource is thus the karst groundwater in the Bac Son limestone. Therefore, and taking into consideration the great depth to hydrological base levels, the region is in severe lack of perennial water access and in need of karst exploration.

4 Folding and faulting

The Devonian formations (perhaps also together with older rocks) form small, wavy folds. At some places they are pushed to rather big anticlines as observed on the right bank of Nho Que River, along the provincial route at Pai Lung commune (Meo Vac district). Over there, the Toc Tat (D_3 tt) thin-bedded limestone, interbedded with coaly shale, plunges to the SW, with the common bedding of about $220\text{-}230^o\angle 20\text{-}40^o$. Seen over a larger area, they rather form a synclinorium underlying younger formations.

The unconformably overlying Bac Son (C-P bs) limestone is seen with gentler bedding, forming big folds a few tens to hundreds meters in width. The Tia Sang (light beam) cave (with a big underground river, found at Ma Le commune, Dong Van district, and described below) developed in this limestone may prove this. The cave width increases up to 10-30 m at some places, with its ceiling quite flat and horizontal. Along the cave walls are seen at many places with limestone beds dipping alternately into 2 opposite directions. Furthermore, the flow action contributed to make quite large meanders. Such details may indicate that the cave and the underground flow develop along the axis of an anticline, on its gentle but more strongly fractured crest part.

The following superimposed formations, from (P_2 dd) up to (T_2 nk) were under a clear control of the three arc-like fault zones, which, within the studied area, stretch roughly in the NW-SE direction.

The Dong Dang and Hong Ngai formations developed into a small, narrow belt adhering to the fault which runs through the central part of the studied area. The rocks affected dip gently from the edges of the belt toward its centre. The dark grey siliceous limestone of the Dong Dang formation does not favour a high degree of karstification, hence a limited water storability. Together with the bauxite layer at the lower part of the formation and conformably overlying terrigenous rocks of Hong Ngai (T_1 hn) formation, they all, as a whole, play the role of the upper barrier to the Carboniferous-Permian limestone aquifer.

Stronger subsidence perhaps, took place along the SW fault, with the formation of Song Hien (T_1 sh) and Na Khuat (T_2 nk) terrigenous rocks;

On contrast, along a similar fault at the NE edge of the studied area, only a small belt of the lower part of the Song Hien formation develops, with sandstone and siltstone interbedded with basalt.

Such observations perhaps imply that although similar in nature and belonging to the same system these faults differ in their active time and intensity. Moreover, detailed description of caves, karstification and karst hydrology shows that considerable relative vertical displacement (up to 500-600 m, with the southern flank sunken down) could have taken place along the fault zone at the NE edge that runs through the Dong Van district center.

Other faulting systems of NE-SW, sub-meridional and sub-parallel directions do not express as clearly their role of structural control as the NW-SE system. Such faults are mostly in the form of single, sporadic, short zones, locally found at some places. For example, the stream at Ma Le commune flows along a NE-SW ($60\text{-}70^o$) fault. One section of this stream (from Ma Le No. 1 sinkhole to Ma Le No. 2 resurgence) flows underground. The stream actually plays as a collector of surface water from all terrigenous rocks in the north to eventually drain out at Nho Que River. In addition, results of cave exploration show that caves develop along faults of NE-SW direction more often than NW-SE direction.

The Meo Vac district center, on the other hand, is located in a karst valley that is up to 700-800 m wide, stretching 6-7 km in the sub-meridional direction. A few hundreds meters to the west, on the way to Lung Vai village, Ta Lung commune, another fault zone of the same direction is found, which is up to 70-80 m wide, crushing and recrystallizing the limestone of Dong Dang formation. Along the large valley a series of filled sinkholes and a temporary (only during rainy season) surface stream can be traced out. Stretching down until Nho Que River, this valley would suggest that all the karst groundwater would drain to this river. However, this is clearly wrong. Actual field survey shows that all caves, both in and along this valley and both at the valley level or higher, are very short, and that there is only one small exsurgent point at Pa Vi commune, where the dark grey, thin-bedded limestone of Toc Tat formation also crops out, all indicating the insignificant role of this fault zone.

Short fragments of sub-parallel faults are observed at other places, especially near Ma and Na Luong villages (Mau Due commune, Yen Minh district). It is there that the tectonic boundary between the Bac Son limestone in the north and younger terrigenous rocks to the south can be found, as well as a long (nearly 1 km) rim of karst water exsurgences stretching in the sub-parallel direction. More details on these exsurgences are presented below.

5 Karstification and karst hydrology

Like many other locations of the North Bac Bo geological region, the studied area is presently subjected to active block uplift, with strongly dissected relief, very steep slopes and severe erosion. Typical tower karst landforms prevail, with peak clusters and intra-mountain closed depressions. The topsoil layer is rarely conserved with bare rock cropping out almost everywhere. The area average altitude is about 1300-1500 m, up to 1700 m at some places whereas the local erosional base is rather low, only about 400-500 m along the Nho Que

Fig. 1: Schematic map of the Dong Van and Meo Vac districts, with the location of the entrances of the most important caves.

River or 250-300 m at the Nhiem River (Fig. 1).

Under such conditions it appears very difficult for water to remain long on the ground surface. In other words, the surface water storability is very low. Most streams in the area are very short, entirely drying up during the dry season. Most of them disappear at some cave entrances or sinkholes. Also under such high hydraulic gradient the usual ground water table actually does not exist, making it almost impossible to predict depth to the ground water.

Most of nearly 50 caves checked in both Dong Van and Meo Vac districts develop in limestone of the Bac Son formation (C-P bs). Their basic characteristics are presented in Table 1. The cave data result from a Belgian-Vietnamese speleological expedition which explored the Dong Van/Meau Vac area for three weeks in December 2003/January 2004 (SPEKUL, 2004).

5.1. Dong Van district

Analyzing some caves surveyed to date in Dong Van district one could draw one essential remark. That is caves in this area are made of mainly alternating vertical and horizontal sections (Fig. 2) and regardless of the different altitudes the caves may start, they all appear to end with a horizontal section with sump, mainly at the absolute altitude of about 950-1000 m, which is the same as that of the valley of Dong Van district center (Fig. 3).

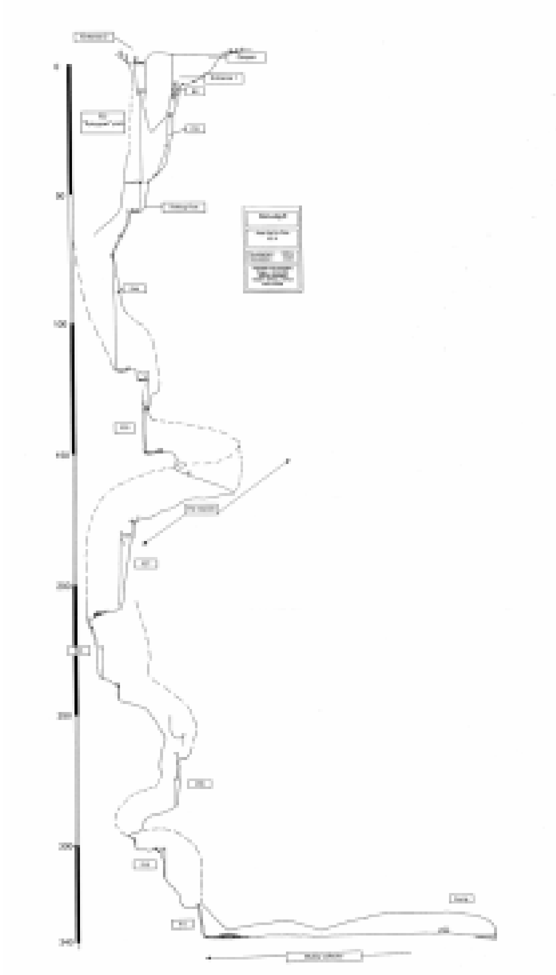

Fig. 2: The vertical section of the Xa Lung 2 cave (Dong Van area).

Table 1: Overview of the most important caves surveyed during the Belgian-Vietnamese speleological expedition (2003-2004) in the Dong Van and Meo Vac districts.

Cave Name	**Develop-ment** (in m)	**Denive-lation** (in m)	**Heigth** (m msl)
Dong Van			
Dong Nguyet	774	78	~1500
Hang Ong*	1523	341	1458
Xa Lung 1	262	178	~1325
Xa Lung 2	700	336	1315
Xa Xa Phin 1	191	32	1370
Xa Xa Phin 3	437	116	1464
Tia Sang	1154	107	1020
Ma Le 1	218	56	~1050
Ma Le 2	899	44	1046
Meo Vac			
Italians Cave	201	47	>1000
Lung Chinh*		340 + ?	1012

*Exploration contiTransnues

Fig. 3: Schematic cross section of the Dong Van area, with an outline of the most important caves.

Perhaps that is the altitude of the zone of horizontal flow, where vertical karstification stops. Based on this, one could further assume the following:

The caves are experiencing strong tectonic constraints. Under quiet conditions they develop right at the local erosional base level in the horizontal direction. Subsequent rapid uplifts force them to develop vertically all the way until these movements cease and the caves can go again horizontal. At present, with most caves ending with a horizontal section, one might conclude that the tectonic conditions are quite stable, which is not in agreement with other studies. Hence, it is very possible that the caves have reached their underlying non-karst stratum, and karstification, if any, would develop mostly in the horizontal direction. This underlying non-karst stratum may well be the Devonian rocks;

The Dong Van district center valley is actually the local erosional base at present, i.e. the main collector of karst underground flows. A proof of this may be the horizontal underground flow in the limestone range behind the district center, which at present supplies water for the majority part of the district center.

In the vicinity of Dong Van district center the karst ground water is relatively abundant and easy to find at the altitude of about 950-1000 m.

5.2 Meo Vac district

Karst survey in Meo Vac district has provided some important information as follows (Fig.4):

Along the Meo Vac valley, most of caves or cave-like features are very short and/or choked. No caves have been found to a considerable depth. It is also worth mentioning that there have been recently several boreholes for water drilled along the valley, with a

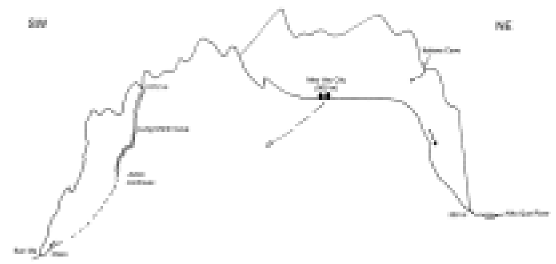

Fig. 4: Schematic cross section of the Meo Vac area, with an outline of the most important caves.

hypothesis that there could be an underground river that drains out to Nho Que River. Drilled to more than 120 m these boreholes failed to reach significant sources of ground water.

Along the right bank of Nho Que River neither interesting caves nor significant water exsurgent points have been found. Only 3 small points were located along the road that stretches tens of km in the NW-SE direction from Pa Vi commune down to the Sin Cai bridge. The exsurgence near Pa Vi commune was found immediately along the bed of the seasonal sub-meridional surface stream, in the dark-grey, thin-bedded limestone of the Toc Tat formation. Meanwhile, the two other points near the Sin Cai bridge were found with water seeping out from the weathering crust and topsoil layer of Devonian terrigenous rocks. Also along the road on the right bank from the SE upstream to Tia Co Si village there are only two small exsurgent points from thin-bedded limestone of the same formation. Remarkably the limestone bedding remains similar, i.e. about 220-230$^o\angle$20-30^o, plunging to the SW;

In the area of Ha Ia village, Can Chu Phin commune, among nearly 10 surveyed caves, worth noting was a horizontal cave that develops for about 150-200 m, with water at absolute altitude of about 1100-1200 m.

In the area of Lung Chinh commune, several caves and water exsurgent points were surveyed, with one cave at Sui Chu Van village, which was descended already down to 340 m depth and still continues with water.

In the area of Lung Vai village, Ta Lung commune, neither caves nor exsurgences were found.

However, in the area of Ma and Na Luong villages, Sung Trai commune (Dong Van district) and Mau Due commune (Yen Minh district) a rim of water exsurgent points was found stretching nearly 1 km in the sub-parallel direction. The water discharge was found huge even in dry season, app. 10 m^3/s (at a single exsurgence), forming a very sizeable surface stream at an absolute altitude of about 350 m. Up to 2-3 cave levels were found with several big entrances. One of these caves was explored (at the end of the 2004 expedition) for about 100 m long ad still continues.

With all these details, coupled with the general bedding of the underlying Devonian barrier plunging toward the SW, some preliminary remarks can be made as follows:

In the vicinity of the Meo Vac district center, especially along the Meo Vac valley, it appears very difficult, if not impossible, to find karst ground water with considerable discharge. The latter does not drain out to Nho Que River as a possible local erosional base.

