

# Did permanent ice exist in karst caves in Australasia during the Last Glacial Maximum?

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## Abstract

Some caves at Wombeyan contain broken speleothems and speleogens. These appear to be relicts of cold-climate processes in the past. Preliminary studies suggest that this was enhanced by the chimney effect combined with past climatic conditions during the Last Glacial Maximum (LGM), allowing ice to build up in the caves. The stress from freeze-thaw was sufficient to fracture the calcite. Additional support is based on the appearance of possible cold-temperature speleothems and bedrock grooves. We briefly discuss the possibility that cold-climate processes may have operated in other caves in Australia and in south-east Asia during the LGM. This article was presented at the ACKMA Wellington conference and is based on Rowling (2025) which has a lot more references and goes into more technical detail.

## Introduction to the concept of ice deposits in caves

As we know, ice is not a permanent feature of Australian karst caves, but in Europe, there are some well-known show caves in which ice is not only present, but in sufficient quantities to make it a major tourist attraction, as shown in Figure 1. The icicles in the figure are slowly creeping from elongated holes in the cave's ceiling. Several factors have led to some European caves having permanent ice deposits, including a higher latitude and the cave's geometry. A higher latitude means that the European caves have a cooler average annual temperature compared with Australia, with snow in winter. Although the bedrock temperature is typically the same as the average annual temperature, the cave's geometry and chimney effects are crucial – cold traps can develop in some chambers. This means that the air temperature is much lower than the annual average. In these “ice caves”, as they are locally called, dripwater freezes upon encountering the cave's cold trap, forming icicles and other permanent ice deposits. Some more European showcave examples include the famous Eisriesenwelt of Austria and Dobšinská Cave of Slovakia.



Figure 1 (above): Demänovská Ice Cave in Slovakia in July, 2013.

## How cold was the Wombeyan area during the last Glacial Maximum?

During the Last Glacial Maximum (LGM), around 19,000 years ago, the Wombeyan area may have been about 8° C cooler on average compared with today according to Barrows et al (2022), which would give it an average annual temperature of about 7° C. Fossil animals from the area included the Mountain Pygmy Possum, *Burramys parvus*, which now only occurs in alpine areas. Fossil pollens indicate the surface had mainly grasses and alpine herbs. Scree slopes at Wombeyan are also typical of alpine regions, and one in Hockey Gully was dated to around 18,000 years ago by Jennings et al (1982). These deposits are often caused by diurnal freeze-thaw cycles, breaking rocks apart. A solifluction deposit in Basin Cave was dated to 27,800 years ago by Gillieson et al (1985). During the Ice Ages, the Wombeyan area may have looked a bit like the Snowy Mountains do today.

## How cold were the caves during the LGM?

Some caves at Wombeyan have loose angular scree in their entrances, similar to the deposits described above. This is sometimes cemented further in. So, we know that the caves were open to air flow during the LGM. As noted above, the LGM average annual temperature (rock temperature) was about 7° C, so water in the sumps would have been a source of moist air. At night in winter, dense cold air descends cave shafts, displacing warmer air which rises from the cave: the chimney effect. In a multi-entranced cave like Fig Tree Cave, in LGM winters, the cave's cold-trap temperatures could have been anything from just below 0° C to as low as -10° C depending on the cave's geometry.

## Could ice buildup break things?

Ice could build up around cold traps as humid air from the sumps (or from outside) condenses in those areas, then freezes. This is a bit like those old-style fridges which had to be de-frosted periodically.

The expansion of ice near its freezing point is a well-known phenomenon. Confined water, when freezing, can easily burst its container with over 200 MPa of pressure (over 29,000 psi).

According to Spötl et al (2023), calcite speleothems such as stalagmites break at around 1 to 5 MPa (Austrian stalagmite studies). Their team showed that the freezing of ice, not flow, was responsible for lifting stalagmites from their bases, about 4.3 MPa. Other lab tests showed that Wombeyan marble breaks at 3.5 MPa (unconfined cantilever) or 100 MPa (confined in a press – Hueckel (2016), pp. 11-12).

## Is there any evidence of ice breakage in caves at Wombeyan?

Fig Tree Cave and Victoria Arch have many features suggesting breakage by ice expansion, such as:

- Bedrock flakes – “platey exfoliation”
- Elongated but shallow phreatic tubes
- Scallop obliteration with shallow horizontal wall grooves
- Large broken stalactites and displaced stalagmites
- Broken speleogens (mainly pendants)
- Bent speleothems
- Cryogenic ridges and dribbly surface textures

Each of these features is discussed below.

