Lake Speleothems of the Nullarbor

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Introduction

In 2001 and 2005, cave divers Paul Hosie, Ken Smith and Stuart McGregor photographed and collected subaqueous speleothems in the lakes of Mullamullang Cave and Tommy Grahams Cave on the Nullarbor Plain (WA). An analysis of the 2001 material was presented at the ASF's "Under WAy" conference in Bunbury, WA in January 2003 (Rowling 2004).

This presentation describes material from the divers' 2005 expeditions, comprising pool crystal, helictites and a cave shield. Several chemical and physical tests were used to estimate the mineral components, and recent XRD analysis by the Australian Museum has confirmed some of these.

The divers' samples include shapes resembling porous helictites, small cave shields and dense pool crystal. Pool crystal is fairly common, but subaqueous helictites and cave shields are not. Subaqueous helictites have been reported from Lechuguilla Cave, USA and other places (Hill & Forti 1997).

It is intriguing as to how these speleothems came to be deposited underwater, in cave lakes, deep in the dark zone.

Some samples are fine-grained, suggesting a relatively rapid rate of deposition. Other material is quite coarse grained and may be of considerable age.

Materials and methods

All samples were supplied by the cave divers. Most samples are from Mullamullang Cave (on private property) and collected by Paul Hosie and Ken Smith. Stu McGregor collected the sample from Tommy Grahams Cave.

Dilute HCl was used to indicated presence of carbonate. Physical tests include observation of crystal shape and cleavage, and response to long wavelength ultraviolet light.

X-Ray diffraction was used to determine the mineral content of some specimens (pers. comm, Ross Pogson, curator of minerals at the Australian Museum).

Results

The HCl, UV, cleavage and optical tests suggested calcite, aragonite, possibly huntite or hydromagnesite, possibly magnesian calcite and a non-carbonate component such as gypsum.

XRD indicates major minerals were calcite and aragonite (and gypsum, in one sample) (Ross Pogson, pers. comm.)

The divers reported that these samples were found underwater in relatively still lakes, and it is assumed these are the conditions under which they were deposited.

Subaqueous helictites and heligmites

Helictites are seepage speleothems, usually with one or more central canals and a tendency to develop worm-like structures.

Heligmites are simply helictites which develop upwards from a flat or sloping surface.

Subaqueous helictites are not often reported. The Nullarbor subaqueous helictites are relatively large and porous, and take several forms: worm-like, shrub-like and conical. Instead of a seepage into an air-filled chamber, these speleothems are most likely formed by a seepage of mineralised water from within the porous limestone to a pool of water.

Grotto Lake tapered helictites

sample 6N37PHGL1

This yellowish lump resembles a large porous tapered helictite with a crumbly prickly coating resembling aragonite, irregular lumpy branches (Figure 1) and fine hairlike crystals similar to “lublinite” (needle-fibre calcite). It forms from a “horizontal layer growing upwards on the edge of the rocks.” (Paul Hosie, pers. comm.) Dried organic material on the surface may be from bacteria (Contos 2000).

Figure 1: Cut helictite 6N37PHGL1, about 80 mm long and 60 mm wide.

Grotto Lake flattened helictites

These white to pinkish, oriented nodules resemble branching helictites with some flattened shapes (Figure 2, sample 6N37PHGL2). Crystal size is very small and helictite branches can re-join. Paul Hosie reported they “had developed on a crystal substrate”. The porous outer yellow layer is cracked (dehydrated?) and surface crystals resemble clear dolomite. Fine dark threads seen on the surface may be organic or fungal.

Figure 2: Base of Grotto Lake helictite 6N37PHGL2, about 23 mm wide.

Lake Sh’bula helictites, sample 6N37KEN2

The samples comprise a few lumps of soft porous material, pale brown to yellow to white, about forming a somewhat crenulated, irregular folded shape comprising a soft outer yellow crystalline coating (possibly gypsum) with a white crystalline inner section. Diver Ken Smith mentioned the substrate was a “large rock covered in white crust”, and the “speleothems occur in lines at 1.7 m depth associated with a yellow band on surrounding rock. Yellow band is extensive in this part of the cave, is 0.2 m high, horizontal, possibly a specific chemical layer in the water.”

