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Helictite was established in 1962 by its foundation editors, Edward A. Lane and Aola M. Richards. It is intended to be wide ranging in scope from the scientific study of caves and their contents, to the history of caves and cave areas and the technical aspects of cave study and exploration. The territory covered is Australasia – Australia, New Zealand, the near Pacific Islands, Papua New Guinea and surrounding areas, Indonesia and Borneo.

In 1974 the Speleological Research Council agreed to support the Journal with financial assistance and in 1976 took over full responsibility for its production. From 1974 to 1997 the Journal was edited by Julia James assisted by other members of the Speleological Research Council Ltd. In 1998 Susan White and Ken Grimes took over as editors with Glenn Baddeley as Business Manager. Stefan Eberhard joined the editorial team in 2003.

In 2000 ownership was transferred to the Australian Speleological Federation, Inc. (ASF) and the Journal is administered by the Helictite Commission of the ASF.

Greg Middleton took over as Chief Editor in 2016. The accidental death of Ken Grimes in August 2016 led to further changes in editors, with Tim Moulds and Kevin Kiernan taking on the role.

The aim of the Helictite Commission of the Australian Speleological Federation is to publish the results of scientific studies in all fields of speleology in *Helictite – Journal of Australasian Speleological Research*.

HELICTITE IN DIGITAL FORMAT

Since 2017 Helictite has been published in digital format only. Papers are published online, and are freely available to all. There is no subscription fee – the ongoing costs of production and archiving are borne by the Australian Speleological Federation.

Submitted papers will still be reviewed and edited as before, but the layout may be varied to suit a digital format. Each paper will be published on line as it is ready as part of what are intended to be annual volumes. Intending authors should read the latest 'Information for Contributors' on the Helictite website.

Helictite website

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VOLUME 47 2022

Contents

Cover: Upward growing rootsicles beneath drip points in Monbulla Cave (L-5) SA. Note AA battery for scale.
Photo: Garry K. Smith.

Helictite, Volume 47, 2022 consists of single issue, published (on line) March 2023.

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Editorial

Greg Middleton

Welcome to *Helictite* Volume 47 for 2022. We have unfortunately only been able to publish two papers in this volume, due to a reduction in the number of papers offered and the fact that some promised papers could not be produced in time. We understand that Covid-19 has disrupted work and outputs across all areas of endeavour but hopefully its impact is declining.

Garry Smith's 'Rootsicles, Roots and Caves', developed from other material he has published, presents an updated review of these unusual speleothems.

In their 'Drainage Derangement at Howitzer Hill', Slee and McIntosh describe the hydrological situation in this little-known north-western Tasmanian karst area.

Helictite is here to record and disemminate the results of speleological research and investigations in the Australasian region, and beyond. If you have any contributions to make in this field, please consider submitting papers to this journal. Your input will enable us to keep *Helictite* interesting and relevant.

We regret that due to some issues beyond our control, this issue could not be published (on line) until March 2023.

We wish all our readers a successful and productive 2023!

Rootsicles, roots and caves

Helictite, (2022) 47: 1-12

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Abstract

The generic term 'rootsicle' has been used for several decades to describe plant roots in caves that are coated in a secondary mineral deposit. Rootsicles are found in shallow caves worldwide and take on a variety of forms and mineral coatings, but most commonly calcite. In caves, rootsicles can take on similar forms to stalactites, columns and stalagmites. There are at least three types of interactions that can take place between roots and secondary cave deposits, one of which results in a form that cannot be considered a rootsicle. There can be large variations in morphology and petrology between rootsicles growing at a cave entrance, to those in the twilight and dark zones. Influencing factors can include microclimate around developing rootsicles (temperature, humidity) and also light intensity. However, rootsicle-like forms are not restricted to caves. Above-ground plant roots can also become coated in secondary minerals and the resulting structure can look very similar to those formed underground. While above-ground forms are obviously not speleothems, it is not unreasonable to also describe them as rootsicles given similarities in their forms and in the multiplicity of influences on their development. A revised definition is therefore proposed to better capture the current knowledge surrounding the formation of rootsicles and associated structures.

Introduction

Rootsicle is the generic term embraced by speleologists for all forms of plant roots that have grown into a cave, been coated in a secondary mineral, usually calcium carbonate ($CaCO_3$) and thus effectively become fossilised (Hill and Forti 1997; Smith 1999; Hill 1999). More recently, the definition was expanded to include speleothems, produced by the coating or replacement of plant roots (Taboroši and others 2004). This process can result in formation of a column, stalactite or stalagmite cast in the shape of the roots, often having a twisted or contorted shape (Figure 1; Hill and Forti 1997; Taboroši 2004, 2006).

Rootsicles are less common than other forms of secondary deposits in caves. In general, only tree roots are able to grow deep enough to enter shallow caves (up to 30 m below the surface) and have a chance to become rootsicles over time. However, fig and boab tree roots have been observed at depths between 40 and 50 m in karst areas across Northern Australia, which are subject to seasonally humid climate (Gillieson 2004, Smith 2018).

Rootsicles should not be confused with 'rhizoliths' which are organosedimentary structures resulting from the preservation of roots of higher plants, or the remains thereof, in soils and sedimentary deposits rather than within caves (Klappa 1980).

Figure 1. Rootsicle embedded into flowstone in Cow Cave (MC-46), Mole Creek, Tasmania. Photo: Garry K. Smith

Creation of rootsicles

Tree roots grow into cave voids in search of water and nutrients, then become rootsicles if they are coated in $CaCO_3$ (or another mineral – see 'Non-carbonate Rootsicles', below) deposited from seepage water splashing onto or running down them. The roots may become a preferential area for the flow of seeping water and for calcium carbonate deposition (Shopov 2004). $CaCO_3$ is usually deposited as 'calcite' as this is a more stable polymorph, than aragonite and vaterite. Provided the supply of seepage water continues, the calcite layers may become so thick that the roots are completely encased and can't be seen (Figure 2).

Figure 2. A broken section of a rootsicle shows consecutive layers of calcite which have grown around a group of small roots. The roots had decomposed and their remnants washed out of the speleothem prior to natural breakage under its own weight. Photo: Garry K. Smith

If the calcite layer is not too thick and the roots continue to grow, the calcite may crack off the roots in strips and fall to the cave floor to form what can look like a pile of sticks. If the tree roots die, the calcite layers may continue to grow thicker, and although the roots will slowly decay they may still provide sufficient support to the developing speleothem until it is strong enough to stand-alone. The slow breakdown of the dead roots occurs because the fungi, mould and other organisms that decay the encapsulated roots are starved of oxygen. Eventually the rotting roots will decay to a consistency of papier-mâché, often jet black in colour (Smith 2010a). If sufficient water then enters these root canals, their contents can be washed out to leave just hollow tubes, with the internal shape resembling the original roots. Well after the roots have decayed the outside may continue to be coated in successive layers of calcite and the deposit preserves the roots approximate shape and original form.

