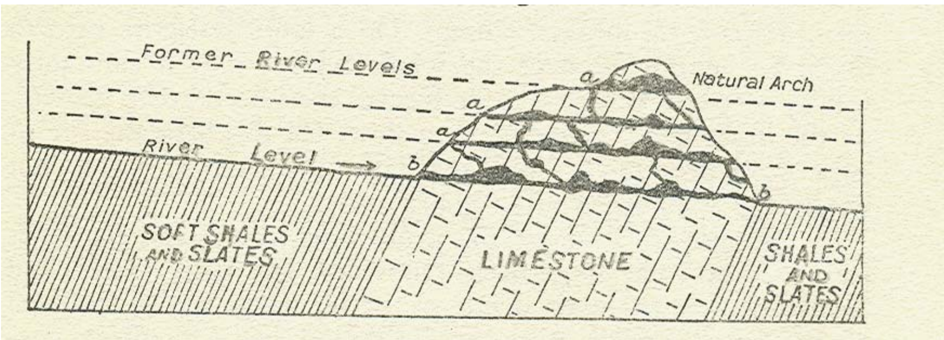
Figure 1. Origin of Caves in Steeply Dipping Limestone (Laseron, 1953)



AGE AND ORIGIN OF THE JENOLAN TOURIST CAVES

– Warren Peck *

INTRODUCTION

Research has established that the tourist caves at Jenolan are much older than had been anticipated and that their creation involved a complex sequence of events that differs from the previously accepted theories of limestone cave origin.

This paper briefly reviews the development of these theories over the past fifty years and considers the consequential implications for karst management at Jenolan, with particular reference to the explanations given to the thousands of tourists who inspect the Jenolan Caves every week. Whilst there have always been a few differing theories of cave origin, the radiometric age data has progressed the question of the age of these caves beyond just being a theory.

The comprehensive research that has now established the age of these caves (and is also unravelling their complex history) is largely the work of Dr. R. Armstrong L. Osborne of the University of Sydney and involves a publication history of numerous refereed papers in Australian and international scientific journals covering the past twenty four years. The references to some of his papers are listed at the end of this article.

DETERMINING THE AGE OF CAVES

The following example illustrates how we can arrive at the minimum age of a cave. The Jenolan Limestone was deposited in the sea about 420 million years ago (Ma). If a cave-shaped cavity within the limestone contains some other distinctive geological material whose age is known, and if it can be proved that this distinctive material formed in the cavity, then the cavity is at least as old as the material that fills it.

Lava and volcanic ash are distinctive materials that could enter a cave at some stage in its history. Volcanic material from nearby volcanoes could have entered the caves at least twice in Jenolan's history, the first about 390 Ma and the second about 340 Ma.

Illite is a clay mineral that can be created by a number of chemical reactions in the natural environment, such as the weathering of rocks to create soil and the breakdown of volcanic ash in heated groundwater.

Research has shown that 'illite is not an abundant component of sediments currently or recently deposited in Jenolan Caves' (Osborne et al, 2006).

Such recent sediments contain <6% illite and most contain <1% illite. Yet the cave samples, whose ages are given in this article, contain between 10% and 47% illite, suggesting that these ancient clays were formed from materials and under conditions that have not been abundant in the Jenolan environment for tens of millions of years (eg. volcanic ash and the heated groundwater associated with volcanic activity).

