3.4 Walli Caves

Introduction

Walli Caves are located about 215 km west of Sydney. The area is presently used for sheep and cattle grazing. Gold and copper is mined about 20 km away at Cadia; barite was mined in the past at Cliefden and Walli from veins in andesite.

The NSW Government Geologist, C.S. Wilkinson, visited the “Belubula” (now Walli) Caves in about 1870 (Wilkinson 1892) and mentioned an occurrence of aragonite in “Long Cave” (now Piano Cave). He also visited Bone Cave and Deep Hole (Deep Cave). In Bone Cave, a quantity of marsupial bones were removed from the red earth. Wilkinson tried to visit the Deep Hole (Deep Cave) at Walli, but did not have enough rope to complete the descent and was only able to observe part of the cave from a landing. About a century after Wilkinson’s visit, some of the caves were mapped by Frank, Fitch and members of the First Cronulla Sea Scouts (Frank 1974). Frank described the relationships between the passages, deckenkarren and the bone deposits. Cave mapping continued to the present, by Peter Wellings and members of the Sydney Speleological Society. Additional information about the Walli Caves is from cavers’ trip reports in the *Journal of the Sydney Speleological Society* and the *Bulletin of the Sydney University Speleological Society*.

Geological Setting

Regional Geology

Referring to the geological map, Figure 3.113, Walli is the area near the centre. The oldest rocks in the region are turbidites of the Ordovician Adaminaby Group (Oa), which crop out about 25km to the south east of Walli. They are overlain by Ordovician volcanics, limestone, intrusives and volcaniclastic sediments which are widespread in the region, represented by the Kenilworth Group (Ok-), Barrajin Group (Ob-) and Cabonne Group (Oc-). To the west of Walli, the Ordovician sediments are cut off by several faults. This region of the Lachlan Fold Belt is highly faulted by major regional N-S trending structures (e.g. the Columbine Mountain Fault and Woodstock Fault). Silurian sediments and volcanics occur mainly to the west of the major faults and are represented by the Ashburnia Group (Sa), Waugoola Group (Sw), Mumbil Group (Northwest) (Sm-) and the Cudal Group (Sc-). The region was intruded in the Silurian by minor dolerite and granodiorite bodies. Major Silurian intrusions include granitic rocks of the Wyangala Batholith, which crop out 10 km to the southeast of Walli. A small outcrop of Early Devonian Gregra Group (Dg-) sediments occurs about 20 km north of Walli. Late Devonian quartz-rich sediments of the Catombal Group (Dt-) crop out unconformably about 5 km north of Walli and extend in a narrow band northwards, east of the Columbine Mountain Fault, for about 40 km.

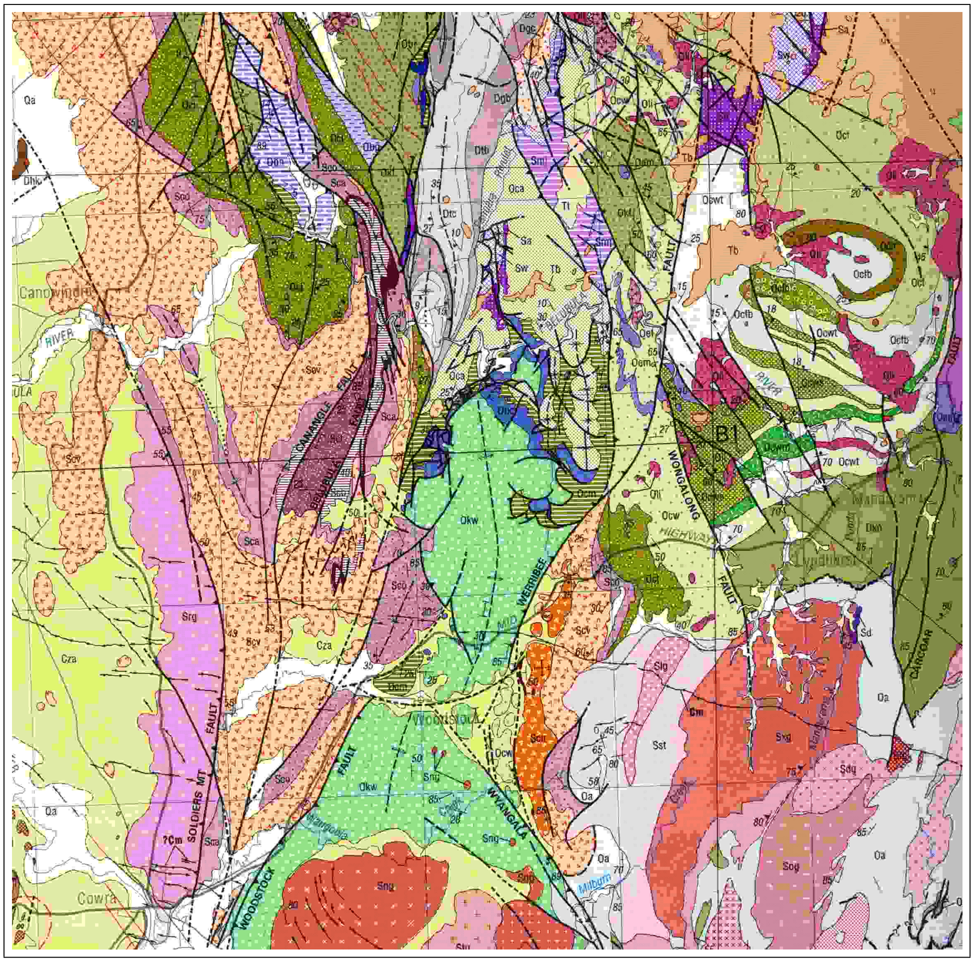


Figure 3.113: Geological Map of Walli Caves region showing geological outcrops mentioned in text. Area map is from Raymond, Pogson et al. (1998). Width of image: approximately 50 km. **Cza, Qa -** Quaternary, gravel and sand, alluvium. **Tb, Tt -** Tertiary, basalt, trachyte. **Dhk -** Devonian, Kadina Formation, Hervey Group. **Dtb, Dtc -** Devonian, Catombal Group. **Dgb, Dgc -** Devonian, Gregra Group. **Sdg, Sfg, Slg, Sng, Sog, Sst, Sxg -** Silurian, Wyangala Batholith. **Sd, Srg -** Silurian, intrusions. **Sca, Scn, Sco, Sct, Scv -** Silurian, Cudal Group. **Smj -** Silurian, Ulah Formation, Mumbil Group (Northwest). **Sw -** Silurian, Waugoola Group. **Sa -** Silurian, Ashburnia Group. **Oli, Oef, Oem -** Ordovician, intrusions. **Oca, Ocf, Ocfb, Ocfc, Ocft -** Ordovician, Angullong Formation and Forest Reefs Volcanics, Cabonne Group. **Oci, Ocm, Ocw, Ocwm, Ocws, Ocwt -** Ordovician, Millambri, Malongulli and Weemalla Formation, Cabonne Group. **Obc, Obn, Obr -** Ordovician, Cliefden Caves Limestone, Canomodine Limestone and Regans Creek Limestone, Barrajin Group. **Okf, Oko, Okw -** Ordovician, Fairbridge Volcanics, Coombing Formation and Walli Volcanics, Kenilworth Group. **Oa -** Ordovician, Adaminaby Group.

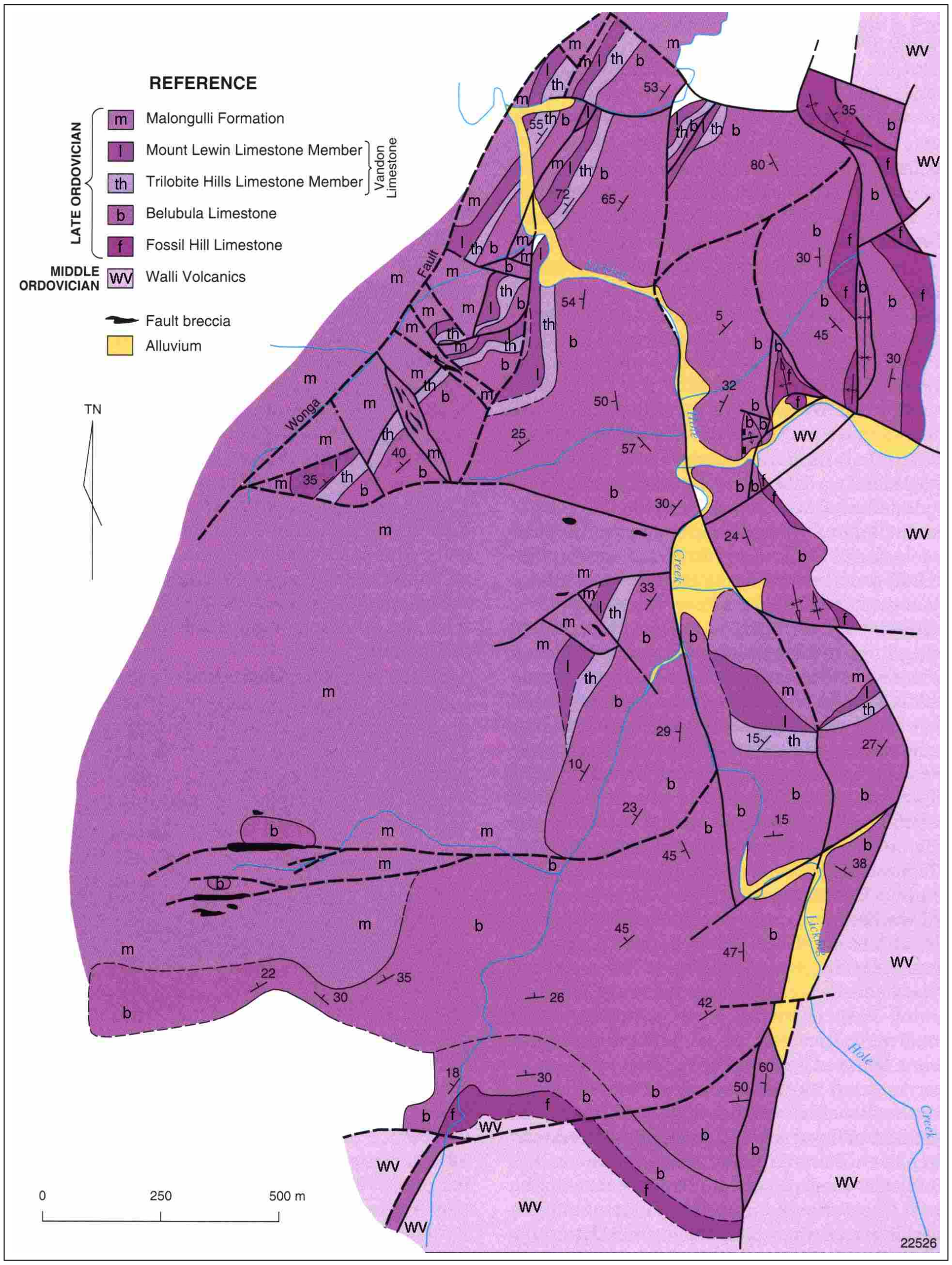


Figure 3.114: Geological Map of Walli Caves showing strata mentioned in text. Geology from Percival (1976), redrawn in Pogson et al. (1995). Width of image: approximately 1.5 km.

Closer to Walli, the Millambri Formation (Oci) (Cabonne Group) siltstone is overlain disconformably by Silurian rocks of the Cudal Group: the Liscombe Pools Limestone (Scl - not marked on map) and the Avoca Valley Shale (Sca). A few km to the north of Walli, the top of the Malongulli Trig (also called the Malongulli Sugarloaf) is Late Devonian, unconformably overlying the Ordovician sediments. Tertiary (effusive) volcanics (Tb,Tc) unconformably overlie the basement lithologies and crop out around Mount Canobolas volcano, about 20 km north of Walli, with small isolated outcrops occurring between Walli and Mount Canobolas. Quaternary alluvium occurs around Licking Hole Creek and its tributaries (Percival 1976).

Local Geology

The Walli Caves are located in the western part of the 460 m thick Cliefden Caves Limestone Subgroup (Webby & Packham 1982, Pogson & Watkins 1995). Cliefden Caves are in the north eastern part of the limestone outcrop, about 4 km away from Walli Caves. To the south and east of Walli caves the Walli Volcanics (Kenilworth Group) crop out. This is considered early to middle Middle Ordovician and stratigraphically underlies the Cliefden Caves Limestone Subgroup. In places the disconformity is due to faulting; in other areas an erosional surface is suggested. It comprises 1100 m of porphyritic andesite, vesicular basalt, pillow lava, volcanic breccia and tuff deposited on a sea floor. (Percival 1976, Webby & Packham 1982).

The Early Eastonian Cliefden Caves Limestone Subgroup (Barrajin Group) is subdivided into three formations: the Fossil Hill Limestone is the oldest, the Belubula Limestone is the middle and the Vandon Limestone is the youngest formation (Webby & Packham 1982). Figure 3.115 shows a stratigraphic column based on Webby & Packham (1982).

The Fossil Hill Limestone is subdivided into 6 members at Cliefden Caves. However in the Licking Hole Creek area near Walli Caves, only one member has been described, the “lower big shell member”. At Walli Caves, this is characterised by large *Eodinobolus* shells (Webby & Packham 1982). The Belubula Limestone is massive limestone where it crops out at Cliefden Caves. At Walli Caves, however, Percival (1976) identified (in order) a “lower thinly-bedded unit”, a massive unit, a faunal unit named the “E Horizon”, another massive unit, an “Aulopora” unit and another massive unit.

At Walli, the “lower thinly-bedded unit” consists of thin beds of brachiopods interbedded with grey limestones. The limestones exhibit some silicification and chert nodules occur in the planes of the bedding. Percival (1976) described some of the limestones from this unit as skeletal grey wackestones, lime mudstones, skeletal grainstones, and pisolitic pelletal-skeletal packstones. Of particular interest to this study were the chert nodules which occur in this unit. Percival noted:

> *Irregular blocky chert nodules, 50-150 mm long and wide, occur sporadically throughout the unit, but are most common in skeletal wackestones. They are usually found on bedding surfaces where they are observed to replace tabulate corals, especially* Tetradium cribriforme (Etheridge)*, and labechiid stromatoporoids. In thin section the chert nodules consist of orange-coloured translucent cryptocrystalline silica with minute dolomite rhombs suspended within. The means of formation of the nodules and their environment of development is unknown.*
>
> (Percival 1976)

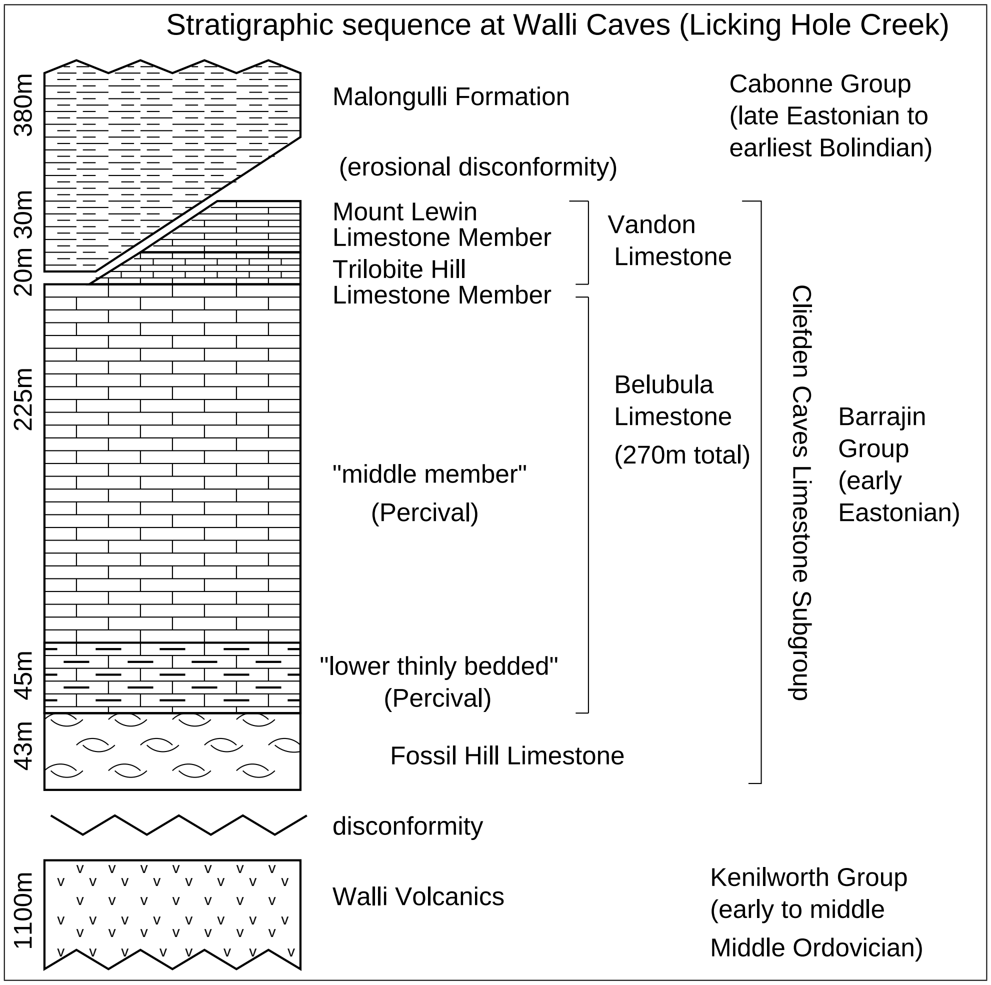
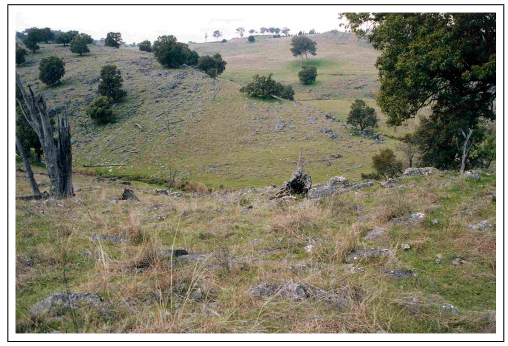


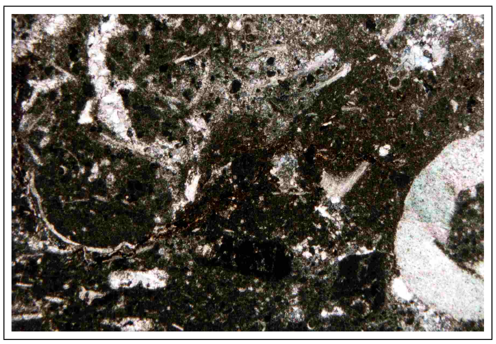
Figure 3.115: Stratigraphic sequence for the Cliefden Caves Limestone Subgroup at Walli based on Percival (1976), Webby and Packham (1982), Pogson et al. (1995).

In the massive limestone beds of the Belubula Limestone, Percival identified algal pisolites in the lowest strata, and skeletal wackestones containing brachiopods, trilobites, corals, bryozoans, echinoderms and small gastropods. The "E Horizon" is a particular faunal assemblage of *Eodinobolus* brachiopods with *Ecclimadictyon*, *Tetradium* and gastropods, forming a shell bank. Above the "E Horizon" are massive limestones, mainly skeletal wackestones grading to packstones and grainstones, then massive wackestones. Some chert occurs in this zone, too. The Aulopora Unit is a coarse pelletal grainstone with abundant stacked *Eodinobolus* shells. Packstones and grainstones form the uppermost layers. The top of the Belubula Limestone is an erosional surface in some areas (Percival 1976). The Belubula Limestone contains chert nodules and is silicified in places. Figure 3.116 is of the massive Belubula Limestone, and Figure 3.117 show how the chert nodules contain dolomite.

Sample site WA17/5: Belubula Limestone exhibits a range of textures.



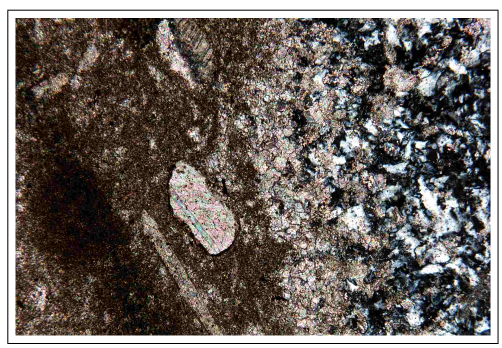
Area south of Deep Hole, near sample site WA17/6 overlooks Licking Hole Creek.



TS WA-17/5 13x XN N35717 Biomicrite (pelloidal).

Sample WA17/6 cut and polished to show silicification.

