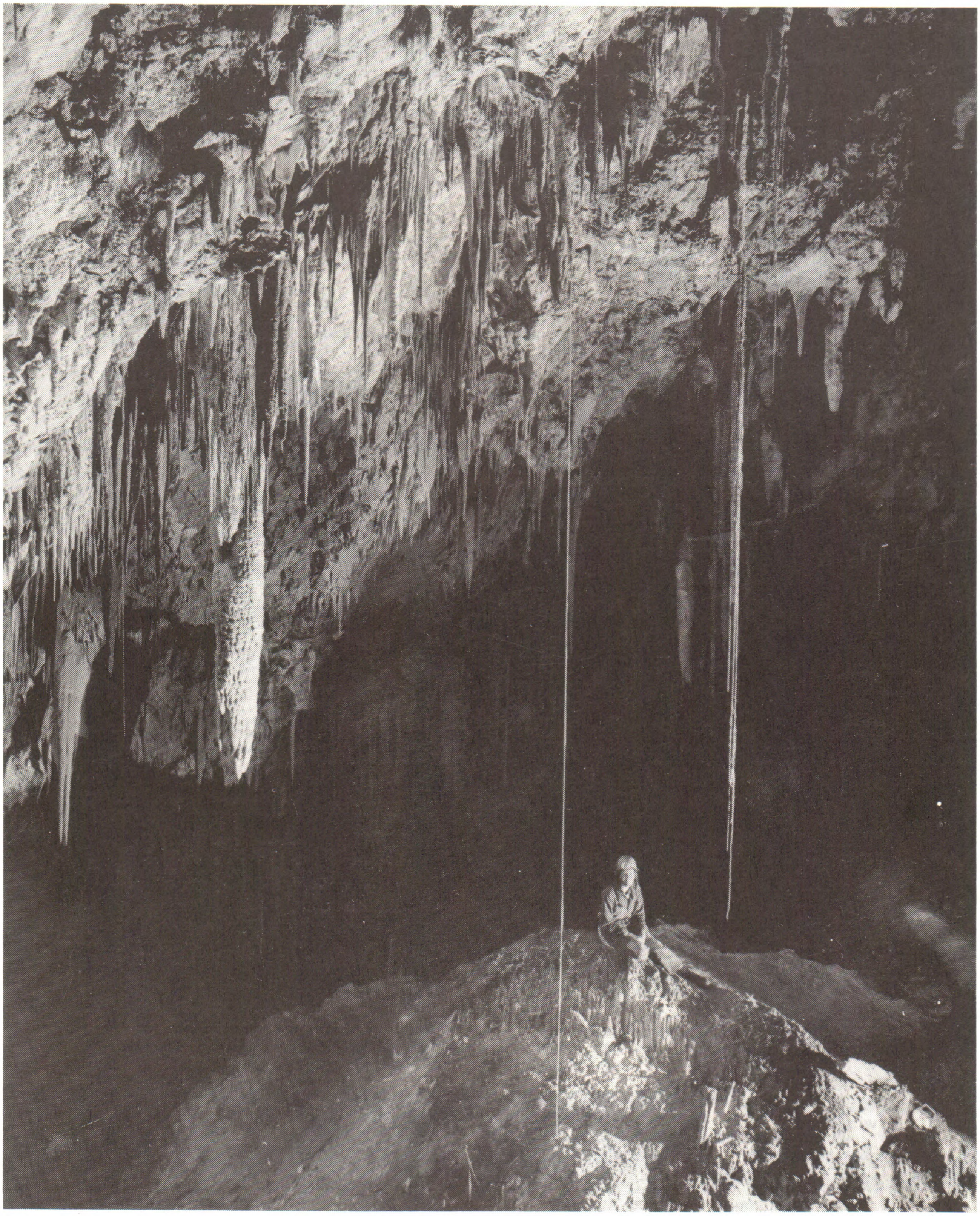
ASF NEWSLETTER Spring, 1980, No. 89



Ev Tulp contemplating a calcified tree root in Crystal Cave, Witchcliffe, W.A. Photo by Rauleigh Webb

THE AUSTRALIAN SPELEOLOGICAL QUARTERLY

Registered in Australia for transmission by post as a periodical — Category "B"

AUSTRALIAN SPELEOLOGICAL FEDERATION
P.O. BOX 388
Broadway N.S.W. 2007

ISSN. 0313 — 413 X

50c
Recommended

EXECUTIVE OFFICERS & MEMBER SOCIETIES

Please write direct to the Officer concerned, as the P.O. Box is only a clearing address

Trustees	J. N. JENNINGS	4 Hobbs St., O'Connor A.C.T. 2601
	B. P. MOORE	16 Lambert St., Lyneham, A.C.T. 2603

EXECUTIVE COMMITTEE OFFICERS :

President	KEN LANCE	37 Armagh St., Victoria Park, W.A. 6100
Vice President	ANDREW PAVEY	45 Arcadia St., Glebe, N.S.W. 2037
	GLENN PURE	8 Teague St., Indooroopilly, Qld., 4068
	JIM CUNDY	Coomandook, S.A. 5261
Secretary	PETER RADCLIFFE	42 Priestley Avenue, Point Clare, N.S.W. 2251
Assistant Secretary	CATHIE ROTHERY	5/59 Oxford Street, Epping, N.S.W. 2121
Treasurer	JOHN TAYLOR	P.O. Box 52, Glen Innes, N.S.W., 2370

CONVENORS OF COMMISSIONS :

Bibliography	GREGORY MIDDLETON	P.O. Box 269, Sandy Bay, Tas. 7005
Biological	ELERY HAMILTON-SMITH	P.O. Box 36, Carlton South, Vic. 3053
Cave Safety	GRAY WILSON	16 Newsom St., Ascot Vale, Vic. 3032
Speleo Handbook	PETER MATTHEWS	66 Frogmore Crescent, Park Orchards, Vic. 3114
International Relations	ELERY HAMILTON-SMITH	Address — as above
	JOHN DUNKLEY	3 Stops Place, Chifley, A.C.T. 2606
Library	ANDREW SPATE	1 Hoskins St., Hall, A.C.T. 2618
Longest & Deepest Caves	ROSS ELLIS	11 Arkana St., Telopea, N.S.W. 2117
Newsletter — Editor	ROSIE SHANNON	44 McCaul Street, Taringa Qld., 4068
Newsletter — Manager	TONY CULBERG	P.O. Box 36, Lindisfarne, Tas., 7015
Conservation	LEX BROWN	C/- School of Environmental Studies, Griffith Uni., Nathan, Qld., 4111
Cave Tourism and Management	ELERY HAMILTON-SMITH	P.O. Box 36 Carlton South, Vic. 3053
	ROY SKINNER	12 Baker St., Lenah Valley, Tas. 7008
Membership	BEN NURSE	11 Nelson Parade, Hunters Hill, N.S.W. 2110
	ANDREW PAVEY	45 Arcadia Rd., Glebe, N.S.W. 2037
Survey Standards	BRUCE WELCH	C/- 108 Queens Parade, East Newport, N.S.W. 2106
"Australian Speleology"	ANDREW PAVEY	45 Arcadia Road, Glebe N.S.W. 2037

CONVENORS OF AD HOC COMMITTEES :

Publications	ANTHONY CULBERG	Address as above
Cave Documentation	PETER MATTHEWS	66 Frogmore Crescent Park Orchards Vic., 3114
Membership	BENJAMIN NURSE	11 Nelson Parade, Hunters Hill, N.S.W. 2110
Nibicon	ANDREW PAVEY	As above
Cavconact	BOB NICOLL	C/- BMR, P.O. Box 378 Canberra City 2600
Waccon	KEN LANCE	P.O. Box 151, Nedlands, W.A. 6009
Cave Convict	PHILIP MACKEY	3 Nowa Court Frankston, Vic., 3199

CONVENORS OF STATE SPELEOLOGICAL COUNCILS :

N.S.W.	IAN BOGG	29 Scott St., Springwood, N.S.W. 2777

COMMITTEE MEMBERS :

(a) VOTING MEMBERS

A.C.T. :	
CANBERRA SPELEOLOGICAL SOCIETY	18 Arabana St., Aranda, ACT 2614
CAPITAL TERRITORY CAVING CLUB	P.O. Box 638, Woden, ACT 2606
NATIONAL UNIVERSITY CAVING CLUB	C/- Sports Union, Australian National University, 2600
N.S.W.	
BAPTIST CAVING ASSOCIATION	P.O. Box 140 Greenacre, N.S.W. 2190
BLUE MOUNTAINS SPELEOLOGICAL CLUB	P.O. Box 37, Glenbrook, N.S.W. 2773
HIGHLAND CAVING GROUP	P.O. Box 154, Liverpool, N.S.W. 2170
ILLAWARRA SPELEOLOGICAL SOCIETY	P.O. Box 94 Unanderra, N.S.W. 2526
KEMPSEY SPELEOLOGICAL SOCIETY	2 Albert St., Kempsey, N.S.W. 2440
MACQUARIE UNI. SPELEO INVESTIGATION GROUP	C/- Sports Assn. Macquarie Uni. Nth. Ryde N.S.W. 2113
METROPOLITAN SPELEOLOGICAL SOCIETY	P.O. Box 2, Crows Nest, N.S.W. 2065
N.S.W. INSTITUTE OF TECHNOLOGY SPELEOLOGICAL SOC.	C/- The Union, P.O. Box 123, Broadway, N.S.W. 2007
ORANGE SPELEOLOGICAL SOCIETY	P.O. Box 752, Orange, N.S.W. 2800
SYDNEY SPELEOLOGICAL SOCIETY	P.O. Box 198, Broadway, N.S.W. 2007
SYDNEY UNIVERSITY SPELEO. SOCIETY	Box 35, The Union, Sydney Uni., N.S.W. 2006
UNI. OF N.S.W. SPELEOLOGICAL SOCIETY	Box 17, The Union, Uni. of N.S.W., Kensington, N.S.W. 2033
QUEENSLAND :	
CENTRAL Q'LAND SPELEO. SOCIETY	P.O. Box 538, Rockhampton, Qld. 4700
UNI. OF QLD. SPELEOLOGICAL SOCIETY	The Union, Uni. of Q'land, St. Lucia, Qld. 4067
SOUTH AUSTRALIA :	
CAVE EXPLORATION GROUP (Sth. Australia) Inc.	C/- South Aust. Museum, Nth Terrace, Adelaide, S.A. 5000
TASMANIA :	
NORTHERN CAVERNEERS	P.O. Box 315, Launceston, Tas. 7250
SOUTHERN CAVING SOCIETY	P.O. Box 121, Moonah, Tas. 7009
TASMANIAN CAVERNEERING CLUB	P.O. Box 416, Sandy Bay, Tas. 7005
VICTORIA :	
VICTORIAN SPELEO ASSOCIATION	G.P.O. Box 5425 CC, Melbourne, Vic. 3001
WESTERN AUSTRALIA :	
SPELEOLOGICAL RESEARCH GROUP, W.A.	P.O. Box 120, Nedlands, W.A. 6009
WESTERN AUSTRALIA SPELEOLOGICAL GROUP	P.O. Box 67, Nedlands, W.A. 6009

(b) ASSOCIATES :

AVONDALE SPELEOLOGICAL SOCIETY	Avondale College, Cooranbong, N.S.W. 2265
BERMAGUI SPELEOLOGICAL ASSOCIATION	P.O. Box 16, Bermagui Sth., N.S.W. 2547
CAMPBELLTOWN CAVING & OUTDOOR GROUP	P.O. Box 281, Campbelltown, N.S.W. 2560
CHILLAGOE CAVING CLUB	7 Martyn St., Cairns, Qld. 4870
HILLS SPELEOLOGY CLUB	P.O. Box 198 Baulkham Hills, N.S.W. 2153
MOUNT ISA CAVING CLUB	76 Pelican St., Mount Isa, Qld 4825
ROYAL AUSTRALIAN NAVY CAVING ASSOCIATION	C/- School of Chemistry, Sydnet Uni., Sydney N.S.W. 2006
NORTH QLD. SPELEOLOGICAL ASSOCIATION	1 Boden St., Edgehill, Qld., 4870
PAPUA NEW GUINEA EXPLORATION GROUP	C/- M. Pound, P.O. Box 3824, Port Moresby, P.N.G.

