KARST FEATURES IN QUARTZITES OF SOUTH AFRICA.

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ABSTRACT: [*this is the English abstract*]
The author describes karst features developed in quartzite and also, but to a lesser extent, in weathered diabase and in wad. In quartzite the karst is due to weathering along joints and bedding planes, producing a softer arenaceous rock by slow dissolution along grain boundaries. Later, vadose caves form by piping in this weathered material, starting at a spring and progressing up-stream. The karst features include dolines, swallow-holes and caves grouped in very localized systems. Over most of the quartzite plateaus, however, real karst features are absent and the drainage remains superficial. The only ubiquitous features, reminiscent of lapies, consist of pinnacles left after erosion of sand. As most of the time they are not associated to deep karst systems, the author proposes that they should not be considered as karst features. Other caves are developed in weathered diabase and dolomite (wad), sandwiched between resistant quartzite layers. They result from the erosion of these soft layers.
The author is of the opinion that the term karst rather than pseudokarst should be used to describe this morphology developed in silica and silicate rocks. The reason is that not only the features produced compare well with the ones observed in "soluble rocks" (limestone, gypsum, etc.), but that the genetical process is very similar, It is suggested that the term pseudokarst should be used only in cases were the genesis is very different.

Key-words; Karst, pseudo-karst, quartzite, pinnacles, caves, weathering, South Africa.

1. INTRODUCTION

Caves and surface morphology strongly evocative of classic karst phenomena seem particularly well developed in the South African quartzites: around 150 cavities have been recorded. They have been briefly reported in the literature since the start of the century (HALL, 1906), but it was not until 50 years later that more in depth studies appeared, principally led by the South African Speleological Association, first in the Cape peninsula then in the Transvaal. More recently, some very distinctive cavities, hollowed out in sills of intrusive diabase in quartzites, have been described. The study of these morphological phenomena, called pseudo-karsts by several authors, extends beyond the regional framework and invites reflection upon the definition of karst in general.

2. GEOLOGICAL ENVIRONMENT

Quartzites are already represented in the most ancient rocks, older than 3 billion years, and are well distributed up to the Carboniferous. Only a portion of them are important for the development of caves and are localised in two regions: Transvaal province and the South of Cape province. The Transvaal basin (fig.1) has been filled by a succession of shallow marine sediments and of lavas several thousand metres thick from the early Proterozoic (2300-2100 Ma). Three groups are distinguished (SACS, 1980) which are from base to summit: the Wolkberg group (lavas, argilites and quartzites), the Chuniespoort group (Black Reef quartzites at the base, followed by dolomites and itabrites) and lastly the Pretoria group (argilites, quartzites and lavas.) These beds are in general little folded, monclinal and of moderate dip. They are intensely intruded by basic rocks forming numerous sills and dykes. The Waterberg beds have been deposited in another basin somewhat more to the north in comparison with the Transvaal basin. They consist principally of quartzites and conglomerates of fluvial origin (1700 Ma) several thousand metres thick. They are in general very little folded and form tabular landscapes (fig.1). In the South of Cape Province and in Natal, the quartzites of Table Mountain occupy very broad surfaces. This is a case of beds several hundred metres thick composed of very pure quartzitic material of Ordovician age. Most often they have been folded in a Subalpine style at the time of the uplifting of the Cape ranges.

3. SUPERFICIAL MORPHOLOGY AND QUARTZITE CAVES

As is generally the case elsewhere in the world, the quartzites form vigorous reliefs with rocky surfaces and poor soils. Particularly when the beds are horizontal or feebly dipping, the sculpturing of the planation recalls that of calcareous surfaces: lapies with grooves, basins with flat bottoms and scored banks, are common.

