CAVES AROUND CANBERRA

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Abstract

The purpose of this paper is to illustrate, primarily for the beginning speleologist, fundamental ideas about limestone cave origins and evolution from caves around Canberra. First, important generalities about the nature of the tiny, impounded karsts involved are set out. Then follows a summary of the relevant hydrodynamic contexts with their related cave morphologies, in which two new terms are introduced to help avoid some misconceptions which arise from present terminology. Next some of the ways, in which these different types of speleogenetic action may combine over time and spatially, are exemplified from local cases. In this the importance of rejuvenation of drainage and relief is apparent but it is stressed that the intervention of very localised factors, especially details of geological structure, tends to be neglected. Some indication of the part that Pleistocene climatic changes may have played in the caves' development is given and the need for more work in this direction, in which cave sediments provide vital evidence, is underlined. Finally, the problems of cave chronology are touched upon, with particular reference to the very difficult case of Bungonia.

Introduction

At the 11th Biennial Conference of the Australian Speleological Federation an account of certain caves around Canberra to illustrate the basic principles relating to the origin and evolution of limestone caves was incorporated in the conference guidebook (Jennings 1976a). In so far as the area close to Canberra was inadequate for this purpose, reference was made to places farther afield in Australia (though the nearest caves that could provide the necessary examples were chosen). So that this discussion will reach more Australian speleologists it has been decided to include it in the proceedings of the conference. Some changes in writing style have been made for this different kind of publication and certain sections have been revised to accommodate subsequent discussion and further field work.

Regional Characteristics of Importance for Cave Formation

The caves around Canberra belong to tiny, impounded karsts, that is the body of carbonate rock is entirely surrounded by impervious rocks. So what goes on in the limestone is very much affected by surrounding areas. Large amounts of water are poured onto and into the limestone from outside, with particular chemical characteristics and with loads of foreign sediment of varied sizes. Generally these waters are aggressive towards limestone because they have carbon dioxide in solution which was not used up in reacting with the surrounding rocks such as the igneous rocks which commonly abut upon or surround limestone in the area. However, in dry spells so much water loss takes place by evaporation and transpiration that these incoming waters may be rich in solutes and not very aggressive towards limestone since they already have much calcium and magnesium in solution. Nearly all the caves have deposits of quartz sand and foreign rock fragments which either are being carried through the caves currently or formerly were so entrained. Therefore mechanical attack on the rocks may be more important in our caves than in those of larger limestone areas.

Precipitation is unreliable, both seasonally and from year to year, even though this is a part of Australia with a lesser degree of such unreliability than most. There are prolonged droughts, which may last several years, and prolonged and heavy rainfalls cause floods at any time of the year. Yarrangobilly and Cooleman Plain are also liable to occasional long periods of snow cover, the chief importance of which may be big flows of water if heavy rainfall combines with their melting as is sometimes the case.

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All the areas are made up of strongly crystalline and highly compacted limestone or even more crystalline marble, generally of high calcite purity, all of low intergranular porosity but highly jointed and sometimes cleaved. It is on this fissuration that passage of water through these rocks depends. With this secondary permeability any notion of a watertable has to be a highly qualified one.

The limestones are of Silurian and Devonian age and they have been caught up in earth movements of Late Silurian and of Middle Devonian age, which have folded and faulted them considerably. Practically nowhere do they lie horizontally. This has the distinct investigatory advantage that more or less horizontal parts of caves are not likely to be a consequence of rock type and arrangement.

Despite the mechanical strength of the limestones here they are more subject to attack and removal by geomorphic agents than many of the rocks which surround them, primarily of course, because of their greater solubility in natural waters. Therefore they are eroded differentially and tend to form lower parts in the relief than the surrounding impervious rocks. At Wombeyan and Cooleman, the Silurian carbonate rocks occupy small basins surrounded by higher plateaus or ranges in igneous rocks. At Cooleman there is also an extension of limestone down the gorges of Cave Creek and the Goodradigbee River valley. This extension resembles the situation at Wee Jasper where Devonian limestones crop out along the bottom of the Goodradigbee valley and that of its tributary, Wee Jasper Creek, even though it does form the well-known but modest protuberance of Punchbowl Hill. Silurian limestone at Yarrangobilly again follows the valley line, recessed relative to igneous rock on one flank and other sedimentary rocks on the other. At Bungonia the relationships are less obvious because the local relief on the plateau is small; nevertheless the limestone strike belts are overlooked by gentle hills of more resistant siltstones, sandstones and quartzites belonging variously to the same Silurian rock formation, to the underlying Tallong Beds and to the overlying Devonian rocks.

Combine this recessiveness in the general relief with the impounded nature of the karsts and with the nature of the precipitation and the result is that these patches of limestone are subject to extremely variable amounts of water and erosional attack, both chemical and mechanical.

A fifth generality which has to be borne in mind constantly is that in all these areas an essential characteristic of the geomorphology is the rejuvenation of the drainage by tectonic uplift of the plateaus in which these tiny bits of limestone are set. The incidence of river incision is crucial. Its effects are most striking at Bungonia and least at Wee Jasper where the river has cut only a little below the limestone. At Yarrangobilly the limestone forms a broad and high shelf or strath on one side of the valley; this was the former valley floor but a gorge has been carved more or less along the western side of the limestone. The basins at Cooleman and Wombeyan differ somewhat in that a strikingly planate surface of erosion in the limestone largely survives at Cooleman though encroached upon by gorges whereas the Wombeyan marble was reduced to hilly relief before gorges developed through later rejuvenation. There are indications that it was similarly an enclosed plain in the past.

Active tectonic movements may be involved in speleogenesis in places like New Guinea, even creating voids and certainly affecting the development of erosional voids. In southeastern Australia the earth's crust has been much more stable for a long time. Some faulting has taken place in the Tertiary and shifts may still be taking place along faults such as the Berridale Wrench Fault and the Jindabyne Thrust Fault (White and others 1976). The Lake George Fault appears to have been reactivated in the Tertiary, though recent work (Coventry 1976) proves there has been no movement in the last 20,000 years. As yet no faults have been demonstrated to have been active in young geological times in the karst areas around Canberra and the most to be attributed to this factor is that earthquakes may act as triggers to rockfall from roofs and walls of caves when solution along joints and bedding planes has already prepared blocks of rock for detachment by gravity. But, of course, the structures of the rock inherited from earlier earth movements exert great influence much later on the course of active agents of cave formation. An outstanding local case is Narrangullen Cave, Taemas. A small body of Middle Devonian Limestone survives there in a downfold due to Taberabberan (Middle Devonian) earth movements. The cave passes through this inlier of limestone along the axis of the syncline; in detail the cave switches from one side of this structural axis at the upstream end to the other at the downstream end.

