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THE WORLD'S OLDEST CAVES: - HOW DID THEY SURVIVE AND WHAT CAN THEY TELL US?

NAJSTAREJŠE JAME NA SVETU: KAKO SO SE OHRANILE IN KAJ NAM LAHKO POVEDO?

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R. Armstrong L. Osborne: The world's oldest caves: - how did they survive and what can they tell us?

Parts of an open cave system we can walk around in today are more than three hundred million years old. Common sense tells even enthusiasts like me that open caves this old should not still exist, but they do! Their survival can be partly explained by extremely slow rates of surface lowering, but this is not sufficient by itself. Isolation by burial and relative vertical displacement by faults are probably also required. Now one very old set of caves have been found, are there more of them? What can they tell us?

Key words: speleology, oldest cave, survival of old caves.

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R.A.L. Osborne: Najstarejše jame na svetu: kako so se ohranile in kaj nam lahko povedo?

Deli odprtega jamskega sistema, po katerem se lahko danes sprehajamo, so stari več kot 300 milijonov let. Zdrav razum celo takemu navdušencu, kot sem jaz, pove, da tako stare odprte jame ne morejo obstajati, a vendar so! Da so se ohranile, je lahko deloma vzrok v izredno počasnem zniževanju površja, toda to samo po sebi ni dovolj. Jama je morala biti najbrž tudi zasuta in s tem odrezana od sveta, potreben pa je bil tudi relativen navpičen premik ob prelomih. Zaenkrat je bil najden en sam niz zelo starih jam, ali jih je morda še več? Kaj nam lahko povedo?

Ključne besede: speleologija, najstarejša jama, ohranitev starih jam.

INTRODUCTION

In June 2004, when I last spoke here at Postojna about dating ancient caves and karst I found it difficult to not to reveal the exciting discovery which this paper follows (see Osborne, 2005). My collaborators and I had been convinced since mid 2001 that sections of Jenolan Caves in eastern Australia had formed 340 million years ago. We had to ensure that our story was published and that we could convince others. The issue was not whether the dates themselves were correct, but did the evidence really mean that the caves containing the clays were of such a great age. This took four years of intensive work on the clays and additional dating.

Now after the publication of the results (Osborne *et al,* 2006), and the following media interest; it seems appropriate to reflect on the significance and implications of the survival of Early Carboniferous open caves.

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THE POTENTIAL FOR CAVES/SECTIONS OF CAVE TO HAVE A GREAT AGE

Despite many years of working on palaeokarst, I initially found the Early Carboniferous (340 Ma) K-Ar dates for unlithified clays in Jenolan Caves incredible (Figure 1).

Fig. 1: Plastic illite–bearing clay, mustard yellow, in the River Cave, Jenolan Caves, NSW Australia. The < 2μm fraction of this clay was K-Ar dated by Osborne et al., (2006) at 357.30 ± 7.06 Ma.

As I pointed out in 2004 (Osborne, 2005), some Permian landforms do survive relatively intact in Australia. Even a Late Carboniferous age would not have been too surprising, as a Late Carboniferous landsurface has been exhumed at Jenolan from below the overlying Permo-Triassic Sydney Basin.

An Early Carboniferous age seemed challenging for two main reasons:

1 The 340 Ma age sits in the middle of the accepted timing for the last folding event in the area (350-330 Ma). Not only the caves, but also the relatively undeformed and well-lithified caymanite deposits they intersected had to be younger than this event. The clay dates upset the accepted chronology for the area and suggested that the last folding was older than previously thought.

2 The 340 Ma age is older than the accepted emplacement age for the adjacent Carboniferous granites (320 Ma). The plateau surface adjacent to the caves intersects granite plutons. Why didn't the process that exposed the plutons wipe out the ancient caves?

My opponents believed that while other landforms in Australia were old, the caves were not. They argued that there was no demonstrably old sediment in the caves. I have already discussed this argument elsewhere (Osborne, 1993a, 2002, 2005). The Early Carboniferous clays from Jenolan are the first evidence for ancient sediments in Australian caves accessible to humans, but they make the problem of the survival of ancient caves even more difficult, because they are so very old.