10/10/80 ***********850 Copies

ASF NEWSLETTER
Number 89, Spring 1980

**** - * - * - ****

This Newsletter features an article by Dr. J. N. Jennings. It was originally written for a three volume work to be published in India on geomorphology. The work will include systematic sections as well as regional Indian geomorphology. This represents Dr. Jennings' present view of our knowledge about limestone caves. The Indian work will be some time appearing, and will scarcely be seen in Australia, so it is being published to make it available to Australian speleos. Only the last paragraph indicates that it is directed at an Indian audience.

To those who sent copy- thank you. It will be in Newsletter 90, because to use it in this Newsletter would leave nothing for Issue 90. Copy is still required for this years' last issue. The closing date is below.

**** - * - * - ****

COVER PHOTOGRAPH

Rauleigh Webb

On a recent trip to Crystal Cave, Witchcliffe, Western Australia, this very long calcified tree root was noted in a chamber. Subsequently, the tree root was measured at 6.8m $\pm$ 0.1m. This measurement is not from the roof of the chamber, but rather from the point where the tree root is the thickness of a straw. It is also the average of three measurements.

An attempt was also made to measure the tree root photographically, but the result was some two metres longer! Can anyone please explain the discrepancy that occurred? Please let me know if any of you avid photographers can explain such an error. If you know of a longer tree root, could you let us know through the Newsletter?

The calcified tree root is about one metre from the rock pile in the photograph, though it may appear to be touching.

**** - * - * - ****

DEADLINE DATES FOR FUTURE ISSUES

For numbers 90 and 91, the dates are 1st. November, 1980 and 14th. February, 1981 respectively.

**** - * - * - ****

Editor ASF Newsletter : Rosie Shannon, 44 McCaul St., Taringa, Q.,4068. (07) 3708959

Distribution : Tony Culberg, P.O. Box 36, Lindisfarne, Tas., 7015. (002) 438546

Back Issues : Brian McQuillan, 27 Liggins Rd., Hazelbrook, N.S.W., 2779. (047) 586868

**** - * - * - ****

THE PROBLEM OF CAVERN FORMATION

J. N. Jennings

In the last three decades when process study and morphometry have appeared to dominate geomorphology, a better understanding of cave formation has been achieved, less by these approaches, than by the classical methods of field observation, followed by inductive and deductive reasoning. Straightforward exploration and mapping of caves have been the greatest source of food for thought. These have been pressed farther and farther afield from the early centres of speleology in Europe and N. America, and pursued with much improved techniques, including the new avenue of cave diving. In this circumstance one should yield tribute to William Morris Davis, whose classic paper on limestone caves of 1930, when he was 70 years old, employing just these basic methods, gave fresh orientation and vital stimulus to this field of study at that time in the English-speaking world.

Of course, there is not one problem of cave formation but many if for no other reason but that caves in different kinds of rock involve various processes and undergo diverse evolutions. Extensive cave systems have been found in gypsum, including the world's third and fourth longest, and also in lavas, into the tens of kilometres, but the most elaborate and extensive ones are still found in carbonate rocks, especially limestone. The world's longest cave, the Flint Mammoth Cave system in Kentucky with over 300 km of passage, and the world's deepest, the Gouffre Jean Bernard in the French Alps 1402 m in depth, are formed in pure limestone.

In these recent decades, the most significant change in discussion about limestone caves has been a shift away from controversy, arising because opposing standpoints were monogenetic and maintained that a particular mechanism or a given locus of activity is generally dominant, to recognition that at different times and places one of a range of mechanisms or combinations of mechanisms takes on supremacy (cf. Halliday 1960; White and Longyear 1962; Ford 1965).

PROCESSES IN LIMESTONE CAVE GENESIS AND EVOLUTION

Despite what has been said above, it is logical to begin by considering the relevant processes, in which also advances have been made in this period.

(1) CORROSION. The single most important process, the chemical removal of limestone, is a most complex matter (Picknett, Bray and Stenner 1976) which can be treated here only in a crude, non-mathematical manner. Simple physical solution is normally the initial phase yet it can only bring about a concentration of 13-15 mg/l according to temperature. Natural concentrations in cave waters are much higher than this, commonly reaching between 100 and 200 mg/l, and this excess is due to carbonation. The carbon dioxide, which mildly acidifies the water for this, dominantly is provided by the life and decay processes of plants, macroscopic and microscopic (including bacteria), in vegetation, its litter and the soil. The atmosphere provides much less. The transport of organic matter to the depths of caves allows for a renewal of CO_2 by decay at considerable remove from the surface (James 1977).

The maximum amount of $CaCO_3$ that can be dissolved - the saturation equilibrium - varies directly with the content of CO_2 (its partial pressure P_{CO_2}) in the water and inversely with the temperature in accord with Henry's law. However the first effect ranges one hundredfold whereas the second has only a threefold range over cave temperatures. Therefore the indirect influence of temperature in promoting organic processes to provide CO_2 overrides its opposite effect through saturation equilibrium.

There are other controls on saturation equilibrium:- ion pairing as with magnesium which has a complex effect (Picknett 1972), fortunately minimal when magnesium is about 15% of calcium, a common ratio in karst; ion strength such as the presence of much NaCl in sea water increasing the saturation equilibrium for calcium; presence of metal ions such as copper which reduces the saturation amount, to mention only some.

It is fortunate, therefore, for our attempts to understand caves and karst that natural waters are much more commonly undersaturated than saturated so that the kinetics of the corrosion process governs the situation mainly, both in time and space, namely the rate at which limestone coming into solution in a thin skin of water at the rock surface is carried away into the main stream that removes it altogether. This mass transfer varies

- directly with the difference between the solute concentration in the main waterbody and the saturation concentration reached at the interface (which is controlled by the factors mentioned above)
- directly with the diffusivity of the solute, itself varying directly with temperature
- inversely with the viscosity of the solute but this in turn varies inversely with temperature
- directly with the velocity of the water
- with the nature of the flow, being greater with turbulent than with laminar flow

THE PROBLEM OF CAVERN FORMATION (Cont.)

- with the nature of the rock surface, whether it is rough or smooth, in open channel or in pipe.

Also where kinetics are in control, the rate of chemical reaction assumes importance and this doubles with every 10°C increase in temperature according to Arrhenius' law.

What generalities can be drawn from all this? Two points of great importance need stress. The prime factor is the amount of liquid water available; how much water is available matters much more than how much limestone can go into solution per unit volume. Water availability depends on the effective precipitation (P-ET) providing the autogenic water supply from the atmosphere above (Williams and Dowling 1979) and on the magnitude of allogenic water inputs from surrounding rocks. With small karst areas, which often are recessive in relief, this last can be of great importance (cf. Jennings 1977a). The second factor is biological activity; the more plant and microbial growth the more carbon dioxide there is available and this in turn depends on precipitation (P-E this time) and temperatures above those minimal for plant growth.

Two other kinds of corrosion need notice. The weathering of pyrites, found in some limestones but more significantly in interbedded shales, produces the strong acid, sulphuric acid, which attacks the limestone powerfully. Some caves owe much to this process but it is of local importance only. Some organic acids, such as fulvic and crenic acids, also act strongly on limestone and these are produced in more widespread fashion, in forest litter, for example, but more in association with bogs, swamps, marshes and mangroves. Unfortunately for our understanding of their role it is hard to disassociate the effects of organic acids from that of carbon dioxide produced at the same time from organic matter (Trudgill 1979) and from sulphuric acid generated by sulphur bacteria in peat (Bray and O'Reilly 1974). Their effects may therefore be restricted to a subcutaneous zone, though they have been thought to be significant in the formation of large blind shafts developed in limestone beneath sandstone covers with peaty soils. Few would think there is as yet evidence to support Jakucs' claim (1977) that in tropical rainforest karst organic acids are as important as carbon dioxide in limestone corrosion.

That large caves have been created by corrosion at great depth, commonly in a water-filled condition from their detailed morphology, presents a problem of process because of the exhaustion of carbon dioxide with its surface sources. Again the rare exception has ready explanation - there are caves formed by hydrothermal waters from below such as in Zbrasovska Aragonite Cave at Hranice in Moravia; the hot water contains much CO_2 but there are other corrosive constituents. The general occurrence has engaged the attention of Bögli (i.a. 1964) particularly and in his view the main factor is mixing corrosion, which depends on the exponential relationship between $CaCO_3$ saturation equilibrium and P_{CO_2} (Fig. 1). When two flows of water, both saturated but at different partial pressures of carbon dioxide, mix, the mixture

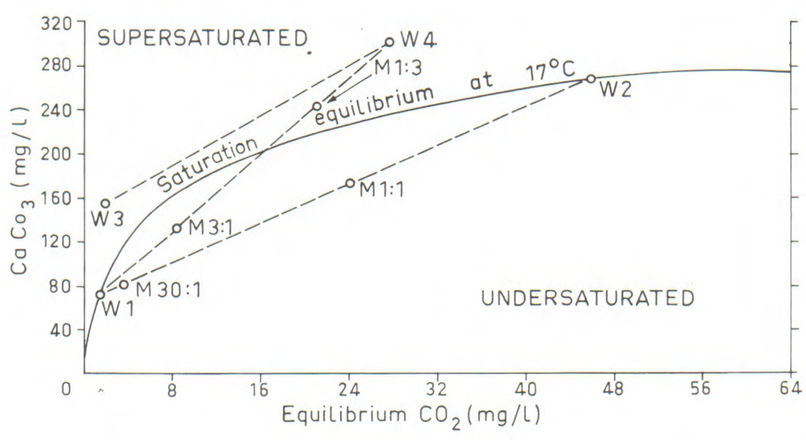


Figure 1 Mixing corrosion (after Bögli and Thrailkill). Mixing of saturated waters W1 and W2 in any proportions yields aggressive water but M 30:1 (30 parts W1 of low P_{CO_2} with 1 part W2 of high P_{CO_2}) is more aggressive than M 1:1, an equal mixture of the two. No mixture of supersaturated waters, W3 and W4, will become aggressive. M1:3 (1 part saturated W1 with 3 parts supersaturated W4) remains supersaturated but M 3:1 (3 parts W1 with 1 part W4) becomes aggressive.

THE PROBLEM OF CAVERN FORMATION (Cont.)

is undersaturated and capable of fresh solution of limestone. This can be the result of the meeting of downwardly infiltrating autogenic water, saturated at high concentration, with allogenic cave stream water, saturated after its underground transit but at lower concentration. Bögli pointed also to cooling corrosion; thus in summertime, water heated at the surface may be cooled as it penetrates underground because cave walls are conservative of heat. This cooling will render previously saturated water aggressive once more. Another source of renewed aggressivity lies in the mixing of waters with different magnesium carbonate contents (Picknett 1972). Another localised effect is where stream currents carry air bubbles into water-filled passages when in descent they are compressed, increasing the partial pressure of carbon dioxide. This can produce a central roof channel (Bögli 1978). Finally one can point again to the transport of organic matter into cave depths, whereby decay produces carbon dioxide. This proceeds faster in the presence of oxygen but some micro-organisms digest organic matter anaerobically so this action can take place in water-filled cavities.

From this discussion it is evident that rates of cave corrosional enlargement will vary tremendously in place and over time and that these will be best obtained by determining the time it has taken whole caves or parts of caves to form, i.e. by speleochronology. Measurements of present day rates of enlargement are valuable, nevertheless, but few are available. Those of the longest term-over a few years - are from caves in Clare, western Ireland, where High and Hanna (1970) used the micro-erosion meter to determine floor lowering in inflow caves of 0.25 mm/year and in outflow caves of 0.17 mm/year.