It follows from the generalisations already made that the karsts around Canberra fall into the category of 'fluviokarsts' of Roglić (1960) as Sweeting (1972) has already recognised. Fluvial processes are as important as distinctively karst processes. Surface river valleys, especially gorges, dominate the landscape; streamsinks, blind valleys and dry valleys are usually more important than dolines. One character frequently found in fluviokarsts does not apply however. The rivers do not

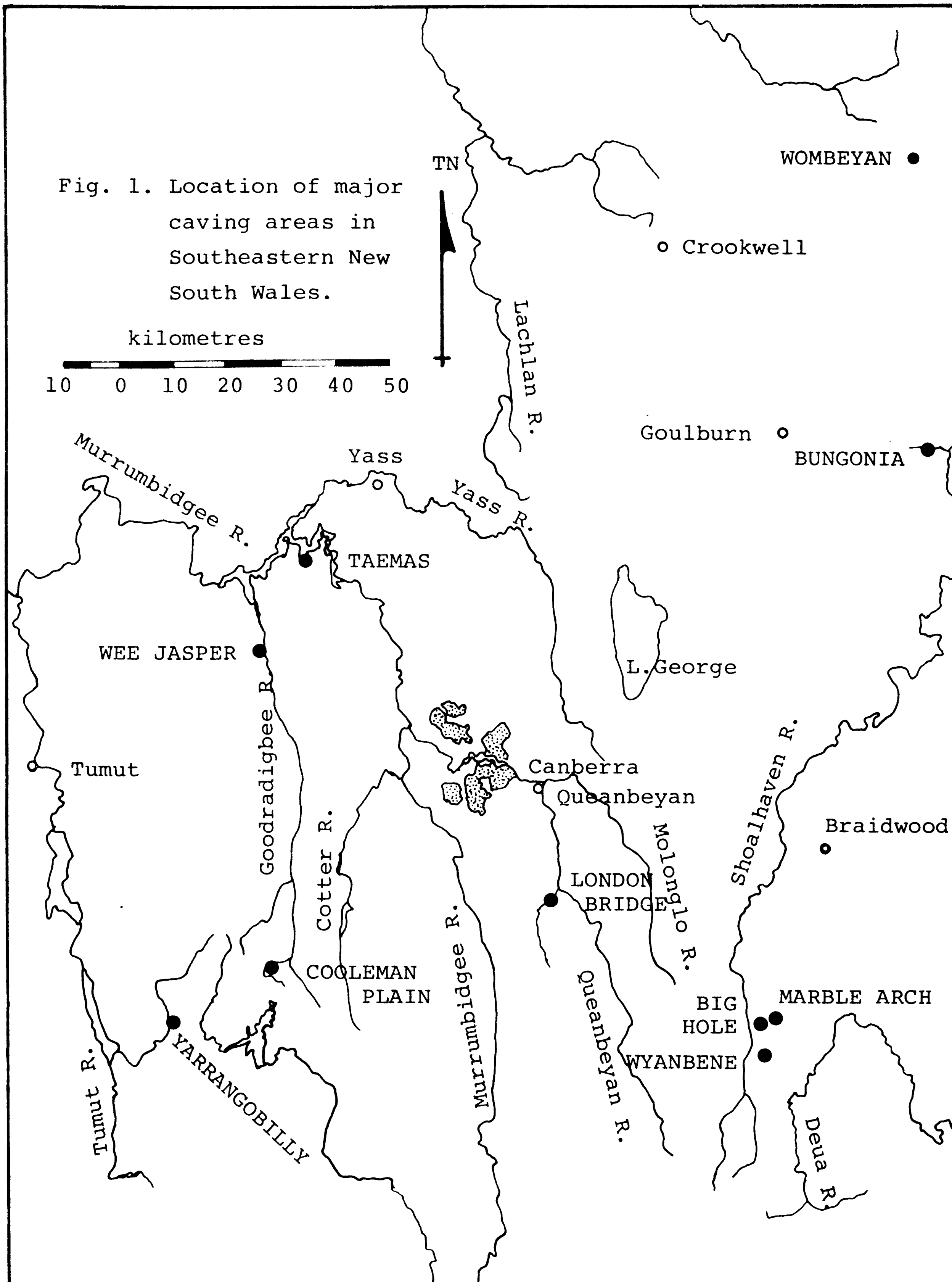
Fig. 1. Location of major caving areas in Southeastern New South Wales.
kilometres
10 0 10 20 30 40 50
TN
WOMBEYAN
Crookwell
Lachlan R.
Goulburn
BUNGONIA
Murrumbidgee R.
Yass
Yass R.
TAEMAS
WEE JASPER
L. George
Goodradigbee R.
Tumut
Canberra
Queanbeyan
Shoalhaven R.
Braidwood
Cotter R.
Molonglo R.
LONDON BRIDGE
Murrumbidgee R.
COOLEMAN PLAIN
Queanbeyan R.
BIG HOLE
MARBLE ARCH
WYANBENE
YARRANGOBILLY
Tumut R.
Deua R.

cut down through the karst rock and compartment it into blocks with impervious basement between. Instead the carbonate rock reaches deep below the lowest associated drainage lines.

Some Elements of Speleogenetic Theory

Most of the general systematic ideas held about the development of karst caves are relevant for the karst areas around Canberra.

Solution is the prime process, though it is true that for a long time there has been neglect of the mechanical aspect of water erosion in caves. Newson and Smith's quantitative work in the Mendip Hills of England has shown this to be a greater factor than has latterly been overtly recognised. Though in total removal of material, mechanical erosion remains subordinate to chemical erosion in the Mendip, (Newson 1971, Smith and Newson 1974), they tend to operate at different times and places within the system. The importance of the mechanical aspect with regard to caves is undeniable and in Mendip there are only small inliers of non-karst rocks to supply durable tools to the cave streams whereas, as mentioned already, in the karsts around Canberra much larger supplies are available to our caves surrounded as they are by other than carbonate rocks. So it is the hydrodynamic circumstances in which solution, and in certain phases mechanical erosion, operates underground that primarily concerns speleogenetic theory.

The contexts relevant to the understanding of the caves near Canberra are those of (a) vadose seepage, (b) vadose flow, (c) the nothephreas and (d) the dynamic phreas; other contexts such as the artesian will be disregarded here. Simple cases will be employed to illustrate the different process regimes at first.

Vadose Seepage

In practically every caving area near Canberra there are numerous simple shafts or rifts leading down from the surface more or less vertically. They commonly express strong structural guidance, joints and joint intersections usually, but it can be bedding where the rocks are on their side as, for instance, in Jap's Hole on Punchbowl Hill at Wee Jasper. Igneous dykes may encourage their development as for instance in an example at Wombeyan. They may open from level or sloping planar surfaces, from hollows or even from gentle convexities. The Putrid Pit at Bungonia illustrates very well how a series of pitches succeed one another downwards, not quite precisely above one another, in different joints. Their walls may be vertically scored by long grooves with sharp ribs between, in German they are called *Höhlenwand Karren,* which can be translated as cave wall solution runnels. They are commonly wider and longer than solution flutes *(Rillenkarren)* on surface outcrops.

These shafts are usually the result of solution by rainwater or soil water seeping downwards through the rock under gravity in a zone where voids are only intermittently or partially filled with water. They may narrow downwards, remain more or less uniform in plan or widen downwards, ending in a blockage of rock fragments, clay, earth or other debris more commonly than in bedrock closure.

As it is known that this vadose seepage often reaches saturation levels for calcite solution at shallow depths, downward closure of the bedrock walls is the easiest form to understand as regards process. The other modes may be due to organic matter in the seepage water, which may generate carbon dioxide biologically during descent to maintain or even enhance aggressiveness towards calcite (Jennings and others in press). Both these explanations imply development from the top downwards. However, it may be that vadose seepage shafts often develop from below upwards, water percolating through planes of weakness for some distance before the process of solutional widening begins. If solution begins below and extends upwards, then greater length of time for solution below could produce forms widening downwards.

Of relevance to this view are blind shafts, which extend upwards from caves but do not reach the surface. Sometimes these features are known to reach nearly to the surface; indeed open shafts often have blind shafts in close conjunction. Some former blind shafts have certainly punched through to the surface, no doubt with a certain amount of help from collapse of blocks, partially detached by solution.