TS WA-17/5 13x XN N35717 Vein in sample.

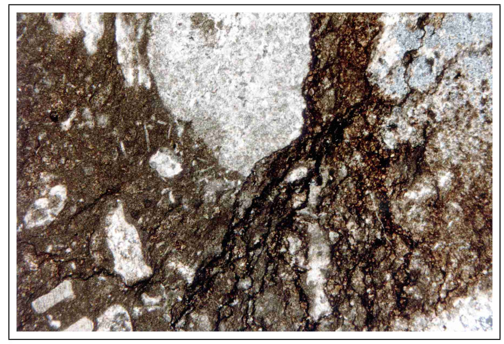


TS WA-17/6 50x XN N35647 Pelloidal biomicrite with silicified regions and some dolomitisation.

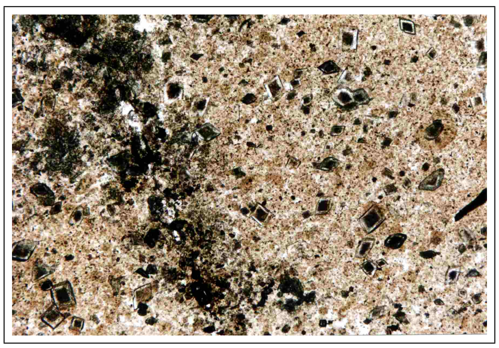
Figure 3.116: Location, specimens and bedrock thin sections, samples WA17/5 and WA17/6

The Vandon Limestone comprises two subdivisions: the lower subdivision is the Trilobite Hill Limestone Member and the upper one is the Mount Lewin Limestone Member. At Walli, the Trilobite Hill Limestone member crops out in the western margin of the limestone as brown and grey thinly bedded fossiliferous limestone. Strike-faulting has resulted in the limestone sequence being repeated on the eastern side of Licking Hole Creek (Percival 1976).

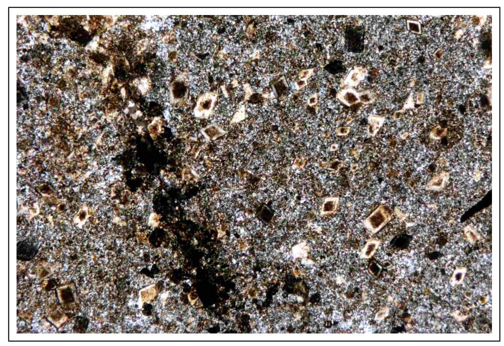
Cut specimen: WA17/7 black limestone, grey on weathered surfaces. Chert is rusty.



TS WA-17/7a 13x XN N35719 Complex dolomitised veins near the chert region.

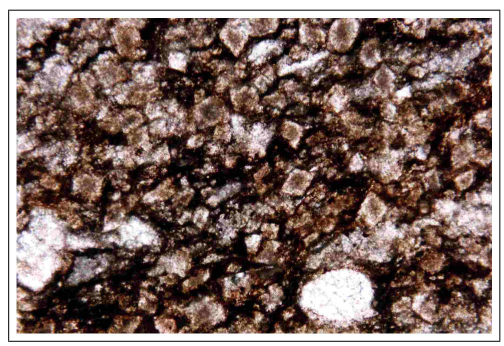


TS WA-17/7a 25x PPL N35719 Zoned dolomite rhombs in the chert.



TS WA-17/7a 25x XN N35719 Zoned dolomite rhombs in the chert.

TS WA-17/7b 13x XN N35720 Micrite is dolomitised leaving bioclasts intact.



TS WA-17/7b 50x PPL N35720 Dolomite detail in limestone. Opaques may be manganese and iron oxides.

Figure 3.117: Bedrock thin sections, limestone with chert nodule, sample WA17/7.

The Mount Lewin Limestone member crops out as a grey massive unit at Walli, stratigraphically conformable with the Trilobite Hill Limestone. It is made of lime mud from algal remains, and fine echinoderm debris. It lacks the silicification and chert which is seen in the Belubula Limestone.

The Malongulli Formation is late Eastonian to earliest Bolindian and disconformably overlies the Cliefden Caves Limestone Subgroup. It comprises graptolitic silts and limestone breccia derived from slumping from carbonate beds to the west. The disconformity is an erosional surface, extending in some places all the way through to the Belubula Limestone. At Licking Hole Creek, it is about 180 m thick (Webby & Packham 1982).

Above the Malongulli Formation lies the Angullong Formation, a thick (1080 m) accumulation of volcaniclastics and flows and is Middle - Late Bolindian. This is the last Ordovician deposit in the area (Webby & Packham 1982). It crops out about 3km to the north of the study area. A small quartz porphyry intrusion of the Silurian Canowindra Volcanics (Cudal Group) crops out about 2.5 km north of the study area.

At Walli, the Cliefden Caves Limestone is cut by the Wonga Fault. To the south west of Walli Caves, the Wonga Fault merges in a shear zone with the larger regional Columbine Mountain Fault (Percival 1976). Several other faults merge in this region. The limestone does not crop out west of the Wonga Fault at Walli. However this is not the case at Cliefden where it strikes roughly north east with limestone occurring on both sides (Webby & Packham 1982). At Walli, the limestone is cut by a large number of smaller faults, some of which have been mapped. The region lies on the western limb of a regional anticline. The limestone generally dips to the west, although faulting and folding allows the dip to vary from northwest, west to southwest. To the north of Walli Caves is a Late Ordovician to Middle Silurian quartz porphyry intrusion (Percival 1976) (Canowindra Volcanics, part of the Cudal Group).

About 4 km northeast of Walli Caves is a warm spring near the “Kalimna” property. This is developed in an exposure of the Vandon Limestone surrounded by quaternary alluvium (Webby & Packham 1982) near the banks of the Belubula River. Temperature was 28.5°C on 11th August 1997 (Rowling 1997), previously measured by Trickett in 1908 as “84°F” (28.9°C) (Middleton 1991) and mentioned in 1876 as “88°F” (31.1°C) (Wilkinson 1892). Figure 3.118 is based on the geological work by Percival (1976), with approximate positions of the caves based on Frank (1974). Positions are only accurate to within about ±50 m.

Records from the Mines Dept. of NSW (now Mineral Resources) indicate that the barite occurs at Walli as a joint or fault filling deposit (Report MR0325). An abandoned barite mine at Walli is developed in the Walli Volcanics close to the limestone (Mines Department various years’ reports). Barite occurs in veins in the limestone but was not considered to be concentrated sufficiently to be an economic resource.

Bedrock Samples - Belubula Limestone

All surface bedrock samples are from the Belubula Limestone near Deep Hole.

Surface sample WA17/5 is a limestone flake from a boulder at the head of a broad gully estimated to be over GR 070,010 on the Deep Hole map. The specimen contained a large brachiopod, possibly *Eodinobolus* Thin section (Figure 3.116) shows a pelloidal limestone with fossils comprising brachiopod and trilobite fragments, algae, bryozoans and crinoid fragments. Limestone texture varies from packed biomicrite wackestone (pelmicrite) to poorly sorted biosparite packstone (pelsparite) with occasional rhombs of ferroan dolomite. Some brown veins contain a reddish mineral (square in thin section) resembling oxidised pyrite. A large sparry vein contains calcite, a clear mineral, possibly barite, and an opaque mineral. XRD of the large sparry vein and some bedrock indicates: Major calcite; Minor stronitian barite, barite, sphalerite, manganoan calcite, magnesian calcite; Trace quartz.

Surface sample WA17/6 is a limestone flake from an outcrop at the south side of a broad gully estimated to be above GR 110,020 on the Deep Hole map and about 20 m east of sample WA17/5. It is a highly silicified foetid limestone. Fossils include bryozoans, brachiopods, crinoids, fenestellid bryozoans, echinoderm and algal coated grains, as well as suspected trilobite fragments and foramnifera. Thin section (Figure 3.116) shows the limestone texture (where not silicified) is a sparse to packed biomicrite wackestone (pelmicrite). The limestone has numerous veins. The oldest appear to be thin, possibly diagenetic. A later group are larger. They have some hydrothermal characteristics such as quartz and barite replacement of calcite. The latest veins are spar-filled. Large veins are filled with chalcedony. Small opaques in the chalcedony may be a sulfide. Some bioclasts have been replaced by a high birefringent mineral. Some areas of limestone are brecciated with intergranular areas filled with black clots (probably a manganese oxide) and diamond shapes (ferroan dolomite).

Surface sample WA17/7 is a rounded limestone cobble from the middle of the broad gully, estimated to be above GR 100,030 on the Deep Hole map. It was collected from about halfway between samples WA17/5 and WA17/6. The limestone is a very dark to black foetid limestone, light grey on weathered surfaces, and contains a large chert nodule. Bioclasts include brachiopod, echinoderm spines, trilobite fragments, fenestellid bryozoans, sponge spicules, algal bored fragments, and possibly foramnifera. The limestone texture varies from sparse to packed biomicrite wackestone, to poorly sorted biosparite packstone (sparite). The matrix is a dark lime mud (micrite) which may also contain small quantities of hydrocarbons as the rock smells strongly when cut. Small opaque cubes are probably pyrite. Zoned ferroan dolomite occurs in brown regions in the micrite, the sparite and throughout the chert (thin sections, Figure 3.117). In the limestone, there are dark veins of dolomite and opaques. Crinoid ossicles are highly birefringent. Sparry veins contain calcite and barite. In the chert, under crossed nicols, the dolomite appears to “float in a sea” of chalcedony. Some dolomite appears to have been replaced by calcite. Brecciation in some areas appears to be perpendicular to bedding. XRD of dolomitised material indicates: Major calcite, magnesian calcite, dolomite, ankerite and quartz; Minor barite; Trace gypsum and anhydrite.

Geomorphological Setting

The Walli Caves area is characterised by gently rolling, rounded hills. The caves occur in the limestone outcrops at an elevation of about 440 m ASL. The vegetation is mostly grassland with occasional stands of Kurrajong and Eucalyptus (white box and red gum - *E. camaldulensis*). The area is drained by Licking Hole Creek, a tributary of Liscombe Pools Creek which flows in to the Belubula River, a tributary of the Lachlan (Murray-Darling system). Licking Hole Creek flows through a relatively level terrain where is it located within the Walli Andesite; where it flows across the limestone the creek meanders around interdigitated hills and bluffs. The creek banks are formed in quaternary gravel deposits that are excavated and redeposited during flood events. The caves are located either side of Licking Hole Creek, about 4 km to the south of the Belubula River. Streamsinks on Licking Hole Creek capture water into underground conduits. Cave entrances are generally located around Licking Hole Creek, and extend in depth to about creek level or slightly below it (Frank 1974).

Geological History

The early to middle Middle Ordovician Walli Volcanics were deposited on the sea floor, which became emergent in the Middle Ordovician, and was eroded to form an offshore site on which the limestone was deposited by organisms (Percival 1976, Webby & Packham 1982). Initial sedimentation began during the Gisbornian, with mainly shallow marine to intertidal deposition of biogenic carbonate, with terrigenous silt. The carbonate deposition continued to keep up with subsidence, with varying local conditions ranging from fringing reefs to offshore shelf. This resulted in the build up of large deposits of limestone of the Cliefden Caves Limestone Subgroup in the early Eastonian (Webby & Packham 1982, Pogson & Watkins 1995). A period of erosion occurred which removed the uppermost layers of the limestone due to its ocean-facing position. This resulted in the easternmost limestones being more eroded than the western ones. In the late Eastonian there was a period of sedimentation associated with deeper water with deposition of mud and limestone breccias slumped from the western carbonate platform. This is represented by the late Eastonian to earliest Bolindian Malongulli Formation. During the Bolindian, there was a period of volcanic activity, depositing the Angullong Tuff (Webby & Packham 1982). Quartz porphyry was emplaced to the north of Walli Caves during the Late Ordovician to Middle Silurian (Percival 1976). The region has been faulted by the Wonga Fault, the Columbine Mountain Fault and numerous smaller faults.

Although there is no date suggested as to the current exposure of the limestone at Walli, bones recovered from Bone Cave by Wilkinson were identified as belonging to Pleistocene fauna by the Australian Museum (Wilkinson 1892), indicating that the caves must have had an open entrance at that time.

Ironstones

Many of the chert nodules in the Cliefden Caves Limestone have a high goethite content, possibly a weathering product of pyrite. Some of this goethite is iridescent, e.g. near the shearing shed at “Boonderoo” property (Cliefden Caves).

Walli Caves

Walli Caves are located on the "Bingera" farm property. The caves are on the eastern and western sides of Licking Hole Creek, with the largest caves on the western side. Cave outlines vary from branching to networks. The caves are formed from solution of more pure limestone around areas of impure limestone. Most caves are formed around the local joint and fault pattern, with bedding influencing some passage cross sections. Typically the caves are developed along strike and down dip with connecting passages developed around joints. Some are developed perpendicular to bedding. Solution has exposed the less-soluble components of the limestone such as chert nodules and filled joints. Thinly-bedded limestone is exposed as cave walls or blind passage terminations.

Gravel deposited in the caves has been covered with flowstone, only to be subsequently re-excavated, redeposited elsewhere in the caves and again covered with flowstone. This process has occurred several times, resulting in the development of false floors in most of the Walli caves (Frank 1974). Frank noticed that both Piano Cave and Deep Hole have extensive deckenkarren development, and identified areas of Piano Cave and Deep Hole where aragonite occurs.

Gypsum is found in many of the caves at Walli, usually as a coating on the limestone but also occurs as selenite needles developed on the surface of exposed chert nodules. In the caves, the surface coatings are most often found in areas where ponds have developed.

Several other caves have been recorded by members of the Sydney Speleological Society on the eastern side of Licking Hole Creek. Box Cave, Stovepipe Cave and Oolite Cave are network caves, developed in the Belubula Limestone. About 70 m to the west of Deep Hole is Horse Cave. This is a vertically developed cave, with a deep entrance shaft similar to Deep Hole. It has a single passage following the strike of the limestone. Some of the caves are occupied by bats, and their guano adds to the cave deposits.

Caves Chosen

Two caves at Walli, Piano Cave and Deep Hole, were chosen for this study, as these were the only caves at Walli in which aragonite had been recorded or mentioned. Piano Cave is important as it is the first reported occurrence of aragonite in a NSW cave. Both caves are formed in the Belubula Limestone member of the Cliefden Caves Limestone Subgroup.

Observations at Walli Caves: Deep Hole (Deep Cave)

Location

Deep Hole (Deep Cave) is located on the western side of Licking Hole Creek near the top of an east-facing hill near the south of the limestone outcrop. It is about 350 m northwest of Piano Cave (Figures 3.118 and 3.121).

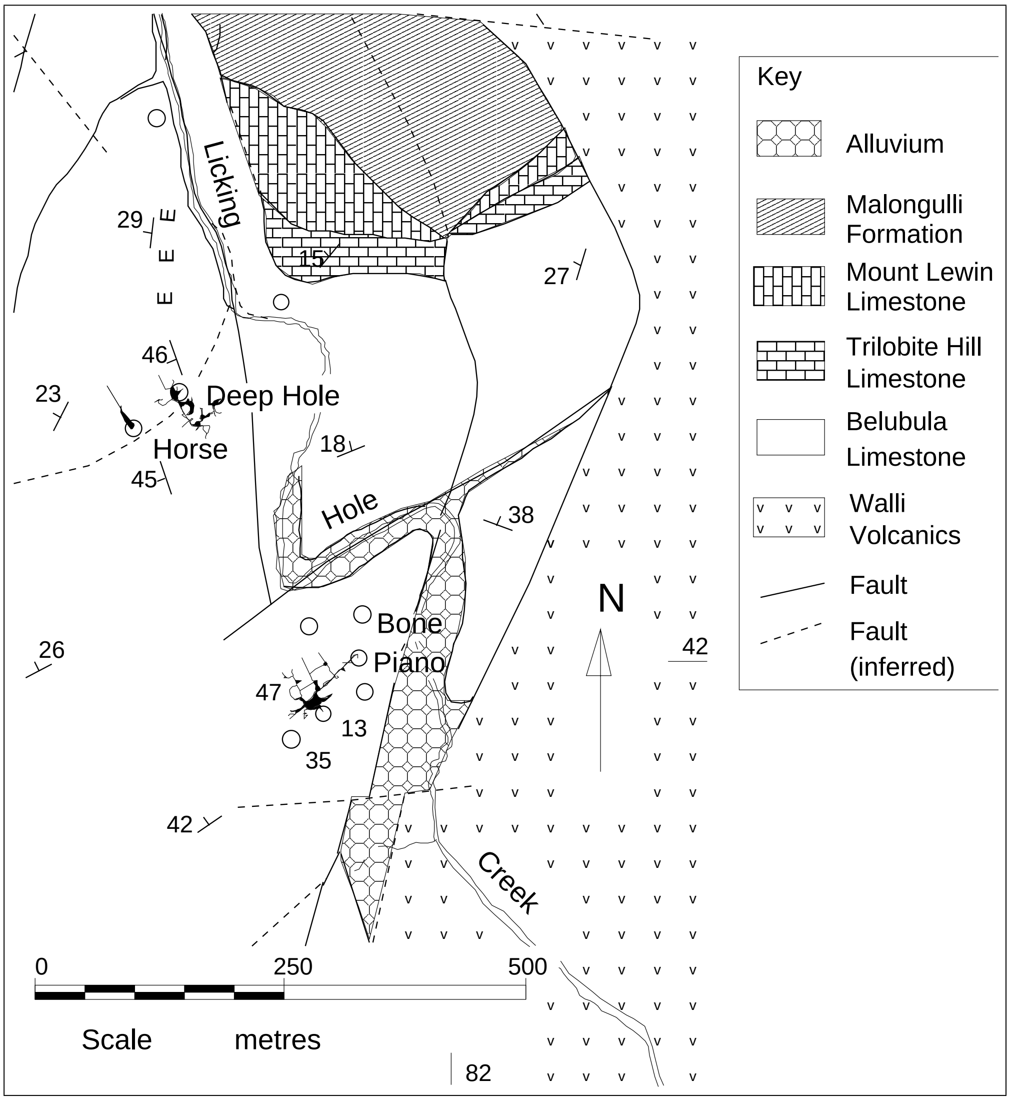


Figure 3.118: Map of study area at Walli, showing approximate cave positions, outlines and outcrops. The cave positions are estimated to be within 50 m. Cave overlay is from Frank (1974). Geological information is from Percival (1976) and Pogson et al. (1995).

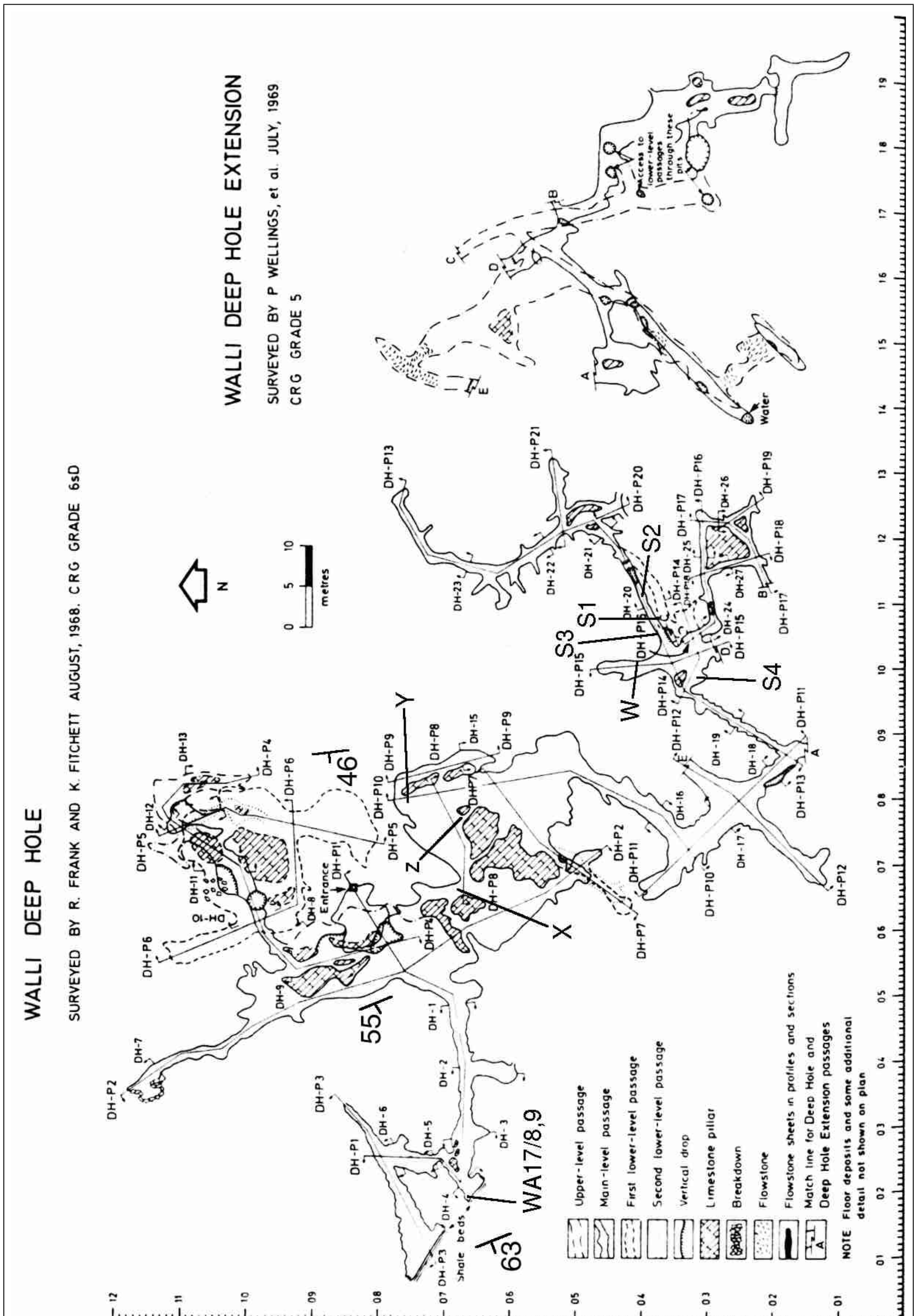


Figure 3.119: Map (plan) of Deep Hole based on Frank (1974) overlaid with dip and sample sites. Key: WA17/8,9, S1-S4, W, X, Y, Z: Sample sites.