(2) CORRASION. In early cave study, mechanical stream work was overestimated because many of the features associated with it - waterfalls, rapids, gorges, meander undercuts, plunge pools, swirlholes (i.e. fluvial 'potholes' or rockmills) - were prominent in the active river caves most frequently explored then. Later it suffered prolonged neglect in favour of the less obvious but more distinctive chemical attack. Nevertheless all aspects of mechanical erosion come into play in caves - impact, cavitation, abrasion, attrition - and as for the most part, there is no difference between their underground and their surface operation, they need little discussion here, except to point out that since caves fill up like pipes, water moves uphill under hydraulic head as well as downhill under gravity so this mechanical work can be carried to roofs as well as walls and beds.

Calcite is a soft mineral and clasts of limestone wear out quickly through attrition, apart from their susceptibility to solution. Therefore there can be a dearth of large tools in cave rivers, though the fine insolubles will constitute some abrasive material. There are, however, sometimes chert and flint nodules in limestones to yield up and cave breakdown may maintain a supply of limestone blocks. Where there are allogenic inputs from neighbouring insoluble rocks, no lack may develop if the caves are of no great length; thus at Cooleman Plain, New South Wales, igneous gravels run right through the systems.

In recent years, when much effort has gone into measuring rates of chemical denudation in karst, only a few attempts have been made similarly to quantify corrasion. The most notable are those of Newson (1971) working in the Mendip caves in England. Elaborating a lead by the famous French cave explorer, Pierre Chevalier, Newson exposed tablets of limestone in cave streams caged in nylon of varying mesh, the finest mesh excluding any corrasion but permitting corrosion, the intermediate allowing sand and silt to abrade, whilst the coarsest exposed the rock to gravel. Much greater weight loss was suffered by the tablets in the two meshes allowing mechanical attack. Jennings (1977b) performed the same exercise over longer term in River Cave, Cooleman Plain, New South Wales, and determined that the tablets lost about as much from mechanical as from chemical attack.

A more comprehensive approach is to measure the solid load as well as the solute load emerging from a cave and this Newson (1971) did for cave springs at Cheddar and Burrington in the Mendip. He found that corrosion was overall more important than corrasion; only in floods was more solid load carried than dissolved. Nevertheless the importance of floods in caves must not be underestimated; an exceptional storm in the Mendip in 1968 made drastic changes to some of the caves; in G.B. Cave speleologists familiar with it were amazed by the changes wrought.

(3) CAVE BREAKDOWN. By cave breakdown the caver understands the breaking away of large bedrock fragments from roof and walls, especially common when passages and chambers get large. It largely corresponds with the dry rockfall and dry rockslide categories of surface mass movements. This is not solely an effect of gravity, aided by the solutional freeing of blocks, and a response to lithostatic load, but also a yielding to tectonic stresses which modern measurements reveal are widespread. Except at depths rarely reached in caves, limestone yields elastically, not plastically, i.e. it fractures. It seems possible that unequal disposition of tectonic stresses may favour development of caves along certain belts within a limestone plateau (Renault 1970). More patently unloading of pressure by surface erosion along valleysides allows release of tectonic stress in the form of sheeting joints more or less parallel to the slopes (Fig. 2). This can lead to the preferential development of caves roughly parallel to valleysides, e.g. Wyanbene Cave, New South Wales,

THE PROBLEM OF CAVERN FORMATION (Cont.)

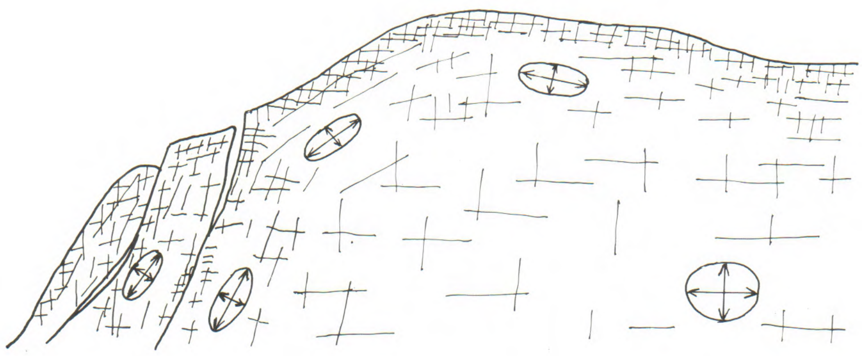


Figure 2 Offloading of valleyside by erosion to cause sheeting joints (after Renault). Distribution of stresses indicated by ellipsoids.

Likewise, when a cave approaches a valleyside more or less at right angles, it is liable to deflection for the same reason and break up into several passages, e.g. Murray Cave, New South Wales.

Loss of support of roof and walls when a cave ceases to be filled with water is commonly cited as a time when cave breakdown will be particularly likely (Davis 1930).

Within a given cave, breakdown resulting from release of stress at its surfaces frequently produces barrel-arched roofs and domes. This may be the net result of many little fractures along joints and bedding planes, e.g. in the Nullarbor Plain caves in Australia, or at greater depth through onion-skin sheeting parallel to the cave surfaces, e.g. the Gross Badlhöhle in Austria (Trimmel 1968).

Cave breakdown cannot enlarge a cave except in conjunction with a stream removing some of its products because rockpiles occupy greater volume than the space the undisturbed bedrock occupied; otherwise the blocks would accumulate to the roof preventing further such action. However, when fallen rock is removed by water transport and erosion, breakdown may stope upwards until the roof falls in, creating a collapse doline at the surface. This can proceed to the total destruction of a cave; indeed some limestone gorges are of this origin, e.g. the Rak valley, Slovenia, though the majority are of surface origin.

(4) WEATHERING. The equable climate of most caves minimises many kinds of rock weathering there but they do not escape all. In cold climates frost shattering may penetrate appreciable distances into caves (as well as creating shallow caves, e.g. in the Nahanni karst, Northwest Territories, Canada); entrances and nearby chambers are enlarged by this mechanism, e.g. in Eisriesenwelt Cave, Austria.

More widely reaching is salt crystallisation. Gypsum in particular shatters limestone as it crystallises in pores or cracks on rock surfaces. This occurs on its largest scale in dry climates where there can be more of the evaporation necessary for $CaSO_4$ saturation and here halite crystallisation can also be important. This kind of weathering is well expressed in Nullarbor Plain caves, where barrel-arched roofs and domes on a medium scale, along with large honeycomb weathering and tafoni, are produced in this way. This most remarkable feature is The Dune 9 m high in Mullamullang Cave, built of detritus from salt crystallisation.

Many other kinds of cave weathering, including biological, but with lesser import, occur.

(5) SUBSIDENCE. This term is more commonly applied to a complex process of mass movement affecting surface sediment and soil in karst but there is no substantial difference between this and similar movement down solution enlarged fissures into caves. Flowing, sliding and slumping of mixed materials from clay to limestone blocks into caves is an important mechanism there as Pengelly (1864) showed for Devonshire caves at an early stage in cave science, though it has received inadequate attention since.

(6) DEPOSITION. Fluvial deposition of clastic sediments from gravel to clay sizes is an important mechanism in cave development also, affecting the course and pattern of bedrock enlargement (Renault 1967-8). Here this must be neglected in favour of the more distinctively spelean process of calcite deposition of the most varied nature and dimensions (White 1976). The formation of stalactites, stalagmites and other speleothems is still attributed to evaporation and this is true in cave entrances and also farther into caves in dry climates (Jennings and Sweeting 1966). However the

THE PROBLEM OF CAVERN FORMATION (Cont.)

dominant cause of supersaturation is diffusion of CO_2 from drips and water films into the cave atmosphere. Soil water in equilibrium with soil air rich in CO_2 passes into a closed system of water-filled, narrow cracks in the bedrock; there much limestone goes into solution, often approaching saturation; then on entering cave spaces, where the partial pressure of CO_2 commonly departs little from that of the open atmosphere, restoration of equilibrium between water and air requires this diffusion.

This happens in active free surface stream passages but the resulting speleothems are liable to destruction, both mechanically and chemically in floods. In passages abandoned by streams, accumulation may continue unhindered to the point of complete choking of passages.

HYDRODYNAMIC DOMAINS

Although there is interplay between these cave processes, far more than has been indicated above, the most important role is played by water and so the different conditions for water to operate underground are of critical importance. In this there is a big difference between the vadose and the phreatic condition; in the latter, voids are permanently filled with water whereas, in the former, air and water occupy them in a manner varying complexly in time and space. After wet weather or in wet seasons, the amount of water stored underground increases and the phreas invades the lower part of the vadose zone; the resulting transitional zone is of great speleogenetic significance. The oscillating interface between the two zones is called the watertable in hydrology; there is, however, serious liability of misunderstanding if this term is applied to karst regardlessly. The same applies to the alternative term, piezometric surface. Water rest level is a neutral term which can be used in karst hydrology without prejudging answers to questions that need careful resolution, answers which may indeed condemn the use of these other terms in specific karst contexts.

(1) VADOSE SEEPAGE. At the surface, water infiltrates into the bedrock, either directly in alpine, polar and arid climates (and in anthropogenically denuded terrain) or through the medium of soil and superficial deposits. If the limestone has much intergranular or primary porosity, percolation can take place areally. Such primary permeability is found, for example, in dune limestones, which are largely joint free, but even here preferential seepage, perhaps under root guidance, soon develops, and soil-filled solution pipes begin to diversify the soil-rock interface. More commonly, limestones have little primary porosity; joints (and bedding planes where the rocks are dipping) concentrate downward seepage along lines or at points such as joint intersections (secondary permeability). In consequence fissures and shafts (karst 'potholes') are formed both in bare and covered karst (Fig. 3). With the latter they are generally filled with debris from the surface but as dolines develop which concentrate water at their low points by overland flow, throughflow, etc., the enlarged joint may be kept open.

Initially flow will be laminar, in the tight joint filling the narrow space or down the two faces when they widen. As the routes enlarge and inputs more concentrated into them, turbulent flow will take over. Since CO_2 from the atmosphere or from soil air dissolved in the water will be progressively used up in corrosion, the vertical features will close up downwards. This should still apply even if organic matter is washed in which renews the water's capacity to dissolve the rock.

Nevertheless many shafts and fissures enlarge downwards so it has been argued that these were developed from below upwards by water which precolated through a tight joint before it began to enlarge its routeway (Maucci 1960). Developing upwards, a shaft may narrow in this direction, the lower the wall the longer it has suffered corrosion. In support of this concept is the occurrence of many blind shafts, which reach upwards near to the surface but don't break through to it. The presence of a cave below to act as a starting point for vadose seepage shafts makes this mechanism more feasible.

(2) THE NOTHEPHREAS. A cave is usually defined as an underground cavity penetrable by human beings. Though segregating our modes of investigation, this anthropomorphic limit has no natural significance and generally there is much more interconnecting void smaller than greater than it in limestone. A natural limit is to be found in a diameter of about 5 mm for circular tubes, below which flow is laminar but above which flow may be either laminar or turbulent (White and Longyear 1962; Howard 1964). Here is also a chemical threshold, a critical level of aggressivity beyond which corrosion proceeds much faster, about 7 times according to White and Longyear.

Though some limestones of high primary porosity may provide tiny interconnecting tubes permitting laminar water movement through them, this is not the case with most and neither tectonic activity nor erosional unloading will provide open, interconnecting joints to permit it. The beginning of cave development therefore is attributed to a state of water saturation, in which slow laminar motion gradually creates interconnecting systems of tiny tubes that fork and rejoin many times. These frequently develop in planes of weakness and become bedding plane and joint anastomoses (Bretz 1942). In rocks of high primary porosity, they may develop in all directions, e.g. White Wells Cave, Nullarbor Plain. Insolubles

THE PROBLEM OF CAVERN FORMATION (Cont.)

