Limestone Coast 2004

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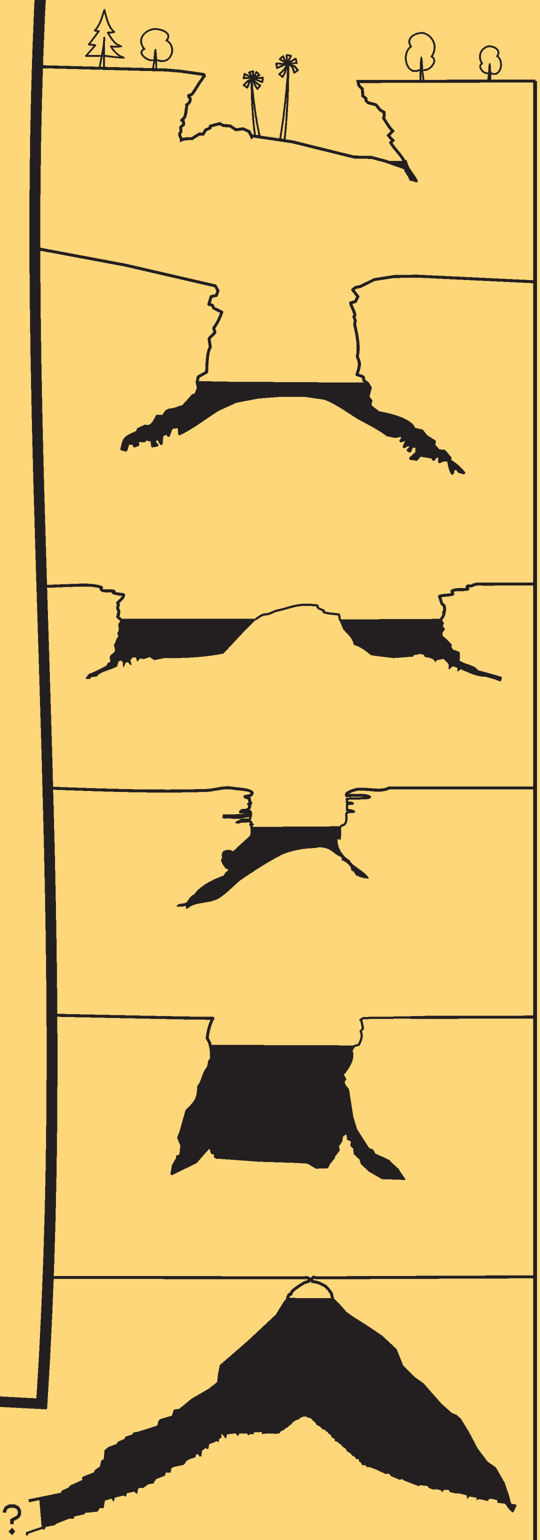
FIELD GUIDEBOOK

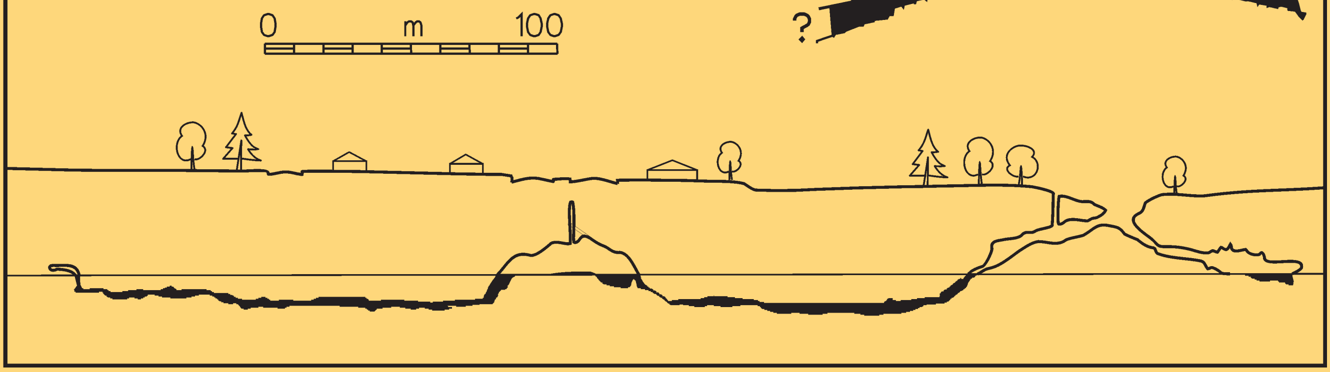
to Karst and Volcanic Pseudokarst Features of

THE LIMESTONE COAST

Southeast South Australia
and
Western Victoria

Edited by
Ken Grimes





Field Guidebook

to Karst and Volcanic Pseudokarst fatures of

The Limestone Coast

of Southeast South Australia and Western Victoria

Edited by

Ken G. Grimes

with contributions by

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CONTENTS

PREFACE

This area of "soft rock" caves developed on youthful, weakly consolidated limestones is quite different from the "hard rock" indurated Palaeozoic or older limestone karsts of eastern and northern Australia. The caves have an entirely different quality, characterised by soft walls, cap rock effects, solution pipes, extensive low horizontal phreatic mazes, abundant collapse modification and extensive large flooded systems. The cenotes are unique within Australia. In addition to karst caves the Western District Volcanic Province of the Victorian part of the region has many lava tubes and other volcanic caves.

The first edition of this Guidebook was compiled by Ken Grimes & Susan White for a Karst Studies Seminar at Naracoorte in 1996. Later revised and expanded versions have been produced for other conferences and the authorship has expanded with each edition.

The guide is in four parts. An introduction describes the geology and karst features of the Gambier Karst Region as a whole. That is followed by a discussion of the volcanic caves and associated features in western Victoria. The third part refers to sites in the Naracoorte - Mt Gambier area, South Australia. The final part describes karst and volcanic sites in western Victoria.

Note that the conference field trips do not stop at all the sites described herein; we have deliberately described some additional sites so as to cater for people who wish to visit these at other times (we are great believers in the continuing usefulness of field guides).

Most of the sites described here are on private land or in government reserves for which permission should be sought before entering. Entry to caves in South Australian National Parks requires a permit obtained from the Department for Environment and Heritage, South Australia (DEHSA) at least one month beforehand. Diving in the cenotes and springs in South Australia requires a permit from DEHSA at Mount Gambier, and divers must show that they are suitably qualified. For Victorian caves permits are needed from Parks Victoria for all caves apart from those that are open to the general public. A requisite of entry permits is that you have suitable experience and equipment.

In accordance with the policy of the Australian Speleological Federation (ASF) we cannot print detailed location information concerning cave sites. Accredited scientists or speleologists can obtain access details from the Victorian Speleological Association (VSA) or the Cave Exploration Group, South Australia (CEGSA), or from the authors during the seminar.

ACKNOWLEDGMENTS

This field guide draws heavily from previous reports and field-guides. Contributors to the present edition are listed on the title page. Most importantly, this guide could not have been written without the extensive exploration, mapping and documentation efforts of numerous CEGSA, VSA and other cavers over the last 50 years.

THE GAMBIER KARST PROVINCE

Ken Grimes, Susan White, Kevin Mott, Mia Thurgate.

The 'soft-rock' karst region of south-east South Australia and western Victoria corresponds to a large extent with the Tertiary Gambier Basin (Smith & others, 1995), although caves in Quaternary dune limestone extend northwest across the adjoining Murray basin. The region is generally low-lying and flat, with Quaternary dune ridges providing the most common relief. Locally, Quaternary volcanoes form unexpected hills. Many of the inter-dune flats were waterlogged for much of each year but have now been artificially drained. The Glenelg River is incised into the limestone to form a major gorge, and some rivers further east in Victoria are also incised. Coastal cliffs of limestone occur in many places, especially in the far east.

The karst is developed on poorly consolidated Tertiary and Quaternary limestones. It is also influenced by the thin younger sediments that overlie the limestones. Most of the karst is covered by soil or thin sediments but some areas of bare karst occur southwest of Mount Gambier.

The climate of the western region is a 'Mediterranean' one with wet winters and cool dry summers. Annual rainfall increases towards the coast and from west to east; ranging from 550 mm in the Naracoorte area, through 850mm at Portland to nearly 1000mm at Port Campbell at the eastern end of the karst region.

During the Quaternary the present type of climate would have alternated with colder, drier and windier climates during the peaks of the glacial stages (Williams, 2001). The windy periods would be responsible for lunette ridges bordering some lakes, and possibly for deflation of some of the enigmatic shallow hollows in the old coastal plains. Much of the region would have been intermittently flooded by the sea during the interglacial periods of the early Quaternary.

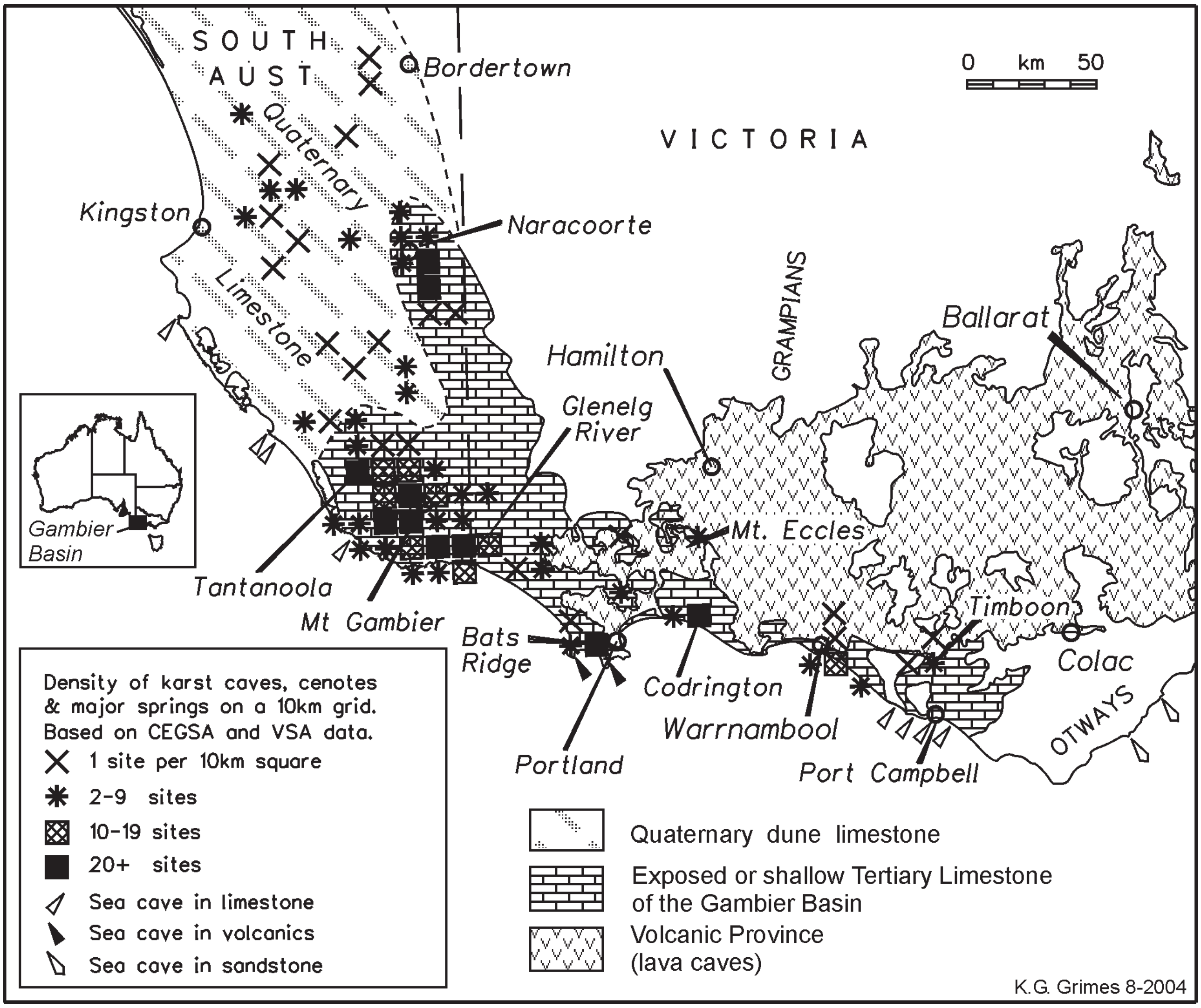


Figure 1.1: Distribution of limestone caves in the Gambier Karst Province.

GEOLOGY

See Marker (1975), Grimes (1994) and White (1994, 2000a) for earlier studies of the karst geology. The limestones fall into two groups, both relatively young: the Tertiary (Oligocene to Miocene) limestones are the Gambier Limestone in South Australia and westernmost Victoria and the Port Campbell Limestone further east (Alley & Lindsay, 1995; Holdgate & Gallagher, 2003); and the younger Quaternary calcareous dune limestones of the Bridgewater Formation and associated calcareous marine and coastal sediments of the inter-dune flats (Belperio, 1995; Cupper & others, 2003).

The ***Tertiary limestones*** were deposited in a shallow sea that flooded the region in the Oligocene and early Miocene (about 15-35 million years ago). Figure 1.1 shows the northern limit of these limestones for the purposes of modern cave development - they continue further to the north in South Australia, but with a progressively thicker cover of non-calcareous sediments that inhibits karst development. In Victoria the Tertiary limestones extend northwards beneath parts of the late Cainozoic volcanic province, but again the karst potential is limited by the cover.

The limestone is relatively soft in the subsurface but develops case hardening and calcrete cappings on exposure. It is locally well jointed with a dominant north-west trend in South Australia, but a north-east trend in the Port Campbell area. The influence of both the vertical jointing and the horizontal bedding are exhibited in the cave passage forms (e.g. Figure 3.16). The Tertiary limestones are similar to those in the Nullarbor, and there are similarities in the cave styles also, though here we have none of the huge passage systems that occur in the Nullarbor. The Kanawinka Fault and its related scarp have a major influence on the hydrology and karst development in the Naracoorte area (Figures 1.2 & 1.4).

In the Bool Region of South Australia (Figure 1.8) the Gambier Limestone is mantled by ***late Pliocene marine*** calcareous quartz sands (the Coomandook Formation) up to 17 m thick (Figure 1.2, Cook and others, 1977; Belperio, 1995). Towards the Victorian border these quartz sands grade into shelly calcareous sands and muds of the Pliocene to early Pleistocene Werrikoo Limestone.

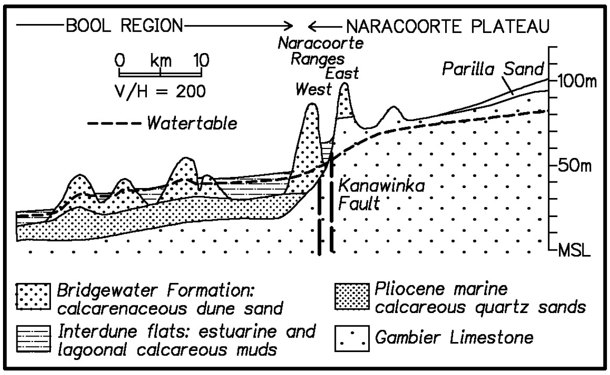


Figure 1.2: Cross-section in the Naracoorte area showing watertable.

The ***Quaternary dune limestones*** are a series of calcareous coastal dunes along old shorelines that developed during an overall regression of the sea during the Quaternary. In South Australia they form linear north-west trending ranges (Figure 1.8), which extend northwards beyond the limit of the Gambier Basin to overlie the sediments of the Murray Basin. In Victoria the distribution of the dune limestones is less regular, and east of Portland they are mainly restricted to a narrow belt along the modern coast, though some older ridges (mostly without karst) occur further inland.

These Quaternary limestones are similar to those on Kangaroo Island, the Eyre Peninsula, and the coastal areas of West Australia. The dune ridges are now partly-consolidated calcarenites and contain syngenetic karst features in which caves and solution pipes developed as the sands were being cemented into a limestone (see later). The limestone has well-developed dune cross-bedding with shallow-angle medium to thin bedding in

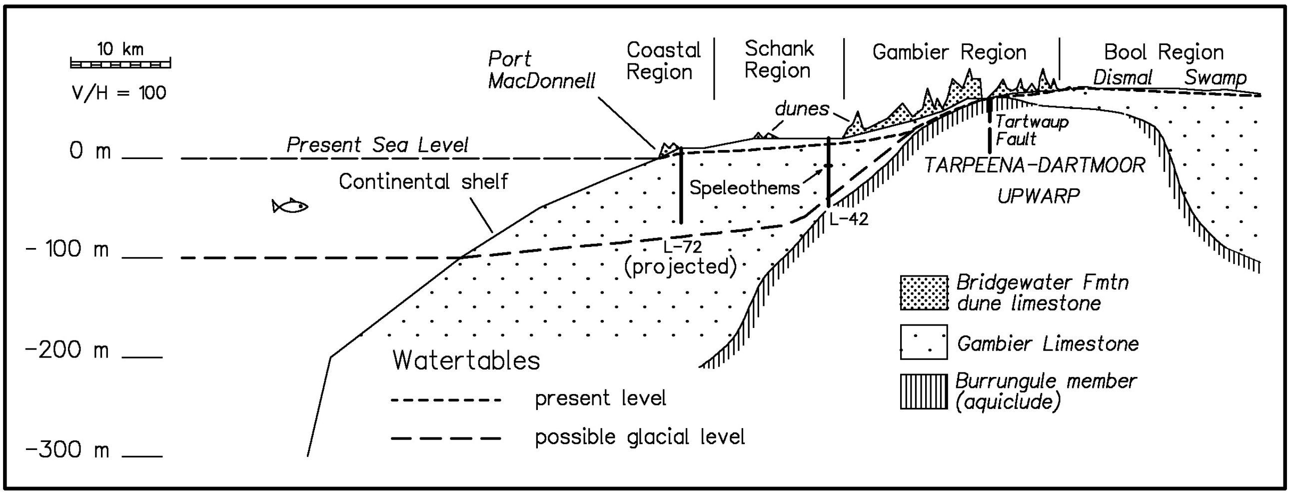


Figure 1.3: Cross-section in the Mount Gambier area, showing present and past watertables.

places. It shows little or no jointing. Some caves are developed mainly in the underlying Tertiary limestones but have their entrances in the overlying dune limestones. Some younger, reworked, dunes are dominantly quartzose.

Between the dune ridges there are extensive swampy plains. These are ***old coastal flats*** and comprise estuarine to lacustrine limestones, dolomites, marls and clays up to 13 m thick (Figure 1.2). These plains have many shallow swampy depressions of complex origin (Figure 1.7).

Pliocene to Holocene basaltic volcanics form the extensive Western District Volcanic Province of Victoria (Figure 2.1, Price & others, 2003), and some isolated volcanoes of this province occur in South Australia (Sheard, 1978). The southern margin of the volcanic area overlies the Tertiary limestones. Lava caves are associated with several of the volcanoes in Victoria (see later).

HYDROLOGY

The Tertiary Limestone forms a major aquifer in the region. The Gambier Limestone has been referred to as one of the best aquifers in Australia (Holmes & Waterhouse, 1983, Stadter, 1999). Much of the ground water from the Mount Gambier area is discharged in major springs along the southern coast, and divers have entered caves below some of these.

At the regional scale the Gambier Karst shows many characteristics of a porous aquifer; for example, it has a continuous, well-defined watertable and the springs show none of the "flashy" behaviour of conduit-driven karst aquifers (Holmes & Waterhouse, 1983, Stadter, 1999). On the other hand the transmissivity in places is much higher than one would expect from the porosity of the limestone alone (Telfer, 1993, Emmit & Telfer, 1994), and at the local scale we see the typical irregular and unpredictable characteristics of conduit aquifers (Emmit & Telfer, 1994). The aquifer is unconfined, deep, and open (uncapped). Most water input comes from rain and normally enters the aquifer diffusely through the porous surface sands, but some point input occurs via "runaway holes" in dolines (Herczeg & others, 1997). Some water enters from the allogenic Glenelg River, and further east in Victoria there are other allogenic rivers that rise outside the karst area but cross it on the way to the sea.

In South Australia there is a well-developed water table. This has a gentle slope towards the coast, with two zones of steeper gradients (Figure 1.4, Holmes & Waterhouse, 1983). One of these is along the line of the Kanawinka Escarpment (Figure 1.2), and the other passes north-west through Mount Gambier (Figure 1.3). Marker (1975) noted a correlation between high cave densities and the zones of steep gradients, and also with areas of greater than normal depth to the water table.

