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Sand Speleothems: an Australian example

K. G. Grimes

Abstract

Sand speleothems have formed in sea caves at Loch Ard Gorge, Victoria, Australia, by the localised precipitation of calcium carbonate in loose sand that fills the caves. Calcite-saturated waters have entered the caves from the surrounding porous limestone, either dripping onto the sand, or seeping directly into it from the walls. Removal of the uncemented sand has exposed the cemented formations which have shapes analogous to those of conventional stalagmites, stalactites and shelves.

Keywords: *caves, karst, sand speleothems, concretions, Australia.*

Introduction

Sand speleothems are small to medium-sized features composed of cemented sand which are found within caves that contain, or once contained, sandy sediments. Hill & Forti (1997, p.219-222) report a variety of sand and mud speleothems that have been found in caves. They describe several types of feature, with "stalagmites" being the most common, and list several quite distinct processes which have been suggested for their formation. Sand speleothems do not appear to be common in the caves of the world, but that might be partly because their significance was not realised.

Setting

This paper describes sand formations found in caves at Loch Ard Gorge, Victoria. Loch Ard Gorge is a deep ravine, with associated caves, cut into the cliffed limestone coast of the Port Campbell area, in western Victoria (Figure 1). The gorge is named from the shipwreck of the *Loch Ard* which occurred in 1878, and has two caves that are named after the only survivors of the wreck, Tom Pearce and Eva Carmichael, who sheltered therein. In addition to the two main caves, Pearce Cave (3SW-2) and Carmichael Cave (3SW-3), there is also a smaller cave which I shall refer to as The Alcove (3SW-29).

The host rock is a soft, porous, Miocene marine limestone, the Port Campbell Limestone (Abele et. al. 1988), that forms coastal cliffs about 30m high. The caves are primarily sea caves, but they also show some karst features. It is probable that marine erosion has intersected prior karst cave passages and enlarged them. Both caves contain numerous normal calcite speleothems; the end chamber of Pearce Cave is particularly well decorated with short stalactites, some columns and flowstone floors. Pools here once contained "cave pearls" (described as "pisoliths" by Baker & Frostick, 1951, who also provide a detailed description of the caves), but those have all since been collected by visitors. An underground stream rises at the back of Pearce Cave and flows out onto the beach.

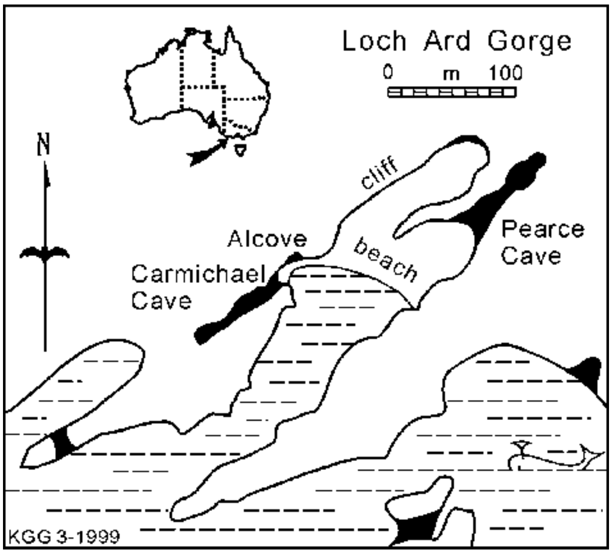

Figure 1: The caves of Loch Ard Gorge.

The gorge is a well-known tourist site, and both it and the caves are heavily visited. Access to Carmichael Cave is not possible at high tide, and The Alcove can also be cut off at times, particularly in rough weather. One needs to be careful of the waves at all times when visiting these caves. Pearce Cave is nearly always accessible.