Figure 3: Base view of Lake Sh’bula subaqueous helictites 6N37KEN2, about 25 mm wide.

The outer tips have multiple pores (canals). Directly below the yellow coating is a white crystalline region (at the base of the pores). Within this white region are aragonite needles radiating from a denser central region which has hollow channels in it. The overall shape is formed by many spherulites.

Another piece from this sample comprises parallel plates of the same material, with an inner low density part filled with fairly loose aragonite needles. Possibly the parallel plate structure develops along the top edges of subaqueous cave shields.

Subaqueous cave coral and related forms

Grotto Lake popcorn and coralloids, sample 6N37PHGL3

Fibrous aggregates: These appear to be a mixture of calcite and aragonite (Figure 4). The porous surface is flattened and recrystallised (calcite). Individual crystals are coated with finer crystals and possibly microbial veils.

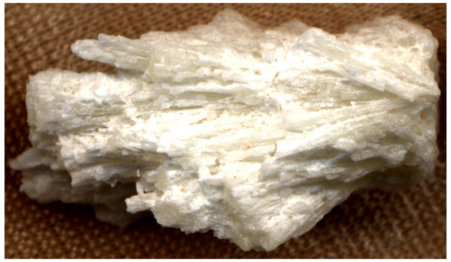

Figure 4: Grotto Lake fibrous aggregate, about 40 mm long.

Coralloids: These form crystalline hemispheres with a yellowish coating, typically 20 mm diameter (Figure 5). The general structure comprises a central core of linear yellow aragonite surrounded by clear radiating aragonite, with clear crystalline (calcite) balls. The outer coating is a very fine yellow brown porous crystal with aragonite aggregates and possibly microbial veils. Some samples have an inner layer of yellow material (possibly gypsum). The inner and outer yellow material has shrunk and cracked since collection. Below the yellow coating is a soft white layer of radiating aragonite crystals and possibly “lublinite” calcite.

Figure 5: Grotto Lake coralloid, about 17 mm wide.

Gurgle Lake coralloids, sample 6N37PHGL7

These creamy yellow nodules are about 40 mm x 30 mm x 20 mm with concentric layers (Figure 6).

The outermost layer is yellowish, fairly thin, and shiny in areas. It has cracked (shrunk since collection) to expose a white powdery layer just below it. Occasional whisker-like crystals may be “lublinite”. Small remnant dark shiny microbial veils are visible.

Below the yellow layer are porous white layers of radiating aragonite crystals, with some layers harder than others.

The innermost area is crumbly, powdery and soft, possibly recrystallised, and may include some hydromagnesite, with isolated coated aragonite crystals and resembles the interior of a subaerial “cave turnip”.

Figure 6: Gurgle Lake coralloid, about 17 mm wide.

Pool crystal, crusts and rafts

Grotto Lake over-coated cave rafts or crusts, sample 6N37PHGL4

These samples are soft and crumbly, coloured white, cream, yellow and brown, and are mostly a flat shape. Typical sizes are 10 mm x 20 mm and are possibly over-coated calcite or aragonite rafts or crusts (Figure 7).

Under the microscope, randomly-oriented fine needle crystals have cemented together to form a soft crust. One side, possibly the up-side, is porous and its yellow and brown surface appears cracked or shrunk. Other parts of the sample resembles pool crystal (i.e. an overgrowth) with small hemispheroidal aggregates which may be aragonite.

It is not clear whether these are sunken rafts or crusts; the flatter samples resemble rafts and the curved ones resemble crusts. Both appear to be over-coated with aragonite, so possibly they originated from the water's surface and have since sunk to the bottom of the lake.

Figure 7: Grotto Lake cave raft fragment, about 16 mm wide.