The finest blind shaft near to Canberra is undoubtedly the Gunbarrel in Wyanbene Cave, 105m high and beautifully ornamented by solution runnels. It is, however, a special case since it reaches through the Silurian limestone, which walls it, to overlying, unconformable Devonian conglomerate. When the Gunbarrel was discussed previously (Jennings 1967a), this circumstance was not known for certain, though neighbouring blind shafts in the cave were proven to do this. However, N. Anderson searched more vigorously than had been done before and found a cobble of unmistakable purple Devonian conglomerate beneath the shower bath that prevails in the Gunbarrel. Burke & Bird (1966) regard diffuse input of aggressive acidic water from overlying jointed sandstone into the Carboniferous Limestone of South Wales as highly conducive to the formation of blind shafts by vadose seepage waters.

Vadose Flow

The cave context where cause and effect are most obviously related is that where a stream equipped with sand and gravel similar to a surface stream with an air space above is rushing through a cave over rapids and even waterfalls. For instance, if the gorge of Mares Forest Creek at Wombeyan is compared with Creek Cave through which Wombeyan Creek penetrates some 250 m of marble, many features are found to be in common because the same processes are operating in the same way. All the mechanical actions of a river are obvious, especially in flood time, and also the invisible action of solution, for which chemical measurements may often be necessary as proof, is evident from scallops or current markings. Circular depressions in the bed, a result of rotary motion, are here a product of solution as well as of abrasion and so they are best called swirlholes, rather than rock mills and certainly in preference to potholes (a most confusing term in the speleological world). Plunge pools at the bottom of waterfalls can be regarded as special cases of swirlholes. Rounded channels and chutes in the stream bed along the line of flow and asymmetrical horns between swirlholes are other characteristic features.

Underground streams tend to meander as do those on the surface so winding passages develop with meander niches in the walls where lateral erosion accompanying channel deepening leaves a succession of curving bevels like an inverted arena. Similarly inverted equivalents of meander spurs or cusps may be left in the roof. However, without such sideways swinging, a free surface stream often makes a series of semi-circular recesses along the walls one above the other, which can be called channel incuts. If deepening proceeds much faster than lateral solution, a canyon may be produced, sometimes meandering though it may not always escape straightening by structural control, but usually leaving some signs of former streambed levels which have been occupied at different stages in its formation. Scraps of fluvial sediment left in niches and incuts are sometimes misinterpreted as evidence for a stage of drastic filling of the cave.

Vadose flow in the small areas of limestone near Canberra is prevailingly associated with streams from the surrounding rocks disappearing underground. A typical case is Cormorant Cave in the Goodradigbee valley near Cooleman Plain; a small stream comes off the steep granite slope of Jackson and enters a cave almost as soon as it encounters the limestone through which it falls in a rather direct vadose passage to the Goodradigbee. However, vadose streams can gather together from seepage water and be quite independent of streamsinks. Originally diffuse flow in the limestone becomes concentrated. Lack of large areas of karst near Canberra militates against clear cases of this kind though the process contributed to all the underground streams. However, the stream in Wyanbene Cave falls into this category. No streamsinks have been found on the limestone outcrop or on the cap of Devonian conglomerate and sandstone on the ridge behind so it must simply be a gathering of seepage from above, exemplified in the shower of drops that one experiences in the Gunbarrel already mentioned.

Seepage waters rapidly become much richer in calcium and bicarbonate ions than streamsink water does. Such seepage waters commonly form stalactites and other speleothems, even stalagmites, in active vadose stream passages, though of course this goes on more freely, with less liability to removal, in passages abandoned by stream flow. A corollary should be that rimstone dams are more likely along a vadose stream channel fed by seepage water than one fed by streamsink water. This is not well evidenced in Wyanbene Cave. Base flow in Black Range Cave at Cooleman Plain is also a collection of seepage water, though it is possible that this is supplemented after a heavy rain by some overland flow entering its entrance doline. Where flow is first met in this cave, there is a good development of flowstone floor and small rimstone dams. Farther in, however, there is a normal streambed so additional water forming the stream may be less rich in solutes.

This contrast between vadose flow derived from sinking surface streams and from seepage is relevant to the outstanding hydrogeological problem at Wombeyan. None of several water tracing exercises there has yet revealed the source of the stream in the Bouverie-Bullio-Mares Forest Creek Caves system (James and others in press). This aligned system heads in the direction of Wollondilly Cave and the geomorphology suggests that some Wombeyan Creek water is diverted into the right bank of its valley, though most goes into the Fig Tree-Junction Caves system in the left bank. Nevertheless no such connection has yet been proven. There is more rimstone dam development in Bullio Cave than in other active river caves at Wombeyan and the calcium and bicarbonate content of Mares Forest Creek cave water is much higher than that of Junction Cave, though both are depositing tufa where they emerge. Nevertheless this content is not significantly greater than those of W47 Spring and some other springs in Wombeyan Creek gorge known to have streamsink water feeding them. Moreover the problematic underground stream seems to have too much water for the area of seepage supply (likely on topographic and geological grounds) to be adequate (Jennings and others in press). The answer may be that it has a larger proportion of seepage water than other underground streams yet it is also fed by a streamsink supply which has still to be identified.

Vadose flow caves are characteristically dendritic in pattern, that is one stream passage joins another to form a larger one like branches of a tree ultimately fusing to form a trunk. Again the small size of the karsts around Canberra militates against much development of this kind, the simple case cited of Cormorant Cave being typical around Canberra. There is a short confluent tributary stream passage in Barber Cave, Cooleman Plain, but it is likely that this is only another line of entry of the stream which flows into the Wet Entrance of the cave from Black Mountain. When in rare occasions in flood time Murray Cave (Cooleman Plain) functions, it receives a tributary along the branch to the north, probably of seepage origin. But Murray Cave is going out of action as a stream cave and even this is not a very good example. Of course, cases are known of separate vadose inflow caves feeding the same spring, e.g. the drainage system of Coppermine Cave at Yarrangobilly; nevertheless dendritic patterns of active vadose passages have not yet been explored there.

The Nothephreas

A turbulent underground stream with airspace above cannot form a cave; it can only enlarge what has been produced in some other way, though it may be only a small thoroughfare penetrating the rock which it inherits. The chance that tectonic activity or erosional offloading or gravitational slip has not only created a connected chain of voids large enough for such flow but created them where one end can collect a surface stream and lead it down to another lower end where it can be disgorged is rare. Therefore most caves inevitably start from tiny tubes and half-tubes that have been dissolved by water saturating the rock mass and developing minuscule threads of flow which take advantage of any planes and other loci of weakness, including such initial voids as there may be. These tiny tubes form anastomosing patterns, forking and rejoining in complex ways, not simply in single planes (though this is the manner in which they are seen most frequently as for example in the Opera House in Fig Tree Cave, Wombeyan) but three-dimensionally.

The phreas is the name for the hydrological zone in rocks where all voids are filled with water. Although this zone takes on a very different character in compacted rocks of low intergranular porosity such as occur around Canberra from that which it possesses in deposits of sand and gravel, for example, the term is used for both. A very important characteristic common to both situations is that water does not simply move downward from a high point to a low point as in a surface channel over impervious rocks but can follow all manner of courses, downward and later upwards, from a high part in the phreas to a lower one.