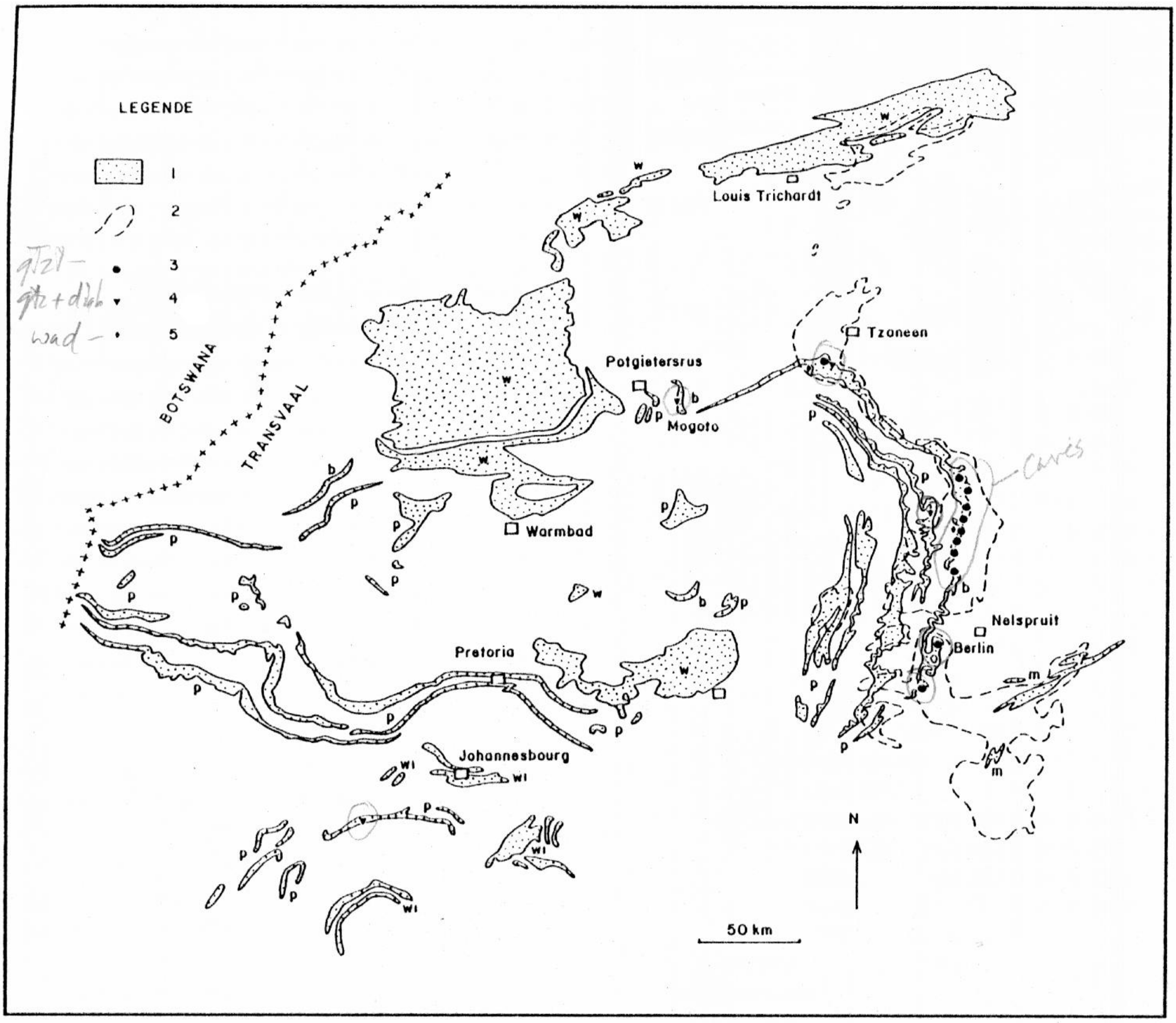


Fig. 1: Répartition des principaux affleurements de quartzite dans le Transvaal. *Distribution of quartzite outcrops in the Transvaal.*
1 - Quartzite (m) = Archéen. *Archaean.* W1 = groupe du Witwatersrand. *Witwatersrand Group.* b = Groupe de Chuniespoort et Formation du Black Reef. *Chuniespoort Group and Black Reef Formation.* p = groupe de Prétoria. *Pretoria Group,* w = groupe du Waterberg. *Waterberg Group.*
2- Précipitations supérieures à 1 m. *Rainfalls above 1 m.*
3- Grotte et groupe de grottes des quartzites. *Cave and cave system in quartzite.*
4- Idem, dans des quartzites et diabases. *Idem, in quartzite and diabase.*
5- Idem, dans du wad. *Idem, in wad.*

However, the forms most characteristic from a distance are the pinnacles creating ruiniform landscapes at the edge of the plateau (photo 1). This morphology is very widespread in all the countryside there where the quartzites level out, the most spectacular developments being seen on the beds of Black Reef, Pretoria, Waterberg and Table Mountain, particularly in regions of high rainfall.

If this quartzite morphology evokes a karst landscape, nevertheless water flow remains superficial in most cases. Forms associated with subterranean circulation, including dolines, stream sinks, caves and resurgences, are rare and very localised; they occupy less than 1% of the lapiés. Subterranean networks are generally localised to the proximity of the edges of plateaus and particularly where cliffs have developed at the downstream edge [en aval pendage]. These networks only extend a short distance from the resurgences, always less than 1 km. This feature is found in Venezuela (ZAWIDSKI et al. 1976; GALAN, 1983) and in Australia (JENNINGS, 1983). In sum, in contrast to calcareous massifs, it seems that karstification of quartzites is not the rule.

In the Transvaal, around 50 caves have been observed in the quartzites of the Black Reef formation and the Wolkberg group, where the rainfall is greater than 1 m per year (fig.1). This correlation with rainfall has also been observed in Africa (MAINGUET, 1972). The most spectacular phenomena are those seen in the Black Reef at Berlin, near Nelspruit (fig. 1 and 2). They comprise big open dolines in a “ruined-tower”

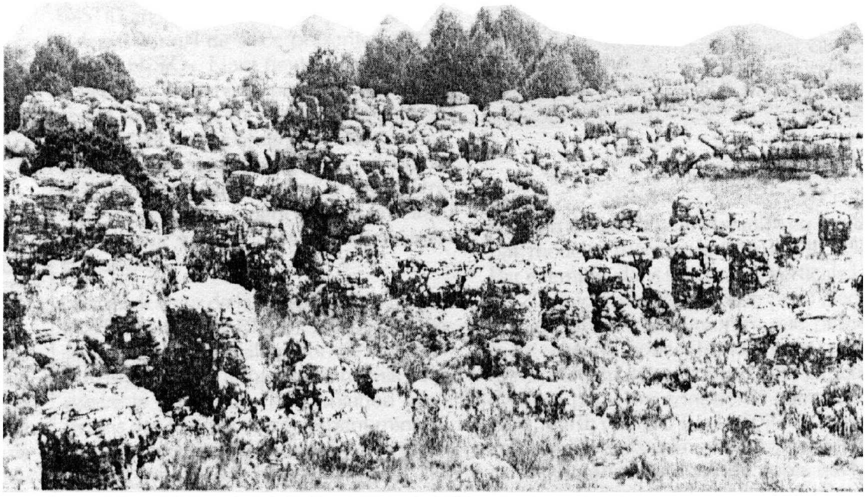


Photo 1: Le «Devil's Kantoor», un lapiaz à pinacles dans les quartzites du Black Reef près de Berlin, Est Transvaal. *The Devil's Kantoor, pinnacles lapiés, in Black Reef quartzite near Berlin, East Transvaal.*