Carmichael Cave and The Alcove contain features analogous in form to the calcite stalactites, shelves and stalagmites found in normal limestone caves, but which are composed of cemented sand. In addition small cemented sand bodies are found lying loose within the sandy floor of Carmichael Cave. Cemented sand also occurs beneath calcite flowstones in Pearce Cave and as shelves on the walls, but it lacks distinctive structures

History

Baker (1942) first described "sand stalagmites" from Carmichael Cave. However, his descriptions are restricted to the small formations that were sitting loosely in the sand floor (see Figures 4, 5 & 6). He made no mention of the larger sand formations that are now visible. A later paper (Baker & Frostick, 1951)

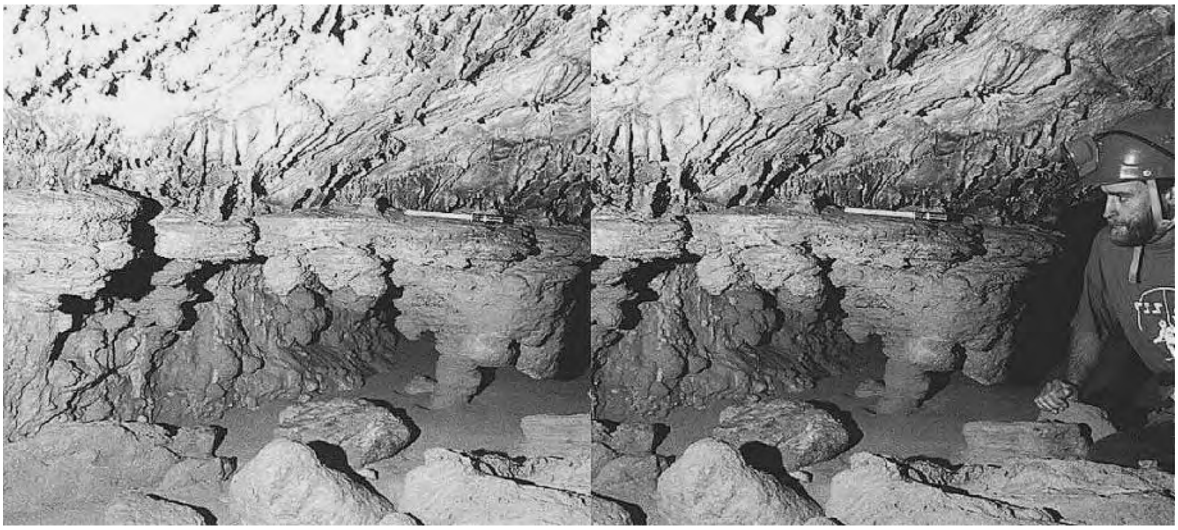

Figure 2: Cemented sand shelf with hanging sand "stalactites". Carmichael Cave. (Stereo-pair)

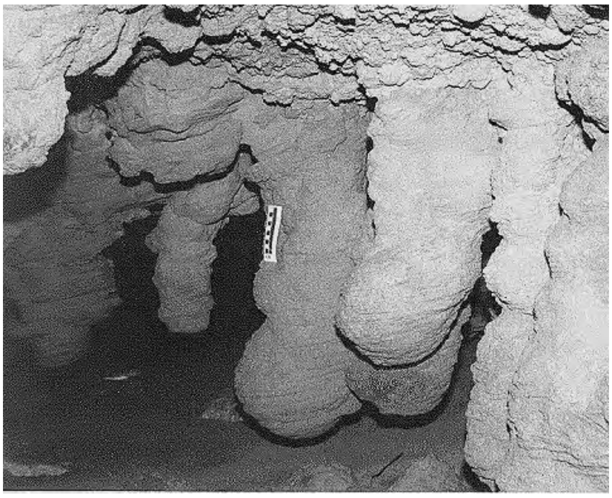

Figure 3: Bulbous sand "stalactites" in The Alcove, Loch Ard Gorge. 10cm scale bar.

mentions that in April 1947, high seas apparently just reached the rear of Carmichael Cave and the previously described sand "stalagmites" had been undermined and tilted. This later paper mentioned the cemented sand "shelves", calling them "sand plasters", but still made no reference to the hanging bulbous sand "stalactites" that are seen at present. One suspects that there has been further erosion since 1951. The present floor of Carmichael Cave is about 0.5m below the top of the sand "shelves" on the wall - which presumably represent the floor level when Baker described the cave in 1942. Baker could well have missed the formations in The Alcove, even if those were not buried at the time, as that small cavity is hidden behind a large fallen block and not obvious. Baker (1943, p380) also described "sand plasters" attached to sea cliffs at the back of partly eroded sandy beaches elsewhere in the region which appear to be similar to the "shelves" seen in the caves.