It appears also difficult to find karst ground water in the whole Meo Vac district. The water, perhaps, is located very deep, with a tendency to accumulate in the SW. At present, only one karst exsurgent rim was found at the altitude of 350 m near Ma village (Mau Due commune, Yen Minh district). There is, however, some chance to find the water at shallower depth, e.g. near the area of Lung Chinh commune.

The exsurgences near Ha Ia village, SE of the Meo Vac district center are located quite high, at about 1100-1200 m m.s.l. The location also marks the end part of the narrow belt of Dong Dang and Hong Ngai formations. It is very likely that these rocks are the supplying sources for this water. Although of limited capacity, this water could be very important for the Meo Vac district center because of it being close to the town. Hence it should be studied in more details.

Comparing the absolute altitudes of the underlying Devonian layer in Dong Van and Meo Vac areas, one may suspect that there is possibly a considerable vertical displacement, up to 500-600 m, between these two areas, most likely along the NW-SE fault zone that runs through the Dong Van district center.

6 Some conclusions

On-purpose speleological and geological studies in karst mountainous areas of Dong Van and Meo Vac districts have helped to give some insights into the nature of underground karst water in these areas and the possibility of locating and using it for the living and the production activities of local people.

Underground karst water in Dong Van district, compared to Meo Vac district, is relatively easier to locate and exploit. On the basis of the investigations (to be completed in the future) a vulnerability map should be established. Indeed, since farming activities are intensive in the areas which drain towards the karst aquifer and since local farmers use increasingly fertilizers, pesticides and herbicides measures should be taken to protect the quality of the karst water. For example: from different observations in the area it became clear that the Tia Sang sinkhole is draining a large part of the water of the Ma Le valley which is cultivated intensively and that most probably this water is resurging at the karst springs around Dong Van city after only a short time underground. Therefore, it could be assumed that the activities in the Ma Le valley affect largely the water quality of Dong Van. Further investigations could provide more accurate and precise information also on other areas feeding the karst springs (for example the areas of Xa Lung and Xa Xa Phin).

On the other hand, because of its great depth, chances for finding out and using underground karst water in Meo Vac district seem to be very limited. Local authorities have already spent considerable amount of money to find water through drilling, however without success (which is – unfortunately – corroborated by our research findings). Perhaps alternative ways of harvesting water should be considered. In this scenario maybe some caves could be favourable for storing underground water.

Moreover, since it seems very unlikely, on the one hand, that karst water will become available and accessible in large amounts as to allow further increase of the productivity of already intensive farming activities and since, on the other hand, these farming activities (and the increasing use of fertilizers, etc.) constitute a real threat to the quality of the water which is actually available and accessible, it seems more wise to look for other and different development scenarios. In these scenarios the scenic beauty of the karst landscape, the presence of beautiful caves and the kindness, hospitality and folklore of the local people could play a preponderant role.

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GEOLOGICAL STRUCTURAL CONTROL OF KARST WATER IN THUAN CHAU AREA, SON LA PROVINCE, VIETNAM

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Abstract. On the basis of available geological data, the authors try to characterize the main geostructural features of the Thuan Chau area (Son La province, Vietnam) in an attempt to understand the karst water resources of the area.

Keywords: geology, stratigraphy, tectonics, karst hydrogeology.

1 Location and tectonic setting

The Thuan Chau-Son La area is part of 2 large structural units i.e. the Ma River anticlinorium in the SW and the Da River Rift in the NE. These structures belong to the Northwest folding system which itself is part of the Bac Bo folding region. The above-mentioned structures are separated from each other by the Son La deep-seated fault of NW-SE direction.

The Ma River anticlinorium is formed by combining three structural zones i.e. Son La, Thanh Hoa and Ma River, established by Dovjikov *et al*. (1965). It developed through several tectonic cycles i.e. the Baikalian, Caledonian until end of the Hercynian when the final structures and morphology formed as observed at present. The oldest, axial part of the anticlinorium is composed of Baikalian metamorphic rocks of the Nam Co (PR_3-$\in_1$) formation, covering a wide area at the SW corner of the study area i.e. the Phong Lap, Chieng Rom, Nam Lau communes, and acting as the water divide of the Su Sung Chao Chai range. Further to the NE, forming the NE flank of the anticlinorium are sporadically weakly metamorphosed caledonian terrigeneous, terrigeneous-carbonate-silicate rocks of the Song Ma ($\in_2$ sm), Ham Rong ($\in_3$ hr), Dong Son (O_1 ds) and Nam Pia (D_1 np) formations. They form a continuous belt to the west of Thuan Chau town from Bon Phang to east of Phong Lap. The Hercynian part of the structure continues further to the NE and is characterized by carbonate rocks of the Ban Pap (D_2 bp) and Chieng Pac (C-P cp) formations. They are seen in Bon Phang, Chieng Pac and sporadically along National Route No. 6.

The Da River rift is composed of Permian to Late Triassic (Carnian), sequential formations, starting from mafic effusive rocks, overlain by terrigeneous, carbonate-terrigeneous, pure carbonate and fine-grained, deep-sea terrigeneous formations. They form the central part of the study area, to the NE of National Route No. 6, from Son La town to Chieng Pac, Thuan Chau to Pha Din Pass. When the rift closed down at the end of Carnian or immediately before Norian (Dovjikov *et al*., 1965) all its formations were subject to strong folding activities, forming complicated NW-SE folds. Overlying these typical indosinian rift formations are rocks of the Yen Son tectonic cycle (Norian to end of Cretaceous) including the Suoi Bang (T_3 n-r sb), Yen Chau (K_2 yc) formations and Paleogene volcanics as well as Quaternary sediments which are not subject to such folding activities.

2 Structural stages

Located in an active tectonic region, which has been subjected to a series of tectonic cycles, the study area is, therefore, divided into several different structural stages; each was formed under relatively uniform paleogeographic and tectonic settings. The inherent diversity of the geological environment, however, makes it possible to divide a particular stage into several sub-stages as described below.

2.1 Baikalian stage

This is the oldest, or basement stage of the study area, containing shallow marine terrigeneous rocks, subjected to green schist grade of metamorphism, of the Nam Co formation (PR_3-$\in_1$ nc) (Dovjikov *et al*., 1965).

The formation is represented by an assemblage of strongly micro-folded, metamorphic rocks e.g. two mica-garnet schist, quartz-micaceous schist interbedded with sericite-chlorite schist, quartz-sericite schist, quartz-feldspar-2 mica schist, micaceous schist, hornblende-garnet schist, quartz-muscovite schist, quartzite etc., totalling 2300 m in thickness. The lower boundary of the formation remains unclear whereas it is overlain by the Song Ma formation. The stage crops out in Phong Lap, Chieng Bom, Nam Lau, Cua Rung etc., acting as the water divide of the Su Sung Chao Chai range.

2.2 Caledonian stage

This stage is composed of rocks of the Song Ma, Ham Rong and Dong Son formations. The Song Ma formation ($\in_2$ sm) starts with a basal layer of conglomerate, changing upward to quartz-sericite schist, sericite schist with thin interbeds of marblized limestone, quartzitic sandstone, totalling 400-1800 m in thickness. The formation unconformably overlies the Nam Co formation while conformably underlies the Ham Rong one ($\in_3$ hr).

The Ham Rong formation consists mainly of fine-grained limestone, oolitic limestone, calcareous claystone, calcareous sandstone, shale and limestone lenses, totalling 500-1000 m in thickness. The formation lies conformably with the Song Ma formation below and the Dong Son formation above.

The Dong Son formation (O_1 ds) contains shale, siltstone, quartzitic sandstone, totalling 360 m. It lies conformably with the Ham Rong formation below and the Nam Pia formation (D_1 np) above.

Thus, the Caledonian stage is made of a series of terrigeneous, terrigeneous-carbonate formations totalling more than 2000 m. In the study area the stage forms a continuous belt to the west of Thuan Chau from Bon Phang to Phong Lap.

2.3 Hercynian stage

This stage can be divided into the following sub-stages:

- The lower Hercynian sub-stage is made of rocks of the Nam Pia formation (D_1 np) i.e. conglomerate, gritstone, sandstone, quartzitic sandstone, shale with interbeds of calcareous shale and limestone lenses, 480 m in thickness. It unconformably overlies the Ham Rong and Dong Son formations and conformably underlies the Ban Pap formation (D_2 bp).
- The middle Hercynian sub-stage is made of the Ban Pap formation (D_2 bp). It comprises siltstone, shale 190 m thick in the lower part, changing upward into 1000 m thick limestone. The formation conformably overlies the Nam Pia formation and unconformably underlies the Carboniferous-Permian limestone.
- The upper Hercynian sub-stage is made of limestone of the Chieng Pac formation (C-P cp). The formation consists of light-coloured, bedded to massive limestone, 1200 m thick.
- The Hercynian stage widely crops out in Bon Phang, Chieng Pac, Thuan Chau town and Phong Lai.

2.4 Indosinian stage

This stage is divided into 4 sub-stages.

- The lower sub-stage is made of effusive rocks of the Vien Nam formation (T_1 vn), seen around Son La Pass, Chieng Den, Chieng Pac and Ban Sang.
- The second sub-stage consists of fine-grained terrigeneous rocks e.g. shale, siltstone, calcareous shale of the Tan Lac formation (T_1o tl).
- The third sub-stage includes the Dong Giao (T_2a dg), Nam Tham (T_2l nt) and Muong Trai (T_2l mt) formations. The Dong Giao formation is represented with fine-to-medium-grained, thin-to-medium-bedded and massive limestone of various, light-to-grey, pinkish colours, totalling up to 1200 m in thickness. Other formations like the Nam Tham and Muong Trai consist of fine-grained terrigeneous rocks and limestone totalling 700-1500 m in thickness.
- The fourth sub-stage is composed of grey, dark grey rocks of the Nam Mu formation (T_3c nm) e.g. very thin-bedded shale with interbeds of siltstone, sandstone of up to 1500 m in thickness.

In brief, the Indosinian stage is made of several conformable formations of Late Permian-Triassic (until Carnian) ages, with the total thickness of 6150 m, forming the rift stage as mentioned above. This stage results in the limestone, limestone-terrigeneous range at the centre and the fine-grained effusive-terrigeneous range at the NE corner of the study area.

2.5 Yen Son stage

This stage is made of rocks of the Suoi Bang and Yen Chau formations, and can be divided into 2 sub-stages.

2.6 Alpinian stage

This stage comprises of 2 sub-stages. The lower sub-stage contains volcanic-sedimentary rocks of the Pu Tra formation (Pg pt) e.g. purple-brown trachite, trachite porphyry, leucitophyr, trachite tuff, sandstone, claystone etc. totalling 400 m in thickness. The rocks are seen at the foot of the Khau Pha Pass and Phai Khon. The upper sub-stage includes Quaternary formations of alluvial, alluvio-proluvial origins, which are less than 10 m in thickness and seen scatteredly along the Nam La, Nam Muoi rivers.

The Alpinian cycle can be considered a continuation of the Yen Son orogenic uplifting cycle, because of which the whole area and its vicinity continue to be uplifted. Rocks formed in depressions during the Yen Son cycle are now often seen on the water divides of mountain ranges near the NE corner of the study area.

2.7 Consequences for hydrology and karst development

The brief division and description above serves as basis for understanding the nature of geological structures in the study area. Carbonate formations that form independent limestone stages are:

- The Ham Rong formation ($\in_3$ hr), 300 m thick of the Caledonian stage;
- The Ban Pap formation (D_2 bp), 1000 m thick and the Chieng Pac formation (C-P cp), 1200 m thick, both belonging to the Hercynian stage;
- The Dong Giao (T_2a dg), Nam Tham (T_2l nt) and Muong Trai (T_2l mt), 1600 m thick, belonging to the Indosinian stage.

In terms of hydrogeology, the above mentioned limestone stages act at the same time as important aquifers in the study area. Of particular importance are the Ban Pap, Chieng Pac, Dong Giao, Nam Tham and Muong Trai formations. In between these aquifers are non-karst aquitards.

3 Folding characteristics

There is a remarkable transition in the area from the Song Ma anticlinorium in the SW via the Son La synclinorium in the center to the Song Da riftogenic super-imposed depression in the NE.

Late Proterozoic-Early-Middle Cambrian formations in the SW part of the area, though having some stratigraphic or tectonic disruptions, can be grouped together to form the NE swing of the Song Ma anticlinorium. Late Cambrian to Carboniferous-Permian rocks, becoming younger from SW to NE, form the Son La truncated synclinorium. On the other hand, starting from Late Permian until right before Norian-Rhetian, rocks of the Song Da rift also get younger from its margin to its center, forming a big negative structure that is further complicated by graben-like structures of the same direction.

Older rocks, including limestone, tend to be more strongly folded, forming small, complicated and alternating folds. Younger stages usually form simple, big folds up to several km wide. Both old and young non-carbonate rocks, rich in clay content are easily subjected to compression, forming small, only several meters wide, folds.