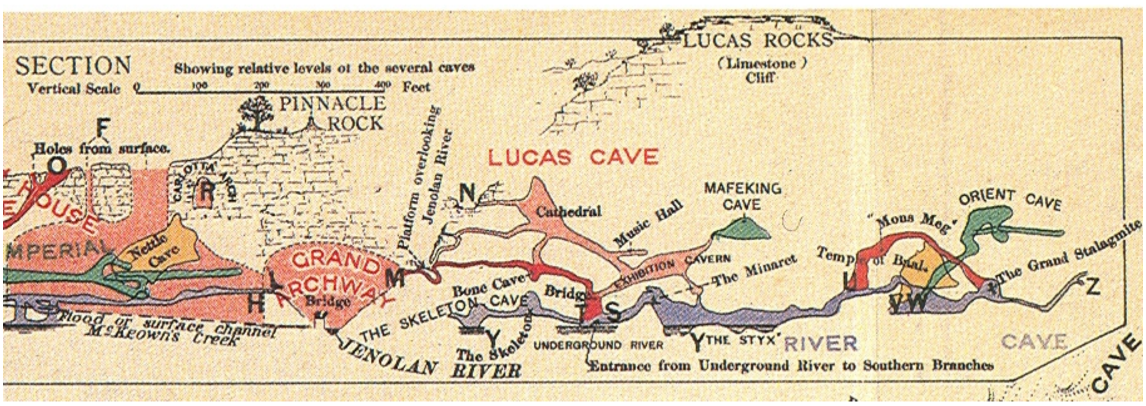
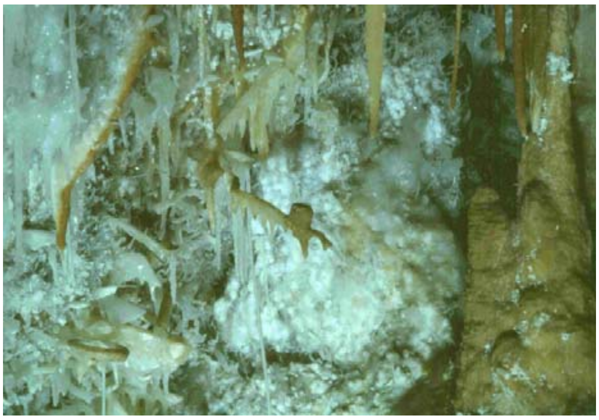


Figure 2. Section through the Southern Tourist Caves (Trickett, 1915)

Figure 3. 'The Jungle' is growing on a clayey sand layer in the Orient Cave with a 336 Ma Radiometric Age. (The width of the photograph is about one metre.)



The illite's 'atomic clock' is switched on as it is being formed. Modern science has the means of determining the age of illite. Electron microscopic examination of the illite can determine if it has been disturbed since it was formed. Newly formed illite has tiny platelets (often six-sided) with straight sides. If illite is moved, such as by being washed or blown along in the natural environment, the edges of the tiny platelets quickly break off.

However, knowing the minimum age of the caves does not tell us exactly how they formed. There are several theories about cave origin and the following paragraphs trace the development of these theories over the past fifty years.

CAVE ORIGIN EXPLANATIONS OF THE 1950s

The author worked as a casual guide at Jenolan over the period 1956 – 1961 whilst an undergraduate student in the field of engineering geology. Some of the cave guides of that period would talk in terms of millions of years after quoting rates of straw stalactite growth of 'one inch per one hundred years' or about a millimetre in four years. All the cave guides said rain water was mainly responsible for the erosion and decoration of the caves. Many guides indicated that underground rivers were the main agent of erosion. Most guides used the then available guidebook to the caves (Dunlop, 1950) as the basis of their commentary during cave tours.

Not all cave guides agreed with the suggestion in the guidebook that it was quite improbable that the age, even of the oldest caves, could exceed 500,000 years and hence the formations in the caves are not 'millions of years old'. The guidebook sourced this suggestion back to the paper by Sussmilch and Stone (1915), on the geology of the Jenolan Caves District.

Their reasoning was based on the assumption that the Jenolan Limestone had been deeply buried for more than 400 million years since its creation in the Silurian Period, until about one million years ago when it had been uplifted as part of the Great Dividing Range. Rejuvenated streams then commenced eroding deep valleys into the Highlands providing access to the limestone for rain water to initiate the cave creation process.

When one looks at Figure 1, a reproduction of a diagram from the popular 1953 Australian Physical Geography book, 'The Face of Australia', by C.F. Laseron, one can understand why many cave guides in the 1950s said that underground rivers were the main cave-creating agent in areas like Jenolan that have steeply dipping limestone beds. The original caption for the diagram in Laseron's book states it shows 'how caves are produced when a highly dipping bed of limestone forms a barrier across a river valley; (a) Entrances to caves on former river levels; (b) Entrance to present underground river.'

Figure 2, part of a survey section through the Jenolan Caves Limestone prepared by Oliver Trickett (whose plans and sections are still used to-day), shows no similarity to Figure 1. There is a zone about ninety metres thick above the southern tourist caves where there are no known caves. This can not be blamed on the local geology, as the almost vertically-dipping limestone beds containing the tourist caves extend up to the Lucas Rocks on top of the ridge.

There is an additional problem. With the exception of the Exhibition Cavern (created by extensive rockfalls), all the larger caverns in the southern tourist caves are vertical solution shafts that are closed at the top (known as cupolas). In the Orient Cave, two adjacent cupolas have coalesced at the top. The only present or past connection to other caves is at the bottom. There is no sign of any past rockfalls that might now obscure former connections to other caves at their top. These cupolas are not small shafts; the Temple of Baal, for example is thirty-six metres high and at least twenty metres across. Underground rivers are most unlikely to have created these cupolas.