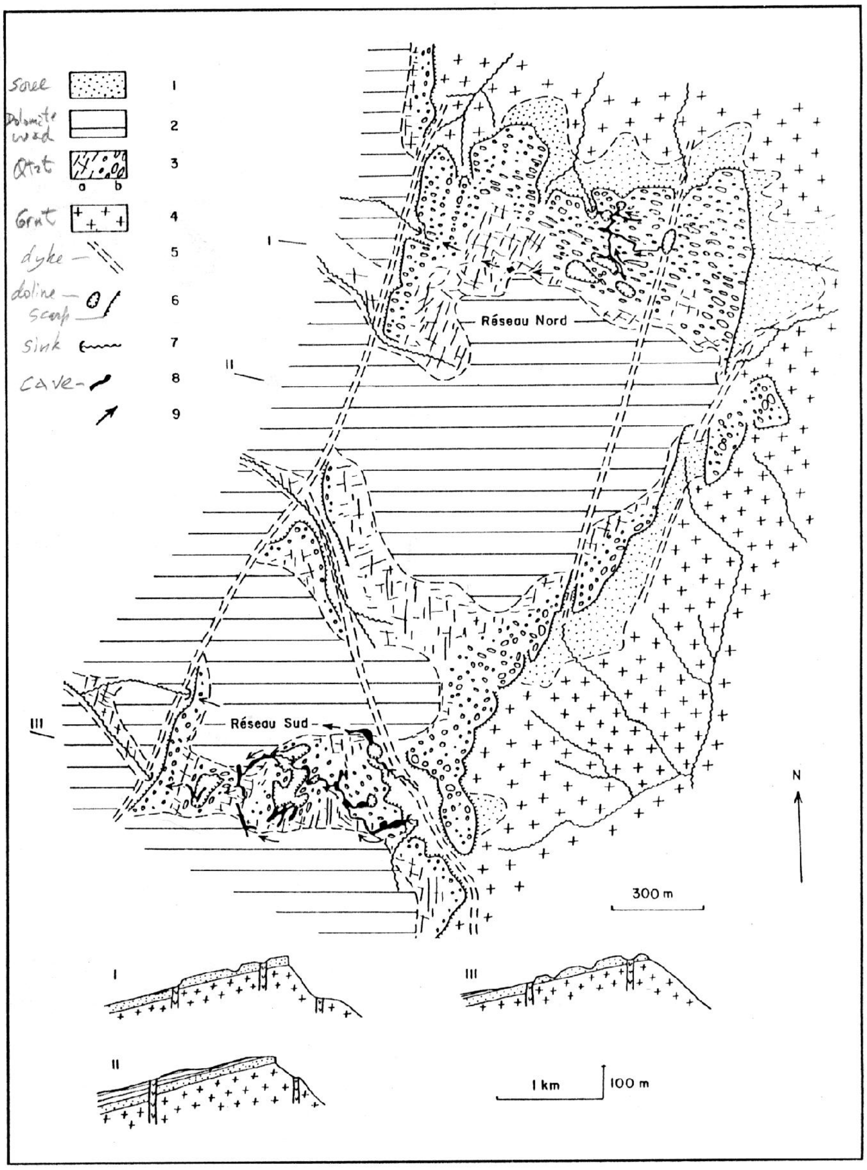


Fig. 2: Plan des deux grottes de Berlin, Transvaal Oriental. *Map of the two cave systems of Berlin, East Transvaal.* 1- Eboulis. *Scree.* 2.Dolomie, presque complètement altérée en wad. *Dolomite, nearly completely weathered into wad.* 3- Quartzite du Black Reef affleurant en dalles (a) et en pinacles (b). *Black Reef quartzite forming paving (a) and pinnacles (b).* 4- Socle granitique. *Granit basement.* 5- Dyke de diabase. *Diabase dyke.* 6- Dolines et rebord de plateau. *Dolines and edge of plateau.* 7- Ruisseau et perte-résurgence. *Stream and swallow-hole/resurgence.* 8- Grotte. *Cave.* 9- Direction d'écoulement. *Direction of flow.*

landscape, with sinks and resurgences. The caves are almost exclusively vadose, the passages being developed at the contact of a thin bed of volcanic tuff which forms an impermeable base level (fig.3 and photo 2). A total of 2.5 km of passages have been mapped in the Berlin systems, which are described in more detail elsewhere (MARTINI, 1979). The caves in the Wolkberg group are quite different. They are developed in thin layers of quartzite intercalated in an essentially clayey succession. The morphology of the surface is characterised by a deficiency of erosion [affleurements], the rock being generally hidden by a thick soil. One sees only small dolines, the sinks and resurgences giving access to feebly developed caves (fig.4).

A large number of caves are known in the Table Mountain quartzites. Most of them are localised in the Cape peninsula (fig. 5) where nearly 100 cavities have been documented (MOORE, 1944). They greatly resemble the Black Reef cavities, but with the difference from these last that they are particularly formed at the expense of fractures [diaclases]. The most important is “Ronan’s Well Cave” with a development of nearly 800 m. Some other caves in the same region are in the class of tectonic origin, formed by subsidence and detachment of the edge of the plateau. However, they capture water from the surface and are strongly reworked.

4. MODE OF FORMATION OF CAVES AND SUPERFICIAL MORPHOLOGY OF QUARTZITES

It seems that development of caves in quartzites depends on two distinct processes: firstly arenisation of the quartzites along fractures and levels of stratification, and secondly formation of caves by subterranean erosion of materials