Grotto Lake pool crystal

sample 6N37PHGL5

This bowl-shaped lump of pool crystal has a layered clay and carbonate substrate (Figure 8).

The laminated clay substrate is composed of both crystalline carbonate sediment, reddish clays and other materials (possibly bat guano, quartz, hydromagnesite). Crystalline carbonate septa or veins separate areas of sediment and cut through the layers, resembling a boxwork.

Between the brown clay and the white pool crystal is a gradual transition from loose sediment, carbonate-cemented clays, laminated carbonate, then radiating aragonite aggregates.

The outer crystal coating is a mixture of white and yellow fibrous, needle-shaped radiating aggregates and massive material (possibly calcite, aragonite and gypsum).

Figure 8: Grotto Lake pool crystal, cut, about 100 mm long.

Apart from the aragonite isomorph, this appears to be a conventional pool crystal deposit on sediment. Carbonate septa in the substrate suggest that the lake may have dried and the clay shrunk and cracked. Septa may have then deposited either subaerially or subaqueously, possibly coincidentally with the lowest layers of pool crystal.

Lake Sh’bula crust, sample 6N37KEN1

A white crystalline coating on a brown clayey substrate forming a shard with a dense cemented layer and a white prickly crystalline surface (Figure 9). Diver Ken Smith noted that this deposit occured at a depth about 1 m as a white crust flaking from the tops of large submerged rocks about 1 m diameter. They are common in shallow water and a similar white crust is common on rocks above water.

Under the microscope, the soft porous brown laminated crystalline substrate has small interlocking grains and contains some aragonite crystals, becoming more dense in the transition to the white area. The white area is porous and is composed of needle to columnar crystals, terminated across the flats of the needles. It appears to be a mixture of calcite, aragonite and lublinite variety of calcite. The aragonite needles terminate as “church steeples”, etched and partially redissolved with some (calcite) cement.

It is unclear whether this is a subaqueous or subaerial deposit as it is reported from both above and below water around the lake. As it is apparently flaking from the tops of submerged rocks, this suggests the deposit is related to the surface of the lake, rather like cave rafts.