The Chicago geologist, Harlen Bretz, had published (in 1943) the results of his detailed studies of about 100 caves in the USA and his work was known to some Australian speleologists in the 1950s. Bretz had concluded that most caves had characteristics which could only be explained by solution below the water-table (the phreatic stage). Bretz also recognised that sediment could find its way into the water-filled caves below the water-table and settle onto the floor, concentrating corrosion upon the walls and roof of these caves and partially filling them (the fill stage). The final (vadose) stage in the evolution of some caves could be their occupation by flowing rivers with turbulent water that generates 'scallops' or 'flutes' on the walls of such caves. Not only could this enlarge sections of the cave, but it could also flush out some of the fill.

The Orient Cave contains a horizontal, yellow clayey sand layer that was deposited in the Orient Cave over 320 Ma and is quite unrelated to the steeply-dipping bedding of the host limestone. This layer hosts some delicate helictites in the well-decorated display called 'The Jungle', shown in Figure 3. The sample for radiometric age determination was obtained from an undecorated site only a few metres from 'The Jungle'.

Clay deposits occur in all of the Jenolan Tourist Caves. The Temple of Baal Cave appears to have been almost full of clayey gravel at one point in its development, since clay and gravel pockets exist at many places on its walls, such as the wall in the background of Figure 4.

The presumption, amongst Australian speleologists at least, was that individual cave systems might experience up to three stages in their development whilst the one erosion cycle was progressively lowering the land surface and the stream beds. To the best of the Author's knowledge, the possibility was not discussed in the 1950s, that the Jenolan Caves might be many millions of years old.

There were never any suggestions that the caves might have experienced more than one erosion cycle, with the caves being dormant for tens of millions of years between each cycle due to burial by sedimentary rocks, such as the 260 Ma Snapper Point Formation.

CAVE ORIGIN EXPLANATIONS OF THE 1980s

It had become clear by the 1980s that the Great Dividing Range in Eastern Australia had come into existence much earlier than previously thought. Since the 500,000 year old age estimate for Jenolan was based on the age of the uplift of the Great Dividing Range, it appeared possible that the Jenolan and Wombeyan Caves might also have come into existence earlier than previously estimated.

The oldest known cave at Wombeyan was thought to have been 'formed well back in the Tertiary' (Jennings et al, 1982). As the Tertiary Period has been dated as commencing 66.4 Ma and finishing 1.8 Ma (BMR, 1992), a cave in the Great Dividing Range could thus have an age of tens of million years.

Professor Jennings also recognised that 'nearly all karst caves begin with phreatic solution by water moving slowly through parting planes in the bedrock, in many this is soon replaced by fast moving water . . . . However, in others phreatic conditions may persist and enlargement takes place without much change in the hydrodynamic conditions.' (Jennings et al, 1982).

Cave ages in the 1980s were mostly being expressed in terms of millions of years and not all karst caves needed an underground river. However, research showed that some cave systems (including Jenolan) in the NSW Highlands, near the Great Dividing Range, may have been subjected to multiple periods of karstification (Osborne, 1984). For example, carbonate crystals in Jenolan's Imperial Cave appeared to have been deposited in parts of an old cave system that subsequently 'controlled the development of parts of Imperial Cave.'

Osborne presented evidence that 'limestone terrains were exposed to subaerial conditions and thus karstification during Middle Devonian and Permo-Carboniferous times and that some karst elements produced during these times might survive today.' These geological formations date from between 260 million years and 390 million years before the present. Thus the search had started for caves that were hundreds of million years old.

EVOLUTION OF THE JENOLAN CAVES

A much longer article would be needed to fully describe the origin and the development of the Jenolan Caves. Only a few aspects relevant to understanding the radiometric age results will be mentioned here.

Most of the caves were initially dissolved below the water-table although some were subsequently invaded by flowing streams. Clayey gravel once almost filled the Temple of Baal and similar fills occur in other caves, particularly the Jubilee. The Temple of Baal is one of several domed, blind shafts (cupolas) that have been evidently eroded by ground water rising from below.

Figure 5 shows the roof of the Persian Chamber of the Orient Cave, which is an excellent example of a cupola. The roof here is almost the highest point in the Orient Cave. Figure 2 shows that the overlying limestone has no known caves. A prominent solution cavity is visible beside the shawl that could only have been formed if the cupola was full of water at the time.