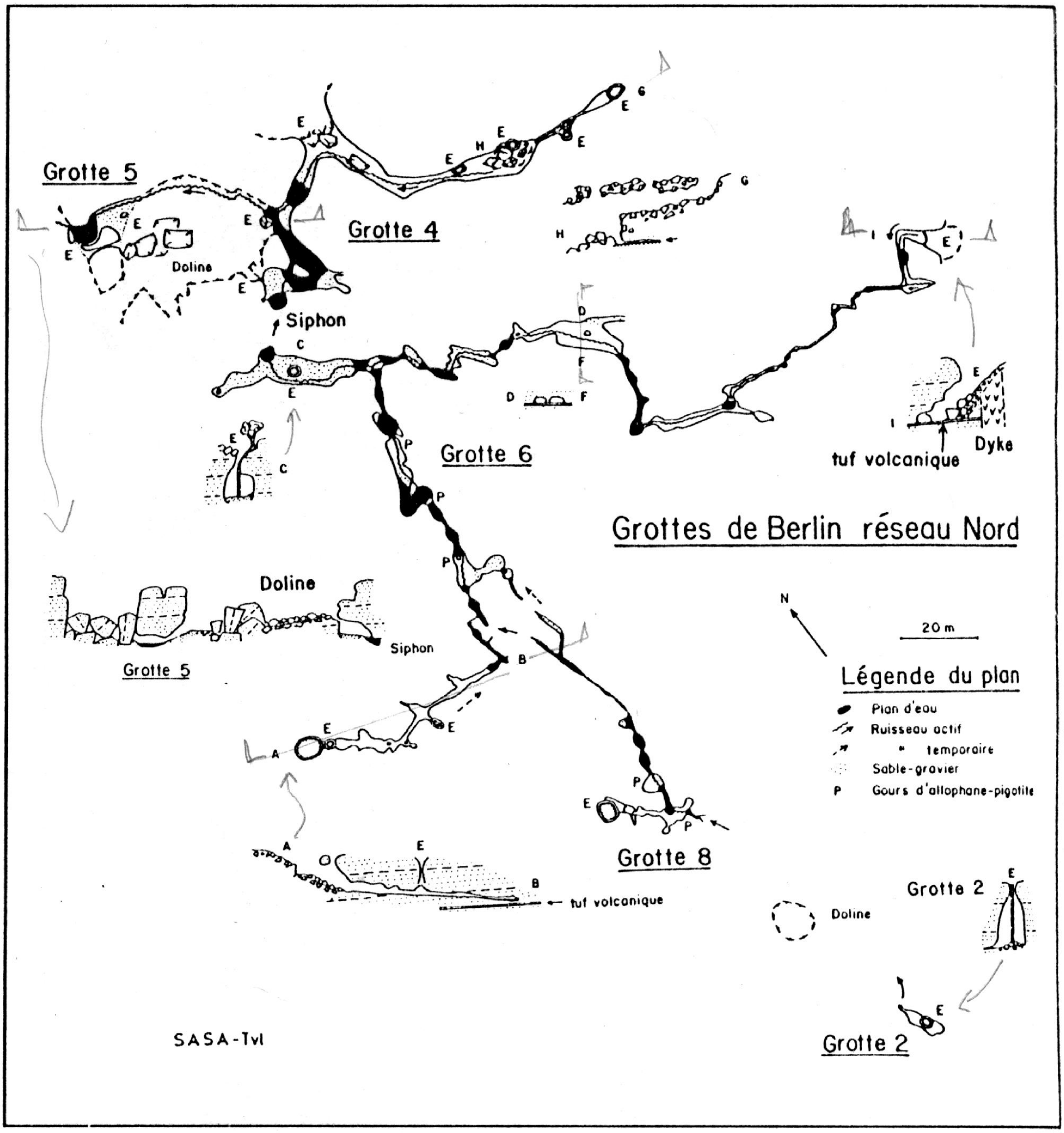


Fig. 3: Grottes de Berlin, réseau nord. *Berlin Caves, Northern System. Legend: pool, active stream, casual flow, sand-gravel, allophane-pigotite rimpool-dam, swallow-hole-resurgence.*

more or less portable [meuble] (COLVEE, 1973). This second process, also known as "piping", consists of regressive erosion away from a source. Although a number of authors accept these two phases of development, hollowing out of caves directly from unaltered rock has been proposed (JENNINGS, 1983). However, the cave on which this author bases this theory seems to have reached a senile evolutionary stage where portable materials have been completely eliminated or cemented by silica secondarily deposited by evaporation. In the numerous South African caves, strongly arenisated quarzites are very frequent.

Many authors seem to hit up against the problem of the solubility of quartz, which according to them is too low under the normal physico-chemical conditions of the surface to explain the formation of the caves. It follows that different hypotheses have been proposed to resolve this problem: preliminary transformation of quartz into opal, which is more soluble (WHITE et al., 1966), hydrothermal action arenising the rock along fractures (ZAWIDSKI et al., 1976), pedogenesis in a very basic environment in which silica would be more soluble (MARKER, 1976) or even particular lithology inherited from Precambrian climatic conditions (POUYLLAU and SEURIN, 1985). These hypotheses are hardly tenable for the following reasons: transformation from quartz to opal, in such conditions, goes against the laws of thermodynamics; in South

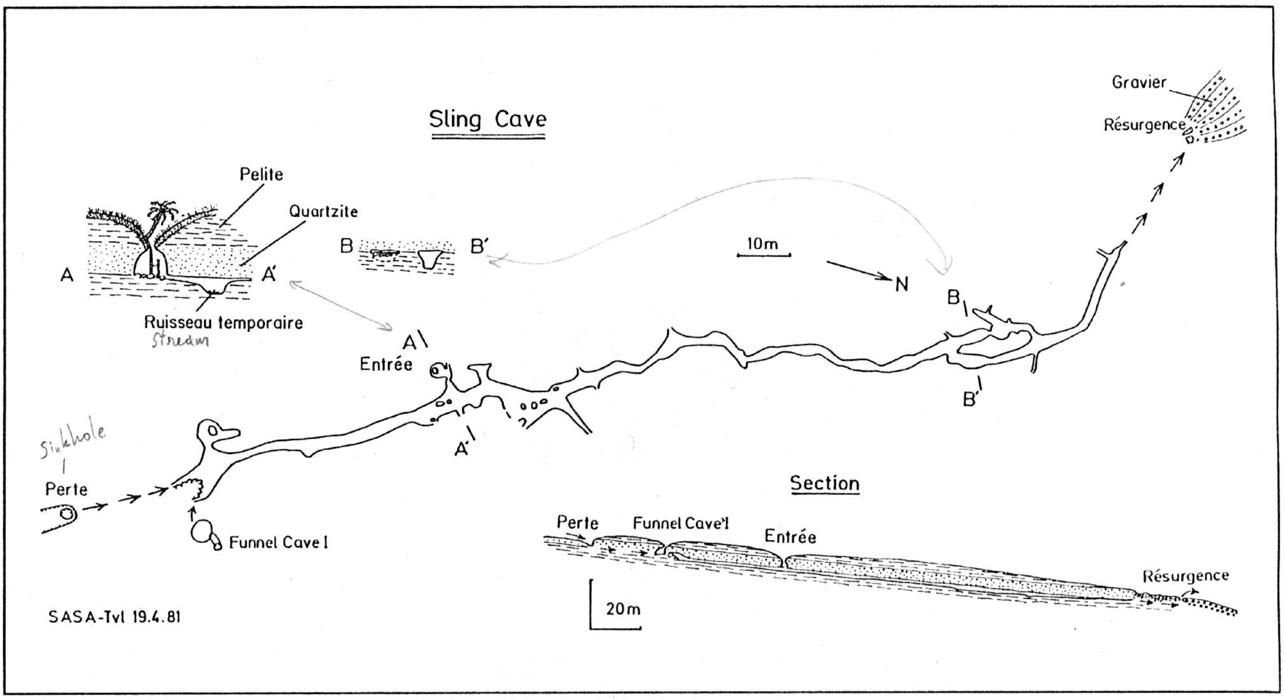


Fig. 4: La «Sling Cave», un exemple de grotte creusée à la base d'un mince banc de quartzite intercalé dans des roches détritiques à grain fin (groupe du Wolkberg).

Sling Cave, excavated at the base of a thin quartzite layer interbedded in shale and siltstone (Wolkberg Group).

African caves the author has not observed the least indication of hydrothermal action (veins, mineralisation and minerals of hydrothermal alteration); pedogenesis in a highly basic environment can be set aside since pH measurements in very leached soils in humid climates, where quartzite caves are best developed, are neutral or acid; finally the petrography of Precambrian rocks doesn't differ noticeably from those of more recent age.

In fact the arenisation of quartzites can be explained very well, simply by solution of quartz under usual pH conditions (MARTINI, 1979; JENNINGS, 1983; CHALCRAFT and PYE, 1984). It is well known that solution of quartz in the superficial environment is simple (ex: RIMSTID and BARNES, 1980): solubility is 5-10 mg/l of silica present in the form H_4SiO_4. Being neutral, this form is very little influenced by ions in solution, which means that the solubility of quartz stays practically constant if chemical conditions change, so long as the pH remains less than 9. This last value is practically never reached in the surface or subterranean waters of quartzites.