When they form inside caves, they are commonly referred to by the informal term "rootsicles", although not every root-associated speleothem should be so termed. There are at least three different types of interactions that can take place between roots and secondary cave deposits, see Table 1. The resultant speleothems are distinct from each other and do not always fit the definition of rootsicle. Type 3, Table 1, is not a rootsicle because in this case the speleothem has formed first, then the root has grown through the solution path, cracks or porous voids in the speleothem (Taboroši and others 2004). Because the root has not been coated in a secondary deposit it can't be considered a rootsicle.

In their study of caves in southern Thailand Taboroši and others (2005) found a large variation in morphology and petrology between stalactites (including rootsicles) growing at a cave entrance and those in the twilight and dark zones. Microclimate (temperature, humidity) and light intensity were found to influence the morphology of stalactites and rootsicles. At the cave entrance largely biogenic stalactitic accretions of calcareous tufa were found growing around the drip-line (and even outside the cave) and there was a transition in their morphology to the dense coarsely crystalline stalactites (speleothems) in the cave's interior. Around the cave entrance, irregular, porous and easily recognizable tufa fabrics had formed around hanging plant roots, "resulting in tufaceous equivalents of cave rootsicles" (Figure 3). They noted that in tropical cave entrances, stalactites are soft and fragile in the most exposed locations, and more dense and solid in better-enclosed areas (Taboroši and others 2005).

In general, when a stalactite and stalagmite join, there are usually characteristic indications in the shape of the resulting column. This is often a step change in the column diameter (larger at the bottom or vice versa) and also a significant change in the external shape. However, when a tree root extends from ceiling to floor in a cave, and then becomes coated in a thick layer of calcite, the resulting rootsicle column is likely to be roughly uniform in diameter for its full length. Rootsicle columns may

Table 1 - Types of root-speleothem interactions in terms of basic temporal relationships between the plant roots and calcite deposits.

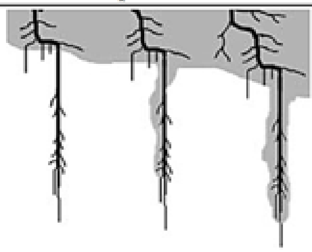
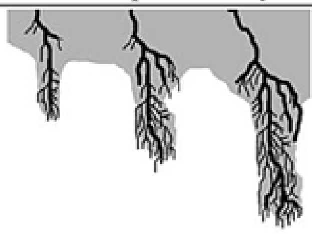
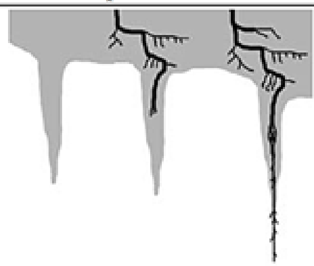
Temporal relationship	1 Roots precede speleothems	2 Roots and speleothems develop concurrently	3 Speleothems precede roots
Sequence diagram			
Effects of roots	Constructional	Constructional	Destructional
Typical deposits	Rootsicles	Tufaceous stalactites	Stal. invaded by roots

Table 1. From Taboroši and others, 2004. Reproduced with permission.

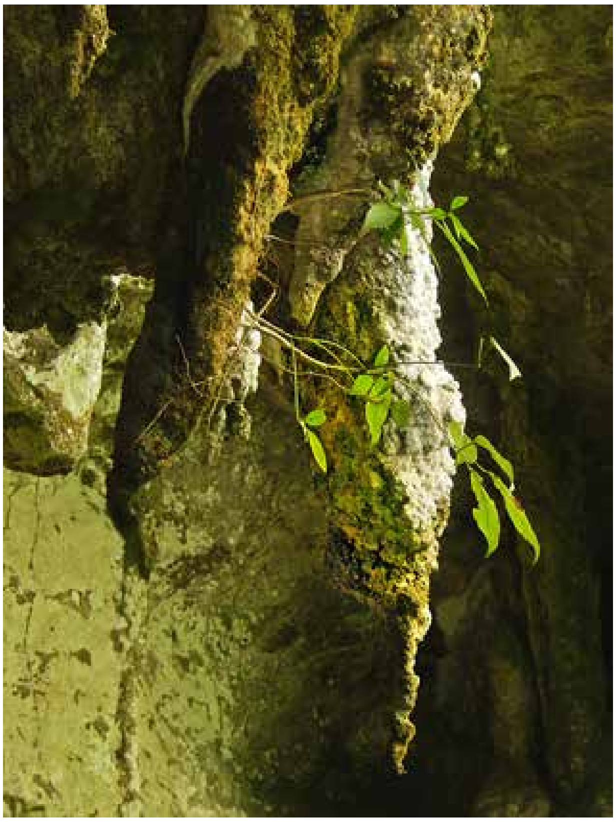


Figure 3. Roots and rootsicles at the entrance of Pop Kan Mai Cave in Chong Phli village, Ao Nang subdistrict of Krabi, Thailand. Both stalactites are rootsicles, i.e. roots coated in a tufaceous calcite and aragonite deposit. The one on the left has more algae and moss growing on its surface. Photo: Danko Taboroši.

also consist of quite a few roots which have grown closely together from ceiling to floor. Thus, the shape may provide a clue to its origin as tree roots that created a path for seepage water to run down.

Breakdown, Damage and Repair

Rootsicles consisting of fine calcite coated roots that have rotted and fallen from the main roots, may form a mass resembling tangled spaghetti (Hill and Forti 1997). They may also look like a pile of calcified 'fiddle sticks' on the floor when relatively straight thin roots have rotted and the calcite structure has broken under its own weight.

Larger rootsicles that are accidently damaged or naturally break under their own weight, typically result in a pile of many broken pieces (Figure 4). If broken due to natural causes rootsicles are typically left untouched, however if wilfully or accidently broken attempts may be made to restored them. If attempts are made to repair humanly-caused damage to rootsicles it can prove very difficult because their centres are usually hollow after the

Figure 4. Broken rootsicle in Wildmans Cave (W-456), Wombeyan, NSW. Photo: Garry K. Smith.

roots decay, thus the surface area at the break points is usually of insufficient extent to provide a strong bonding surface for adhesives. Cleaning out the rotten tree root canal for some distance into the broken segments and inserting threaded pins with water resistant adhesives up the central holes, can achieve limited success (Smith 2010a). Details of environmentally friendly adhesives are available elsewhere (Smith 2010a).

Occurrences of Rootsicles

Rootsicles can be found in many caves around Australia. For example, at Wombeyan (NSW) a 2.5 m calcified tree root has formed a column in Shawl Cave (W-12) (James and others 1982) and another 2 m long (now broken) rootsicle stalactite was formerly present in Wildmans Cave (W-456) (Smith 2009, 2010a). At the entrance to Wollondilly (W-144) and Creek (W-149) caves there are distorted, irregular stalactites that appear to be calcified tree roots (James and others 1982). Rootsicles in other NSW caves include Stove Pipe (WA-5) at Walli Caves, (Smith 2001); a 30 cm rootsicle in Gaden Caves (WE-2) at Wellington (Ian Eddison pers. comm. 2022); and a 3.5 m rootsicle forming a column in Death Trap Cave at Glenrock (GR-124) (Smith 2010b). In Rock-me Cave at Timor, NSW there are slender rootsicle stalactites ~5 m in length (Figure 5) (Baker 2007; Rutledge 2008).