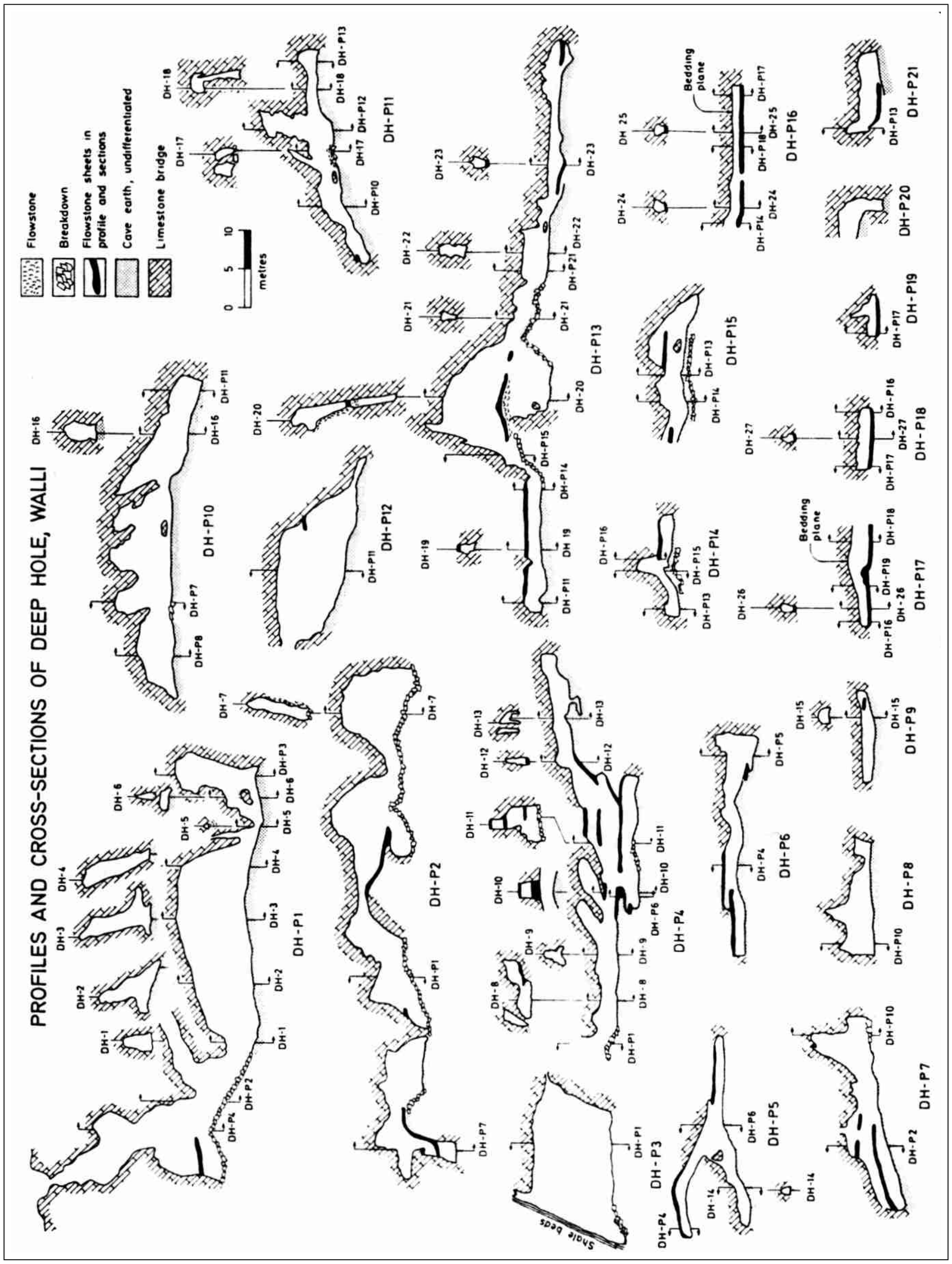


Figure 3.120: Cross sections of Deep Hole from Frank (1974).

Geological Setting

Figure 3.121: Entrance, Deep Hole.

Deep Hole is developed in massive Belubula Limestone of the Cliefden Caves Limestone Subgroup. Percival (1976) noted that this limestone has chert nodules and some thinly bedded subunits. However the subunits have not been formally studied in the vicinity of the caves.

A few metres east of the cave entrance, the limestone exhibits a variety of textures from massive to cherty. The more impure beds tend to form small raised ridges near the cave. Just outside Deep Hole the bedding strikes 173° and dips 46° to the west. About 10–15 m to the west of the cave is a thinly-bedded unit resembling a small road (and sometimes used as one). The surface outcrop is about 3 or 4 metres thick and is thought to be related to a thinly bedded unit seen in the western branch of the cave. A grassy swale between Horse Cave and Deep Hole is most likely part of the same thinly-bedded unit. A fault shown south of the cave entrance (Figure 3.118) may correlate with faults seen in the southern part of the cave. Percival (1976) indicated a curving fault trending NE-SW in an area estimated to be within 50 m of the cave. There may be additional faults and folds not shown on the map (Figure 3.118 as the measured dip varies considerably between Deep Hole and Horse Cave (to the west). For example, the strike at Horse Cave was north-south and the dip was about 45° to the east. About 10 m east of this, the strike was north-south and the dip was about 80° to the west.

Cave Description

The overall shape of Deep Hole is an open network developed on multiple levels. The main passage orientations are aligned parallel to strike of the limestone (Figure 3.119). Passages running at right angles to the strike follow joints and, in the south of the cave, faults. Passage cross sections vary from elongated ovals, semicircles and asymmetric curved shapes to inverted teardrop and keyhole shapes. Frank (1974) noted deckenkarren in places. Flowstone sheets occur in Deep Hole, developed on multiple levels (false floors). Passage sizes vary with a “halls and narrows” pattern in some areas, e.g. near the “Shale Beds”, and near site “S3” (Figure 3.122).

Deep Hole has a very steeply sloping entrance shaft. The upper 14 m is developed steeply down dip. The lower 7 m is a vertical drop, partly blocked by sediment and speleothems. Most of the rest of the cave is horizontally developed. At the base of the entrance pitch is a talus cone of shattered rocks, some of which have been thrown down by people. Here, the limestone strikes 146° and dips 55° to the southwest (measured underneath the calcite canopy).

The north-western part of Deep Hole was only cursorily examined during this study. It is developed along a series of canyons, well-coated in places by a clear speleothem with large crystal facets (presumed to be barite and selenite from samples elsewhere in the cave).

At the furthest west point of the cave (map grid ref 020,065 and 010,075), the passage is terminated by the "Shale Beds" – an overhanging wall of thinly bedded limestone (Figures 3.122 and 3.123). The bedding at this wall strikes 168°, dips 63° to the west and is conformable with the limestone (the orientation of this feature on the cave map is questionable). This thinly bedded rock appears to be the same thinly-bedded unit exposed on the surface to the west of the cave. The passage at this point is very high, and forms a narrow slot about 4 m wide and possibly 15 m high. Although not shown on the map, this passage opens up about 15 m above the floor and may become part of the entrance passages. This would partially explain the drier nature of this part of the cave compared to a parallel passage to the north of this chamber which also exposes the thinly-bedded unit but does not have the high ceiling. The lowest part of the south-easterly end of the cave near GR 070,012 is also terminated by a wall of thinly-bedded limestone similar to the "Shale Beds". A few metres to the east of this wall are thin beds of a reddish material. At the foot of the wall, marks indicate that a standing pool of water can occur at times.

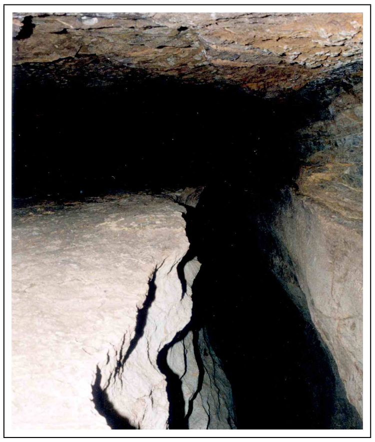
Further to the south-east, small fault displacements of about 10 to 15 cm are visible in exposed sections of bedrock near GR 086,018. At GR 105,035 (near "W") is a large chamber, formed at the junction of two narrow but tall passages. The bedding in this area is difficult to determine, but appears to be vertical (Figure 3.122). The northeast striking passage near "S1" and "S3" follows a fault as samples (WA17/3, see below) suggest.

Bedrock Samples - Deep Hole

All bedrock samples in the cave are from the Belubula Limestone unit.

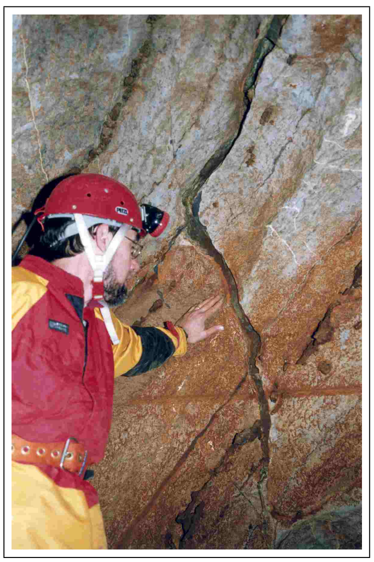
Cave sample WA17/8 is from the western side of the "Shale Beds" at GR 022,067 about 1.5 m from the ground. The material was very crumbly in the cave, with some layers softer than others. Gypsum, barite and small platy metallic crystals occur on the specimen surface. Thin section shows at least two different beds (Figure 3.123) of mudstone, siltstone and sandstone. The finer layers are a pyritic mudstone grading to siltstone, with some secondary gypsum in the material. The sandstone layers comprise equal quantities of lithic fragments of quartz and another silicate in a fine brown (silt) matrix, with occasional pieces of phosphatic bioclasts and opaques. Some of the quartz shows stress. The sandstone has subrounded grains, and is a moderately sorted, fine to medium sandstone or arenite.

Cave sample WA17/9c is from GR 022,065, from the south-eastern wall of the "Shale Beds". This piece of weathered thinly-bedded unit is similar to WA17/8. XRD indicates: Major quartz and calcite; Minor gypsum and maricite (NaFePO4); Trace biotite and strontian barite.

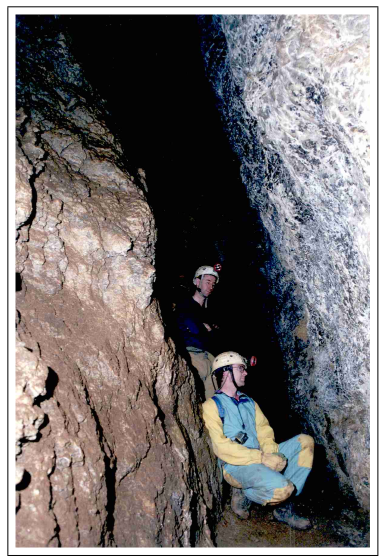


Ceiling above “The Shale Beds”, looking upwards and to the north-east.

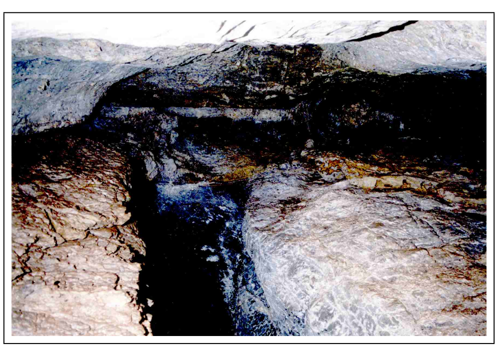
“The Shale Beds”. View is to the NW.



Vein contains mica. Chert layer behind and above Dr Osborne’s head. Deep Hole, site “Y”, sample WA17/11.



Area “S1” (RH wall) and “S3” (LH wall) with Drs Lake and Maynard.



Ceiling west of junction above “W”; left is to the NNE and right is to the SSW.

Ceiling above north wall, “S3”.

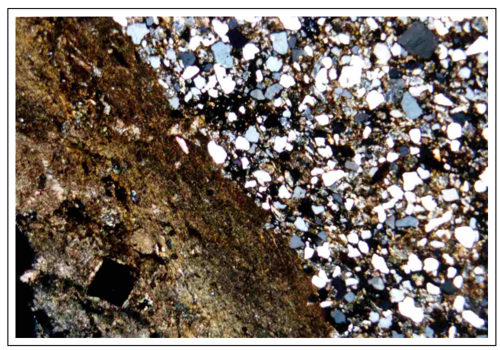
Figure 3.122: Deep Hole features

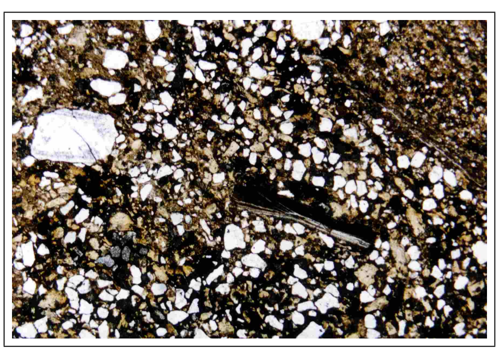
Cave sample WA17/11 was from GR 081,077, sample point "Y". The material is a grey laminated vein that cuts across the bedding (Figure 3.122), striking NNW and dipping almost vertically. The hand specimen is a fairly low density, fine-grained greenish grey rock with a micaceous, clayey surface and a tendency to fracture into angular pieces. Under the microscope, a layer of creamy, flaky crystals could be seen. XRD indicates: Major quartz, calcite, muscovite 1M & 2M and gismondine; Minor vermiculite, clinochlore, illite 2M1 and phlogopite; Trace parnauite (Copper arsenate silicate, hydrated). This appears to be a vein rock, possibly associated with faulting.

Wall coatings and reflective facets

The Deep Hole has unusual wall coatings. In the many parts of the cave, shiny crystal facets reflect circles in the cap lamp. These facets occur on exposed bedrock surfaces and are quite unlike the facets of calcite often seen on dry speleothems. At first, it was thought that they were altered crinoid ossicles as they were about the same size and shape, and occurred on bedrock surfaces.

Sample WA17/8 from the "Shale Beds".


TS WA-17/8 x13 XN N36083 Two lithologies are present: a silt and an arenite.


TS WA-17/8 x13 PPL N36083 Phosphatic bioclasts in the arenite.

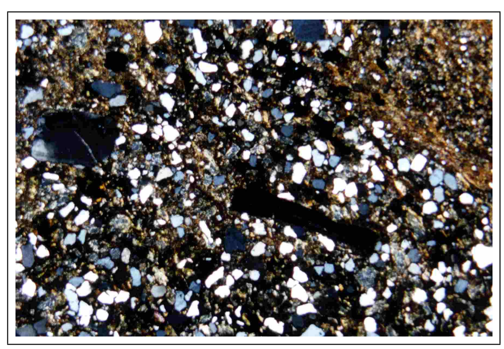

TS WA-17/8 x13 XN N36083 Phosphatic bioclasts in the arenite.

Figure 3.123: Bedrock thin sections from the "Shale Beds", Deep Hole sample WA17/8

Further investigation suggested reflective facets may be hydrothermally deposited selenite and barite forming a thin coating over the limestone. They have only been observed in the lower levels of the cave and only coat the bedrock: they do not coat the calcite speleothems. They have not been recorded by the earliest visitors to the cave, possibly because they are only visible when the lamp and observer's eyes subtend a small angle with the object, such as with an electric mining lamp. **Samples WA17/10, 10A, 14 and 15a** include some of this coating (Figure 3.124).

Cave samples WA17/10 and 10A are from **Location "X"** (Deep Hole map GR 070,066) Sample WA17/10 is a tiny fragment of rock: foetid limestone with a corroded-looking surface. WA17/10A, also from point "X", about 2.5 m from the ground in a wall niche, is a wall scraping from a corroded **-** looking area which had a thin grey substance coating the surface of the rock. The material resembles concrete dust with some small sparkly crystals. XRD of powder: Major calcite, gypsum, quartz and barite; Minor montmorillonite, chalcopyrite, manganocalcite and metaschoderite ($Al_2PO_4VO_4.6H_2O$); Trace of other barium-rich minerals.

Location "S4" is at GR 099,030 and is the underside of a bedrock pendant about 1 m from the ground near the southern side of the passage. **Cave sample WA17/14** is a bedrock chip with a brown, sparkly crystalline coating. The bedrock is fine dark foetid limestone with black specks (hand specimen in reflected light) which are monocrystalline fossils, probably small echinoderm fragments. Although the limestone looks corroded, the corrosion is only on the surface and the interior of the limestone is firm and dense. The crystalline coating is only very thin, on the surface of the limestone, and very sparkly due to crystal aggregate facets (suspected barite). Some clay was present. The coating has penetrated a small crack in the limestone and filled it with a vein of drusy crystals (Figure 3.124).

Aragonite Samples and Observations

Samples of aragonite were collected from the "Shale Bed" (Deep Hole map GR 022,065), "S3" (GR 110,039) and location "Z" (GR 078,069).

The "Shale Bed"

The "Shale Bed" has yellow and white speleothems (coatings). The sample site is on the south corner of the wall, about 2 m above the floor. WA17/9b is mainly clay coated with white powder and small squarish crystals that look corroded and resemble gypsum. WA17/9a is a pinky flake (coating) with a fibrous mamillary crust made of soft, white and clear fibrous crystals, forming a very fine speleothem surface. Under the microscope, the underside has fine needles (similar to sample WA12/18), mud and clear crystals (Figure 3.124). The needles have a parallel habit, not radiating. XRD of the speleothem indicates: Major aragonite; Minor natron, epsomite and braunite; Trace variscite. Calcite-inhibitors present in this speleothem are mainly epsomite (magnesium sulfate). The small size of the aragonite crystals infers rapid precipitation, possibly aided by cold dry air descending the entrance pitches during winter and drying out the surface of the

Aragonite speleothem coating (middle specimen) clay and soft sediment from the "Shale Bed", sample WA17/9.

Coating of bedrock surface near "X".

Specimen WA17/14 looks corroded from the outside but inside the limestone is intact. Vein contains barite.

Edge view, sample WA17/14 showing how the crystal coating only coats the surface and does not penetrate deeply into the bedrock.

Figure 3.124: Speleothem coatings. Deep Hole sample WA17/9, 14.

rock, concentrating the minerals. The lower humidity of the entrance area is also discussed with weather measurements. In the parallel passage north of the "Shale Beds", the silty floor has signs of having had standing water and organic debris. This chamber also has an overhanging thinly-bedded wall which is lacking speleothem efflorescences like the first exposure of the wall. The CO_2 measurements were much higher than in the entrance chamber, so possibly organic debris is washed into the cave and settles in this chamber. The lack of ceiling holes and a more restricted connection to the entrance area would suggest that humidity fluctuations in the entrance have little influence in this chamber. Aragonite precipitations in the more southerly chamber are mostly influenced by evaporation concentrating the salts in solution.