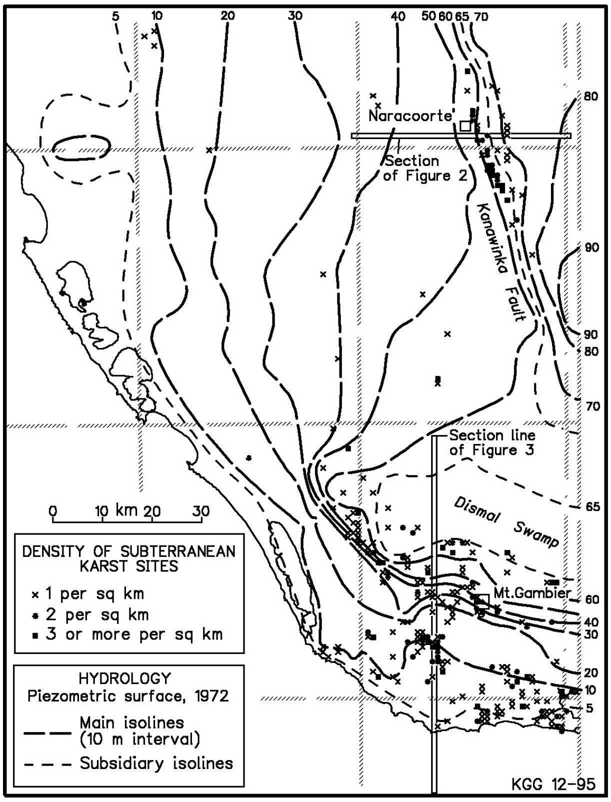


Figure 1.4: Ground water-table contours, after Holmes & Waterhouse (1983).

During glacial periods the lowering of sea levels would have caused a significant drop in the ground water levels in the coastal parts of the region (Figure 1.3) - as demonstrated by submerged speleothems and mudcracks in some South Australian caves. There is also evidence for recent drops in the water table. For example, stromatolites are found up to 2 m above the present water level in the cenotes, and there are historical records of higher levels in some cenotes. Fluctuations of over a metre have been recorded in association with land clearance (a rise) and the growth of exotic pine plantations (a drop).

KARST LANDFORMS

Syngenetic Karst and Soft Rock Karst

In the calcareous Quaternary dunes some karst features are syngenetic, in that they have developed at the same time as the sand was being cemented into a rock (Jennings, 1968; White, 1994, 2000a, Grimes, 2002). Unconsolidated calcareous sand is converted to limestone gradually by solution and redeposition of calcium carbonate by percolating water. The downward percolating water also dissolves vertical solution pipes, and simultaneously cements the surrounding sand. At the same time, enhanced mixing corrosion occurs where percolation water meets the water table - typically at the level of an adjacent swampy plain.

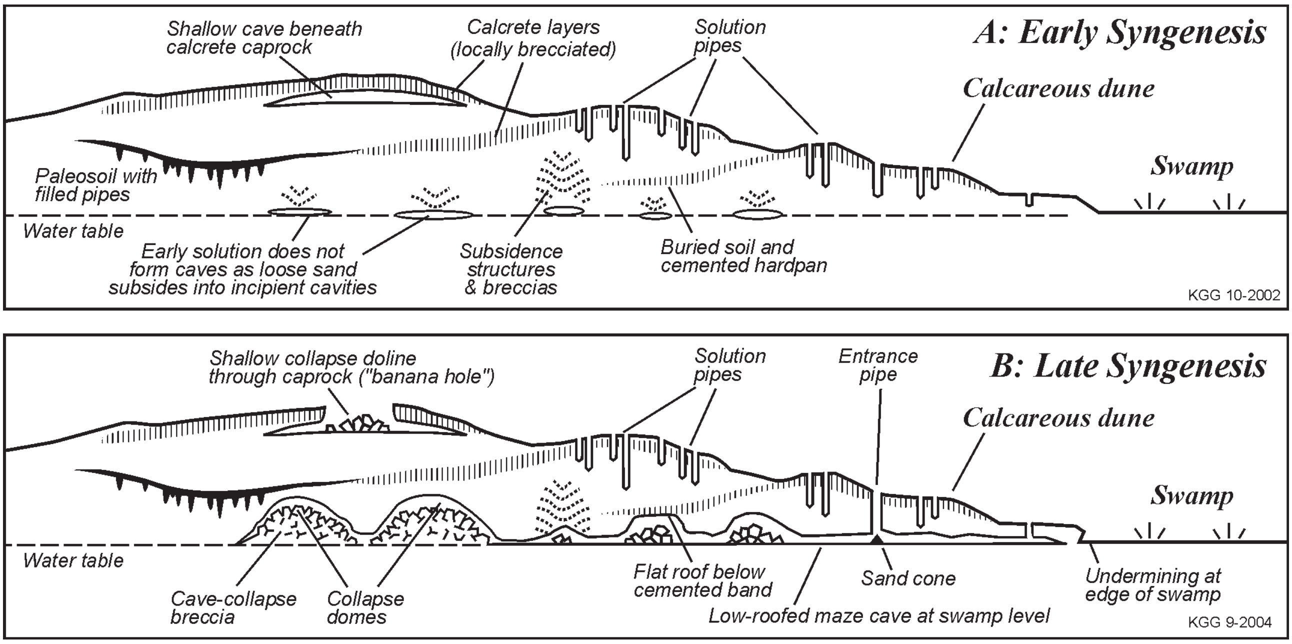


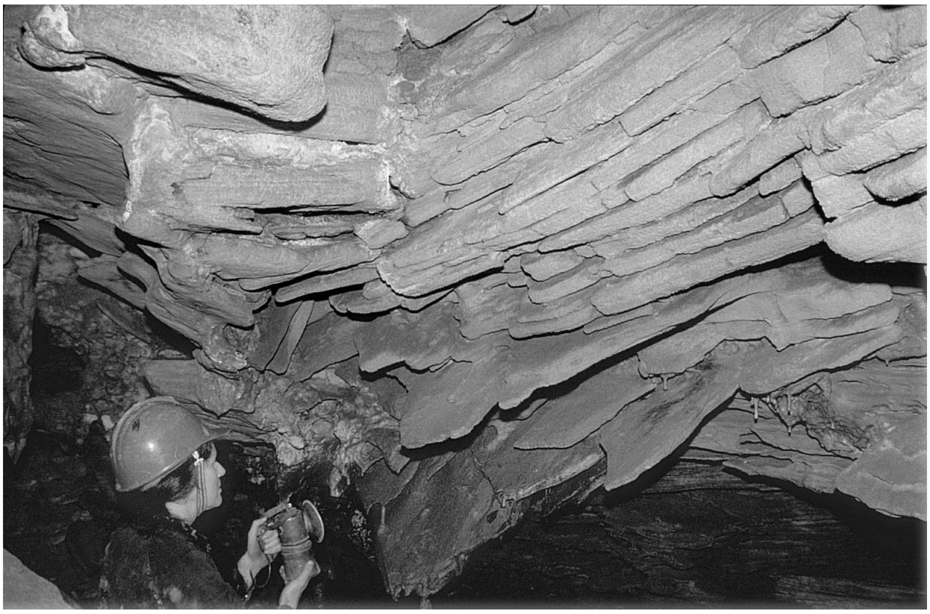
Figure 1.5: Features of syngenetic karst developed on a calcareous dunefield next to a swamp.

In the early stages of dissolution (**Early Syngenesis**, Figure 1.5a) the loose sand subsides at once into any incipient cavities, possibly forming soft-sediment deformation structures. Subsidence dolines may form without caves. An exception is that beneath the cap-rock, which appears to form quite early, some shallow caves may form. Once the bulk of the rock is sufficiently hardened to support a roof (**Late Syngenesis**, Figure 1.5b), caves can develop.

In the early stages, when the sea was present adjacent to the dune ridges, mixing between a freshwater lens and an underlying body of sea water could also have contributed to the development of caves. This is the “flank margin” model of Mylroie & others (2000, 2001) developed for the soft-rock caves of the Bahamas. However, in Australia this sea water effect may have less importance than the acidic swamp waters. Mylroe & others used the term “eogenetic karst” in a context which overlaps with “syngenetic” as used here (see Grimes, 2002).

The uniform matrix porosity, slow moving groundwater, and lack of joint control means that directed linear conduits seldom form. Instead, horizontal cave systems of low, wide, irregular, interconnected chambers and passages (Figures 3.9 & 3.13) form either in the zone of maximum solution at the water table, or by subsidence of loose material from beneath stable cap-rock layers. Flat cave ceilings are common: either marking the limit of solution at the top of the water table, or where collapse has reached the base of an indurated (cap-rock) zone.

The distinctive characteristics of syngenetic karst are the development of a cemented (calcreted) caprock near the surface, of vertical solution pipes, and of low, wide,



Subsidence structures exposed in a syngenetic cave formed in a flat-bedded beach sand.

The beds were weakly cemented into plates, but undermining by solution caused them to subside, rotate and slip against each other before being further cemented to form a more solid rock. Later solution of a stable cave passage has exposed the synclinal structure.

Caprock with irregular base formed in a dune limestone and small early-syngenetic caves in the soft sand beneath it.

horizontal maze caves either beneath the caprock or at the level of the adjoining swampy plains (Figures 1.5, 3.9 & 3.13). The poorly consolidated nature of the rock means that collapse plays a very important role from an early stage. Re-cemented breccias are seen in the walls of several of the dune limestone caves.

Solution pipes are one of the most distinctive features of syngenetic karst (Grimes, 2004). They are vertical cylindrical tubes, typically 0.5 to 1 m in diameter, which can penetrate down from the surface as far as 20 metres into the soft limestone. The pipes may be associated with roots (though which came first is debatable), and their margins may be a case-hardened cylinder. They occur as isolated features, or in clusters with spacings as close as a metre or less (e.g. Site V-2). Many of the caves are entered via such pipes.

Syngenetic karst development is typical of the Quaternary dune calcarenites; however, the Tertiary limestone is also a relatively soft porous limestone, and consequently it shows some of the features of syngenetic karst, in particular the development of solution pipes and calcreted caprocks.

Surface Karst

Surface karst features are extensive in some parts of the area, but inhibited by thick cover material in others. Features include uvalas, dry valleys, a variety of doline types, exposed subsoil karren and coastal phytokarst.

The most spectacular surface karst features are the ***collapse dolines***, especially those in the Mount Gambier area that extend below the water table to form ***cenotes***. These have formed by the collapse of large phreatic caverns. Figure 1.6 shows several typical cenotes and related features. In the Gambier region the watertable is lower and the collapse dolines are only partly flooded (e.g. Hells Hole & Umpherstons), however, further south in the Schank region, the water levels are higher and we find deep lakes (e.g. Little Blue Lake). The Shaft is an example of the situation before the roof of a large flooded collapse dome falls in to form a cenote - the present entrance is a small solution tube.

Fields of shallow dolines and uvalas are extensive in South Australia and extend into the westernmost part of Victoria (e.g. Figure 3.6). Isolated doline fields also occur further east. These shallow hollows generally have sandy or muddy floors and rarely have cave entrances.

Solution pipes, with a red soil fill, exposed at the contact between two dune units.

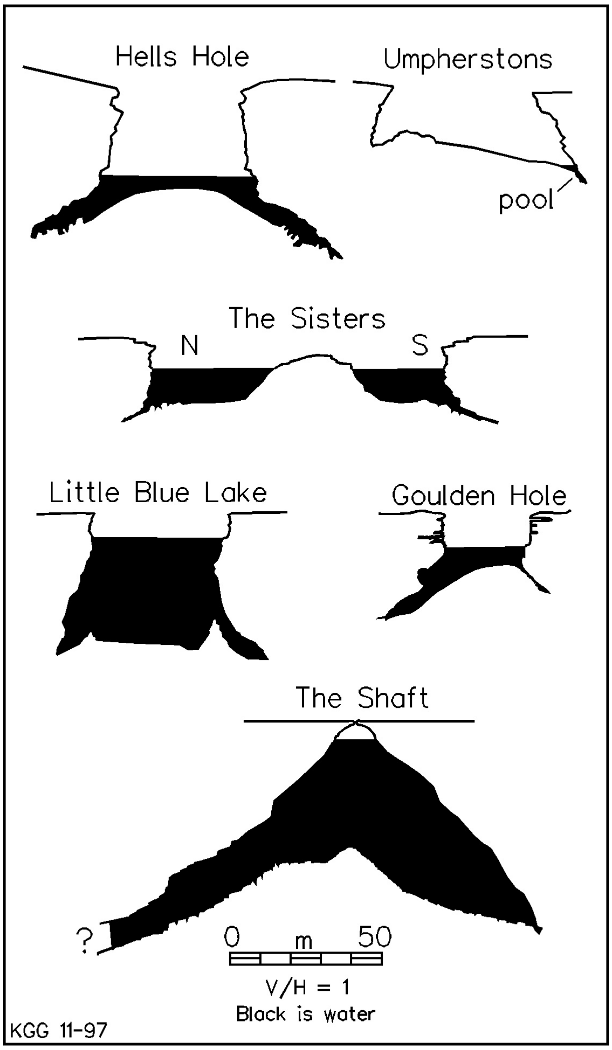
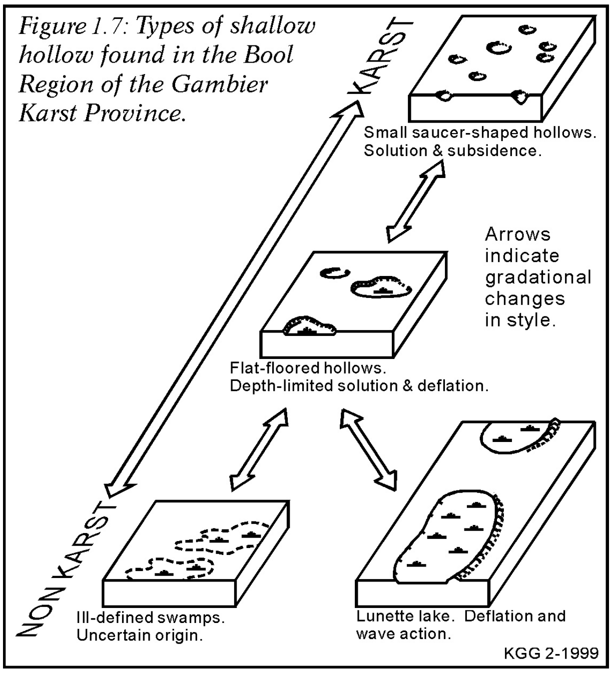


Figure 1.6: Cross-sections of typical cenotes. Black is water

In the Pleistocene coastal plains which form the Bool Region many of the shallow hollows are poly-genetic; with solution, deflation and other processes operating in parallel, or in sequence, or alternating in step with glacial - interglacial climatic fluctuations. The resulting hollows range from small well-defined saucers which appear to be true karst to large shallow lunette lakes which appear to owe their origin mainly to deflation and wave modification of primary coastal lagoons, though there is a possibility of subjacent karst influences in places (Figure 1.7). Some ill-defined hollows are irregular in plan or form chains which suggest the influence of the original drainage on the coastal plain.

In the dune fields many of the larger depressions are dune hollows, but these may be modified by karst solution to produce uvala-like features. The distinction between dune hollows and karst depressions is difficult to make in many areas. The 'hummocky' terrain north of Mount Gambier is a case in point (Site 7).

Figure 1.7: Types of shallow hollow found in the Bool Region of the Gambier Karst Province.

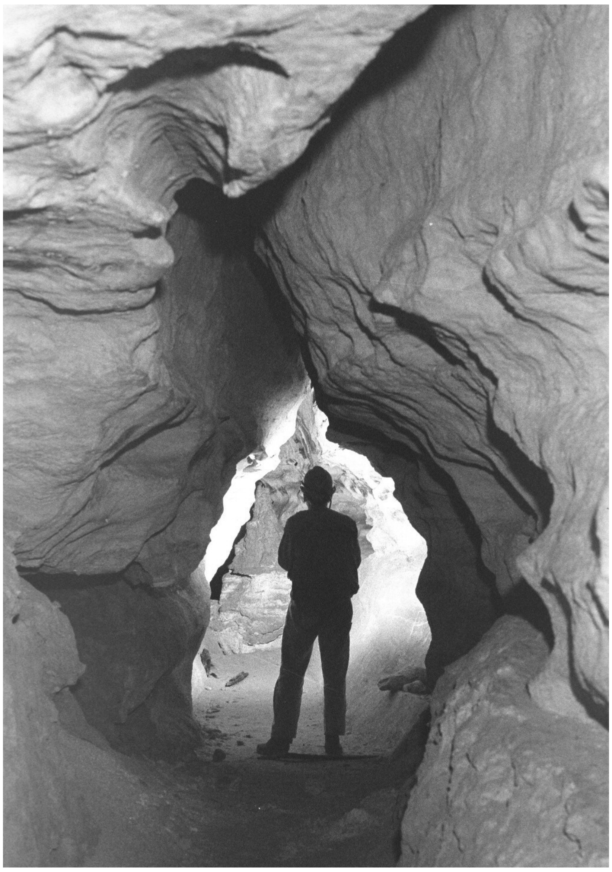


Caves

The caves in the Tertiary limestones are dominantly phreatic in origin, i.e. formed by slow moving ground water at and below the water table. The syngenetic caves are mainly epiphreatic - formed in the zone of mixing just below the water table; but vertical vadose seepage is responsible for the solution pipes. The limited local relief means that vadose stream flow features are extremely rare in South Australia, but some vadose streams occur in the caves beside the Glenelg River gorge in Victoria, and also further east in the Warrnambool and Timboon regions. Both joint and bedding plane control can be seen (Figures 3.3, 3.12 & 3.16), but solution at temporary water-table levels can make the latter hard to recognize in this area of flat bedded limestone. Many of the primary phreatic caverns and passages have been modified by breakdown to form collapse domes and rubble-filled passages (Figure 3.8).

Cave diving has demonstrated the existence of extensive underwater cave systems in South Australia. It appears that in the southern part of the Lower Southeast area most of the cave conduits may be below the present water table though these passages would have been partly or wholly drained during the low sea levels of the last glacial period (Figure 1.3).

Typical syngenetic cave forms in the dune limestones are shallow horizontal systems developed beneath the caprock or at the level of an adjoining swamp (Figure 1.5). They have multiple entrances (often via solution pipes or the collapse of the surface crust) and an irregular outline of chambers, pillars and short connecting passages, generally with a roof height less than one metre throughout (Figures 3.9 & 3.13). The walls are often difficult to see (and map) as they are out of reach where the roof slowly drops to floor level.



Joint-controlled phreatic passage in Tertiary limestone

The dune limestone caves differ from those in the Tertiary limestone in generally having smaller chambers and passages and only limited joint control.

Speleothems are generally not abundant – a consequence of the frequent collapse. However, there are some spectacular exceptions to that rule, and these include some extensive and very delicate forms; especially clusters of long straws and soft deposits of moonmilk. Moonmilk is composed of micro-crystalline carbonate needles with a high water content between the crystals and is generally rare in hardrock limestone areas in eastern Australia. Cave-coral is also well developed. Still pools may be partly covered by calcite rafts.

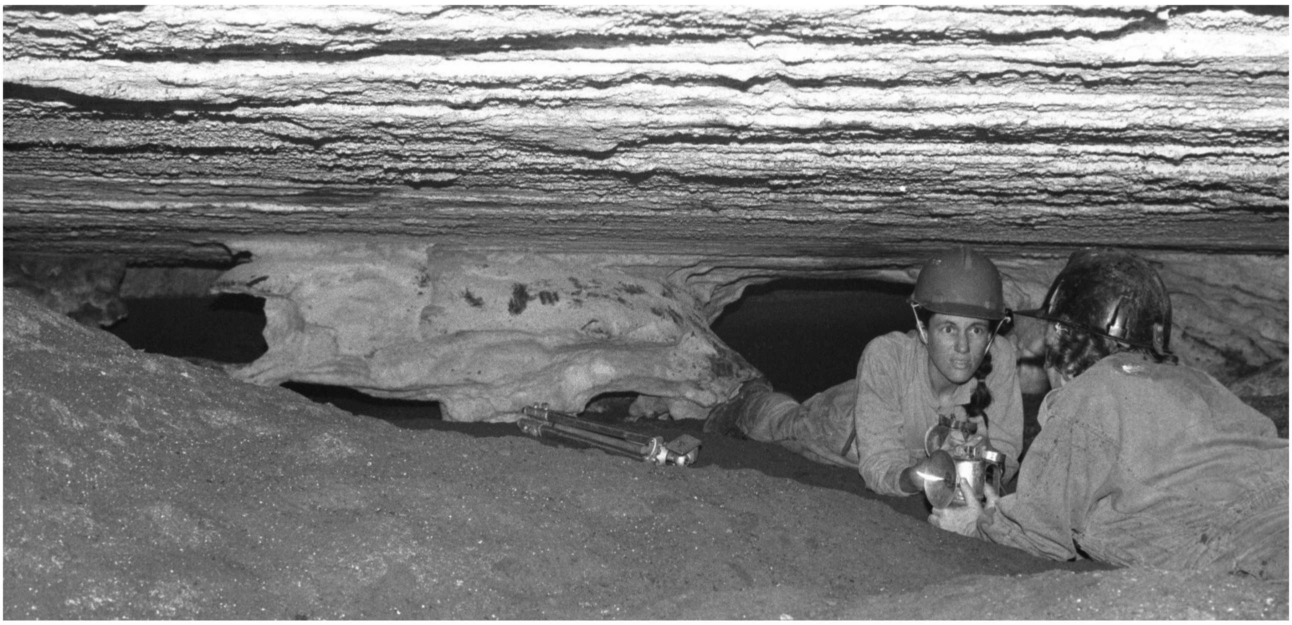
South Australian Karst Regions

Marker (1975) and later Grimes (1994) divided the South Australian part of the Gambier Karst Province into several distinctive regions (Figure 1.8).