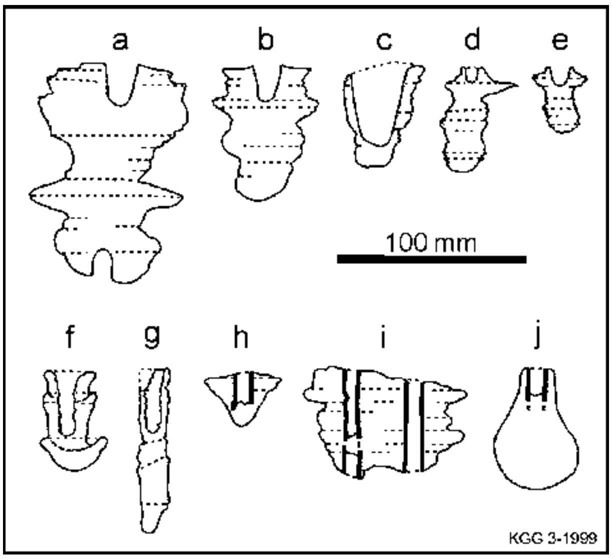

Figure 4: Cross-sections of sand pots from Carmichael cave. Top row is Baker's specimens. Bottom row sketched by author. Heavy lines are calcite linings in drip-pits.

The Sand Speleothems

Description

The sand speleothems are formed in calcareous beach sand that has been washed into the caves by the sea. The medium-grained sand is 70 percent carbonate and 30 percent quartz and other insoluble material (Baker, 1942). The thin, gently-inclined bedding of the original sand bodies is still visible on the sides of the sand speleothems and indicates its origin. The sand has buried prior calcite speleothems in places and a broken fragment of a calcite stalactite was found embedded within one of the sand speleothems.

The sand speleothems exposed at Loch Ard Gorge comprise four forms.

1: Horizontally banded *sand "shelves"* occur plastered to the cave walls up to 0.5m above the floors of both Pearce and Carmichael Caves, and are up to 0.5m wide and 0.3m thick (Figure 2). Some shelves

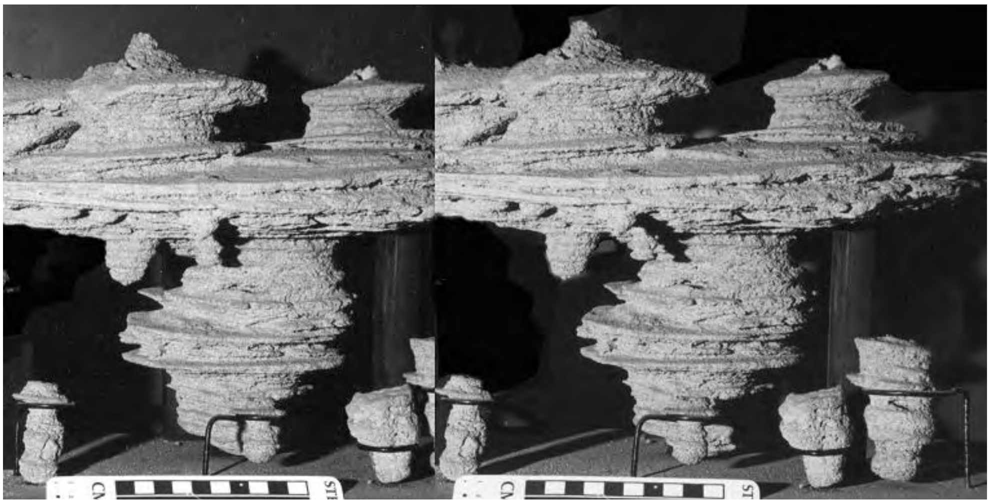

Figure 5: Stereo-photo of Baker's specimens, held as a mounted display at Melbourne University. Scale bar is calibrated in centimetres.

now have a hard, smooth, impermeable upper coating of calcite flowstone. These are the "sand plasters" of Baker (1943).