The extreme slowness of solution of quartz (RIMSTIDT and BARNES, 1980) plays an important role in the alteration of quartzites. Thus because of the very long time taken to attain saturation, solution can act in extremely thin fissures, as for example along intercrystalline joints, which is impossible for limestone where the speed of solution is considerably faster. This explains how the quartzites are arenised by superficial alteration, which is not the case for limestones. This slow dissolution of quartz can be demonstrated by theoretical models (MARTINI, 1984). For example, in a vertical fissure 20 microns wide in which water flows by gravity, calculations show that practically no concentration is reached after 100 m of flow. This width of fracture can be considered as standard (DREYBRODT, 1980). By comparison, in the case of limestone, 90% saturation is reached after only a few tens of centimetres. In consequence, solution of quartzites doesn't result in the formation of cavities as in limestone, but in a progressive arenisation of quartzites starting at fractures and at inter-layered [? interbancs = between layers?] joints (fig. 6). Thus the general rule is the absence of caves, except in some cases where, because of favourable geological and topographic conditions, regressive erosion ("piping") can occur. For example, such conditions are met in the case where a quartzite cliff with its impermeable sub-basement forms the downflow edge [? affleure en aval pendage]. From the fact that caves only develop a scant distance from the edges of plateaux, it seems that fissuring by decompression of the slopes could play a role. However, with the exception of certain caves of the Cape peninsula (see above), it is not possible to evaluate with certainty the role of this effect.

Contrary to what has been assumed, the poor solubility of quartz is not an obstacle to the formation of caves in quartzites, for rainwater becomes saturated with silicon essentially at depth and not on the surface as is the case for limestone. In this latter case, if one assumes a mean solubility of calcite of 200 mg/l, if one takes account also of the fact that 90-95% of saturation occurs very close to the surface, it is apparent that the "deep solubility" of limestones and quartzites are quite similar as far as the initial phase of karstification goes.

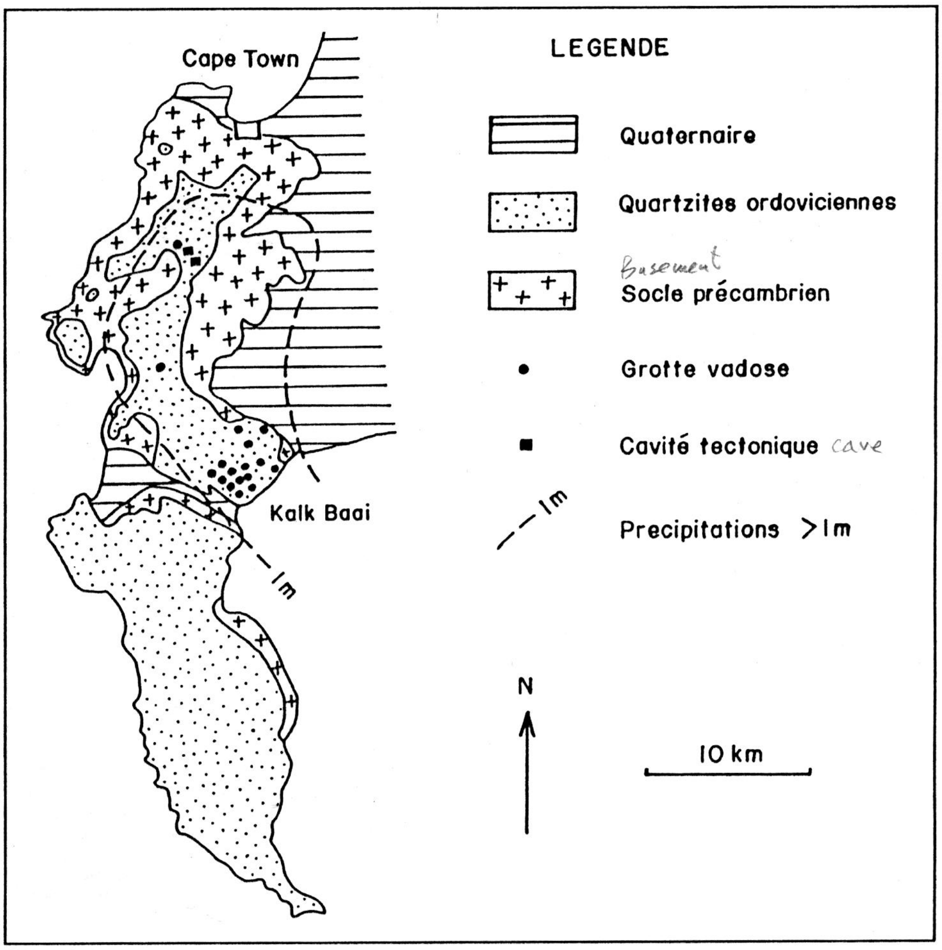


Fig. 5: Carte de la péninsule du Cap montrant la répartition des grottes dans les quartzites de la Montagne de la Table (Ordovicien) et dans la zone pluvieuse.
Map of the Cape Peninsula showing the cave distribution in the Table Mountain quartzite (Orvodician) and in the high rainfall area. Quaternary. Ordovician quartzite. Precambrian basement. Vadose Cave. Gravity tectonic cave. Rainfall above 1 m.