An example of the transition from complicated, micro-folds to simple, big folds can be observed in older rocks along geological cross-sections at Nong Choc, Ban Bien, Na Hat, Ban Pha, Ban Phe villages, south of Thuan Chau Town. One can trace there complicated micro-folds both in the quartz-sericite-chlorite schist (PR_3-$\in_1$ nc), and in the clay rich limestone of the Ham Rong suite. In the mean time, quartzitified sandstone, xericite sandstone, quartz-xericite schists of the Dong Son (O_1 ds) in the NE flank of the Ban Lai-Ban Bien fault can just form a simple, big syncline, slightly complicated in the central part as already described above.

Limestone of the Ban Pap and Chieng Pac suites usually form nice folds, several hundreds meters wide on the average, stretching in the NW-SE direction, sporadically forming overturned folds near faults as described above.

On the other hand, Dong Giao limestone (T_2a dg) also forms big folds, up to several km wide, and stretching also in the NW-SE direction. Anticlines usually line along intra-formation faults to form karst cones, sinkholes, dolines whereas big synclines serve as good water collector-basins which eventually drain out along their strike to local denudational bases, along such streams as Nam La, Nam Muoi as described above.

In contrast, being thin, clay rich terrigeneous rocks, aquitards such as Tan Lac

(T_1 tl), Co Noi (T_1 cn), Nam Tham (T_2l nt_1) or Suoi Bang (T_3n-r sb) etc., often form complicated, intra-layer micro-folds, only several meters wide, which is also important in making them perfect aquitards.

4 Faulting characteristics

The following main fault systems can be classified within the map area:

- NW-SE system, which is further divided into 3 sub-systems, striking respectively in the following ranges: 285-300° (dipping 210-220°∠80-90°), 320-330° (dipping vertically or 40-50°∠60-80°, there are also gently dipping fractures, only about 20°) and 330-345° (70°∠30°), of them the second sub-system is relatively rarer;
- NE-SW system, which is divided further into 3 sub-systems, striking respectively in the following ranges: 20-35° (dipping 110-115°∠20-30° to 75-80°), 40-50° (dipping 130-150°∠30-80°, including 2 generations, the gentle one intersecting the steeper one) and 60-70° (dipping 330-340°∠30-70°), of which the second sub-system is also relatively rarer;
- Sub-parallel system (dipping vertically, to the North, 0°∠60° or very gentle, 10-20°∠5-10° (tension, short and narrow joints));
- Sub-meridional system (dipping either vertically or to the East 90°∠30-40°).

4.1 The NW-SE fault system

This is the most strongly developed fault system, which includes quite a few regional, deep-seated, zone or strata bordering faults. The 330-345° sub-system develops more in the NNW of the map, whereas the 285-300° sub-system prevails in the center and SSE of the map. It is this fault system that governs the belt-shaped zoning structure of the map. In greater detail, these sub-systems meet near the Thuan Chau Town, giving birth to the unique crooked arm-like morphology of this area, which flares out at the two ends in the NW and SE and narrows at the intersection. Together with other fault systems, e.g. the NE-SW system (the Ban Pha-Ban Phe fault), they help form a very developed hydrologic drainage network in the vicinity of Thuan Chau Town, with year round sufficient water for productive paddy fields.

Among NW-SE system some main faults can be traced out as follows:

- Ban Lai-Ban Bien fault, striking 330-345°, separating the Nam Co (PR_3-∈1 nc) and Song Ma (∈$_2$ sm) formations in the SW from younger rocks in the NE of the area;
- Phong Lang-Thuan Chau fault and its companion, Ban Han-Ban Lanh fault, striking 330-345°. The faults still continue further to the NW, beyond the area. However, to the SE, they are stopped by the Ban Pha-Ban Phe NE-SW fault. The Phong Lang-Thuan Chau fault separates non-carbonate rock (O_1 ds) in the West from Mid-Devonian (D_2 bp) limestone east of Thuan Chau Town. Besides, within the area covered by the Nam Pia (D_1 np), Ban Pap (D_2 bp) and Cam Thuy (P_2 ct) east of Thuan Chau Town, these faults help form a downwarped block compared to the same formations (D_1 np and D_2 bp) east of the Ban Han-Ban Lanh fault, serving as a pathway for the extrusion of the Cam Thuy basalt to overly the Ban Pap limestone. From an observation point near Khau Rum Mountain, it can be seen that a thrust has developed along the Ban Han-Ban Lanh fault, causing the NE flank thrusting over the SW one. This very sinking block has explained the abundance of surface and near surface water in Phong Lai area, NNE of Thuan Chau Town.
- Chieng La-Ban Nong Giong fault of the same direction, which separates Devonian formations in the West from Triassic ones in the East.
- Chieng Pac-Ban Phang fault of the same direction, which separates Devonian limestone in the West from Carboniferous-Permian one in the East, serving as the path for the Cam Thuy basalt to overly the Chieng Pac limestone. It is noteworthy that the basalt there did not cross this fault to overly the Ban Pap limestone in the West, which proves that there was considerable topographic differentiation between both limestones. It is furthermore noteworthy that the artesian discharge forming thick travertine accumulation in Chieng Pac is also located along this fault.
- Chieng Ngam-Muong Bu deep-seated fault. In the map area, this appears as a deep-seated fault striking 285-300° with multi-compositional, multi-temporal volcanic activities, from the Nam Muoi basalt (P_2-T_1 nm) to Pu Tra (Pg pt) trachite, trachite-rhyolite, local depressions and basins filled up with the Suoi Bang (T_3n-r sb) polynomic

sediments. At the same time, this fault separates riftogenic rocks of e.g. Tan Lac (T_1 tl), Dong Giao (T_2a dg) formations in the SW from reddish continental rocks of the Yen Chau (K_2 yc) suite. This is probably a fragment of the famous Song Da fault. However, the presence of the Muong Trai suite NE of this fault indicates it is not the NE boundary of the Song Da rift. In other word, the Song Da fault does not work as the boundary for the Song Da rift, playing that role perhaps only for younger, e.g. the Yen Chau (K_2 yc) or Pu Tra (Pg pt) formations.

In the center of the map there are two more important faults of the NW-SE (285-300°) direction, which run nearly parallel to each other, stretching continuously from Tong Lenh commune in the NW via Ban Tong, Ban Co villages of Son La Town and further to the SE. They separate the Chieng Pac (C-P cp) limestone, Cam Thuy (P_2 ct) basalt, Co Noi (T_1 cn) terrigenous rocks in the SW flank from Dong Giao (T_2a dg) limestone in the NE, forming almost a graben-like trough filled up with rocks of the Nam Tham (T_2l nt) suite.

4.2 The NE-SW fault system

The NE-SW faults exist in the form of short, discontinuous fragments. They seem not to control geological formations or stages except a small fragment near Ban Nguong village, southernmost of the map, which separates the Ban Pap (D_2 bp) and Chieng Pac (C-P cp) limestones. In the neotectonic framework, however, the role of this fault system in forming Quaternary valleys, channelizing streams (e.g. Nam Muoi, Nam Nhop, Liep etc.), causing block displacements, river captures etc. is quite clear. An example can be the NE-SW faults near Ban Muoi-Ban Pang villages. By reconstructing the paleo-relief of the top and bottom of the Tan Lac (T_1 tl) in the NE and Co Noi (T_1 cn) in the SW, an uplift block with the amplitude of up to 300-400 m, 3-4 km wide can be traced out stretching in the NE-SW direction. This uplift block helps form a natural underground watershed that divides the Dong Giao, Nam Tham karst catchment into 2 halves, one to the NW collecting water to the Ban Hinh-Ban Thum villages before draining further to Nam Muoi, another one to the SE collecting water to the Tham Ta Tong-Ban Ca before draining out to Nam La.

Evidence for the above described uplift block can also be witnessed extending further to the SW of the map, at Noong O-Nam Tien villages, along Route No. 6, near the Chieng Pac Pass. One can observe water draining out from Ban Lay, Ban Tat villages all flowing in the NW direction, via Ban Phang village before confluencing with Nam Muoi stream. At the same time, most surface water from the SW follows the Ban Nguong stream to Dong Hung village. There is almost no surface water in the area between (i.e. Noong O-Nam Tien area) Ban Phang and Dong Hung villages. There is evidence to believe that most surface water from few streamlets in Noong O and Nam Tien gathers along the NW-SE fault along Route No. 6 before flowing underground to Dong Hung village.

A similar uplift block might have been formed near the Khau Pha Pass, blocking the Nam La stream and forcing the water to go underground. However, this block may be quite recent as traces of a surface stream can still be found beyond the Khau Pha pass along the district route No. 601. It is remarkable that the hydraulic gradient difference between the swallow hole of Nam La near the Khau Pha Pass and the resurgent point at Nam Liep is almost 400 m.

Similar local block displacements have been mentioned in another report for the Muong Trai area in the NE part of the map. It is quite desirable to establish a geodetic monitoring network in this area to determine the amplitude of local displacements, which could help estimate the timing of such displacements.

As they cross the general strike of all stages in the map area, the NE-SW fault system in the neotectonic framework play a very important role in connecting these stages, serving as important drainage paths in particular.

4.3 Sub-parallel and sub-meridional fault systems

Except for a large tectonic shear zone near the Dong Hung-Ban Ca villages, the sub-parallel, as well as the sub-meridional fault systems are not quite abundant in the area. The Dong Hung-Ban Ca fault, however, plays an important role in separating the Chieng Pac (C-P cp) limestone in the South from the Dong Giao (T_2a dg) limestone in the North. A very large crushed zone at the intersection point between this fault and the Ban Nguong NE-SW fault can be traced out. Observations also show this is quite a big water collector. A considerable amount of surface water from non-carbonate rocks in the SSW flows out and gathers along this fault. Speleological expeditions also discovered several fragments of an underground river that flows sub-parallel in this area before draining out at Ban Ca village.

5 Some correlations between lithologic-structural characteristics of Thuan Chau area and other karst hydrologic, hydrogeologic characteristics

The lithologic-structural characteristics of Thuan Chau area with the alternation between belt-shaped carbonate and non-carbonate stages in the general NW-SE direction indicate the localized character of karst catchments that are connected with each other mainly via the NE-SW faults. It is very probable, therefore, that there are some physico-chemical differences in underground water of these stages.

Lithologic-structural characteristics also help explain the abundance of surface and near surface water in the exposure area of the Ban Pap (D_2 bp) limestone in Phong Lai area.

Structural analyses with the finding of local uplift blocks that work as underground watershed for the Dong Giao and Nam Tham limestones, along with their folding characteristics allow explaining the abundance of water in Ban Hinh-Ban Thum (Tong Lenh commune) and Tham Ta Tong-Ban Ca villages (Son La Town).

In the vicinity of Ban Phang-Nam Tien-Nong O-Dong Hung-Chieng Den villages, the most important source of water may be concentrated along the two NW-SE and sub-parallel fault zones that develop in this area.

The artesian discharge along with thick travertine accumulation near the Chieng Pac cement factory also requires structural explanations. Note that the site is located almost at the intersection between the Chieng Pac-Ban Phang NW-SE fault with other NE-SW faults. Determining the rate of travertine accumulation could help estimating the reactivated timing of the NW-SE fault. Local people recall that years ago this artesian source was much higher, several meters above the ground surface. This source appears to be the lowest hydrostatic point of the local water catchment, with the height of the water head indicating the level of underground water of this catchment. The decrease in the water head in recent years might be related to the decrease in the recharge capacity. On the other hand, the water here is of extremely high quality, with almost no impurity, which is totally different from the surface water along the Ban Phang stream nearby. This may indicate that the two waters are not inter-connected. In other words, the Chieng Pac-Ban Phang fault might be intermittently an aquitard. This can be supported by the abundance of surface water along this fault where agricultural production can continue throughout the year.

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GEOLOGICAL CHARACTERISTICS AND VALUES OF THE PU LUONG NATURE RESERVE, THANH HOA PROVINCE, VIETNAM

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1 Introduction

FFI (Fauna & Flora International) Vietnam, together with its Vietnamese national counterpart, the Forest Protection Department (FPD, under the Vietnam's Ministry of Agriculture and Rural Development, MARD), is currently undertaking a project on the possibility of establishing a continuous protected karst area, including the existing Cuc Phuong National Park and the Pu Luong Nature Reserve (PLNR) to its northwest. At its request, a team of geoscientists from the Research Institute of Geology and Mineral Resources (RIGMR) conducted 2 field surveys in late 2002 to study geological-geomorphological and speleological characteristics of the PLNR area. The importance of these studies can be shortly and best described by the saying of Prof. Elery Hamilton-Smith, Chair IUCN/WCPA Task Force on Cave and Karst Protection, that "biodiversity is dictated by geodiversity". In fact, as shown in the team's full report, the PLNR is very unique in its geological, geomorphological and hydrological as well as speleological characteristics, which can, not only become a geopark on its own, but also justify the above-mentioned initiative to be part of the expanded Pu Luong-Cuc Phuong National Park.