The Naracoorte Plateau is an uplifted area of Tertiary limestone to the east of the Kanawinka Fault (Figure 1.2). Along the western margin a pair of large dune ridges are separated by the Kanawinka Escarpment. The westernmost ridge (The West Naracoorte Range) is a thick calcareous dune sand and has little karst development. The eastern ridge (The East Naracoorte Range) is perched above the old sea cliff of the Kanawinka Escarpment and has only a relatively thin dune cover over Tertiary Limestone. This is where most of the known caves occur. Most of the larger depressions in the ranges are dune hollows. However, on the main plateau to the east there are many well developed uvalas, dolines and dry valleys, but fewer caves.

The Bool Region comprises extensive flat swampy plains crossed by linear calcareous dune ranges. Watertables beneath the plains are very shallow – at the surface during the wet season! Caves are almost entirely restricted to the calcareous dune ridges. The flats overlie marls and limestones that have minor karst potential. They have numerous enigmatic hollows illustrated in Figure 1.7.

The Nangwarry Region is a low undulating sand plain, but differs from the flat sandy parts of the Bool



Syngenetic cave in dune limestone, with low flat roof developed at an old water-table.

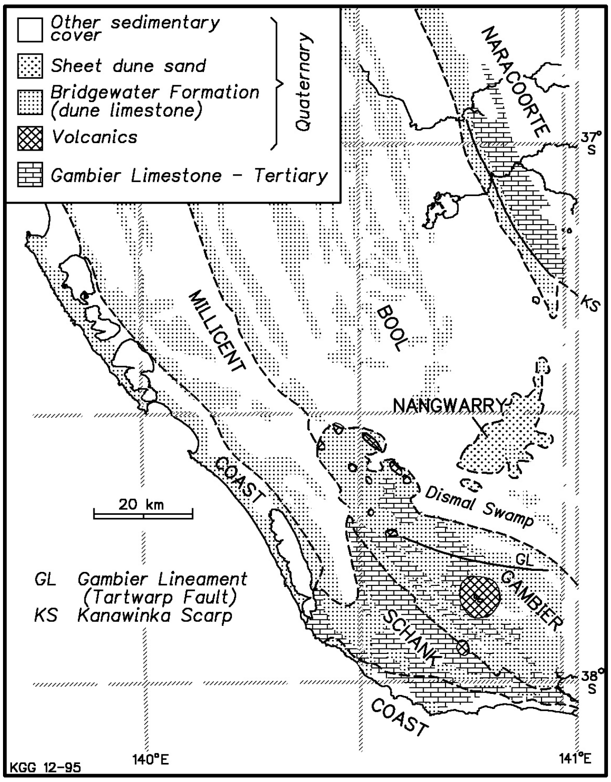


Figure 1.8: Karst regions and geology in south-eastern South Australia.

Region in having a stronger relief and a thicker cover of quartz sand. The undulating surface is a dune sheet. Shallow dune hollows are common throughout the region, and many of them are pocketed by small subsidence dolines. Small dolines are also common on the sandy rises. No collapse dolines or caves are known in the area; probably the thick sandy soil clogs any potential entrances.

The Gambier Region is a composite area comprising several different geological and geomorphic zones. High dune ridges together with exposures of Tertiary limestone and some flatter swampy country, form the Mount Burr and Gambier Forest areas. The northern part of the Tantanoola Forest also is dune country, but the southern part is a series of low beachridges that form only a thin cover over Tertiary limestone. About Mount Gambier there is a strong ‘hummocky’ terrain in which rounded hills built partly of calcareous dune limestone stand above broad hollows in Tertiary limestone. Further east the hummocks become much smaller in the pine plantations of the Myora and Caroline Forests. The southern part of the Caroline Forest is a composite series of high coastal dunefields which separate into several discrete ridges further to the north-west. A major west-northwest trending structural lineament (the Gambier Lineament, Figure 1.8) is associated with the Tartwaup Fault that runs through the core of the region. A line of elongated dolines and uvalas follows the surface trace of the fault.

A variety of caves occur both in the Tertiary limestone and as syngenetic karst in the dune limestones. Many spectacular large collapse dolines occur, some of which extend below the water table to form cenotes. Swamp and saucer dolines are abundant in some localised areas, but absent in much of the region. Good examples of solutional uvalas occur to the north-west of Mount Gambier but are difficult to pick from the adjoining ‘hummocky’ terrain which appears to be a combination of dune and karst landforms. Dry valleys occur in the Dry Creek area adjacent to the Glenelg River gorge in the far south-east.

The Schank Region is an area of relatively bare karst on a flat, stripped Pleistocene coastal plain to the south of the Gambier Region. The narrow Coastal Region separates it from the sea. Much of the region has thin soil or bare pavements of Tertiary limestone. Karst features include spectacular cenotes, a few uvalas, well-developed exhumed subsoil karren and caves. Many of the caves are partly or wholly submerged by the present high watertable though they would have been drained during the low sea levels of the last glacial period.

The Millicent Region is similar to but younger than the Bool Region. Unlike the older region it lacks the characteristic hollows on the flats, and caves are rare in the dune ridges.

The Coastal Region is a narrow belt of land that extends up to 6 km inland from the present coast, its inner margin being a 120,000 year old coastline. It consists of a low erosional coastal plain developed on Tertiary limestone, and partly covered by recent coastal dunes and beach ridges. The watertable is close to the surface. Numerous springs occur, many of them rising from submerged dolines and caves. Most of the caves can only be entered by diving. Coastal karren (lapies) are well developed on the limestone cliffs and there are some small sea caves.

Victorian Karst Regions

In Victoria the Tertiary limestones are variable in their purity, and only limited parts of the region show significant karst development.

The ***Glenelg region*** has mainly linear joint-controlled fissure caves in Tertiary limestone. The river has cut a magnificent gorge up to 35 m deep into an otherwise gently undulating limestone surface. Many of the caves are entered at the base of the river cliffs, and have out-flowing streams and vadose features. The flat country north of the Glenelg River is similar to the Bool Region, whereas that to the south is an extension of the Gambier Region and dominated by dune landforms.

The ***Portland region*** is a broad diverse region covering sea caves and isolated dune limestone caves, as well as the densely cavernous areas of Bats Ridge and Codrington. The low-lying plain north of Codrington

(Figure 1.1) is analogous to the Bool Region and has similar small swampy depressions. At Whalers Bluff in Portland, a paleokarst is developed in the Miocene Port Campbell Limestone and buried beneath Pliocene sediments and volcanics.

The ***Warrnambool*** area includes both Tertiary and Quaternary limestone karst. An active stream occurs in one cave. The caves are mainly collapse-modified phreatic systems, with some joint control. There is a well-developed field of basin-shaped dolines west of Peterborough (Site V-6).

Timboon is a small area near the eastern end of the Tertiary limestone belt. The caves occur in or near the deep valley of the Curdie River which has cut through a thin basalt cover. They are small, but some are well-decorated and several contain streams.

CAVE BIOLOGY and ARCHAEOLOGY

There are two maternity caves for the Bentwing Bat (*Miniopterus schreibersii*) – one near Naracoorte and one at Warrnambool (Dwyer, 1969). Several caves along the Glenelg River host the (locally) rare Large Footed Bat (*Myotis adversus*). Maternity sites and other caves regularly used by bats contain guano deposits that host diverse communities of invertebrate fauna. Over sixty different species have been recorded from these guano deposits so far, including spiders, pseudoscorpions, mites, springtails, cockroaches, pscopeterans, beetles, flies and moths (Moulds, 2004).

The cenotes, water-filled cave passages and big springs contain an interesting aquatic fauna and flora. The springs contain a number of endemic and threatened species such as Southern Bell Frog (*Litoria raniformis*), Yarra pygmy-perch (*Nannoperca obscura*), Ewen pygmy-perch (*Nannoperca variegata*), Dwarf Galaxis (*Galaxiella pusilla*), and Australian Grayling (*Prototroctes maraena*). A diverse invertebrate fauna are found in these subterranean wetlands. Most notable are several of the crustaceans - syncarids (*Koonunga crenarum*) and amphipods (*Uronyctus longicaudus*), both of which are stygobites (adapted to subterreanean aquatic life). Both of these crustaceans have evolved from Gondwanan ancestors (Thurgate et. al. 2001).

Another important feature of the subterranean wetlands and other wetlands in the area, including the Blue Lake, are stromatolites (Thurgate, 1996a &b, 1999). The stromatolites are columnar or platy underwater calcareous growths formed by microbes such as bacteria and algae. These have been found as deep as 25 m in the cenotes, and 45 m in the Blue Lake crater, and also extend 2 m above the present water level – implying a higher watertable at some time in the past. Twenty-three different stromatolite morphologies have been identified in these wetlands, which represents an extremely high level of diversity of international significance.

The solution pipes and collapse dolines form excellent pitfall traps and thus bone deposits of Quaternary age have been found in many caves (e.g. Wells & Pledge, 1983). The most important, and world famous, bone deposit is in the Victoria Fossil Cave at Naracoorte (Wells & others, 1984), but significant bone sites occur in both states, including the volcanic caves and some underwater bone deposits in the cenotes.

The Tertiary limestones in the Mount Gambier area have bands of chert nodules which make excellent stone tools. Evidence of aboriginal mining of chert is seen in several caves, as is also aboriginal art in the form of scratch marks and finger marks (Bednarik, 1986).

MANAGEMENT

Water Supplies

The Gambier Limestone has been referred to as one of the best aquifers in Australia (Holmes & Waterhouse, 1983). Unfortunately it has also suffered from pollution and over-exploitation (Emmit & Telfer, 1994, Stadter 1999, Schmidt, 1999, Hopton, 1999). There will be a growing problem in maintaining supplies in the face of increasing demand for private, agricultural and industrial usage.

A one metre high face of stromatolites exposed on the walll of a cenote by a drop in the water table over the last 100 years. Gouldens Sinkhole, Mount Gambier (Site 12).

Water quality can be compromised by pollution from a variety of sources: stormwater, sewer and septic drainage in the towns, farm activities (in particular wastes from the dairies and piggeries), and some major industries such as those involved in the timber business (treatment of mill timbers, paper pulp, cellulose etc.). In the past, abattoirs have been a source of pollution with some still a cause for concern. Cheese factories also introduced major pollution plumes into the aquifer and these are still travelling through the system.

Of increasing concern is contamination of the groundwater from diffuse agricultural sources such as grazing and cultivation (Harvey, 1983). In some areas, particularly in the north, increased salinity from clearance and irrigation is becoming a greater problem (Stadter, 1999).

Although regulatory controls exist under the Environment Protection Act these only cover large scale operations. Small scale operations come under a general duty of care and are usually only scrutinised when there is a direct complaint. Often a number of small, badly run, operations can cause more problems than the reasonably run large ones. Unfortunately, these small operations have more severe budgetary constraints so the owners are more reluctant to upgrade, despite programs of public education.

Surface karst management

The main problems here have to do with introduction of pollutants into the aquifer via the dolines, cave entrances and "runaway holes". Infilling and direct damage to dolines and cave entrances also occurs from forestry and agricultural activities. Many dolines and entrances have been, and still are, used as rubbish dumps. There have been major clean-ups of some dolines and caves, for example: Engelbrecht Cave in the town of Mt Gambier is now a tourist cave, and Rendelsham Cave near Millicent has been cleaned up and developed as a recreational area.

The Lower South East region is of national significance for the conservation of stromatolite biodiversity, as there is greater stromatolite diversity in this region than has been recorded elsewhere in Australia (Thurgate, 1996a,b, 1999). Modern stromatolites are important palaeoenvironmental indicators as they preserve information about past climatic and hydrological regimes. The stromatolites in the cenotes may be endangered by water pollution; either directly or indirectly by the growth of surface algal mats which block the sunlight (Thurgate, 1996, 1999). Swimmers in some of the spring ponds have caused damage to the aquatic vegetation.

Ewens Ponds and Piccaninnie Ponds are important for conserving rare coastal fen environments that were once extensive between Cape Northumberland and Nelson. The Ponds are listed on the Register of the National Estate. A nomination is being prepared to list Piccaninnie Ponds as a Ramsar subterranean wetland.

Ripping of limestone for increasing irrigation activity can disturb karst pavement areas and change the hydrology (Bourne, 2002). Subsequent irrigation or intensified land usage with increased fertiliser and insecticide applications will also have an impact on he groundwater.

Cave management

Management problems within the caves are mainly related to people access, and the damage that results therefrom. About a third of the known caves in South Australia are on crown land (mainly State Forests). The region has four sets of show caves: Several caves at The **Naracoorte Caves**, and also **Tantanoola Cave**, **Engelbrecht Cave** in Mount Gambier, and **Princess Margaret Rose Cave** on the Glenelg River. There are no show caves in the volcanic region, but two lava caves at Mount Eccles are open to the general public and access steps have been put into one of these.

Diving in caves and cenotes is a special activity in the Mount Gambier region that is stringently controlled by a certificate and permit system (Collins, 1999). Beneath pine plantations evapotranspiration is much higher than under other vegetation and this can drop the local water table by several metres, drying up cave pools and speleothems. A few caves have been intersected by quarries; one of these became a major fossil bone site - with the quarry operations continuing beside it (Barrie, 1997, Site 2).

A worry with syngenetic karst caves, and to a lesser extent with those in the Tertiary Limestones, is stability. "Soft-rock caves" are not as strong as the typical "hard-rock" cave in older limestones, and so roof fall is statistically more likely. This is not a major problem, but cavers have to be a bit more careful about bumping the roof, and cave managers should do regular inspections of their tour caves.

CONCLUSION

This area of 'soft rock' caves developed on youthful, weakly-consolidated porous limestones is quite different from the 'hard rock' indurated limestone karsts of eastern Australia and elsewhere. The caves have an entirely different quality, characterised by soft friable walls, cap rock effects, solution pipes, extensive low horizontal phreatic mazes, abundant collapse modification and extensive large flooded systems. The cenotes are unique within Australia. The karst aquifer is one of the best in Australia, but careful management will be needed to maintain that quality. Management is also required to maintain the surface karst features, the caves and their environment.

VOLCANIC CAVES AND RELATED FEATURES

Ken Grimes

The Western District Volcanic Province

The Western District Volcanic Province of western Victoria (previously known as the Newer Volcanics Province) is one of the world's larger volcanic plains, and has formed by a succession of eruptions and basaltic lava flows over the last five million years. The isolated volcanoes at Mount Gambier are a western outlier of the Province (Figure 2.1). Eruptions have continued up to quite recent times and further eruptions could occur in the geological future. Current dating suggests that the youngest volcano may be Mount Schank, south of Mount Gambier, which erupted 5,000 years ago. The flows associated with these younger eruptions show better lava caves and surface features than those of the older volcanics. None-the-less, a few of the caves are in flows several million years old.

Lava tubes and other volcanic caves are scattered across the province, but the majority of them are in the western area where they are associated with two of the younger eruptions in the region (Webb & others, 1982, Grimes & Watson, 1995).

Surface landforms

The volcanics are dominantly built up from basalt lava flows, but there are numerous small volcanic cones built by explosive activity, as well as larger maar lakes formed by major explosions (Price & others, 2003; Joyce & Webb, 2003).

The older volcanoes of the region have degraded features, and thick lateritised soils, which make their recognition difficult. By contrast, the flows from the younger eruptions have only minimal soil development and rough undulating surfaces known as *stony rises*; isotope dating suggests that these are all less than 500,000 years old.

The best modern model for the nature of vulcanism in this region is provided by the Hawaiian volcanoes. There we see broad lava shields built up by successive flows of very fluid basaltic lava spreading out from a central crater or fissure. In the crater area we see lava pools with fountains jetting into the sky and building local small cones of welded spatter or loose scoria. The long lava flows are seen to be fed either by surface channels, or underground by lava tubes.

Local examples of lava shields are the lower slopes of Mount Napier and the lava fields surrounding Mount Eccles. However, in Victoria we also have slightly more explosive eruptions which build larger scoria cones; and the maar lakes, which are large but shallow craters formed by major steam-driven explosions where rising magma intersected water-saturated limestone. At Mount Eccles a line of scoria cones running southeast from the main crater could have formed along a fissure eruption (Figure 4.6).

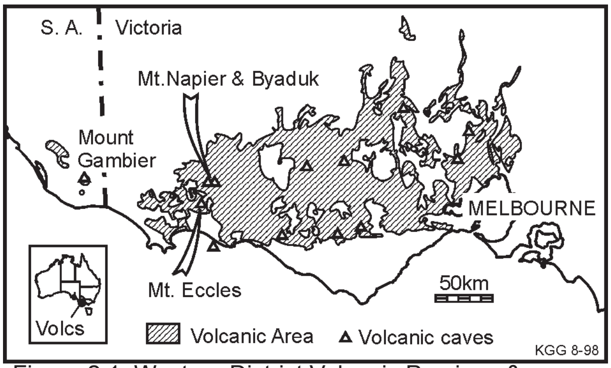


Figure 2.1: Western District Volcanic Province & caves.

Lava flows:

Basaltic lava is a hot (1100°C) liquid that can flow readily. There are two main forms of basaltic lava flow, which grade into each other. *Pahoehoe* lava is the most liquid form - characterised by the formation of thin smooth skins that become wrinkled (hence its alternative name of 'ropy lava'). Pahoehoe lavas advance as a succession of lobes, each of which develops a skin, is inflated by the liquid pressure within, then ruptures at one or more points to release liquid lava to form new lobes (Figure 2.3).

As pahoehoe loses gas and cools it becomes frothy and stiffer. The surface tends to crack, twist and break into angular, often spiny, blocks to form what is called *aa* or 'blocky' lava.

Behind the advancing lava front solidification of stagnant areas restricts lava movement either to narrow surface *channels*, or internally in *lava tubes* beneath a surface crust. Overflow from the surface channel builds up a *levee* bank of thin sheets or spatter. Larger flows across the levee can feed lateral lava lobes with small internal lava tubes. A major breach of a levee may result in a large side flow, fed by its own channel, and the original channel may be abandoned. Good examples of lava channels (locally referred to as 'canals') occur at Mount Eccles (Figure 4.6). A number of shallow lava tubes are known in flows that have run off to the sides from these channels (Grimes, 1995 & in press).

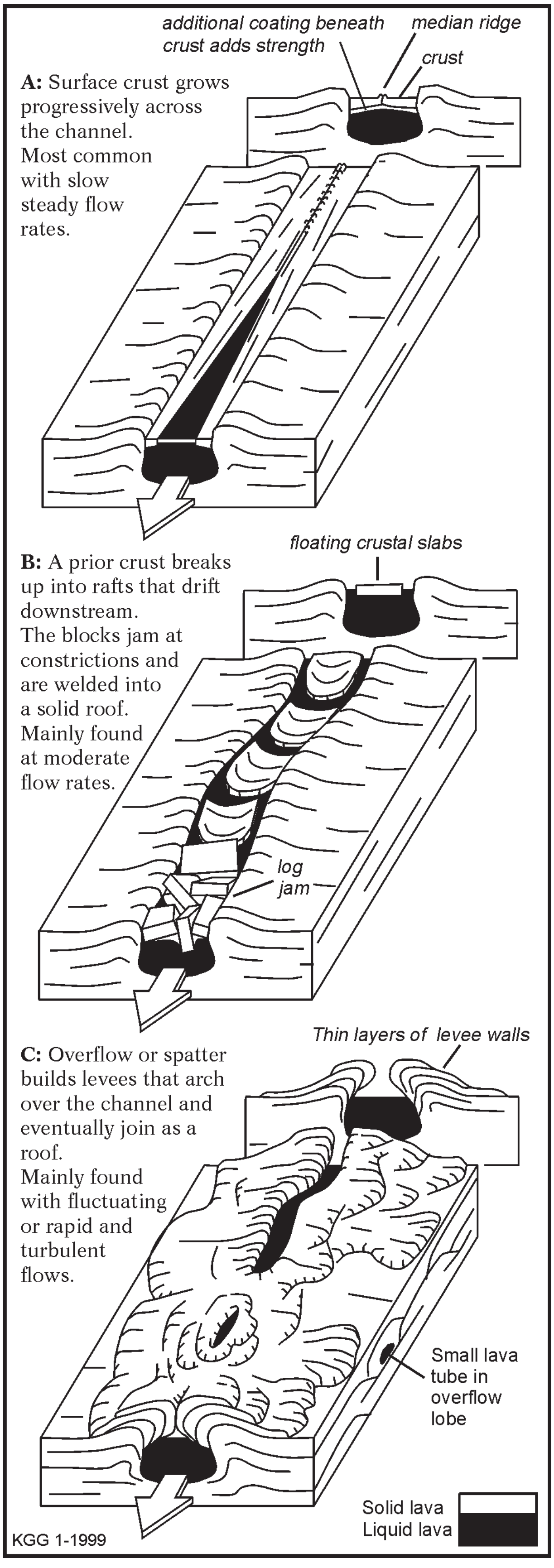


Figure 2.2: Three ways to make a lava tube by roofing a lava channel.