Chamber near area marked "Z"

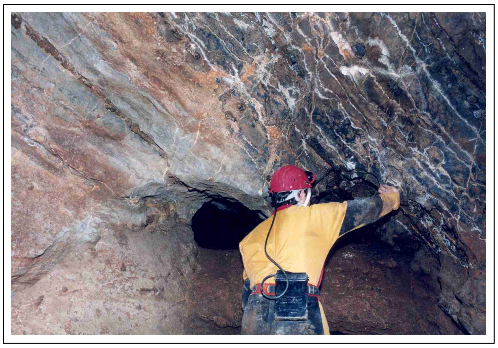
A spacious chamber, at Deep Hole map GR 075,070, has good examples of reflective facets (most likely barite) about 4 mm diameter. These form part of a clear coating on a large bedrock pendant, about 4 m long by about 2 m wide and high, long side oriented NW. This pendant exhibits the varying colours and textures of the limestone bedding.

Near the southern side of this chamber (location “Z”, map GR 078,069), small orange aragonite efflorescences have developed along a seam or joint, contrasting with the grey and black limestone and white calcite / barite veins. This aragonite was discovered after flash photography showed unusually long-persistence blue phosphorescence along this seam. Phosphorescence of calcite from light excitation is usually green. A small sample was taken of the aragonite (WA17/13) and of the seam (WA17/12). The sample site is about 2.5 m from the ground, above a solution hole (Figure 3.125). **Specimen WA17/12** is the substrate for the aragonite. It has bands of black foetid limestone, yellow to pale orange and grey-white veins. The crystals in the veins are etched. The surface of the bedrock is corroded but the inside is firm and intact. There are also small brown veins in the seam. XRD of yellow and white material indicates: Major barite; Minor calcite, gypsum and hexahydrite (MgSO4.6H2O); Trace other barium minerals.

Sample WA17/13 is a small orange spheroid of aragonite and clay from this site. The material is relatively hard, with a growth habit and cleavage typical of aragonite (Figure 3.125). XRD of small sample indicates: Major aragonite, gypsum and calcite; Minor kaolinite and pyrolusite; Trace meta-alunogen. The most likely explanation for the aragonite at this site is the presence of two calcite-inhibitors, sulfate and Mg, in the substrate (vein).

Further to the south-east in the cave, some cave coral in a wall niche near GR 080,040 resemble aragonite. However they may be simply directional (calcite) coralloids as the acicular edges appear to be aligned with the direction one would expect air currents to take. High near the ceiling near GR 073,034 large, upturned helictites appear to be developing from solutions seeping from a particular bedding plane (Figure 3.125). Below the helictites is a large vertical cave shield with a canopy. Upturned helictites seem to be common in caves where the magnesium ion is present, such as in Wollondilly Cave (Wombeyan) and Tantanoola Cave, South Australia.

The seam from the northern side of this chamber was described earlier.



Area “Z” where the blue phosphorescence was noted (orange and white veins).

Area “Z”; aragonite occurs as small orange spheroidal coatings.

Aragonite sample WA17/13, x25.

Aragonite sample WA17/13, x25.

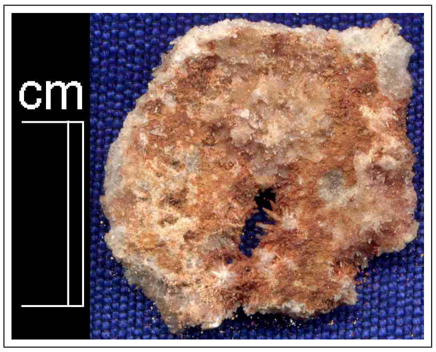
Sample WA17/12. This vein is the substrate of some of the aragonite. Yellow mineral is mainly barite.

Upturned helictites in an area about 20 m south of “Z”. Width of image about 0.5m.

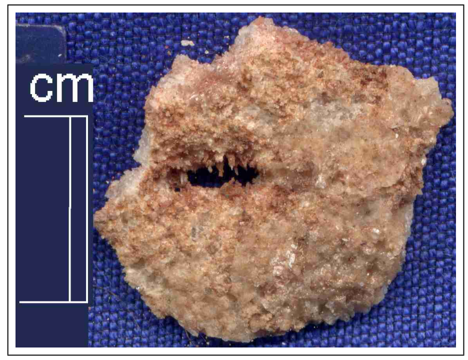
Figure 3.125: Samples from area “Z” and speleothems south of the area.

Sample sites "S1"-"S4", "W"

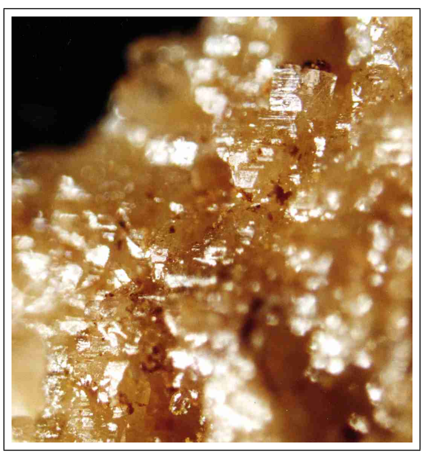
Frank (1974) reported aragonite from a site near GR 105,036 (the exact location is unknown). The lowest parts of the junction area near S4, GR 101,031 are coated with clear probable barite with large crystal facets. **Cave sample WA17/15** is from Deep Hole map GR 102,029, east of "S4" about 2 m from the ground at the base of an upper-level wall. It was a speleothem crust forming a small (1.5 cm dia) rosette of crystals (Figure 3.126).



Rosette of barite, clay and gypsum (inner sample WA17/15).



Rosette of barite, clay and gypsum (outer sample WA17/15).



Barite, sample WA17/15, x25.

Needle crystals resemble aragonite but no aragonite was detected. Sample WA17/15, x25.

Figure 3.126: Deep Hole barite rosette, sample WA17/15

It was fairly dense despite its high porosity. Four types of textures were visible:

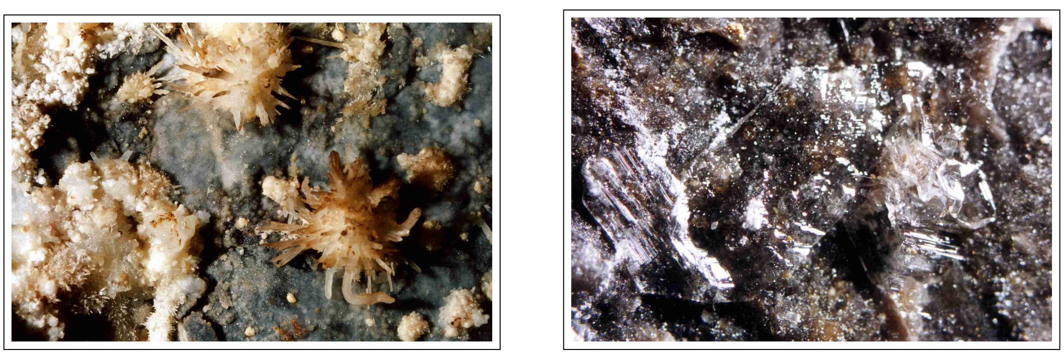
- Flat, shiny crystals with small facets all with the same orientation. Vitreous to specular reflection from crystal faces, presumably tabular barite.
- Corroded-looking needle crystals which resembled paramorphs of aragonite. Terminations are brush-like. Presumed to be wollastonite.

- A brown clay, most likely illite.
- A fine powder containing cube shapes coated with clays, resembling gypsum.

XRD indicates: Major illite 2M1 and barite; Minor heulandite (strontian), gypsum, clinoptilolite and wollastonite 1A; Trace tridymite and other minerals.

Near site "S1" the upper canyon-shaped passage trending east-northeast is remarkable for the differences between its walls (Figure 3.122). The southern wall is slightly overhanging, with numerous flakes of dark foetid limestone spalled from the wall by crystal wedging. Speleothems include aragonite rosettes and small anthodites. A small spathite has formed around a slowly-dripping stalactite. Brown colouring near this may be due to bats. (Figures 3.127, 3.128). On the floor of this passage are a number of fallen chert nodules and spalled bedrock.

Figure 3.127: Small stalactite with anthodite-like speleothems. Area S1.



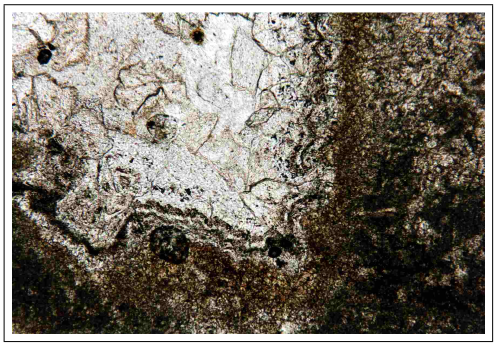
Aragonite-like speleothems in area S1-S2.

Surface of sample WA17/2, site S2, shows barite and gypsum crystals.

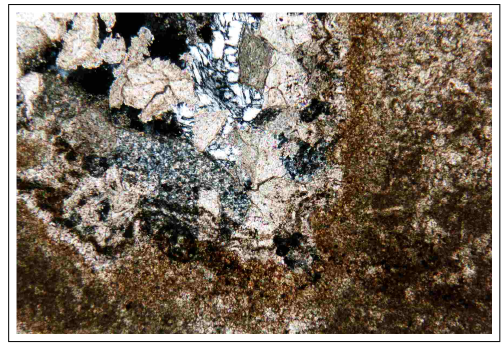
Figure 3.128: Deep Hole sample sites S1, S2.

Cave sample WA17/2 from GR 110,038 (S2) is of naturally fallen material spalled off the south wall of the rift. Three textures / sample types were collected from the floor:

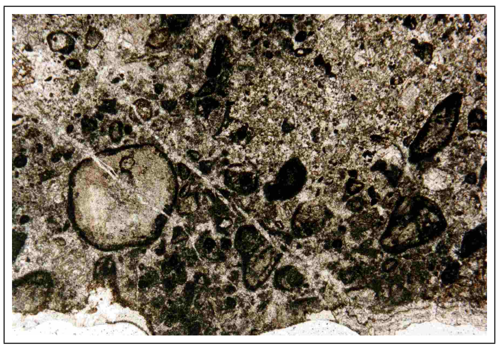
- Shards of foetid pelletal limestone, with the surface covered with hard, clear tabular diamond shaped crystals with a high refractive index (Figure 3.129). The tabular crystals were much harder than gypsum and were assumed to be barite. Some crystals with lower refractive index may be gypsum. Small amounts of aragonite may have also been present. When tested with dilute HCl, the material gave off a slight H_2S smell and left a dark residue. The other crystals do not react with HCl. Thin section indicates there may be small amounts of a phosphate and quartz in the coating.



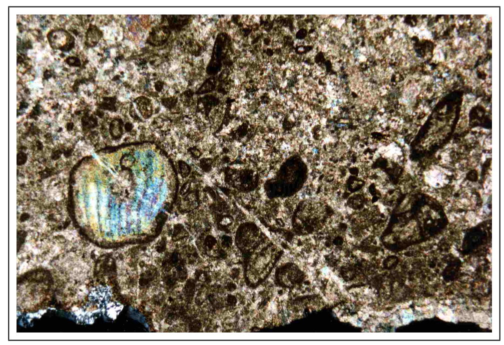
TS WA-17/2 50x PPL N35757 Crystal-lined vugh appears to be phosphatic.



TS WA-17/2 50x XN N35757 Crystal-lined vugh appears to be phosphatic.



TS WA-17/2 13x PPL N35757 Bedrock with acicular and clear speleothem coatings on lower edge.



TS WA-17/2 13x XN N35757 Bedrock with acicular and clear speleothem coatings on lower edge.

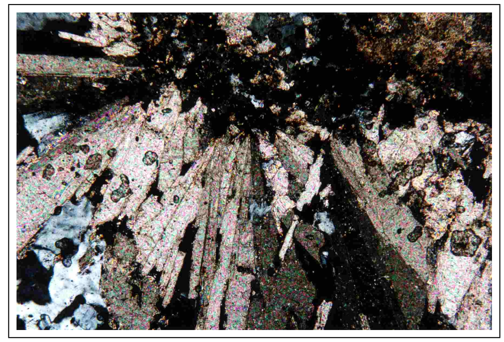
Figure 3.129: Bedrock thin sections with speleothem coatings and vugh filling, sample WA17/2, area S1, Deep Hole

- Gypsum, as clumps of small powdery crystals. The Australian Museum has a sample of this and verified it is gypsum (Ross Pogson, pers. comm.). It was also found to be entirely mineral in origin (not biogenic, not formed from bat guano).
- A mixture of the two types. Possibly the bedrock is flaking due to gypsum crystal wedging.

XRD of spiky coating from the bedrock (not the tabular masses) indicated: Major gypsum; Minor calcite; Trace quartz, cuspidine, vesuvianite and rustumite.

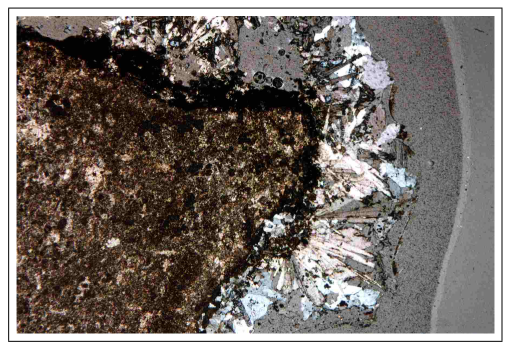
The northern wall of this passage is covered with brown sparkly nodules (Figure 3.130). **Cave sample WA17/3** from **site "S3"** (Deep Hole map GR 110,039) is a small nodule of limestone with a corroded-looking surface covered with crystals. The sample site is about 1 m from the floor and about 3 m east of the rift junction on the north side of the rift. XRD of the sparkly surface indicates: Major gypsum and calcite; Minor aragonite, quartz and barite; Trace anhydrite and pyrolusite.

TS WA-17/3a 13x PPL N35767 Acicular speleothem coating bedrock.

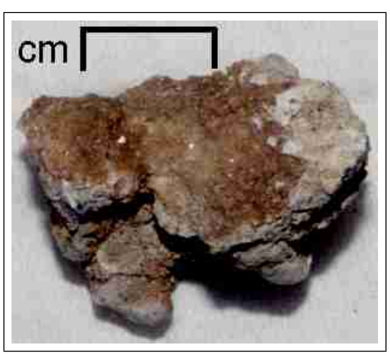


TS WA-17/3 50x XN N35767 Detail of acicular speleothem.

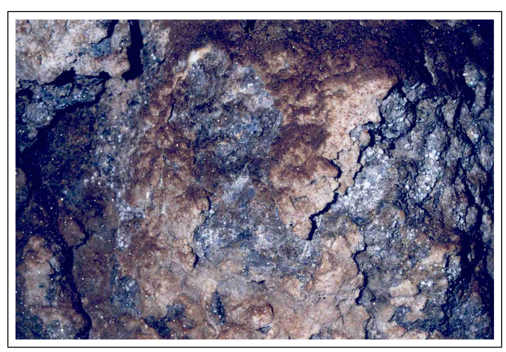
TS WA-17/3 13x PPL N35767 Nodule comprises two different limestone facies displaced by a small fault.



TS WA-17/3 13x XN N35767 Detail, speleothem coating. Gypsum (bluish) and aragonite (acicular) have developed from an opaque layer (possibly pyrolusite). Some bioclasts are highly birefringent.



Specimen WA17/3 is a nodule projecting from the surface at “S3”.



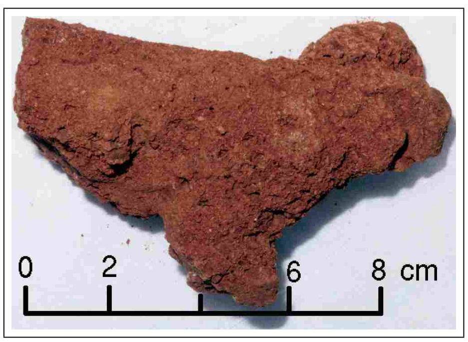
Area “S3” is covered with sparkly nodules.

Figure 3.130: Area “S3” has nodules of fault-breccia coated with sparkly crystals of aragonite and gypsum.

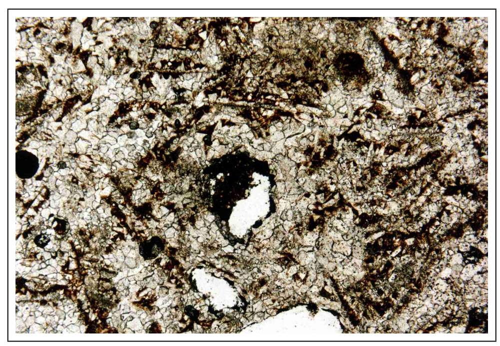
Thin section shows there are two facies present. It appears to be part of a fault slip breccia, as parts of the sample were dark foetid limestone (sparse to packed pelloidal biomicrite) whereas other parts of the same rock were from a lighter grey limestone (poorly sorted biosparite) with a small displacement between the two facies. Some bioclasts in the dark facies appear to be replaced by a mineral with a high refractive index. The sparkly crystal covering is only on the surface, with a mildly corroded rock surface underneath. Aragonite occurs as small hemispheroids originating from a thin opaque layer (probably pyrolusite) on the limestone.

The northern passage (**site "W"**) is formed along a couple of levels and terminates in a narrow area. There was no aragonite visible in this passage. The high ceiling of the passage has some irregularly shaped stalactites which appear to have developed along a white bedrock layer (assuming vertical bedding). The southern passage branches into multiple levels. Speleothems include coatings, conventional stalactites and some irregular stalactitic forms which could be calcite paramorphs after aragonite. On the floor is a reddish cave fill. Some fills have been covered with calcite flowstone forming the thick false floors that are characteristic of Walli caves.

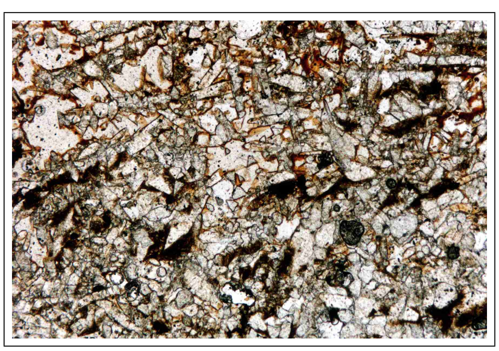
Cave sample WA17/4 from **site S4** (map GR 100,031) is a bone-shaped altered chert nodule found loose with other nodules in an ochreous deposit on the floor of the rift near site "S4".



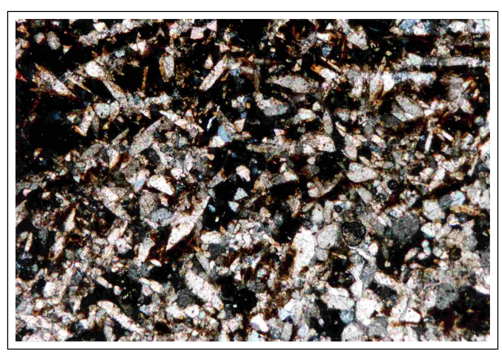
Bone-shaped chert nodule, WA17/4.



TS WA-17/4 13x PPL N35758 Material is porous with numerous opaques.



TS WA-17/4 25x PPL N35758. Appears to be a replacement fabric.



TS WA-17/4 25x XN N35758.

Figure 3.131: Bone-shaped replaced chert nodule, area "S4", Deep Hole

The sample surface is a sandy red ochre. The material is porous, rather heavy, hard and crystalline. Broken surfaces are sparkling. XRD indicates: Major chalcopyrite, calcite and strontian barite; Minor quartz and manganocalcite; Trace hematite and rectorite.

Thin section shows a bizarre texture quite unlike conventional chert nodules and also unlike fossil bone (Figure 3.131). On low power, the material comprises quartz, and interlocking double-terminated crystal laths resembling anhydrite and gypsum. As there was no gypsum in XRD, then possibly the double-terminated crystals are pseudomorphs of barite and quartz after gypsum and anhydrite in a chert nodule. The long rod-shaped structures are reminiscent of rafts. There is no phosphate, and no internal bone structure so it is assumed not to be bone. On high power, small opaque triangles are visible inside the barite laths, and could be the chalcopyrite noted in XRD.

Cave Weather Measurements

The change in temperature and humidity is noticeable from the entrance to the base of the upper 14 m entrance pitch. The cave mud is relatively dry at this point. Below the lower 7 m pitch, there is another increase in humidity. In a small chamber to the east of the entrance chamber talus cone, the humidity is much higher again and the cave mud is more plastic. The cave is relatively warm, about 19°C (Table 3.6) compared with the average annual temperature of 16°C for the area (Carcoar).