There is no evidence that this 30m high chamber 'is a deep, symmetrically scoured pothole' (Dunlop, ninth edition, 1975). Likewise, there is no evidence of stream flow on this level of the Orient Cave.

Figure 4. Gabriel's Wing, Temple of Baal. Patches of clayey sediment occur on the wall behind Gabriel's Wing and the cave was once almost filled by this sediment.

Figure 5. The Banner of Jenolan shawl on the roof of the Persian Chamber of the Orient Cave. Note the solution cavity in the roof.

Dr Osborne has demonstrated that there is no need to equate big rivers with big caverns and passages in limestone caves. Paragenesis 'is the process of limestone dissolution at the upper limestone-water interface above an accreting sediment mass in a cave'.

'As the sediment continues to be deposited, water is forced up against the passage ceiling which it dissolves away. As a consequence paragenetic passages tend to have relatively flat ceilings. By forcing aggressive water up against the cave ceiling, paragenesis allows relatively small and slow water flows to produce high cave passages with large cross-sections.' (Osborne, 1999).

Paragenetic passages often contain concave wall niches that undulate quite independently of the geology. Osborne describes a paragenetic passage north of the Pool of Reflections in the River Cave.

Figure 6 shows the northern end of it, at the junction with the path to the Pool of Cerberus Cave. Concave wall niches are visible on the right-hand side.

The concept of the Jenolan Caves being deeply buried below the ground surface until the last few million years, envisaged the distinctive basal conglomerate beds (Snapper Point Formation) of the Sydney Basin being deposited (in the Permian Geological Period about 260 Ma) on a relatively flat erosion surface (peneplain) at an elevation of about 1180 metres at Jenolan. This is 270 metres above the limestone outcrop forming Lucas Rocks at elevation 910 metres, with the highest known tourist caves at about 820 metres elevation (Figure 2).

Several researchers have found erosion residuals of the conglomerate at the base of the Snapper Point Formation at various levels in the landscape near Jenolan, such as at 1040 metres elevation in the valley of Camp Creek to the south of the tourist caves.

One possible interpretation is that a valley floor had existed 260 Ma (million years ago), close enough to the limestone for karstification to be feasible down to at least the level of the tourist caves. Conglomerate resembling the Snapper Point Formation has been seen in the Dreamtime Cave at less than 900 metres elevation (Osborne, 1999). This latter occurrence overlies the northern end of the Jubilee Cave.

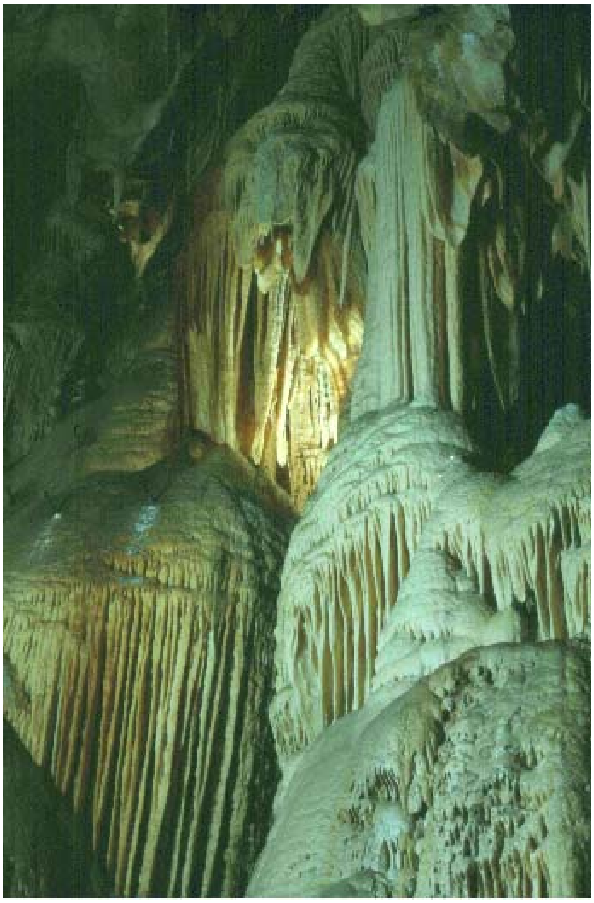
The Jubilee Cave consists of two main branches that terminate in highly decorated, gravel-filled shafts known as the Alabaster Hall and the Victoria Bower. The fill in both shafts appears to have lithified to conglomerate resembling that of the Snapper Point Formation, of Permian age.