Figure 5. Andrew Baker next to a >5m long delicate rootsicle in Rock-Me Cave (TR-52) Timor, NSW. Photo: Garry K. Smith.

Giants Cave (WI-21), south of Margaret River, WA contains several very impressive calcified bunches of tree roots hanging from the ceiling and referred to locally as arborites (rootsicles) (Smith 2003). Bastian (2014) states that these speleothems (arborites) are very common in caves developed in aeolian calcarenite along Australia's western seaboard. The roots in caves, north and south of Perth WA are mostly of the Tuart tree (*Eucalyptus gomphocephala*), which has an affinity for limestone.

Figure 6. Submerged rootsicles in Dos Pisos Cenote (Two Levels Cenote) - Yucatan region. Photo: Neil Vincent.

Overseas, rootsicles up to 5 m long have been reported as being prevalent in caves of Mexico's Yucatan peninsula, where they may form the basis of most of the columns that form in these shallow dry caves (Bunnell 2021). They are also found in subsequently drowned caves, such as Dos Pisos Cenote (Two Levels Cenote) in the Yucatan region, which has large rootsicle columns in excess of 3 m high, at a depth of ~5.5 m below the present water surface (Figure 6). Images provided by cave diving photographer Neil Vincent, show well-formed stalactites, and other speleothems including rootsicles that were created during a period when the cave passages were dry. Many of the presently flooded caves and cenotes were dry during the Last Glacial Maximum at the peak of the Ice Age (about 22,000 years ago) when the sea level was 120 meters below its current level, postglacial sea level rise then causing back-flooding of many of caves (González-González and others 2008; Blanchon and Shaw 1995). The calcium saturated cave water has preserved the rootsicles for thousands of years.

There are some fine examples of calcite rootsicles in Caverne de La Vierge on the Mauritian island of Rodrigues (G. Middleton, pers. comm.) (Figure 7). The roof thickness above the cave is about 10 m and the passage where the main rootsicles occur is about 1.5 m high. The karst is developed in aeolian calcarenite very similar to that found on Australia's west coast.

Figure 7. Rootsicle column in Caverne de La Vierge, Rodrigues Island, Mauritius. Photo: G.J. Middleton.

Rootsicle Stalagmites

Tree roots can do strange things and have been observed growing upwards from the cave floor in search of moisture. For example, some roots in Monbulla Cave (L-5) near Naracoorte in SA (Figures 8 and 9) grow upwards from the earth floor and have been partly coated in calcite (Smith 2007). The roots are growing upward beneath a localised drip point in search of water. In both examples the lower halves of the central roots are completely encased in calcite, yet fine rootlets continue to grow out of the top and side of the calcite casing. They are considered rootsicle stalagmites under the current definition.

Figures 8 and 9. Upward growing rootsicles beneath drip points in Monbulla Cave (L-5) SA. Note AA battery for scale. Photos: Garry K. Smith.

In Deepdene Cave (AU-1) in WA, tree-root-entwined stalagmites were reported by De Waele (2014), whose report includes a photo depicting a stalagmite that appears to be at least 40 cm high with a considerable amount of partly calcite-encrusted rootlets covering most of it. From the photo it appears that the stalagmite has grown first, and the fine roots have grown up the outside and have been gradually encased in calcite. Again, this raises the question - Is it, or is it not a rootsicle?

Du Preez and others (2015) described what they called, 'hairy stalagmites', a new type of speleothem, which had only been observed in a couple of Botswana caves (Dimapo and Diviner's caves) which were previously sealed. The description of these (Namaqua fig tree) root stalagmites almost completely coated in calcite, fits the definition of rootsicles. Their stereo and electron microscopy study revealed the structures to consist of multiple intertwined tubes created when thin films of $CaCO_3$ are deposited around fine lateral roots. The hairy stalactites ranged in height from just a few centimetres to more than a metre, and their diameter varied between 3 and 5 cm.

Globally, rootsicle stalagmites (speleothems) appear to be quite rare, however the occurrence of roots growing upwards to create a structure resembling a stalagmite, appears to be more common than was thought by authors of early papers (Winkelhofer 1975; Lamont and Lange 1976). While not rootsicles, they have the potential to be transformed if seepage water contains minerals that may be deposited on them.

Winkelhofer (1975) was the first to describe root stalagmites from sandstone caves in Germany. These were described as conical and/or cylindrical dense networks of roots. Voids between the main roots in the stalagmite structures consisted mainly of living terminal roots often coated by symbiotic fungi, and were filled with sandy grains and organic matter. No calcite crust was deposited on the root stalagmites, due to the chemical composition of the host rock. The height of these structures was up to 60 cm.

Lamont and Lange (1976) described vertically growing fibrous root structures occurring in ten limestone caves near Yanchep National Park, Western Australia. They called these structures 'Stalagmiform' roots and determined that they were the roots of large trees (*Eucalyptus gomphocephala*) growing above the caves. The tallest structure was 12 cm and a few had calcite deposited from dripwater amongst the root structures.

Marais and others (1996), reported that in Pofaddergat Cave, Namibia, there are rootlets having a stalagmitic form (root stalagmites), which have preferentially grown immediately below dripping sites. "They form small stalagmites of densely packed thin roots, which are not more than a couple of centimetres in diameter and up to 20 cm high". From the description there appears to be no calcite deposition on the roots.

Mlejnek (2010) identified that in late 2009 there were 78 localities with 245 root formations documented (mostly stalagmites) in the Czech Republic. In the Poseidon sandstone cave system, root stalagmites grew up to 60 cm high and 10 cm or more in diameter (Mlejnek and others 2008). "In the rest of the world there are only 38 [root stalagmite] localities documented (Poland, Germany, Austria, Slovakia, Hungary, Sweden, Spain, South Africa, Australia) and in these localities 81 root stalagmites and stalactites were discovered" (Mlejnek 2010). By far the majority of these were found in sandstone talus caves. In 2009 only a handful of root stalagmites were reported in carbonate caves: one known location in the Czech Republic's Moravian Karst, one cave in Austria, three caves in Hungary, and one cave in Australia (Mlejnek and others 2008, 2009; Mlejnek 2010).

Non-carbonate Rootsicles

Speleothem rootsicles have also been reported in Galeria da Queimada lava tube, on the Portuguese island of Terceira in the Azores archipelago (Daza Brunet and Bustillo 2014). The rootsicles have a mineralogical composition and developmental association with biomineralization induced by microbial activity in caves. Three types of rootsicle were defined, namely white hard and black spongy types, both composed of allophane, and a third hard, red coloured type composed of hydrous ferric oxi-hydroxide minerals (Daza Brunet and Bustillo 2014).