### Bedrock flakes: platey exfoliation

Platey exfoliation resembles an unloading effect, as if the wall had been subjected to even pressure.

The plates are quite delicate. Part of the passage may have been ice-filled, expanded and cracked the bedrock. Later, it would have flaked off by unloading once the ice melted away. These occur in several places such as Upper Marble Way and Creek Cave Overflow.



Figure 2 ( left): Platey exfoliation, Upper Marble Way near Victoria Arch.

### Elongated holes

Elongated holes are often associated with platey exfoliation. These holes, abandoned phreatic tubes, do not go very far and appear to be oversized (enlarged) for their depth – see Figure 3. Was this enlargement caused by ice building up in a smaller tube, and grit abraded the lower part of the hole during ice expansion and contraction? Compare the holes in Figure 3 with those in Figure 1.

Figure 3 (below): Elongated holes in Victoria Arch.



### Scallop removal

Scallops have been partially removed from some areas of Fig Tree Cave. Some of these sites are associated with platey exfoliation and grooves in the rock as shown in Figure 4. Grooves may have been caused by conventional solution, or they could be caused by ice pressure with entrapped rock debris.

Figure 4 (left): Bedrock in Creek Cave with scallop removal, exfoliation, and rock grooves.

In Victoria Arch, rock grooves may have been caused by slowly moving ice and rock debris. They don't line up across the arch, so were not considered to be caused by water flow. Also, they don't have scallops. This is in contrast to the current streamway which is well-scalloped. They occur at different heights in the Arch, for example, Figure 5, and pre-date the stalactite shown in the figure.



Figure 5 (right): Bedrock grooves in Victoria Arch.

### Broken stalactites in Fig Tree Cave

There are many broken stalactites in Fig Tree Cave, but this article will concentrate on the biggest and most famous, known as the “Large Broken Stalactite” which lies at the junction of the Colonnades, Bush Ranger Hall, Marble Way and the Drawing Room. It is actually a large canopy, broken in half – see Figures 6 and 7. Underneath the upper half, one can see straw stalactites, but these can be temporary and don't really give an age to the break. The lower half of the canopy lies nearby on the ground with only minor damage to the tips.

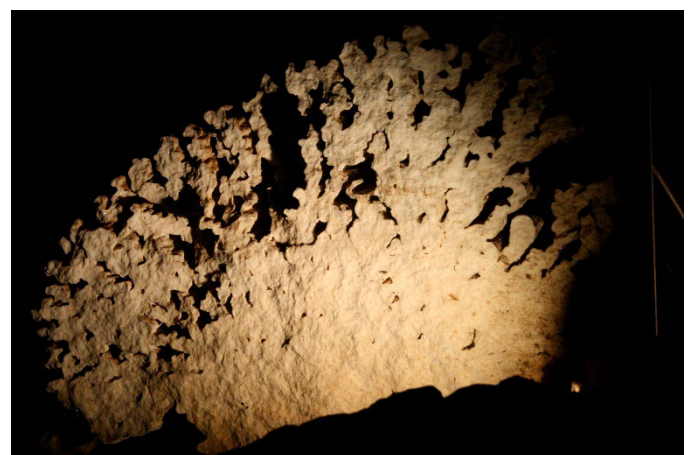


Figure 6 (above left): The “Large Broken Stalactite” upper half.

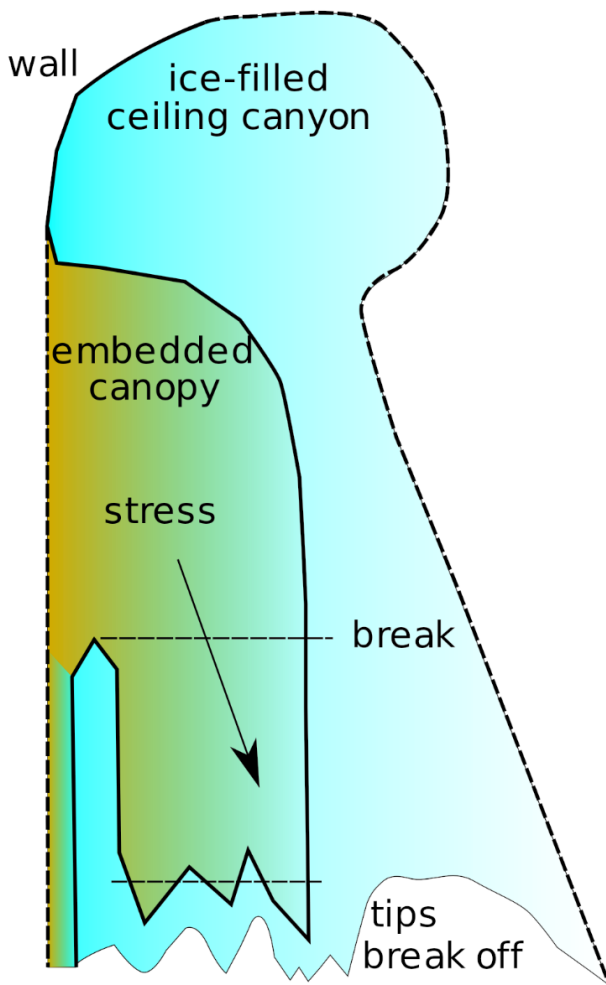
Figure 7 (above right): End view of lower half of “Large Broken Stalactite”, looking upstream.