The full report integrates all the existing geological data and results of the 2 additional field surveys mentioned above and its main points are summarized hereinafter.

2 Geological characteristics

Located at the boundary of the two so-called tectonic zones, i.e. the Song Ma (Ma River anticlinorium, relatively older) and Song Da (Da River synclinorium) zones, the area is characterized by very diverse, long and complex geology. At the very first glance, it can be divided into 2 parts along the famous Son La deep-seated fault that stretches in the NW-SE direction. The SW part belongs to the Song Ma zone while the NE part belongs to the Song Da zone. Many rock types of different origins (including metamorphic, magmatic and sedimentary rocks, belonging to 15 Formations and equivalent) and ages (from approximately 800 million years till present days) exist in the area. This is radically different from the Cuc Phuong National Park, which is composed almost from carbonate rocks only. Interestingly, stacked in a vertical, chronological sequence, these rock Formations can be re-grouped into "intercalated" carbonate (karst) and non-carbonate (non-karst) strata. Laterally, this trend of intercalation, moreover, is also observed in the SW-NE direction.

Along with the above mentioned NW-SE Son La deep-seated fault, many other faults of similar direction and of other directions e.g. NE-SW, sub-parallel and sub-meridional, also develop in the area, dictating the development of the landscape, the drainage networks, both surface and underground, and the development of caves. However, the big (up to 4 km) block displacement along the Ban Cong-La Han sub-meridional fault, both in the past and at present, makes the area probably most distinct. As a result, many NW-SE faults on the left hand side of this sub-meridional fault open, facilitating the wide development of serial inter-connective caves and the drainage network along them. On contrary, the right hand side block is compressed and closes, discouraging cave development and drainage network. Moreover, one can also notice a deviation in the structural pattern of the area, from NW-SE to more WNW-ESE via this sub-meridional fault.

3 Geomorphological characteristics

The present day relief of the area also inherits the above mentioned features, i.e. it is divided into narrow, elongated mountain belts, subjected in the past to numerous cycles of destruction-planation under continental regimes. As a result, the relief of the area has both step-wise and linear characteristics, changing alternately from high mountain ranges with plateaus to low mountains with valleys and tectonic-denudation depressions.

Intensive exogenous processes under humid tropical conditions also contribute to the strongly dissected relief, with slope surface accounting for the major part of the area, indicating it is at present, subjected, at different extent, again to an uplifting process.

A very distinct feature of the area is the development of different types of tropical karst relief due to different types of limestone, forming different types of karst and karst-erosion landforms, e.g. karst plateaus, karst-erosion valleys, karst fields etc. However, erosional and tectonic landforms such as erosional slopes, planation surfaces, pediments, gullies etc., that develop on magmatic and terrigeneous rocks are the ones that make the PLNR very different from the Cuc Phuong National Park.

4 Soil characteristics

One more feature that makes the PLNR distinct from the Cuc Phuong National Park is that it has many more different types of soil that result from the weathering of different types of rocks. Those soil types that develop on non-karst rocks deserve special attention as they may be suitable for development purposes. As a considerable part of the PLNR is now conserved, local people are left with much less land for their living than before. This would mean that in order for a conservation project in the area to be successful, the left over agricultural land should be more productive or more capable of income generation. Else the way of living, of cultivation, crop types etc. of the local people should change considerably. A lot of room is thus open for research in these directions.

5 Speleological and hydrological characteristics

Initial speleological and hydrological studies have mapped a number of interesting caves. Developed mostly along NW-SE faults, these caves are, in many cases, interconnected, facilitating the development of underground river systems. At least 2 such systems of considerable scale are strongly evidenced within the PLNR while 2 others develop in the buffer zones and along the Ngoc Lau-Ngoc Son-Tu Do corridor that connect the PLNR with the Cuc Phuong National Park. The majority of surveyed caves are wet and active caves and quite a few of them are very beautiful, deserving a proper conservation and management approach. Thus further, more in-depth studies on cave development and karst hydrology in the area, including tracing experiments to confirm the existence of those underground rivers, seem worthwhile.

Geological, geomorphological and speleological studies in the area have indicated very strongly the flow of the ancient Ma River through the PLNR. This can result in unexpected implications in future activities concerning development/conservation of the area.

The existence of underground river systems both and outside the PLNR once more underlines the idea that in fact there is no clear physical demarcation between the PLNR and its surrounding buffer zones, and that the PLNR could be well conserved if and only if its buffer zones are well protected and developed. Further, given the unique and interesting geodiversity of the area as a whole, one could even be brave enough to suggest the PLNR be expanded to its present buffer zones.

Interestingly, the same team of geoscientists from RIGMR has undertaken several more field surveys during 2003-2004, within the framework of the FFI-LLINC cooperation, in the Ngoc Son-Ngo Luong area to the NE of the PLNR. The surveys, along with other studies on biodiversity, have resulted in a general recommendation, that this buffer area too, become a Nature Reserve to be managed by the Hoa Binh provincial authority. Interested readers are referred to a similar article in the proceedings.

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GEOLOGICAL STRUCTURAL CONTROL OF KARST WATER IN THE PROPOSED NGOC SON-NGO LUONG NATURE RESERVE, HOA BINH PROVINCE, VIETNAM

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Abstract. The Feasibility Study on “Establishing the Ngoc Son-Ngo Luong Nature Reserve” has been proposed by the Hoa Binh Provincial People’s Committee and supported by FFI/LLINC. The Study has been carried out under the main responsibility of the Northwestern branch, Forestry Inventory and Planning Institute (FIPI). Contributions by RIGMR’s geoscientists, within LLINC project, were to conduct additional geological research and surveys, so as to form a basis for other studies and to add more values to the Nature Reserve. On the basis of available geological data, the authors try to characterize the main geostructural features of the proposed Nature Reserve in an attempt to understand the karst water resources of the area.

Keywords: nature reserve, geology, stratigraphy, tectonics, karst landform.

1 Location

FFI (Fauna & Flora International) Vietnam, together with its Vietnamese national counterpart, the Forest Protection Department (FPD, under the Vietnam’s Ministry of Agriculture and Rural Development, MARD), is currently undertaking a project on the possibility of establishing a continuous protected karst area, including the existing Cuc Phuong National Park and the Pu Luong Nature Reserve (PLNR) to its northwest. According to the initial proposal, the project area consists of 6 communes belonging to the districts of Lac Son and Tan Lac (Hoa Binh province). The 6 communes are Ngoc Lau, Ngoc Son and Tu Do (Lac Son district, Vu Ban map sheet, F-48-127-D) and Bac Son, Nam Son and Ngo Luong (Tan Lac district, Mai Chau map sheet, F-48-127-A). However, this geological study indicates a possibility to expand the boundaries of the proposed project area to include some neighbouring communes possessing analog physiographic characteristics and hence create a project area delimited by natural boundaries. Thus the geological characteristics and values of the proposed Nature Reserve will be presented here in the “expanded version”.

2 Geological characteristics

In the general geological context, being located in the same major tectonic zone, the project area has more similarity to the Cuc Phuong National Park than the Pu Luong Nature Reserve. The most prominent and clearly visible feature is the intercalation and/or alternation between limestone and non-limestone (terrigenous) rock belts, forming strips stretching NW-SE, i.e. in accordance with the general structural direction of the area. However, unlike the Cuc Phuong National Park, where limestone prevails, in the Ngoc Son-Ngo Luong area a better balance between these rock types can be observed. Nevertheless, being located adjacent to the Pu Luong Nature Reserve, research on geology and other natural characteristics of the area of interest can not be carried out separately and viewed independently from those for the Pu

Luong Nature Reserve.

2.1 Topography

The project area is part of the NW-SE plateau-like, limestone range of Northwest Vietnam, being the southeastern continuation of a series of famous karst regions e.g. Moc Chau, Son La etc. In essence, it can also be considered a plateau highly rising above the surrounding areas. The plateau is dissected into parallel strips, where relics of planation surfaces at different altitudes can still be observed, which make the plateau both linear and stair-like. The plateau scarp also stretches in the NW-SE direction, serving as its natural boundary with the low hill and plain landscape underneath.

The absolute altitude of the area ranges between 100 m and more than 1000 m, increasing from SE to NW. The averagely low (300-500 m) to high (800-1000 m) mountainous topography prevails upon the hilly lowland and stream valleys. Peaks correspond to limestone rocks, with rugged and complicated topography. The summit areas show up to 200-300 m vertical denivellation and considerable, up to 0.5-0.8 km/km^2 lateral extent. An exception is the central part of the Ngoc Lau and part of the Ngoc Son communes, where the topography is relatively level at the average altitude of 500 m.

2.2 Stratigraphy

The study area is covered mostly with Mesozoic rocks which belong to the Co Noi (T_1cn), Dong Giao (T_2a dg) and Nam Tham (T_2l nt) formations. To a limited extent, loose Quaternary sediments accumulate along streams.

a. Co Noi Formation (T_1 cn)

These rocks are observed mainly at the NE and SW edges of the study area, especially in the Tu Do and Ngo Luong communes, forming NW-SE striking narrow belts. Totalling 650-700 m in thickness, the formation consists mainly of shale, siltstone, sandstone with interbeds and lenses of calcareous shale and limestone. The rocks conformably underlie limestone beds of the Dong Giao formation. Their terrigenous composition suggests that whole formation is in general, an aquitard.

b. Dong Giao Formation (T_2a dg)

This formation extensively develops in the study area, forming rigorous limestone belts that stretch in NW-SE direction. Totalling about 1000 m in thickness, the formation consists of siliceous, clayey and mostly pure limestone, thinly bedded at the lower part to massive structured at the upper part. Based on their bedding structure and clay content, therefore 2 sub-formations can be distinguished.

c. Nam Tham Formation (T_2l nt)

Conformably overlying the Dong Giao limestone, the formation develops in the central part of the study area, forming NW-SE belts. It can be divided into 2 sub-formations. The lower sub-formation is mainly observed at Ngoc Son-Ngoc Lau communes, forming a NW-SE trending syncline. Totalling 430-660 m in thickness, it consists of shale, micaceous and calcareous shale, limestone lenses and siltstone that are strongly pressed into micro-folds. The upper sub-formation consists of mainly siliceous limestone and massive limestone, alternating at some places with shale and miceceous shale, totalling 170-340 m in thickness. The lithological composition indicates that the lower sub-formation is an aquitard while the upper one can be a water bearing layer.

2.3. Tectonic setting

Tectonic structure

In general, the study area, along with other adjacent areas such as the Cuc Phuong National Park, the Pu Luong Nature Reserve is located at the interaction between two major tectonic zones i.e. the ancient Ma River anticlinorium at the SW and the younger Da River synclinorium at the NE. Both develop in a NW-SE direction and are separated by the Son La deep-seated fault.

Similar to the Cuc Phuong National Park, the Ngoc Son-Ngo Luong area is located wholly in the Da River tectonic zone, with Mesozoic rocks of the Co Noi, Dong Giao and Nam Tham formations as described above. They form a big, NW-SE trending synclinorium with total thickness up to 1900-2900 m. The central axis of this synlinorium consists of rocks of the Nam Tham formation, but in addition, there are other synclines, which terminate with the upper Dong Giao sub-formation.

Further to the NE, near Kim Boi, are located the basalt massif of the Cam Thuy formation (P_2 ct) and granitic bodies of the Phia Bioc complex (γT_3n pb). Subsequent folding and faulting activities, especially in late Triassic (T_3n) when the area became under continental regime, has generated the NW-SE trending strip form of the area, that is furthermore a bit concave to the NE, surrounding the above mentioned magmatic massifs. These tectonic movements are strongly reactivated in the Himalayan neotectonic stage (about 54 Ma until now). Pulsating uplift alternated with relatively quiet periods, resulting in a series of ancient planation surfaces at altitudes of 900-1200 m, 700-900 m and 300-500 m.

Stratabound units

With regard to the water bearing properties, the following stratabound units can be identified:

- the Early Triassic non-carbonate stratum, Co Noi formation (T_1 cn);
- the Middle Triassic carbonate stratum, Dong Giao formation (T_2a dg);
- the Middle Triassic non-carbonate stratum, Lower Nam Tham sub-formation (T_2l nt_1);
- the Middle Triassic carbonate stratum, Upper Nam Tham sub-formation (T_2l nt_2);
- the Cenozoic non-carbonate, loose Quaternary sediments.