Speleothems such as flowstone, stalactites, stalagmites and coralline can occur in other non-carbonate caves. Rootsicles can be found in quartz sandstone overhangs and shallow caves of the Central Coast, Sydney and Blue Mountains regions of New South Wales. They can be created when calcium carbonate is leached from the overlying sandstone strata (Wray 1995, Smith 2015). Alternatively, they may be created from the deposition of iron oxides/hydroxides, or opal-A interlayered with chalcedony. They are physically robust and range in colour from white through to orange and almost black, depending on the chemical composition and proportion of included organic matter (Wray 1995, 1999). Figure 10 shows bright orange rootsicles coated in iron oxides/hydroxides and algae at the entrance to a small overhang cave in the Watagan Mountains, NSW.

"Related forms" (Hill and Forti 1997) are those deposits that resemble rootsicles, but are not speleothems in the strictest sense because they are not composed of true minerals but of mud or organic material

Figure 10. Rootsicles coated in iron oxides/hydroxides and algae, at the entrance to a small overhang cave in the Watagan Mountains. They are physically robust and range in colour from bright orange through to almost black. Photo: Garry K. Smith.

Roots Above and Below Ground

In the tropical and monsoonal areas of Australia, tree roots can grow to an enormous size. Such examples can be found in the Northern Territory, at Bullita caves, where boab and fig trees extend their roots down into the caves in search of water and nutrients (Figures 11 and 12). The wet and dry seasons mean that most of the ~550 mm average annual rainfall occurs in just 4 or 5 months (approx. between November and April) while little or no rain falls during the rest of the year. It is during the dry periods when the trees particularly need long roots to extract moisture from soil beneath the cave floor. When it rains the trees on the karst tend to catch droplets causing water to preferentially flow down their trunks, then follow the root systems into the cave. Despite this there is typically little calcite deposited on the tree roots because of the high flow rates when it rains. The calcium carried in solution is transported out of the cave and discharged at effluxes into surface perennial creeks flowing toward major river systems. In places so much calcite is carried out of the cave systems that tufa dams are created along surface stream beds, due to evaporation and degassing from the solution. Deposits similar to rootsicles can form on grasses, twigs and roots, mainly on the downstream side of tufa dams (Figure 13).

Figure 11. In Two Fishes Cave (BAA-11), Bullita, NT, large tree roots penetrate to great depths in search of water. Photo: Garry K. Smith.

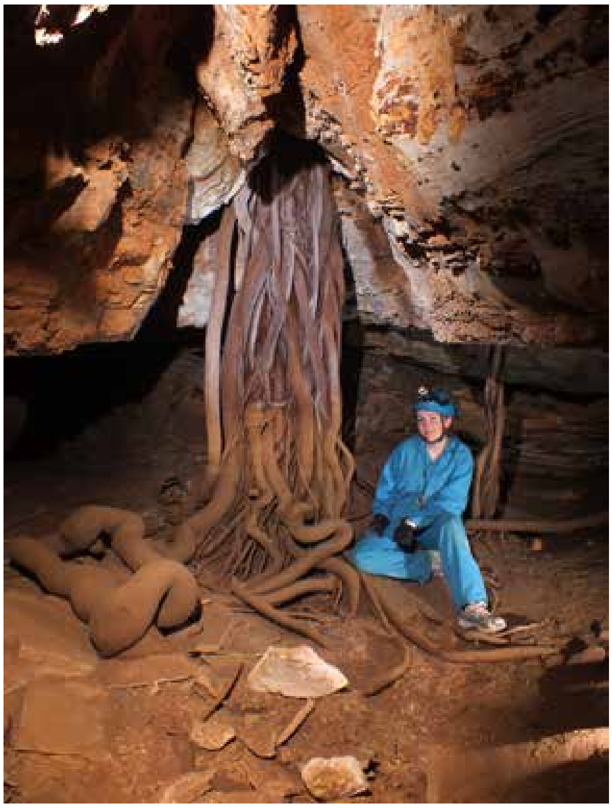


Figure 12. Melissa Hadley next to tree roots that are flooded during the wet season and completely dry the rest of the year, in Neighbours Block (BAA-51) Bullita NT. Note the water-level mark on roots. Photo: Garry K. Smith.

Figure 13. Heiko Maurer and above-ground rootsicles at Calcite Waterfall, Gregory National Park, NT. Photo: Garry K. Smith.

Tree roots in caves play an important role in the subterranean food chain and can support a wide range of fauna, discussion of which is beyond the intended scope of this article.

From a safety aspect, speleologists should be aware that roots can be a source of elevated CO_2 in a cave. Plant root respiration can elevate CO_2 to dangerous concentrations in cave atmospheres where there is little air movement to disperse it. Also, microbial and fungal activity, breaking down dead roots, will reduce oxygen and increase CO_2 concentrations in caves.

In regions with less rainfall or with soils and porous rock which quickly drain water away, trees and other vegetation have adapted by sending roots down into caves where they hang from their ceilings like drapery. These fine rootlet masses hang in the cave's high humidity atmosphere, absorbing droplets which condense on them (Smith 2007). An example is in L-23 cave (incorrectly called Quarry Cave by Smith 2007) near Naracoorte, SA (Figures 14 and 15).

Discussion

At what point does a plant root become a rootsicle and does it only apply to speleothems? These are the questions that the author grappled with when writing this article. Current definitions don't clearly define the percentage of tree root that must be coated in a secondary mineral deposit (e.g. calcite), to make it a rootsicle. Is it >50% coated, and how thick should the coating be? The root could be partly encased with a hard coating over 25% of its length and the rest might have just a visible thin white film, which may be powdery (e.g. Figure 16). What happens if a root is completely encased for its full length and is considered a rootsicle for many years and then a branching root breaks out of the calcite casing and continues to grow without a coating? Is there a point where the rootsicle ceases to be one, because the root has grown a certain percentage longer than the original rootsicle?

Figure 14. Jessica Bayles amongst roots absorbing condensation from a high humidity atmosphere in L-23 near Naracoorte, SA. Photo: Garry K. Smith.