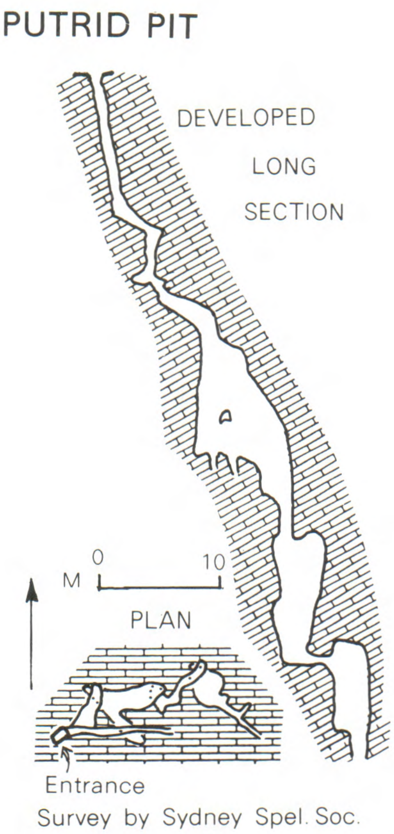


Figure 3 Putrid Pit, Bungonia Caves, New South Wales. Open shaft cave in joint planes due to vadose seepage solution.

may accumulate on the lower side of a plane of weakness, inhibiting solution there so that half-tubes develop rather than tubes. Earth tides may play a big part by pumping water through tight planes of weakness to initiate through movement (Davies 1966); joints have been shown to dilate and contract with appropriate periods for this in caves in Hungary and the United States.

When tubes pass the critical size, turbulent flow may take over but if velocities remain small through lack of hydraulic head, further enlargement may not change its style drastically. The result can be spongework - irregular interconnecting cavities, which are either symmetrical (Fig. 4) or if systematically asymmetrical this reflects structural control. The Boneyard in Carlsbad Caverns, New Mexico, provides an example in large dimensions. Alternatively network mazes of joint and bedding plane controlled passages may develop, e.g. Cameron Cave, Missouri. Rock pendants are another cave form characteristic of these hydrodynamic conditions. These smoothly moulded projections from roof or upper walls can be of large dimensions, e.g. in Ryan Imperial Cave, Chillagoe, Queensland. Smaller rock pendants ending in flat surfaces at a common level have found two explanations, which probably imply form convergence rather than contradiction. In the one the flat surfaces belong to one side of a plane of weakness, the other side of which has been completely removed by breakdown. In the other, aggradation has confined slow flow against the roof of a passage and this has resulted in anastomosing phreatic solution deep enough to give pendants (Bretz 1942). This is one kind of paragenetic cave development of Renault (1967-8).

Caves developed in this domain can become large yet with no connection of penetrable size to the surface; the magnificent Ochtinska Aragonite Cave in Slovakia was encountered in mining.

Slow flow characteristic of this domain of cave development corresponds in large measure to Darcy flow through

THE PROBLEM OF CAVERN FORMATION (Cont.)

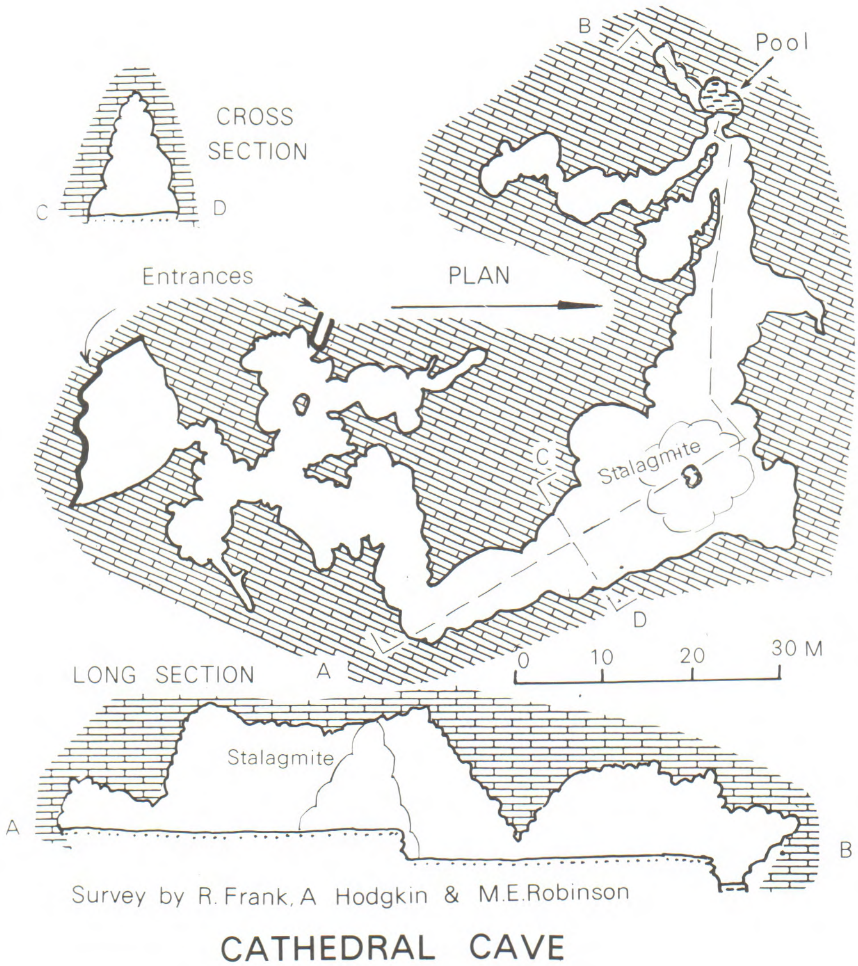


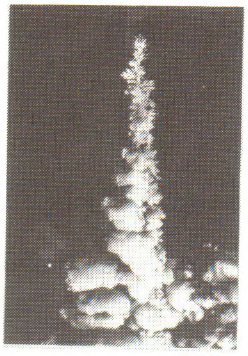
Figure 4 Cathedral Cave, Wellington, New South Wales. Cave largely due to solution in a water-filled state with slowly moving water producing symmetrical hollowings on roof and walls. Bedrock floor buried beneath fine clastic sediment.

sands and gravels and is to be measured in a few metres per day, whereas with the following domains it is rather a matter of hundreds of metres per day. It is the diffuse flow of White (1969). The domain is also called the deep phreatic zone but it can occur near to the surface and be of narrow vertical dimension, e.g. in dune limestone caves near Augusta, Western Australia. Glennie (1958) argued that phreatic should be restricted to this zone and not extended to others where pipe flow with much larger Reynolds Number takes place, since phreatic has Darcy flow connotations. His plea has gone unheeded. Therefore the present author (1977) has put forward the term nothephreatic for it.

(3) THE DYNAMIC PHREAS. Slow flow permits the co-existence of numerous interweaving routes but if there is sufficient hydraulic head to drive water through at speed, a few or a single route will grow at the expense of the others (Ewers 1966). It is a self-promoting effect; as a tube gets larger, the frictional loss of energy against the cave surface becomes smaller in relation to the total loss and velocity increases; as velocity increases, mass transfer of solute from that surface is enhanced, enlarging the passage further and velocity also. In the roof of the Grand Arch, Jenolan Caves, New South Wales, a large solution half-tube can be seen meandering through a large area of roof pendants, all in a bedding plane; the development of this passage must have reduced movement through the neighbouring pendants greatly.

Speleo Prints © A **great** way to fill a wall!

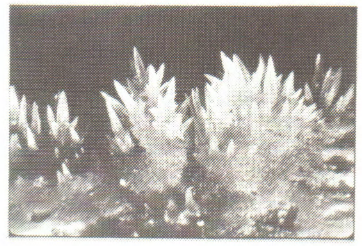
Poulter's Speleo Prints. P.O Box 120 Nedlands, Western Australia, Australia 6009


TV5

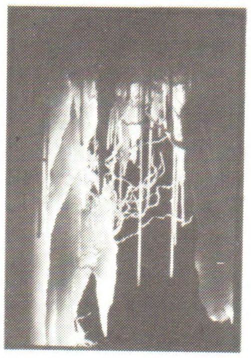

TV1

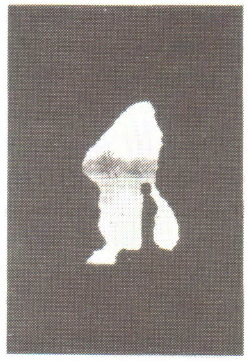

TV7

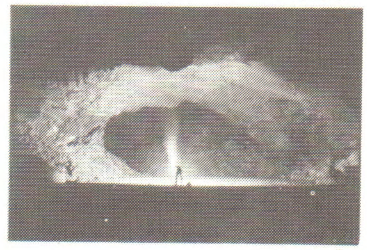

WH4


WH5

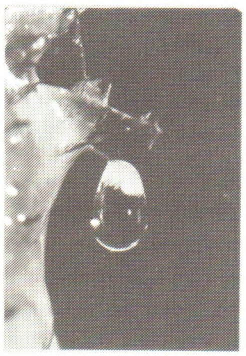

TV3


WV3


SV1


WH7

The Speleo Print range, reproduced here, are but a poor mirror of the actual Prints, which are all in superb COLOUR.


WV1

Speleo Prints are now available in two sizes,
20 x 25cm for $10.00
51 x 61cm for $21.00⁺
⁺(six times the size for about twice the price!!)

The smaller size are posted flat, while the larger size are sent rolled in a heavy duty tube - maximum of four per tube.

All Prints are guaranteed undamaged to the point of departure.

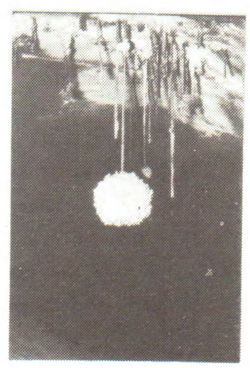

WV2

Postage costs

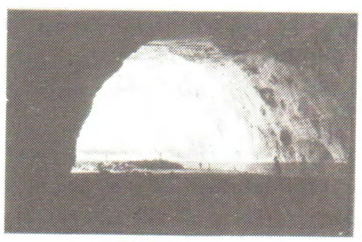
West. Aust. - rail 80c
East Coast - rail 90c, Airmail $1.35
Overseas ---- surface $1.00, SAL $4.00, Airmail - Europe $6.90
USA $6.30

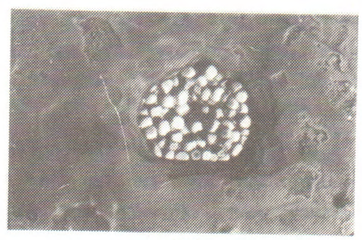
Postal Insurance is an additional $2.00

All prices quoted are in Australian Dollars and are subject to change without notice.


TV4

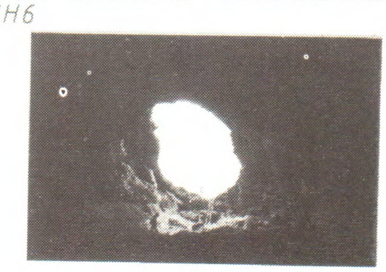

TH6


NH2


WH6


NH4


NH1


NH3

Each Speleo Print comes with a self adhesive title block and mounting suggestions

NOTICES AND NEWS

CAVE CONVICT is not only coming, it's nearly here! Registration forms are available from the secretary of your club/society. These forms have been sent out to all member clubs and societies. Help the CAVE CONVICT Committee and register as soon as possible. Some details are below:-

The thirteenth bi-ennial conference of the Australian Speleological Federation will commence on Saturday 27th. December, and continue to Wednesday 31st. December, 1980. The Conference will be conducted at the Pharmacy College, Parkville. The accommodation is at International House and the Speleosports will be held at Princes Park. All venues are within walking distance of each other. Living-in at the Conference should be considered a vital part of it, as it means meeting other cavers in an informal atmosphere and freely participating in the evening social activities.

The photographic competition will be conducted along similar lines to that of preceeding Conferences, except for one important point. The entry does not have to have been taken since the last Conference. Black and white prints must be a minimum of 20 x 25cms, mounted and colour prints a minimum of 12.5 x 17.5 cms, mounted. Slides should preferably (but not necessarily) mounted in glass.

CAVING EQUIPMENT AWARDS

At CAVE CONVICT, Caving Equipment propose to award two $50 open orders for the funniest (or most humorous) article or cartoon and the "best" map published in Australian speleological literature. Caving Equipment wishes to improve the interest and standards of club/society newsletters and journals. They feel that by offering these awards, they will be doing something positive to encourage more stimulating articles and improve surveying and mapping standards. Some suggestions for criteria of the "best" map are survey grade (the higher the better), closure accuracy, completeness (plan, long section and cross sections), adherence to ASF survey standards, presentation, drafting and quality of printing. Low grade sketches on blotchy stencils are not going to win! Some consideration will be given for the longer and deeper the cave. Send your nominations to the CAVE CONVICT Committee. Address below.