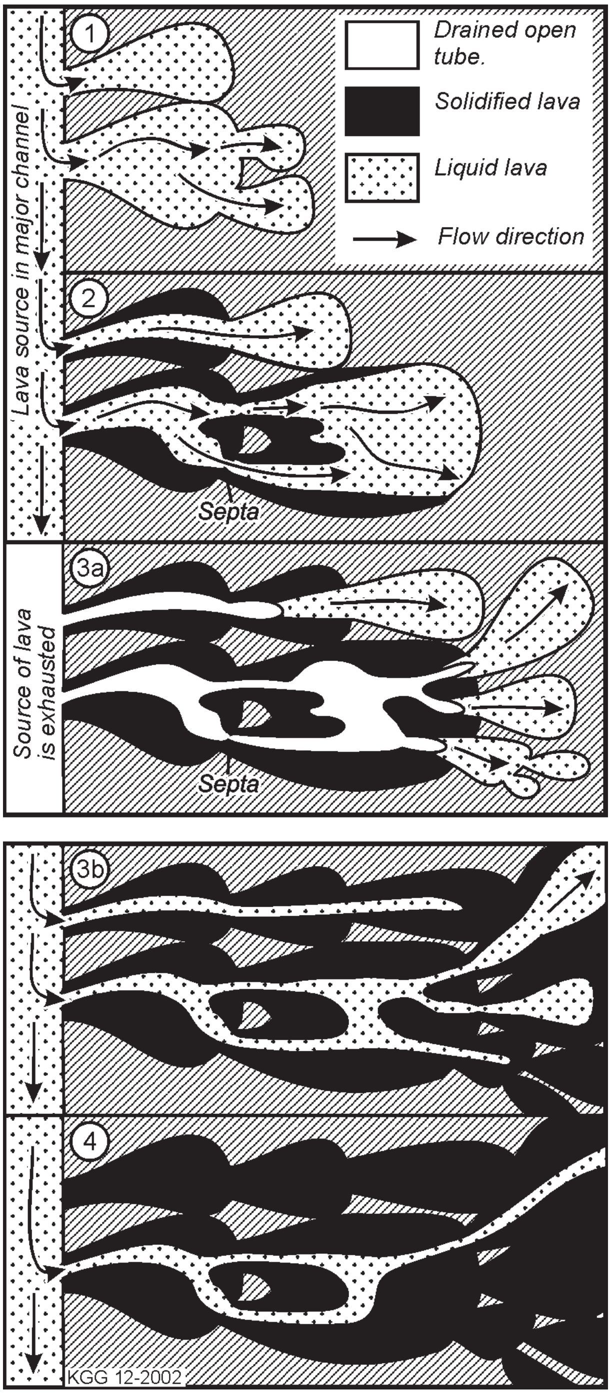


Figure 2.3: Stages in the formation of lava tubes by draining of lava lobes.

Step 1: Thinly crusted lobes of lava expand by breakouts through ruptures and budding of further lobes.

Step 2: Stagnant areas of the older lobes solidify, but flow from the source keeps the feeder conduits liquid.

Step 3a: If the source flow ceases some of the conduits may drain to form air-filled cavities.

Steps 3b and 4 indicate the further evolution into more linear feeder tubes as lava continues to flow through the system.

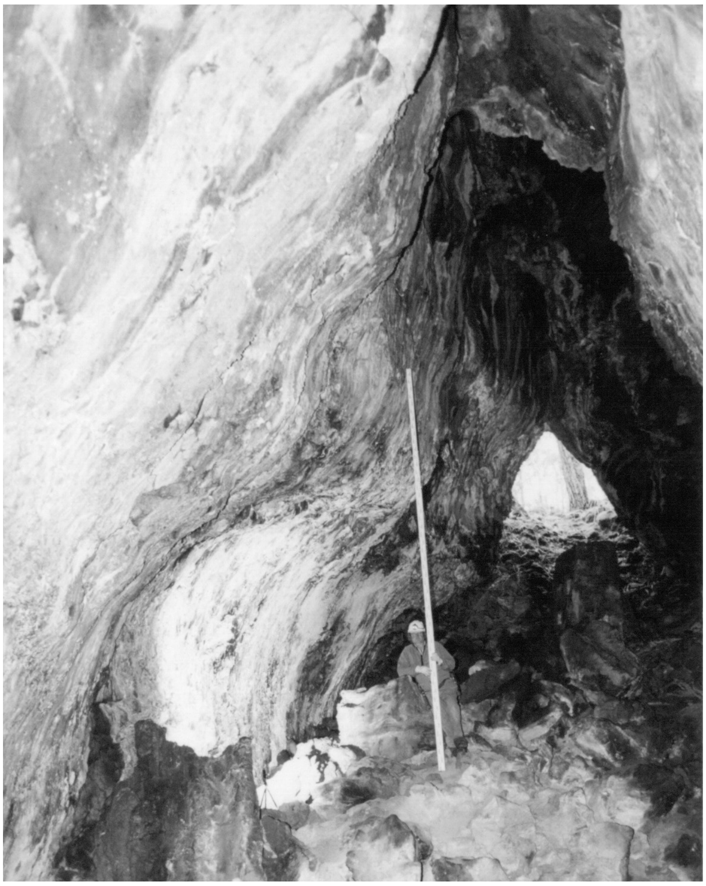
Lava tubes provide good insulation for the hot lava flowing within them. This allows the formation of very long flows such as the 50km Tyrendarra Flow from Mount Eccles, which extends offshore across the continental shelf (which was dry at the time), and the older 60km flow from Mount Rouse, which may also extend offshore (Figure 4.1).

When a lava flow follows a valley, as in the Harman Valley flow from Mt. Napier and the Tyrendarra flow from Mount Eccles, it disrupts the drainage. Twin *lateral streams* may run down each side of the original valley. *Swamps or lakes* will form where the flow enters the valley, and where tributary valleys have been dammed by the flow.

Formation of Volcanic Caves

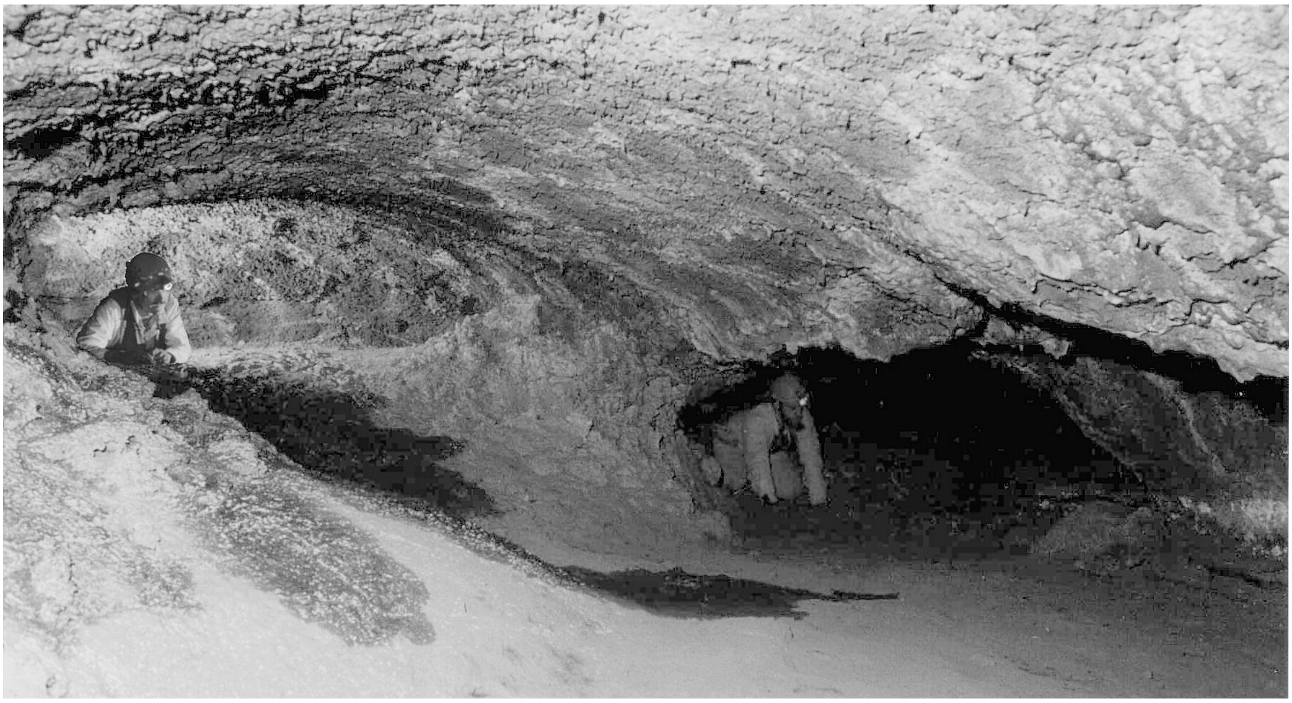
Lava tubes form in basaltic lava flows by two main processes (Peterson & others, 1994; Halliday, 2004): first by the roofing over of surface lava channels in several ways (Figure 2.2); and second by the draining of still molten material from beneath the solidified crust of a flow (Figure 2.3).

Tubes formed by draining of crusted lava lobes and flows are generally smaller than those formed by the roofing of a channel, but tend to have more complex forms. Lava lobes can be stacked vertically as well as advance forwards so that a complex three-dimensional pattern of branching tubes can form. The long lava flows in the region would all have been fed by large cylindrical lava



The ceiling of Natural Bridge, Mt. Eccles (Site V-13) has a "Gothic" shape that suggests it formed by levee overgrowth, as shown in Figure 2.2c,

See also Fig 4.8.



Caves formed by draining of lava lobes tend to have low broad chambers and passages (see Figure 2.3).

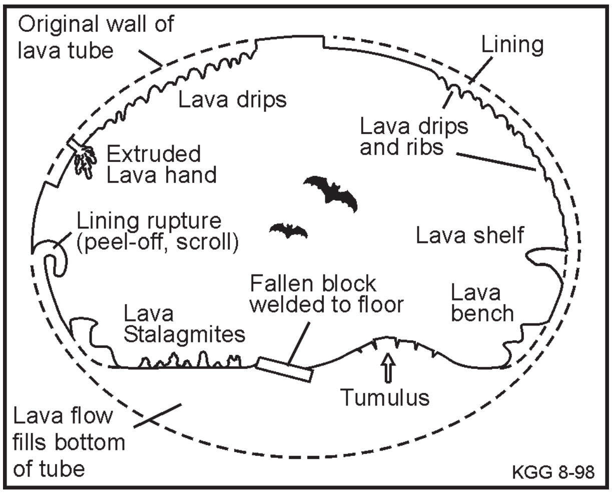


Figure 2.4: Formations found in lava tubes

tubes; but these need not have drained at the end of the eruption to form open caves.

Features found in Volcanic Caves

The lava caves contain a distinctive suite of lava structures or "decorations", some of which are illustrated in Figure 2.4.

The level of lava within the tubes tends to fluctuate during the course of the eruption, and so we find thin linings plastered onto the walls and roofs, and 'tide-marks' are indicated by solidified benches or shelves on the sides of the tubes. Some shelves can reach right across a passage to form a false floor.

The thin wall linings can rupture, peel back and curve over to form draperies and scrolls. Some linings are smooth, but others have a sharp hackly surface which may be due to the bursting of many small gas bubbles. Rafted slabs floating on a flow surface may leave grooves and striations on the semi-solid wall linings. Lava "hands" of semi-solid lava can be squeezed out through cracks or holes in the lining.

Small round-tipped lava stalactites, (lavacicles, lava drips) form where molten lava has dripped from the roof. Lava ribs form where lava dribbled down the walls of the cave, or where the whole lining has sagged and wrinkled. If the floor was already solid (unusual) drips of lava from the ceiling can build up lava stalagmites.

The floor of the tube is often flat or slightly arched; being the surface of the last flow of lava through it. If a lava flow within a tube forms a solid crust, and then drains away from beneath it, we get a tube-in-tube effect with a thin false-floor bridging the tunnel. Small lava mounds, or tumuli, may be heaved up by pressure from below. In some caves the crusted floor has buckled and broken into a jumble of heaved up plates, or cracked into a mosaic of jostling plates with rounded or upturned edges. Material falling from the roof may be rafted some distance downstream and may end up welded into the floor, or piled up in 'log jams'.

Management of Volcanic caves

The formations found in lava tubes are even less renewable than those in limestone caves. At least a broken calcite stalactite ***might*** regrow in a few thousand years, but a broken lava formation will ***never*** do so; unless someone builds one heck-of-a hot campfire in the cave!

The stony rise country of the recent lava flows is similar to karst in that surface water goes underground quickly and, if moving in lava tubes, it is unlikely to be filtered of any contaminants (Kiernan & others, 2003).

A major conflict in land use comes from the scenic and geologically interesting volcanic cones being also a source of scoria. Many have been or are still being quarried away. There are several active and abandoned quarries at both Mt Eccles and Mt Napier, and some interesting volcanic features have been destroyed while others are threatened (Guerin, 1992).

A more recent threat has arisen from the development of heavy machinery which can crush the rocky surfaces of the "stony rises" - allowing its use for improved pasture, but destroying the surface lava features, and potentially collapsing any shallow lava caves.

The push for tourism development in the region is putting increasing pressure on the lava caves, with the development of access steps and viewing platforms and consequent increases in visitation levels in the well-known caves.

SITES IN SOUTH AUSTRALIA

Ken Grimes, Steve Bourne, Susan White, Kevin Mott, Mia Thurgate, Elery Hamilton Smith

NARACOORTE AREA

Site 1: Naracoorte Caves World Heritage Area.

Naracoorte Caves National Park is a World Heritage Fossil Site covering 600 hectares. There are 26 caves within the park with 20 fossil deposits identified to 2000 (Reed & Bourne 2000). Research into these fossil deposits in the park has contributed greatly to the knowledge of Australia's extinct Megafauna with the research findings providing the basis for a strong interpretive program. The Park attracts over 70,000 visitors per annum providing important revenue for management and making a major contribution to the economic health of the region.

The caves are formed in Tertiary limestone beneath a low ridge of the East Naracoorte Range (Figures 3.1, 3.2). Although the ridge has a dune topography, the dune sediments are very thin or absent in the caves area.

Surface karst features

Several surface features are of interest (Figure 3.2). The entrances U-9, U-12 and U-98 are solution pipes (U-98 is a pair of coalesced pipes) as is the entrance to Wombat Cave (U-58) further east. Peppertree hole (U-89) is a small undercut ledge and tunnel in the bottom of a broad shallow subsidence doline. Near the old western entrance to the park is a cluster of small subsidence pits in sandy soil and calcrete. These are 1-3 m across and up to 2 m deep. They probably are subsiding into solution pipes above a possible cave. A walking trail from the main cave area runs south along the western side of the road to Victoria Fossil Cave. This passes several outcrops with irregular solution tubes, and the entrance to Appledore cave (U-7) Beyond Victoria Fossil Cave the track continues south to Mosquito Creek which is an example of superimposed drainage - the creek entrenched its channel and maintained its course as the East Naracoorte Range was uplifted along the Kanawinka Fault. The cliffs beside the creek have a couple of small caves and some examples of solution pans, rain pits and horizontal solution ripples, but karren are not well developed here.

Victoria Fossil Cave (U-1)

This is an extensive, rambling, horizontal, network of collapse-dome chambers connected by low phreatic passages and flatteners (Figure 3.3). The tourist section is mostly collapse and the low connecting passages have been artificially enlarged. There are some extremely well decorated areas, especially in the chambers beyond the tourist section. The cave contains an important fossil bone site which is the main reason for the World Heritage status of the area. This is an extensive area of bone-bearing sediment beneath an old (now filled) pitfall entrance (Wells & others, 1984). Guided adventure cave trips are led into the non-tourist section.

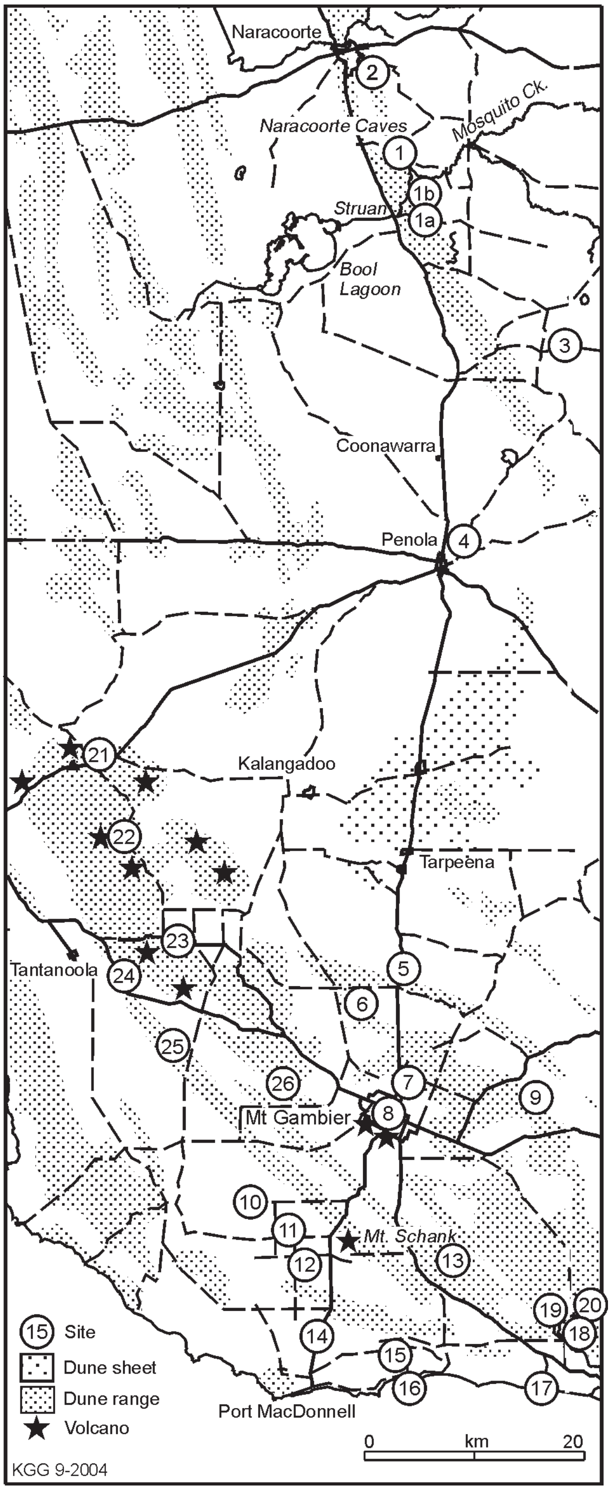


Figure 3.1: Field sites in the Naracoorte - Mount Gambier area. See Figure 3.7 for location of sites 8a to 8e within the city of Mount Gambier

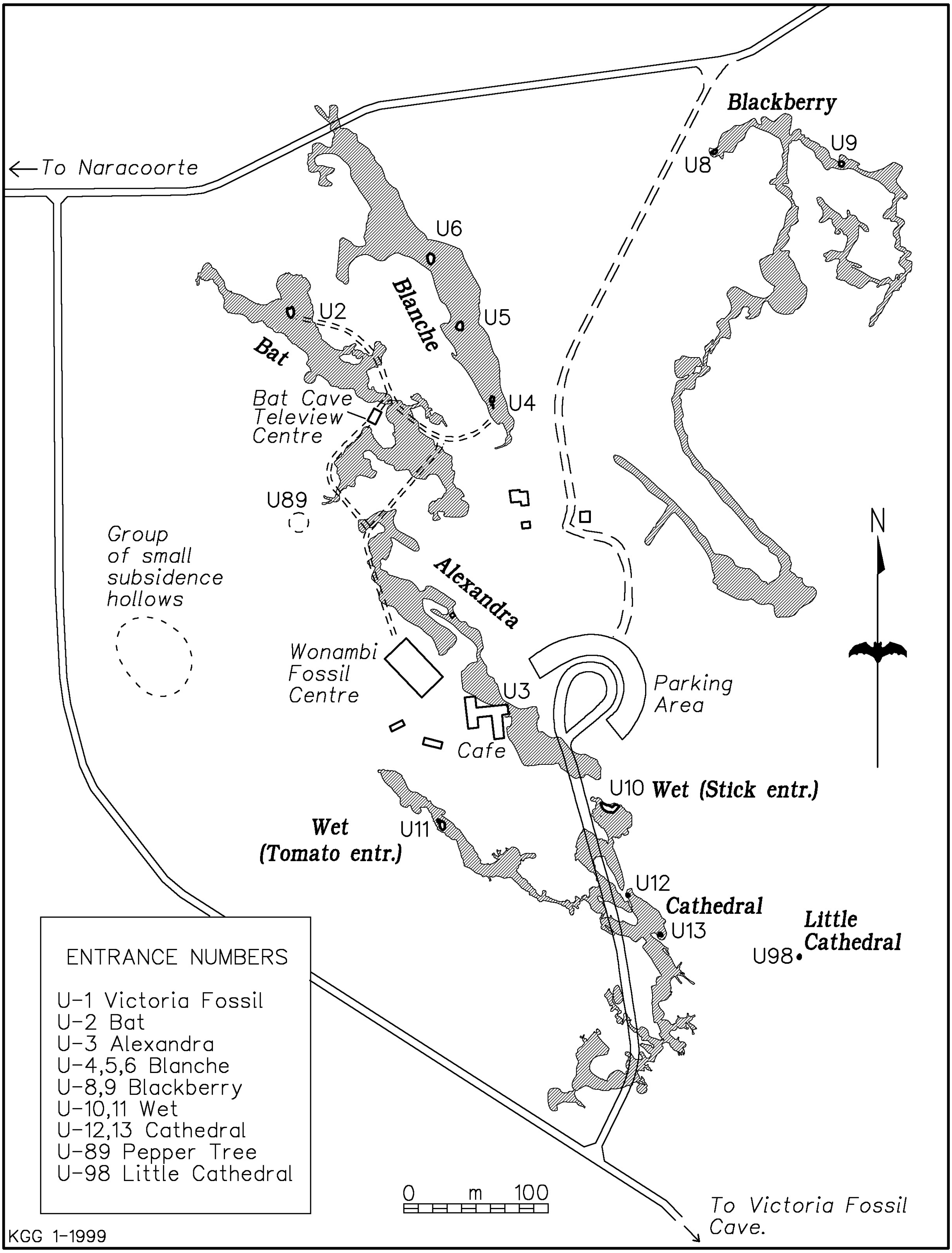


Figure 3.2: The main Naracoorte Caves area. See Figure 3.3 for Victoria Fossil Cave.