Defining this speleothem can be quite difficult as there are so many variables. Even setting an arbitrary percentage of secondary deposit coating and thickness on roots is prob-

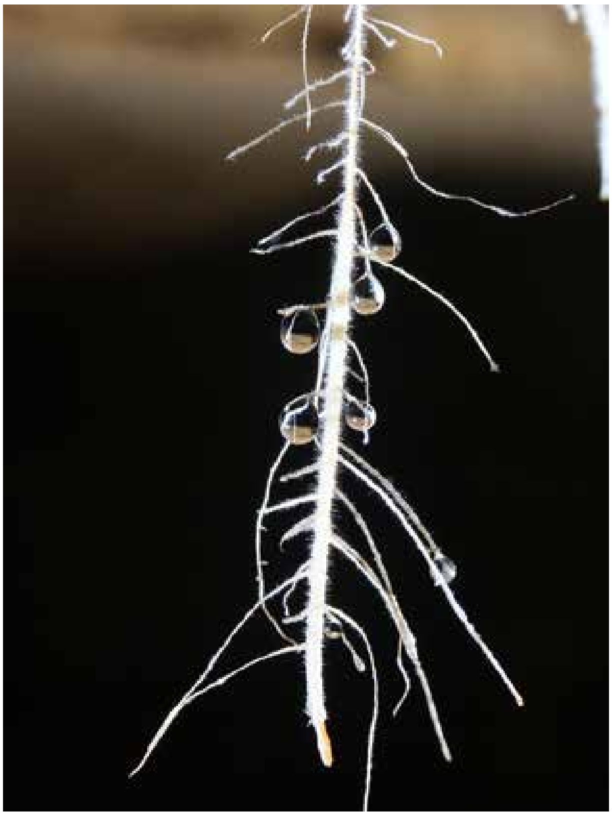


Figure 15. Fine rootlets suspended from cave ceiling, capture condensation in L-23 cave near Naracoorte SA. Photo: Garry K. Smith.

Figure 16. The two groups of tree root either side of caver are about 50% coated in a layer of calcite and the remainder is a very thin powdery coating. Are they rootsicles? The roots on far left have no coating. Reto Zollinger in Dingo Cave, Bullita, NT. Photo: Garry K. Smith

lematic when it comes to accurate measurement. The easiest solution might be to leave the definition open to interpretation, by saying it becomes a rootsicle if part of the root is coated in a secondary mineral deposit.

If a rootsicle can only be a speleothem, there is also the dilemma of, can it be a rootsicle if outside a cave? A cave is typically defined in conventional lay dictionaries as being "a natural void in the ground, specifically a space large enough for a human to enter", whereas in most speleological literature the definition also includes "must have a dark zone". So, if a cave fits the description in speleological literature and has numerous rootsicles from the back of the cave (dark zone) right through to the drip line at the entrance (daylight), is there a point where they should not be considered a rootsicle? An overhang (large enough for a human to enter) under a waterfall can be considered a cave according to the lay dictionary definition, but not according to a speleological definition. If there are roots coated in a secondary mineral deposit under the drip line (Figure 10), are they considered to be in a cave or not? The answer appears to depend on how pedantic one is in interpreting and applying the definition of a cave.

Then there is the situation when a mixture of roots and vegetation is coated in a secondary deposit above ground (outside the cave environment) (Figure 13). Should these still be called 'rootsicles' even though they cannot be considered 'speleothems'? The term "speleothem" as introduced by Moore (1952), is derived from the Greek words *spēlaion* 'cave' + *théma* 'deposit', which specifically defines speleothems as secondary deposits formed in a cave.

Even in their acclaimed book *Cave Minerals of the World*, Hill and Forti (1997), leave room for interpretation between their descriptions of rootsicles on page 224 and their definition on page 363. Their description suggests that the root becomes covered with $CaCO_3$ so that it, "may be obscured or decayed, leaving only a calcium carbonate cast of the root", while their definition says the root becomes calcified. Since the term rootsicle is a 'generic term' for roots covered in a secondary mineral deposit (typically calcite), it makes sense that similar occurrences above ground should be called the same thing, however above ground they can't be considered a speleothem. This would also align with the generic terms 'stalactite' and 'stalagmite', which are often used to describe the shape of a secondary mineral deposit or structure in non-cave locations such as on cliff faces, and hence which are not necessarily speleothems even though speleothems are the most common form of stalactite.

Bastian (2014) argues that 'rootsicles' should be called 'arborites'. His reasoning is that, "speleothems generally have the suffix '-ite', which is normal for mineral materials". However, this argument is undermined by the fact that calcified tree roots very often form a 'column' stretching from ceiling to floor, yet a 'column' in a cave is a speleothem. Other secondary cave deposits such as flowstone, rimstone dam, cave pearls, dog tooth spar and many others similarly lack any '-ite' at the end of their name. Also, the term 'arborite' implies trees, from the Latin *arbor* 'tree'. The roots in caves may be from trees, but they may also be those of bushes, shrubs or even grass. In 1948, the word Arborite became a registered company name with manufacturing and distribution around the world, for a large product range of high-pressure urea formaldehyde laminates plus other products commonly referred to as arborite. So, for clarity the term 'rootsicle' is the best generic term for a root coated in a mineral deposit.

Conclusion

Given there are so many possible variables associated with roots that have been partly or completely coated by a secondary mineral, inside and outside caves, it would be logical to use the generic term "rootsicle", without defining the amount or thickness of mineral coating. If it occurs in a cave then it can be classed as a speleothem but if it occurs outside then it is not a speleothem. If a root grows through or around a pre-existing speleothem or above-ground secondary mineral deposit, it is not a rootsicle, unless it has a subsequent layer of secondary mineral deposited around the actual root.

Original definition (Smith 1999)

ROOTSICLE. *n*. roots of trees or plants which grow into a cave cavity and become calcified. The roots and speleothem comprising the rootsicle.

Proposed new definition

ROOTSICLE. *n*. roots of trees or plants which have become partly or fully coated by a secondary mineral deposit, above or below ground. The roots (or remains of roots) and mineral deposit comprising the rootsicle. If the root completely decays then the remaining secondary mineral skeleton or part thereof, is still considered to be a rootsicle.

If the rootsicle occurs inside a cave, then the mineral deposit is considered to be a speleothem, but if outside a cave it is not. If the growth of the speleothem (or above ground secondary mineral deposit) precedes the root, then it is not a rootsicle (refer Table 1).

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Drainage derangement at Howitzer Hill in the Trowutta-Sumac Karst, north-west Tasmania

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Abstract

The Trowutta-Sumac karst is the most extensively karstified dolomite terrain in northwest Tasmania. Here, exposed surface dolomite karst covers an area of more than 140 km^2 within a triangular-shaped 380 km^2 region. In the region Precambrian dolostone units of the Black River Group crop out either as extensive hills or as karst pockets and interstratal karst lying adjacent to or beneath Cambrian and Tertiary volcanic rocks. To date studies on this karst system have been limited, except for those around well-known locations. Elsewhere hundreds of sinkholes pockmark the region; in some locations they form complex polygonal karst terrain. The subsurface hydrology of the area is unknown. Although karst stream sinks and small cave systems have been located, the abundance of sinkholes indicates that regional karst aquifers may exist, but stream resurgences are rare and those that have been documented are associated with small meander cut-off caves on large streams with clear direct surface connections between stream sinks and resurgences, notably at Julius River and Lamprey Creek. Recent field investigations by the authors have documented an intensely karstified area in the eastern Howitzer Creek catchment north of the Arthur River. Here, the informally named Howitzer Hill presents a complex polygonal karst landscape associated with karstic subsurface flow. This study describes the Howitzer Hill karst, the landforms present, dye tracing methodology and results obtained.