Temperature measurements on 30th June 2001 were taken using a Mercury-in-glass thermometer, -10 to 110°C. All other temperature and humidity measurements used a “Zeal” whirling hygrometer. In the western-most chamber with the “Shale Beds”, the CO_2 readings were much higher than at the entrance chamber, possibly from organic decomposition.

Although no readings were taken, warm moist air was observed flowing out of the cave entrance into the cool dry night air on the June 2001 trip. “Steamers” are often reported from these caves on early winter mornings (P. Wellings and S. Zanker, pers. comm.). Given the shape of the entrance chambers, it is reasonable to expect meteorological conditions in the entrance area to be affected by cold air flowing down the pitch during winter evenings as the warm air is expelled. Areas affected by this would include the entrance pitch, the west-trending passage nearby and the “Shale Beds”.

Date	**Location**	**CO_2 (%)**	**Temp (°C)**	**RH (%)**
30th June 2001	R, GR 105,035	0.15	19	high (not measured)
17th August 2002	B, GR 060,086	0.18	18.83	$>$95
17th August 2002	S, GR 012,072	0.5	18.5	100
17th August 2002	R, GR 101,031	0.18	18.5	$>$95

Table 3.6: Deep Hole temperatures and humidities. GR = Grid Reference, Frank (1974). R = Rift junction near site S1. B = Bottom of entrance pitch, under canopy. S = Western “Shale Beds” chamber.

Synthesis: Aragonite in Deep Hole

Aragonite is not common in Deep Hole. There are two types of aragonite occurrence: one type is associated with the “Shale Beds” and the other is deeper in the cave associated with minerals developed in veins and faults.

Aragonite at the “Shale Beds” is associated with an area affected by drying near the cave entrance. Minerals in this area include gypsum, natron, epsomite, variscite and barite. The first three are soluble minerals containing calcite-inhibitors, namely magnesium and sulfate. Variscite (a phosphate) was detected in the aragonite speleothem. If this mineral was present in colloidal form (prior to precipitation) it may also inhibit calcite precipitation. Barium is a calcite-inhibitor, but as barite is extremely insoluble, it is unlikely to affect the carbonate polymorph. A potential source of sulfate and phosphate near the entrance is the organic decomposition of bat guano but another more likely source is in the “Shale Beds” themselves. The presence of both epsomite (near the “Shale Beds”) and hexahydrate (near “Z”) would infer that magnesium sulfate is inorganically derived from minerals present in the bedrock. Pseudomorphs of goethite after pyrite were seen in thin sections from the “Shale Beds”, which suggest an inorganic origin of sulfate from weathering pyrite.

The second type of aragonite occurrence is associated with inorganic processes in areas with very high humidity. At location “Z”, aragonite (as small orange spheroids) was associated with vein minerals containing Ba, Mg, $S0_4$ and Mn: barite, other Ba minerals, hexahydrate, gypsum, metaalunogen and pyrolusite. Small amounts of other barium minerals were noted in trace quantities. Some of these are be more soluble and therefore more likely to inhibit calcite (and enhance aragonite deposition). For example, the solubility of barium carbonate is similar to that of calcium carbonate.

At location S1,S2 and S3, the passage has developed along a fault. Limestone flakes have spalled from the walls by gypsum crystal wedging. Aragonite (as coatings, small crystalline hemispheroids and anthodites) was associated with Ba, SO_4, Mg, Mn: barite, gypsum, anhydrite and pyrolusite. The main calcite-inhibitors in this case are sulfates, with smaller amounts of Mg and Ba. Barium (as barite) is unlikely to influence aragonite precipitation due to its insolubility. A coating of pyrolusite (MnO2) appeared in one case (WA17/3) to form the substrate for the aragonite.

The origin of the (inorganic) gypsum masses may be from two sources: both primary deposition from hydrothermal waters, and from sulfuric acid released by oxidising sulfides in the bedrock and in the chert nodules. Precipitation of gypsum in the second case appears to have caused the bedrock to be wedged apart in an area near a fault (S1, S2, S3). It is worth noting that aragonite occurs where the bedding is very steep, or is cut by near-vertical faults, which is strongly suspected to allow oxygen-rich groundwater derived from downward-percolation of rainfall to penetrate the beds, oxidise any pyrite and mobilise ions.

The most likely source of Mg is dolomite in and around the cherts, again being liberated by the oxidisation of various pyritic minerals in the cherts. Mn may have a similar origin.

One possible origin for the barite is as a direct precipitate onto the cave walls from hydrothermal waters during an earlier period of the cave's development. Another possible origin is the slow migration of barite from veins in the limestone, re-precipitating further down the cave as a speleothem coating. Given the extreme insolubility of barite at current cave temperatures, this may be less likely. Other barium minerals may be released during the weathering of pyritic cherts.

Observations: Piano Cave

Location

Piano Cave is located near the southernmost extent of the limestone at "Bingera", on the western side of Licking Hole Creek near the top of an east-facing bluff (map, Figure 3.118).

Geological Setting

Piano Cave is developed in the massive Belubula Limestone Member of the Cliefden Caves Limestone Subgroup. The limestone at Piano Cave dips mainly to the west. Between Piano Cave and nearby cave WA13, there is a marked change in the dip of the limestone, suggesting a fault. Some dolomitised beds are seen on the surface. Beds with chert nodules are associated with an abundance of bryophyte plants which prefer the nodules compared with the limestone. Grikes and rillenkarren are common features of the surface above Piano Cave. Above the cave, several metres northwest of the cave entrance, there is a grassy roadway-sized region about 20 m long and about 4 m wide, striking east-west, where the limestone does not crop out. This is suggestive of a thinly-bedded unit (not shown on map) which may limit the northern extent of the cave. The eastern side of the cave may be developed in a fault breccia, as there is a marked change (not measured) in bedding dip between Piano Cave and the entrance of nearby cave WA13 east of Piano Cave.

In the north-west part of the cave a fault strikes 150° and dips 51° to the SW, (map GR 015,079 "U", Figure 3.133). Nearby, at site "S1", the bedding strikes 207° and dips 45° to the WNW. In the northern part of the cave the bedding strikes roughly north and dips about 70° to the west (map GR 052,075 near "S5", Figure 3.133). One of the limestone beds in this area is more yellowish than the others, and is separated from the adjoining beds in this area by a small gap.

Cave Description

Piano Cave is a mainly horizontally developed system with some vertical shafts, one of which has been artificially blocked. The cave (Figure 3.133, 3.132) is formed along two main joints, one striking NE-SW and the other striking NW-SE.

The two main passages are cross-connected by smaller chambers, forming arcs roughly from south-east to north-west. The northern part of the cave has a series of small passages with oval to elongated cross sections. At map grid reference GR 052,075 is a high chamber with roughly oval cross-section, discovered during this study. It is short, and contains a large amount of bat guano. The largest chamber is in the south east part of the cave. Between the largest chamber and the high chamber, the passages form a vertical rift with elongated rectangular cross-section. In the ceiling of the largest chamber, there is a prominent joint or bedding feature. It strikes NW-SE and dips NE (actual angle not measured). The eastern part of the cave has a rockpile and a chamber with a loose rocky floor. This is the area where the vertical shaft entrance has been artificially blocked and is thought to be close to a fault. It may be a fracture zone.

The southernmost end of the cave is the lowest point in the cave (Figure 3.132). Ceiling channels in the southernmost area terminate at gravel-filled pits (sumps). During wet periods, water rises in these sumps. Parts of the bedrock in this area are corroded into swiss-cheese forms and bell-holes. These passages are reminiscent of hydrothermal gypsum karst development as described by Klimchouk (2000). Underground deposits in the caves examined suggest a hydrothermal origin, such as passage shape and some of the barite and gypsum deposits.

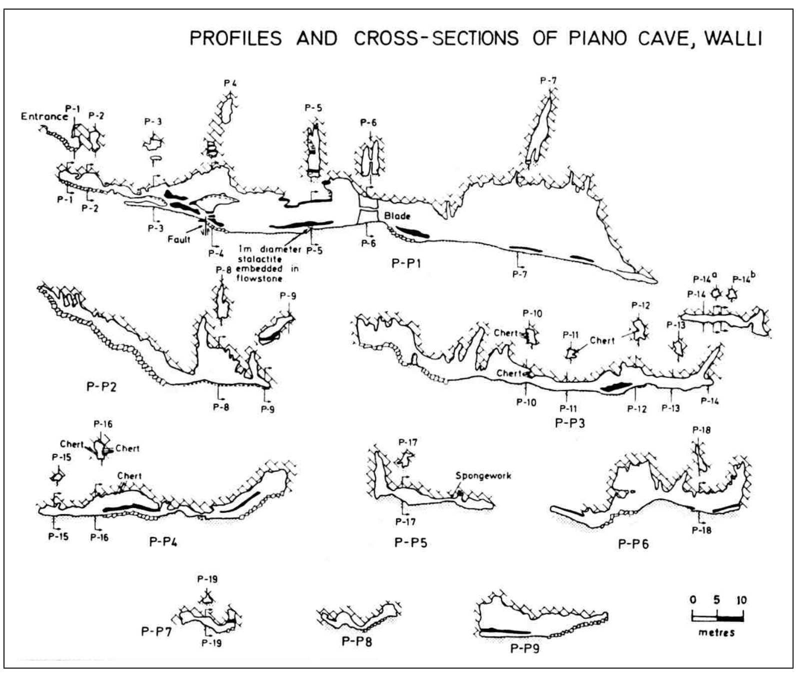


Figure 3.132: Cross sections of Piano Cave based on Frank (1974).

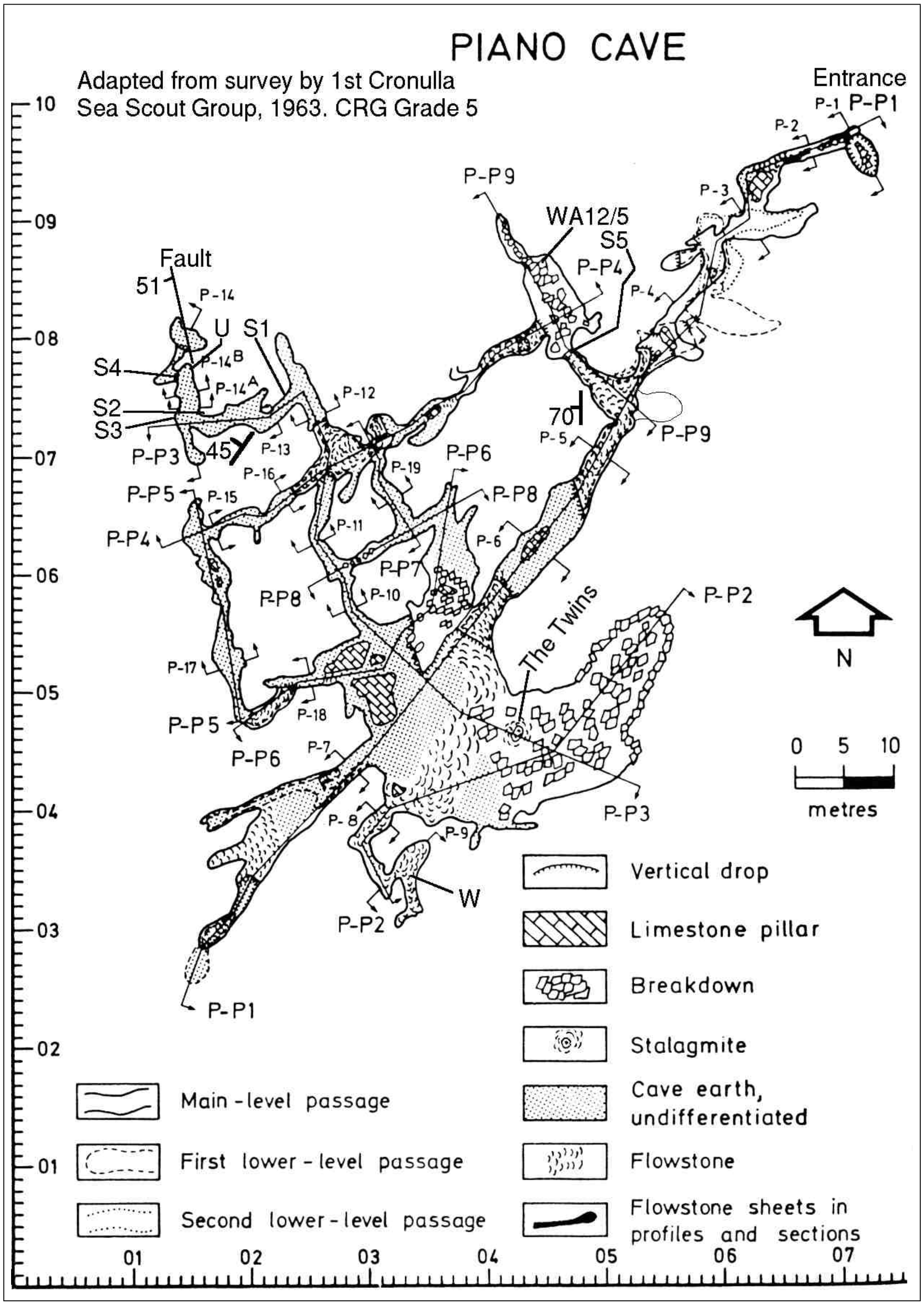


Figure 3.133: Map (plan) of Piano Cave based on Frank (1974) overlaid with joints and bedding. Key: WA12/5, S1-S5, U, W: Sample sites.

In the far south east part of the cave is another pit (sump) with a circular floor, filled with clay and broken chert nodules. During wet periods, this area may contain water. Possibly this pit was the area which Wilkinson described as being “rather difficult to get into” due to its vertical and constricted nature.

The passage near S4 lies partly along a fault shear zone. Partway along this passage is a high level passage (not examined) with circular cross-section. It rises almost vertically about 5 m above the other passages, in a south-westerly direction. Chert nodules are common in the south-west part of the cave, particularly along the west wall of the passage between GR 024,074 and GR 030,054. People have excavated the sediments near GR 014,077.

Bedrock Samples

Cave sample WA12/6 is from **sample point S2** (GR 016,074) about 1.5 m from the ground in a niche on the northern wall. It is a small piece of “rotten rock” comprising layers of reddish (to purple) clays and layers of yellow ?calcite with slickensides. Under the microscope, a small radiating crystal group resembles gypsum.

Cave sample WA12/13 was from near **sample point S1** about 1 m from the floor, on the south wall (GR 023,074). It is a small crumbly chert nodule with a coating of pinkish crystals. Under the microscope, the coating looks like gypsum and selenite on chert with clay and a black material (possibly a manganese mineral). The chert is grey, translucent and porous with a white porous coating of ?moonmilk, a reddish ”ochre” (possibly clay) and black coatings (Figure 3.134). XRD of the pink crystals indicates: Major calcite; Minor gypsum and quartz.

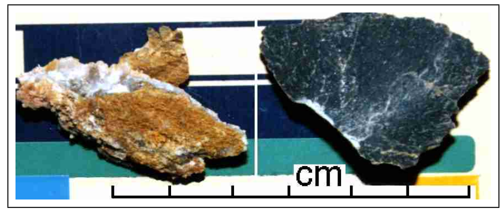
Cave sample WA12/16 is from **sample point “U”**, map GR 015,078, about 1 m from the ground, sampled from a vein on the eastern wall. It comprises small pieces of bedrock and vein which appear to be in a fault zone as the edge is slickensided. There is also some fracturing at right angles. (Figure 3.134). XRD of the vein indicates: Major calcite; Minor gypsum and kaolinite; Trace briartite (a copper sulfide).

Speleothems and Observations

The most common speleothems in Piano Cave are calcite flowstone (false floors), stalagmites and stalactites. Gypsum commonly occurs as wall coatings, extrusions and selenite needles. The northern part of the cave has many false floors. It is very dusty, partly due to air movement and closeness to the entrance and partly due to crystal wedging. One chamber in this part of the cave has fairly thick (about 3 cm) crystal coatings as though the chamber had been filled in the past with mineral-rich water (GR 045,087 Figure 3.133). The floor of this chamber is mud containing a number of semi-fossilised bones, mentioned by Wilkinson (1892).

Cave sample WA12/14 is a small piece of cave fill with a “tray” (type of stalactitic speleothem with a flat base).

Chert sample WA12/13 at "S1" with pink calcite and gypsum coating. Width of view is about 20 cm.



Sample WA12/16: Chips from vein at "U".

Sample WA12/14. Underside of part of "tray" speleothem at S5. Width of view is about 4 mm.

Sample WA12/14: Inside. Width of view is about 1 mm

Area S5: Pendant with (calcite) speleothem coating.

Sample WA12/15 at S5: Underside of coating forms overlapping scales. Width of view is about 5 mm

Figure 3.134: Piano Cave: Samples from areas S1, U and S5.

It was taken from the underside of a clastic fill at map GR 049,078, near site "S5" (Figure 3.134). XRD indicates: Major calcite; Minor magnesian calcite; Trace aragonite, barite, anhydrite and wollastonite.

Cave sample WA12/15 is from near site "S5", map GR 046,087, about 2 m from the ground on the underside of a pendant with a thick crystalline coating of overlapping scales. The crystals and powder were at first thought to be gypsum (Figure 3.134). XRD indicates it is calcite.

High in the ceiling of the largest chamber in the south east part of the cave, masses of helictites are associated with a prominent joint. In this chamber are "The Twins", a pair of stalagmites, and a (broken) stalactite which appear to be the ones depicted by Wilkinson (1892). In the far south east part of the cave, near the sump ("W" on map) there are canopies and flowstone. Below the flowstone, and over most of the walls of the sump is a prickly coating of gypsum, calcite, barite, clays, quartz and other minerals. This pit has a false floor (probably calcite) partially covering a floor of clay rubble, coated chert nodules and fallen speleothems. Above the false floor, numerous crumbly projections in the ceiling are chert nodules thickly coated with the same minerals which occur in the prickly coating. In the ceiling above the sump, stalactites are coated with this prickly speleothem. This material looks like a calcite paramorph after aragonite and coats much of the walls and ceiling of the sump area. Some of the stalactites are broken, showing a clear (presumed calcite) interior and a creamy white layer, with the light brown prickly layer on the outside (Figure 3.135). Small, clear vermiform helictites project from the sides of the stalactites. There are also small white coralloid speleothems (thought to be hydromagnesite) in this area. As neither the coralloids nor the helictites are coated with the prickly material, it was assumed that they are younger than the prickly deposit.

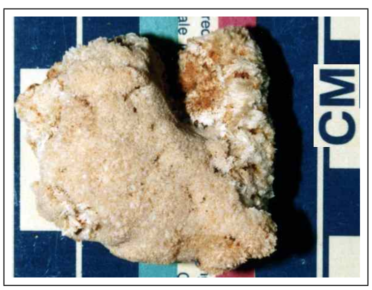
Cave sample WA12/17 is from sample site "W" about 2 m from ground (map GR 034,033). The sample comprises spiky material said to be aragonite. It was coating the chert nodules however it does not look like aragonite. The white spiky crystallites are very soft and have tattered terminations. The XRD spectrum was noisy due to clays. XRD indicates: Major clays (possibly montmorillonite and illite); Minor quartz, gypsum and calcite; Trace various barium minerals (Figure 3.135).

Cave sample WA12/18 is from sample site "W" at map GR 034,033, loose on the ground. The material is a coated chert nodule with a soft feathery patterned crystal coating. XRD of the coating indicates: Major calcite; Minor barite and gypsum; Trace ferrimolybdite and other minerals (Figure 3.135).

The western part of the cave is very humid and has more wet clay than the other parts of the cave. Sampling has been done in this area, mainly very small samples of speleothems. Some samples were too small to obtain X-ray data (obtained before quantity requirements were known).

Above the sump: Spiky coating over flowstone canopy. Width of view: about 0.5 m.

Upper part of area “W”: spiky coatings. Width of view about 20 cm.



Sample WA12/18. Coated chert nodule, area “W”. Width of view is about 4.5 cm.

Above the sump: smooth helictites are developing over spiky coatings. Width of view about 30 cm.

Sample WA12/17: Tattered crystal terminations. Width of view about 0.5 mm.

Sample WA12/18. Detail of tattered crystal coating on chert nodules. Width of view is about 5 mm.

Figure 3.135: Piano Cave: Area “W” in the southern part of the cave has spiky coatings.

Samples WA12/1, /2 and /3 are very small samples of gypsum from site “S1” (GR 023,075) on the NW wall and ceiling, about 2 m from the ground. They were too small to test using XRD and were determined from morphology. The substrate for all these speleothems was the bedrock. WA12/1 is from the wall and /2 and /3 are from the ceiling. Sample WA12/1 is a very small gypsum ramshorn; /2 and /3 are “transistors” (small aggregates of crystals forming a coating with parallel crystallites).