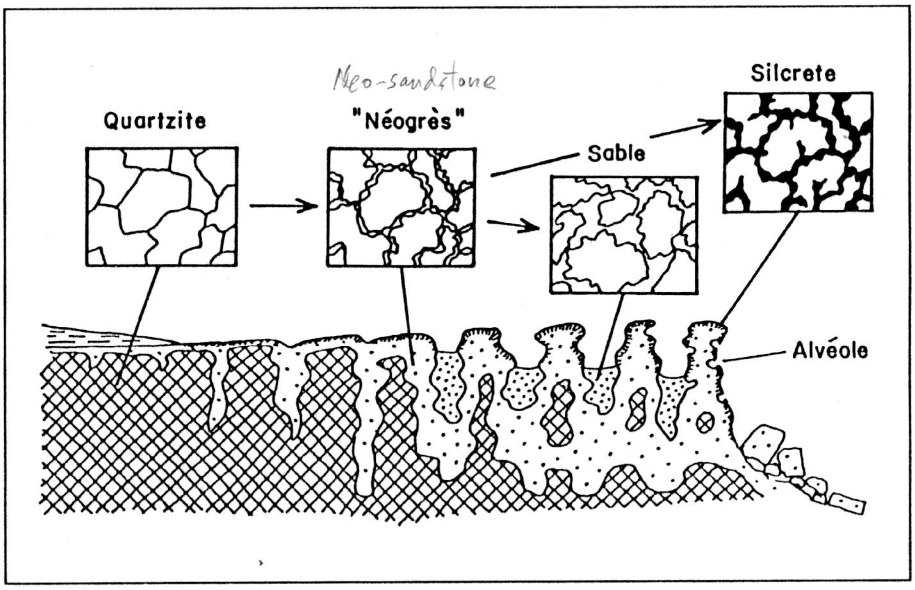


Fig. 6: Schéma illustrant l'altération superficielle des quartzites. Par dissolution le long des espaces intercristallins, la quartzite se transforme en matière plus meuble («néogrès») puis en sable lorsque la cohérence disparait. Par érosion des sables, les «néogrès» sont exhumés et en partie recimentés par de la silice amorphe déposée par évaporation (silcrete), et deviennent résistants à l'érosion, formant des pinacles.
Diagram showing the weathering of quartzite. By dissolution along inter-crystal space, the quartzite is transformed into soft «neosandstone» («néogrès»), then sand (sable) when all cohesion disappear. The pinnacles form when the sand is removed by erosion. They become erosion resistant due to amorphous silica deposited by evaporation and cementing the «neosandstone» (silcrete).

On the other hand, the formation of proper caves properly speaking by "piping", is certainly much faster than in limestone. It is possible that systems like those of the Berlin caves (fig. 2) only form over several million years.

The role of climate is evident for the location of caves in zones of high rainfall is certainly not fortuitous. The reasons are multiple. In a humid climate, the percentage of rainwater infiltration is much more significant than in arid regions. For example, in the Transvaal, infiltration is respectively 18 mm and 130 mm for 0.5 and 1 m annual precipitation (ENSLIN, 1970). Another factor is the well developed vegetation cover in humid regions, which checks the erosion of arenised zones and protects underground systems.

5. CAVES OF ALTERED QUARTZITE-DIABASE TYPE

Apart from the cavities already described, hollowed out exclusively in quartzites, caves developed in diabase sills have been explored in the Transvaal. These sills are intrusive in quartzites belonging to various stratigraphic levels: Wolkberg group, Black Reef formation and Pretoria group (fig. 1). In most cases the quartzites are not as altered as in the case of the quartzite caves. On the other hand the diabase is always completely decomposed into a bulky ferruginous clay. In Mogoto Cave (MARTINI, 1984c), which is by far the most significant with a development of 1.6 km (fig. 8), one can distinguish two

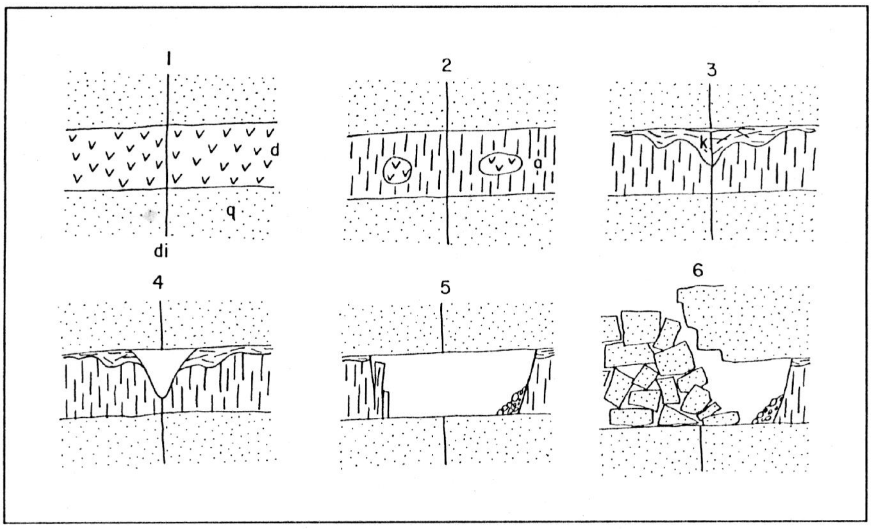
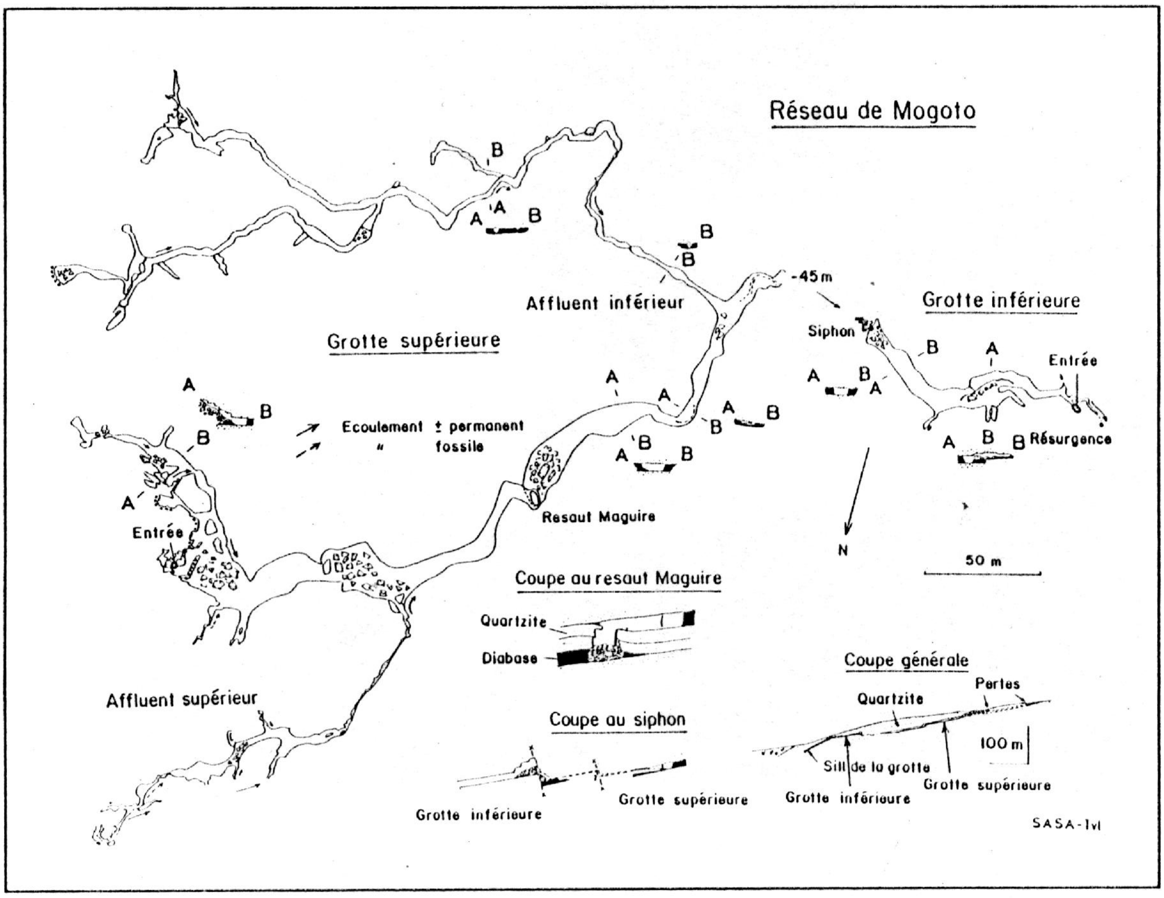