Because of this a cave can take on a distinctive style if solution continues to go on in phreatic conditions after connected ways through have been established, but without rapid flow being established. Spongework caves develop with irregular cavities of various dimensions interconnecting to form a complex maze. Only diving can reveal such caves in their active state and none have yet been discovered in the Canberra area in this way; the southeast of South Australia is a better hunting-ground for them. However, they may survive in large measure to be still recognisable after being emptied of their water and becoming inactive. Much of Basin Cave at Wombeyan is of this nature. In some of the Walli caves there is the same aspect though joint and bedding control of the pattern is much more evident there. Dip Cave at Wee Jasper has suffered so much breakdown and secondary deposition that its origins are not as clear as might be wished though its set of parallel passages strongly governed by nearly vertical bedding bears no obvious relationship to relief and drainage, and seems to be dominantly due to slow phreatic solution (Jennings 1963). Spongework is limited, however, and more common are symmetrical hollowings on bedding plane surfaces indicative of eddying flow but no substantial current.

Caves of this type, the phreatic caves of W.M. Davis and J. Harlen Bretz, have latterly tended to be called deep phreatic or true phreatic caves to distinguish them from shallow phreatic caves to be discussed next. However, any phreatic cave is truly phreatic if the interpretation that development took place in a water-filled state is correct. Nor do caves of this type require very deep circulation. In some circumstances they can form close to the surface and within a narrow vertical zone as, for instance, caves such as Easter Cave near August, W.A. in Quaternary aeolian calcarenites, which are dominantly spongework caves. Therefore the terms 'nothephreas' and 'nothephreatic flow' are proposed in this connection, "nothes" being the Greek for 'sluggish' or 'torpid'.

The Dynamic Phreas

If there is an appreciable head of water tending to drive water through a developing phreatic system at some speed from higher to lower levels, there is a strong tendency for a few routes, indeed ultimately a single route, to grow at the expense of others. As a tube gets larger, the effect of frictional drag on its surfaces becomes proportionately less, so the speed of flow increases and the mass transfer of solutes from the rock-water interface proceeds faster also. There is positive feedback in the system.

In these conditions, pressure conduits develop of circular or elliptical cross-section, with solution attacking all surfaces. If the ellipse is disposed horizontally, there may or may not be structural control; if it is vertical or inclined, such control is operative. Because of hydrostatic head, pressure conduits can rise and fall along their length and such loops in long profile are likely to be structurally controlled. A common arrangement as Ford (1971) stressed some time ago from Mendip examples is for conduits to descend in dipping bedding planes and rise in chimneys in joint planes. Ford and Ewers (pers. comm.) distinguish between 'bathyphreatic' (a term originating with Glennie) and 'multiple loop' caves. In 'bathyphreatic' caves, the pressure conduit describes one big downward loop to considerable depth, though this may be complex in detail; in 'multiple loop' caves, there are many down and up loops reaching to a common level, the rest level of water in the cave system or the watertable of general hydrological literature.

Dynamic phreatic action of these types is even more difficult of exploration in the active state than the nothephreatic state just described and once again no local instances can be provided. Even relict, abandoned systems of this type are rare. The best instance seems to be in Odyssey Cave at Bungonia where James and Montgomery (1976) have demonstrated with the aid of current markings a former phreatic loop of 45 m amplitude, now eliminated by a horizontal shortcut of the stream which formerly fashioned it. It is interesting to note, however, that this dynamic phreatic loop has as great a depth as any that can be demonstrated in the Canberra area for nothephreatic action, once again indicating that the adjective 'deep' should be avoided for the latter.

The mention of current markings in this connection is salutary because some speleologists have tended to associate scallops with vadose flow only. Ceiling scallops are commonly observed in pressure conduits, demonstrating that this restriction is false. Likewise mechanical action is not restricted to vadose passages. Sand and gravel can in fact do a great deal of work in pressure conduits.

Known phreatic lift in the Canberra area is usually much smaller than the example cited from Odyssey Cave, and is typified by the 6.5 m amplitude of the inverted siphon of the first watertrap in Murray Cave, Cooleman Plain, still intermittently in action (Jennings and others 1969). This is in keeping with the fact that in the Canberra area the dynamic phreatic action is what has been called that of the water table stream by Swinnerton, epiphreatic by Glennie and shallow phreatic by Davis. With this there is development of a more or less horizontal pressure conduit at or close below the level of the spring which it feeds. In the absence of structural conditions forcing downward loops in the phreatic circulation, action concentrates at the top of the phreas. Here the shortest route can develop with dynamic advantage. There are many abandoned examples in the area to some of which reference will be made below and there is good reason to think that active examples as yet unexplored link such points as Eagles Nest Cave and Hollin Cave at Yarrangobilly and Odyssey Cave and The Efflux at Bungonia. These links are at the bottom of the deepest cave systems in the Australian mainland so care must be taken not to be misled by use of the term "shallow phreatic action" in this connection; 'shallow' refers to the narrow amplitude of the dynamic phreatic action involved.

Cave Breakdown and Offloading

Another process in cave development – cave breakdown – has been referred to already but it needs further comment. The inward fall of blocks from cave roof and walls cannot by itself enlarge a cave because the fallen material occupies a substantially larger volume than the space it previously took up. For a cave to be stoped upwards by this process there has to be progressive removal of material from below, mainly of course by solution though there is also some traction of material along a cave stream.

It has been proposed that a favourable circumstance for cave breakdown is when a cave ceases to be waterfilled, e.g. when phreatic conditions are replaced by vadose ones. This is no doubt so but there is plenty of evidence from the successive incorporation of speleothems into rockpiles that it can be a protracted process persisting long after such draining of a cave. A vadose stream undercuts walls to this effect. Additionally, Renault (1970), amongst others, has stressed the importance of residual stresses in the body of the rock which will tend to be released by movement of rock into the voids created by erosional processes. Again there is positive feedback in this effect, the enlargement of the cavity makes more breakdown possible than before as long as material is removed for its accommodation.

A related point of Renault's is that offloading through loss of material from valley walls, mainly by solution, can cause sheeting joints more or less parallel to the valleyside, which promote cave formation in such locations. This needs to be considered with regard to some of the caves around Canberra such as Cooleman-Right Cooleman Caves and Wyanbene Cave. Some means of testing this idea needs devising because both of these linear caves paralleling a neighbouring valley also run along the strike.

The locations of pronounced breakdown within cave systems also call for explanation. At Yarrangobilly, for instance, big rockpiles are encountered shortly after entry into several of the more important inflow or streamsink caves such as East Deep Creek Cave. Is it simply that the sinking streams are most effective in their erosional action here, and bring about most collapse by undermining?

Combination in Time and Space

In the past the tendency was to lay stress on one or other hydrodynamic context as favourable to cave formation and the result was controversy in which one such context was set against another as the locus of cave genesis. These attitudes have long seemed quite mistaken to many speleologists. Their persistence has eventually led to overt criticism. In the Speleo Handbook (1968), I wrote about cave theories "that each of the mechanisms envisaged does operate and that nearly all caves are composite in origin. The problem is to determine the relative importance of each kind of action in producing the present form and pattern of each cave system". Monogenetic approaches have been attacked by White (1969) and Ford (1971), each identifying a variety of modes of cave evolution applicable to different circumstances. Relying mainly on his knowledge of karst areas in central and eastern United States, White based his types on overall geological structure. Ford (1971) and Ford and Ewers (pers comm) depend on examples from N. Canada to Mexico in N. America and from Britain for their scheme which incorporates a wider range of controlling factors. It will be useful to relate the caves around Canberra to their findings.