2: Bulbous *sand "stalactites"* up to 30cm wide and 80cm long descend from either the roof, or from beneath the shelves, and occasionally reach the floor to make a column (Figure 3).

3: Less common are bulbous to platy, round or flat-topped *sand "stalagmites"* seen rising from rock-slabs at the entrance to The Alcove. These are up to 40cm wide and 80cm high. The plates appear to be cemented bedding planes of the original sand deposit and the flat top may have been the original surface of the sand. No pits were seen on the tops of these "stalagmites"; the largest had a calcite coated top with a small calcite stalagmite forming beneath an active drip.

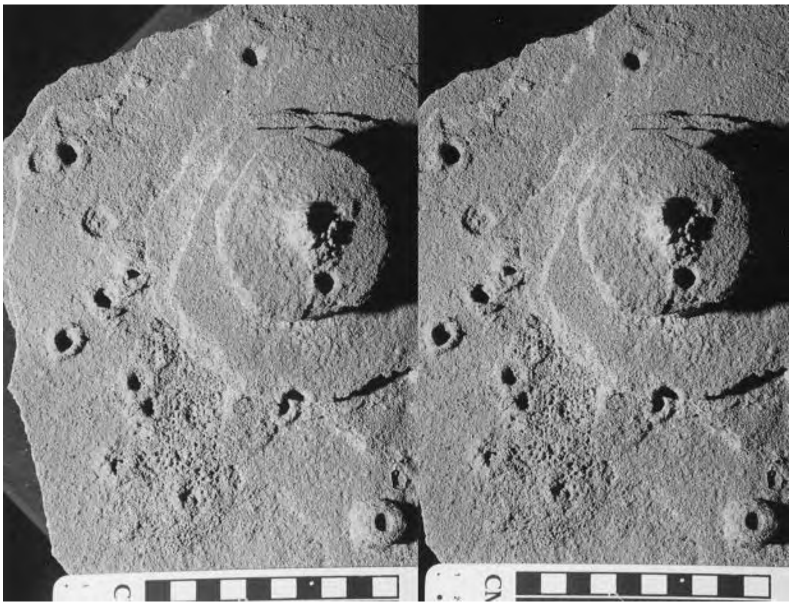

Figure 6: Stereo-photo of upper surface of Baker's large specimen, showing drip pits with marginal rims.

4: Smaller unattached *sand pots* occur in Carmichael Cave (Figures 4, 5 & 6). These are the sand "stalagmites" described by Baker (1942) and also resemble the "drip pots" described by Bull (1974). The descriptive name "sand pot" is suggested here for these distinctive types that have complex bulbous forms with a central pit. Baker described these as apparently floating free in the sand, unattached to either the wall or floor of the cave, with only the tip exposed above the sand surface. None of these are currently seen in situ, but in 1998 several loose specimens were found lying in pockets of wave-washed gravel within the cave.

The smallest of the sand pots was only 25mm wide and 40mm high. The largest of Baker's specimens was a composite form, nearly a metre wide and 0.75m high, that was formed of several of the simpler pots joined by a stacked series of horizontal ledges (Figure 5). The bottoms of the pots were rounded, the tops generally had a small mound around a central pit, typically 6-20mm wide and of variable depth; some pits penetrated right through the pot (Figure 4). The deepest pit, found on the composite specimen, was 70mm deep, but only 7mm in diameter. The composite specimen had a number of drip pits on its upper surface (Figure 6). Rounded bulges protruding from the underside of the composite specimen correspond to drip pits on the top. Most drip pits are unlined, but several had calcite linings about one mm thick. These lined pits have a uniform width of 6 to 7mm and are up to 60 mm deep.

One broken sand pot showed several cemented bands, which in thin section appeared to be a denser micritic cement (see below). One small sand pot was found rotated and embedded within a larger sand "stalactite", indicating reworking of the sand sediment followed by further cementation.