If we think about the geological history of karstification at Jenolan then the formation of caves in the Carboniferous should not be surprising. The best dates for the Jenolan Caves Limestone put it in the Latest Silurian (Pridoli, 410-414 Ma)(Pickett, 1982).

As well as telling us about the 340 Ma event, the K-Ar clay dating indicated that the limestone underwent a pre-tectonic period of cave development in the Early Devonian before 390 Ma when the caves were filled with the unconformably overlying volcaniclastics. There was also a post-tectonic period of ancient speleogenesis before a marine transgression filled the second generation of caves with lime-mud and crinoidal debris. I suspect if we had announced a third-phase of lithified palaeokarst some 340 million years old at Jenolan, there would have been little reaction, although the problem of its survival and the problem with the timing of folding would have been the same as the problems with our relict sediments.

It would not be surprising for limestone anywhere in the world to have undergone speleogenesis some 70 Ma after its deposition. The development of a modern cave in Late Cretaceous limestone is hardly unusual.

So, what is the problem? I suspect that while geomorphologists think surface lowering will destroy old caves, many geologists expect that:

1 open caves fail relatively quickly by breakdown (by analogy with mines and quarries)

2 palaeokarst caves only survive because they are filled with rock; the rock supports the roof preventing destruction due to breakdown.

3 cave sediments become lithified quickly, so old unlithified relic sediments cannot exist

These ideas are refuted by the findings of palaeokarst workers, surface cavers and the oil industry so I will not expand on them here, rather I will concentrate on geomorphological challenges to the survival of 340 million year old caves.

HOW COULD THEY SURVIVE?

WHY CAVES MAY SURVIVE LONGER THAN SURFACE LANDFORMS

Landforms are always under threat from the processes of weathering, incision and surface lowering. Weathering in the normal sense of the word is irrelevant in karst since, except in the case of Nadja's incomplete solution (Zupan-Hajna, 2003), carbonate weathering results in almost total removal of the rock mass. Incision may re-activate or expose ancient caves, but will rarely affect enough of the rock mass to lead to the destruction of ancient caves. It is surface lowering that is the greatest threat to ancient caves and the main process that leads to their late stage modification into unroofed caves. What processes may protect caves from surface lowering?

Protection by the rock mass

Since caves form below the surface, there is a thickness of rock between them and the zone where surface lowering is progressively removing the surface of the Earth. This means that caves have a head start in survival compared with surface landforms of the same age. Caves unroofed at the surface are always substantially older than the surface in which they are exposed.

Isolation and "karst resistance"

Not a lot happens once a cave space enters the vadose zone, there may be breakdown or speleothem deposition, but many cave openings just sit there, inactive while the water is directed through active conduits at a lower level.

The "god" that protects cave walls

Apart from speleothem and lithified sediments that may outlive all of the cave they formed in (Figure 2), it is the walls of a cave that survive the longest, right up to the very last stage of an unroofed cave (Figure 3).

Why don't the cave walls fail and simply fall into the void beside them and why don't they allow the whole cave to fill with speleothem during its siesta in the vadose zone? Some process must protect cave walls from failure and penetration by potentially lethal vadose flow. I am indebted to Andrej Mihevc for the concept of a '"god" that protects cave walls'. I am sure this god is a useful addition to the karst panoply.

Three factors are probably important for the survival of cave walls, particularly in teleogenic karsts: -

- rock strength
- Slow and gentle cave excavation, leading to gradual stress release (caves are not mines or tunnels)
- Degassing and precipitation from seeping water makes cave walls self-sealing

Fig. 2: Speleothem, exposed on surface above Dip Cave, Wee Jasper, NSW, Australia. Cave entrance can be seen top of photo. This speleothem has outlived all of the cave it formed in.