Meander and In-and-Out Caves, and Natural Bridges

Simple cases are much rarer than the selection made to illustrate the main hydrodynamic contexts would suggest. This can be illustrated by reference to the small caves closely associated with the rivers which dominate the local fluviokarsts. Meander caves such as are found at a number of points along the Yarrangobilly River constitute one of the few types of cave which are perfectly plain and straightforward. Even then Verandah Cave at Borenore (Jennings 1970a) is a double-decker due to the river cutting down more rapidly for a time or swinging away from that river flank for a while.

Short in-and-out caves are also common along our rivers, though they can vary very much within a single area. Thus at Cooleman Plain in its northern part, only shallow valleys a few metres deep occur and here only two caves are known; they are similar to one another where a stream has branched through a low, horizontal passage across a slight bend in a valley side. There is a sand and gravel bed and normally air space through most if not all of it. The rocks are dipping and there is no joint control in long or cross-section, though there may be some in plan. Most enlargement will take place during flood when they will be full of water. They are short watertable stream caves. Anabranch Cave (Montgomery 1971) though fulfilling a similar function is very different in character. It takes a substantial part of the flow of the Goodradigbee River in its deep valley below the junction of Cave Creek in almost a straight line through a steep spur end. It consists mainly of a tall oblique passage in a bedding plane like a tilted canal tunnel, though it has a watertrap near its upstream end. It may be objected that Anabranch Cave is not in Cooleman Plain proper. However, the cave in the right bank of Cave Creek at the Blue Waterholes has similar tall fissure passages. It does belong to Cooleman Plain but to that part of it where gorges have been cut into it.

Many natural bridges are formed where rivers breach meander spurs. London Bridge on Burra Creek was originally classified as a simple case of a karst meander cutoff (Jennings 1971). Later work showed at least two complications (Jennings and others 1976). The lesser of these lay in the role of the alluvial fan which now largely fills the abandoned meander channel. The nature of buried soils in it indicates it belongs in the main to the Late Pleistocene when fan building seems to have been going on widely in the Southern Tablelands because of colder climate and its geomorphic effects (Coventry and Walker in press). The role of the fan may therefore have been a dynamic, not simply a passive one. After part of the base flow of Burra Creek started to go through London Bridge Cave, the independent tendency of the tributary to dump a lot of sediment in the meander channel may have helped to round off the capture by blocking flood flows and forcing them also through the enlarging cavern in the root of the meander spur. None of the earlier cave breaches of the spur here reached completion of capture in this sense.

The second complication at London Bridge is witnessed by the longitudinal profiles of the older, inactive caves at London Bridge; Douglas Cave has a steeply dropping profile down valley and it is evident that Burra Cave formerly had a similar one. The conclusion was that the only satisfactory way to explain this drop was to postulate that a waterfall or rapid, retreating up the river through erosion, was held up in the meander by a resistant greywacke found there. Whilst it was held there, caves developed, descending through the limestone of the meander spur in a manner resembling the presently active Fish and Easter Caves system on Cave Creek below Cooleman Plain.

The Natural Bridge at Yarrangobilly is also not as simple as a casual inspection might suggest. There is a good deal of Quaternary tufaceous breccia in its construction and there are indications that there may have been a surface cutoff at one stage here, which was barred by fallen blocks of bedrock and by tufa building. This may have returned flow to the meander bend, which is now only followed in flood with the development of the present underground cutoff through the blocking materials. The geological structure needs mapping in detail to prove this. A collapse doline exposes part of the cutoff course beyond which the underground stream forks into a major and a minor arm. On steep slopes in the valley here, there are vegetated, fixed screes which belong to a past phase of much more active weathering of the limestone faces; once again the cold period of the Late Pleistocene in the Snowy Mountains comes to mind.

Thus major themes for cave study around Canberra emerge by reference even to these very simple kinds of cave.

Alternation of Vadose and Epiphreatic Activity

The mention of waterfall retreat in connection with London Bridge leads to one of these themes, namely, the effects of rates of valley incision. The larger caves owe much of their complexity to this as is well exemplified in the Punchbowl-Signature and Dogleg group of caves at Wee Jasper (Jennings 1964a, 1967). In the dry Punchbowl-Signature system, mainly from flat solution roofs in nearly vertical beds and from remnants of elliptical tubes, four levels of epiphreatic or watertable cave development can be recognised whereby a stream passed through Punchbowl Hill. In the intervals between, vadose downcutting took place. In the lowest part of the system nearest to Dogleg, spongework and related features prevail where nearly stagnant water enlarged the cave for a time whilst its former dynamic role was being taken over by Dogleg Cave, the active river cave. When the 7 m inverted siphon at the Opera House in Dogleg comes into action, much of the forward, low meandering part of the cave can fill to the roof so that it is intermittently epiphreatic in nature now. Phases of vadose flow before and after these peaks of erosional activity are separated by low stages when a lower, impenetrable route to the outflow comes into sole use.

This theme of alternation of different kinds of cave development through time as surface rivers cut down their valleys in or close by the limestone repeats itself through the area (e.g. at Marble Arch, Nicoll and others 1975). Epiphreatic cave development is much more common than other kinds of phreatic development. There may not be so many levels in the one cave as in the cave cited. For example, Barber Cave at Cooleman Plain has only two. Both of these exhibit the dominance of vadose activity at the inflow end of this through-cave with epiphreatic activity taking on a greater role in the morphology at the outflow end. Cave enlargement seems to have been propagated from the spring end upwards in the manner envisaged by Rhoades and Sinacori (1941). Slight further incision of Cave Creek has turned the lower epiphreatic level into a vadose state.

Another arrangement is one where one epiphreatic cave is replaced by another. There can be little doubt but that there is an active epiphreatic cave behind the Blue Waterholes at Cooleman Plain similar to the abandoned one upstream now constituting the dry Cooleman-Right Cooleman Caves system some 10 m higher than it but quite detached from it (Jennings 1970b). Study of the characteristics of the various springs at the Blue Waterholes indicates that the normal flow at any rate comes from the one conduit (Jennings 1972). A short phase of increased rate of incision has here been accompanied by a sideways jump in the point of outflow but the cause of the displacement, structural or otherwise, has not been perceived as yet.

Other variants on this theme are plentiful in the area as the guide to the excursions will reveal. Therefore the question arises as to why epiphreatic (watertable) caves as distinct from bathyphreatic or multiple loop caves are prevalent in the area. Ford and Ewers (pers comm) point out that for obvious reasons in steeply dipping rocks developments of the latter kind are favoured whereas gentle dips promote the former type. The Canberra area would tend to contradict this. Another thesis of Ford's helps out, namely that if the drainage from inflow to outflow tends to be mainly along the strike, this in its turn favours horizontal development along the strike. The Punchbowl-Signature and Dogleg Caves are elongated along the strike (though there is meandering along substantial sections). Again at Bungonia, the long Fossil Cave – Hogans Hole Extension has much epiphreatic passage along the strike, whereas the big loop in Odyssey Cave occurs where the chief underground stream is descending the dip in accord with the Ford/Ewers concept.

Nevertheless many of the epiphreatic cave passages run in the sense of the dip and cross the strike, e.g. Coppermine at Yarrangobilly, as must the link between Eagles Nest and Hollin Cave there also (Pavey 1974). To help with these instances and for perhaps the overriding factor generally there is another factor in the Ford/Ewers general theory, namely fissure frequency. With increasing fissure frequency in low or in steep dips, hydraulic conductivity increases also and this permits the most direct routes down the hydraulic head to develop readily. So as fissure frequency increases, the favoured sequence is from bathyphreatic through multiple loop to epiphreatic caves. There is no doubt that highly fissured rocks (even in the case of the Wombeyan marble) are prevalent as a result of a long tectonic history, the proximity of igneous intrusion in many cases, and also the nearness to valley walls which results in offloading joints.