Thin sections were made from two specimens, a fragment of sand "shelf", and a small broken sand pot. The sand "shelf" had a porosity of about 30% and the grains were cemented by a thin isopachous rim of clear calcite spar only a single crystal wide. The sand pot had a similar isopachous rim cement, in places two crystals thick with the initial crystals finer than those outside. But there were also bands and patches with (additional?) fine cloudy micritic cement that almost completely filled the pore space. Within these areas isopachous spar occurred again at the edges of some of the remaining pore space. No specifically vadose features, such as meniscus or pendant cements were seen. The inner edges of the micritic cemented bands were gradational to less well-cemented areas but the outer edges were sharply defined and marked by a continuous layer of isopachous cement, a single spar crystal wide, that could be traced right across the thin section. These bands could be seen in the hand specimen as a series of "growth bands" approximately concentric with the outside of the pot.

Thus the sequence of development appears to have been one of discontinuous thin sparry rim cement, followed by (or contemporaneous with) several stages of localised cementation in bands by micrite cement, each of which ended in continuous thin layer of sparry isopachous cement.

Age of the Loch Ard Gorge sand speleothems

The age of the sand speleothems is uncertain. The loose sand fill appears to be a beach-derived sand with dips similar to the present beach sediments. It buries older speleothems and has been partly removed in all three caves since it formed. So it may have been deposited during a sediment build-up at the maximum sea level of the post-glacial transgression (about 6000 years ago). If so, the sand speleothems have formed since that time, and may be continuing to form at present in some places where the sand floor escapes disturbance by waves, cave streams, or people.

Related features from elsewhere

Hill & Forti (1997, p219-222) describe a variety of sand and mud formations that have been found in caves, and list a comprehensive bibliography. Many of the published descriptions differ in form or apparent genesis from the features described here, but there are some that appear similar. Bull (1974) described sand "drip pots" from caves in Wales; they are very similar to the sand pots described here and by Baker (1942), including the presence of a drip-pit. Bull attributed the banding (i.e. Baker's "ledges") to the primary sedimentary bedding. Wojcik (1958) described from a cave in Poland cemented concretions within loose quartz sand; these were stuck to the walls and had been exposed by subsequent erosion of the sand. They were mostly spherical to onion-shaped balls 20 to 50mm in diameter, but there were also larger loaf-shaped concretions. His photographs show that these are rather different in appearance to most of the formations at Loch Ard Gorge, but a few rounded forms were seen attached to the wall beneath a sand shelf in Carmichael cave (back of photo in Figure 2). Reto Zollinger (pers comm) has described spherical concretions, 1 - 3cm in diameter, that were found embedded in a quartz sand fill in the Barenhöhle in Switzerland. In Marakoopa Cave (7MC-120) in Tasmania, Jill Rowling pointed out some knobs and finger-like formations of cemented sand within a subsiding sandbank. These had a lustre-mottled cement. Unfortunately none were in-situ and no further work has been done on them.

A related feature is the ***conulite***. This term is now mainly applied to thin crystalline linings of drip pits in soft sediments (Hill & Forti, 1997, p57-59), but originally it seems to have also been applied to features that involved the local cementation of the surrounding sediments. For example, Peck (1976) applied it to "any drip-drilled pit in sediments which has been secondarily impregnated and, **perhaps**, lined with a mineral coating" [my emphasis]. His examples were only a few centimetres thick. Some of the smaller sand pots at Loch Ard Gorge could fall within this description, but not the larger features.

In a completely different context, Stoddart & Scoffin (1983, p380) describe phosphate deposits on a coral island in which phosphate-cemented sand and gravel overlies loose carbonate sand with an abrupt contact that shows "an irregular stalactitic relief, indicating variable downward percolation of phosphatic fluids". An accompanying photograph shows bulbous structures that appear similar to the sand "stalactites" seen at Loch Ard Gorge. I have personally seen slightly similar effects at the basal surface of calcrete and other duricrust bands, but the depth of penetration of the bulges was much less than that at Loch Ard Gorge and they are usually embedded in a more cohesive soil which makes them less likely to be eroded out.

Concretions in sedimentary rocks are a related form, but these generally form within the body of sediment and grow outward from a nucleus such as a shell fragment. By contrast the sand speleothems all start their growth at the point of entry of the water into the sand, and expand outward from that point.