NOEL PLUMLEY PHOTOGRAPHIC COMPETITION

The ASF Committee has accepted this competition on the proviso that the copyright on the photograph remains the property of the photographer. The competition is to held bi-ennially to encourage an interest in biospeleology and an awareness of cave ecology. A cash prize will be awarded to a photograph (laboratory shots will be allowed) of any form of cave flora or fauna of Australia, Papua-New Guinea or New Zealand, which is adjudged to be of outstanding biospeleological interest and photographic excellence.

Conditions of entry

1. The entries must have been taken since the end of the previous Conference of the Australian Speleological Federation.
2. No more than two entries per person.
3. Entries must be in 35mm slide form.
4. Details must supplied with each entry :- Identification of depicted specimen(s) if possible, date of collection/photography, name and location of cave, collection/photographing point in cave, name and address of collector/photographer, exposure details and other pertinent technical details and any other features of interest.
5. The definition of the word "cave" will be at the discretion of the ASF Committee.
6. If none of the submitted entries are, in the opinion of the judge, to be of a satisfactory standard, a winner will not be chosen and the prize money ($100) will accumulate until the next competition.
7. The decision of the judge will be final.

The judge is to be appointed by the conference organizing Committee, to be of an impartial nature, and preferably a professional photographer with some knowledge of cave and/or biological photography.

Send your entries to the CAVE CONVICT Committee, (Clearly marked Australasian Cavelife Photographic Competition)
G.P.O. Box 5425 CC,
Melbourne, Vic., 3001.

THE PROBLEM OF CAVERN FORMATION (Cont.)

In this way pressure conduits come to play a greater and greater role in the water movement and so of cave development. Circular or elliptical in cross-section, according to whether planes of weakness in the rock exert a strong influence or not, but with solutional attack on all surfaces, these conduits may rise and fall because they are under pressure head. Both in plan and profile, they are liable to structural control however; Ford (1965) pointed out, for example, how in steeply dipping beds, Mendip caves such as Swildon's Hole have former pressure conduits repeatedly alternating between longer, gently inclined downdip tubes in bedding planes and shorter steep chimneys in joints.

Pressure tubes characteristically have smoothed surfaces but these may alternatively carry current markings of the scallop type; these are asymmetrical hollows with a crescentic steeper upcurrent side and a gentler downcurrent one ending in a point because of intersection with neighbouring scallops. If these are on lower walls and floor only, they may be due to later vadose flow modelling but when found on high walls and roofs, it is evident that they developed during dynamic phreatic flow. Similarly although solution is dominant at all times, velocities are frequently great enough to carry abrasive materials through, even above sand size, and corrasion can contribute to their formation.

Fluvial deposition takes place in them, influencing the further course of enlargement. Whether cave breakdown plays a similar role in this domain is a matter to which little attention has been paid. In some deep caves of the Nullarbor Plain massive breakdown extends into phreatic parts but this has so far been attributed to periods of lowered water rest levels during Pleistocene glacial low sea levels (Lowry and Jennings 1974).

It has already been emphasized that at the top of the phreas there are passages alternatively subject to vadose flow at lower discharges and to dynamic phreatic flow at higher discharges. This, together with the top part of the phreas proper, is regarded as a zone of particularly effective speleogenesis by many investigators (Sweeting 1950; Davies 1953; Moore 1960). Velocities are likely to be great here because routeways to the outflow points (the Vorfluter, a German term misunderstood by some English-language workers (Bögli 1978)) are the most direct and involve least undulation. There is also more likely to be undersaturation and most opportunities for the renewal of corrosive power in the ways already discussed. More or less horizontal caves at and just below the level of the springs are the product, e.g. the caves of the R. Ourthe, Belgium (Ek 1961). Flat solution roofs are typical, e.g. the Punchbowl, Signature and Dogleg Caves system at Wee Jasper, New South Wales (Fig. 5). The caves developed in this transitional zone between vadose and dynamic phreatic

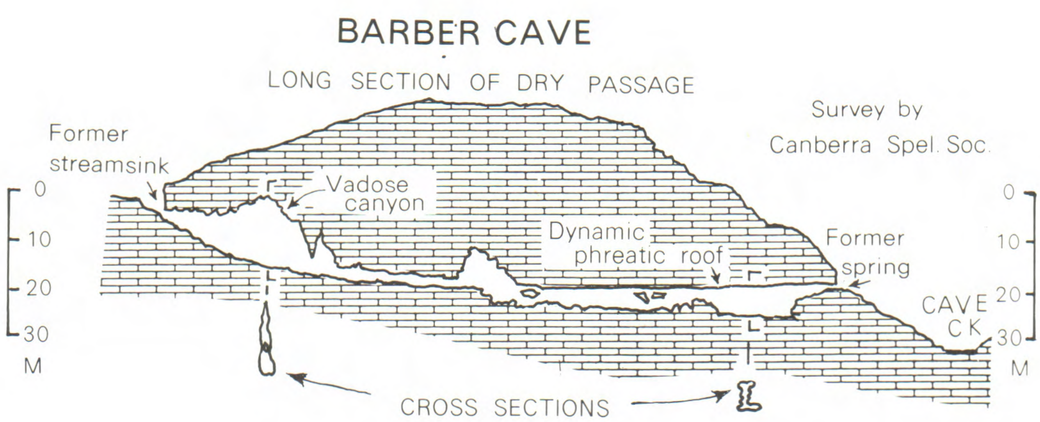


Figure 5 Inactive passage of Barber Cave, Cooleman Plain, New South Wales, Upper part dominantly a vadose flow canyon; lower part an epiphreatic cave modified by vadose flow.

THE PROBLEM OF CAVERN FORMATION (Cont.)

zones have been variously named: 'water-table stream' (Swinnerton 1932) has the disadvantage already mentioned that many karst hydrologies do not justify this term at all; 'shallow phreatic' (White 1960) has the disadvantage that such development can occur at great depth beneath the surface, it is only the vertical amplitude of the action which is intended; 'epiphreatic' (Glennie 1958) has the appropriate eytmological derivation with no misleading overtones.

Despite the importance in many caves areas of the epiphreatic type of cave, there would have been much less controversy between the protaganists of vadose and phreatic cave development if other kinds of dynamic phreatic action did not also loom large in the overall picture of cave evolution. Ford and Ewers (1978) present a penetrating analysis in this direction, recognising three states between the nothephreatic and the epiphreatic (Fig. 6).

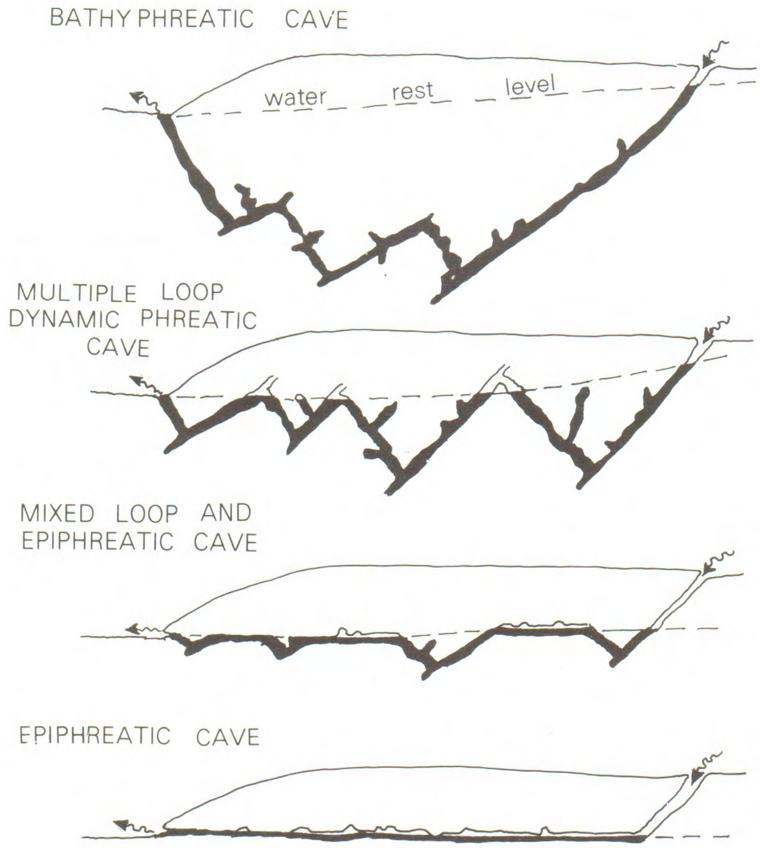


Figure 6 Four states of dynamic phreatic caves (after Ford and Ewers). See text.

(a) The bathyphreatic. Davis (1930) was the first to point to the possibility of caves developing to great depth because groundwater has the capacity to descend under pressure head to considerable depth and rise back much of the way to emerge at the surface. For this he was relying on Darcy law hydrology, which applied to primary permeability, whereas most karst depends mainly on secondary permeability in pipe flow obeying different laws. Nevertheless caves which flow such courses are now known, partly through the boldness of cave divers. Thus the Fontaine de la Vaucluse in southern France rises up a smooth pressure tube of some 15 m diameter from a water depth of more than 100 m. In the Sierra de El Abra in eastern Mexico, such a system but now relict loops downwards more than 300 m (Fish 1978). It is not sufficient to have a great thickness of pure limestone, mechanically strong and of great depth, in high effective precipitation, for such bathyphreatic action. Ford and Ewers maintain that widely spaced planes of bedrock weakness are also necessary, though what joints or bedding planes there are may be extensive. The El Abra caves are in massive reef limestones. Steeply dipping beds also favour this kind of hydrology, provided the tectonics involved have not increased joint frequency unduly.

(b) The multiple loop phreatic. With greater frequency of planes of weakness, a sequence of loops develop below water rest levels. Ford and Ewers cite the Hölloch in Switzerland, the second longest cave in the world. Many but still substantial

THE PROBLEM OF CAVERN FORMATION (Cont.)

loops make up this system.

(c) The mixed loop and epiphreatic. Ford's study (1965) of Swildon's Hole in the Mendip provides the type case for this condition. Some horizontal passages form, linking the lower parts of phreatic loops; these are called bypass tubes.

(4) VADOSE FLOW. The enlargement of phreatic caves will entail a lowering of water rest levels (assuming a uniform water supply) so that a vadose zone is created. The gathering of seepage waters to form underground streams is not the only source of autogenic vadose flow; as closed depressions grow at the surface so will autogenic streamsinks appear. However vadose flows will also derive substantially from surrounding and inlying impervious rocks - the allogenic contribution; these streamsinks often accompany blind valleys and poljes, many of which are partly walled and/or floored by impervious rocks.

Vadose flow operates only under gravity and so there is a strong vertical component in this circulation; nevertheless in most circumstances the horizontal component is the greater. With vadose streams corrasion can be actually as well as visually important as discussed above so erosional forms characteristic of surface rivers come to the fore. River canyons are cut in the floors of former pressure tubes and these may exhibit sequences of curved channel incuts in their sides. Ford and Ewers (1978) term caves where vadose streams inherit and modify phreatic passages in this sort of way drawdown vadose caves; such is G.B. Cave in the Mendip (Ford 1964). Vadose canyons will entrench the tops of phreatic loops as drawdown occurs, helping to convert caves in the multiple loop state into the mixed state described above.

To be distinguished from them are the invasion vadose caves of Malott (1937) where vadose flow has developed along small routeways due to vadose seepage and early phreatic solution. In these, vadose characteristics dominate and mainly vertical caves are the most likely to reach this state.

A vadose cave necessarily assumes a branchwork plan, resembling a surface stream system in plan, though its active passages may comprise only a part of an inherited phreatic network. In addition, since a cave stream is confined and has no flood plain over which to dissipate flood discharges, it may well maintain in intermittent action higher level passages as flood overflows and so a three-dimensional braiding system persists. Therefore there can be no easy distinction between phreatic and vadose nature of caves by simple examination of cave plans.