This stress on the various modes of dynamic phreatic action must not lead to disregard of the role of the nothephreas. In this respect White's system is more useful than that of Ford and Ewers who do not retain a place for it as a significant cave-forming hydrodynamic context. This latter standpoint may be justified against a canvas of large karst areas and very big cave systems. With the small karst areas around Canberra it occurs sufficiently frequently to warrant it being classed as a normal case. White's diffuse flow category approximates to what is here termed nothephreatic but his restriction of it to impure limestone and coarse dolomites does not apply in the Canberra area where the instances cannot be differentiated on this basis. Some of the caves placed in this class appear to relate to an early and different stage in the relief development. Durins Tower Cave at Wombeyan is in the top of a knoll which is one of the highest points of the karst there (Jennings and others in press). It probably formed when the present ridges belonged to a former basin plain. The Wellington Caves also relate to a time when the limestone there formed a valley floor instead of a low ridge (Frank 1971). Clown Cave at Cooleman antedates the gorge it overlooks. These and others correspond to the classic Davisian situation of phreatic development beneath a planation surface; subsequent rejuvenation of drainage has left them high and dry, unrelated to present relief. However, not all cases are explained in this way. Basin Cave at Wombeyan is best interpreted as the result of a blind input from Mares Forest Creek, which may have developed a certain degree of throughflow initially but failed to keep pace with faster incision of the creek and eventually lost sufficient supply for even nothephreatic growth. Fred Cave still taps the river water and must still be enlarging slowly.

Rejuvenation in General

Rejuvenation of drainage and relief lies behind much of the previous discussion and it is useful now to look at this in more general terms in relation to the caves.

At Cooleman Plain there is a pronounced contrast between the slight dissection of the limestone planation surface over the northern part and round the margins of the southern part and the pronounced dissection above and below the Blue Waterholes (Jennings 1967a). Caves are insignificant in the first context; Devil Hole is probably the largest and it is only a short inflow cave for one of the largest of the many streams flowing off the igneous rim onto the karst. All caves of appreciable length and size are associated with the gorges. Circulation was promoted here, hydraulic gradients increased and probably fissure frequency also, though this may not have mattered so much as that frequency is generally high. The caves are mainly outflow caves such as Murray Cave and between-caves such as River, Frustration and New Year Caves.

Caves are more frequent and larger at Yarrangobilly because the main river runs for the most part along the side of the limestone outcrop and has cut a deeper gorge than Cave Creek; favourable conditions for cave development reach more widely and more strongly. Substantial inflow caves occur as well as outflow. At the downvalley end where the depth of incision below the old valley floor is greatest, there is a fine sequence of replacement of higher caves by lower caves functionally (Jennings 1964b). Jersey Cave, the two Glory Caves, River and Federation Caves represent a sequence of the former and present outflow caves of the sinking Rules Creek over a height range of 120 m. The shortness of the tunnel which had to be cut for the North Glory self-guided circuit indicates how near it was to becoming a through-cave at one stage. Indeed collapse may have blocked off such a cave. Jillabenan and Harrie Wood Caves are former outflow points of Mill Creek. That creek now sinks in Mill Creek Swallet whereby it flows towards River Cave to join Rules Creek in that vicinity. So Jillabenan, Harrie Wood, River and Federation Caves also form a descending sequence.

To add to the interest here Castle and Grotto Caves must also have let out Mill Creek water at certain stages so Mill Creek has had a very complex history, which should become clearer when the careful surveys now well on the way to completion are interpreted.

In all the instances so far, cave development seems to have kept pace with valley degradation or nearly so. The active outflow caves of today are either right at river level, e.g. the Blue Waterholes at Cooleman Plain and Bubbling Spring at Yarrangobilly, or nearly so, e.g. Federation, Hollin and Coppermine Caves at Yarrangobilly and Zed Cave at Cooleman.

Along valley bottoms, even with an unreliable climate allowing rivers to dry up, there is likely to be water in planes of weakness in the rock persisting with embryonic speleogenetic preparation so there is a strong chance that fresh outflow cave development will soon accompany the downcutting of the streambed. For example Federation Cave and the lower level of River Cave soon developed to fulfil the function of the upper level of River Cave when the Yarrangobilly River put that out of action by lowering its bed. The interval is of small amplitude. Junction Cave Spring at Wombeyan has to drop down a little fall of 7 m to Wombeyan Creek; its replacement has yet to form.

The possibility that pace of incision may be too great for cave formation to match valley deepening on a greater scale is a real one. At Bungonia, the water from Main Gully Springs drops steeply nearly 100 m down to Bungonia Creek and limestone crops out between the two. The Efflux, which drains most of the caves on the southern side of Bungonia Gorge by a low gradient, probably mainly waterfilled passage from Odyssey Cave, feeds Breton Creek which then falls about 190 m down to Bungonia Creek. Although Breton Creek flows mainly over impervious rocks interbedded with limestone, previous geological mapping suggested there was no structural impediment to the development of caves in limestone along the strike for water to emerge at or close to the level of Bungonia Creek. On this basis it was thought that incision had been too rapid for cave formation yet to have taken place in the lower levels of the limestone strike belts (Jennings and others 1972; Jennings and James in press). However, more recent mapping (James, Francis and Jennings in press) indicates that faulting may have cut out part of one of the limestone belts near The Efflux and this may have caused its perched position. Whatever the final answer is in this regard, there can be no doubt that rapid incision has had an important effect on cave development at Bungonia because here vertical development is more pronounced than in any of the cave areas around Canberra which have been mentioned, and this is matched by the depth and narrowness of Bungonia Gorge. Of these vertically developed caves, the greater ones such Odyssey, Drum and Grill Caves have small catchments feeding them with surface runoff so they have vadose flow into them. However, some of the other deep shafts here rely on seepage water only for their formation as has been mentioned earlier.

Co-existence of Different Speleogenetic Actions

In the previous section the idea of one phase of cave development being succeeded by another of a different kind and so on in the evolution of the cave over time was stressed. It is important to be well aware, however, that different kinds of cave enlargement go on at the same time both in caves which are near together and within the one cave.

The great difference in nature between Dip Cave and the Punchbown-Signature and Dogleg group at Wee Jasper has already been underlined yet they occupy much the same position in the general relief of the Goodradigbee valley and must have formed at much the same time (Jennings 1967). The same is true of Basin and Bullio-Mares Forest Creek Caves at Wombeyan (Jennings and others in press). There also the active level of the long Fig Tree-Junction Caves system includes alternating vadose flow and epiphreatic sections along the streamway. Again this applies to the River-Murray Caves system at Cooleman Plain (Jennings 1969). As a model for interpreting cases of this kind there is an excellent account by Palmer (1972) of Onesquethaw Cave in New York State, United States, where the detail of the geological structure can be shown to be responsible for lengthwise variety of this kind. It is true that obvious structural controls are not evident in the Canberra caves of ours cited but this direction of detailed geological mapping is one which badly needs pursuing more rigorously here.

Palmer also stresses the important role of floodwaters in Onesquethaw and other caves, which really masks the differentiation between vadose flow and epiphreatic. This has already been emphasised with regard to caves around Canberra so liable as they are to large, rapid changes in discharges; cave rivers readily developed three-dimensional anastomosing complexes of passages (Jennings 1967a, 1968a). A surface stream is free to braid into many channels over its flood plain thus reducing rise in stage level; passages fill to capacity in caves in flood, forcing levels up to maintain high level passages in intermittent action along with lower ones carrying base flow. Palmer (1975) calls these floodwater mazes. One of the best active ones in Australia to my knowledge is in the Honeycomb Caves at Mole Creek in Tasmania.