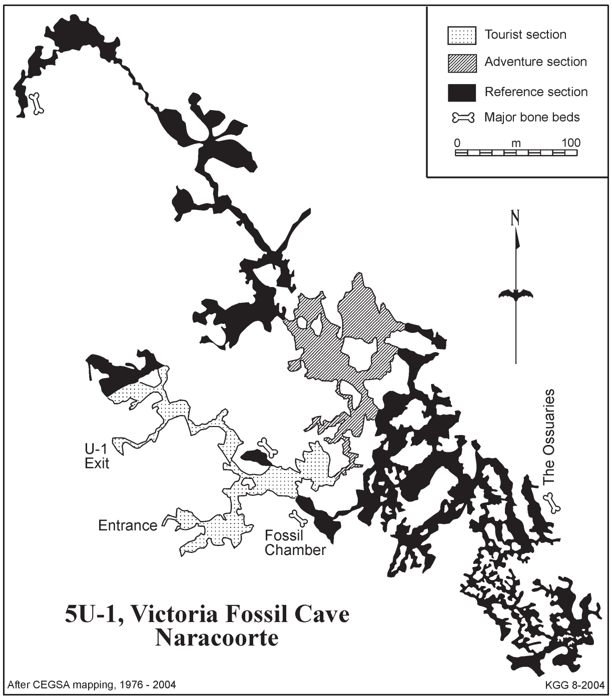


Figure 3.3: Victoria Fossil Cave is in Tertiary limestone

Bat cave (U-2)

A roof window leads to a series of large high-domed chambers and collapse passages. This is the maternity site for *Miniopterus schreibersii* for South Australia and is also the type location for a number of invertebrates. Access is prohibited. In the past, extensive areas of the cave were mined for guano. Infra-red cameras have been installed in the cave, allowing visitors to the Bat Cave Teleview Centre to watch the bats interacting in the cave below. An extensive invertebrate fauna has been recorded from the guano (Moulds, 2004).

Alexandra Cave (U-3)

This show cave comprises several large well-decorated phreatic chambers connected by low sand-floored passages. The northern extensions were largely sand and silt-filled before they were excavated to extend the tour area. This is the type locality for the local cave weta (cricket).

Blanche Cave (U-4)

Blanche Cave is a tourist cave comprising a line of large collapse passages and chambers with several roof windows. It is a good example of collapse beneath a calcrete caprock. The formations had dried up and degraded, but since the overlying pine trees have been removed seepage has resumed and deposition recommenced.

Appledore Cave (U-7)

A small collapse entrance leads into a collapse dome and a line of rubble-filled passages and chambers.

Blackberry Cave (U-8)

This is an extensive well-decorated system of phreatic and collapse passages and domes. Entry is by prior permit only, and there is a locked gate at the start of the southern extension. Adventure cave tours are run by Park staff. A new map of the cave has recently been completed by CEGSA, but has not been incorporated in Figure 3.2.

Wet Cave (U-10)

Also known as Tomato-Stick Cave, the original name, Wet Cave, was reinstated when it was converted to a self-guided cave. In addition to the self-guided section, adventure cave tours are run into the western section (U-11) by Park staff. A large roof window leads to a group of interconnected chambers and passages showing both collapse and original phreatic character. In the final chamber of the self-guided tour there is a flat roof with well-developed avens (bell-holes) and rock pendants. A study of the small mammal bone deposits in this cave was recently completed (Pate & others, 2002).

Cathedral Cave (U-12)

A group of solution pipes (U-12) and a roof window (U-13) lead to a large chamber, then alternating areas of high collapse domes and passages and smaller phreatic and collapse chambers, passages and flatteners. Sand cones occur beneath several soil-filled solution pipes. There are significant fossil bone deposits which are currently under study (Brown & Wells, 2000). Entry is by prior permit only.

Robertson Cave (U-17)

This cave is about 8 km south of the main Naracoorte Caves area (**1a** on Fig. 3.1). A pair of roof windows lead into a large collapse dome with some dry formations. Broken and tilted columns indicate floor subsidence in the past. Farther, beyond a constriction, a second large chamber was a bat roost prior to construction of an artificial entrance in the roof in the 1880s to allow removal of guano. This shaft was closed off in 1993 and the bats have since re-occupied the chamber.

Fox Cave (U-22)

Fox Cave is about four kilometres south of the Naracoorte Caves (**1b** on Fig. 3.1). A collapse entrance section leads via a gated tight squeeze to a series of large collapse-modified passages and chambers connected by smaller phreatic passages and low-roofed chambers (Figure 3.4). A feature of the cave is the large sand cones beneath soil-filled solution pipes. These had suffered from excessive foot-traffic but have now been restored, and marked trails added around them. Several chambers are well decorated and require careful movement. There is a growing problem from sand falling from cavers clothing onto the floors of the decorated areas. Adventure cave tours are run by Park staff.

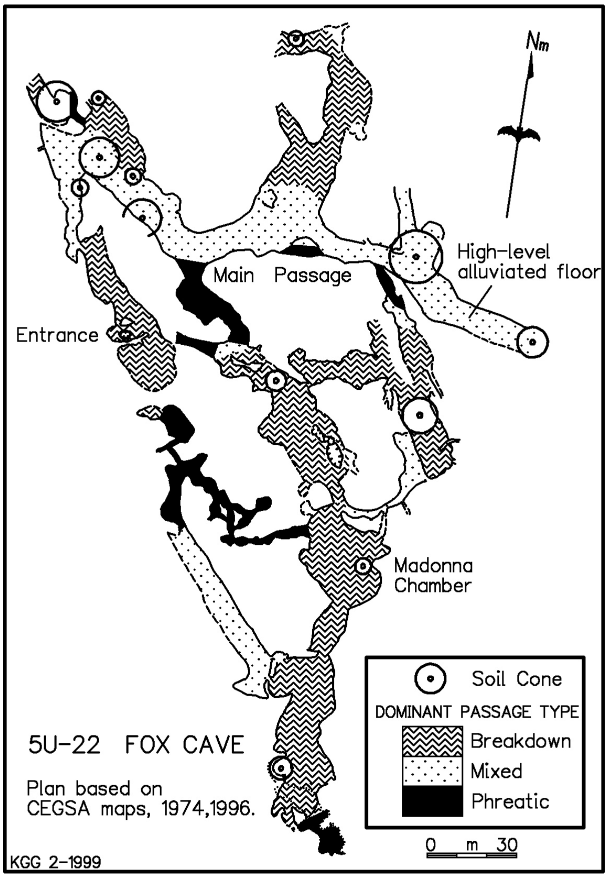


Figure 3.4: Fox Cave, in Tertiary limestone

Little Victoria Cave (U-44)

A small cave adjacent to Victoria Fossil, and genetically related to it. It comprises a set of collapse chambers and flatteners. Adventure cave tours are run by Park staff.

Wombat Cave (U-58)

A short solution tube leads to a line of large collapse-dominated passages. Adventure cave tours are run by Park staff; however, the cave is currently closed for the duration of an experiment in taphonomy - the processes of decay and distribution of bones within a cave.

Little Cathedral Cave (U-98)

This is little more than a pair of vertical coalescing solution pipes 7 m deep in a small subsidence pit. A small passage exists at the base.

Management of the Naracoorte Caves World Heritage Area

Management of the Naracoorte Caves is a careful balance of providing access and opportunities for research, delivering stimulating interpretive programs and recreational opportunities while ensuring the integrity of the site is maintained.

The Department for Environment and Heritage has managed Naracoorte Caves since 1972. In 1994, the Park was inscribed on the World Heritage List "*as an outstanding example representing significant ongoing ecological and biological evolution*". The World Heritage values are only realised through research into the fossil deposits and the transmission of this research through scientific journals and on-site interpretive programs.

The Scientific Research Committee oversees the research program. Approved projects are assessed by the Park Manager to minimise potential impacts the project may have on other cave values and visitor safety. Included in this assessment are the location of the area to be sampled and its access, size of sample area, logistical problems such as removing sediment from the cave for further analysis and very importantly, how the site will be managed post excavation.

A Researcher's Protocol has been developed that binds researchers to a code of conduct. The Protocol covers submission of a research proposal, cave access and fossil laboratory guidelines and general Department for Environment and Heritage regulations. Researchers are also introduced to the Australian Speleological Federation's Code of Minimal Impact for caving if they have no previous caving experience.

Sampling requirements change with scientific advances, but as fossil resources are finite and non-renewable, maximum information must be retrieved from each excavation. Only a portion of each deposit is sampled. Speleothems and sediments are also extracted from the caves for dating and if possible are retained for future analysis. It is critical to avoid duplication of projects and unnecessary sampling and a "State of the Research" project is underway which will provide a basis for sound management of future research. This project will assess each existing site for the knowledge gained to date, its possible future contribution to research and its ongoing management.

Several caves are open to visitors including Alexandra Cave, Blanche Cave, Wet Cave and Cathedral Cave. The Fossil Chamber in Victoria Fossil Cave was opened to visitors in 1971 to present science as a tourism product (Wells *et al* 1979). Since 1995, the Bat Observation Centre has provided visitors with a view the interior of Bat Cave via infrared cameras. The Wonambi Fossil Centre opened in 1998 and recreates the time represented by the fossils found in the caves. Models of extinct Megafauna have been constructed as accurately as scientifically possible and placed within the environment of the time, immersing visitors in a "Pleistocene experience".

Just as scientific investigation is never finished, scientific interpretation is not static so ongoing staff training is critical to ensure the interpretation and presentation of the Park is up to date, relevant and retains the vibrancy of current science. Turnover of guiding staff is always a critical issue in maintaining a high standard of interpretation, but the increase in visitation after the opening of the Wonambi Fossil Centre has increased the available work and stabilised the pool of guides.

All tours have group size restrictions, to aid in better visitor experiences and conservation of the caves themselves. Data loggers are placed in high visitation areas and in control locations to record and compare temperature and humidity fluctuations attributable to people.

Infrastructure to provide safe access for visitors is designed under the philosophy of 'reversible management' (Bourne and Bradford *in press*). Materials used in the caves are non toxic and resistant to the humidity of the cave environment, but most importantly, any installation may be easily removed with minimal disturbance to the cave. This sensitive infrastructure forms an important part of interpretation and clearly demonstrates careful and thoughtful Park management to visitors.

Recreational caving in the Park is conducted under a permit system and is restricted to cavers belonging to an Australian Speleological Federation-affiliated caving club. Visitors may also join adventure tours led by experienced interpreters. However, sensitive fossil sites are totally avoided by recreational caving and only visited by researchers or management for monitoring and scientific purposes.

Building partnerships with the local community has been an important step in increasing visitation to the Park and protecting fossil sites in caves that do not fall within the boundaries of the Park. Local landowners are protective of their caves and play an important role in preserving the fossil heritage of the Naracoorte area. A "Friends of Naracoorte Caves" group has been established to allow the local community to assist with the management of the Park.

The Park is well placed to continue investigations into its fossil history, deliver the findings through informative and interesting interpretation, and contribute to the local economy. By achieving this, Naracoorte Caves National Park will continue to realise its World Heritage values.

Site 2: Henschke's and Elderslee Quarries.

This pair of quarries in the East Naracorte Range, on the outskirts of Naracoorte, are cut into the Tertiary Gambier Limestone, and in places also exposes younger units such as the Pliocene Coomandook Formation (shallow marine gravels and sands) and the Quaternary Bridgewater Formation (dune limestone).

Here, as in any karst area, caves are often found during quarrying, road building and more recently during viticultral developments. What happens then is largely determined by the attitude of those who discover the cave. The Department for Environment and Heritage (the managing agency of Naracoorte Caves NP) has developed strong relationships with local council and landholders through careful management of discoveries and building a trust that land will not be seized or construction stopped. A pivotal point was the discovery of a small fossil-rich cave in early 1999. The manager alerted Naracoorte Caves' staff to the fact he wished work to continue and a salvage operation retrieved virtually all of the fossil material. Subsequent positive publicity precipitated a number of calls to investigate more caves.

The Henschke family have been particularly helpful about discoveries in their quarry, always alerting Naracoorte Caves' staff to new caves. When a cave is discovered, a thorough investigation is undertaken for its fossil and other values. If significant fossils are identified, quarrying avoids the site for as long as is necessary. In the case of a famous cave found in 1969 in the quarry, this was until 1994! (Barrie, 1997).

Caves found during viticultural development are quickly assessed and if deemed to be of little significance, no request is put forward to preserve the entrance. If, however, the cave is significant, efforts are made to construct a barrier that preserves an entrance and allows future investigation. This cooperation has led to the discovery of *Megalania,* a giant varanid not previously found at Naracoorte and the preservation of a unique whale skeleton in another cave.

Site 3: Wrattonbully doline karst & Rule Swamp

This part of the Naracoorte Plateau has a good range of uvalas, solutional and subsidence dolines and some possible traces of dry valleys (Figure 3.5); all developed on the Tertiary limestone with local thin cover of younger sediments. However, to the west the karst terrain grades into one of Pleistocene dunes in which the main hollows are dune forms, with some modification by karst processes. The dune areas tend to have thicker sandy soils with pine plantations, whereas the karst is open country.

Rule Swamp is a pleasant picnic spot in a broad, shallow uvala that extends across the Victorian border. The lagoon in the main hollow now appears to be permanent, though the dead and dying trees suggest that this was not so in the past. Possibly the drainage point in the floor of the hollow has been blocked recently.

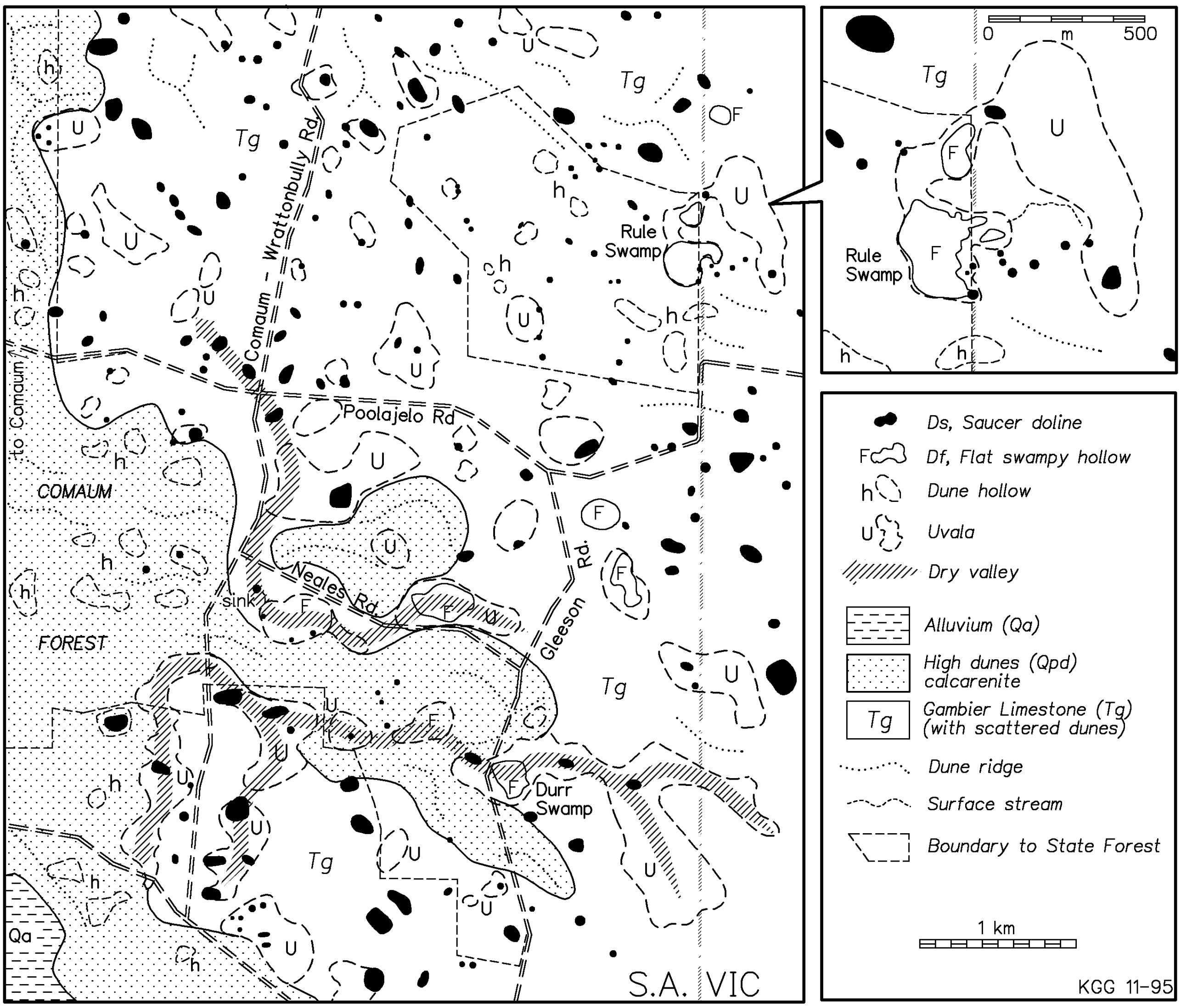


Figure 3.5: Doline karst of the Wrattonbully area, with detail of Rules Swamp uvala.

Site 4: Lunette Lakes near Penola

Between 1 to 7 km northeast of Penola the Old Comaum Road passes a set of large lunette lakes, and in places runs along the crest of the lunette ridges. The surrounding flat country is an old coastal plain of the Bool Region, and has scattered small swampy hollows of uncertain genesis.

Mount Gambier Area

Site 5: Dismal Swamp

North of the Mt. Gambier airport the main road drops down from a dune ridge onto the flat swampy Bool Region – an area known as the Dismal Swamp. Here is a densely-spaced set of small to moderately-large flat-floored and saucer to basin-shaped hollows and a couple of lunette lakes (Figure 3.6). This area has examples of all the main types of shallow depression discussed in part 1 (Figure 1.7).

Site 6: Airport Cave (alias Sheathers Cave, L-144)

Essentially a pair of parallel, flooded, flat-roofed, joint-controlled passages; the main interest in this cave is its history of drying up of the lake in step with the growth of the pine forest above. When first discovered in 1963 only the small entrance chamber was air-filled and the initial exploration, which started in 1982, was by cave divers (Horn, 1988a). Between 1982 and 1986 the water dropped a metre as the pine trees grow above the cave – eventually allowing exploration without scuba gear.

Site 7: Hummocky Terrain North of Mount Gambier

Along the highway we see an example of one of the areas that we call *hummocky terrain*. These areas occur in several places in the Gambier Region and consist of an irregular to elongated pattern of rounded hills separated

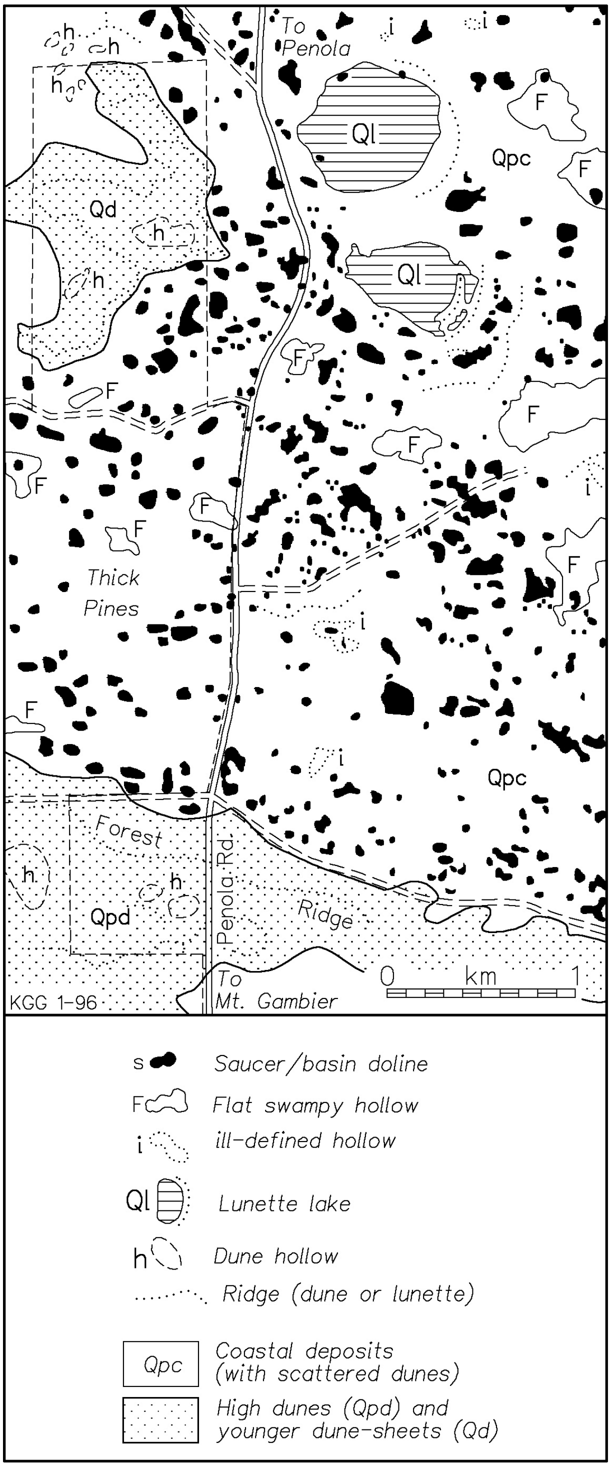


Figure 3.6: Part of Dismal Swamp, showing the variety of shallow hollows.

by broad basin-shaped hollows. The hills are built partly of calcareous dune limestone but the lower parts are in Tertiary limestone. The larger hummocks, close to Mount Gambier, have a vertical relief ranging from 10 to 25 m and a 'wavelength' of between 300 and 700 m. The hollows are nearly always dry – suggesting a well-developed underground drainage. This terrain may be a dune topography modified by karst processes, as the bottoms of the hollows extend below the contact between the old calcareous dunes and the underlying limestones.