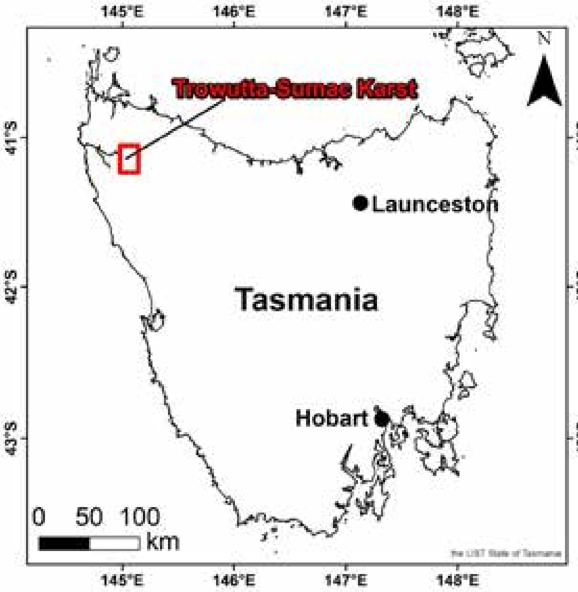
Introduction

The study was focused on an area covering 56 ha centred on the significantly karstified informally named Howitzer Hill rising 40-80 m above the surrounding valleys to a maximum altitude of about 140 m a.s.l., approximately 1 km north of the Arthur River-Rapid River confluence (Figure 1). The hill is underlain by Precambrian Black River Dolostone, a mixture of chert, siltstone and minor dolomite mapped as Pbdc on the Holder geological map sheet (Seymour and Everard 1999). The area forms a small subsection of the larger Trowutta-Sumac Karst which spans an area of approximately 380 km^2 between Nabageena in the north and the Horton River in the south, including the Julius River Caves, the karst sinkhole forming Lake Chisholm, the cenotes and caves at Trowutta Arch (Kiernan and others 1991; Kiernan 1995; Sharples 1997) and the Lamprey Creek Caves (Slee 2019). The Trowutta-Sumac Karst is a registered geoconservation site on the Tasmanian Geoconservation Database available on The List Tasmania website (https://maps.thelist.tas.gov.au/listmap/app/list/map).

Karst surveys

The study area (Figure 1) lies entirely in State Forest managed by Sustainable Timber Tasmania. There is evidence of past forestry operations dating around the 1960-70s over the entire study site. An old forestry road winds between sinkholes on the karstified Howitzer Hill. In 2016 work by foresters and the FPA Earth Scientist identified many large cone-shaped sinkholes up to 45 m wide and 15 m deep (Figure 2), making much of the hill unsuitable for harvest.

Further work by the senior author identified small caves and several streamsinks and resurgences in the area (Figure 2). To the northeast of Howitzer Hill is a large impenetrable streamsink with two entrances (Maryanna 1 and 2) named after the nearby forestry road, into which an intermittent class 4 stream (a stream having a catchment of <50 ha as defined in the Forest Practices Code (FPA 2020)) informally named Eastern Creek, sinks at the base of a steep backwall within a large doline. West of the Maryanna 1 and 2 streamsinks, Maryanna 3 is a small impenetrable streamsink in a bedrock bluff within a large sinkhole north of Howitzer Hill.



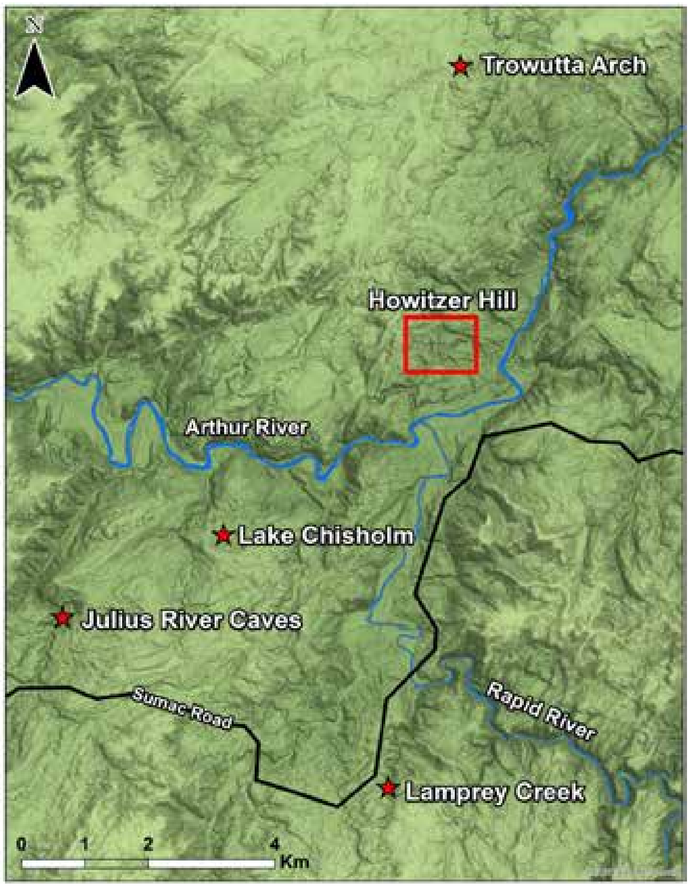


Figure 1. Location of the Trowutta-Sumac Karst and the study site.

Further investigations found that the eastern branch of Howitzer Creek, a large perennially-flowing class 4 stream, flows into a streamsink descending into a collapsed cave passage to the west of Howitzer Hill (Figure 2 and Figure 3). The large basin with an area of approximately 21 ha and an uneven bottom associated with this streamsink fits the definition of a *uvala*, an intermediate form of large karstic depression significantly larger than a sinkhole but smaller than flat-floored regional scale poljes (Kiernan 1995; Sauro 2019). The western face of Howitzer Hill on the eastern margin of the basin is composed of pinnacle dolomite karst and at least one tiny cave is present along the hillslope north of the Howitzer Creek streamsink and blind valley (Figure 2). Large dry valleys entrenched in bedrock are present downstream of both the Maryanna 1 and 2 streamsinks and the large depression on the eastern branch of Howitzer Creek. Subsequently three resurgences (Howitzer 1-3), one of which (Howitzer 1) forms a skylight in a continuing passage (Figures 2 and 4), were identified in a blind valley on the south-east side of the hill. These resurgences contribute water to the informally named Outflow Creek (Figures 2 and 6). A further stream rises from an impenetrable cave on the eastern margin of Howitzer Hill. We speculated that the water from the Howitzer Creek streamsink west of the hill was connected with one or more of the Howitzer 1-3 resurgences.