Palmer's work in general draws attention to local factors of various kinds within active caves, inducing areas of different hydrodynamic development from that prevailing generally within each cave. This theme is particularly relevant in southeastern Australia as a result of various of the regional characteristics set out above. For instance, rockfalls and big inputs of allogenic gravels (which of course are especially liable to jam up at rockfalls) can bring about small sectors of phreatic action and of phreatic features in a prevailingly vadose cave, not only of epiphreatic action but also nothephreatic, as for instance in Old Inn Cave (Y10) at Yarrangobilly.

All this means that in working out the evolution of a cave, reliance on one or two scattered geomorphic features for inferring particular hydrodynamic contexts for the whole of a cave at a given stage of development must be avoided. Simple situations are and have been rare.

Effects of Climatic Change

The impact of climatic change on cave development in the Canberra area has been touched upon already once or twice. This again is a factor which needs exploring more thoroughly than has been done so far. Pursuing this will be helped by the reconstruction from other sources of the climatic history of the area (Bowler and others 1976). Study of glacial and periglacial geomorphology and pollen analysis of organic materials in the Snowy Mountains have demonstrated the occurrence of a colder period than at present starting at a little before 30,000 B.P. and lasting till around 10,000 B.P. There probably were earlier colder periods but no positive evidence survives. Since 10,000 B.P. there hasn't been much change in temperature though it was probably a degree or two lower about 3,000 – 2,000 years ago.

The direct effects of lower temperatures in the caves were probably slight, though angular material in the Antechamber of Murray Cave, Cooleman Plain, may have been due to frost wedging reaching into that chamber at the time there were glaciers in the Snowies. However, lowered temperatures resulted in reduced vegetation cover over some higher parts of the Southern and Central Tablelands and exposed soil and rock slopes to more rigorous weathering and mass movements of materials. At Wombeyan angular debris was fed by accelerated slope processes into the lowest entrance of Basin Cave (Jennings and others in press). Another consequence was that more material was fed into the rivers and this indirectly affected caves.

But perhaps the greater impact of temperature change on local speleogenesis was by its influence on evaporation, which altered the amounts of water available for cave formation substantially. Undoubtedly there were also variations in precipitation causing direct variation in water amounts for geomorphic action. The evidence, which survives for reconstruction of past climates, largely reveals changes in amounts of water in rivers and lakes; it is a much harder task to determine the extent to which these changes are due to alterations in evaporation or in precipitation, in other words in effective or in absolute precipitation. For cave study, this difference could be important because the two climatic elements may have different effects on stream inflow and percolation into karst rocks. For instance evaporation may reduce input of streams from surrounding rocks more than it reduces percolation of rain falling directly into the limestone. For the Snowy Mountains, Galloway (1963) has inferred that the small size of the glaciers which formed there in the main cold period, coupled with the estimated substantial temperature drop, implies reduced precipitation at that time. Nevertheless streams in the area probably had higher peak discharges and shifted bigger loads of sediment then (Ritchie and Jennings 1955). About this time also Lake George was much larger and deeper than at present (Coventry 1976) but water balance estimations show this was due to reduced evaporation, not to increased precipitation. Singh's pollen work at Lake George (Bowler and others 1976), though in an early stage, gives a preliminary picture of paleoclimatic history back to 50,000 – 60,000 years during which time temperatures were varying but always lower than they have been in the last 14,000. Effective precipitation was also varying and Lake George alternated between long periods of high level and of drying out.

Little or no work has yet been done to determine what effects these changes had on the caves around Canberra. The deposits in a dry valley on Cooleman Plain have been investigated (Jennings 1976b). It was formerly a blind valley, in form much like that of River Cave nearby, but then it was filled up to its threshold level by a mudflow from the igneous slopes above, which nowadays do not suffer such mass movements. This behaviour can be related to periglacial activity in the cold period of 30,000 – 15,000 years ago which also gave rise to periglacial blockstreams elsewhere on the plain. This fill blocked up the cave which must formerly have taken the stream that cut down the valley to produce the threshold. The stream, now flowing down the whole length of the valley, proceeded to sort the very mixed mudflow materials, redepositing first loose gravels, then a fine loam. Eventually the stream sank through superficial deposits at the head of its valley over the limestone. Close by, the South Branch of Cave Creek has buried, with coarse gravels, its main sink into the limestone; base flow still sinks here though at a higher level than previously and this may have increased the likelihood of flood flow travelling farther on into Ev's Cave, the overflow streamsink. Goede (1973) has described similar happenings in the Junee karst in Tasmania and caves at Mole Creek have been partially filled with outwash gravels from the ice-capped Lakes Plateau there (Jennings 1967). Such developments as these have drastic effects on developing cave systems, rerouting water flow significantly.

There was probably also the tendency to develop new caves through new points of input and augmentation of that input, i.e. there was the development of 'invasion' vadose caves (Malott 1937) as distinct from the normal 'drawdown' vadose caves such have already been described (Ford and Ewers (pers comm) There are peripheral channels along the sides of glaciofluvial and periglacial fluvial fans below the Great Western Tiers, which pumped water into the limestone alongside (Jennings and Sweeting 1959). Goede (1969) considers part of Exit Cave to be of similar origin. So there appear to have been contradictory effects in cold periods, filling and blocking some cave passages, opening up new ones. Permafrost which would have prevented the latter event was apparently absent from both the southeastern mainland and Tasmania. At Jenolan Caves there is evidence that both excavational and depositional effects of cold periods in the Pleistocene are involved significantly in the development of caves such as Mammoth.

It will have been evident from the preceding discussion that study of cave sediments is the main key to elucidating such climatic effects on cave development. The most detailed work on cave sediments so far in Australia has been that of Frank in the western Central Tablelands a little beyond Canberra's ambit. Some climatic history conclusions were derived from the cave sediments (Frank 1975) but perhaps of more direct relevance to the present theme is part of the story he established for Tunnel Cave at Borenore where a dry period around 28,000 B.P. permitted flowstone and dripstone to build right across a stream passage as a result of its reduced flow. Stream flow has been restored through it in wetter conditions since.

Speleochronology

There is great difficulty in giving ages to the caves around Canberra; this is part of the wider problem of the general denudation chronology of the Canberra district about which most divergent views have been held. Reliable dating means were just not available and one was forced mainly to proceed by dint of rather speculative inferences. Many of the methods for speleochronology set out by Ollier (1966) either have not been applied or were not applicable in this area. The situation is improving but there is a long way to go as yet.

The host rocks are very ancient and their age has little relevance for cave dating here since the voids in them were created very much later. Generally the area has been a land surface since before Permian time (c.280 million years) though the eastern margin including Bungonia was under the sea for a time within the Permian. Again this upper limit is well beyond the times in which the caves formed.

Dateable materials within the caves set minimum age limits for the spaces they partially fill but sometimes the cave geomorphology shows some chambers or passages to be younger than the dated deposits. Radiocarbon dating of charcoal and other plant material, animal bone and even bat guano in flowstone, as well as of flowstone itself, has been the chief absolute or physical dating method employed so far in Australian caves, unfortunately not yet within the Canberra area. It will be useful nevertheless to refer briefly to Frank's work on cave sediments from the western Central Tablelands by way of illustration. In the last 30,000 years, deposition has been the rule in Douglas Cave at Stuart Town, though one entrance has become blocked by this fill and another small entrance has opened (Frank 1969). Wellington Caves appear completely to antedate extensive fills, much of them mined out for phosphate; the sediments range back to 40,000 to 50,000 B.P. (Frank 1971). The Walli Caves failed to yield dateable material but the interesting sequence of sediments is effectively subsequent to the formation of the caves (Frank 1974). At Borenore two new cutoff passages have developed since sediments dated at 27,000 B.P. accumulated in an earlier one and Tunnel Cave was extended significantly headwards to a new entrance and its passages were deepened since 28,000 B.P. (Frank 1972, 1973). In both cases, however, the earlier phases of their development go back much further in time than the dated sediments.