Some cave walls do fail for a variety of reasons. We can observe this in many breakdown chambers and it is possible to recognise the sources of the weakness in the walls that resulted in their failure.

Lack of substantial entrances

Some caves, e.g. cryptokarst caves of thermal /hydrothermal origin, may have no entrances or very poor connection to the surface. If there is no entrance or surface connection then surface processes cannot get in and modify the cave.

Entrance Blockages

It is very easy for cave entrances to become blocked. Prograding entrance facies talus cones reaching the ceiling, talus from the surface or breakdown, growth of flowstone masses, logs, vegetation and biogenic deposits such as guano piles can all easily block cave entrances. With a small amount of vadose cementation, these blockages can become effectively permanent and the cave can become isolated.

Fig. 3: Looking towards the surviving cave wall from the floor of an unroofed cave, Trieste Carso, Italy.

Protection by filling
If a cave is filled with easily removed material, it is possible for the cave to remain "fossilized" for a geologically significant time and then become exhumed. If the fill is impermeable to vadose seepage, it will not become cemented. Even if it is cemented, if the fill contains minerals that are unstable when exposed to oxygen-rich vadose water it can be removed from the cave with little effect on the enclosing walls.

Protection by cover/burial
Cover by sediments, volcaniclastics or lava flows can protect not only the caves, but also surface karst landforms. For the process to be effective, the cover must be removed without a great effect on the underlying older karst. It helps if the cover consists of relatively weak rock or of rock that is easily weathered. An outstanding example of this process is the burial by Permian basalt and later exhumation of the Shinlin karst in southern China.

DENUDATION RATES

Both biblical prophets and geomorphological pioneers predicted a flat future, the "rough places a plain" of Isaiah 40:4 and the peneplanation of W. M. Davis. While peneplanation may be out of favour, surface lowering is a real phenomenon. The problem for survival of old caves is that even with the slowest rates of surface lowering most Mesozoic and all Palaeozoic caves should have been destroyed, except those that have been deeply buried and later exhumed following tectonic movements.

In some parts of Australia, extremely low denudation rates apply. Wilford (1991) reported rates as low as 0.5 metres per million years in the Officer Basin of Western Australia over the last hundred million years.

Surface lowering rates in the eastern Australian highlands, where Jenolan Caves are located, are said to range between 1-10 metres per million years (Bishop 1998). If this is so, then the limestone exposed at the surface today in these areas was between 65 and 650 metres below the surface at the end of the Mesozoic. While these rates are slow by world standards, they are not slow enough to account for the survival of extremely old features.

Surface lowering and early incision may be slower than we think
Studies of past erosion rates in the Shoalhaven Catchment in eastern Australia by Nott *et al.,* (1996) show that we must approach incision and denudation with some care. Their relevant findings are that:

- summit lowering and scarp retreat were insignificant when compared to the process of gorge extension
- the rate of summit lowering was 250 times less and the rate of scarp retreat was 15 times less than the rate of headward advancement of gorges
- stream incision in the plateau upstream of the erosion head is very slow compared to the rate of gorge extension
- there was "insignificant lowering of the interfluves throughout the Cainozoic" (Nott *et al.,* 1996, p 230)
- "Over the long term, the highlands…will become considerably more dissected well before they decrease substantially in height or are narrowed" (Nott *et al.,* 1996, p 224)

The stream incision rate is important when we consider the age of relict caves. If incision rates early in the history of the landscape are much slower than at later stages, present incision rates will lead us to seriously underestimate the age of relict caves located high in the sides of valleys.

If lowering of interfluves, i.e. surface lowering, is much slower than incision, scarp retreat and nick-point recession then plateau karst, high level caves and surface caves exposed on hilltops could be very much older than we have previously thought. In dissected terrains the caves will not just be *as old as the hills,* but considerably older.