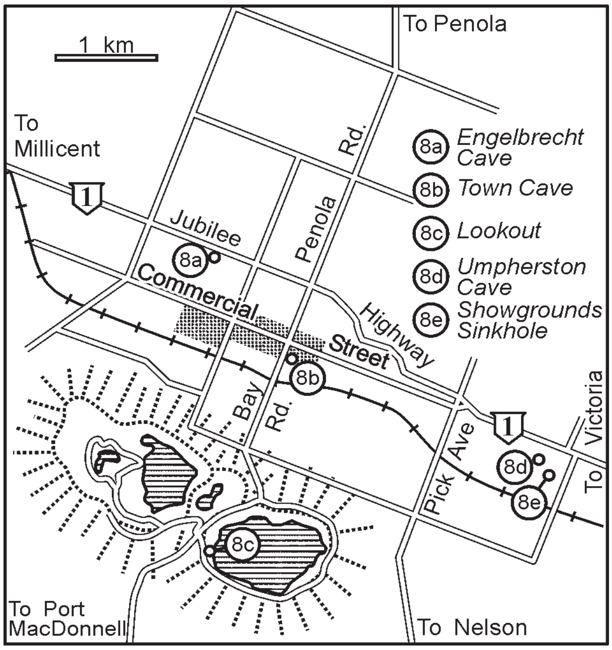


Figure 3.7: Sites within the city of Mount Gambier.

To the north-west of Mount Gambier the hummocks are gradational to both a high dune topography and also to true karst dolines and uvalas in Tertiary limestone.

Mount Gambier City, Site 8

Elery Hamilton Smith (1993) has reviewed the somewhat chequered history of the caves within the city, and the landscaping of their entrances. Figure 3.7 locates the sites of interest within the city.

Site 8a: Engelbrecht Cave (L-19)

This is in a park (signposted) on the southern side of the West Jubilee Highway within Mount Gambier city. It is a large linear system of phreatic and collapse passages with some large collapse domes (Figure 3.8). Most of it is submerged and only accessible to cave divers. The collapse doline was once used as a rubbish dump. It was cleaned out by the Lions Club in 1979 and Lifeline now runs guided tours of the initial air-filled section of the cave. The display area shows videos of divers in the submerged sections. There is a large solution pipe in the roof of the western chamber. The eastern section has good examples of phreatic sculpture and roof avens in the lake chamber. The north-western submerged section leads to a large collapse chamber directly beneath the Princes Highway – drive gently!

Site 8b: Doline of Town Cave (L-4)

This small but impressive collapse doline is in a small park beside Bay Road in the centre of the city of Mount Gambier. The surface has been made into a formal garden (Hamilton-Smith, 1993). The 18 m deep doline

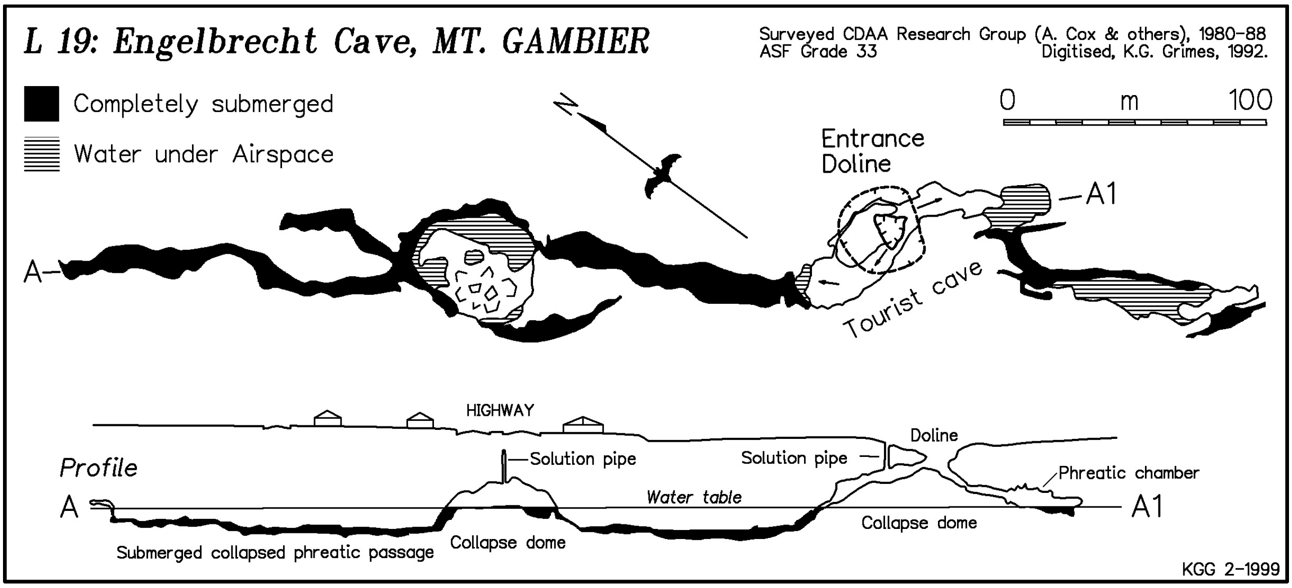


Figure 3.8: Engelbrecht Cave runs beneath the city of Mount Gambier, in the Tertiary limestone.

bells out at the base into a chamber with a small lake. Note the sections of solution pipes exposed in the walls at the lowest view-point. This is the type section for the Gambier Limestone.

The cave was the original water supply for the settlers in the area. Stormwater was first directed to the cave in about 1906 and water quality has deteriorated since. In 1916 a major drainage scheme for town stormwater was constructed with the cave being the main recipient. Several clean up projects have been done in the cave. In 1914 they removed 503 cubic yards of silt. In 2002 the site was re-landscaped and a centrifugal trap added for solid rubbish. However, chemical pollutants such as fuel spills can still enter the hydrological system.

Site 8c: Blue Lake (crater lake)

The Mount Gambier volcano is a set of maars produced by steam-driven explosions when rising magma intersected ground water in the limestone about 28,000 years ago (Sheard, 1978, Leaney & others, 1995). The walls of Blue Lake show a sequence of grey volcanic ash over darker basaltic lava flows over white limestone. There are several small caves near the waterline and also at the basalt-limestone contact. At the central lookout one can see outcrop of dipping volcanic ash that contains numerous fragments of limestone blasted up from below.

While the origins of this lake are not directly related to karst processes, the crater rim sits on top of the Gambier Limestone, and the waters of the lake are derived directly from the same regional karst aquifer system that is exposed by the cenotes.

Allison & Harvey (1983) discuss the blue colour which appears suddenly each November, when the lake becomes thermally stratified, and disappears in April-May when mixing occurs. The colour is thought to be due to finely-divided calcite crystals which grow when the surface water above the isocline warms up and looses CO_2. The reason for the rapidity of the colour change probably lies in some sort of seeding process as the crystals form.

Actively-forming stromatolites occur in the Blue Lake (Thurgate, 1996). At least eight stromatolite growth forms are present, with complex internal structures that are very different to the cenote examples. They are found on both the vertical walls, and on the sediment-covered, sloping lake floor. The stromatolites are best developed at depths of 5-10 m below the surface of the lake, where a single structure may attain heights of up to 12 m. Generally the size and abundance of these stromatolites becomes increasingly less with depth, however, the clarity of the water and the seepage of carbonate-rich groundwater through even the deepest parts of the lake allow the development of large structures to depths of up to 45 m.

Site 8d: Umpherston 'Cave' (L-6)

This large collapse doline (Figure 1.6) is in a park on the south side of the highway at the eastern outskirts of Mount Gambier. A set of stairs, first constructed in 1886, gives access to the floor which has been landscape gardened (Hamilton-Smith, 1993). Apparently, the floor was a lake in the early 1900's (the display area has photographs of row-boats), but the ground-water levels have dropped since. There is a small water-filled cave beneath the eastern wall, and good exposures of Tertiary limestone in the walls. Beware the large diurnal possums which prey on passing tourists! This doline has been classed as a geological monument of National significance.

Site 8e: Showgrounds Sinkhole (L-28)

This collapse doline in the timber yard adjacent to Umpherston Cave has a long history of pollution. None-the-less it has been classed, along with Umpherston Cave, as a geological monument. The sinkhole was originally used to water stock, with a ramp cut down to the water in the southern side. The state mill was established on the site in 1955. Stormwater from the mill site and blowdown water from boilers was directed to the sinkhole via drains. Several chemical spills have occurred on the site including a major one in 1983. Investigations showed that the base of the sinkhole and groundwater were contaminated with CCA and phenolic compounds. A site clean up and rehabilitation project was commenced in 1999.

Site 9: Snake Hill Caves (L-119, 262, 263)

The main Snake Hill Cave (L-119) is formed in a dune limestone ridge and the adjoining plain. It is an extensive horizontal maze of phreatic chambers, passages and flatteners with numerous entrances and daylight holes through the calcreted caprock roof. The small scale map (Figure 3.9) is misleading for navigation, as much of the apparently large chambers comprises low flatteners at ankle level and these areas are not obvious as one travels through the cave. The cave has suffered badly from physical damage, marking and rubbish but there was a cleanup operation in 2000. The other caves in this area (L-262, L-263)are mainly smaller collapse dome chambers, but have suffered less damage.

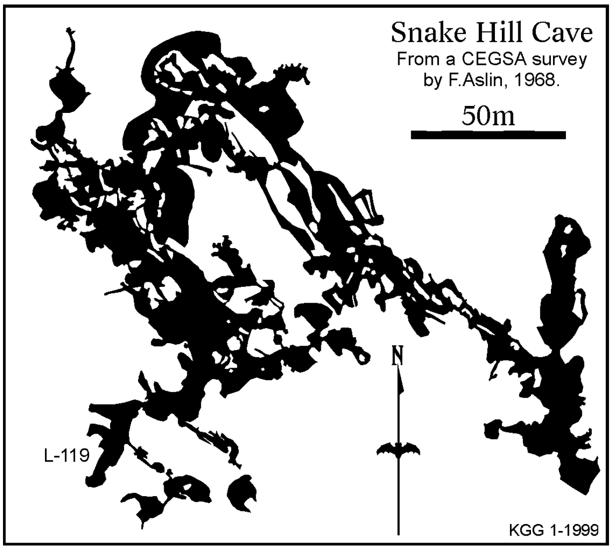


Figure 3.9: Snake Hill Cave is a syngenetic karst maze developed in Quaternary dune limestone.

South of Mount Gambier

Site 10: Sister's Road limestone pavements.

The Mount Salt area, southwest of Mount Gambier in the Schank Region, has numerous limestone pavements which show subsoil karren that have been exposed by stripping of the soil. The soil stripping appears to postdate European settlement and is thought to be a consequence of the combined impact of vegetation clearing, overgrazing, rabbit plagues, and bushfires. Good examples of rundkarren etc. can be seen on the southern side of The Sisters Road. Occasional high points have sharper surface karren forms and must have been exposed prior to the stripping of the soil.

These pavements are now threatened by the introduction of large machinery that rips the surface to improve its use for irrigation and improved pastures - but destroys the karren (Bourne, 2002).

Site 11: Little Blue Lake (L-9)

A popular swimming hole, this cenote is a water-filled collapse doline about 45m across with cliffs 6m high above a water depth of 40m (Figure 1.6). It has been classed as a geological monument of national significance. Diving is by permit only.

Site 12: Goulden Hole (L-8)

Goulden Hole is not the largest of the cenotes in the region, but it shows a good range of the features typically found in them (Figure 1.6). It is a deep sheer-walled collapse doline containing a lake and widens out into an underwater cave that is a single large collapse chamber with a central silt-covered rubble cone (Horne, 1988b). The water is 26 m deep and the cliffs rise 12 m above the lake surface. Access to the lake is by an artificial cut ramp, with a shed and water pump. The walls above the lake contain many horizontal solution tubes typically 0.5 - 1.0 m in diameter. It is worth noting that none are exposed in the cut walls of the ramp, implying that they only form in proximity to the original cliffs. The ramp walls also provide a convenient exposure of the Tertiary Gambier Limestone: a friable bryozoan limestone with bands of chert nodules. A long, dry, horizontal, cylindrical cave passage extends back beneath the ramp.

This is one of several cenotes in the region that contain live stromatolites: calcareous formations built up on the submerged walls by microbes such as bacteria and algae (Thurgate, 1996a,b, 1999). Active stromatolites occur in depths down to 15 m, but are most abundant in the top 10 m. Old stromatolites can also be seen as overlapping

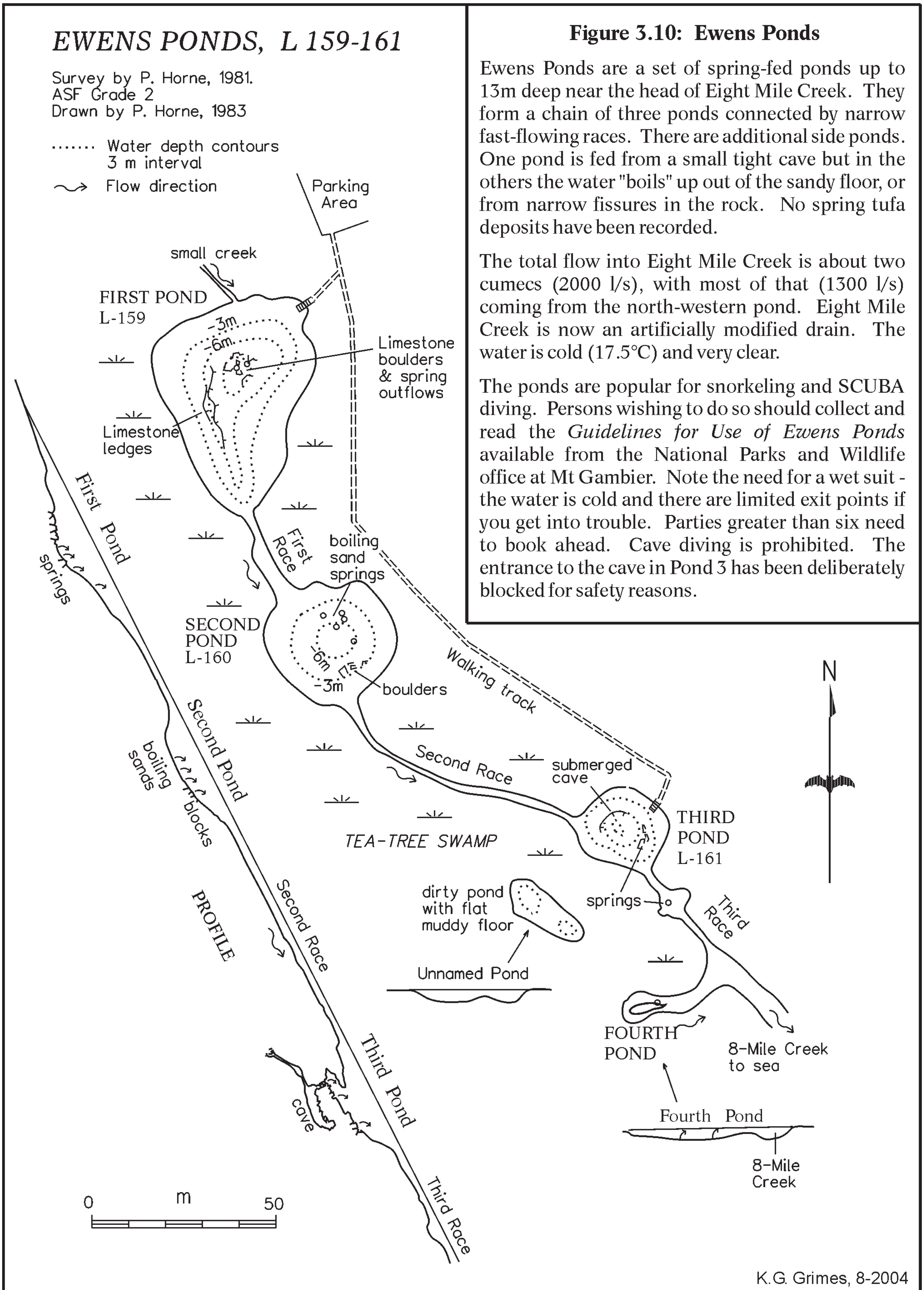


Figure 3.10: Ewens Ponds

Ewens Ponds are a set of spring-fed ponds up to 13m deep near the head of Eight Mile Creek. They form a chain of three ponds connected by narrow fast-flowing races. There are additional side ponds. One pond is fed from a small tight cave but in the others the water "boils" up out of the sandy floor, or from narrow fissures in the rock. No spring tufa deposits have been recorded.

The total flow into Eight Mile Creek is about two cumecs (2000 l/s), with most of that (1300 l/s) coming from the north-western pond. Eight Mile Creek is now an artificially modified drain. The water is cold (17.5°C) and very clear.

The ponds are popular for snorkeling and SCUBA diving. Persons wishing to do so should collect and read the *Guidelines for Use of Ewens Ponds* available from the National Parks and Wildlife office at Mt Gambier. Note the need for a wet suit - the water is cold and there are limited exit points if you get into trouble. Parties greater than six need to book ahead. Cave diving is prohibited. The entrance to the cave in Pond 3 has been deliberately blocked for safety reasons.

Little Blue Lake, a cenote south of Mt. Gambier (Site 11). See Figure 1.6 for cross-section.

plates on the walls up to 2 m above the present water level – indicating higher water tables in the past.

The syncarid, *Koonunga crenarum* is an obligate groundwater species (stygobite) found at Gouldens Hole which is endemic the groundwaters of the South East. Syncarids are regarded as 'living fossils' with an extremely conservative morphology that closely resembles their fossil ancestors. *K. crenarum* is the largest mainland species recorded to date and is thought to have Gondwanan origins.

The hole is an important training site for cave divers, and the wooden deck is for their access.

Site 13: Hells Hole (L-40)

This impressive, deep, sheer-walled, collapse doline is in a small patch of native scrub on the side of a high dune ridge in the Caroline Forest. A viewing platform allows one to see the water table lake 27metres below the surface. The water reaches depths of 26 m under the overhang (Figure 1.6). The vertical walls expose dune limestone in the upper part, and Tertiary Gambier Limestone lower down. Case hardening effects and weathering pockets can also be seen. This site is on both the National Estate register, and listed in South Australia as a Geological Monument.

Site 14: Allendale Sinkhole (L-11)

The Allendale Sinkhole first appeared in the roadway at the southern end of the town of Allendale East in the mid nineteenth century. It was filled in with rubble but reopened and was refilled several times. In 1971 the road was finally diverted around the hole which remains in the central island - fenced in but triumphantly defiant! The feature is a small water-filled collapse doline (cenote) that leads to a submerged cave 28 m deep that is a simple collapse dome continuing from the doline.

Site 15: Ewens Ponds (L-159, 160, 161)

Ewens Ponds are a set of spring-fed ponds up to 13 m deep near the head of Eight Mile Creek south of Nelson Road (see Figure 3.10 for details). This is a geological monument classified at national significance and is also listed on the Register of the National Estate.

Most of the originally extensive swamp has been drained and cleared for agriculture. However, the small conservation park containing Ewens Ponds supports a number of aquatic plant communities (Thurgate, 1999) including closed grassland communities of *Phragmites* and *Typha* with scattered emergent tea-tree thickets; and aquatic (open water) vegetation community within the pond basins and connecting streams. A diverse aquatic invertebrate community is also present that is dominated by insects, crustaceans and molluscs. Vertebrates include reptiles and amphibians such as tortoises and frogs. Fish include the rare Ewens pigmy perch (*Nannoperca varigata*). Waterbirds include the Pacific black duck, swamp harrier and straw-necked ibis. Mammals are poorly known but include the swamp rat and water rat.