All these strata display an interbedding and alternation between carbonate and non-carbonate rocks both vertically and laterally in the SW-NE direction. Thus hydrologically, there could be two separated, water bearing carbonate strata i.e. the Dong Giao (T_2a dg) formation and the Upper Nam Tham sub-formation (T_2l nt_2), interbedded with the Co Noi (T_1 cn) and Lower Nam Tham (T_2l nt_1) non-carbonate aquitards.

Folding and faulting characteristics

Rocks of the Co Noi formation crop out only along the NE and SW edges of the study area, forming a basal aquitard for the whole area. Field surveys found some exsurgences only along the boundary between these underlying rocks and the overlying limestone of the Dong Giao formation.

Looking at the absolute altitude of the Co Noi outcrops, one tends to conclude that the Ngoc Son-Ngoc Lau plateau has been uplifted considerably compared to the NE plain strip underneath. On this plain there are still some relics of the Dong Giao limestone overlying the Co Noi rocks, indicating the vast majority portion of the younger Dong Giao and Nam Tham formations have been eroded while they are still preserved in higher position on the Ngoc Son-Ngoc Lau plateau. The absolute altitude of the plain along the road from Tu Do via Ngoc Lau to the district center is about 100 m while that at the Co Noi-Dong Giao terrigenous-carbonate boundary often reaches 300-400 m, implying at least a 200-300 m uplift of the plateau compared to its NE marginal plain. Similarly, compared to the limestone belt at the SW edge, the same plateau might have been uplifted by 100-200 m.

Limestone of the Dong Giao formation forms NW-SE stretching belts. However, its tectonic structure appears more complicated. At Ngoc Lau commune, the strata grade into the rocks of the Nam Tham formation, forming a perfect, 3 km wide x 15 km long syncline (Fig. 1). On the contrary, to the NW, at Ngoc Son, Ngo Luong, and even Nam Son and Lung Van communes, the Dong Giao limestone appears strongly faulted to leave only small, narrow strips for the Nam Tham formation. Around Bac Son commune, these small and narrow strips spread widely and the Nam Tham rocks no longer keep a belt-shape form.

At Tu Do commune, rocks of the Co Noi and Dong Giao formations form a big NW-SE anticline. A fault (partly followed by the Mon stream), however, runs along the axis of this structure and considerably destroyed its SW flank. There could be a major displacement along this axial fault as terrigenous rocks of the Co Noi formation crop out on the NE flank while the SW flank is still composed of the Dong Giao limestone.

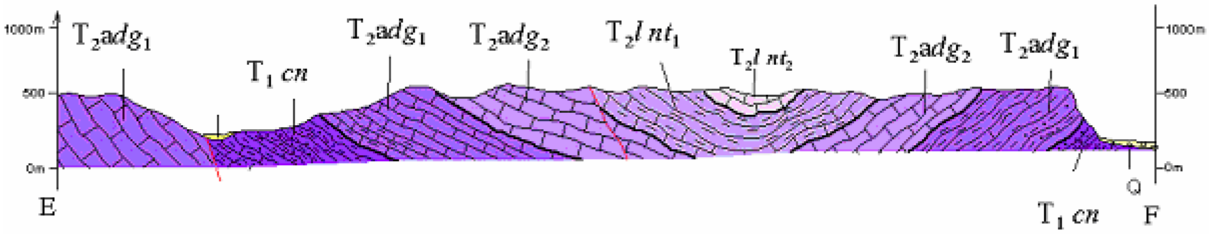

Fig. 1: Perfect synclinal structure through Co Noi, Dong Giao and Nam Tham formations at Ngoc Lau commune.

A SW-NE cross section from Tu Do commune to the district center reveals some repetition of these terrigenous-carbonate rock belts, forming a series of alternating anticlines and synclines, to result in a huge synclinorium with the core made up of rocks belonging to the Nam Tham formation which outcrops around Ngoc Son and Ngoc Lau communes.

Faults and shear zones are frequent, serving as the boundary between tectonic zones, geological formations, or destroying and/or complicating folding structures. They all can be grouped in four regional systems of NW-SE, NE-SW, sub-meridian and sub-parallel directions (Fig. 2). Being the predominant system, the NW-SE faults can be further divided into 2 sub-systems, i.e. the NNW (320-330^o) in the NW part, around Bac Son, Nam Son and Lung Van communes, and the WNW (300^o) in the SE part, around Ngo Luong, Ngoc Son, Ngoc Lau and Tu Do communes. This shift in the overall structural direction is thought to be due to the big, sub-meridian, left lateral strike (up to 4 km relative displacement) Ban Cong-La Han fault (just to the west of the study area).

The syngenetic NE-SW faults are often short and small. There are only a few sizeable faults that cut the NW-SE mountain ranges into blocks. One fault is observed near Ban Ho village of Bac Son commune.

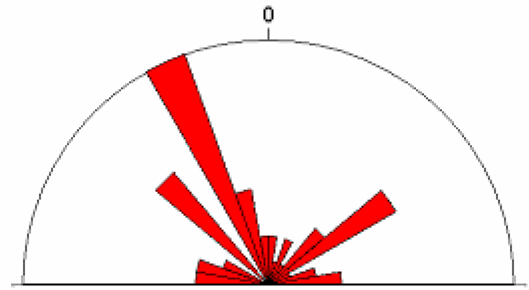

Fig. ***2:*** *Rose diagram of principal fault directions.*

Other faults of the sub-meridian and sub-parallel systems are less abundant, often cutting and displacing NW-SE and NE-SW faults, implying they are more active in later tectonic stages.

3 Karst development and hydrological characteristics

3.1 Karst development

Initial speleological surveys and a cumulative cross-section representing the surface topography and cave development show that caves develop mostly at 3 altitude ranges (Fig. 3) i.e.:

- higher than 1000 m;
- between 850-900 m;

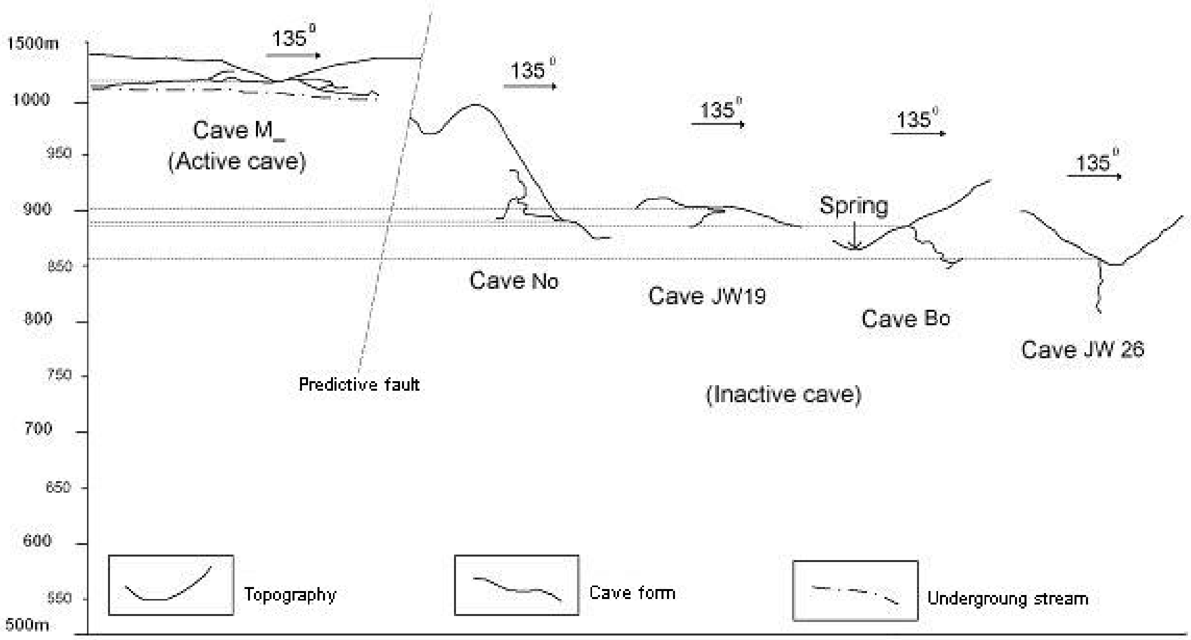

Fig. 3: Cumulative schematic cross-section showing stages of cave development, showing fault-bounded independent aquifer systems.

- between 650-800 m.

In addition, caves mostly develop in the Dong Giao limestone and to a much lesser extent in the Nam Tham limestone. Most of them not only are located along NW-SE faults but also develop in this direction. Fossil caves are mostly at the altitude of 780-900 m but at the same time, some active caves (e.g. Hang My and Hang Ton caves in Nam Son commune) are found with considerable discharge at similar or even higher altitudes. This again confirms the fault governed block tectonic settings of the study area.

It can be noticed that the current depth of karstification is at the altitude of about 650-700 m, i.e. comparable to the highest point of the roof of the Co Noi formation. This implies that in case of further karstification the uneven roof of the Co Noi formation could serve as an underground water divide.

3.2 Hydrological characteristics

Geological characteristics determining the regional hydrology are:

- The Ngoc Son-Ngo Luong terrigenous-carbonate rock belt, 7-10 km wide, 35-40 km long, stretching without interruption in NW-SE direction from Mai Chau district town toward the Cuc Phuong National Park, has been uplifted 100-300 m as a tectonic block relative to the surrounding areas.
- There is an alternation and/or interbedding between aquitards (terrigenous rocks of the Co Noi (T_1 cn) formation and Lower Nam Tham (T_2l nt_1) sub-formation) and aquifers (limestone of the Dong Giao (T_2a dg) formation and Upper Nam Tham (T_2l nt_2) sub-formation) both vertically and laterally in the SW-NE direction. The Co Noi formation serves as the basal aquitard, preventing groundwater seepage to deeper levels. Moreover, all these strata form a large synclinorium that also assists in preserving water in the area. Thus, just a few low-lying exsurgent points are found at the top boundary with the Co Noi strata.
- The lateral alternation between terrigenous aquitards and carbonate aquifers in NW-SE direction is expressed by emerging limestone ranges and submerging terrigenous valleys. This feature can result in locally independent hydrological systems that run parallel to each other and become interconnected only at the intersections with other, e.g. NE-SW, sub-meridional and sub-parallel fault systems.

As a result, the karst hydrology is quite complicated as proven by the following features:

- Some very important resurgent points from limestone ranges, with discharge rates ranging ca. 5-20 m^3/s, as seen in Ban Mu and Xom Hung villages, may suggest a quite sizeable recharge area. In addition, there may be some inter-connection between different aquifers and/or local hydrological systems, which complicates the general NW-SE structure-controlled flow pattern of the area. Well-developed travertine terraces downstream of these resurgences indicate the CO_2 rich mineralised water has been in contact for quite long time with limestone, which may also imply a long journey of the water in limestone underground and consequently, a sizeable recharge area.
- There are some sizeable resurgent points at relatively high altitudes (300-400 m) along the NE slope of the plateau, adjacent to some big, ancient travertine terraces near Xom Lo, Xom Khua villages. This may indicate that the NE slope in the past might have been the major

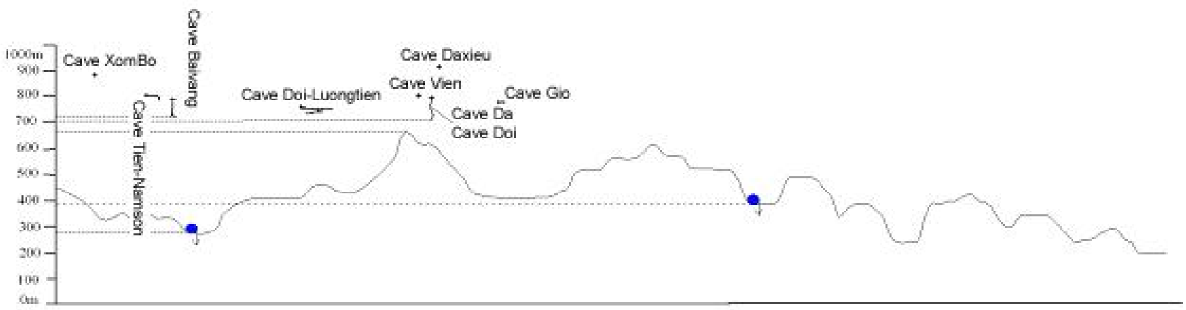

Fig. 4: SW-NE topographical cross section showing location of major exsurgence points (vertical scale exaggeration 10x).

discharge point of the whole area, a hypothesis that very well fits with the formation of the Ngoc Son-Ngoc Lau karst field also in this part of the study area (Fig. 4).

- In addition, there are quite a few small resurgent points at even higher altitudes (right on the surface of the Ngoc Son-Ngoc Lau karst field, i.e. about 500 m), just next to sinkholes at the foot of limestone ranges. This strongly confirms the idea that independent, parallel local hydrologic systems co-exist without local interconnection, which may result in local artesian resurgences. Meanwhile, major underground flows still develop at the foot of limestone ranges, along major fault zones, where among large-sized and deep valleys, sinkholes often develop.