TECTONIC PROCESSES ARE NECESSARY FOR EXTREME SURVIVAL

Low denudation rates, low relief and low rainfall, the Australian trifecta, can only go so far to preserve old landforms. Stephen Gale recognised this point: "Although low rates of denudation are an important factor in ensuring the survival of ancient landscapes, this alone is inadequate as an explanation of the maintenance of landforms over ten and even hundreds of millions of years" (Gale, 1992, p 337). Gale went on to discuss how denudation needed to be localized if old landsurfaces were to survive. One way the landsurface can be isolated from surface lowering is through the relative adjustment of adjacent blocks by faulting.

The Fault-Block Shuffle

The problem at Jenolan is the elevation of the old caves relative to the adjacent plateau surface. The plateau surface to the south of Jenolan Caves exposes and intersects post-tectonic Carboniferous granites, thought to be 320 million years old. Figure 4 is a cartoon drawn to explain in simple terms how the caves may have survived.

The caves must have been relatively close to the surface when the cupolas formed and the volcanic ash that formed our old clays entered them (Step 1 in Figure 4).

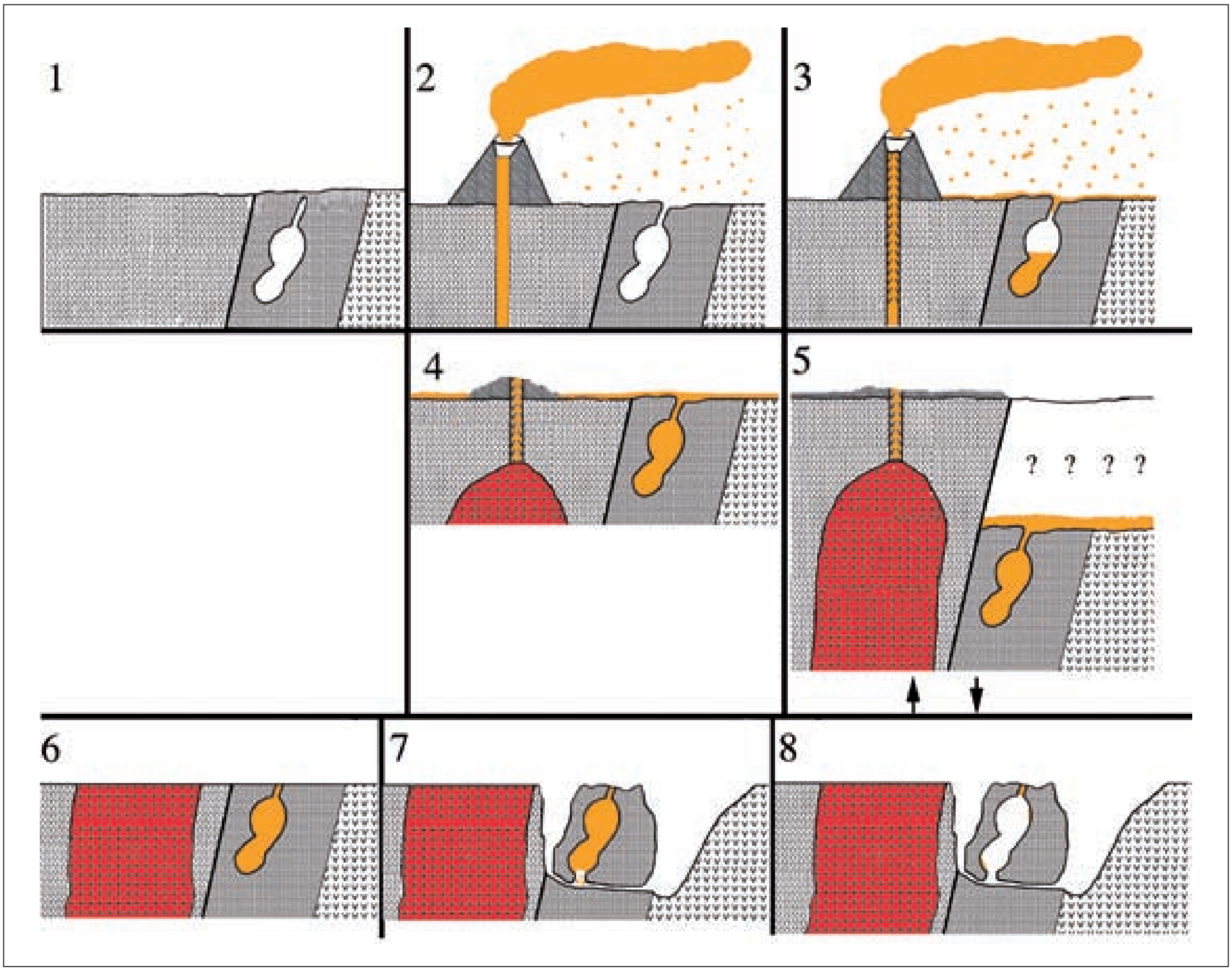

Fig. 4: Cartoon of postulated events at Jenolan Caves to explain the survival of caves with Carboniferous clays

1 *Cave excavated by thermal processes following folding of limestone*

2 *Volcano erupts; tephra falls to ground and enters caves.*

3 *Fine tephra begins to fill caves and reacts with water in caves to produce clay minerals. These clays have been dated at 340 million years.*

4 *Volcano stops and begins to be eroded. The caves are full of clay. Granite intrudes the rock near the caves (? 320 Ma).*

5 *The rock mass containing the granite moves up along the fault, while the rock mass containing the caves moves down.*

6 *Late Carboniferous: At least 8 kilometres thickness of rock is eroded away, probably partly by glaciation. This cuts off the top of the granite and brings the cave back close to the surface.*

7 *Late Mesozoic: Valleys erode into the surface and a new stream cave forms below the level of the filled cave. The clays, still soft, are undermined. They fall down and are carried way by the stream.*