Due to other commitments, the author has not yet had the time to prove, or disprove, the possibility that the Jubilee Cave already existed when the Snapper Point Formation was deposited at Jenolan, on an undulating erosion surface and spilled into the underlying caves, about 260 Ma.

A hole in the floor of the lower chamber of the Victoria Bower, gives access to 'tortuous and difficult passages, which open into grottoes and chambers of unusual beauty' (Trickett, 1915). The author has been into these passages, past the sign 'Sydney Smith Cavern', and seen clear evidence (vadose criteria) that streams once flowed out of these passages and into the main Jubilee Cave.

Figure 6. The north end of the paragenetic passage described by Osborne (1999) at the junction of the River Cave with the Pool of Cerberus Cave

Figure 7. Queen Esther's Chamber in the River Cave is a cupola. Nearby samples yielded radiometric ages in the range 335 Ma to 391 Ma



It is possible that sometime after the deposition of the gravel (? Snapper Point Formation), stream flow from the 'Sydney Smith Cavern' flushed out some of the gravel to create the Victoria Bower and allow deposition to occur on its walls from the carbonate-charged groundwater.

Research in the Jubilee Cave may well prove that it existed 260 million years ago and hence confirm the above suggested theory as to the origin of the Victoria Bower, as well as providing a much clearer picture of the evolution of the landscape in the Jenolan area. Such research requires researchers, time, laboratory studies and funds to make it happen.

AGE OF THE JENOLAN CAVES

Radiometric tests to determine the age of the caves were performed in 2005 on cave samples from eight locations using the Potassium-Argon method and on 11 zircons using the Fission Track method. This research included scanning electron microscope examination of the samples. The lead researcher was Dr Osborne of The University of Sydney and his co-researchers were Dr Zwingmann of Curtin University, Dr Pogson of the Australian Museum and Dr Colchester, also of the Australian Museum. Their paper was rigorously peer-reviewed prior to its acceptance for publication in the prestigious *Australian Journal of Earth Sciences*.

The Potassium-Argon dating of illite-bearing clays in the eight samples yielded ages from 394 Ma to 258 Ma. There were two distinct clusters among the dates. Seven dates ranged from 342 to 335 Ma and three dates ranged from 394 to 389 Ma. Under the scanning electron microscope, the illite grains showed no sign of damage to their crystalline grain boundaries due to transport.

Much detailed work was reported, establishing that these ages were not derived from rocks formed outside the caves, since there are no nearby rocks with matching ages. Fission track dating from one sample yielded pooled ages of 345.9 Ma (nine grains) and 207.2 Ma (two grains).

Osborne and his co-workers suggest that the 342 Ma to 335 Ma illite clays were most likely formed within the caves from the reaction of warm water with volcanic ash from eruptions likely to have occurred about 340 Ma during the intrusion of the Bathurst Granite (Osborne et al., 2006).

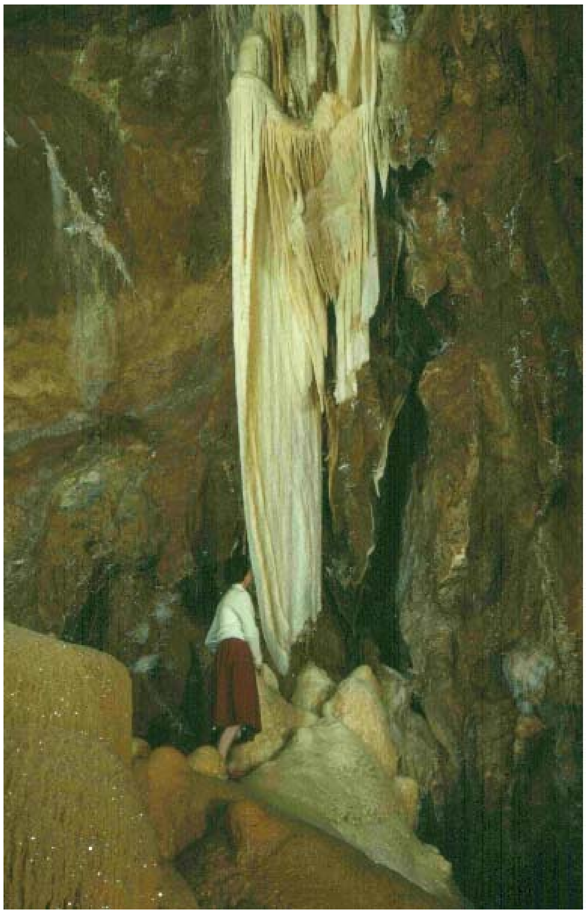


Figure 8. The Angel's Wing Shawl in the Temple of Baal Cupola is 9m long. A clay sample from floor level yielded a radiometric age of 325 Ma.