Site 16: Mouth of Eight Mile Creek

The flow of 2,300 l/s through the mouth of Eight Mile Creek at the coast demonstrates the large volume of water that is rising from the karst springs in this area. Most of this (2,000 l/s) comes from Ewens Ponds.

Site 17: Piccaninnie Ponds (L-72)

Piccaninnie Ponds is one of the major springs on the coastal plain. The enclosing Conservation Park covers an area of 397 ha including 4 km of coastline. The main section of the park is comprised of shallow swamps (fen communities) surrounding a series of spring-fed lakes that have formed in karst depressions. The wetland area is bounded by a stable coastal sand dune system to the south and a low dune limestone range to the north.

The main spring system, Piccaninnie Ponds, is located near the centre of the park and is a complex system of wetlands, swamps and spring ponds. It includes the First Pond, which is a 10 m deep, gently-sloping bowl-shaped basin. This leads to The Chasm, a funnel-shaped, steep-sided feature that is over 90 m deep. A wide channel leads off the Chasm, terminating in Turtle Pond, a shallow 6 m deep basin. A large flooded phreatic chamber (the Cathedral) is located at the western end of the Chasm, and is over 33 m deep. The Chasm intersects the salt/freshwater interface and consequently the waters of Piccaninnie Ponds are brackish.

A walking track leads to the outflow point on the beach, where one can view the total flow from the system of about 1000 l/s.

The eastern section of the park is fed by several small shallow springs and there are two springs on the beach between here and the Victorian border. The ponds contain a very interesting aquatic flora and fauna (Thurgate, 1999), and are a major attraction to skindivers. Diving is by permit only – several divers have drowned in this cave.

Site 18: Glenelg River Gorge

The Glenelg River is a permanent river with its headwaters outside the limestone province. In this section it is incised into the limestone plain as a 30 - 45 m deep gorge. This tract of the river shows evidence of Pleistocene river piracy and major changes in river direction and mouth location.

The caves are small joint-controlled vadose systems found mainly in the Tertiary limestone; the overlying aeolianites only contain solution pipes or dolines which allow access to the underlying caves. These caves are concentrated in particular areas e.g. around Princess Margaret Rose Tourist Cave, and along small tributaries e.g. Dry Creek. From the river one can see cave entrances at several levels in the limestone. Most caves are now perched 3-5 m above current river level and formed when the river levels were raised by higher Pleistocene sea levels. They clearly formed considerably later than the caves in similar limestone at Naracoorte. Many of those at river level have outflowing streams. Active solution at the present river level is undercutting the cliffs to form notches and small cavities.

Site 19: Dry Creek

A meandering tributary of the Glenelg River has incised its channel, and then disappeared underground to leave a deep meandering dry valley. Limestone outcrops on the side contain rain pits and other poor-quality karren forms and there are several small caves. A side road leads down the valley to where it meets the Glenelg River.

Site 20: Princess Margaret Rose Cave (3G-6)

This show cave is a single joint-controlled fissure passage with extensive good decoration (Figure 3.11). A continuation of the cave (3G-3) opens into the river cliffs to the southeast, but there is no passable connection. Other caves occur in the area. Tracks lead down to the river, and to cliff-top view points. There is a pleasant bush camping area with cabins. The operation of the tourist cave has recently been privatised, but management of the Park remains with the government.

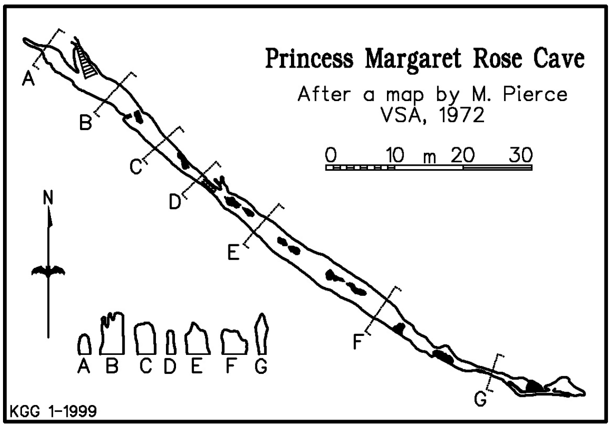


Figure 3.11: Princess Margaret Rose Cave in Tertiary limestone.

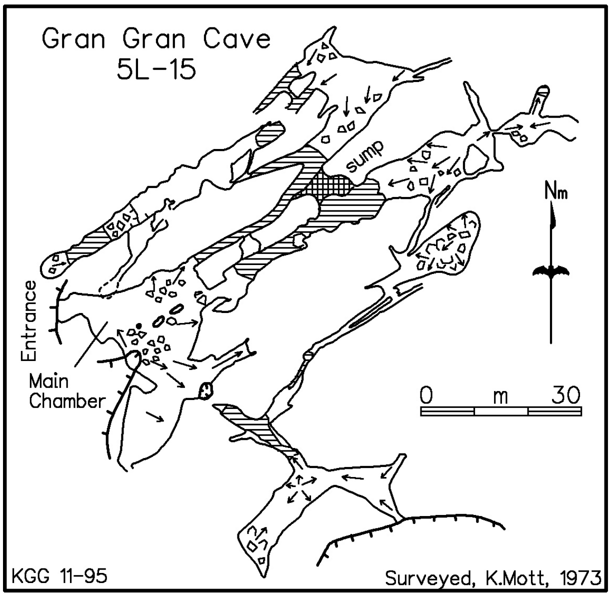


Figure 3.12: Gran Gran Cave is in jointed Tertiary limestone

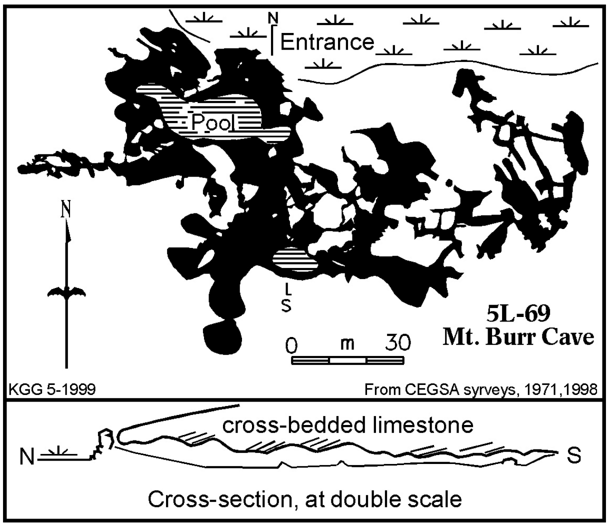


Figure 3.13: Mount Burr Cave is syngenetic karst in dune limestone. The pool size is that seen in 1992.

West of Mount Gambier

Site 21: Gran Gran Cave (L-15)

This cave is in the Tertiary limestone and is a set of joint-controlled phreatic passages and collapse chambers (Figure 3.12). The passage going east from the main chamber has sculptured roof pendants and a pronounced zone of phreatic spongework in the lowest 1m of the wall. Extensive pools occur, but the water levels fluctuate over time. As well as being a representative example of a Tertiary limestone cave, the site has special significance in the presence of both aboriginal markings and evidence of their mining of the chert nodules that occur within the limestone. The cave entrances have been gated but the matter of access has not yet been finalised.

Site 22: Mount Burr Cave (L-69)

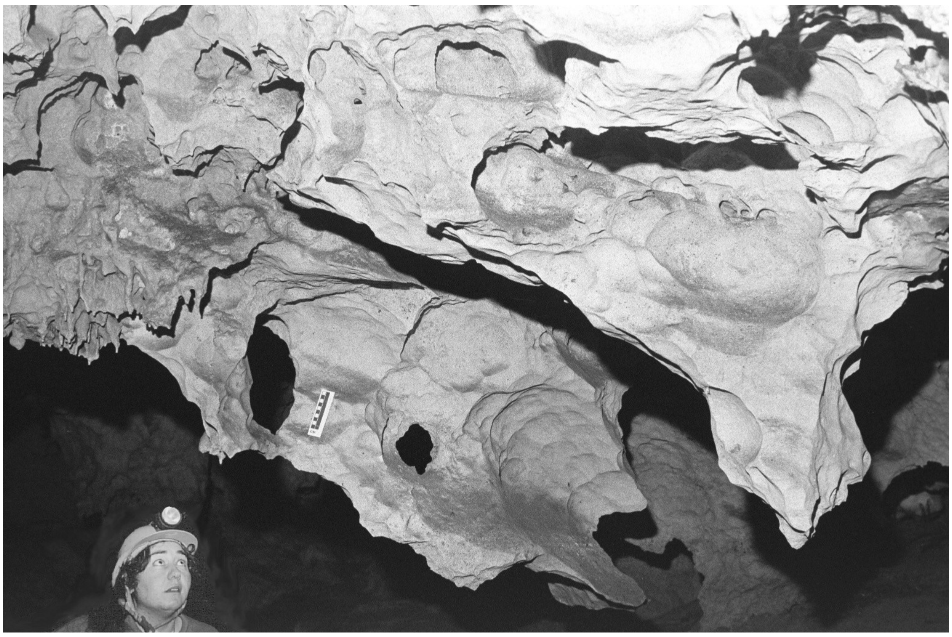
This is an extensive, horizontal, irregular, phreatic maze system developed in dune limestone at the level of an adjoining swamp (Figure 3.13). Parts have been considerably modified by collapse. The entrance chamber has excellent examples of phreatic spongework sculpture and used to contain a lake. The levels of the lake have varied in response to the vegetation on the surface, which is an exotic pine plantation. At the peak of the plantation growth the lake dries out. Following bushfires in 1983 the level rose about a metre to cover most of the floor of the chamber, but has fallen again in recent years as new pine forest has grown.

Site 23: The Wombat Holes (Glencoe Area)

The Wombat Holes, 5 km west of Glencoe, are in sandy soil at the edge of the high dunes. They consist of numerous deep basin-shaped subsidence dolines, a few small but deep uvalas, and one long swampy hollow which has been used as a rubbish dump by the council for many years. In 1983 alternative sites were looked at but the karstic nature of these made them less suitable than the current site which is in a perched swamp with about 9m of sandy clay underlying it. A waste transfer station was opened on the site in 1994 and the previous fill was capped.

Site 24: Tantanoola Tourist Cave (L-12) and Up-and-Down Rocks

Tantanoola Cave is a show cave beside the Princes Highway that is managed by National Parks and Wildlife, South Australia. It has a complex genesis (ASF, 1983).



Phreatic spongework in Mount Burr Cave, a syngenetic cave in cross-bedded dune limestone (Site 22).

The cave occurs in partly dolomitised Tertiary limestone behind the Up-and-down Rocks, which are an old sea cliff. This coast existed about 300 000 years ago, and the sea broke into an earlier phreatic chamber which was then modified by wave action and partly filled with marine sediments with well rounded pebbles and some bone material, including seal bones (Figure 3.15). These deposits were later cemented to varying degrees and then partly eroded. The final stage was one of extensive speleothem development.

The cliff face shows well-developed solutional pitting and many small irregular tubes. Some of this could be a type of surface karren, and some might be exposures of older phreatic solutional tubes and cavities. On the ridge above the cliffs there are small, linear pavements of limestone flush with the soil which contain occasional solution pans and tubes. Apart from some grikes immediately beside the cliff there is little karren development.

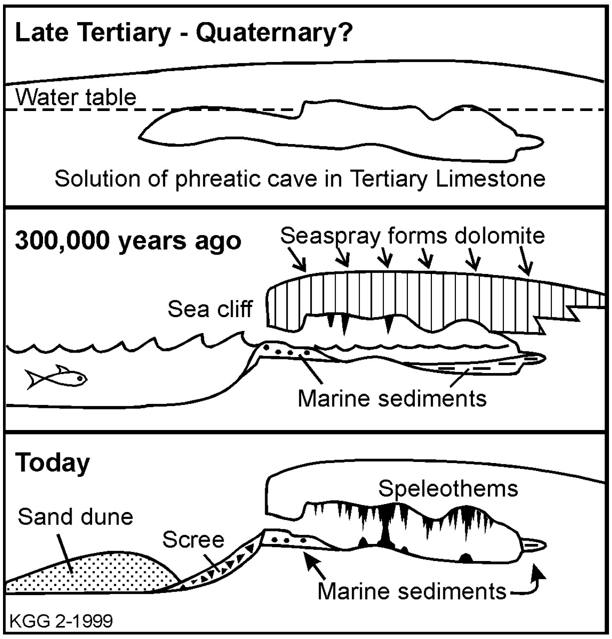


Figure 3.15: Stages in the development of Tantanoola Cave (not to scale)

Site 25: Morgans Cave (L-34)

Morgans Cave is a good example of a complex joint-controlled fissure system in the Tertiary limestone, albeit rather spoilt by abundant graffiti. Adventure caving tours can be arranged via the Tantanoola Tourist Cave. The entrance is a nice example of a solution pipe that leads to the main fissure. To the southeast is a single fissure choked with tree roots from the pine plantation above and a final pool. To the northwest the fissure leads to an area of mazy crawls along two intersecting joint sets. Note that the broad areas on the map (Figure 3.16) are not chambers, but areas of low flatteners alternating with higher fissures.

Site 26: Stone Pit of Stafford & Earl Quarry

This privately owned quarry produces Gambier Stone for buildings. Access is by prior arrangement only. The stone was previously cut out of the soft limestone with wire saws, but circular saws are now used. The site has good examples of solution pipes and other epikarstic features and soil profiles exposed in the pit walls.

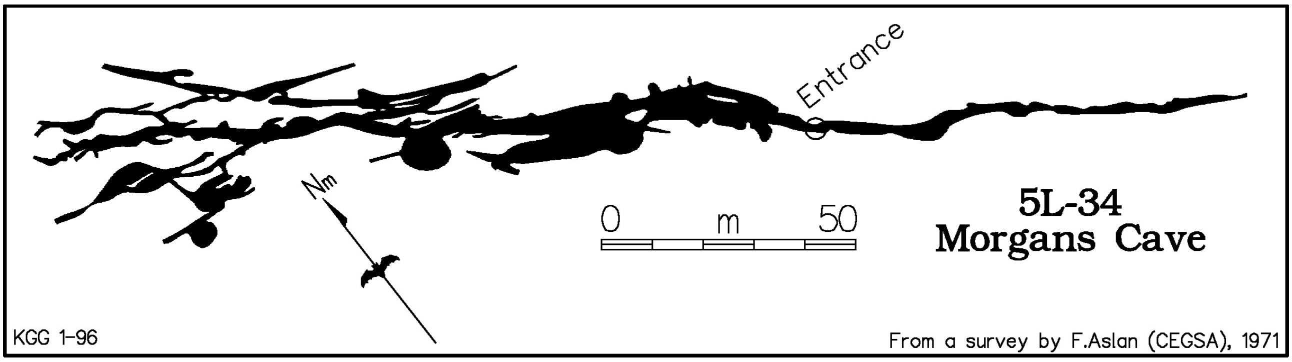


Figure 3.16: Morgans Cave shows strong joint control in the Tertiary limestone.

VICTORIAN SITES

Susan White, Ken Grimes

INTRODUCTION

This section describes the coastal soft-rock karst of western Victoria along with associated volcanics and volcanic caves.

WEST VICTORIAN KARST AREAS

In Victoria the Tertiary limestones are variable in their purity, and only limited parts of the outcrop region show significant karst development. The main areas of Tertiary caves and karst are the Glenelg River area (including Kentbruck and Drik Drik) in the west, and Warrnambool and Timboon in the east (Figures 1.1 & 4.1). Quaternary dune limestones host syngenetic karst and caves such as those at Bats Ridge and Codrington. In addition, there is the coastal scenery that is a world-famous feature of the coast east from Warrnambool. More detailed descriptions are given in White (1989, 1995a,b, 2000a).

COASTAL AND SYNGENETIC KARST OF THE PORTLAND AREA (SITES V-1 TO V-4).

Site V-1: Bridgewater Lakes and Caves.

The best view is from the road at the top of the hill north of the lakes. The lakes resulted from drainage disruption by the coastal dune barriers. The caves are relict sea caves in an old sea cliff that may also be fault-controlled. In the Bridgewater area much of this former coastline has been obscured by younger mobile dunes.

Site V-2: Cape Bridgewater and Cape Duquesne.

Cape Bridgewater has a number of sea caves in the Pliocene tuffs and basalts. The volcanics are overlain by the Pleistocene calcarenites so both the sea cliffs and the caves show tufa and other secondary calcite deposits derived from calcite saturated springs. An area on Cape Duquesne has been called a ***"Petrified Forest"*** from the tree-like features. These features are actually solution pipes which are quite common in the calcarenites of

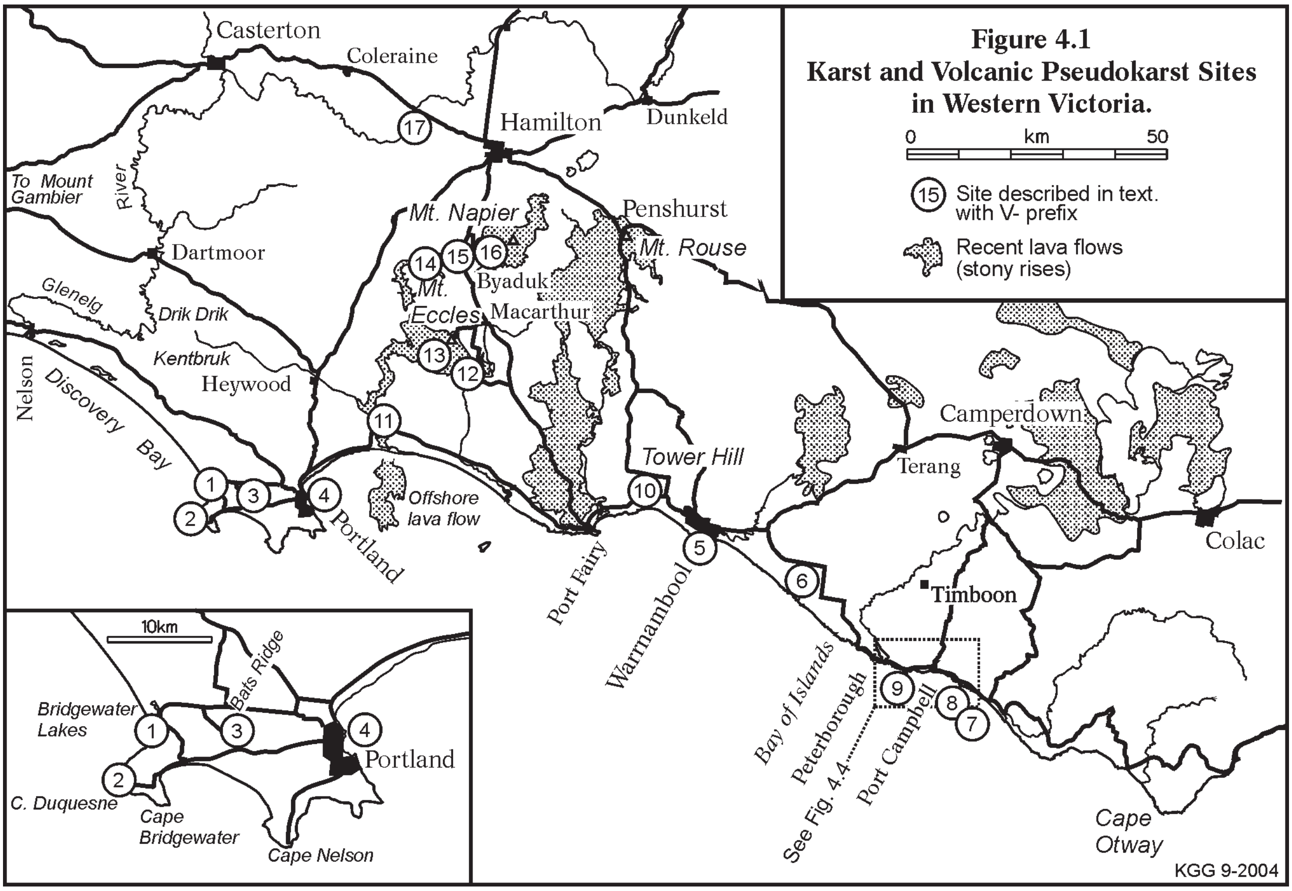
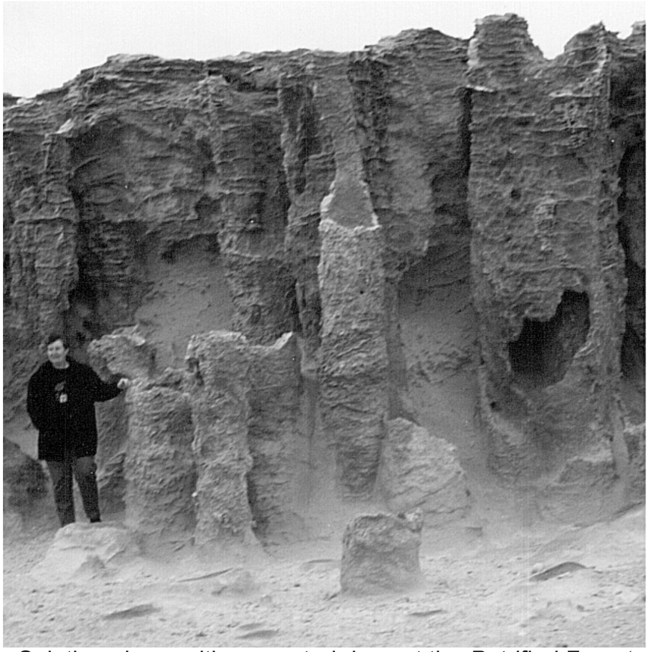


Figure 4.1
Karst and Volcanic Pseudokarst Sites in Western Victoria.