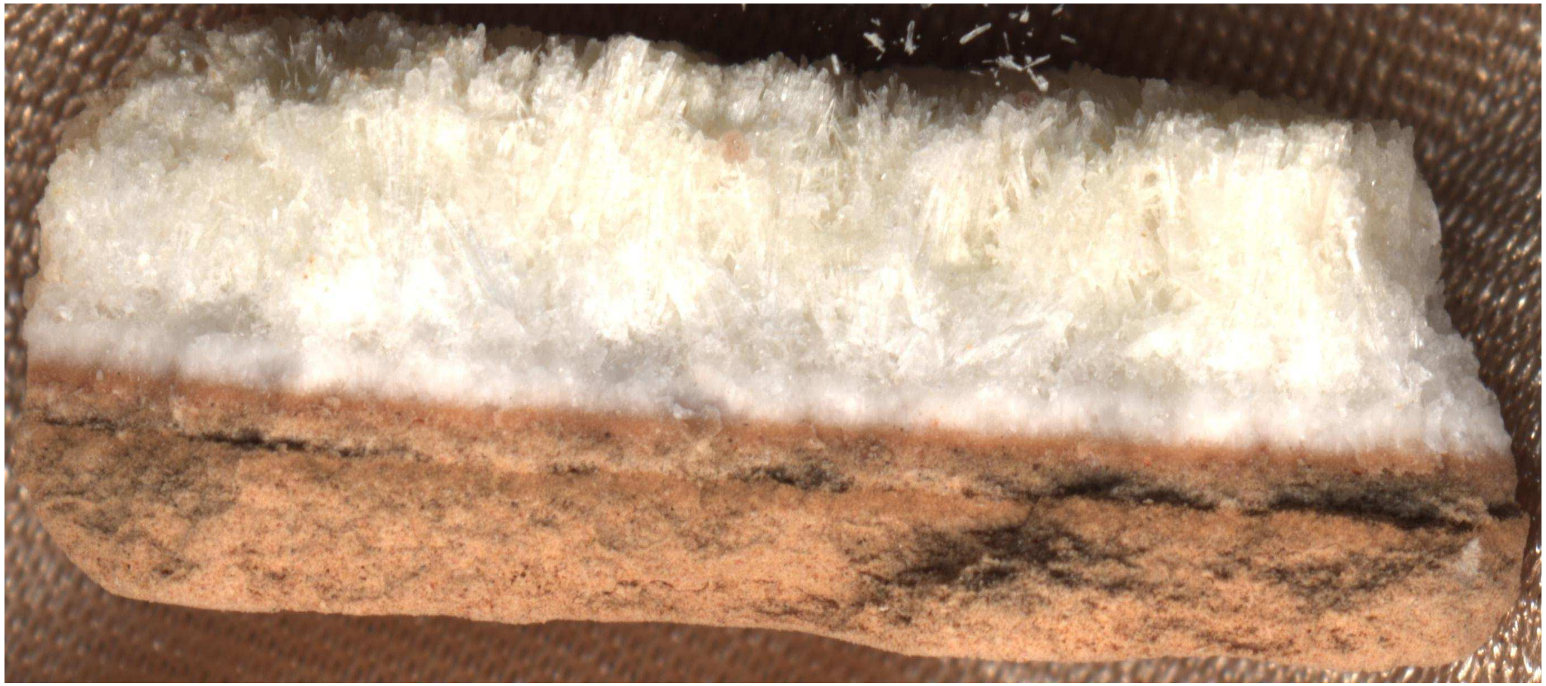

Figure 9: Lake Sh'bula crust is about 10 mm thick.

Tommy Grahams Cave: Massive pool crystal, sample 6N56SMTG1

This rock was found loose in the sediment of the lake in Tommy Grahams Cave by diver Stu McGregor (Figures 11, 10). One side is limestone, the other side is pool crystal, partially eroded. The eroded area contains lots of delicate needle crystals, originally greenish and full of water, and since sunken in. The divers report that the walls of the lake are covered with a similar pool crystal.

Under the microscope, highly porous pale orange Nullarbor Limestone with sand-sized grains is coated with a fine-grained, dense white cement layer, 5 mm thick, which merges with a pale olive aragonite layer, 10 mm thick featuring typical aragonite ray-fan needles, developed from clusters on the white cement layer. The pale olive layer is surmounted by clusters of aragonite forming a hard, dense layer 40 mm thick.

Figure 10: Pool crystal, Tommy Grahams Cave. Cut surface, 125 mm wide.

This is a massive deposit featuring larger and longer aragonite crystal blades compared to the pale olive layer, and is terminated by a white powder (possibly hydromagnesite). Part of the massive layer was exposed to the lake water where it had developed a solution notch, indicating that at times the water is agressive to aragonite. The porous outer layers are complex, with several different types of coatings and textures.

Figure 11: Pool crystal, Tommy Grahams Cave, photo by Stuart McGregor. 50c coin for scale.

This material appears to have been deposited underwater as aragonite, possibly at a particular depth where mineralised groundwater in the limestone meets the lake water in Tommy Grahams Cave. The general form could be described as aragonite pool crystal. The outer surface of the material may have housed microbial veils, and the chemistry appears to have at times favoured the deposition of a variety of minerals on the surface such as calcite, dolomite and gypsum. Judging by the massive aragonite of the main structure, this deposit may be very old, and has broken off the main deposit due to structural failure of the soft porous underlying bedrock.

Cave shields and related forms

Grotto Lake cave shield, sample 6N37PHGL6

This small hollow crystalline “shell” is a small brown/tan cave shield about 40 mm x 20 mm x a few mm.

Figure 12: Subaqueous cave shield, about 40 mm wide, after brushing.

The “shell” outer surface has a rough surface caused by neat pyramids (crystal terminations).