Calculations were made as to how the famous canopy broke (see Rowling (2025) for full calculations).

Estimated weight of original intact canopy: 43 tonnes. It did not break under its own weight; it's at least an order of magnitude too small. No evidence remains of a mass-flow event at the time of breakage, and the tips of the lower half point upstream. It could have been broken by earthquake, but there would have been more destruction elsewhere. Other canopies nearby have been broken at a similar level, as measured using a laser disto.

Suppose during the LGM, part of this chamber contained ice. As the temperature varies, ice expands and contracts, applying sufficient force to the speleothem to crack it (fatigue) – see Figure 8. The lower half may have gently landed in its current position on a bed of ice and debris.

Figure 8 (left): Proposal as to how ice broke the “Large Broken Stalactite”.



### Broken Stalagmites

Broken stalagmites can be found mainly in Upper Marble Way, the Drawing Room, Chalkers Retreat and the Colonnades. Many of these are broken at the same local level, and in most cases it looks like a tension break with small steps in the calcite where different layers have different mechanical properties (see Figure 9). Some of the broken pieces are cemented in flowstone, indicating that the break was not recent.

Figure 9 (below): Broken stalagmite in Upper Marble Way.



### Broken and “bent” speleothems

Apparently-bent speleothems occur in Fig Tree Cave in the same areas as broken ones. Calcite can bend under constant pressure, but one would have to check for other causes, such as wind deflection, drip point movement, subsidence and so on. Figure 10 shows some apparently-bent stalagmites which broke at the same height. In the background are cracked columns and a couple of apparently-bent stalagmites.

Figure 10 (right): Broken and apparently bent stalagmites in The Colonnades.



## Broken and damaged bedrock pendants

Damaged rock pendants present a similar situation to the broken stalactite problem. Several bedrock pendants have been broken or damaged and are associated with grooves and missing scallops. In Figure 11, the right-hand side of the pendant is missing. A rock of similar shape to the missing bit is embedded in nearby flowstone below. In Figure 12, a bedrock pendant is not quite worn through. Elsewhere in the cave, pendants are lying on the floor.

Figure 11 (right): Broken bedrock pendant in The Drawing Room.

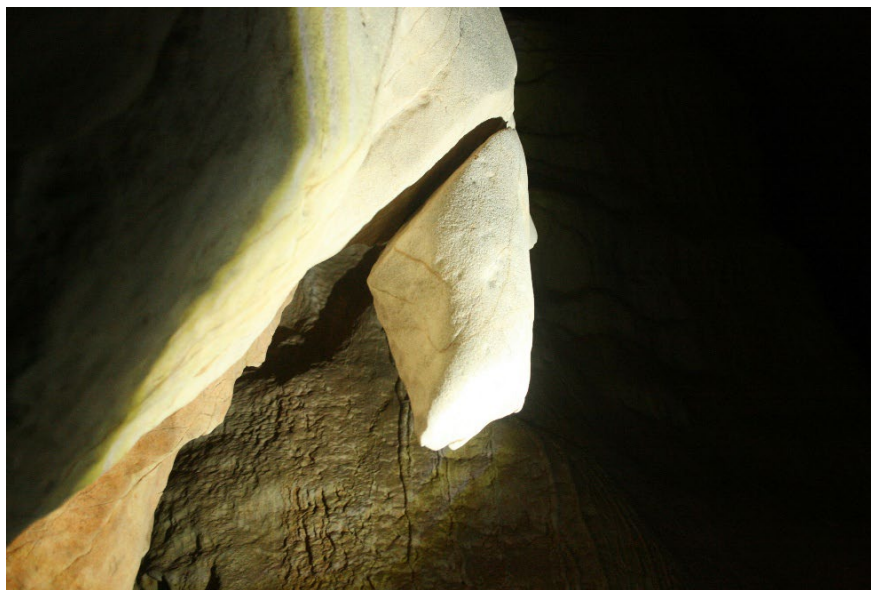


Figure 12 (left): Rock pendant in Chalkers Retreat is almost worn through.