8 *Today: Almost all of the 340 million year old clay has now been removed from the caves, small remnants are found and dated.*

Even if the granites did form close to the surface, something between hundreds of metres and a few kilometres of rock must have been removed from the plateau surface to expose the granite. This amount of surface lowering should have removed any older caves, particularly those shallow enough to fill with surface-derived sediment.

For the caves to survive there must have been a relative change in elevation between the mass of rock intruded by the granite and the mass of rock hosting the caves (Step 5 in Figure 4) before significant regional denudation took place.

For the sake of simplicity and because the history is not well understood, several steps have been left out in Figure 4 between Step 6 and Step 7. In the Late Carboniferous, the upper sections of the present valleys were incised and fluvial caves formed. These filled with glaciofluvial sediment and the whole landscape was buried under the Sydney Basin.

In the late Mesozoic, the Sydney Basin was stripped back and the valleys re-juvenated. New fluvial caves formed below the level of the old filled ones (Step 7 in Figure 4). Underhand stoping has now removed most of the old clay and only tiny remnants of clay remain in the caves.

WHERE ARE THE OTHER OLD CAVES?

When speaking here in 2004 (Osborne, 2005) I suggested a number of characteristics of localities where one might expect to find very old caves, interestingly Jenolan has only some of these. So how might we recognize "funny old caves" and ancient cave sediments?

"ABNORMAL CAVES" AND "ABNORMAL" SECTIONS OF "NORMAL" CAVES

My work on palaeokarst in caves and on non-fluvial cave morphology frequently takes me to caves that others regard as unusual. The Carboniferous clays from Jenolan are found in cupolas and other non-fluvial sections of the caves. Interestingly, these same sections of cave also intersect caymanite palaeokarst.

Fieldwork on non-fluvial morphology in Europe during 2005 took me to Belianska Cave in Slovakia and Račiška pečina in Slovenia. Co-incidentally, (or not) these are the same localities where Pavel Bosak and co-workers have found the oldest relict cave sediments in Europe (see Bella *et al.,* 2005 & Bosák *et al.,* 2005).