In the vadose caves, breakdown, subsidence and weathering come fully into action. Also deposition of their products and those of corrosion (speleothems) and of corrasion not only contribute directly to the cave morphology but also modify further bedrock excavation in ways too manifold to venture upon here (see Renault 1967-8).

FACTORS IN CAVE EVOLUTION

To identify the main spelean processes and the domains in which they operate is only to note the ground rules for cave evolutions which have all the complexities of games of chess. It is impossible here to do more than indicate some of the factors at work to produce the kaleidoscopic variety of the underground.

The tectonostatic geological framework (Tricart 1974), on which the active agents operate, conditions them in turn to a degree far greater than previous discussion has suggested, despite much reference to the nature and density of planes of weakness. Fissuration, as the French call this, is crucial to the development of most limestone caves and innumerable writings have been devoted to the relative roles of joints and bedding planes (e.g. Bögli 1969). It must suffice here to refer to Ford (1970, 1971a) who has attempted the highest level of generalisation in this regard. The role of faults is conflicting, sometimes their influence is small. However, at Bungonia Caves, New South Wales, more detailed mapping (James and others 1978) revealed previously unknown faults, which gave answers to unresolved speleogenetic issues and disproved some earlier interpretations (Jennings and others 1972).

In the discussion so far there has generally been the implicit assumption that limestone is the bedrock, with or without soils and superficial deposit as cover. This is by no means always the situation in karst as the example of the huge Flint Mammoth Caves system reminds us with its overlying sandstone (and locally shale) several tens of metres thick. These overlying strata have localised much of the water input near and at their margins and saved the cave system from more dismemberment than it has suffered, almost divided as it is into the Flint Ridge, Mammoth Cave Ridge and Joppa Ridge sectors (Quinlan 1970). Palmer (1975) also argues that diffuse input from the sandstone has resulted in a maze of solution passages.

Effects of this subjacent condition are inevitably greater when the rocks are folded and hydrostatic pressure forces water down the limestone deep under an aquiclude. Such an artesian condition is incapable of being explored and resort must be had to drained systems relict from this special hydrodynamic domain. At depth it becomes nothephreatic and White (1969) describes the product as three-dimensional network caves inclined down the beds. In so far as much limestone is impermeable, i.e. it lacks primary permeability, many limestone caves may take on something of an artesian character in their phreatic sections (Glennie 1954), provided there is substantial dip. Ford and Ewers (1978) point to the contrast between cave systems in flat-lying strata where epiphreatic systems predominate and those in steeply-dipping beds where the

THE PROBLEM OF CAVERN FORMATION (Cont.)

bathyphreatic and multiple loop systems are more frequent. They go on, however, to consider that, in tight, isoclinal folds, high joint frequency may be induced so that here again the epiphreatic predominates. This is probably one of the factors causing the poverty of New South Wales karsts in deeply looping caves (Jennings 1977a). It is relevant to note that Cailleux and Tricart (1956) found in a statistical analysis of dips that there are three modes corresponding with these three categories of geological structure.

The geological frameworks in which karst processes operate have their tectonodynamic aspects as well; earth movements take place during the time that caves evolve. The caves of Mount Hoyo in eastern Zaire are of dynamic phreatic nature, though inactive and opening out some 300 m up a fault scarp. The fault has moved since the caves formed and there is only modest vadose modification of the phreatic character. Brook (1976) maintains that the Finim Tel caves, including the great Selminum Tel, in Papua New Guinea, formed as the high Hindenburg Wall hinged up along a fault in the late Pliocene and the Pleistocene, tilting back caves. Thus the higher relict caves now have gradients directed down to the former input points.

General epeirogenic uplift and depression affect cave development more widely but their effects resemble those of other factors such as glacioeustatic sea level change, which ranged from a few tens of metres above sea level to more than 100 m below repeatedly in the Upper Pleistocene. The lowering permitted cave development below sea level in coral reefs, e.g. in the Bahamas (Dill 1977) and in aeolian calcarenite, e.g. in the Bahamas (Bretz 1960), which was subsequently drowned in the Holocene transgression. It is also thought that many of the submarine springs off the high limestone coasts of Yogoslavia, Greece and Turkey represent the mouths, not simply of bathyphreatic caves adjusted to present sea level, but of other kinds of cave developed when sea level was low.

High relative sea level can interfere in the evolution of caves also; thus the sea has pushed gravels into Kairimu Cave at about 100 m A.S.L. in the North Island of New Zealand and into Wet Neck Cave at about 60 m A.S.L. at Paturau in the South Island. To what extent these are due to interglacial high sea level and to epeirogenic uplift is as yet uncertain.

The commonest factor intervening in the evolution of caves is rejuvenation of drainage as a result of a negative movement of base level, whether this be sea level or a local temporary base level. Valley incision increases hydraulic head, energising underground water circulation. At Cooleman Plain, New South Wales, there are only two caves to be attributed to a phase of planation of the limestone prior to the cutting of gorges, to which all the larger caves are related (Jennings 1967). Incision incurs the substitution of a vadose regime for a phreatic one of one kind or another. Frequently it leads to multi-level caves, each level of which may exhibit that substitution. Such a sequence is most plainly exhibited where epiphreatic caves develop at each outflow level; the nine levels of the Demanovske Caves in the Low Tatra Mountains of Slovakia have been related to the terraces of the Vah R. and its tributaries. Another possibility is the abandonment of caves entirely, even in a nothephreatic state. The Cathedral Cave at Wellington, New South Wales (Fig. 3), is not quite so completely unmodified from this condition as is the Ochtinska Aragonite Cave in Slovakia. The Hölloch in Switzerland consists of a sequence of abandoned multiple loop cave passages and one active such level (Fig. 7).

With flat-lying beds sequences of levels in caves may be a simple expression of structure; the controversy about the Flint Mammoth Cave system is apposite here because both structural and rejuvenation explanations have been preferred for its five levels mapped as long ago as 1908. The last detailed study, however, by Miotke and Palmer (1972) firmly maintains that the main passages cut at a low angle across beds of varying resistance and are related to Green R. terraces going back well into the Pleistocene, dating now supported by palaeomagnetic determinations from the cave sediments by Schmidt.

Positive movement of base level leads to the filling up and even burial of caves with sediment so that our knowledge of such is likely to be less than for any other kind. Only when their contents are economically valuable are they likely to be excavated, though sometimes they are also microtomed by the quarrying of the surrounding limestone. Caves beneath a deep Tertiary valley fill were partially excavated in search of gold in the Canadian Lead at Gulgong in New South Wales (Jones 1940). This alluviation probably has its origin in epeirogenic movement but more commonly the filling of caves is associated with Pleistocene climatic change acting directly, not through sea level change. Baldocks Cave at Mole Creek, Tasmania, is partly filled with gravels washed from glaciers on the plateau above (Jennings 1967). The paragenesis of Renault (1967-8), whereby caves are stoped upwards by phreatic solution at the top of accumulating fills, is favoured in circumstances such as these.

Even without filling in caves, glaciofluvial and periglacial fluvial sedimentation may intervene in cave development; the big development of caves in the divide between the Mole Creek and Lobster Rivulet valleys in Tasmania is attributed by Jennings and Sweeting (1959) to the decanting of water from the flanks of gravel fans of this origin into the limestone to form invasion vadose caves. Glacial meltwater at the base of the Columbia Icefield in the Canadian Rockies is feeding the active part of Castleguard Cave and its inactive upper level ends against a plug of glacier ice (Ford 1971b). Permafrost inhibits cave formation within its zone and restricts it in the thin seasonally thawing layer above it but phreatic action still proceeds beneath it where geothermal heat keeps water liquid. The presence of gaps in the permafrost

THE PROBLEM OF CAVERN FORMATION (Cont.)

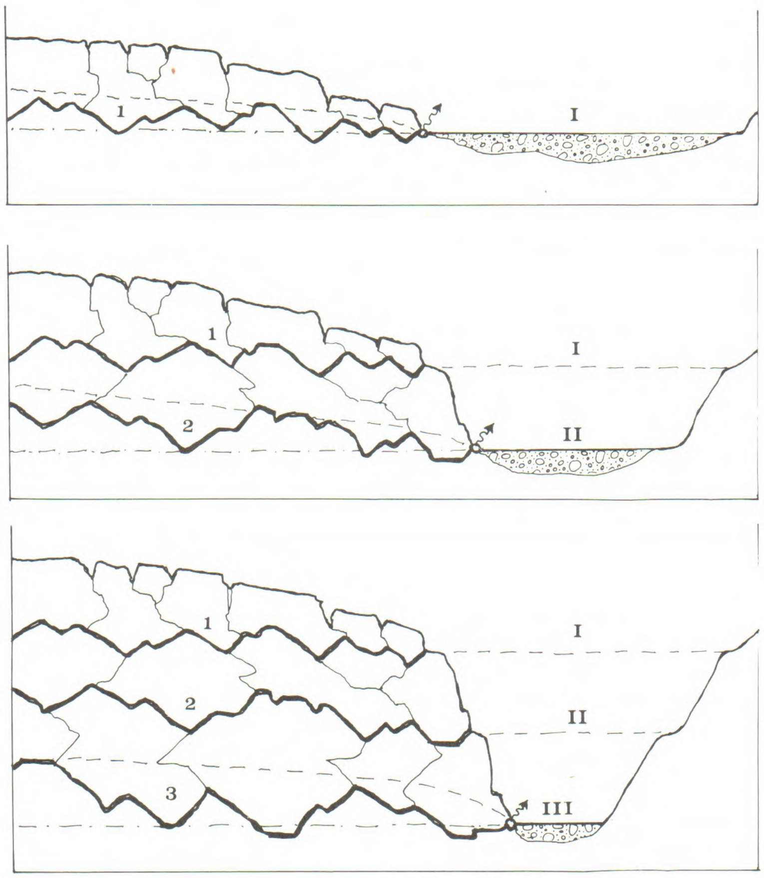


Figure 7 Development of an alpine karst cave of the Hölloch type (after Bögli). I,II,III = valley floor and outflow levels. 1,2,3 = cave evolution levels of multiple loop dynamic phreatic type.

(taliks) in Central Siberia allows phreatic water to burst up in large springs (Popov and others 1972); this pattern is bound to exert an influence on the pattern of cave development below.

Glacial erosion has alternated with karst action in many karst areas in the Pleistocene, making it hard for example to weigh their relative roles in the production of closed basins as in the Mt Owen Plateau in the South Island of New Zealand, which are part glacial erosion basins and part dolines. Caves lead off from these depressions so their history is involved as well. In the Craven karst of England, the recognition of glacial valley deepening, together with the exploration of new caves, has lead to significant revision of ideas about the cave development in general. Sweeting (1950) considered the main speleogenetic theme was in terms of successive levels of epiphreatic/vadose cave development in accord with Tertiary-Pleistocene fluvial valley deepening but in the light of the later knowledge, Waltham (1970) thinks that the valley deepening between the two main levels of caves about 90 m apart was due to glacier erosion in a glaciation earlier than the Weichselian.

Cases of climatic change affecting caves could be multiplied but the question remains whether there are any substantive differences between caves in different climates or whether it is a matter of the same processes operating in the same domains. This was the tenor of an earlier glance by the present author (1968) at this problem, since the differences mainly concerned deposits near the entrances and scarcely reached into the waterfilled parts, which are vital in cave development. Though their examples range widely in the world, Ford and Ewers (1978) did not bring in any climatic factors for their important generalisations. The question is, of course, beset by the perpetual problem of geomorphology that the factors involved are so manifold that the available array of cases may not be sufficient to disentangle them.

THE PROBLEM OF CAVERN FORMATION (Cont.)