Figures 7, 8 and 9 show some of the decorations that have developed in the cupolas of the River and Temple of Baal caves. Samples from these two caves yielded ages in the range 325 Ma to 391 Ma. There is clear evidence in both of these caves that they were invaded by streams that flushed out much of the clayey fill material sometime more recently than 325 Ma.

On the floor in the north-east corner of the Temple of Baal, the pale yellow clay (? altered volcanic ash) with an age of 325 Ma is overlain by a pink fluvial sediment with an age in the range 240 Ma to 333 Ma. When these clays were viewed under the electron microscope, only the pale yellow clay showed no sign of having been transported and hence only its 325 Ma age is applicable to the Temple of Baal cave.

The clay matrix from the gravel with cobbles that appears to have once largely filled the Temple of Baal was sampled from the west side of the cavern and gave a radiometric age of 240 Ma. The clay matrix of this gravel showed fragmented clay platelets with rounded or broken edges suggesting transport (Osborne et al, 2006).

This, plus the presence of non-limestone pebbles and cobbles, suggests the gravel has been washed into the Temple of Baal more recently than the clayey gravel's creation age of 240 Ma.

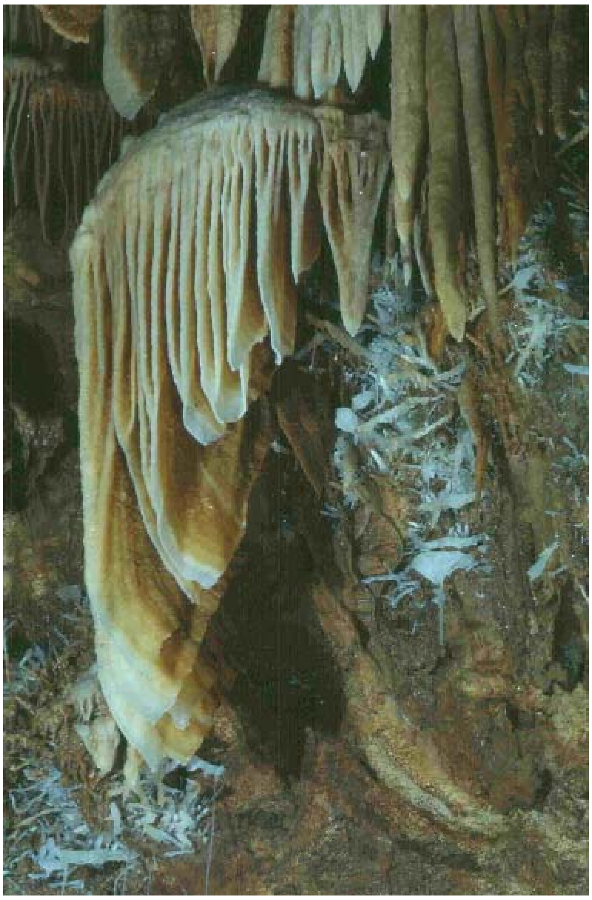


Figure 9. Pockets of clayey gravel occur at all levels on the walls of the Temple of Baal Cupola and host some outstanding shawl and helictite displays

The clayey gravel could have entered via the meandering stream channel that comes into the Temple of Baal near the Gem of the South. The flute and scallop patterns on this stream channel's walls, clearly indicate the flow direction was into the Temple of Baal.

It eventually became choked and has been partially dug out by generations of cave explorers, who call it the 'Baal Dig'. The route out of the Temple of Baal probably taken by the clayey gravel, is the stream passage that leads to the River Cave.

Guides Wiburd and Edwards, the discoverers of the Temple of Baal, needed to remove significant quantities of clayey gravel from this stream passage in order to gain access to this cave for the first time.

The Cathedral in the Lucas Cave is a cupola that possibly formed at the same time as the other cupolas for which we have radiometric ages. Figure 10 shows the Exhibition Cave which, as a collapse cavern, must post-date the initial cave development in its vicinity. The Exhibition Cavern is certainly more recent than the paragenetic passage that contains 'The Slide' and which can be seen, from the 'Lace Curtains' viewing platform, to extend along the western edge of the Exhibition Cavern's roof.