Non-fluvial caves, the *per ascensum* caves of Ford (1995), are characterised by being isolated from or poorly integrated with the modern hydrological system. Some have no natural entrances, while others have poor connection or secondary breakdown entrances. This gives them a head start in the survival stakes when compared with fluvial caves. Generally odd caves may survive longer than normal ones.

THE OLDEST CAVES ARE NOT ALWAYS AT THE TOP

When I first discovered the caymanite deposits in Jenolan Caves in the 1980s, I could not understand why they were intersected by cave passages at low levels in the limestone mass, not by (older) high-level passages. I did not realize then that while level in the landscape is a good indicator of the age of fluvial caves, it has little to do with the age

Fig. 5: Palaeokarst sandstone filling spar-lined tube intersected by more recent cave in the entrance area of Lucas Cave, Jenolan Caves, NSW, Australia. The strongly cemented sandstone is younger than the plastic clay shown in Figure 1.

of non-fluvial caves. In fluvial caves you look to the top for the old sections of cave, but in non-fluvial caves, you must look high and low.

RECOGNISING OLD SEDIMENTS

How can we recognise very old relict sediments in caves? The old clays at Jenolan were not found by looking for old material, we were originally looking for unusual minerals. The clays that looked different contained larger than normal amounts of illite and so we were able to date them. After the first old date, samples were chosen strategically, to get the maximum amount of chronological information from the minimum number of samples. This was only possible because there were existing palaeokarst and cave morphology stratigraphies to test (Osborne, 1999).

Unconsolidated Relict Sediments May Be Older than Lithified Palaeokarst Deposits

In my last presentation here, I raised the idea of the *lithification trap:* the idea that strongly lithified cave deposits and palaeokarsts may be *younger* than some unconsolidated or uncemented cave sediments (Osborne, 1995). This makes sense if we think about flowstone growing over mud and recognise that cementation, rather than compaction is the main agent of lithification in caves. Above ground geologists often find this idea conceptually challenging.

At Jenolan Caves, a crystal-lined cave passage is filled with strongly cemented sandstone (Figure 5). We have no problem with the sandstone being younger than the crystal, but stratigraphy suggests that this sandstone is younger than the unconsolidated clay shown in Figure 1.

WHAT CAN THEY TELL US?

GEOLOGICAL HISTORY OF THE CAVES

During the 1980s and 1990s, the aim of my research on palaeokarst was to show that speleogenesis and karstification in eastern Australia had a *geological* history (Osborne 1984, 1986, 1991b, 1993 a & b, 1995, 1999). That is, palaeokarst deposits intersected by *"modern" accessible* (open) caves indicate repeated periods of cave development at the same locality over periods of hundreds of millions of years. Cavities filled with strongly lithified palaeokarst deposits represented the older periods of cave development.

The discovery of 340 million year old clays in open accessible caves at Jenolan (Osborne *et al.,* 2006) demonstrated something significantly different. The open caves themselves, not just cavernous karsts, can have developmental histories extending over geologically significant periods of time (i.e. hundreds of million years).

Not much happens during the life of an old cave; they just snooze like an old pet cat. Sometimes dramatic events above, below or beside the cave may wake it from its slumber and leave their mark for us to find in the future.

GEOLOGICAL HISTORY FROM THE CAVES

Much has been said about the *potential* of the stratigraphic, geomorphic and climatic record in caves. Even the most generous previous estimates for the age of caves (not palaeokarst) suggested that such evidence would be limited largely to the younger end of the Cainozoic, and might perhaps in places like eastern Australia with old landscapes extend to the late Mesozoic. The survival of Palaeozoic open caves presents a new vista of using caves as a source of geological information. Both ancient caves and palaeokarst deposits could contain records of "missing sequences" for which there is no other record. While there has been significant progress in reading the ancient record of palaeokarst, lack of suitable dating techniques and a lack of expectation make geological history from the caves an open and uncultivated field.