In brief, with regards to the area karst hydrology, one may conclude that there could be several (at least two) separate karst aquifers in the vertical section. Laterally, there could also be locally independent hydrological systems, which may become interconnected at some fault-controlled interaction points.

4 Acknowledgement

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GOVERNMENT CANYON STATE NATURAL AREA: A MULTI-DISCIPLINARY AND MULTI-PARTNER APPROACH TO KARST MANAGEMENT AND EDUCATION

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Keywords: land management, watershed protection, endangered species, Texas.

Government Canyon State Natural Area (GCSNA) is located on the edge of San Antonio, Texas, USA. It was land planned for urban development but purchased by a partnership of three state agencies, with the assistance of two non-profit organizations. Coordination with the city and federal agencies has increased the size of the property to 33.2 km^2, and GCSNA has served as the focus for purchases of additional adjoining land to create 40.5 km^2 of contiguous parkland.

About 90% of the property is located on the recharge zone of the karstic Edwards (Balcones Fault Zone) Aquifer, and is designated as a karst preserve to effectively manage all of its resources. Karst attributes of GCSNA predominantly determine the location, type, magnitude, and management of its most significant natural and cultural resources. Federally listed endangered invertebrate species and the county's largest known bat population occur in its caves. Springs and deep canyons provide habitat for a diverse flora and fauna, including the endangered Golden-cheeked Warbler. These springs and species in turn, along with chert deposits and natural trails through rugged terrain, have supported human occupation since prehistoric times.

Urban development from the city of San Antonio is encroaching onto the Edwards Aquifer karst and threatening groundwater quality. While San Antonio lacks adequate parkland for its residents, GCSNA has resisted pressure to rapidly open to the public. Instead, it has served as model for park development by first defining existing resources, restoring impacted resources, monitoring and protecting groundwater quality and quantity by encompassing 60% of the 30.46-km^2 Government Canyon watershed and 9 km^2 of smaller karst watersheds, preserving the unique cave fauna, limiting all development to non-karst areas, using state-of-the-art construction techniques and infrastructure to minimize water and ecological impacts, and monitoring land use conditions for an adaptive resource management plan. Partnerships with multiple agencies and volunteers have minimized individual costs, provided more thorough and complete assessment of karst resource issues, and deflected criticism about GCSNA's slow development period. Further, this cooperative program has developed direct educational programs for the public on the values of karst and provided indirect but major educational experience for private organizations and government agencies in effective karst resource protection and management.

SOCIAL LEARNING REVISITED: LESSONS LEARNED FROM NORTH AND SOUTH

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1 Introduction

Some ten years ago, we[1] developed a concept of 'social learning' which should enable researchers and practitioners to understand better the nature of the learning processes taking place in groups, communities, networks or other social systems engaged in trying to solve social problems. Various authors drew our attention on the increased importance of collective reflexive processes in response to the many challenges our society deals with. Especially in the fields of environmental planning for development and natural resource management 'social learning' became an important topic of interest, due to the limitations experienced with reductionist technocratic approaches (Leeuwis and Pybur, 2002).

Now, the time has come for an evaluation. We have applied our theory of 'social learning' as an interpretive framework to understand processes of change in various settings such as project groups in university settings (Wildemeersch, 1999), community action groups (Van Rhede, 1997), public debate on environmental issues (Vandenabeele and Wildemeersch, 1998; Janssens and Wildemeersch, 2003), policy planning (Janssens *et al*., 2001), and multi party negotiations in the third world settings related to water management projects (Dang, 2003) and nature conservation (De Greve, 2004)[2]. In our reflection on this research, we will limit ourselves, for reasons of comparability, mainly to projects which focus on environmental issues both in the North and the South.

2 The origins of social learning

Initially we defined social learning as the 'learning taking place in groups, communities, networks and social systems that operate in new, unexpected, uncertain and unpredictable circumstances; it is directed at the solution of unexpected context problems and it is characterised by an optimal use of the problem-solving capacity which is available within this group or community' (Wildemeersch, 1995, p.33, translation DW). The learning within these systems is basically experiential and therefore can be characterised as learning by doing. Experiential learning had in the past been conceptualised mainly with reference to individuals. Our challenge now was to conceive of a kind of experiential learning taking place within groups or systems and to make clear how these groups or systems learn. In view of this, we identified four different activities taking place in groups involved in processes of collective problem solving: action, reflection, communication and negotiation.

Action: social learning is linked to processes of social action (e.g. developing a policy plan, organising multi party negotiations, engaging in participatory processes, establishing a task force or a study group, etc..); the action is triggered both by a particular 'need' (need motivation) and a set of 'competences' (competence motivation) which are present in the social system involved;

Reflection: social learning triggers processes of reflection inside and outside the social system; the reflection dimension balances between 'distance' and 'identification'; taking a distance may help to question the self-evident aspects of the issue at stake; simultaneously, learning goes together with a process of (dis)identification with particular people, norms or values expressed through symbols, narratives, rituals, etc.; social

[1] Various researchers, both from the University of Leuven and the University of Nijmegen have been involved in the development and application of this concept in the context of different research projects. The main contributors have been Joke Vandenabeele, Marc Jans, Theo Jansen, Christin Jansen and Katrijn Van Duffel.

[2] Other research which has taken place from this perspective, which has been reported about only in Dutch, is not mentioned here

learning is about finding a balance between these 'rational' and 'emotional' aspects of reflection.

Communication: the learning inevitably is linked to (supported or inhibited by) various communication processes taking place inside and outside the social system; these communication processes can either be 'unilateral' (e.g. inspired by a dominant voice) or 'multilateral' (e.g. inspired by different voices).

Negotiation[1]: the learning is related to processes of negotiation which result from differences of interest represented inside and outside the social system involved; the management of these differences can be concordance orientated or discordance orientated, or a combination of both. The creative tension between concordance and discordance can trigger learning within the system.

The actual learning takes place when the social system which is engaged in the process of action somehow manages to find a creative balance along the four axes or dimensions. The balances will be different for every social system, depending on the composition of the system (large or small, homogenous or heterogeneous), its internal and external challenges (high pressure or low pressure), its history (young or old system), the particular context in which it operates (vertical or horizontal), the available competences, its relative openness vis-à-vis the outside world etc…

3 Social learning and the regime of 'governmentality'

While doing research on social learning, and simultaneously being involved in discussions and readings on new concepts of governance, we began to consider these processes of participatory planning in a different way. Before, we had interpreted communicative planning mainly as possible processes of emancipation and enlightenment, because we had learned to frame them as attempts to redistribute power, resources, and (learning) opportunities. Due to the readings of authors engaged in so-called governmentality studies (Rose, 1999, Dean, 1999), we now began to see these communicative planning processes as expressions of new forms of governance which are not necessarily emancipatory but which create, next to opportunities, new forms of dependency. In the conditions of 'advanced liberalism' (Rose, 1999) and 'welfare reform' policies in the North, traditional forms of coercion are increasingly replaced by new technologies of persuasion and normalisation. These new orientations build upon the ambition of modern citizens who want to be regarded as 'free subjects' that are able to choose among various products, services, lifestyles, policy orientations, both in the private and in the public sphere.

Participatory planning could be considered as one of these new technologies which seemingly create opportunities of (collective) self-improvement and free choice for the participants involved. Therefore, it could be viewed as belonging to the regime of 'governmentality', a power regime which considers people as citizens of the state, as opposed to the regime of 'sovereignity', which treats people as subjects of a sovereign or of sovereign institutions (Henman and Dean, 2004). In conditions of 'sovereignity', people are forced by violence or by the threat of violence to comply with the wishes of the authorities. Governmentality on the contrary creates a power base which does not simply operate from above, but which functions as 'the conduct of conduct'. This horizontal power base is supportive in transforming the behaviour of people with help of complex assemblages of persons, forms of knowledge, technical procedures and modes of judgement and sanctions. These practices are fairly new and complex. Therefore participants or stakeholders have to engage in 'social learning processes' teaching them how to operate in these conditions of self-direction. This learning is not the result of conventional teaching, which would be the expression a regime of sovereignity. Governmentality rather requires self-organised processes of 'learning by doing'. In line with this, social learning could be conceived as a way to manage the complexities, tensions and contradictions of the new conditions of governance which are currently being developed in various contexts

[1] Initially we called this dimension 'cooperation'. Later we transformed it into 'negotiation' because the latter notion reflects better the potentially discordant character of the learning process.

of policy making and management in advanced liberal societies.

4 Experiences from the North

After our presentation of the basic dimensions of social learning and an initial attempt to frame social learning in the context of governmentality practices, we will now go deeper into two examples of research on social learning conducted in Flanders (Belgium) between 1995 and 2003. This should result into a deeper understanding of the strengths and limitations of social learning with regard to the context in which the process takes place. It will also help us to (re-)frame our understanding of the power dynamics interfering with processes of social learning.

Nature development planning in Flanders

With the help of case study research methodology, we studied the development of 'Communal Nature Development Plans' organised in two separate communes in Flanders in the second half of the nineties (Vandenabeele and Wildemeersch, 1997, 1998). This type of planning is an example of the new policy practices which are being stimulated nowadays on the local and the regional level. In our case study, we analysed in two communes, two contrasting cases of small scale experiments concerning nature development planning: a so-called successful case and a so-called unsuccessful case. It helped us to understand the reasons of success and failure. We defined 'success' both in terms of realising a positive learning and participatory process and of achieving a nature development plan guaranteeing a balanced improvement of the ecological, economical and social conditions in which tensions and conflicts could be balanced in a productive way.

Forest extension in Flanders

During the period 2001-2003 we engaged in a research project on forest extension in Flanders, together with experts on forestation (Wildemeersch and Lust, 2003, Janssens and Wildemeersch, 2003). The research was related to a policy initiative by the Flemish minister of the environment by which forest land in the territory should be extended by 10000 hectares. The measure was fairly controversial. The environmental movement in Flanders was very much in favour. The farmers' organisation opposed to it because they expected a considerable piece of their farmland to be sacrificed to forest land. We did case study research in various locations in Flanders. The main question was how a participatory process could be linked most adequately to a technical process of so-called localisation studies. A 'localisation study' is a planning approach aimed at deciding what territory in a particular area is best suited for the establishment of a new forest, taking into consideration ecological, economical and social aspects. The research mainly focused on two cities in Flanders (Gent and Roeselare) where a city forest was planned by the authorities of the Flemish Region.

5 Experiences from the South

In the context of the VIBEKAP research project (VIBEKAP: Vietnamese Belgian Karst Project) on 'Sustainable Water and Land Management and Social Learning' two micro projects were developed in the commune of Bon Phang, more particularly in the villages Noong O and Nam Tien in the province of Son La (Dang, 2003; Tessier *et al*., 2004). Noong O is known as a black Thai village. It means that most of the inhabitants belong to the Thai ethnic minority. The village counts 62 households and 330 inhabitants. The Nam Tien village is a Khin village, which is the largest ethnic group in Vietnam. This village has 128 households and 650 inhabitants. The projects took place with the support of UNICEF and in collaboration with the local Vietnamese authorities and institutions, including the Water Management Board of each village and a newly established Forest Protection Board. The two micro projects aimed at helping the local people in managing the water supply in their village; supporting them in thinking about their own role and responsibility in land and water management; giving information about the research project; and studying how people participate and learn in the project. In the two villages a participatory planning process was started, aimed at including the local inhabitants and the village leaders in a process of decision making on the provision of individual households with water. They were asked to invest an amount of money in the project, symbolising their personal commitment. They were also asked to sign a contract regulating the management of the system after completion and the price to be paid for the use of water. The village leaders of the two (neighbouring) villages signed a convention aimed at protecting the upstream forest, so as to assure a regular flow of water from the source of Nam Tien, located for the largest part on Noong O land. So, everything was designed and prepared well and resulted into in interesting process of participation and social learning.

Social learning and nature conservation: the Ngoc Son – Ngo Luong Case

The last case is about the establishment of a nature conservation area in the Pu Luong – Cuc Phuong limestone range, situated in the North West of Vietnam, approximately 150 kilometers southwest of the capital of Hanoi. The range stretches 90 kilometers from Cuc Phuong National Park in the South East up to the two ridges of the Pu Luong Nature Reserve in the northwest and covers approximately 170.000 hectares. The area is characterised as Karst landscape which is an irregular limestone region with underground streams, caverns and potholes. Karst landscapes have a high ecological and cultural value. To further protect the nature in this area a discussion has started with three different provincial authorities involved to develop protection measures for the area connecting the nature reserve and the national park, namely the Ngoc Son – Ngo Long area. The actions towards conservation have been initiated by following partners: the Forest Protection Department (FDP) within the Ministry of Agriculture and Rural Development of Vietnam (MARD) and the NGO mentioned earlier Fauna and Flora International (FFI). The project is funded by the World Bank. Other players in the game are FIPI, the Forest Inventory and Planning Institute of Vietnam, specialised in study activities concerning (de)forestation, and the LLINC project also mentioned earlier.