Animal bone and human artefact assemblies from caves have been rendered useful as means of dating now that many sequences of cave deposits containing them have been radiocarbon-dated. It now appears that all extinct species belong to the Pleistocene so that deposits with such bones and so the containing caves are at least about 14,000 to 15,000 years old. A case in point is (or rather was) a cave at Wombeyan, practically sediment-filled and exposed in quarrying there, which included the bones of several extinct species (Hope in press).

As already mentioned, some superficial deposits at Cooleman Plain can be attributed by correlation, not by dating, to the last Pleistocene cold period established in the Snowy Mountains. They permit other inferences. For example, Barber Cave has two levels low down in Clarke Gorge which has a periglacial blockstream not far away, reaching down to about 15 m from its bottom (Jennings 1968b). It is likely that at least the upper level of Barber's had formed before this time. At Cooleman also, River Cave entrance lies in a dry valley with a threshold and with coarse aggradation deposits farther up which make it resemble the neighbouring dry valley with its threshold buried by a mudflow probably emplaced in a periglacial environment. Thus it is inferred that the tributary passage of River Cave leading down the main river passage is likely to be older than the last Pleistocene cold period also (Jennings 1969). Murray Cave, Cooleman Plain, exhibits three phases of development in its forward part (Jennings 1966). The middle appears to be related to a coarse aggradation terrace in the valley outside, again referable to colder conditions and the third phase includes at a late stage the frost-wedged gravels in the Antechamber. So it appears the two later phases of Murray Cave probably belong to the late Pleistocene. It is evident, however, from these examples that certainty and precision are rapidly diminishing when compared with Frank's results where cave deposits were dated.

In the future, however, a firmer basis can be expected reaching farther back into cave history when uranium/thorium dating of speleothems, particularly in conjunction with oxygen paleotemperatures, comes into use in southeastern Australia. This has proved itself in N. America and New Zealand already. Results of this kind will soon be forthcoming from Tasmania (Goede pers comm). Preliminary experiments with speleothems from Murray Cave, Cooleman, and from Fossil Cave – Hogan's Hole Extension show there are suitable materials for this kind of attack (James pers comm).

Much of the local cave history will, however, go back beyond the 300,000 year range of uranium/thorium dating and beyond this limit chronology of caves becomes much more difficult. For example, only very broad conclusions have been published about the age of the Wee Jasper caves (Jennings 1963, 1964). They formed subsequently to the time when a valley bench about 60 – 70 m above the present level of the Goodradigbee formed the valley floor. This valley bench is some 300 m below nearby plateau surfaces which carry basalt remnants only ascribable on stratigraphic evidence to the Tertiary as a whole.

However, recently potassium-argon dating of the Tertiary basalts here and elsewhere is helping to sharpen up the denudation chronologies of which cave developments form part. In the ranges west and southwest of Canberra the dated lavas all belong to the Snowy River lava province dated at 22–18 million years; the undated ones within the same area are assumed to be of the same age at present.

A few kilometres up the Wee Jasper Creek from the caves, basalt within 40 m of the valley floor and overlying river terrace deposits has been dated in this way and belongs to the Lower Miocene. Thus the oldest caves at Wee Jasper belong to the period since then but may well be of considerable age within it. Much erosion has taken place since, for example, the uppermost level of Punchbowl Cave formed.

There are problems in relating the lavas to the geomorphic history however. Thus at Yarrangobilly there are lavas on the limestone shelf in which the caves have formed. This suggests a close relationship between the date of the lavas and the beginning of cave formation. However, there is the difficulty that covering rocks on limestone are very liable to solution subsidence so that these lavas may have been lowered along with the limestone shelf through solution. The shelf surface may in part be younger as a geomorphic feature than the lavas forming as a rock. Solution subsidence disturbs the rocks lowered in this way and this provides a tool for resolving this issue.

The nearest basalt to Cooleman Plain is a cap on the top of Peppercorn Hill some 250 m above the Long Plain which is separated from Cooleman Plain by the ridge of the Cooleman Mountains. There are other hill caps in the area which suggest that they are residuals and the valley plains around have developed subsequently. But there are also valley fills such as have been described from Yarrangobilly so that this evidence is ambiguous about the age of the planation surface in the limestone at Cooleman Plain. A closer analysis of the geomorphology of the sub-basaltic surface in the whole area is needed. The oldest caves relate to the planation surface but most belong to the phase of incision of the gorges into it, indeed to late in that period. The evidence of dating from Wee Jasper Creek farther down the Goodradigbee valley has a bearing on developments here, since it shows that a good deal of the valley incision had taken place before the Lower Miocene (Rieder, Jennings and Francis in press).

At the present stage of investigations it is at Bungonia that the greatest chronological problems are found and further work is in progress at the present time. To do more than outline the nature of the problem would be inappropriate here. On the one hand evidence is accumulating that the uplift of the plateau which set in motion most of the cave development is very old. From their datings of basalts and the geomorphic relationships of the lavas, Wellman and McDougall (1974) consider there were two major phases of uplift, one in the early Tertiary and one ending some 10–15 million years ago. Young (1970, 1974) has argued that uplift was completed even earlier, some 25 – 30 million years ago, and additional evidence can be brought in support of his standpoint (James, Francis and Jennings in press). In discussion of Jennings (1975), Wellman pointed to a lava-filled valley along the Endrick River valley well upstream of Bungonia (Craft 1931); this is at a level which makes it likely that much of the Bungonia Gorge incision must have taken place before these lavas were emplaced and these are Eocene lavas, 45 – 40 million years old.

On the other hand, the gorge at Bungonia has the appearance of being a youthful geomorphic feature and it is only 80 km from the margin of the plateau. The Blockup in the Slot at Bungonia is the product of a huge but young rockfall and is emphatic evidence that widening of the gorge is actively in progress. One or two million years is the sort of length of time most geomorphologists would have thought necessary for headward erosion to have retreated from the edge of the plateau to the waterfalls and rapids at the head of Bungonia Gorge. Apart from some shallow cave development of phreatic aspect close below the plateau surface, the main cave development is active and vadose down to a more or less horizontal level of active, epiphreatic nature roughly 120 – 150 m below the plateau. Once again this cave development is youthful and no great age seems acceptable for it.

There is a very stern conflict here and though some suggestions have been put forward to mitigate it – Young (1974) relies on great resistance to erosion of the Permian sandstones of the lower Shoalhaven gorge to slow down headward retreat of erosion; James, Francis and Jennings (in press) point out that erosion may proceed much more slowly up small tributaries such as Bungonia Creek compared with the major rivers such as the Shoalhaven River – , more work will be needed to resolve it. Dating of more speleothems from the lower levels of the Bungonia deep caves should provide additional evidence to constrain theorising and may be rebuff some preconceptions about rates of gorge development and cave evolution.

Dating the caves around Canberra more precisely and reliably and determining the rates at which they have been excavated is one of the great fields for future speleology in this part of Australia especially.

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