Figure 10. The Exhibition is a collapse cavern that post-dates the initial cave development in its vicinity. The iconic Broken Column is visible on the right.

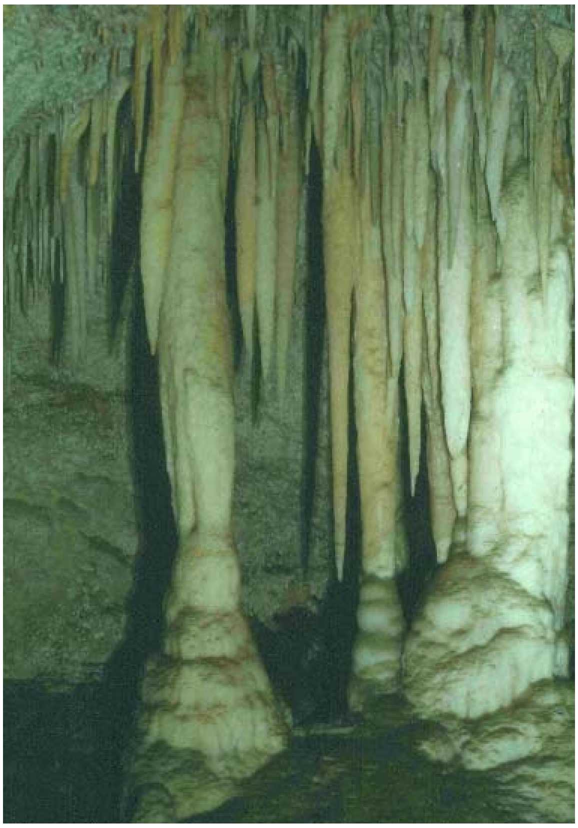


Figure 11. The Grand Stalactites, Imperial Cave. Radiometric dating of one sample of nearby clay gave ages of 341 Ma, 313 Ma and 258 Ma.

Figure 12. The Lucinda Cavern of the Chifley Cave. A radiometric age of 389 Ma was obtained for a blue clay sample from the Wilkinson Branch of the Chifley Cave.

TOURIST CAVES NORTH OF THE GRAND ARCH

The evolution of these caves is quite complicated, as was indicated in the earlier discussion about the Jubilee Cave, which has definitely undergone phreatic, filling and vadose stages of cave development, as part of possibly two cycles of erosion. The other northern tourist caves contain at least one cupola, which is in the Imperial Cave and which contains the 'Queen's Diamonds' as well as the 'Grand Stalactites' that are shown in Figure 11.

Whilst there is little doubt that the Underground River has flowed on two levels through the Imperial Cave, there seems to be little evidence of turbulent stream flow in the Chifley Cave. The Chifley Cave does contain paragenetic passages in the Katies Bower – Lucinda Cave – Madonna Cave area that have produced relatively large caverns. The Lucinda Cave is shown in Figure 12.

Radiometric dating of two cave samples, one from the Imperial Cave and the other from the Chifley Cave, gave ages of 258 Ma to 389 Ma. Electron microscopic examination of these two clay samples detected no sign of transport.

CONCLUSIONS

Whilst there have always been competing theories as to cave origin, the radiometric age data has progressed the great age of the Jenolan Caves to beyond just being a theory. The Jenolan Caves are not only millions of years old, as some of the cave guides used to say in the 1950s, they are hundreds of millions of years old and have a complex evolutionary history.

The Jenolan Caves pre-date the Age of the Dinosaurs, the Gondwana Break-up and the creation of the Sydney Basin. Australia was probably a long way from its current location on the planet when many of the caves were formed.

The challenge for management is twofold:

- How to present to the general public a factual, yet readily understood description, of the complex cave development processes that have occurred at Jenolan; and
- How to use the great age of the caves to promote all aspects of cave conservation, sustainable tourism and community awareness.

One of the first steps, for example, could be the preparation of additional printed material, for distribution to the guiding staff and the general public, about the origin and age of the Jenolan Caves based on all the available scientific research.

The full story as to the origin of the Jenolan Caves and the evolution of the landscape is still being pieced together. The research of Dr Osborne, Professor Jennings and others has already revolutionised scientific thought on this subject during the past fifty years. There is much more research that could be done and the Author has presented, as an example, a possible research project involving the Victoria Bower of the Jubilee Cave.

It is strongly recommended that management enthusiastically support such research, in partnership with cave conservation and community awareness programs.