6 Conclusions

We realise now that during the last ten years, we have been engaged in quite a variety of research projects linked to processes of social learning taking place in various contexts. These projects have generated a wealth of data which we have tried to interconnect in a systematic way in this paper. It is important to realise that the concept of social learning is a construction which helps to make sense of social transformation in a particular way. There is no clear indication that a framing of processes of social change in terms of ‘social learning’ will directly help to improve these processes. What we have first and foremost tried to make clear is that it is relevant to consider social transformation as a social learning process. Sometimes we have had difficulty to make that acceptable because learning is too often associated with formal educational settings. We hope that the conclusions below will invite some more researchers and (hopefully also) practitioners to look differently at the processes they engage in.

Similarities in social learning in North and South

- We have found that social learning is a relevant framework to look at processes of social change and that the four dimensions, including the tensions, are interesting analytical tools to make sense of learning in complex settings of collective action.
- We have experienced that in almost all cases, social learning is a vulnerable activity which can be largely influenced by the context in which it takes place.
- Especially, when contexts are turbulent and discordant there is a great chance that these characteristics will affect the inner dynamics of social learning within the systems involved. Attempts to neutralise these external dynamics may have counter-productive effects.
- In many of the researched processes the social action consisted of planning initiatives. This probably has to do with the fact that our societies increasingly become planning societies which increasingly experience the need to shape and control the future. We have noticed that often these planning activities are fairly abstract and alien to citizens. This privileges the social learning to a planning elite that understands the language and the procedures. This elite enjoys engaging with the abstractness and long term perspectives proper to planning.
- A more concrete action orientation may improve the chances to involve rank-and-file citizens into the participatory planning activities. Small scale actions which are precisely defined and limited in time, and which are linked to concrete needs have a

potential of mobilising people at the base and to link the learning to wider issues on a more abstract level.

- In participatory planning approaches, the reflective dimension of social learning is often achieved in an instrumental way. The planning constraints limits the scope to 'single loop' learning processes, meaning that the knowledge and the competences gained from the experience were instrumental to the optimisation of the decision making process. Apparently, 'double loop learning', which creates opportunities for more fundamental questioning of the assumptions, only comes about in 'protected zones' where the participants involved are somewhat liberated from the time and context constraints and pressures.
- Also multilateral communication is hard to achieve. Unilateral communication is the dominant communication pattern in many participatory planning activities. Opening up for unexpected perspectives is rare and, just like double loop learning, only emerges in conditions which are (made) free of too strong external pressures
- Adequate facilitation can certainly help to create balances of social learning within the system and to keep the external pressures at some distance. Yet, it cannot completely neutralise the external dynamics, unless it reduces the learning process to an a-sceptic and irrelevant activity.

Differences in social learning between North and South

- A sense of 'ownership' is not necessarily a major condition for stakeholders in the Vietnamese projects to participate and to learn from their participatory experience. Other motivational factors such as sociality, solidarity, obedience to authority and conventionalism seem to play a more important role in the commitment of the participants.
- Consequently, the learning which comes about will rather reflect a top-down expert-layperson relationship, or a more 'paternalistic' or 'pastoral' relationship reproducing predefined, close ended answers to particular problems. In Western settings we encountered more situations where the relationship between the participant and the facilitator was horizontal, whereby the knowledge of the latter could be openly contested, and whereby insights were gained from active self-directed research processes on behalf of all stakeholders. Participants who had not learned to behave like this would feel very uncomfortable in these situations where truth and competence are continually scrutinised by all stakeholders involved.
- This brings us to the last conclusion about power relationships. Apparently, power seems to operate both in a similar and in a different way in the contexts of the North and the South which we researched. Both in the North and in the South, we have encountered informal circuits of power operating next to and influencing formal circuits of power, and vice versa. However, in the Flanders, interests and power issues are negotiated more openly with less respect for hierarchy and tradition. Therefore, direct multilateral settings of negotiation are more common in the Flemish cases than in the Vietnamese cases. We probably may conclude that power in the Vietnamese cases rather operates under the regime of 'sovereignity' characterised by more direct and coercive control. Features of social learning are: a unilateral transmission of knowledge, competences and value orientations, vertical relations between leaders and participants and close ended processes. In the Flemish cases, power rather operates under the regime of 'governmentality' creating opportunities for participants to engage in more open ended planning and learning processes, including more horizontal relationships, and to experience a more autonomy in setting the learning and planning agenda. However here too, these governmental practices are restricted when strong pressures resulting from conflicts of interest come into play.
- The very last remark is not a conclusion but just a question: to what extent are action researchers from the North, who operate in projects in the South, agents of advanced liberalism?

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Eds. O. Batelaan, M. Dusar, J. Masschelein, Vu Thanh Tam, Tran Tan Van, Nguyen Xuan Khien

VOLCANO-KARSTIC SITES OF JEJU ISLAND IN KOREA: POSSIBLE NOMINATED SITES FOR WORLD HERITAGE LIST

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Keywords: nature protection, volcanic landforms, lava caves, speleothems.

Scientific research on various aspects in Jeju Island has been carried out for nomination on the list of World Heritage Sites. Jeju Island includes a variety of volcanic landforms and more than 100 lava tubes of geologic and speleologic significance. Jeju Island essentially consists of one major shield volcano, Hallasan (Mt. Halla), with satellite cones building out around its flanks. Other features include maar (Sangumburi), parasitic cones (Geomunoreum and Seongsan-Ilchubong), lava tubes (Bengdwi Cave, Manjang Cave, Sa Cave and Dangcheomul Cave), columnar jointing, Mt. Sanbang (volcanic dome) and Suwolbong tuff deposits. Especially, lava tubes show a complete flow system and display perfectly preserved internal structures despite their old age of formation (0.2-0.3 million years BP). Dangcheomul Cave contains calcareous speleothems of superlative beauty.

Four aspects are identified which emphasize the significance of the nominated sites in relation to the World Heritage Criteria.

1. The volcanic exposures of the nominated sites provide accessible sequence of volcanogenic rocks formed by eruptions in three different periods between 1 million and thousands years BP. The volcanic activities that made Jeju Island are quite different from those for adjacent volcanic terrane, because Jeju Island formed by huge plume activity at the edge of the continent.
2. The nominated sites include a remarkable range of internationally important volcanic landforms that contain and provide significant information on the history of the Earth. Volcanic eruptions have created diverse volcanic landforms depending upon the environmental conditions of the eruptions.
3. While lava caves are located all over the island, the largest and most spectacular are located in the western and north eastern parts. The most voluminous is the impressive 7.416km-long Manjang Cave, comprising a single passage containing two and in some places three levels. Other, shorter caves, such as the 4.481km-long Bengdwi Cave are more complex in form, or 4.393km-long Susan Cave is a beautifully formed classical lava tube.
4. Of great significance are the abundant carbonate formations in some of the low elevation lava caves, making these unusual and spectacular caves, generally acknowledged to be the best of this type of cave in the world. Especially, Dangcheomul Cave can be considered to be the most beautiful lava tube filled with various calcareous speleothems.

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CURRENT STATUS AND CONSERVATION OF LIMESTONE VEGETATION AND FLORA OF HAINAN, CHINA

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Keywords: botany, protection, vegetation survey, karst biodiversity.

Limestone flora is characterized by calcicole plants. Similar to the plants on oceanic islands, it shows a higher percentage of endemism, and has long been receiving attention from botanists. There is a considerable amount of research on the vegetation and flora of limestone area in South and Southwest China (Liang *et al.*, 1985; Xu, 1993; Wang *et al.*, 1997; Zhu *et al.*, 1997; Cen *et al.*, 1999) and the tropical rainforest in Hainan (Hu and Li, 1992; Jiang *et al.*, 2002). However, specific studies on Hainan’s limestone flora and its community are largely lacking. Under the influence of tropical monsoon climate, Hainan's limestone flora shows considerable difference to that of Guangxi and Yunnan, but similarity to that of Indochina and Malaysia. Limestone areas of Hainan are mainly found in the southern and western part of the Island, where 6 counties (cities) have considerable limestone coverage. In particular, the region along Changhua River and Wangxia Xiang in Changjiang County forms a central area of limestone outcrops with extensive cover of monsoon rainforest.

The soil in Hainan limestone region is mainly composed of brown limestone soil and dark limestone soil. The former is usually distributed at the gentle slope of limestone foothills with relatively good vegetation cover and few barren rocks. It tends to be rich in humus and high in water content, and appears to be light brown or dull brown. The latter one is common in crevices and excavations near the peak of limestone hills. Made up of mainly decomposed litter, it tends to be rich in humus and usually appears to be dull dark brown or brown. As it is distributed on exposed limestone, the soil is usually thin and dry.

Preliminary surveys showed that Hainan's limestone areas have a rich flora with over 1,800 vascular plants species and nurture a number of endemic species and limestone specialists. So far up to 13 plants species that are restricted to Hainan’s limestone area were found, including *Euphorbia hainanensis*, *Clausena hainanensis*, *Begonia peltatifolia* and *Impatiens hainanensis*. As research advances, more endemic species are expected to be discovered. Hainan's limestone flora also includes plenty of rare and endangered plants, such as *Arthromeris palisotii*, *Cycas hainanensis*, *Hopea hainanensis*, and many orchid species. It is estimated that there are nearly 30 orchid species in Hainan limestone area. Some of them, such as *Dendrobium nobile* and *Flickingeria fimbriata* are threatened by over-collection.

Hainan's limestone areas harbour diverse vegetation types. Preliminary survey at Wangxia has identified tropical monsoon rainforest, tropical monsoon humid rainforest, and tropical montane dwarf forest. Following the change of altitude and environment, vegetation also showed considerable variation even within close vicinity. Abrupt transition is common along vertical gradients and between habitats, from tropical monsoon rainforest at limestone foothill to dwarf forest and shrubs on exposed limestone peaks, while monsoon humid rainforests can sometimes be preserved in montane ravines above 700m. Tropical rainforest is mainly distributed on shady slopes and in humid ravine valleys. The forest structure can be divided into 3 layers. The first layer may reach over 16m. Inside the forest it is dark and humid, with sparse understorey. Buttress roots, cladanthy, and large lianes are prominent. Large epiphytes such as Orchidaceae and *Neottoperis* spp. are common.

Tropical monsoon humid rainforests are distributed in shaded humid ravines at higher altitude near gaps and peaks. These forests can reach up to 14m and can usually be divided in

2 levels. The lower tree layer has higher coverage, though its number of species is fewer than that of the second tree layer. Barren limestone areas are often covered with small trees and shrubs. Vegetation coverage is high. Plants developed typical characteristics such as low and dense branches, and coarse and thick bark to adapt to the special arid environment. A number of orchids specially adapted to arid environment, such as *Dendrobium* spp., *Flickingeria* spp., *Eria* spp., and *Cleisostoma* spp. could be found here.

Limestone vegetation located between 300m and 500m was most seriously damaged by human interference because minorities' settlements are mainly found at around 300m. Larger trees in these areas have all been logged for timber. While more gentle degraded limestone hillsides will be transformed to farmland, most of them will be covered in shrubland communities dominated by exotic shrubs, such as *Eupatorium odoratum* and *Lantana camara*, and vines. Relatively good vegetation can only be found in rugged mountains and among steep barren rocky slopes. Such forest is characterised by considerable coverage of barren rocks, thin soil and arid environment. Major species in these forests included *Terminalia nigrovenulosa*, *Dolichandrone cauda-felina*, *Lagerstroemia balansae*, and *Taxotrophis ilicifolius*, among which deciduous species accounted for a substantial proportion, especially for the canopy tree species. Vines and epiphytes such as *Hoya* spp. and *Rhaphidophora* spp. are abundant on barren rock surface and crevices.

Between 500m and 700m, a relatively extensive cover of monsoon rainforest still exists in areas further away from villages. The canopy layer of the forest at the shady hillside is mainly composed of *Drypetes* sp., *Lasiococca comberi*, *Firmiana hainanensis* and *Walsura robusta*. While on the sun-facing hillside which tends to suffer more disturbances because of their general proximity to villages, relatively undisturbed vegetation could only be found in the ravine valleys impossible to cultivate for farmland. Such forest is codominated by *Dimocarpus longan*, *Toona microcarpa*, *Aphanamixis grandifolia*, *Cryptocarya chinensis*, *Radermachera hainanensis*, *Hydnocarpus hainanensis*, *Lasiococca comberi* and *Taxotrophis ilicifolius* in the canopy layer, and rich in larger lianes, such as *Tetrastigma planicaule* and *Bauhinia kerrii*.