Thus, whilst recognising many effects of geological structure, Lowry and Jennings (1974) attribute a dearth of caves in the Nullarbor Plain to a history of low precipitation since the area emerged from the sea in the middle of the Miocene. On the other hand, Williams (1978) thinks that this dearth may reflect lithology and relief rather than climate. To reverse the argument, one can point to a great difference in cave development in Oligocene-Miocene limestones not very much disturbed tectonically between those on the perhumid west coast of the South Island of New Zealand (Nile River; Paturau) and those on the much drier east coast (Craigmore; Mt Cookson). Effective precipitation may well exert a detectable control despite the complications of time and structure.

More difficult altogether is the question of temperature, though its net effect on corrosion must be a positive one. The fact that the longest and deepest known caves lie in mid-latitudes may well not be an artefact of intensity of application of Western science but one has a subjective impression that caves of large volume are proportionately more common in hot humid climates with such examples to mention as the cave near Koripobi in Bougainville, Solomon Islands (Parker 1970) and the Clearwater Cave in the Mulu in Sarawak (Brook and Waltham 1978). Ford and Ewers (1978) have similarly ventured a notion that epiphreatic and mixed systems will be relatively more numerous than bathyphreatic and multiple loop systems in the tropics, though they link this also with young limestones of high primary permeability and joint frequency. The Mulu Caves limestones have low porosity however (Wilford 1964). It may be some time before the intensity of cave exploration and mapping in the tropics will match that in the mid-latitudes to permit such speculations to be put to statistical test.

It will be as well, however, to end on lesser considerations more readily elucidated. Not all vicissitudes in cave evolution are due to large external factors. Thus the progress of cave preparation - in the sense of initial enlargement of planes of weakness by vadose seepage and nothephreatic action - alters by itself the parameters for cave development. If density of fissuration in this sense is critical to the hydrodynamic domains to be established, it follows as Ford and Ewers (1978) argue that there can well be change in cave style as time progresses from bathyphreatic caves, with early fissure infrequency, through multiple loops to epiphreatic caves when fissuration is dense. Again, there occur at a given level in a cave variations in style from vadose to phreatic. This association may be due to purely local factors such as big rockfalls and inputs of allogenic gravels, which block flow along roomy vadose passages and bring about mazes of even nothephreatic kind through deflection of it. Palmer (1975) proposes the first pattern occurs in Skull Cave, New York, and the second in Big Brush Creek Cave, Utah.

CONCLUSION

It has been necessary to confine this essay to limestone caves, though much of its content applies also to dolomite caves and some to gypsum caves. However, this restriction is unfortunate in a book intended primarily for use in India since much of India was part of Gondwanaland. This applies also to Australia and carbonate rocks are of limited extent in these ancient lands compared with countries built more of Mesozoic and Cainozoic rocks by the Alpine-Himalayan orogency. Consequently more attention proportionately has been given by Australian speleologists to lava tunnels, caves in laterite breakaways, weathering caves in sandstone and other rocks, and sea caves than is the case elsewhere. It is true that there is much limestone in the Himalaya so that India has an advantage over Australia in this respect. Preliminary cave exploration suggests, however, that some of the Himalayan limestones have behaved plastically rather than in brittle fashion and so joints, which promote cave development, are not numerous in them (Waltham 1972). So as speleology grows in India one can expect a greater interest in non-limestone caves than is at present common in European and N. American nations.

References

BÖGLI, A. 1964 : Mischungskorrosion - ein Beitrag zur Verkarstungsproblem. *Erdkunde* 18: 83-92.

BÖGLI, A. 1969 : Neue Anschauungen uber die Rolle von Schichtfugen und Klüften in der karsthydrographischen Entwicklung. *Geologische Rundschau* 58: 395-408.

BÖGLI, A. 1978 : *Karsthydrographie und Physische Speläologie*. Springer, Berlin

BRAY, L.J. & O'REILLY, P.M. 1974 : Preliminary oxidation studies in some waters from the Ogof Ffynnon Ddu system, Breconshire. *Transactions of the British Cave Research Association* 1: 75-84.

BRETZ, J.H. 1942 : Vadose and phreatic features of limestone caverns. *Journal of Geology* 50: 675-811.

BRETZ, J.H. 1960 : Origin of Bermuda caves. *Bulletin of the National Speleological Society* 22: 19-22.

BROOK, D. 1976 : The karst and cave development of Finim Tel. *Transactions of the British Cave Research Association* 3: 183-91.

BROOK, D.B. & WALTHAM, A.C. 1978 : *Caves of Mulu*. Royal Geographical Society, London.

THE PROBLEM OF CAVERN FORMATION (Cont,)

BURKE, A.R. & BIRD, P.F. 1966 : A new mechanism for the formation of vertical shafts in Carboniferous Limestone. *Nature, London* 210: 831-2.

CAILLEUX, A. & TRICART, J. 1956 : Le problème de la classification des faits géomorphologiques. *Annales de Géographie* 65: 162-85.

DAVIES, W.E. 1960 : Origin of caves in folded limestone. *Bulletin of the National Speleological Society* 22: 5-18.

DAVIS, S.W. 1966 : Initiation of groundwater flow in jointed limestone. *Bulletin of the National Speleological Society* 28: 111-9.

DAVIS, W.M. 1930 : Origin of limestone caverns. *Bulletin of the Geological Society of America* 41: 475-628.

DILL, R.F. 1977 : The Blue Holes - geologically significant submerged sink holes and caves off British Honduras and Andros, Bahama Islands. *Proceedings of the Third International Coral Reef Symposium, Miami, Florida* 2 Geology: 238-42.

DROPPA, A. 1966 : The correlation of some horizontal caves with river terraces. *Studies in Speleology* 1: 186-92.

EK, C. 1960-61 : Conduits souterrains en relation avec les terrasses fluviales. *Annales de la Société Géologique de Belgique* 84: 313-40.

EWERS, R.D. 1966 : Bedding-plane anastomoses and their relation to cavern passages. *Bulletin of the National Speleological Society* 28: 133-40.

FISH, J.E. 1977 : Karst hydrogeology and geomorphology of the Sierra de El Abra and the Valles-San Lius Potosi region, Mexico. Unpublished Ph.D. thesis, McMaster University.

FORD, D.C. 1964 : On the geomorphic history of G.B. Cave, Charterhouse-on-Mendip, Somerset. *Proceedings of the University of Bristol Speleological Society* 10: 149-88.

FORD, D.C. 1965 : The origin of limestone caverns: a model from the central Mendip Hills, England. *Bulletin of the National Speleological Society* 27: 109-32.

FORD, D.C. 1971a : Geologic structure and a new explanation of limestone cavern genesis. *Transactions of the Cave Research Group of Great Britain* 13: 81-94.

FORD, D.C. 1971b : Alpine karst in the Mt Castleguard-Columbia Icefield area, Canadian Rocky Mountains. *Arctic and Alpine Research* 3: 239-52.

FORD, D.C. & EWERS, R.D. 1978 : The development of cave systems in dimensions of length and depth. *Canadian Journal of Earth Sciences* 15: 1783-98.

GLENNIE, E.A. 1954 : Artesian flow and cave formation. *Transactions of Cave Research Group of Great Britain* 3: 55-71.

GLENNIE, E.A. 1958 : Nameless streams: proposed new terms. *Cave Research Group of Great Britain Newsletter* 72-7: 22-3.

HALLIDAY, W.R. 1960 : Changing concepts of speleogenesis. *Bulletin of the National Speleological Society* 22: 23-9.

HIGH, C. & HANNA, E.K. 1970 : A method for the direct measurement of erosion on rock surfaces. *British Geomorphological Research Group Technical Bulletin* 5.

HOWARD, A.D. 1964 : Process of limestone cavern development. *International Journal of Speleology* 1: 47-60.

JAKUCS, L. 1977 : *Morphogenetics of Karst Regions*. Hilger, Bristol.

JAMES, J.M. 1977 : Carbon dioxide in the cave atmosphere. *Transactions of the British Cave Research Association* 4: 417-29.

JAMES, J.M., FRANCIS, G. & JENNINGS, J.N. 1978 : Bungonia Caves and Gorge: a new view of their geology and geomorphology. *Helictite* 16: 53-63.

JENNINGS, J.N. 1967 : Some karst areas of Australia. Pp.256-92 in *Landform Studies from Australia and New Guinea*. (eds.) J.N. Jennings & J.A. Mabbutt. Australian National University Press, Canberra.

JENNINGS, J.N. 1968 : Underground geography. *New Zealand Geographical Society Record* 45: 1-4.

JENNINGS, J.N. 1977a : Caves around Canberra. *Proceedings of the Eleventh Biennial Conference Australian Speleological Federation Canberra 1978*: 79-95.

JENNINGS, J.N. 1977b : Limestone tablet experiments at Cooleman Plain, New South Wales, Australia, and

THE PROBLEM OF CAVERN FORMATION (Cont.)

their implications. *Abhandlungen zur Karst - und Höhlenkunde A - Speläologie* 15: 26-38.

JENNINGS, J.N., JAMES, J.M., COUNSELL, W.J., & WHAITE, T.M. 1972 : Geomorphology of Bungonia Caves and Gorge. *Sydney Speleological Society Occasional Paper* 4: 113-43.

JENNINGS, J.N. & SWEETING, M.M. 1959 : Underground breach of a divide. *Australian Journal of Science* 21: 261-2.

JENNINGS, J.N. & SWEETING, M.M. 1966 : Old Napier Downs Cave, West Kimberley, W.A. *Helictite* 4: 23-32.

JONES, L.J. 1940 : The Gulgong Goldfield. *Mineral Resources of New South Wales* 38: 1-139.

LOWRY, D.C. & JENNINGS, J.N. 1974 : The Nullarbor karst Australia. *Zeitschrift fur Geomorphologie* 18: 35-81.

MALOTT, C.A. 1937 : Invasion theory of cavern development. *Proceedings of the Geological Society of America for 1937:* 323.

MAUCCI, W. 1960 : La speleogenesi nel Carso Triestino. *Bolletino Societa Adriatica Scienze Naturali* 51: 233-54.

MIOTKE, F.D. & PALMER, A.N. 1972 : *Genetic Relationship between Caves and Landforms in the Mammoth Cave National Park Area.* Bohler, Wurzburg.

MOORE, G.W. 1960 : Introduction to the origin of limestone caves. *Bulletin of the National Speleological Society* 22: 3-4.

NEWSON, M.D. 1971 : A model of subterranean limestone erosion in the British Isles based on hydrology. *Transaction of the Institute of British Geographers* 54: 55-70.

PALMER, A.N. 1975 : The origin of maze caves. *Bulletin of the National Speleological Society* 37: 56-76.

PARKER, F. 1970 : Notes on a large cave in the Keriaka Limestone, Bougainville Island, Solomon Islands. *Helictite* 8: 63-67.

PENGELLY, W. 1864 : The introduction of cavern accumulations. *Report and Transactions of the Devonshire Association* 3: 31-41.

PICKNETT, R.G. 1972 : The pH of calcite solutions with and without magnesium carbonate present, and the implications concerning rejuvenated aggressiveness. *Transactions of the Cave Research Group of Great Britain* 14: 141-50.

PICKNETT, R.G., BRAY, L.G. & STENNER, R.D. 1976 : The chemistry of cave waters. Pp. 213-66 in *The Science of Speleology.* (eds.) T.D. Ford & C.H.D. Cullingford. Academic Press, London.

POPOV, I.V., GVOZDETSKIY, N.A., CHIKISHEV, A.G. & KUDELIN, B.I. 1972 : Karst of the USSR. Pp. 355-416 in *Karst Important Karst Regions of the Northern Hemisphere.* (eds.) M. Herak & V.T. Stringfield. Elsevier, Amsterdam.

QUINLAN, J.F. 1970 : Central Kentucky karst. *Méditerranée* 7: 235-53.

RENAULT, P. 1967 : Contribution a l'étude des actionsmécaniques et sedimentologiques dans la spéléogenese. *Annales de Spéléologie* 22: 5-21, 209-67; 23: 259-307, 529-96.

RENAULT, P. 1970 : *La formation des cavernes.* Presses Universitaires de France, Paris.

SWEETING, M.M. 1950 : Erosion cycles and limestone caverns in the Ingleborough district of Yorkshire. *Geographical Journal* 115: 63-78,

SWINNERTON, A.C.T 1932 : Origin of limestone caverns. *Bulletin of the Geological Society of America* 43: 662-93.