Genesis

Hill & Forti (1997, p.219 - 222) suggest two modes of formation of sand and mud "stalagmites". The first involves water dripping onto soft sediment and displacing it to pile up mounds around a central pit. The second involves sediment-laden water that builds up a mound from the sediment that is left behind as the water soaks into the substrate. In both cases cementation of the sand or mud is also invoked. I have seen examples of the second case in a cave on Christmas Island (Indian Ocean), where the cave is flooded with muddy water every wet season which leaves the roof and stalactites coated with mud. After the flood this mud is slowly washed off the roof by seepage water and drips to the floor where it builds up soft rounded mounds. This is quite a different process

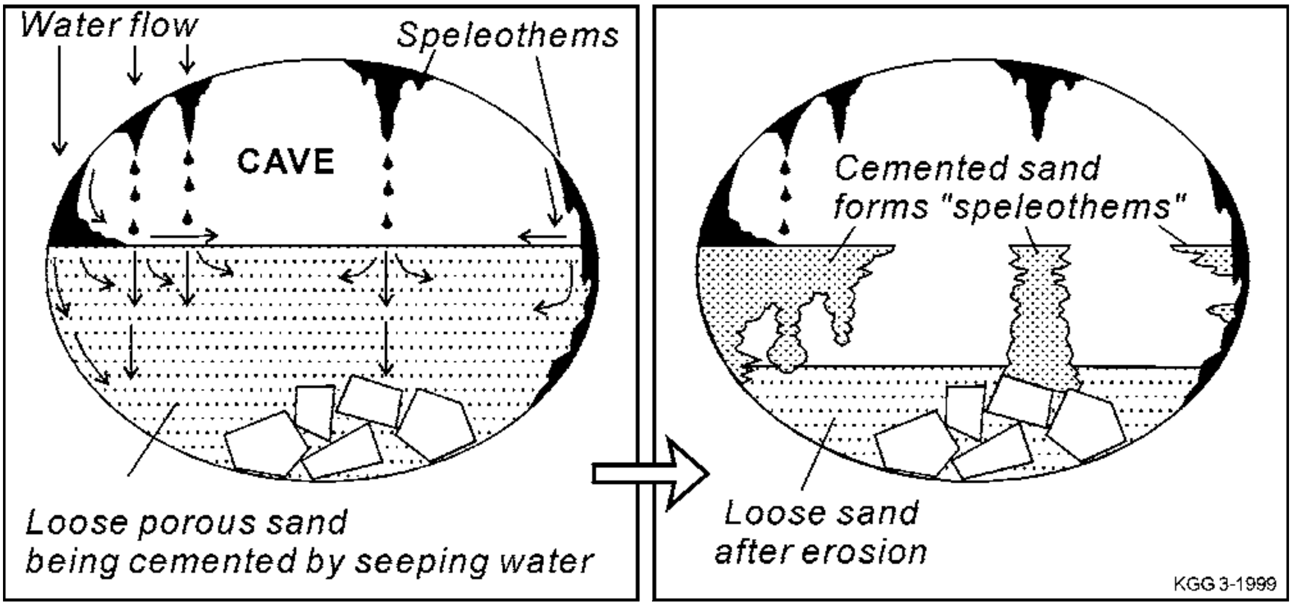

Figure 7: Mode of formation of sand speleothems. The sand is cemented in localised areas, and then uncemented sand is removed.

to that which appears to have occurred at Loch Ard Gorge.

The first process seems more relevant, though actual dripping of water, and the formation of drip pits and mounds, does not seem to be an essential part of the process.

The Loch Ard Gorge Formations

At Loch Ard Gorge, it seems that calcite-saturated waters have entered the sand, either by dripping from the cave roof, flowing down the walls, or across normal flowstone sheets that built over the sand surface. In some cases the sand fill seems to have reached the roof, and the waters would have entered it directly from pores or cracks in the limestone. These waters moved through the sand and cemented it in localised areas close to the source. Once the excess dissolved calcium carbonate was used up precipitation ceased, and the rest of the sand body was left uncemented (Figure 7a). Later erosion (storm wave or cave stream) removed a metre or so of the loose sand to expose the cemented parts (Figure 7b). The smaller sand pots with drip pits would have formed similarly, but in addition the dripping water kept a small pit open in the top of the cemented formation, with a small rim of displaced material, and splash and overflow water cemented the surrounding sand surface.