Site S2 is at GR 016,073. A small pocket on the north wall has a laminated cusp and some veins resembling a fault shear zone. WA12/4 is a very small sample of a white hemispherical speleothem from site S2. The specimen feature yellow radiating crystals, white powder, and some crystal terminations and cleavage like gypsum. XRD indicates: Major gypsum; Minor brushite, aragonite, calcite and barite; (traces not examined).

Sample WA12/5 is a very small piece of a laminated wall cusp from sample site S2, taken from a few cm above sample WA12/4. The material fractures like gypsum and is assumed to be mainly gypsum. Crystal terminations are indistinct and there are possibly some radiating crystals. **Sample WA12/12** is a small piece of gypsum (selenite) needle from site “S1” on the south wall, about 2 m from the floor. The site contained chert nodules in the bedding. The bedrock has a drusy surface coating (presumed to be gypsum). Gypsum needles (selenite) stuck out of the chert nodules like hairs. The hairs are associated with an ochreous surface coating on bedrock. The sample has a light response to UV and has crystal terminations like gypsum (Figure 3.136).

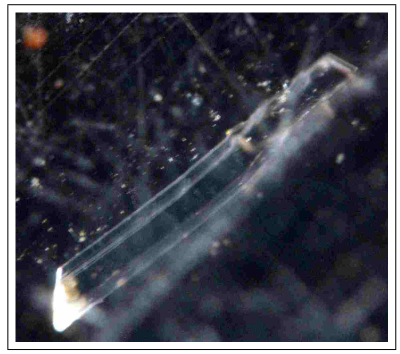
Sample WA12/7 is a very small white sphere from sample site S2, near the “rotten rock”. Crystals are indistinct but resemble aragonite. There was insufficient material to test with XRD.

Sample point S3 is on the western wall at GR 014073. Here there are a number of white speleothems, some resembling gypsum extrusions and others resemble small aragonite anthodites (Figure 3.137). **Sample WA12/8** is a small piece of “aragonite needle” from sample point S3, from the right hand side of a white speleothem group. XRD indicates: Major gypsum; Minor brushite, aragonite, magnesian calcite, strontian barite and talc. (traces not examined). The talc appeared to be genuine; the speleothem may have developed over a fault zone. **Sample WA12/9** was a very small piece of white powdery speleothem from the left hand side of the speleothem group at sample point “S3”. The powder was of two colours: an off white and a more “pure white”. XRD was noisy (insufficient material) but the following minerals were detected: aragonite, gypsum, huntite, hydromagnesite.

Sample WA12/10 was a small piece of pink crystalline material from the ceiling of a low archway near site “S4” (GR 014,077). The material resembled aragonite under the microscope. XRD indicates: Major magnesian calcite and gypsum; Minor aragonite, huntite and hydromagnesite.

Sample WA12/11 are very small crystals from the ceiling at site “S4”. It comprised powdered portions of radiating crystals on the ceiling of the low archway. The substrate was the bedrock. The sample was too small to use XRD. Under the microscope, the material looked like a mixture of calcite and gypsum.

Sample WA12/5: Small radiating crystals. Width of view about 1 mm.

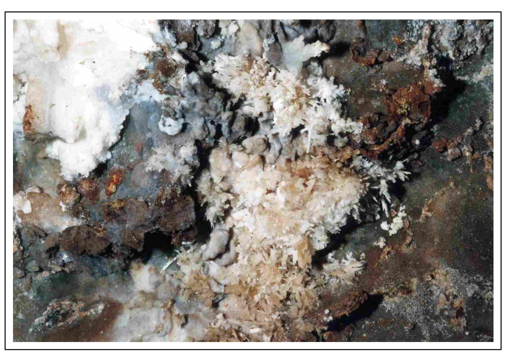


Sample WA12/12: Single crystal of gypsum. Width of view about 3 mm.

Figure 3.136: Piano Cave: Samples WA12/5 and 12.

Area S3, left hand side: White minerals contain magnesium. Width of view: about 20 cm.

Area S3, middle: This area appears to have been damaged. The long speleothem may be part of a spathite or gypsum extrusion. Width of view about 20 cm.



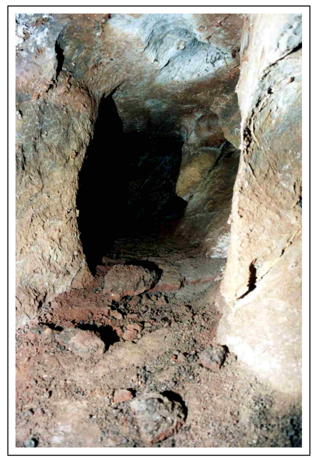
Area S3, right hand side: The acicular helictites contain aragonite. Width of view about 20 cm.

Figure 3.137: Piano Cave: Area S3.

Area S1: Gypsum efflorescences follow veins.

Area S2: Possibly a fault zone breccia. Gypsum has extruded at the right hand side. Width of view about 20 cm.

Area S4: The pink spot contains aragonite. Width of view about 30 cm.



Area S4: General passage view.

Figure 3.138: Piano Cave: Areas S1, S2, S4.

Cave Weather Measurements

The temperature and humidity in Piano Cave are generally lower than those in Deep Hole. As the cave has multiple entrances, it is more influenced by air flow and external conditions than is Deep Hole. For the 1st July 2001 temperature measurement, a Mercury-in-glass thermometer was used (Table 3.7).

A series of low tunnels in the western area are known to have CO_2 as Wilkinson noted:

> *We could not explore to the end of some of the passages, owing to the foul air met with, which, if we had inhaled it, would have extinguished our lives, as it immediately did our candles.*
>
> (Wilkinson 1892)

On the first trip in June 2000 the CO_2 levels were mildly raised (but not measured). On a later trip, low levels were experienced. At site S4, 0.08 to 0.1% CO_2 was measured.

Date	**Location**	**CO_2 (%)**	**Temp (°C)**	**RH (%)**
1st July 2001	J GR 050,075	0.05	16.5	(not measured)
18th August 2002	U GR 015,078	0.08 – 0.1	18.2	91

Table 3.7: Piano Cave temperatures and humidities. J = First major passage junction; U = Sample point U.

Synthesis: Aragonite in Piano Cave

Aragonite is not a major mineral in Piano Cave. Where it does occur, it is associated with barite and anhydrite in an area with air movement (Site S5); it is associated with barite, gypsum, huntite and hydromagnesite in areas with faulting (e.g. sites "S2"-"S4"). Paramorphs of calcite after aragonite occur in a sump in Piano Cave (site W), associated with gypsum and barium.

During the course of this study, it is believed that Wilkinson's "aragonite" sites have been re-located in Piano cave. Of the two sites examined, only one (site "S3") has a small amount of aragonite present and is damaged. The other site ("W" GR033,034 Figure 3.133) is lined with numerous small spiky crystals, some of which may be paramorphs of calcite after aragonite but no aragonite was detected at this site.

It would appear that aragonite deposition at Piano Cave is enhanced wherever huntite and hydromagnesite are present. The most likely source of these minerals is dolomite in the chert nodules, where exposed to oxygenated water such via fault zones. During wet periods, mineralised water may rise in the sumps. Aragonite may be deposited during these times (or while the water is going down again) but there are insufficient quantities of calcite-inhibitors to prevent it from reverting back to calcite.

Other Caves at Walli

Two other caves were inspected but not sampled. Cave number WA-13 (no name) is a small cave about 20 m long formed as a very steep sloping passage with some small horizontal extensions. Between WA-13 and the entrance to Piano Cave, the dip of the bedrock changes and is possibly faulted. Cave WA13 has an air connection to the eastern chamber of Piano Cave via a small solution tube from which warm moist air is often reported. WA13 contains some calcite speleothems and small "cave turnips". Many of the "turnips" are broken open, exposing a spiky interior superficially resembling aragonite.

Bone Cave is a historically significant small cave in which animal bones were discovered (Wilkinson 1892). It also contains "cave turnip" speleothems which have broken open to expose an acicular interior.

Synthesis: Aragonite at Walli

The most common cave minerals at Walli are calcite, gypsum and barite. Aragonite is not common. Aragonite is associated with two situations at Walli: areas with relatively low humidity and areas with relatively high humidity.

In areas with relatively low humidity, calcite-inhibitors are concentrated sufficiently to cause aragonite to precipitate. The form taken by aragonite speleothems is as a chalky wall coating with very small crystals. The most likely calcite-inhibitors are sulfates, magnesium, barium and phosphates. The dryness was attributed to cold air pooling in the cave entrance in winter (in the case of Deep Hole) and flowing through the cave (in the case of Piano Cave).

In areas of relatively high humidity, aragonite may deposit where calcite-inhibitors are mobile. Magnesium, sulfate and Mn appear to be the major calcite-inhibitors, with Ba present in some cases. Barite in the cave is not very soluble, and in most cases it does not appear to be the main calcite-inhibitor but other barium salts such as witherite may be released in small quantities. Gypsum may be the main source of sulfate at Walli. The bedrock contains ferroan dolomite, concentrated in / near the chert nodules. Faulting has allowed oxygen-rich water to penetrate the bedrock and expose pyritic limestone and cherts to fresh water. Weathering of the pyrite from the chert nodules and dolomitised bedrock may be the main source of Mg and Mn, and some of the SO_4.

3.5 Other Areas

Introduction

Samples of aragonite-like speleothems from other areas were examined and in some cases were identified as aragonite. These areas were Bungonia, Jaunter, Wyanbene, Cliefden, Colong and Wellington. As these areas were not studied in depth by this project, they are introduced briefly and observations noted. The reason why these caves are mentioned is because of their aragonite, or aragonite-like speleothems.

3.6 Jaunter

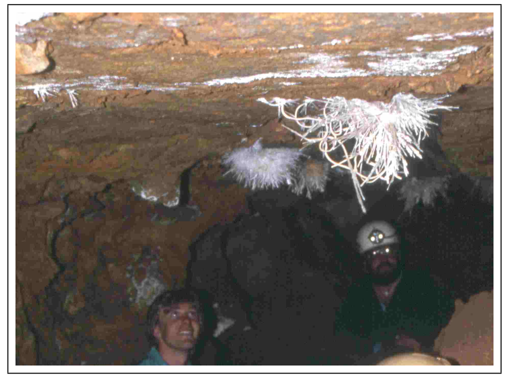
The Silurian Tuglow Limestone crops out about 30 km south of Oberon. The area mapped by Scott (1991) includes a property then known as "Iona" (later "Tarakuanna") which has a small cave containing a large number of (probably aragonite) anthodites. Other small caves on the property do not appear to contain aragonite. The site was not included in the present study as the current property owner does not allow visitors.

In 1989, when the previous property owners were running a farmstay holiday business, Martin Scott, myself and other members of the Sydney University Speleological Society and the Hills Speleological Society visited the cave a few times to photograph the anthodites. At times the cave has been called "Aragonite Cave" and "Crystal Cave".

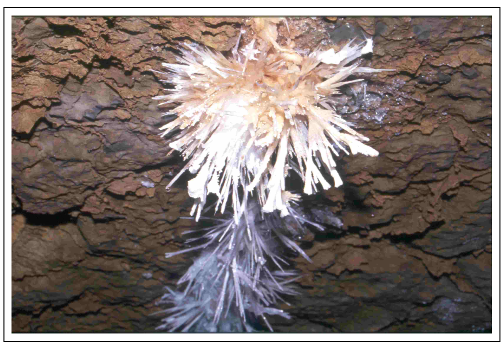
The cave contains conventional calcite speleothems, and the anthodites are restricted to a large chamber which was discovered by digging out a small passage (Ernst Holland, pers. comm. 1989). The aragonite area ceilings include domes, flat ceilings and an anastomosed area. The "aragonite" substrate is a porous, rusty coloured material, resembling a gossan or weathered dolomite. It is not known what the material is, although Hills Speleological Society suggest it is an eroded dyke. No mineral sampling has been performed in the cave, and only the form of the speleothems has been recorded. Forms include surface coatings which grew about 1 cm over about two years, anthodites and helictites (Figure 3.139). A white pasty material coats some of the anthodites.

The Tuglow Downs property to the south of Tarakuanna has a long horizontally developed cave called Tugellella which contains a small amount of aragonite-like speleothems (Geoff McDonnell, Andrew Trafford and Andy Fulton, pers. comm. 2002–2004).

Anthodites and helictites (with Jill Rowling).

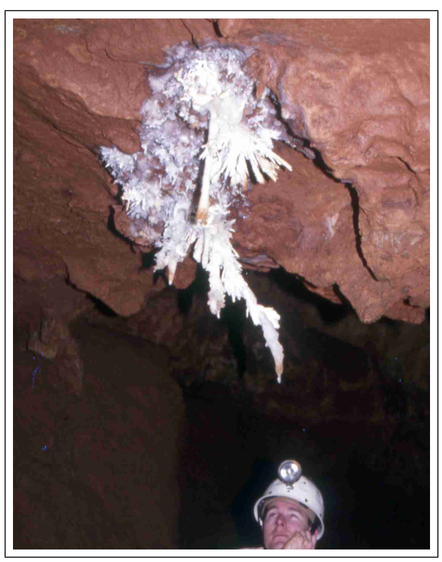


Anthodites and helictites (with Martin Scott and Kevin Moore).



Anthodites along ceiling joint; ferruginised rock.

Anthodite has white encrustations on tips (with Sue Bonar).



Stalactite, spathite and helictites (with Mike Lake).

Figure 3.139: Anthodites, Tarakuanna.

3.7 Bungonia Caves

Introduction

Bungonia Caves are located approximately 155 km to the south-west of Sydney (Figure 1.3). The caves area is managed by the NSW National Parks Service as a recreational area. Due to its position in a rainshadow to the west of the moist coastal strip, the area does not currently receive much rain in comparison to the surrounding regions so the vegetation is more sparse and semi-arid compared to Wollongong to the east, Mittagong to the north or the Wollondilly area to the west.

Geological Setting

East of Bungonia, Upper Ordovician turbidites of the **Tallong Beds** (Wass & Gould 1969) crop out (Figures 3.140, 3.141). These sediments feature tight to isoclinal folds superimposed on a NS strike and an easterly dip. They comprise shale, chert, arenite, slates, flysch and phyllites. Secondary mineralisation in these sediments includes arsenopyrite, copper and gold which has been mined at Tolwong Mines. The Late Silurian-Early Devonian **Bungonia Limestone Group** (Bauer 1994) crops out in an elongated deposit with prominent north-south orientation, about 750 m to 1 km wide and about 15.5 km long. The limestone is very nearly equivalent to Silurian sediments (Towrang Beds) which crop out about 15 km to the west, near Goulburn (Pickett 1982). Early Devonian **Tangerang Volcanics** (Wass & Gould 1969, Carr, Jones, Kantsler, Moore & Cook 1980*b*) comprising tuffacous arenite and dacites crop out west, north-west and north of the limestone and overlie it conformably. The Tangerang Volcanics are suggested to be a southern extension to the Bindook Porphyry (Pickett 1982) correlating with its early stages (Carr et al. 1980*b*). They are close in age to the Early Devonian Marulan Batholith with hornblende dacites forming the upper parts of the sequence. The Late-Middle Devonian **Glenrock Granodiorite** (Woolnough 1910) intrudes the Tangerang Volcanics and includes xenoliths of material derived from the Tallong Beds. It forms a skarn where it truncates the northern end of the limestone (Counsell 1973). Other Devonian outcrops include Lumley Adamellite to the west, and Springponds Granodiorite to the north and north-west (Carr et al. 1980*b*). Carboniferous granites crop out about 15 km south-east of Bungonia Caves. Permian sediments include the Berry Formation about 5 km to the east, and Snapper Point Formation about 10 km to the north-west. Tertiary outcrops include the Eocene Reevesdale Basalt about 10 km to the south-west, silcrete and quartz arenite to the west. A deep red weathered bauxite with pisolitic texture is associated with weathered Eocene basalt at Reevesdale (Carr et al. 1980*b*). Regional alluvium includes the flood plain of Bungonia Creek near Carne and the Shoalhaven river valley.

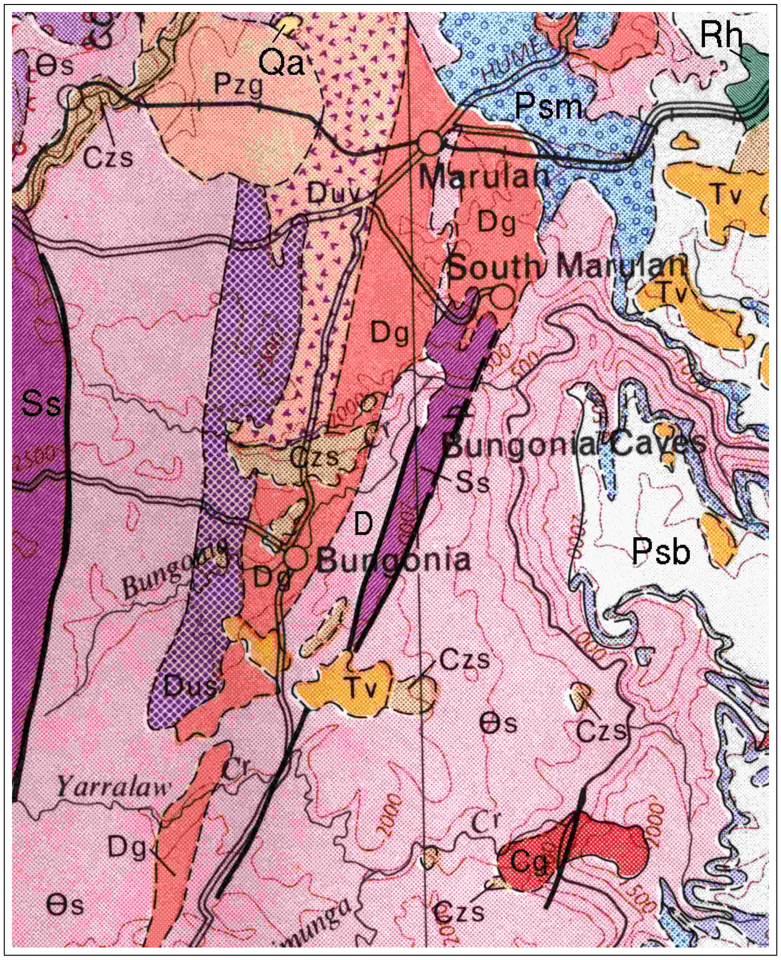


Figure 3.140: Geological Map of Bungonia Caves region. Area map is from Brunker & Rose (1967). Includes work by Carr (1980). Width of image: approximately 30 km. Key: Qa - Quaternary: Gravel, sand, silt and clay. Czs - Undifferentiated Cainozoic: Poorly consolidated sandstone, conglomerate, siltstone and "perched" alluvium. Tv - Tertiary: Basalt, dolerite, microsyenite, trachyte and tinguaite. Rh - Triassic, Hawkesbury Sandstone: Quartz sandstone with some shale. Psb - Permian, Berry Siltstone (Sydney Basin): Siltstone, sandstone and shale. Psm - Permian, Snapper Point: Quartz sandstone, conglomerate, sandstone, siltstone, silty sandstone. Cg - Carboniferous: Granite and granodiorite. Pzg - Possibly Devonian: Granite and diorite. Dg - Devonian, granite, tonalite and granodiorite. Duv - Upper Devonian, Bindook Porphyry, Comerong Volcanics (undifferentiated): Porphyry, dacite, tuff, basalt and siltstone. Dus - Devonian, undifferentiated: Sandstone, conglomerate, siltstone and claystone. Dg - Middle Devonian: Granite, tonalite and granodiorite. D - Early Devonian, Tangerang Volcanics: Tuffaceous arenite, dacite, hornblende dacite. Ss - Silurian (undifferentiated): Sediments, volcanics and limestone. Θs - Ordovician, undifferentiated: Grey slate, quartz rich and feldspathic greywacke and andesite.