## Cryogenic Ridges

Cryogenic Ridges are a new speleothem defined in Onac et al (2023). They have characteristic ridges caused by ice cracking the stalactite's internal plumbing. Speleothems resembling cryogenic ridges have been seen in Fig Tree Cave's Drawing Room and Upper Marble Way (small broken stalactite as shown in Figure 13), and in Junction Cave. Isotopic analysis could confirm if it was made of cryogenic calcite or not, and this would need further work.

Figure 13 (right): Possible cryogenic ridges on broken stalactite in Upper Marble Way

## Dribbly speleothems and “concrete” flowstone

These are possibly new types of speleothems and are associated with other potential ice features.



They occur in several caves at Wombeyan and take the form of sinuous runs or dribbles of a chalky material, sometimes terminating on the floor in a small pile of speleothem which resembles concrete as shown in Figure 14.

They may be a deposit of two variants of fine and coarse cryogenic calcite. Further work would need isotopic analysis, for example, to confirm this. They don't appear to be currently active.

*Figure 14 (left): In Chalkers Retreat there are many “dribbles” of calcite and “concrete” flowstone.*

## Other caves at Wombeyan with these features

Other caves at Wombeyan which may have had ice in the past include Kooringa Cave, which has many large broken and re-cemented speleothems, as well as rock breakages resembling the results of ice heaving the substrate. Junction Cave has broken cave shields, stalagmites, stalactites and bedrock pendants as well as a scree slope. Wollondilly Cave similarly has large broken speleothems and “dribbles”. Tinted Cave has elongated tubes, platy exfoliation and a broken re-cemented stalactite. Guineacor Cave has a bent stalagmite and a wall of “dribbles”. Sigma Cave has embedded scree. There may be many more.

## Further afield

Jenolan Caves is higher in altitude compared with Wombeyan Caves. It has large broken speleothems e.g. Mons Meg, several large broken speleothems in the Orient and Baal, and possibly the Big Rift above Wiburds Lake Cave. Mystery Creek Cave in Tasmania has a large broken column with smaller stalagmites growing on it (reported on social media by several cave photographers). Yarrangobilly Caves are reported to have breakages similar to those described here. Cathedral Cave at Wellington has a large broken stalactite, well cemented to the flowstone (seen during the conference).

Outside of Australia, the Cave of the Drunken Forest at Mulu Caves, Sarawak, has a chamber in which several large stalagmites are tilted at various angles and smaller stalagmites are growing on them, reported by J. Crockett on social media and by several others, see also Eavis (1985) pp 17-18.

Paradise Cave in Vietnam has an enormous stalactite cluster which lies at a considerable angle to the vertical (reported on social media by D. Stuckey). Preliminary temperature calculations suggest these caves may be candidates for having been broken by ice deposits in the distant past.

## Future work can include you

The author is still investigating caves featuring broken speleothems as described here and proposes the following questions for people who work in caves:

- Have you seen large broken speleothems in your show caves? Ignore known breakages from people, mining or known earthquakes.
- Especially look for re-cemented broken speleothems as these are usually a lot older than the development of the showcave.

- Does your cave have a cold trap or multiple entrances?
- Are there any broken speleothems or speleogens near the cold trap?
- What is your cave's cold trap winter temperature compared with the annual average for your area?
- Do you have areas of seasonal condensation?

## Conclusion

Fig Tree Cave, and other caves at Wombeyan, experienced very cold conditions during the last glacial period. Due to the cave's geometry, it has cold traps. During one or more past glacial periods, large permanent ice deposits built up in these cold traps due to moisture condensing from the air and then freezing onto surfaces. As the temperature in the caves fluctuated around the freezing point of water, ice expansion and compression cycles applied sufficient stress to the cave walls and speleothems to cause fractures and eventual breakage. The results of this can be seen today in the caves. It is suggested that many other cave sites in Australia and elsewhere may have experienced similar permanent ice deposits during previous glacial periods.

This work started after the author had difficulties explaining some of the features of Fig Tree Cave using a conventional understanding of its speleogenesis. Understanding speleothem breakage required calculating the forces involved, checking with articles on glaciology, climate science, atmospheric physics and rock mechanics. The author hopes others (maybe you?) will have a look at your local show caves in a different light.

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All photos are by Jill Rowling.

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