Evidence for Global Events

Cave sediment research, particularly in the UK and Australia, began with a focus on a geological problem of global significance. Today we call it the Pleistocene extinction. The protagonists at the time saw it in terms of the "deluge" and the extinction or not of "antediluvian" faunas (see Osborne 1991a). Caves were an obvious focus for this research as Pleistocene vertebrate fossils occur in great abundance in the red earths of caves throughout the globe.

If the surface of some interfluves dates back to the Mesozoic, then ancient caves have the potential to contain evidence of the K-T boundary. What signal should we expect to find in the caves from the K-T event and how would we recognise it? Commentators have suggested that the K-T event involved dramatic changes in the pH of meteoric water, with strongly acidic rain falling from the sky. If this were sustained it should have left an imprint of extreme surface karstification and enhanced vadose and fluvial speleogenesis. Given how effectively caves have trapped Pleistocene loess, we might also expect to find iridium-rich silt in caves that were open at the K-T boundary. I don't know if anyone has looked, but perhaps they should.

Caymanites & unknown transgressions

Lazlo Korpas has been able to make great progress in understanding the evolution of the karst of Hungary by dating caymanites, because these contain fossils and they correlate with magnetostratigraphy (Korpas, 1998, Korpas *et al.,* 1999). Caymanites provide very useful evidence for marine transgressions (Korpas, 2002).

Caves intersect caymanites in at least six karst areas in eastern Australia. None of the caymanites have been directly dated. The 340 Ma old caves at Jenolan intersect caymanites, indicating a minimum age. The eastern Australian caymanites indicate one or more marine transgressions, probably in the Early Carboniferous for which there is no other geological evidence.

Volcaniclastic cave sediments/palaeokarst

Given the close physical relationship between stratovolcanoes and carbonate terrains in island arcs and active margins, volcaniclastic cave sediments and palaeokarst deposits should be common in both modern and ancient island arcs and active margins. There seems, however, to be scant reference to such deposits in the literature. Perhaps this is due to the concentration of karstological effort on Tethyan karsts.

Volcaniclastic cave sediments and palaeokarst deposits should be expected to occur around the Pacific rim, particularly in volcanically active island arcs e.g. Indonesia, Philippines, Malaysia, Japan, New Zealand and in southern Europe (Mts Etna and Vesuvius). They should also be expected where I work in the early Palaeozoic island arc environments of the Tasman Fold Belt of eastern Australia. While andesitic and silicic stratovolcanoes are likely to be the most common sources of tephra for volcaniclastic deposits in caves and karst depressions, basaltic tephra can also fill caves.

Five volcaniclastic palaeokarsts and volcaniclastic relict sediment deposits, including the 340 million year old clays, have now been recognised in eastern Australia (Table 1). It seems likely that more will be recognised, given that many of the cavernous Palaeozoic limestones are overlain by volcaniclastics.

Tab. 1: Volcaniclastic Palaeokarst and Relict Cave Sediments in eastern Australia

Type	*Likely Age*	*Karst Area*	*Chemistry*	*Reference*
Pk	? Tertiary	Crawney Pass	Basaltic	observed by author
Pk	Mid Devonian	Jenolan	Silicic	Osborne *et al.* 2006
R	Early Carboniferous	Jenolan	Silicic	Osborne *et al.* 2006
Pk	Mid Devonian	Wombeyan	Silicic	Osborne, 1993
Pk	?	Wellington	Silicic	Osborne in prep

Pk = palaeokarst
R= relict cave sediment

SPECULATION

We still know very little about extremely ancient caves. There are good prospects for making new geological discoveries in very old caves. All we have to do is identify funny old sediments in funny old caves, ascertain their meaning and find ways to date them. This sounds easy, but it is not.

The Jenolan team consisted of a karst geologist, a dating guru (essential so there is no argument about the technical aspects of the dates) and two mineralogists. It took six frustrating years and a sponsor with deep pockets to get the work completed and published.

A new world of geology of and from ancient caves awaits those with a stout heart, a thick skin, a good sponsor and eyes for caves and sediments that don't seem quite right; something like the qualifications for Antarctic explorers.

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