Dry sand would provide air space for carbon dioxide to diffuse out of the water and trigger cementation, and also would seem more conducive than wet sand to vertical infiltration which would produce the vertical "stalactitic" forms. However, the isopachous cement seen in thin section is generally interpreted as indicating water-saturated (i.e. phreatic) conditions (James & Choquette, 1984). At Loch Ard Gorge the precipitation may have been within a localised area of water-saturated sand, possibly just behind the wetting front. In a completely water-saturated sand one would expect the saturated waters to diffuse in all directions and produce spherical forms except where constrained by variations in permeability - i.e. typical concretions. This might have been the situation with the spherical features described by Wojcik (1958), and Zollinger (pers comm.). The bands of micritic cement may indicate faster precipitation at a series of drying fronts, with the super-saturated waters being replenished from behind the front. John Webb (pers comm.) has suggested that as microbial cements are also micritic these might also be an additional influence. However, no organic structures were seen.

Baker (1942) attributed the "ledges" in his specimens to splashing and overflow from the pits onto the surrounding sand surface, which was cemented; the repetition of the ledges he attributed to progressive build up of the sand surface. Bull (1974) believed that similar "banding" in his specimens reflected the bedding in the sand, which seems a more likely situation. However, one of the loose sand pots seen in the cave had a repetition of rims that suggested progressive upward development of three pots nested within each other (Figure 4.f), and this would agree with Baker's concept of deposition building up the sand floor simultaneously with cementation. The presence of a rotated pot embedded within a sand "stalactite" also implies several stages of cementation, erosion and redeposition of sand.

The process appears to be a special case of that which forms concretions in porous sediments. The distinctive feature is that most concretions form in fully saturated sediments, and grow outwards from a central point, whereas the sand speleothems at Loch Ard Gorge have formed by localised flows through unsaturated loose sand, and have grown down into the sand from the surface or outwards into it from a wall or roof of porous limestone.

Thus the study of sand speleothems can assist in our understanding of meteoric diagenesis in sandy carbonate sediments.

Nomenclature

Baker used the term "sand stalagmites" and in this paper I have referred to "stalactite", "stalagmite" and "shelf", subtypes in quotes to distinguish them from conventional speleothems. However, the analogy to true cave stalactites, stalagmites and shelves is limited to their position relative to the roof, floor or wall of a cave, and the mode of formation is quite different; in particular the sand "stalagmites" are so-called only because they are now seen sitting on the cave floor. In fact, they have grown downward through the sand until they reached the solid rock and remained bonded to it when the loose sand was removed (Figure 7). Bull (1974) used the term "drip pots" in his title, but referred to the pots as "calcreted drip-pits" in his text. Baker (1943, p380) used the term "sand plaster" for the sand "shelves" where they were exposed against the coastal cliffs.

Thus it would be better to avoid "stalactite" and "stalagmite" and use only the general term ***sand speleothem*** for features formed by the cementation of loose sediments. In fact, it might be more appropriate to reserve the term sand/mud stalagmite for features that have actually built up from a floor by physical deposition of clastic material from a drip, as in a true stalagmite (e.g. the Christmas Island "mud stalagmites" mentioned above). The smaller formations found sitting loosely within the sand at Loch Ard Gorge are, however, quite distinctive and I suggest the term ***sand pot*** for those.

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John Webb and Jill Rowling provided useful reviews of this paper and John also commented on a revised version. Bernie Joyce located Baker's 1942 specimens in the geological collection at the University of Melbourne! John Webb arranged for the thin sections to be made at La Trobe University. Jill Rowling pointed out the sand formations in Marakoopa Cave and Reto Zollinger described formations from a Swiss cave. Sue White and John Dunkley assisted in providing copies of some references. Part of the study was done while the author was a Research Associate at La Trobe University.

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