Experimental work

The aim of the experimental study was to establish whether a connection exists between the Howitzer streamsink and one or more of the Howitzer resurgences. On 25 May 2021, before dye injection, three activated carbon receiver bags were suspended in streams. One was suspended above the dye injection point on the eastern branch of Howitzer Creek (Figure 2) to confirm no prior presence of dye in the stream. Two were hung in the Howitzer 1 and Howitzer 3 resurgences. (We hung bags in both resurgences as they lie 50 m apart on differing valley slopes and therefore there was a need to test whether either or both these streams were connected with the Howitzer streamsink.) The Howitzer 2 resurgence was not dye-traced owing to its valley floor location 35 m downslope of the Howitzer 1 resurgence with which it is very likely to be directly connected. At 16:00 on 25 May, 425 grams of Rhodamine dye were injected (Figure 5) into the Howitzer streamsink (inflow). Over the following 24 hours, 28.8 mm of rain was recorded at the nearest weather station at Luncheon Hill (Forestry 91259), 6 km to the south-east (BOM 2021). Sample bags were picked up from all three sites on the morning of 27 May 2021. Charcoal bags were shipped to Ozark Underground Laboratory, Missouri, for dye analysis.

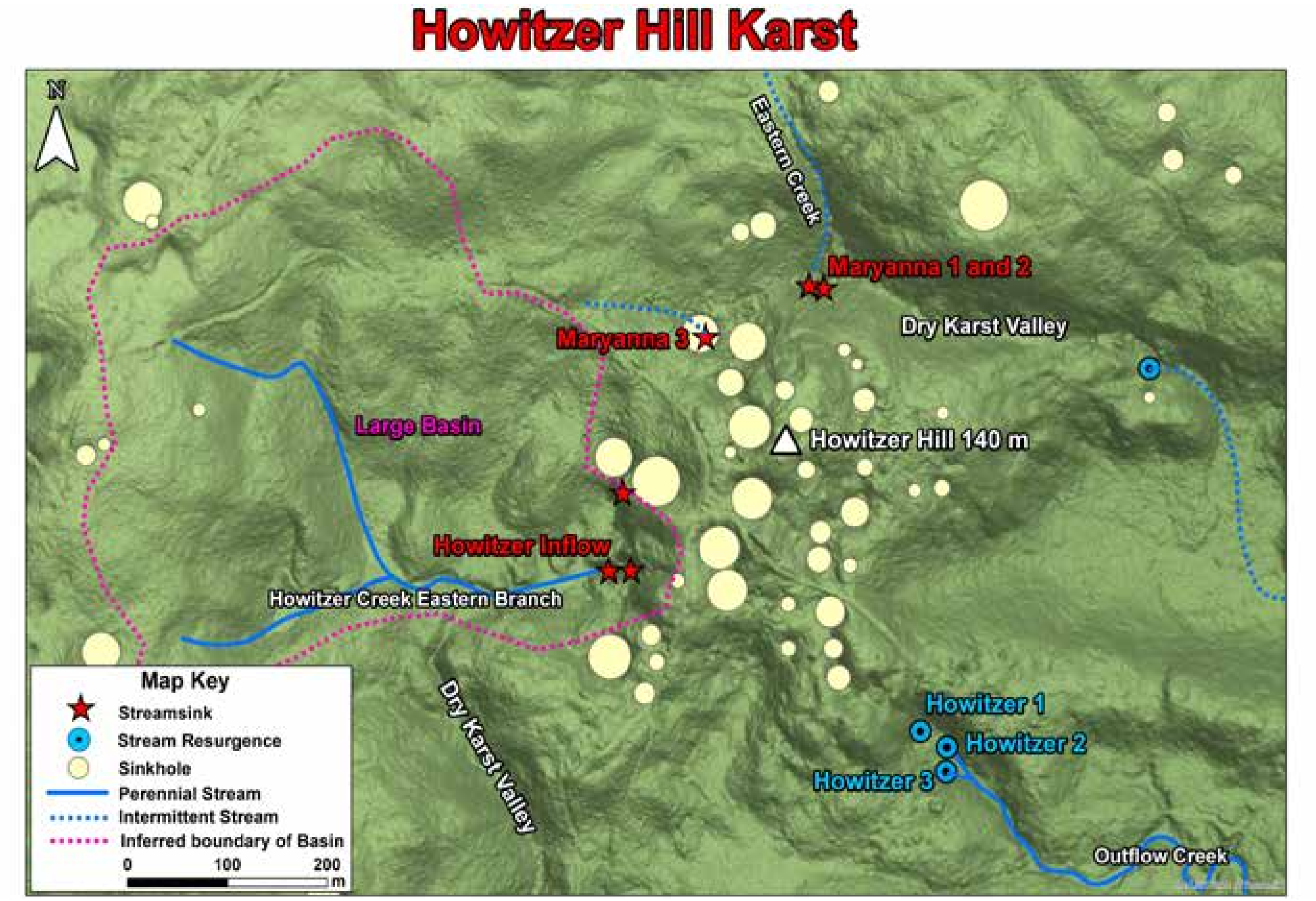


Figure 2. Major features of the Howitzer Hill Karst mapped during surveys.

Results and Discussion

The results of the Rhodamine dye-tracing experiment are summarised in Table 1. The Howitzer Creek sample above the streamsink and dye injection point showed no trace of Rhodamine dye, as expected given the remote location of the Howitzer Creek catchment. Somewhat unexpectedly, both the Howitzer 1 and 3 samples returned strong positive values at 567 nm, producing concentrations of 3800 and 3210 parts per billion for Rhodamine dye. These results indicate that water reaching both resurgences was at least partially sourced from the Howitzer streamsink (Figure 6). The lower Rhodamine concentration in the Howitzer 3 charcoal than in the Howitzer 1 charcoal may indicate that the water source of the Howitzer 3 stream is more diffuse than that of Howitzer 1.

Four named stream-sinks lie to the north of a heavily karstified hill in the upper reaches of Howitzer Creek and a neighbouring un-named valley to the east, informally named Eastern Creek. The largest streamsink is associated with karstic capture of the eastern branch of Howitzer Creek, which sinks underground in a blind valley 20 m west of a dolomite backwall with collapsed boulders and small cave entrances at its base. The proven underground drainage between the Howitzer streamsink and the Howitzer 1 resurgence (skylight) is 345 m, or 380 m if this skylight is ignored and the water at Howitzer 1 flows onwards to Howitzer 2. The traced distance to the Howitzer 3 resurgence is approximately 375 m. The fact that both resurgences contained water traced to the Howitzer streamsink but lie 50 m apart on different sides of the outflow valley implies a multi-passage anabranching cave rather than a single passage.

Table 1: Rhodamine tracer results

OUL Number	Station Name	Date / Time Placed	Date / Time Collected	Rhodamine WT Results	
				Peak (nm)	Conc. (ppb)
F2684	**Howitzer 1**	25/05/21 13:15	27/05/21 9:15	567.2	3,800
F2685	**Howitzer 3**	25/05/21 13:30	27/05/21 9:40	567	3,210
F2686	**Howitzer Inflow**	25/05/21 16:00	27/05/21 10:30	ND	

Figure 3. Top: View looking east down the blind valley towards the Howitzer streamsink lying under the log to the left of the image (circled), Yellow arrow indicates location of the caves in lower image.