A sparkly appearance when rotating the specimen is caused by the alignment of numerous 3-sided crystal terminations, possibly en-echelon calcite similar to “Bizarre forms” (Folk, Chafetz & Tiezzi 1985). Crystal terminations on the specimen faces are aligned in arrays up to 10 mm wide, resulting in reflective lines (rows) at some angles. This material covers the outer surface of the speleothem, especially around the edge of the plates. At a broken edge, the pale coloured corner has spiky crystals on the inside (Figure 13).

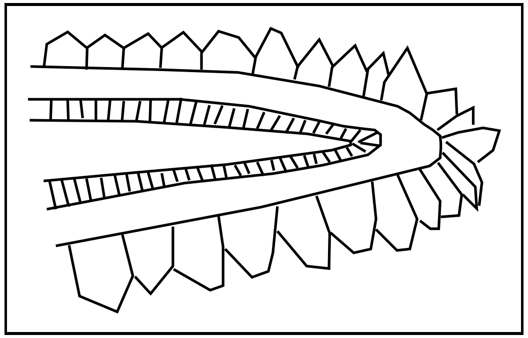

Figure 13: Symmetrical ridge development

The two halves of the shell are cemented by a seam with a symmetrical edge (Figure 14) and a small hole.

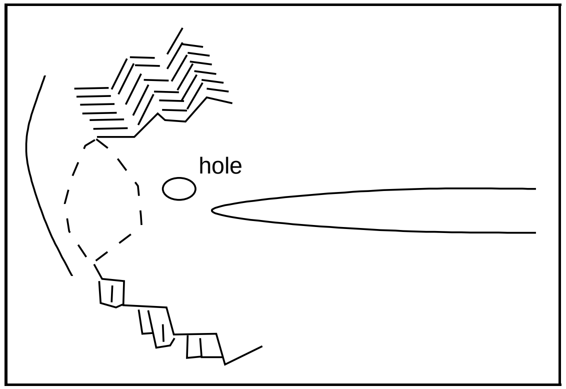

Figure 14: Sketch: area close to edge

A dimple in the base of the structure leads to a tepee shape.

This appears to be a conventional cave shield, only developed underwater. Development may begin like a helictite, only with a capillary slot rather than a capillary tube. The edge seems to be the main region of growth. Imagine a small capillary tube around the edge, similar to that depicted in Figure 14, like the central canal of a conventional helictite only connected to the substrate at both ends.

Figure 15: Cave shield interior, about 40 mm wide

Such a structure may originate from a small crack in the substrate. Like conventional helictites, this small tube can be slightly dissolved by the water in the substrate, however instead of breaking open at one end like conventional helictites, it breaks open along the outer edge of the crack. Growth may continue in this way due to the alignment of crystallites and the thickness of the inner wall. Where the tube opens, carbonate precipitates. Additionally, calcite can glide / cleave without breaking. If the pressure of crystal growth inside the shield is sufficiently high, the material may glide apart while still precipitating carbonate. This would result in symmetrical crystal development at the edge and develop a cave shield.

Lake Sh'bula flat speleothem: cave shield or coating? Sample 6N37KEN3

Figure 16: Cross-section of flat speleothem 6N37KEN3, about 54 mm wide.

This flat, porous speleothem has a soft prickly outer coating and has formed in two halves like a cave shield. Diver Ken Smith described its growth habit as "part of a flake . . . cemented to the base rock."

All rocks at the 2.8 m depth had this cover, which covered several square metres.

Under the microscope, the surface appears to be recrystallised aragonite, with occasional loose, shiny fragments (dried microbial veil?), easily disturbed. The needles radiate from the median plane of the speleothem (Figure 16) which contains a white powder resembling hydromagnesite.

Discussions

Helictites and heligmites

Subaqueous helictites from the Nullarbor cave lakes are mainly heligmites, as the divers noted they developed upward from a substrate (typically from boulders or from pool crystal).