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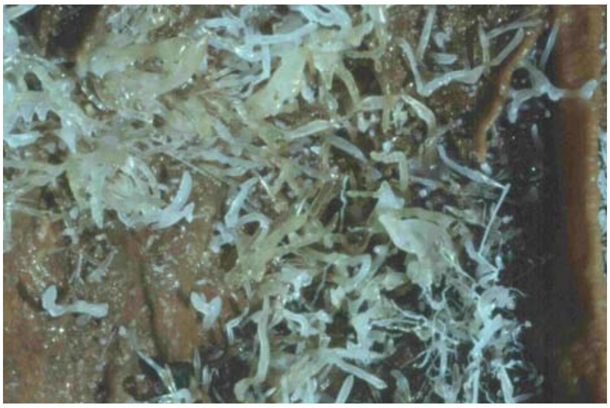
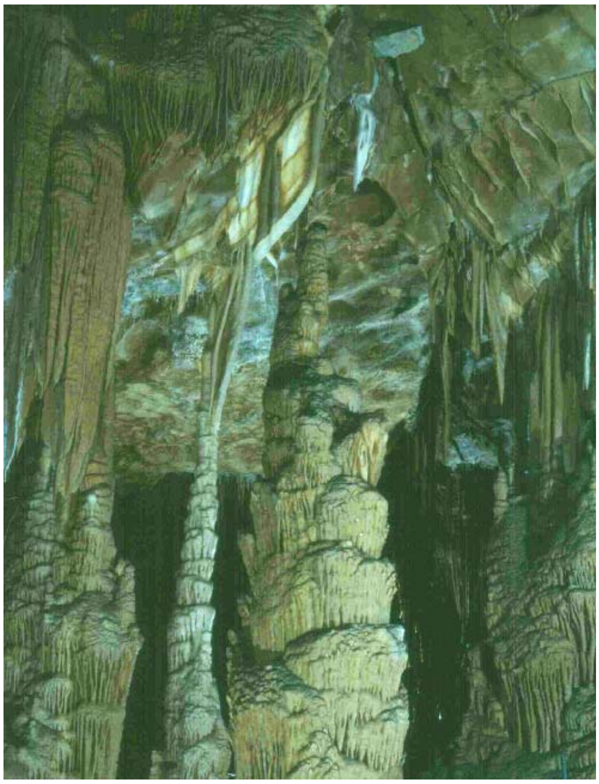
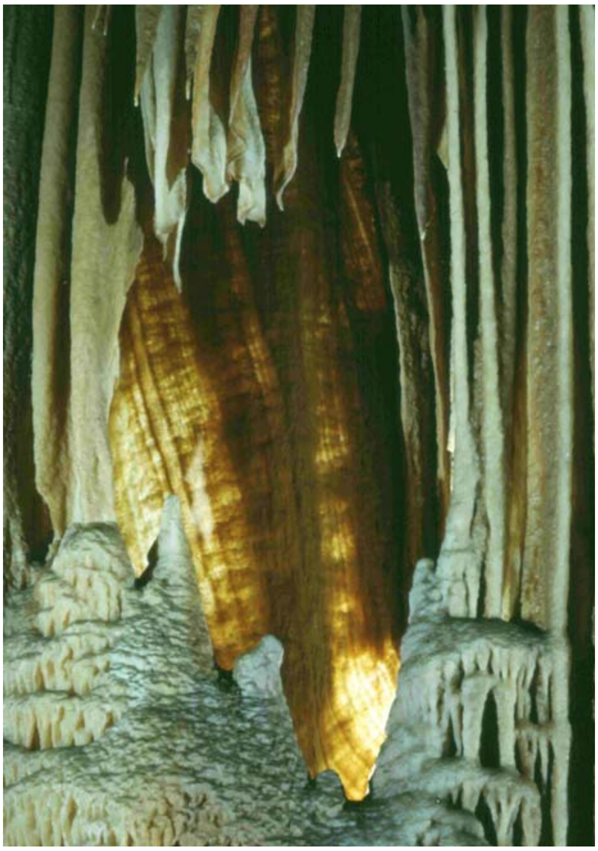


Helictites (some as fine as about 200 microns) growing on a very thin coating of flowstone covering a clay bank.



The Pillar of Hercules stalagmite in the Persian Chamber is about nine metres high



The Egyptian Shawl is located in the Orient Cave above the 336 Ma clayey sand layer at The Jungle

Four Metre High Formations in Katies Bower, Chifley Cave. Note the clayey gravel in the centre of the photograph