Being more remote from the villages and protected by the rugged landscape, the region between 700m and 870m still preserves intact tropical monsoon rainforest, especially in inaccessible ravines. Major canopy tree species at the sun-facing sides include *Meliosma thorelii*, *Syzygium brachyantherum*, *Lasiococca comberi*, *Turpinia*, *Ilex kudincha*, *Toona microcarpa*, *Drypetes* sp., *Horsfieldiaglabra hainanensis*, *Ficuss* spp., *Dehaasia hainanensis*, *Psychotria asiatica*, *Reevesia longipetiolata*, and *Taxotrophis ilicifolius*. Forest on the shady sides shares similar appearance and structure as the sun-facing side at similar altitude and its canopy is mainly composed of *Nephelium topengii*, *Aglaia dasyclada*, *Dillenia turbinate*, *Litchi chinensis*, *Polyalthia laui*, *Microcos chungii*, *Stereulia hainanensis*, *Gironniera subaequalis*, *Lasiococca comberi* and *Taxotrophis ilicifolius*. Coverage of barren limestone in the forest is about 30% and the soil is usually thicker and more fertile than that of the sun-facing side.

Areas around limestone peak between 870m and 1190m are dominated by exposed limestone peaks and outcrops. Differences in vegetation with respect to slope aspects are not prominent. It is mainly covered in simply-structured dwarf forest and shrubland dominated by *Quercus bawanglingensis*, *Sinosideroxylon wightianum*, *Ficuss* spp., *Celtis biondii*, *Picrasma quassioides*, *Euphorbia hainanensis*, *Schefflera arboricola*, *Cycas hainanensis*, and *Dracaena cambodiana*, and epiphytic orchids such as *Eria* sp., *Dendrobium* spp. and *Cleisostoma* sp. Depression and mountain gaps at this altitude are more protected from human disturbance and have a humid microclimate, and often have well-developed vegetation showing characteristics of tropical monsoon humid forest. Common dominant canopy species in these forests are *Chukrasia tabularis*, *A. grandifolia*, *Walsura cochinchinensis*, *Lagerstroemia balansae*, *Lasiococca comberi*, *Dehaasia hainanensis*, and *Taxotrophis ilicifolius*. Exposed limestone outcrop is often colonized with limestone specialist species, such as *Neottopteris* spp., *Begonia peltatifolia*, *Euphorbia hainanensis*, *Cycas hainanensis*, *Dracaena cambodiana* and Gesneriaceae spp.

plants, as well as vines such as *Tetrastigma* sp., *Rhaphidophora* sp. and *Hoya* sp.

Following the rapid economic development in the recent decade, demand for limestone, an important raw material for cement production, increased drastically. Extraction of limestone by explosives from areas with better accessibility resulted in complete destruction of the vegetation and habitats. Most limestone areas in Hainan are in remote mountainous region with impoverished farmland and lack surface water. Minorities live here are mostly poorly educated, and local economic development is rather slow, which makes these areas the major ecologically fragile and poverty sites in Hainan Province. Local villagers tend to rely heavily on the natural environment for their survival or even their income source. "Slash and burn" practise for establishment of sugar cane plantation or orchards was the major cause of deforestation. Currently some county level forestry departments misunderstood the real meaning of “Grain for Green” programme, and encouraged local people to burn large area of hillside to develop monoculture of banana or rubber plantation, bringing catastrophic damage to limestone vegetation in some region. Although logging of natural forest is explicitly prohibited, many people still sneak into forests and illegally fell timber for sale. In certain places, the whole forest of *Dalbergia odorifera* was destroyed by uprooting of adult trees or saplings, leaving big holes in the ground. Such action not only causes damage to the species and the surrounding trees, but also seriously impairs the integrity of the vegetation. Apart from logging, many people go to the forest for medicinal plant collection, including endangered wild orchids such as *Dendrobium* sp. Some even commit illegal hunting. All these activities contribute to destruction of ecological equilibrium. The original vegetation of some limestone areas were destroyed long ago as a result of extended impact from human activities, leaving only secondary shrubland or grassland. Being characterised by thin soil, exposed barren rocks and lack of surface water, regeneration of vegetation in such environment after disturbance is often slow and will result in severe erosion under Hainan's seasonal rainy climate. In severe cases, rock-desertification may arise.

Problems of alien plant species invasion seemed to be more serious where the vegetation are disturbed. Major invasive alien species included *Eupatorium odoratum*, *Lespedeza pilosa*, *Tithonia diversifolia* and *E. catarium*. Among them, *E. odoratum* is distributed from the hillside to 850m in places with damaged vegetation. Its dominance increases with the degree of vegetation damage, and often forms dense monospecific thickets, preventing natural regeneration. For *E. catarium*, it mainly spreads around farmland in low altitudes. If the farmland is not managed properly, this invasive species will turn it into a monospecific community, making vegetation recovery a big problem. *Tithonia diversifolia* often dominates shrubland communities in humid and sunny habitats. Its encroachment also brings tremendous damage to habitats. Human disturbance and destruction to vegetation often promote the growth of climbers, especially fast growing vines, which encroach on shrub or trees and form dense thickets, and further impedes the recovery of vegetation and communities seriously.

Currently, there is not yet any protected area in Hainan, targeted at its limestone vegetation and flora. Vegetation of limestone region are being damaged at a disastrous rate, there is thus a pressing need to protect the limestone flora in Hainan. Comprehensive survey of limestone areas is urgently needed to identify key areas to be designated as a nature reserve. The result of vegetation survey of limestone region in Hainan will provide scientific basis for sustainable utilization of limestone resources, eco-restoration and afforestation in the region, and will shed lights on the limestone floristic studies of Hainan and China. It will have important scientific and practical implications for biodiversity conservation and remediate rock-desertification of China's limestone habitats. How to attain a balance between conservation and use of resources from limestone area to attend a long-term sustainable solution is a ticklish issue. Some recommendations for more long-term solutions in regard to Hainan's current threats included:

1. Modification of the agricultural structure. Traditional monoculture should be modified. Agroforestry, sustainable forestry and husbandry should be promoted to reduce

reliance of single products and increase the income of the farmers.
2. Increasing the amount of investment and subsidy in education in the region to raise the educational level and financial income of the future generations, thus reducing their reliance on the natural environment.
3. Developing eco-tourism to protect ecological resources, increase income and serve as a kind of public education.
4. Promoting birth control to reduce growing pressure on the environment.
5. Strengthening public education to raise awareness of importance of environment protection and conservation;
6. Strengthening the enforcement of laws and legal framework on wildlife resources to fight against illegal logging and illegal hunting.

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CONSERVATION STUDY OF THE CRITICALLY ENDANGERED *PSEUDOTSUGA BREVIFOLIA* POPULATION IN DASHIWEI TIANKENG, LEYE, GUANGXI, CHINA

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Keywords: *Pseudotsuga brevifolia*, critically endangered, conservation, Dashiwei area, China.

Dashiwei Tiankeng (the Great Doline) is located in Leye, Guangxi Province in southwestern China on the southeastern Yunnan-Guizhou Plateau. The region has a subtropical monsoon climate, with distinct dry and wet season and abundant rainfall. The Dashiwei Tiankeng group is comprised of 28 dolines at various development stages, which are linked by an underground river system. Being protected by the doline cliffs, pristine natural forest patches are preserved above and within the dolines, and *Pseudotsuga brevifolia* Cheng et L.K.Fu is the constructive species of the forest.

Pseudotsuga brevifolia is endemic to China and is under Class II National Protection. This critically endangered species is restricted to karst mountains in southwestern China, mainly in western Guangxi. It is a shade-intolerant species showing high tolerance to drought, and is often found on karst hills with cragged hillsides and steep walls.

In this paper, possible threats to the species' survival, conservation strategies and utilization of the species have been proposed.

Between 2001 and 2003, a field survey was carried out to investigate the current status, the population structure, natural regeneration, population development, seed setting ratio, the seed developmentof *P. brevifolia*. Greig-Smith contiguous grid of quadrate and line transect were used to collect initial data of *P. brevifolia* population, and the number of plants in the grids was recorded. Poisson distribution variance, average rate (S^2/m) and negative binomial parameter (k) as well as Morisita pattern index (I) were determined for the population.

This study revealed that:

1. The distribution pattern of *P. brevifolia* in Dashiwei area can be classified into 4 types namely small patch, sparse woodland, mixed forest and pure forest. Drastic decline of natural population is noticed.
2. The diameter size structure and survival curve of the *P. brevifolia* population suggested a growing trend to decline in the past 50 years. The decline should be primarily caused by human disturbance such as over-collection, forest clearance, severe soil and water erosion, and the species' own limitation to bear fruit and regenerate.
3. The spatial distribution of individuals within the population also shifted from clustered distribution to Poisson distribution. Such decline is attributed to the population's reduced reproductive capacity, human disturbance, habitat degradation, as well as other environmental factors such as climate, and nutrition.

The populations of *Pseudotsuga brevifolia* in Dashiwei area are threatened by many factors, including as main threats habitat degradation and reduced regeneration. It is suggested that drastic conservation measures are necessary to allow sustainable exploitation of the ecological resources of the area. These should combine strengthening the habitat protection, promoting ex situ conservation, formulating relevant regulations and reasonable development plans for the Dashiwei area.

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DEVELOPMENT PROCESS OF CASH CROPS ON THE LIMESTONE PLATEAU IN MOC CHAU DISTRICT OF SON LA PROVINCE, VIETNAM

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Keywords: agricultural development, Moc chau, maize, cash crop, network.

Rapid land use changes have been observed in all regions of Vietnam. Many factors including the intrusion of the market-oriented economy, ethnicity, government policy and natural settings, play a large role in determining these processes. If we look at the agricultural development at the commune level, however, it can be seen that all factors do not drive the changes to the same extent. How much these factors affect changes depends on the regional conditions. Since the lime stone plateau has an unique process of agricultural development due to fertile and good-drained soil originated from lime stone, not only listing up, but also ientifying key factors in the local context becomes important in order to avoid a standardized policy implementation and contribute to solving the local problems arise within the processes of agricultural transformation. This paper, therefore, focuses on 1) describing the development process of the agricultural production systems in a lime stone plateau in Vietnam, 2) identifying regional differences in those processes in terms of agricultural intensification and diversification, and 3) attempting to clarify the reasons for the regional differences. The Moc Chau District in the Son La Province was selected as the study site. Regarding the adoption and spread of F1 maize varieties, the study has shown that there was no difference among the communes of Moc Chau. Introduction occurred at the same time, and the new varieties spread evenly despite different natural and socio-economic variables - such as distance from the main road, ethnicity and infrastructure. On the other hand, the spreading of canna and plum culture was travelled different routes in the communes of Moc Chau. The first in introduction of these new crops was from a migrant Kinh. But the following development did not proceed along ethnic lines or according to infrastructure, as there were no particular developments in road access or information availability. In both cases – the spreading of F1 maize varieties and an area-specific introduction of canna and plum – information, market demand, and the historical process of land acquisition were the key determining factors in the process of agricultural development since the late 1980s. Moreover, networking through the Kinh immigrants and the promotion activities on the part of the government were important factors in accelerating the expansion of these cash crops. Price fluctuation of agricultural products is an inescapable reality of the market-oriented economy, and farmers cannot escape a certain degree of vulnerability to more or less short-term boom-bust cycles for cash crops. Broad networks help farmers to reduce this risk by providing access to information and technology, which farmers can then translate into alternative crops. The experience of agricultural development in Moc Chau suggests that dynamic local decision-making processes based on these network linkages have enabled farmers to effectively respond to their environmental conditions and economic opportunities.

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CORROSIONAL SOIL EFFECT IN THE EPIKARST

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In the past decades became verified the influential, in some cases determinant importance of the soils of the karst terrain on the karstification process. Related to this fact and to other observations, the epikarst (subcutan zone) became an important area of the scientific research.

This most intensive zone of the karst corrosion can be defined from different point of views:

- functional: zone of the strongest infiltration and most karst aggressive fluids;
- topographical: zone under the karst terrain having variable thickness ("the skin of the karst" by M. Balakowicz);
- geomorphological: zone of the intensive formation of corrosional forms on and under the surface and of the most diffuse karstification;
- structural: zone of the highest degree of fissuring;
- hydrological: zone of the undifferentiated horizontal and vertical water infiltration and movement;
- biogeographical: zone of the abundant presence of karst biosphere.

According to our research it can be added that the epikarst is the main stage of the soil effect on karst. Conversely, the corrosional soil effect is the main factor of the creation of the epikarst.

As a consequence,

- the epikarst does not occur everywhere, it is a discontinuous zone, like the soil coverage;
- the thickness and the morphological image of the epikarst, and its waterflow and groundwater storage is connected to the effectiveness of the corrosional soil effect;
- the stage of the creation of the soil effect overlaps the epikarst, therefore, the karst soil and the regolith are also parts of the epikarst.

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