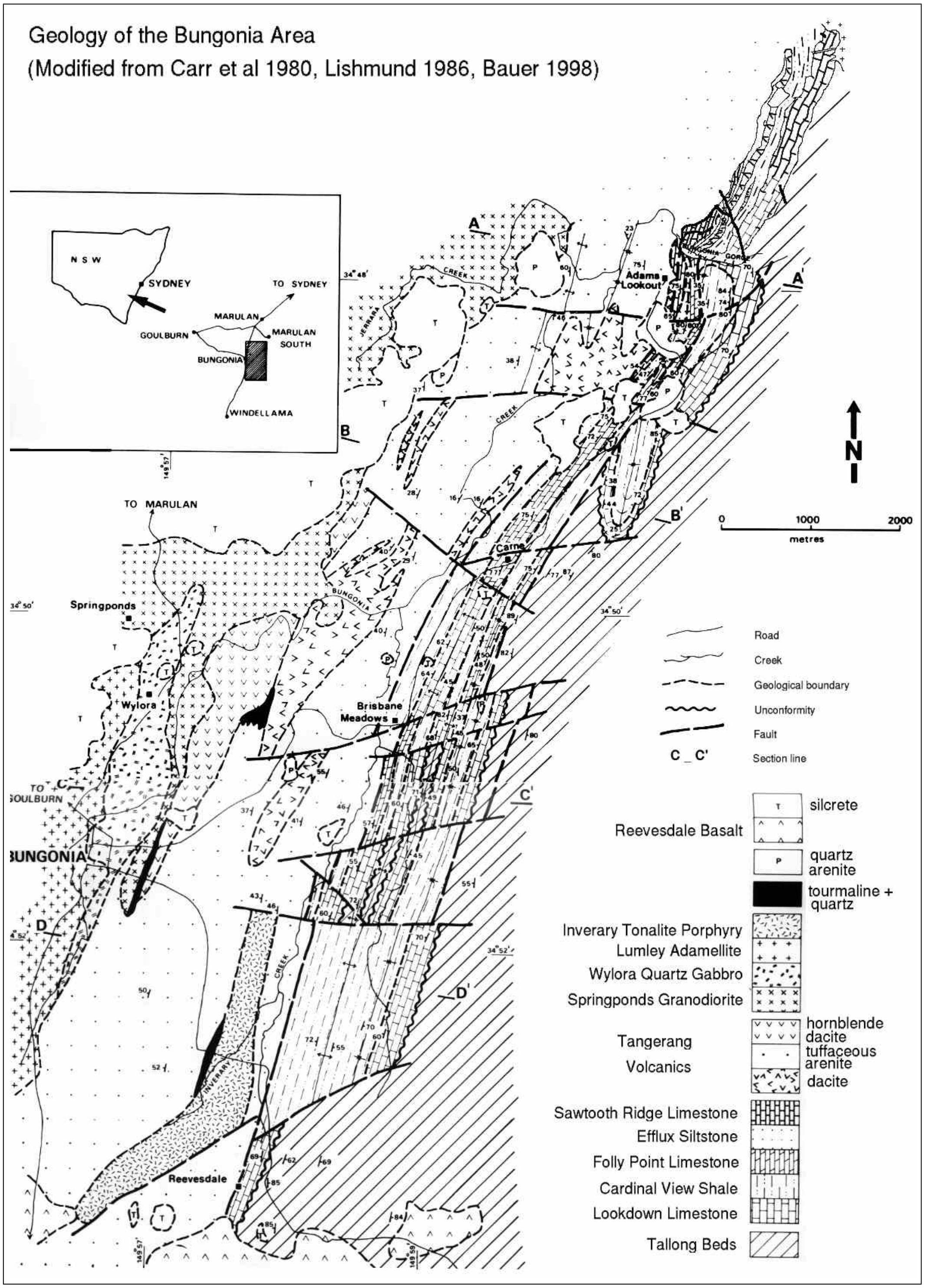


Figure 3.141: Geological Map of Bungonia area based on Counsell (1973), Carr et al. (1980), Lishmund (1986) and Bauer (1994).

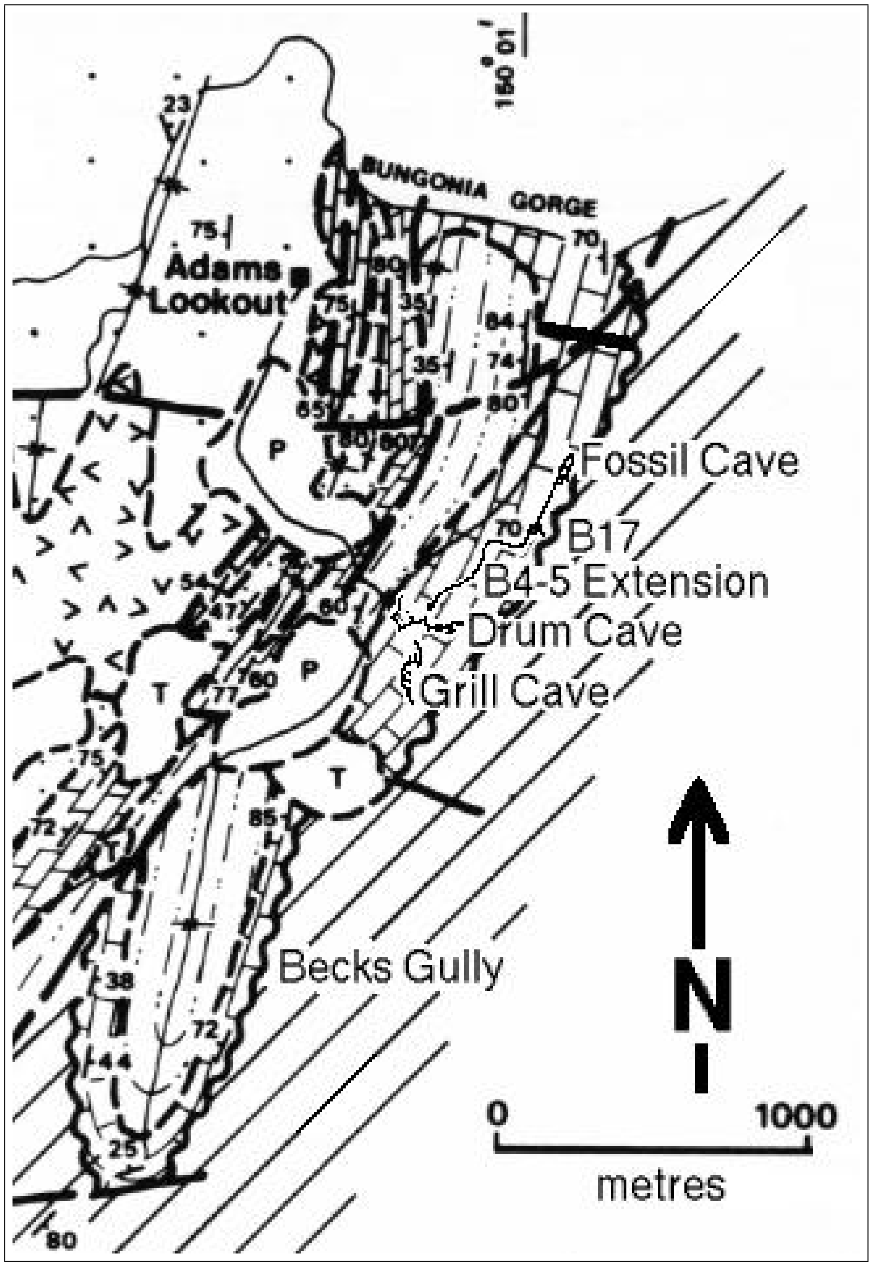


Figure 3.142: Geological Map of Bungonia Caves local area showing approximate positions of caves mentioned in the text. Geology after Carr et al. (1980); rough cave outlines after Bauer (1998). Position of caves within about 100 m.

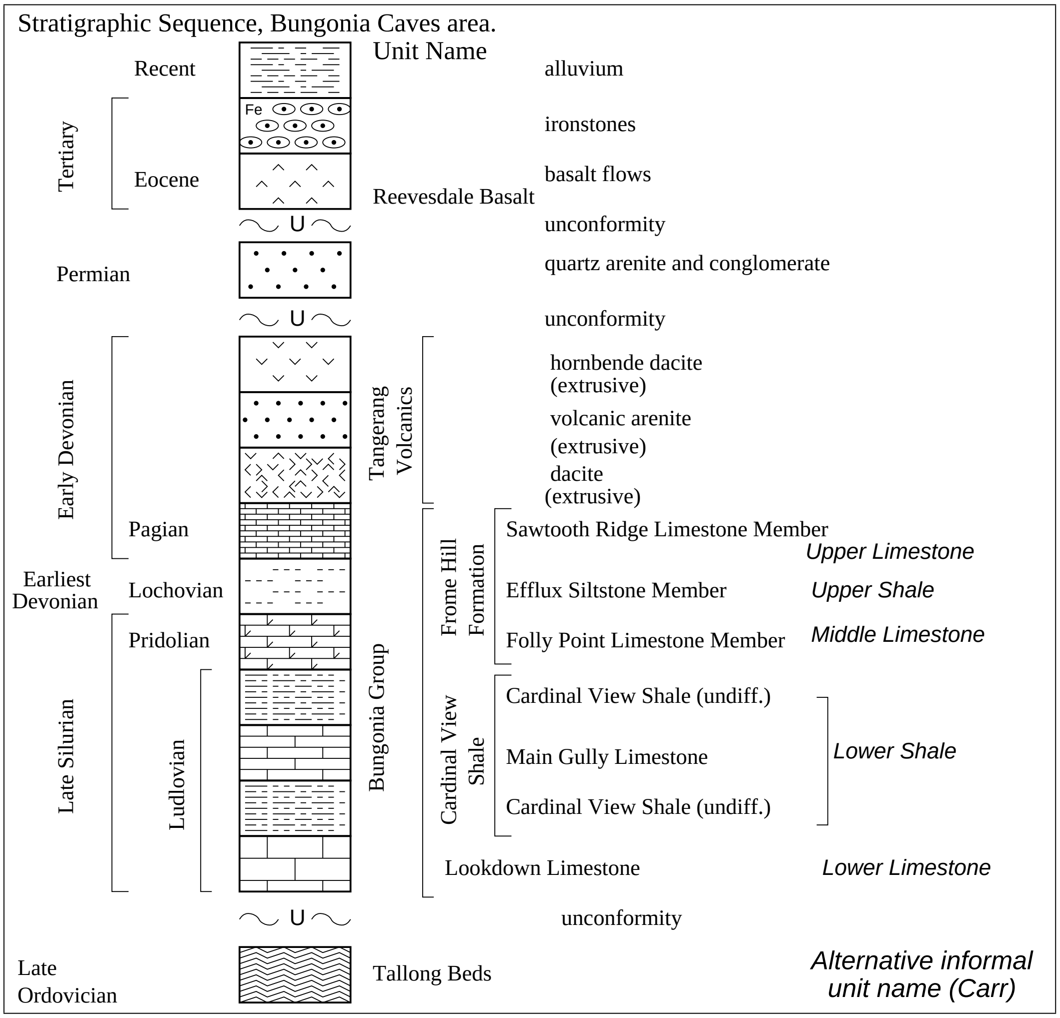


Figure 3.143: Stratigraphic sequence, Bungonia Caves area. From Counsell (1973), Carr et al. (1980) and Bauer (1994, 1998). Intrusives are omitted.

Local geology

The Late Silurian-Early Devonian **Bungonia Group** (Figure 3.143) generally dips steeply and faces west. South of Bungonia Gorge, the outcrop is broken by small faults for most of its 12 km length and is obscured at the south by the Reevesdale basalt (Figure 3.141). It has been subdivided into the Frome Hill Formation (Bauer 1994) and another portion which mainly comprises rocks east of the Reevesdale Fault.

The eastern boundary of the limestone is disconformable with the Late Ordovician Tallong Beds and is faulted in some areas (Counsell 1973). The limestone was folded during the Bowning Orogeny (Carr, Jones & Wright 1980*a*).

The Ludlovian **Lookdown Limestone** (Counsell 1973, Bauer 1994) is generally a massive unit, recrystallised and dolomitised in places. It is cavernous and steeply bedded in most places, with the bedding angle shallowing with depth in some caves (Bauer & Bauer 1998). Where the limestone is more pure, it weathers with characteristic rillenkarren and solution pits. Dolomitisation occurs in regions of the limestone, roughly aligned parallel to bedding. For example, at Becks Gully, the micrite is dolomitised leaving the large bioclasts (stromatoporoid and coral) intact. The dolomitised limestone in that area weathers more like sandstone and is eroded preferentially along calcite veins. Lichens grow on the surface of the dolomitised limestone in preference to the more pure limestone. The main structure is a plunging syncline, truncated at the west by the Reevesdale Fault.

The Ludlovean **Cardinal View Shale** (Counsell 1973, Bauer 1994) crops out conformably between the Lookdown Limestone and the Folly Point Limestone. Counsell (1973) suggested the shale unit should be further subdivided to take into account a lens of limestone near Frome Hill – referred to as the **Main Gully Limestone** (Bauer & Bauer 1998). The main structure is the shale forming the core of a syncline, underlain by the Lookdown Limestone.

The Pridolian **Folly Point Limestone Member** (Frome Hill Formation) (Counsell 1973, Bauer 1994) is less cavernous than the Lookdown Limestone due to its higher silica content (sandstone and chert) (Bauer & Bauer 1998). It is usually massive and recrystallised, and is thinly bedded near the Carne property (Counsell 1973).

The Lockovian **Efflux Siltstone Member** (Frome Hill Formation) (Counsell 1973, Bauer 1994) comprises siliceous siltstone with calcareous mud interbeds and is locally fossiliferous. It conformably separates the Folly Point Limestone from the Sawtooth Ridge limestone.

The Pagian **Sawtooth Ridge Limestone Member** (Frome Hill Formation) (Counsell 1973, Bauer & Bauer 1998) is a more thinly bedded and silicic unit forming Sawtooth Ridge and the Devils Staircase and is the most westerly limestone outcrop. It comprises massive limestone with lenses of siliceous siltstone and fossiliferous rubble. There are not many caves developed in this limestone unit and it is more resistant to weathering due to its less pure nature. Counsell considered the western boundary of the Bungonia Limestone to be conformable with the eastern boundary of the Tangerang Volcanics.

Close to Bungonia Caves, the Early Devonian **Tangerang Volcanics** comprises at least two different types of rock: tuffaceous arenite west of Adams Lookout and dacites in the camping ground west of the limestone. The latter are extrusive, submarine dacitic lavas and associated pyroclastics with the tuffaceous arenite formed in a marine environment by (probably pyroclastic) volcanic silica precipitation (Carr et al. 1980*b*).

Local Permian sediments include a quartz arenite which crops out in two small locations to the west of the limestone and about 1 km west of Adams Lookout (Carr et al. 1980*b*). A small outcrop of sandstone and pelite overlaid the contact region between the Bungonia Limestone and the Tangerang Volcanics (Wass & Gould 1969).

(Probably Tertiary) silcrete crops out to the south-west of the camping ground, and east of the park entrance near Becks Gully along with some quartz arenite. It is most likely a sedimentary fluvial deposit which has been partly cemented. The material has not been heated and contains some fossil tree roots (Counsell 1973). Cementation of the upper few metres appears to have occurred some time after deposition by chemical precipitation of silica in solution.

(Undated) basalt dykes and dolerite dykes may be related to the extrusion of the Eocene Reevesdale Basalt (Carr et al. 1980*b*).

Ferricrete is widely distributed as a ferruginous sandstone, fluvial sands with limonitic cement, pisolitic and nodular concretions, false breccia and false gossans. This is assumed to be Tertiary gravel with cementation some time after deposition and after the uplift which formed the dolines (Counsell 1973).

Quaternary sediments overlie the Bungonia Limestone in many places, for example, on the Caarne property west of the Lookdown Road. Highly weathered Tertiary basalt crops out in various places as pillow lavas, e.g. near the head of Becks Gully and on the road (now tarred) between Argyle Hole and Acoustic Pot.

Main local structural features: The Lookdown Limestone is folded along its north-south axis into a syncline which has been normally faulted by the N-S Reevesdale Fault. Near Becks Gully the dip varies as both sides of the syncline are exposed. Near the head of the gully, the strike is roughly north and the dip is almost vertical. Some caves have exposed dolerite dykes (Bauer 1993). In general, these dykes are aligned east-west and are rarely exposed on the surface except near Troy Walls (Bauer 1993, Bauer 1994). Caves with dykes include Flying Fortress Cave, B4-5 Extension, Grill Cave and caves B72 and B98.

Ferruginisation has occurred in several areas in and around the caves and is most pronounced in areas adjoining the limestone. A ferruginised, cemented breccia (cave B98) is associated with a basalt dyke (Bauer & Bauer 1998), and weathered, ferruginised dolomite occurs in the Lookdown Limestone. North of the Gorge, the easternmost limestone outcrop is surrounded by a zone of ferruginisation (Lishmund et al. 1986). A ferruginised region separates the Lookdown Limestone from the Tallong Beds near Troy Walls, and ferruginisation is also seen near the head of Becks Gully at the edge of the limestone outcrop associated with weathered basalt, gossan and ferricrete. It also occurs as an outcrop adjoining the limestone on the Green Track east of the camping ground.

Geomorphological Setting

Bungonia Caves lie on a dissected plateau on the edge of the Sydney Basin. The plateau was uplifted during the Cretaceous, with a rejuvenation of creeks and waterfalls (e.g. Jerrara Falls) during the Tertiary. Cave development has not kept up with the creeks, leaving The Efflux as a perched spring (Counsell 1973). The limestone is drained to the north partially by The Efflux and intermittent springs at Troy Walls which flow into Bungonia Creek at Bungonia Gorge and thence to the Shoalhaven River. It is drained to the east by Becks Gully which flows eastwards into the Shoalhaven River (Figure 3.142). At Bungonia Gorge, Bungonia Creek flows through a spectacular 600 metre deep limestone canyon (the Slot). Many of the caves drain into the B4-5 Extension (cave), which sumps underground at St. Patricks Lake at its southern end. Water from this has been traced to The Efflux (cave) which is a spring. The hillslopes of the Tallong, Efflux Siltstone and Tangerang rock units form unstable scree slopes. At the top of the plateau, the land is undulating with occasional breaks around karstic features such as cliffs and gullies around cave entrances. Karst features include rillenkarren, dolines, deep grikes and a lack of topsoil in some areas.

Introduction to Caves

Caves tend to be vertically developed and generally lack speleothems. There are no show caves, but most of the caves are open to the public for adventure caving. Foul air is a common hazard and is due to organic decay (Smith 1998). Common features of many caves at Bungonia include deep shafts, flatteners (near-horizontal slots), rifts (vertical slots) and erosion canyons often with flat ceilings and slotted floors. Bauer (1993) examined the limestone and several caves at Bungonia as part of a study of the area's stratigraphy. Large caves at Bungonia are Grill Cave and Drum Cave, Fossil Cave and Hogans Hole which all hydrologically connected via the long and partially sumped B4-5 Extension. The B4-5 Extension is a long tube-shaped cave aligned N-S, parallel to strike, forming the flood passage for water entering Hogans Hole and other caves on the plateau. It terminates at a sump in its south end, which has been hydrologically traced northwards to "The Efflux", a spring in Bungonia Gorge. Two other deep caves, Argyle Hole and Odyssey Cave, have a hydrological connection to The Efflux. The water appears to flow parallel to the Reevesdale Fault. Three caves contain areas where the ceiling bedrock has been wedged apart by growth of fine acicular speleothem coatings (observed prior to this project): Flying Fortress Cave, "The Roundabout" in Argyle Hole, and dry areas of "Kings Cross" in Fossil Cave. Bauer described gypsum and dolomite from bedrock in different areas of Argyle Hole. Some of the caves contain aragonite. Aragonite occurs in Flying Fortress Cave and from the ceiling of "Coffin Chamber" in the B4-5 Extension associated with a dolerite dyke (Bauer & Bauer 1998).

Caves Chosen

Flying Fortress Cave was chosen as it contains aragonite and is easily accessed. It has been documented previously for biological and structural geology (Bauer 1993) and a sample of aragonite was available from Osborne. Although the B4-5 Extension may contain aragonite, its CO_2 levels are too high to work in, e.g. 4% to 6% and O_2 levels below 16% (measured by Highland Caving Club in May 2001, Joe Sydney and Evalt Crabb pers. comm.). The B4-5 Extension was entered once before this study via abseil from Flying Fortress cave, but high levels of CO_2 prevented studying the creekway for more than about 10 seconds.

Observations at Flying Fortress Cave

Location

Flying Fortress Cave is located on the limestone plateau about mid-way between Grill Cave and the Lookdown, at the steep south-western side of a deep doline (Shaduf Cave), under a limestone overhang (Figure 3.142). Flying Fortress Cave is part of the B4-5 Extension, and joins the latter about half-way along its length at Largest Chamber.