Bottom: East of the streamsink is a steep valley backwall approximately 15 m tall featuring dolomite bluffs, collapse boulders and two or more small cave entrances only one of which is penetrable for a short distance.

Figure 4. View of the two small cave passages extending from the downstream edge of the Howitzer 1 skylight. Passage dimensions around 0.5-1 m across.

Figure 5. Injecting the tracer into the east branch of Howitzer Creek on day 1 during heavy rain.

The streams entering Maryanna 1-3 streamsinks on the north-eastern slopes of Howitzer Hill were not dye traced due to their low flows but are assumed to be associated with the Howitzer 1-3 resurgences (Figure 6). This assumption is supported by the absence of other resurgences in the area and by the chain of large sinkholes running approximately north to south across Howitzer Hill towards the Howitzer 1 resurgence (Figure 2). If the assumed flowpaths are correct, they imply further karstic drainage extending underground for ~445 m (Figure 6). However, the minor stream resurgence associated with the small cave at the eastern extremity of Howitzer Hill (Figure 2) could conceivably relate to one of more of the Maryanna streamsinks.

The Howitzer karst is of limited significance in the Tasmanian context owing to the caves present being impenetrable and small, and the presence of caves and karst of more impressive dimensions that occur in dolomite karst landscapes elsewhere in Tasmania, notably at Hastings (Houshold and Bradley 1994) and Mt Anne (Kiernan 1995) in the state's south. However, Howitzer Hill is the third site in the Trowutta-Sumac karst in which

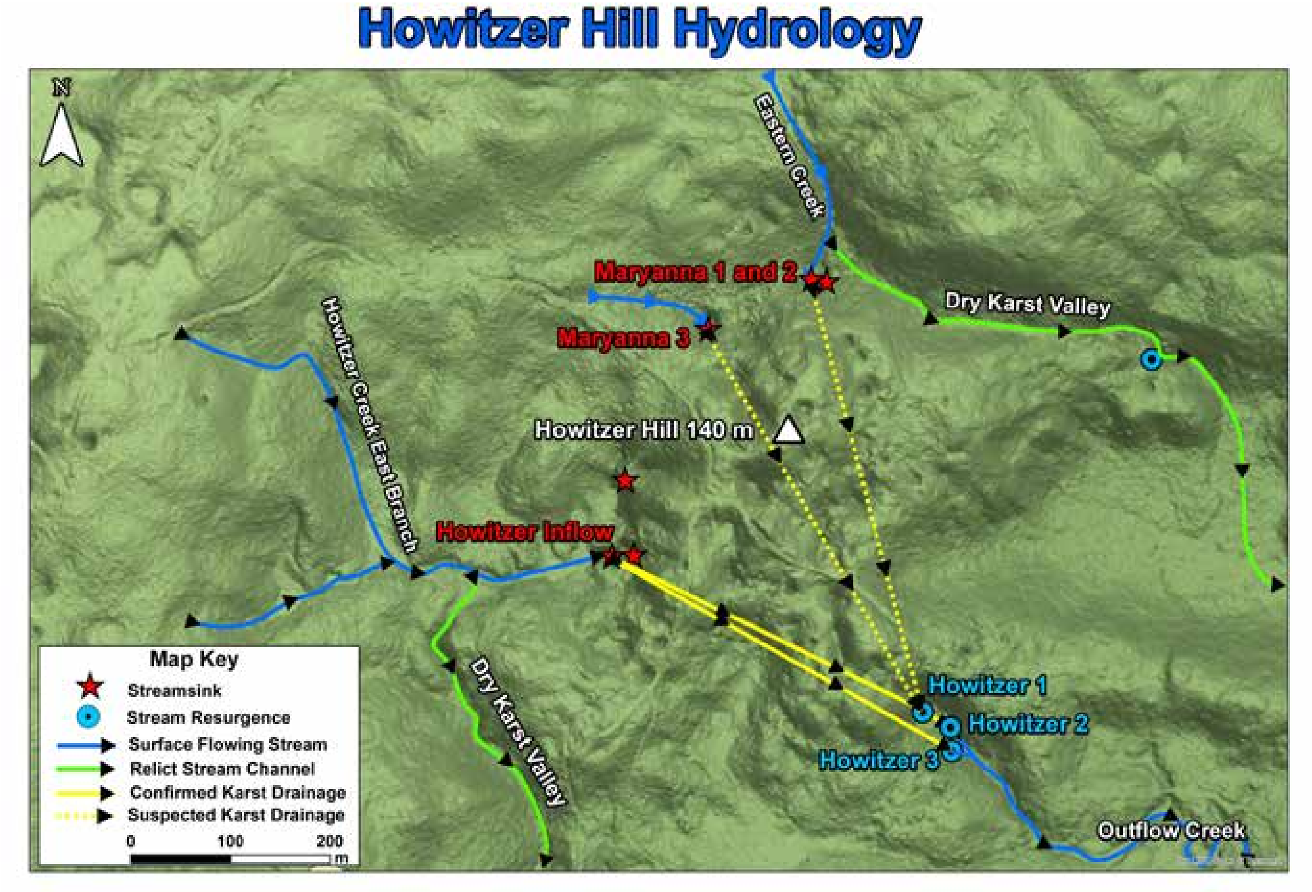


Figure 6. Hydrology at Howitzer Hill showing relict stream channels and underground flow paths.

underground drainage has been confirmed from streamsink to resurgence. The other sites are Julius River cave and Lamprey Creek cave, which have subterranean flow paths of ~150 m and ~50 m respectively, in contrast to the 345 m and 375 m recorded in this study. Of interest is that both the eastern branch of Howitzer Creek and Eastern Creek sink underground into blind valleys leaving dry deeply entrenched karst valleys downslope of the streamsinks. In the case of the eastern branch of Howitzer Creek the stream flow has been captured and entrenched into its new drainage pathway prior to sinking at the Howitzer streamsink, leaving a dry south-trending relict karst valley perched above the channel of Howitzer Creek in a clear example of stream capture by a karst system, forming a large, enclosed basin (Figures 2 and 6). When capture occurred is unknown, however the deep and narrow nature of the dry karst valley suggests thousands of years of fluvial incision prior to capture.

The area in the vicinity of Howitzer Hill presents significant karst management issues relating to the numerous sinkholes and proven subsurface drainage. These present challenges for forestry operations and prescriptions in line with the Forest Practices Code (2020) and Forest Sinkhole Guidelines (McIntosh 2014) will need to be implemented. The results of this study will help define the future harvest boundary and highlight the careful management required for both the Howitzer Creek and Eastern Creek catchments. Given the relatively undocumented nature of large extents of the karst at Trowutta-Sumac, further examples of complex karst development and underground drainage can be expected, although the likelihood of finding large undocumented caves appears to be limited given the scarcity of massive and contiguous, relatively pure non-silicified dolomite lenses in the area.

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