Fig. 7: Formation des grottes dans un sill de diabase.
1 - Etat initial. q = quartzite, d = diabase (épaisseur, environ 3 m), di = diaclase. 2 - Altération de la diabase en une matière argileuse brune et cellulaire (a) sans changement de volume. 3 - Par lessivage plus poussé du sill, dans des conditions acides et légèrement réductrices, l'argile brune se transforme en une matière blanche (k), kaolinique et plus dense. Des fissures de retrait se forment et, dus à la compaction différentielle, des vides de décollement se développant au contact sill-quartzite. 4 - Utilisant les vides formés précédemment, la grotte se forme. 5 - Stade plus avancé où le plancher du sill est dégagé. 6 - Effondrement dû à un agrandissement excessif de la galerie.

Formation of caves in a diabase sill. 1 - Unweathered state: q = quartzite, d = diabase (thickness, about 3 m), di = joint. 2 - Weathering of diabase into brown cellular clay (a) without volume change. 3 - By more advanced leaching of the sill top, under acidic and slightly reduciding conditions, the brown clay is altered into kaolin (k) which is denser. Cracks are forming and due to differential compaction, a void is developping at the top of the sill. 4 - Starting from these spaces, the cave forms. 5 - More advance stage where the quartzite floor appears. 6 - Roof breakdown due to excessive enlargement.

levels in the sill. The middle and lower part consists of a very porous brown and pink clay resulting from alteration without change of volume. The top of the sill is discoloured by more advanced leaching and transformed into denser kaolin with shrinkage fissures. Observation shows that the passages develop from the roof of the sill using the shrinkage [? de retrait] fissures as initial voids (fig. 7, photo 3). Most of the passages are of vadose type with the exception of certain cases where the hollowing has been effected in a phreatic milieu as for example the downstream part of the upper Affluent and the siphon of Mogoto cave (fig. 8). In addition, in this cave one observes that the diameter of the passages varies considerably as a function of the slope: passages parallel to the drainage/dip [pendage] supply the maximum diameter while,

Fig. 8: Plan du réseau de Mogoto.
Map of the Mogoto system. Affluent-tributary. Ecoulement - *flow.* Siphon - *sump.* Entrée - *entrance.*



when the direction becomes subsequent or obsequent, the area of the section can be reduced by a factor of 100. The reason for this is obviously the speed of water flow, on which depends the intensity of erosion. From a certain point of view, this type of cave bears some resemblance to "bad lands", but with pits [?], which suggests that their formation must be rapid, perhaps only centuries. From the climatic point of view, these caves seem able to form under more arid conditions than caves in quartzite, for most are located in regions of rainfall less than 1 m/year (fig. 1).

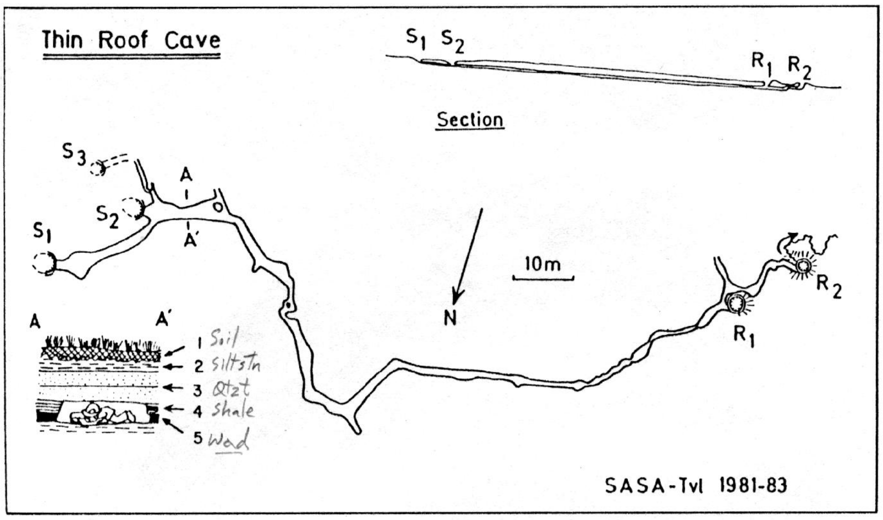


Fig. 9: La «Thin Roof Cave», un exemple de grotte creusée par action mécanique dans un mince niveau de dolomie, au préalable complètement altérée en wad.

Thin Roof Cave. excavated by piping in a thin bed of dolomite previously completely weathered into wad. 1 - Sol . *Soil.* 2 - Grès fin. *Siltstone.* 3 - Quartzite. 4 - Argilite. *Shale.* 5 - Wad.