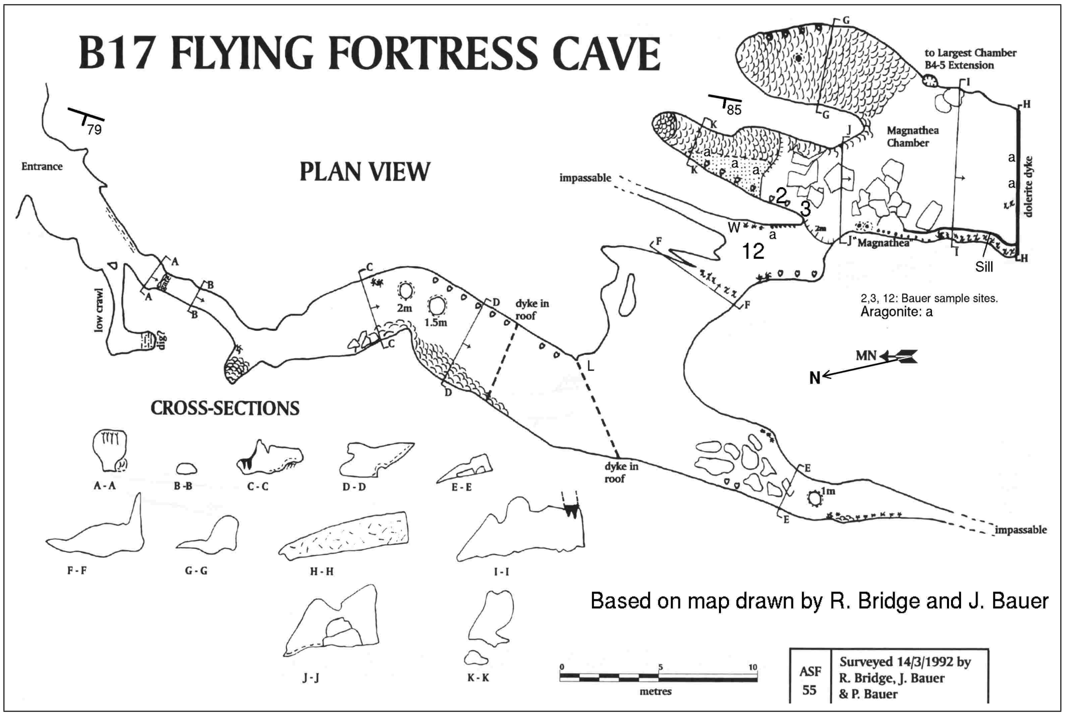
Geological Setting

Flying Fortress cave lies in steeply dipping, partially dolomitised, fossiliferous Lookdown Limestone. Bauer (1993) described the limestone in the cave as mainly biolithite, with biomicrite fills and some intramicrite. Fossils are numerous, including large thick-shelled bivalves, ostracods and gastropods. Bauer noted the passages are partly silicified and reported a small pocket of white clay. The cave entrance was dug through a sediment fill of red earth, containing Pleistocene fossils (Bauer 1993). Bauer noted a brown dolomitised sediment near the entrance passage which is unconformable with the bedrock. On exposed bedrock surfaces, a variety of silicified Silurian fossils occur. The entrance area beds also include vertically bedded clastic sediments, siliceous mud, quartz, crinoid and limestone detritus with a different strike to the rest of the limestone. The limestone has been intruded by dolerite dykes, none of which are exposed at the surface. The largest dyke forms the southern wall of Magnathea Chamber. It is about 5 m thick where a cross section is exposed in Largest Chamber (B4-5 Extension). Smaller dykes exposed in Flying Fortress Cave are more weathered but are recognisable by plagioclase laths (Bauer 1993).

About 50 m northwest of Flying Fortress Cave, the bedrock is steeply bedded with alternating dolomitised / nondolomitised beds. At the cave entrance, pronounced joints strike 185° and dip 79° to the west. About 20 m to the ESE of the cave entrance, a set of cross joints strike 263° and dip 65° to the south. Near these cross joints, solution of more pure limestone has left the less-soluble dolomitised limestone exposed. Dolomitisation appears to have replaced the micrite, not the fossils. Some of the algal beds appear to be dolomitised (J. Bauer, pers. comm.).

Cave Description

Flying Fortress Cave is a small cave with a “Halls and Narrows” pattern in plan view (Figure 3.144, see also Osborne (2001) and Osborne (2003)). In elevation or long section, the cave passage dips gently towards the SE with a 2 m drop to Magnathea Chamber. Each “Hall” in Flying Fortress Cave is a spindle-shaped passage developed along the NE-SW strike of the limestone. They usually have arched ceilings, some domes and sloping floors. In the “Narrows” regions, the floor is usually very steep and in one place (the climb down to Magnathea Chamber) resembles a dry waterfall. One long low passage is developed parallel to a small dyke.



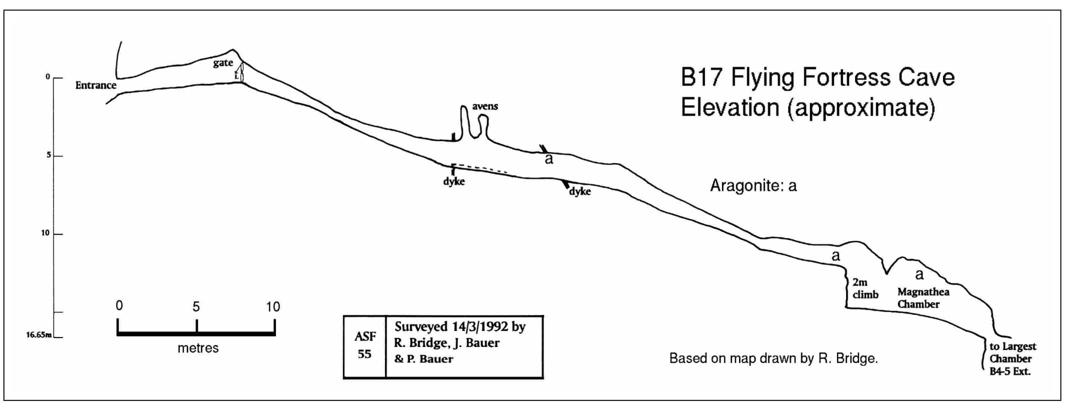
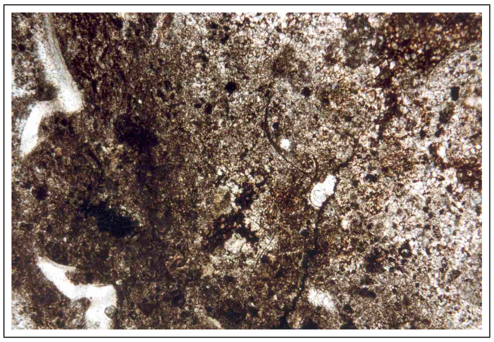
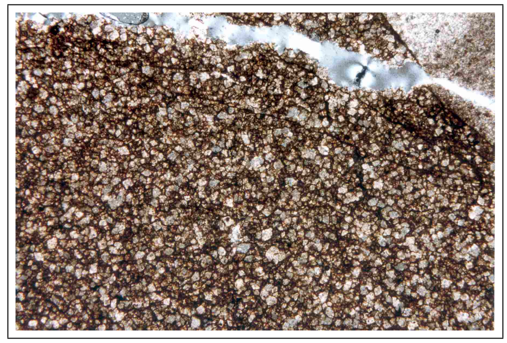


Figure 3.144: Plan and elevation of Flying Fortress Cave, modified from Bauer (1998), annotated with aragonite speleothem locations and dip measurements.

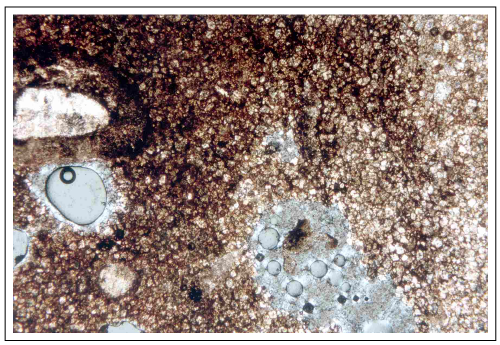
The entrance area (SW of the initial crawlway) has small domes and numerous fossils in the ceiling which appears to be partially dolomitised. Magnathea Chamber, the largest "hall" at the south end of the cave, has a domed and arched ceiling (Figure 3.147), and a rockpile and sediment-covered floor. The boulders in this chamber have a brown colouration, thought to be ferroan dolomite. A hole in the chamber's lowest end is the top of a 12.5 m pitch into Largest Chamber. A dolerite dyke (Bauer 1993) forms the southern side of Magnathea Chamber.



Bauer thin section 11453 XN, 25x.
Dolomitised biolithite, location 2, Magnathea Chamber.



Bauer thin section 11457 XN, 25x.
Dolomitised pelmicrite, location 3, Magnathea Chamber.



Bauer thin section 11468 XN, 25x.
Dolomitised biolithite, location 12.

Figure 3.145: Thin sections of dolomitised rock, Flying Fortress Cave. Other Bauer samples showed much lower dolomitisation. Blue mounting media.

Observations - Bedrock

At the base of a short drop south of the entrance crawlway, rusty coloured weathered laminated material resembles a dolomitised cave fill or an altered speleothem, with a different orientation compared with the bedrock. NW of Magnathea Chamber (point W in plan, Figure 3.144) the exposed black limestone in the ceiling is nearly vertically bedded (strike about 358° and dip about 85° to the west). Bauer's thin sections were examined for dolomite content (Figure 3.145). The "Narrows" are in more dolomitised limestone compared with the "Halls" which are in more pure limestone. The limestone in Magnathea Chamber is fossiliferous, with dolomitisation of micrite but not of the fossils. The alteration zone between the dyke and the limestone is about 1 m for the large dyke in Magnathea Chamber (Figure 3.146).

Near a smaller dyke (sill) west of the drop into Magnathea Chamber, the bedrock is exposed as a dark foetid limestone with contrasting white speleothems and grey alteration zone. One feature of the bedrock in Magnathea Chamber is the orange colouring of the dolomitised bedrock, in contrast with the darker grey bedrock with white surface coatings (Figure 3.147).

Northern end of Magnathea Chamber looking along strike. Limestone is rubbly with fossils surrounded by dolomitised rock.

White moonmilk on black limestone, area “W”.

Dyke, Magnathea Chamber, with speleothem efflorescence around joints.

Irregular ’fin’ off dyke is along strike of limestone (sill). SW corner, Magnathea Chamber.

Speleothem, probably aragonite, encrusting dyke.

Dyke, helictites and alteration zone on ceiling. Field of view about 0.5 m. Small dark sills penetrate the limestone.

Figure 3.146: Bedrock features near southern end of Flying Fortress Cave.

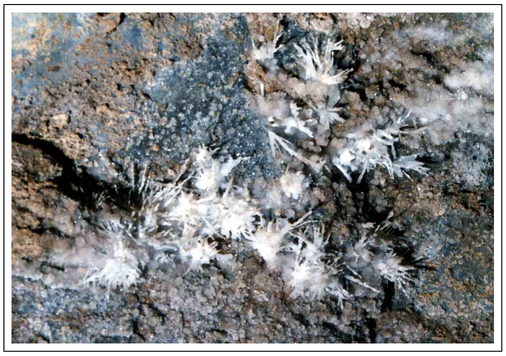
Sample sites and observations - Speleothems

Some small efflorescences, probably aragonite, occur near the first dyke (point L, Figure 3.144). Near point W (Figure 3.144), some speleothems comprise a small dark erratic column resembling a (probably calcite-coated) furze bush, beaded and smooth helictites, moonmilk, (probably aragonite) needles, hemispheres and crusts. Beaded helictites indicate rhythmic aragonite and calcite deposition (Figure 3.147). They are associated with part of a dyke, some dark foetid limestone and dolomitised limestone beds and occur on the side facing the entrance passage (possibly affected by air currents; air movement is dependent on the difference in temperature between the cave air and the outside). The main site for speleothems in Flying Fortress Cave is Magnathea Chamber. There are some conventional calcite speleothems near the drop at the western side of the chamber comprising white stalactites, shawls and stalagmites (one is named the Magnathea). Orange-brown calcite speleothems also occur in the north-eastern chamber. Forms include deep gours, microgours and reddish brown flowstone. Aragonite occurs in the upper northern end of Magnathea Chamber, where speleothems include helictites (flos ferri), orange-brown stalactites and spathites associated with a particular layer in the steeply-dipping limestone. Small helictite hairs have developed on some of the straws. The fossils stand out in white relief. Between them is a reddish fill, which appeared to be dolomite. This stands out in relief too, with the junction of the fossils and the dolomite deeply etched. The dolomite appeared to be a replacement for the inter-bioclast cement. The white coating on the fossils is very thin, with dense calcite underneath the surface coating. The brownish flos ferri comprises radiating clusters of (probably aragonite) crystals, each crystal about 5 mm – 10 mm long. One small ball of finer, bluish flos ferri resembling a hairball is associated with a rather white pasty moonmilk, which appears bluish over the dark limestone (an optical effect). The substrate for these (probably aragonite) speleothems appears to be the dolomitised bedrock. Long wave UV light on the speleothems indicated green for the tips of the straws and a mixture of green and white for the (probably aragonite) clumps. The white powder on the fossils appeared whitish under UV.

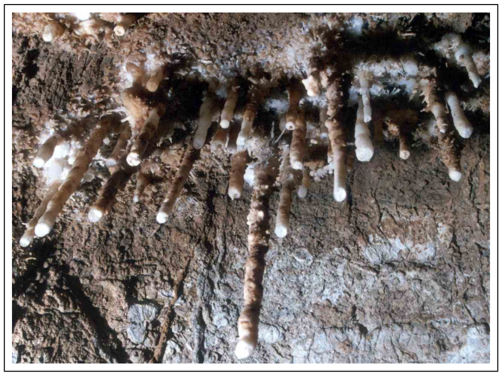
On the dyke in Magnathea Chamber, numerous small white crystal spherulites resemble aragonite. They are deposited in the numerous joints in the dyke and on its black surface. These efflorescences glowed a blue-white under long wave UV light. In some areas, they appear to be wedging pieces of the dyke apart. Some of these were sampled by Bauer and were found to be aragonite (J. Bauer, pers. comm.). The dark coating on the dyke is most likely a manganese-rich mineral (e.g. pyrolusite, birnessite) and this appears to be the substrate for the spherulites. Many smooth helictites on the dyke are curved upwards, a particular form which is often associated with minerals containing magnesium.

In the (dry) orange cave soil below the dyke, some cobbles are coated with almost bluish powdery white moonmilk (possibly needle form calcite) and black dendritic material, resembling a manganese-rich mineral. This combination is often associated with bat guano in other caves.

Osborne's sample B69 is a small spheroid from near the large dyke, made of calcite-coated aragonite needles with huntite near the base of the speleothem. Raman spectroscopy of the outer quills of the speleothem indicated calcite with high fluorescence. Raman spectroscopy of the base of the speleothem indicated aragonite with high fluorescence from other minerals. XRD of a small portion of the speleothem's base indicates about equal quantities of magnesian calcite, manganoan calcite, aragonite, huntite and hydromagnesite (Figures 3.147 and D.1).



Beaded helictites near small dyke, area "W", west of Magnathea Chamber.



Stalactites with probable aragonite, Magnathea Chamber.

Brown, white and bluish flos ferri in ceiling associated with dolomitised limestone.

Osborne sample B69 (cut, 5 mm wide) has aragonite and huntite interior and calcite coating.

Figure 3.147: Speleothems in and around Magnathea Chamber, Flying Fortress Cave.

Synthesis - Bungonia Caves

Aragonite in Flying Fortress Cave is associated with magnesium-rich minerals such as huntite, in an area with steeply-dipping, weathered dolomitised beds close to a weathered dolerite dyke. Manganese may be significant. Air currents may be significant in one site. Substrates for aragonite appear to be dolomitised limestone and weathered dolerite, as well as existing speleothems. Aragonite reported from Coffin Chamber (B4-5 Extension) is also associated with a weathered dyke (Bauer & Bauer 1998). The main calcite-inhibitors at Bungonia appear to be magnesium (as huntite in Flying Fortress Cave). Sulfate may be significant in Argyle Hole and Fossil Cave.

3.8 Wyanbene Cave

Wyanbene Caves are located about 255 km to the south-west of Sydney, about half way between Canberra and the coast (Figure 1.3). The area, managed by the NSW National Parks service, includes the large, wet Wyanbene Cave and several smaller dry ones.

The Late Silurian - Early Devonian Wyanbene Limestone is part of the Long Flat Volcanics (Carne & Jones 1919, Pickett 1982). The limestone overlies the Ludlovian De Drack Formation sediments, which unconformably overlie unnamed Ordovician sediments. The limestone is truncated to the north by an Early Devonian porphyry intrusion, and is overlain to the south and west by Late Devonian Minuma Beds (conglomerate, siliceous sandstone, shale and volcaniclastics). A low-grade base-metal ore, which is disseminated in the De Drack Formation close to its contact with the limestone, fills steeply-dipping joints in the limestone and may be hydrothermally emplaced (Richardson et al. 1981, Rowling 1995). The material includes oxides and sulfides of various heavy metals. Elements significantly above background levels were: lead (high), gold, silver, copper, zinc, iron, arsenic, tin, tungsten, molybdenum, nickel, cobalt and cadmium. The limestone is dolomitised near these ore bodies. Wyanbene Cave has developed along a major NS joint in the limestone and has exposed some of these ore bodies during the weathering process.

Aragonite-like speleothems in Wyanbene Cave take several forms: as helictites, anthodites, columns, stalactites, stalagmites and coralloid coatings. The substrate appears to be a type of gossan but has not been analysed. A recrystallised wedge-shaped speleothem near the bat chamber may have once been aragonite. Small needles of a soft, acicular mineral resembling gypsum occur in mud banks near the creek near Helictite Chamber (Rowling 1995). Flos ferri near Helictite Chamber appears to be associated with a gossan. A green-blue column in a rift a few metres north of the Wet Stretch may be coloured by copper in ironstones in the ceiling bedrock and may be partially made of aragonite. Clear stalactites in Rockfall Chamber have the general morphology of anthodites and are recrystallised (most likely to calcite). Similarly, macrocrystalline (?calcite) coralloids in Lower Rockfall Chamber, Caesars Hall and near the Gunbarrel may have once been aragonite. Anthodites occur near the creek in Caesars Hall and near Frustration Lake. Webb & Brush (1978) analysed fragments fallen from anthodites using XRD and found the material was a mixture of calcite and aragonite. Possibly if the material had been sampled directly from the anthodites, it may have had a higher proportion of aragonite as this study found aragonite in contact with cave mud in wet caves often reverts to calcite. The chemical influences on aragonite development at Wyanbene Cave appear to be magnesium and possibly manganese (from eroding ferroan dolomite), sulfate (possibly from oxidising pyrite) and heavy metals in gossans: copper, lead, cadmium, gold, zinc, nickel and cobalt. Recrystallised speleothems are most likely caused by the loss of calcite crystal “poisoners” from the surface of aragonite speleothems due to the wet nature of the cave.

3.9 Colong Cave

Colong Cave is a large cave system in the Blue Mountains about half way between Jenolan Caves and Wombeyan Caves. It is developed in Colong Caves Limestone, possibly related to the Late Silurian Cobra Formation. An aragonite-like speleothem coating was reported from near the dyke in Colong Cave (R.A. Osborne, A. Pryke pers. comm.). A sample of this material, collected by Osborne, was analysed using XRD during this study and was found to be primarily needle-form calcite with traces of aragonite. Alan Pryke and Geoff McDonnell have reported (2003, 2004 pers. comm.) aragonite-like speleothems such as helictites and small anthodites from other sites in Colong Cave.

3.10 Wellington Caves

Wellington Caves are about 240 km NW of Sydney, near the Bell River, and are developed in limestones of the Devonian Garra Formation. The caves have unusually high levels of CO_2. Although no aragonite was found at Wellington Caves, it is worth noting some of the aragonite-like speleothems found there.

The Gaden Coral Cave contains speleothems reminiscent of calcite paramorphs after aragonite. These include acicular rosettes of cave coral (possibly originally aragonite pool crystal), irregularly shaped stalactites (possibly recrystallised from anthodites) and a small group of helictites which are morphologically similar to the one sampled in Sigma Cave (Wombeyan). Near the CO_2 pit, speleothems are eroded leaving acicular shapes. On the surface above the cave, limestone boulders have brown patterns reminiscent of dolomitisation.

The Phosphate Mine has been excavated as a tourist mine, exposing sedimentary layers of phosphorite, probable gypsum and calcite. The calcite is unusual as it has formed acicular needles over the phosphorite and probable gypsum layers. XRD (Osborne sample IA2) indicates it is calcite. It exhibits unusually dense, curved twinning for sedimentary calcite and may have developed initially as aragonite. Possible chemical influences on the original suspected aragonite include magnesium (from dolomite), sulfate (from gypsum) and phosphate during the deposition of phosphorite.