TRIMMEL, H. 1968 : *Höhlenkunde.* Vieweg, Brunswick.

TRICART, J. 1974 : *Structural Geomorphology.* Longman, London.

TRUDGILL, S.T. 1979 : Chemical polish of limestone and interactions between calcium and organic matter in peat drainage waters. *Transactions of the British Cave Research Association* 6: 30-35.

WALTHAM, A.C. 1970 : Cave development in the limestone of the Ingleborough district. *Geographical Journal* 136: 574-84.

WALTHAM, A.C. 1972 : Geological environment of cave development. *International Geography 1972* 2: 1328-330.

WHITE, W.B. 1960 : Terminations of passages in Appalachian caves as evidence for a shallow phreatic origin. *Bulletin of the National Speleological Society* 22: 43-53.

WHITE, W.B. 1969 : Conceptual models for carbonate aquifers. *Ground Water* 7: 15-21.

WHITE, W.B. 1976 : Cave minerals and speleothems. Pp. 267-327 in *The Science of Speleology.* (eds.) T.D. Ford & C.H.D. Cullingford. Academic Press, London.

WHITE, W.B. & LONGYEAR, J. 1972 : Some limitations on speleo-genetic speculation imposed by the hydraulics of groundwater flow in limestone. *Nittany Grotto Newsletter* 10: 155-67.

THE PROBLEM OF CAVERN FORMATION (Cont.)

WILFORD, G.E. 1964 : The geology of Sarawak and Sabah caves. *Geological Survey Borneo Region, Malaysia Bulletin* 6.

WILLIAMS, P.W. 1978 : Interpretation of Australasian karsts. Pp. 259-88 in *Landform Evolution in Australasia*. (eds.) J.L. Davies & M.A.J. Williams. Australian National University Press, Canberra.

WILLIAMS, P.W. & DOWLING, R.K. 1979 : Solution of marble in the karst of the Pikikiruna Range, northwest Nelson, New Zealand. *Earth Surface Processes* 4: 15-36.

****-*-*-****

"It was in the Haute-Loire that Grive suddenly became aware of bats. As the narrow valley brimmed with dusks, bats were everywhere, flying so fast and so erratically that it was hard to say whether there were innumerable bats or the same bats in a dozen places at once. As birds surpass fairies,(he said), bats surpass birds. They were the magicians of flight. With a flick they could turn at any angle, dart zigzag above the stream, flicker in and out of the trees, be here, be gone, never hesitate, never collide. They were flight itself."

Sylvia Townsend Warner, *Winged Creatures*.

" 'Lucy! Coming! Lucy-it's all right!'

'Oh...Oh gee...' The voice trailed away.

'She's fast down yon wee crack,' said Geordie.

'She'll likely stay there till she dies...'

'Oh shut up, do,' snapped Charlotte."

Barbara Willard, *The Battle of Wednesday Week*.

****-*-*-****

WHEN IS A SUMP A DUCK? OR WHAT CONSTITUTES A CAVE DIVE? Rauleigh Webb

The topic of cave diving is one that is at the forefront of current speleological literature throughout the world. The topic of sump free diving, in theory an even more dangerous pastime, seems to receive little attention in the literature.

The reasons that I wish to discuss such matters are basically twofold: (1) The last ASF Committee meeting accepted the Cave Divers' Association of Australia (CDAA) as the recognised authority on cave diving in Australia. The second part of the motion (Number 20 in the minutes) accepted the CDAA Safety Code- SIGHT UNSEEN! (2) I was recently criticized by some members of WASG for allowing a "cave dive" by a non-CDAA member on one of my trips to explore UNIWA Cave at Eneabba, Western Australia.

I hope that by using recent examples I can suitably illustrate the following points that I am trying to make:

WHEN IS A SUMP A DUCK? OR WHAT CONSTITUTES A CAVE DIVE? (Cont.)

(a) An air tank is not always necessary to undertake "cave diving".

(b) Alternatives such as siphoning may be possible in some places where a duck of unknown length is to be tackled.

(b) The use of tanks by divers (not necessarily CDAA qualified divers), in caves, should not be discouraged where their use significantly increases the safety of the caving being undertaken.

Points such as these, and others that I'm sure I have neglected, should be considered when, hopefully, a new Cave Diving Safety Code is drawn up. This code should include all forms of cave diving. Then cavers as well as the CDAA cave diver would have some idea of what the majority of cavers believe are safe practices when cave diving.

Firstly, consider point (1). To date, I have not been able to establish just what the CDAA Safety Code covers or includes. However, I find it almost unbelievable that the ASF Committee should accept the Safety Code of a related sport while not considering the restrictions under which it MAY be placing its members. This is not to say that the ASF should not accept the Safety Code, but rather that it should have at least examined it to consider if it truly covered all the aspects of "cave diving" with relation to the cavers of Australia.

All too often I see where two organizations combine in one particular aspect of their activities they each accept, often blindly, the "rules" that the other may apply. In this case, I think that an entirely new "Safety Code" for cavers (including cave divers) should have been considered.

On the second point, (2), I would like to use this as an example of why I do not believe that the present CDAA Safety Code will encompass a true Safety Code for cave diving in Australia.

A complete report of the exploration of UNIWA Cave is published elsewhere (Webb,1980) but for the purpose of this article, I wish to expand on that report. Prior to the use of an air tank in UNIWA, a tight duck about 0.5m had been passed and an air bell found in the then terminal sump. A diver (not a CDAA member) on this trip expressed an interest in using an air tank to try and find other air bells to allow cavers to penetrate the sump. We definitely did not wish to find water-filled passages as this would have halted the exploration as most of the cavers had no SCUBA experience.

The result of the initial "dive" was exactly as we had hoped. A series of five air bells leading to more cave. The air tank in this instance was only used to increase the safety factor. A seven metre polypropelene line was used and the "diver" agreed that this would be the extent of his dive, if no air bells were found. As it happened, this line just reached from one end of the air bells to the other and served as a line to guide cavers through the ducks. The diver returning from his success, without use of the tank, checked the air in the bells and upon finding one a little "stale" he blew some air from his tank into the air bell.

It can be seen that the use of the air tank was not really necessary. I believe however in this case it was highly advisable. The air bells could not easily be found by a free diver and there was still the possibility of foul air in the air bells when they were found. I don't see the need to call-in a qualified cave diver (of which there are only three or four in WA) to pass such ducks when a normally qualified diver taking standard, simple precautions can easily negotiate such obstacles.

On that same trip, the diver, using a face mask for assistance free dived a 2.5m long sump into a new chamber. So from this example alone, it is obvious that no hard and fast rules can be applied. Each sump is encountered and must be tackled individually, by whatever means its explorer sees fit.

I should add that on a subsequent trip, the diver passed three longer sumps through which we believed it was too risky for cavers to free dive. A monitor was placed on the water, for if it fell 20cms then it would have been possible.

Other recent exploration in Western Australia includes free diving of a sumped gour pool in Old Napier Downs Cave, in the Kimberleys (Nunnink & Jolly, 1979). This duck gives access to about one kilometre of lake passage (Aquarius Extension).

At Cape Range (Vine,1980), the first horizontal cave in this area, Shothole Tunnel, was explored to Stop Pool, a rather large gour pool. Siphon hoses drained the water into a lower pool. The sump opened, and exploration continued. After rain, this flooded, and a duck was necessary BUT with the knowledge of what lay on the other side, it was easily done.

I hope that these few examples have shown that a Safety Code for cave diving should be all encompassing, and it is necessary for the ASF to reconsider this matter at the next committee meeting.

References

NUNNINK, R. and JOLLY, S. 1979 : Old Napier Downs Cave Extension. *The Western Caver* 19 (3):76.

VINE, B. 1980 : Cape Caverneers Reports. *The Western Caver* 20(1):9.

WEBB, R. 1980 : Surveying and more extensions of UNIWA Cave. *The Western Caver* 20:16.

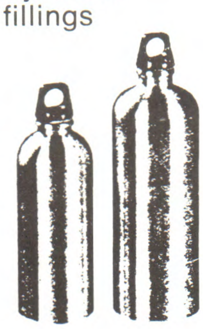
**** - * - * - ****

BUSHGEAR Pty. Ltd.

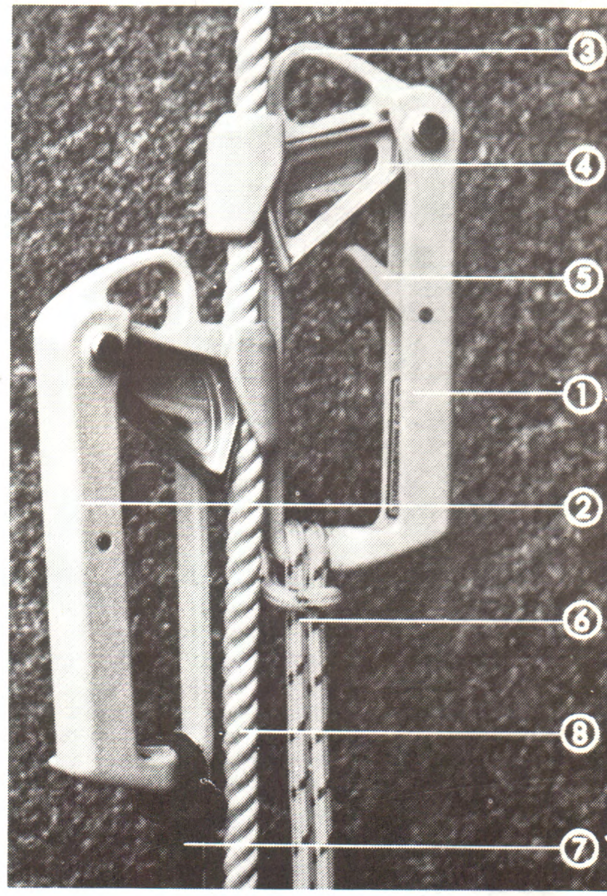
sell practical high quality clothing, boots, gear, books and maps for all Outdoor People.

Sleeping bags for all occasions

Down or Synthetic fillings



Sigg Aluminium bottles watertight and fuel-tight.



JUMAR

Made in Switzerland
Patent applied for

For ascent and descent operations on ropes. The universal and compact rescue device in pocket-size

Ideal for

mountaineers — expeditions — cave explorers — rescue work-inspection and renovation work on high buildings

Ski Touring is going places and Bushgear can help you get there and back with a full range of Touring skis, boots, bindings and waxes.

Wool Clothing–best for Australian wet-cold conditions–shirts, breeches, pullovers, socks, balaclavas, mittens, underwear.

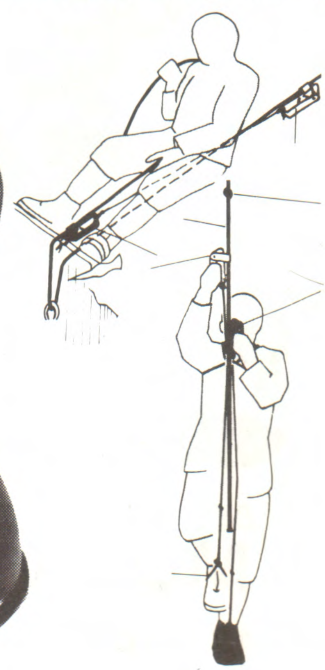
Down Clothing–lightest insulation for dry cold such as Himalayas–duvets, trousers, boots, mittens, waistcoats.

Synthetic filled–good designs can offer a reasonable compromise.

Wind and Waterproof outer clothing of oiled cotton japara or good coated nylon–parkas, overtrousers, gaiters, mittens, overboots.

plus packs, tents, stoves, compasses, whistles, survival bags and blankets, sleeping mats, cooking gear, ropes, chocks, tapes, karabiners, iceaxes, crampons, icescrews, mountain skis, caving ladders and lamps, prussikers.

Write for our catalogue *(please enclose 80c, refundable on purchases)* **or call upstairs at**



46 Hardware Street, Melbourne 3000

Phone 67 3354 or 67 7966