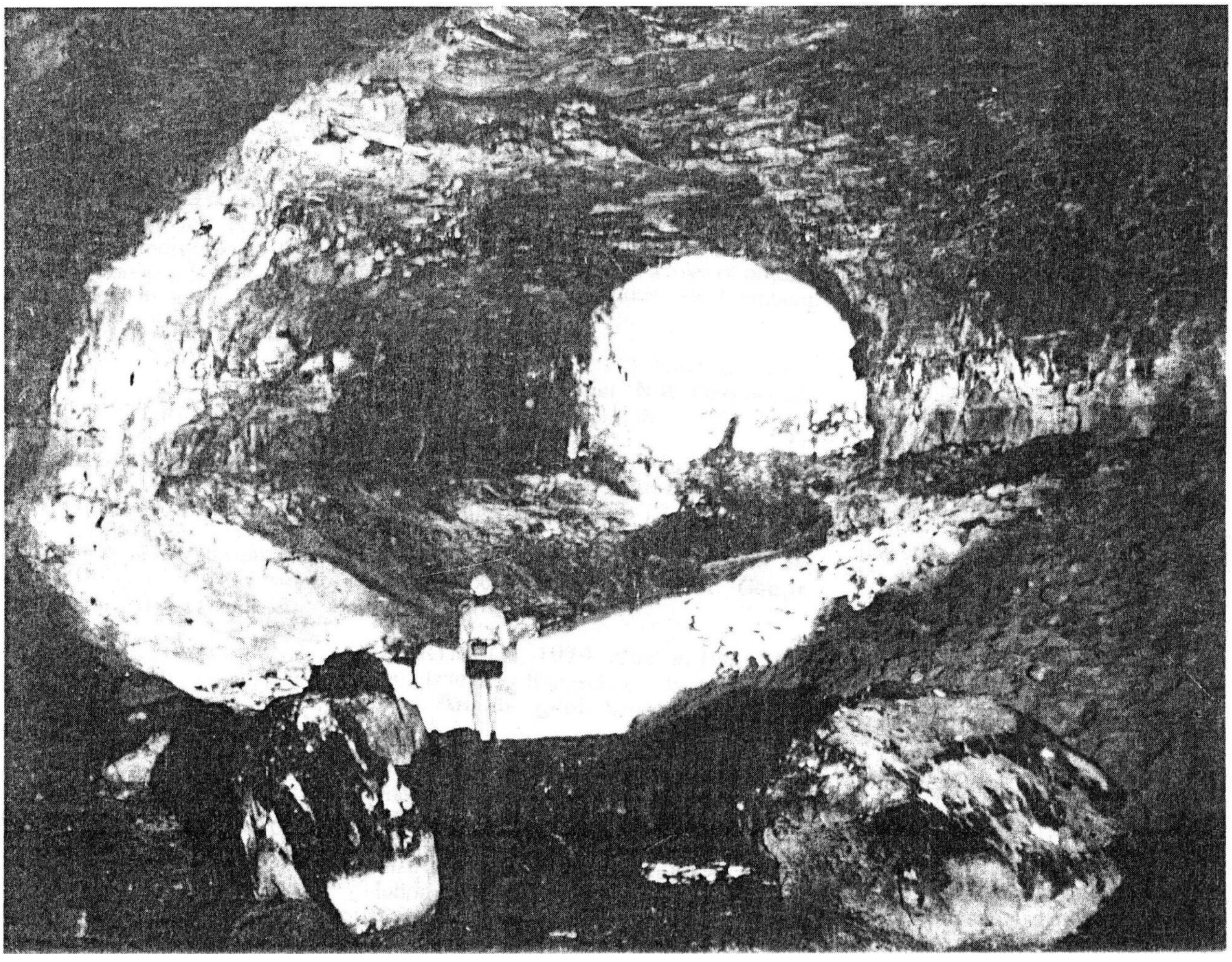


Photo 2: Grotte-perte de Berlin n°10, réseau sud,dans les quartzites arénisées de la formation du Black Reef (cliché M. Sefton).

Berlin Cave 10, Southern System, capturing stream in deeply weathered Black Reef quartzite.

6. CAVES OF QUARTZITE-WAD TYPE

These caves are very similar to the preceding type, except that the altered diabase has been replaced by wad. Wad is a very light earth, with cellular structure, composed of oxides of iron and manganese, which results from weathering of dolomite. Four small holes of this type have been observed in East Transvaal, at the extreme base of the dolomitic series of the Chuniespoort group and in the Wolkberg group (fig. 1 and 9). Their genesis is by "piping",

7. CONCLUSIONS AND DEFINITION OF KARSTS

In general, the most notable character of karstic morphology is the presence of caves which capture surface water and cause more or less complete disappearance of fluviatile systems. In the case of limestones, the development of this relief is above all due to solution. In the three cases examined in this article, a similar morphology is the result of a slightly different process, involving two phases: (1) weathering of quartzite, diabase and dolomite producing more portable [meuble] rocks (neo-sandstone [neogres], clay and wad); (2) formation of caves by regressive erosion. The development of subterranean circulation is thus a uniquely mechanical process. For this reason one party of authors (BLANCANEAUX & POUYLLAU, 1977) uses the term pseudo-karst in describing caves and lapies of quartzites, granites etc. Nevertheless another party, including the author, ask themselves whether the simple term karst would not be preferable (COLVEE, 1973; JENNINGS, 1983).

Here one should recall that the definition of karst, as it is generally accepted these days, in substance refers to a morphology essentially due to solution of rocks. It follows from this that the term pseudo-karst is used in the case of forms resembling karst but whose origin is not due to dissolution.

Lapies are observable in most rocks, be they "soluble" such as limestones, dolomites, gypsums and salts, or "insoluble" such as quartzites, sandstones, and basic (HOLMES, 1965) and acidic (TWIDALE, 1984) eruptive rocks. For these forms, it seems that the term pseudo-karst is particularly inadequate when it comes to siliceous rocks, for solution in fact plays an essential role (fig. 6). It is at this stage of the discussion that the definition of karst as relief resulting from solution appears unfortunate. Indeed superficial weathering of rocks, so important in pedogenesis, is a solution phenomenon: certain minerals in rocks such as gypsum, calcite and quartz dissolve in a congruent fashion. Others, such as feldspars, pyroxenes, manganesiferous dolomites, are apparently only partially soluble; in fact they dissolve as completely, but as the solutions produced are supersaturated with regard to other stable phases in the conditions of pedogenesis, clay minerals and various oxides form immediately, giving the impression of incomplete solution. Nevertheless, it would be absurd to use the term karst for all phenomena linked to pedogenesis. Moreover one can ask oneself the following question: whether the constituents of a rock are carried away molecule by molecule (solution) or

Photo 3: Galerie principale de la grotte de Mogoto supérieure. A noter le toit et le plancher en quartzite.
Main passage in the Upper Mogoto Cave. Note roof and floor in quartzite.

grain by grain (erosion), does it make such an important difference if in both cases the resulting morphology is similar?

It seems then that the definition of karst should be modified and could be expressed as follows: "A morphology due to circulation of subterranean waters and characterised by more or less complete disappearance of the superficial drainage system." It should be noted that it is essentially because of this last character that the karst of Slovenia was chosen as the type region. The characteristic forms would thus be dolines, poljes, sinkholes, resurgences and caves, on condition certainly that the origin is tied to the circulation of subterranean water. Lapies, whatever the rock on which they develop, should not be considered as typically karstic (MARTINI, 1979). In fact, although they are often associated with karsts, they are not essential to the formation of this morphology as it has been defined above. The term pseudo-karst should only be used in cases where the action of subterranean water is absent: for example volcanic and tectonic cavities, morphology of dunes and depressions due to aeolian erosion.

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BIBLIOGRAPHY
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