Finger-shaped forms typically have a central canal (or set of them), supprounded by radially-oriented carbonate crystals such as calcite or aragonite. Pores near the tip (growth point) are connected to the central canals through less dense mats of needle crystals. The outer surface is coated with materials such as magnesian calcite, dolomite or gypsum.

In **branching forms**, the branches may join up, forming a structure consisting of both cylindrical and flattened shapes. The cylindrical parts have cylindrical central canals, and the flattened parts have a slot-shaped central canal, similar to a cave shield.

Microbial veils (also known as snot-tites) have been recorded from Nullarbor cave lakes (Contos 2000). Several samples have what appears to be remnant microbial veils attached to their surfaces.

Cave coral and related forms

Conventional cave coral is a layered subaerial speleothem, formed by a film of mineralised water on the surface. Growth is near the area of maximum air movement, where CO_2 exchange is highest. Sub-types include cave popcorn and coralloids, usually made of aragonite, and developing along the lines of aragonite “shrubs”.

Nullarbor cave lake coral appears to be alternating calcite and aragonite. Development is larger and less dense than subaerial cave popcorn and coralloids.

Similar structures have been previously reported from a marine (coral reef) setting as aragonite “mamelons” (Ginsburg & James 1976).

Pool crystal, crusts and rafts

These are conventional, often reported from caves. The Nullarbor **pool crystal** occurs at specific depths, corresponding to either particular layers in the rock, or a halocline. The usual subaerial polymorph deposited is calcite, whereas the Nullarbor lake samples appear to be mainly aragonite (Tommy Grahams Cave) and calcite with other minerals, suggesting crystal poisoning by Mg and SO_4 leaching from the bedrock.

Cave rafts are caused by the outgasing of CO_2 from the surface of a lake to an air filled chamber, allowing carbonates to precipitate at the water-air interface. What is unusual in the raft samples is the crystal polymorph, which is normally calcite but in the samples they appear to be aragonite. One possibility is the rafts precipitated as calcite, but were later overgrown with aragonite after they sunk.

The divers report a **crust** which occurs both above and below water, flaking off the rocks. This is most likely formed at the water's surface, dependent on the lake level, and is a simple carbonate coating formed on the rocks by CO_2 outgasing from mineralised water. The flaking is most likely due to the clay in the substrate expanding and contracting with water level. They appear to be a mixture of carbonates, including calcite and aragonite.

Cave shields

Two types of cave shield were identified:

1. A relatively conventional cave shield, comprising two halves like a bivalve, hollow inside, and with a fine linear capillary along the edge. Growth appears to be by pressure-gliding along cleavage planes, with the edge crystals oriented such that they form a mirror image of each other about the two halves. Cave shields resemble helictites with the direction of growth at 90° to the central canal.

2. A porous structure forming a blade with a powdery core (possibly hydromagnesite) surrounded by acicular carbonate e.g. aragonite. The divers report they develop on pool crystal. Perhaps cracks in the substrate seep mineralised water along with calcite crystal poisoners. The less dense aragonite structure may develop where water supports the speleothem's weight.

Conclusions

A variety of subaqueous speleothems occur in some cave lakes on the Nullarbor Plain. Conditions leading to the deposition of carbonate speleothems on rocks in a cave lake may include:

- Porous bedrock (limestone and dolomite) in the lake area.
- Higher concentration of HCO_3 in the rock pore water than that of the lakes.
- Exchange of CO_2 between the rock pore water and the lake water allows CO_2 to escape from the rock pore water, thus precipitating carbonate.
- The rocks may be conducting highly mineralised groundwater to the lakes. As some of the speleothems were reported from isolated rocks, possibly the rocks are dissolving.

- The actual form (helictite, shield, pool crystal etc) depends on the physical conditions during deposition.
- The mineral species deposited depends on the chemistry during deposition. For example, aragonite may deposit instead of calcite if there are sufficient calcite crystal poisoners present (Mg, sulfate and Mn are the most common).
- Two possible sources of Mg and SO_4 are: Dedolomitisation of the bedrock (including pyritic decomposition) and the prevailing winds carrying seaspray to the area.

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