Solution pipes, with cemented rims, at the *Petrified Forest* (Site V-2).

the Bridgewater Formation. However, the concept of the "buried forest" still lingers on (Grimes, 2004). The pipes at Cape Duquesne have formed syngenetically by solution of the dune limestone. They were infilled with calcareous sand or soil which was then cemented and later exposed by further erosion. The smaller hard root-like bodies are rhizomorphs, formed by calcite cementation adjacent to plant roots that have grown down through the dune sand.

In several places you will see bare, eroded surfaces, where attempts have been made at stabilisation and re-vegetation. Surface erosion increased dramatically after the introduction of rabbits in the 19th century but present day management practices appear to have reduced it. Erosion is exacerbated by the extreme weather conditions experienced in this area

Spring tufas form extensive terraces and ponds at 'The Springs', two km north from the parking area at Cape Duquesne. Along the walking track you will pass areas with dune cross-bedding, calcrete bands, rhizomorphs, and solution pipes. At an unnamed lookout 1,800 m from the car park (230 m SE of the Springs Lookout), look down to see polygonal jointed basalt with some large (5-10 m) circular structures that Boutakoff (1963, p35) thought were large gas bubble vents; can you think of a better explanation?

Climb down the cliffs at a post 150 m beyond the 'Springs Lookout' and head back to the south. **Warning:** do this only when the sea is calm, several people have been washed off the platforms at the base of these cliffs by unexpected waves. Half way down you pass a palaeosoil in the cross-bedded dune limestones which includes solution pipes with a reddish soil fill. At the base of the cliffs, which is the contact between the limestone and the basalt, springs emerge and the water has built up large platforms of tufa with pools and overhung edges. Walk south around a headland to see a set of small streams cascading down a large tufa mound. This stream is fed from a small cave. In places the tufa has grown over and enclosed the channels.

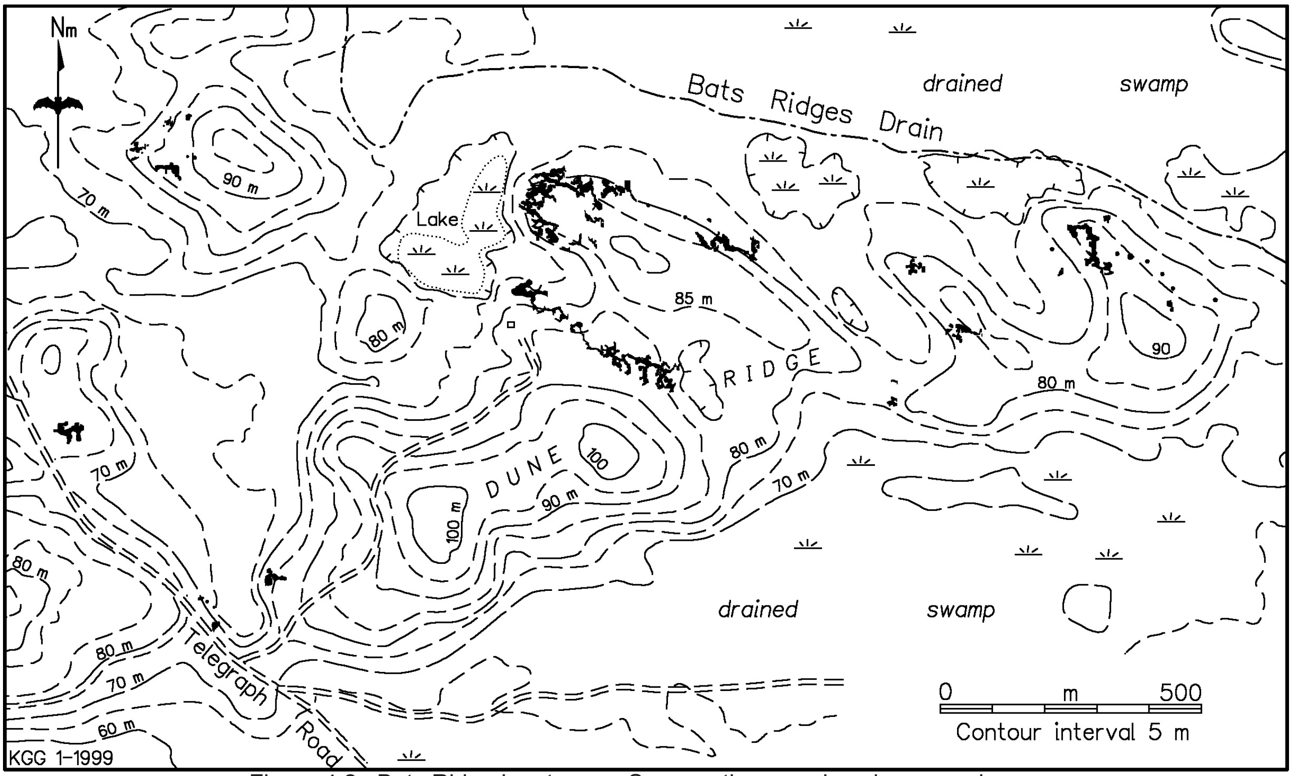


Figure 4.2: Bats Ridge karst area. Syngenetic caves in calcareous dunes.

Site V-3 Bats Ridge

This area is best visited with a guide as many of the features are hard to find in the thick scrub. Access is via Telegraph road, then down an overgrown track to the hut. The ruins of an old lime kiln can be found hidden in the undergrowth in one place.

The Bats Ridge area is a particularly intensive example of syngenetic karst caves developed in Pleistocene dune calcarenites (White 1989, 1994, 1995b, 2000a). The dune limestone here has been dated by TL at 290,000 ±34,000 years old (White, 2000b).

There are peat swamps on both northern and southern sides of the main dune ridge. The swamps to the north are more complex and connect with swamps in the swales between the spurs (Figure 4.2). The ridge has the appearance of a longitudinal strandline dune which has been subjected to "blowouts" at right angles to the dune axis during periods of sand instability. The large enclosed depressions appear to be swale lakes modified by solution.

The caves are shallow sinuous horizontal systems, often with a number of entrances. They have formed horizontally under a hardened cap rock or calcrete layer. Some solutional chambers and broad flatteners are preserved, but collapse has extensively modified the entrance, passage and chamber shapes (Figure 4.3). The cave floors, as well as having rock piles, are covered with clastic sediments derived predominantly from the insoluble residues of the calcarenite host rock. The caves contain a range of calcite speleothems including large expanses of moonmilk. Solution pipes, roof avens and bell-holes are common. However, no soil-filled pipes were found at Bats Ridge, despite their presence in other areas of Bridgewater Formation.

Syngenetic karst processes are clearly present. The caves have developed on the spurs of the main ridge (Figure 4.2) and at the top of a previous water table, about 5 to 8 m above the present water table. This concentration may be a consequence of the influence the small swampy depressions and lakes have had on the aggressiveness of the ground water, or may be related to varying water-tables and mix-water corrosion at times in the past when the sea was nearby.

Site V-4: Whalers Bluff, Portland

In the cliffs of Whalers Bluff in Portland, a Pliocene paleokarst is developed in the Miocene Port Campbell Limestone. As well as the karstic unconformity seen in the upper part of the cliffs, where the limestone is overlain by Pliocene sediments (Whalers Bluff Formation) and volcanics, the lower parts of the cliffs expose many small solutional cavities and channels that are filled with a grey mud which is part of the Whalers Bluff Formation (Boutakoff, 1963, p.23.).

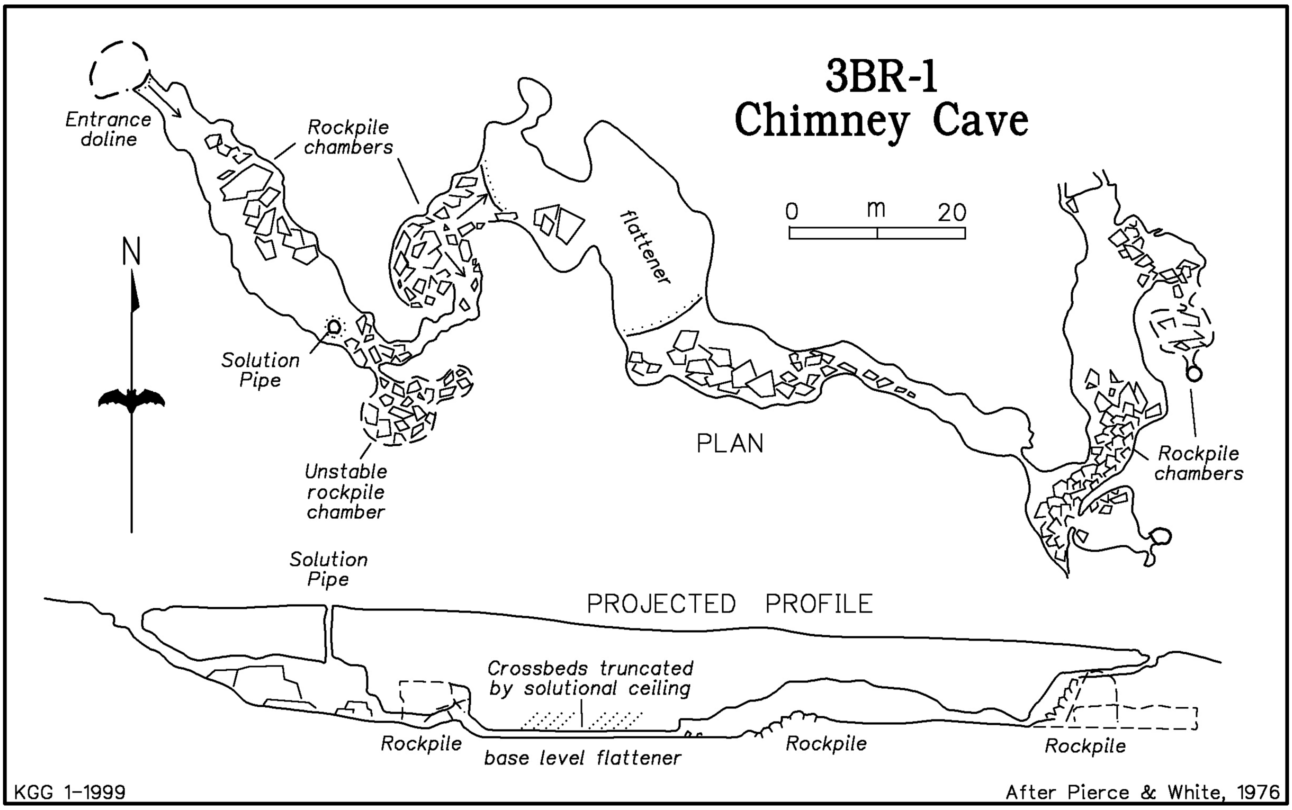


Figure 4.3: Chimney cave, at Bats Ridge, shows syngenetic characters modified by collapse.

Coastal Karst of The Great Ocean Road (Sites V-5 to V-9).

Site V-5: Bat Maternity Cave, Warrnambool

Warrnambool city is built on top of dune limestone at about 50 m ASL. A major bat maternity cave (3W-8) was reported by Dwyer (1969) in the actively eroding sea cliffs at Warrnambool; but the cave was being threatened by wave erosion. In 1991 the bats were still present, but it was uncertain if they were using the site for breeding. In January 1998 the main breeding dome had been partly breached and no bats were present (Ackroyd, 1998). The bats have moved to the larger Starlight Cave (3W 5) which has its entrance in a sea cliff 10 km to the southeast, but is a true karst cave modified by marine action. Starlight Cave was originally a transition site for bats on the way to the old bat maternity site. It has been suggested that concrete caps be placed on some of the pipes at the original maternity site (3W-8) and that a temporary cap be tried at the daylight hole above the dome which is now being used at Starlight Cave to improve conditions there (Ackroyd, 1998).

Coast from Warrnambool to Twelve Apostles.

See Figure 4.4. The Tertiary limestone has cliffs up to 60 m high topped by calcareous and or siliceous sand in some places. The limestone plain has a number of karst features. Dolines up to 300 m in diameter have developed in an area with very little surface drainage. The Tertiary Limestone is thinly bedded and has concretions and secondary limestone deposition along the seaward-dipping beds. Prominent vertical jointing which strikes north-east controls the gorge and promontory formation; vertical and 45° jointing controls cliff development and cave formation. The area shows a wide range of spectacular features including reefs, offshore stacks, overhanging cliffs, hanging valleys up to 50 m above present sea-level, wave cut benches and notches at various levels. About 45 caves are recorded at the cliff base with several about 5-10 m above present sea level.

Site V-6: Doline field east from Allansford

Between Allansford and Peterborough there is an extensive field of large subsidence dolines developed in Tertiary limestone. There is an extensive limestone cave system at Childers Cove in the west section of the Bay of Islands Coastal Park.

Site V-7: Twelve Apostles:

These impressive limestone stacks extend along several kilometres of coast east of Loch Ard Gorge. They are the best examples of the rock stacks along the coast and show prominent basal notches. The taller stacks are 50 m high.

Site V-8: Loch Ard Gorge:

Loch Ard Gorge is developed along close jointing in the Tertiary Limestone and has a narrow entrance widening to form two small bays separated by a headland (Figure 4.5). A stairway gives access to the beach. There are two small caves, both of which have well-developed speleothems. The eastern cave receives water from an underground stream as well as from percolation through the porous limestone and it may be a karst cave

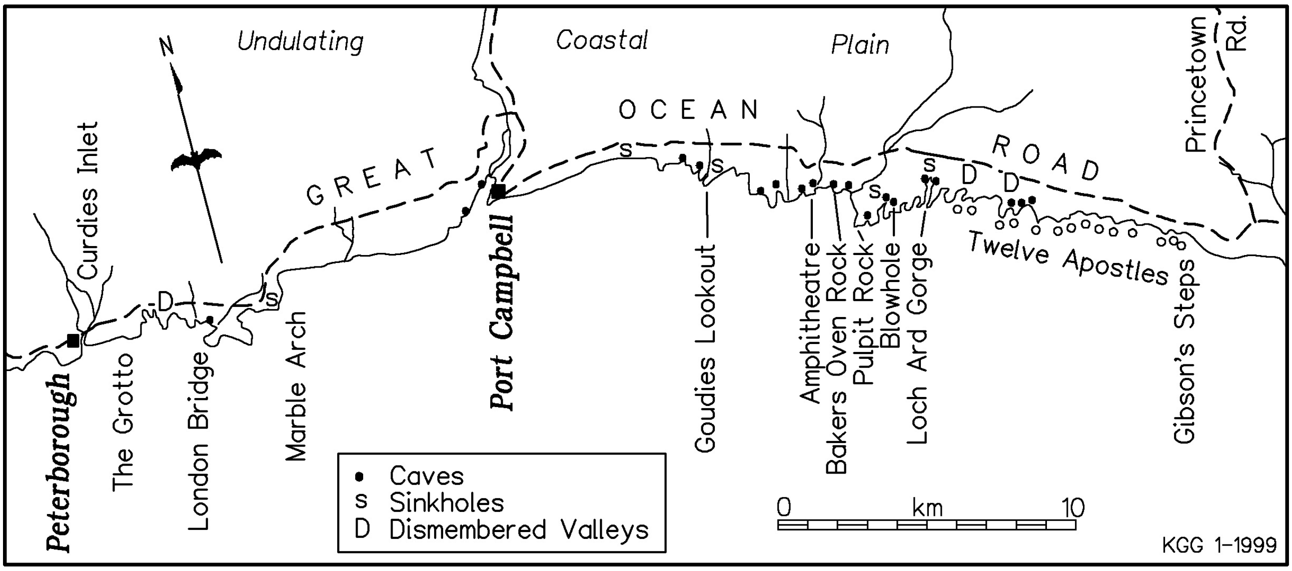


Figure 4.4: Features of the Port Campbell coast, after Baker (1943).

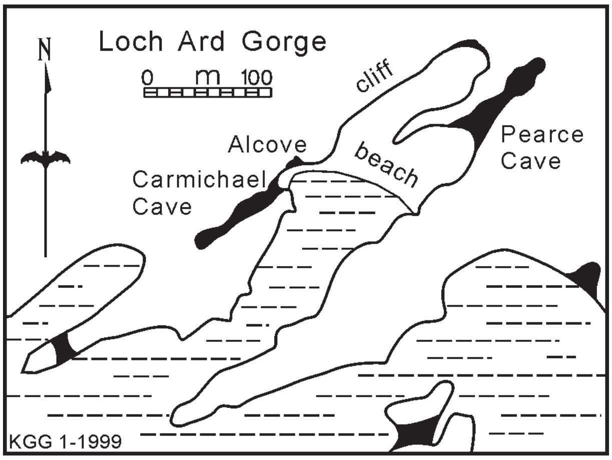


Figure 4.5: Loch Ard Gorge and its caves.

that has been modified by the sea. The western cave (accessible at low tide) has 'sand speleothems' (Grimes, 1999) formed by cementation of sand below drip points followed by the removal of the surrounding uncemented sand (the best examples are actually hidden in the back of a small rock shelter you pass on the way to this cave). The Gorge is named after the clipper "Loch Ard" which was wrecked in 1878 and the caves (Carmichael's Cave and Pearce's Cave) are named after the two survivors who sheltered in them.

The Blowhole, 600m to the west of the main gorge, is an 18 m deep overhanging collapse doline above a cave which connects to the sea 100m away. The cave is incompletely explored, as th econstantly surging waves make it dangerous, but a line of hollows can be traced inland for 1000m.

Site V-9: Other coastal features:

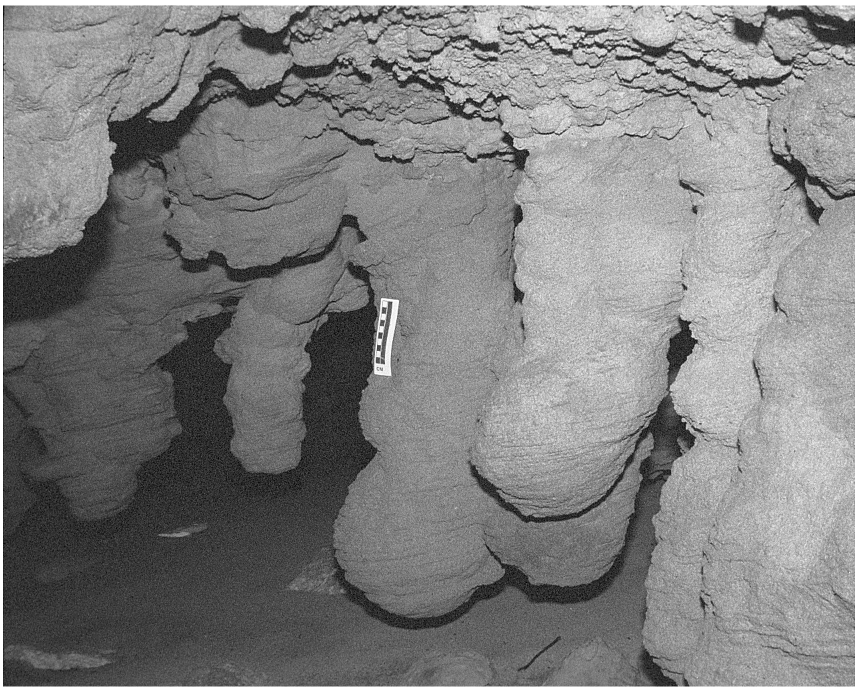
A series of features along the coast show the interaction of marine and karst processes. From west to east some good sites are shown on Figure 4.4: West of Peterborough a field of basin-shaped dolines lies inland of ***the Bay of Martyrs & Bay of Islands*** which have undercut red limestone stacks and fretted limestone outcrops. In the ***Curdies Inlet*** area there is syngenetic karst and a collapse doline. East of Peterborough ***The Grotto*** is a dissected sinkhole opening onto the cliff through an archway and contains a boulder beach 13 metres above present sea level. One of the more spectacular sites is the remains of ***London Bridge*** which was once a promontory with two arches. In 1990 the larger arch collapsed leaving an arched rock stack, and stranding several tourists on the far end! West of Port Campbell ***The (Marble) Arch*** is small but nice, with a floor 6 m above sea level. Further east ***Bakers Oven Rock*** is a rock stack that has a tunnel 6 m above present sea level.

Volcanic Caves and other volcanic features (Sites V-10 to V-16)

Site V-10: Tower Hill

There is a good viewpoint right beside the highway. Although not a karst feature, this is worth a stop. A useful booklet by Orth & King (1990) can be purchased at the Information Building within the crater. About 30,000 years ago rising molten magma intersected the water-saturated Tertiary limestones and the resulting steam pressure "blew the top off" to form the crater. The

Sand speleothems in an alcove at Loch Ard Gorge. The cave was filled by loose beach sand, which was then locally cemented by water percolating through it from the porous limestone above. Later erosion exposed the cemented parts. Scale bar is 10 cm.



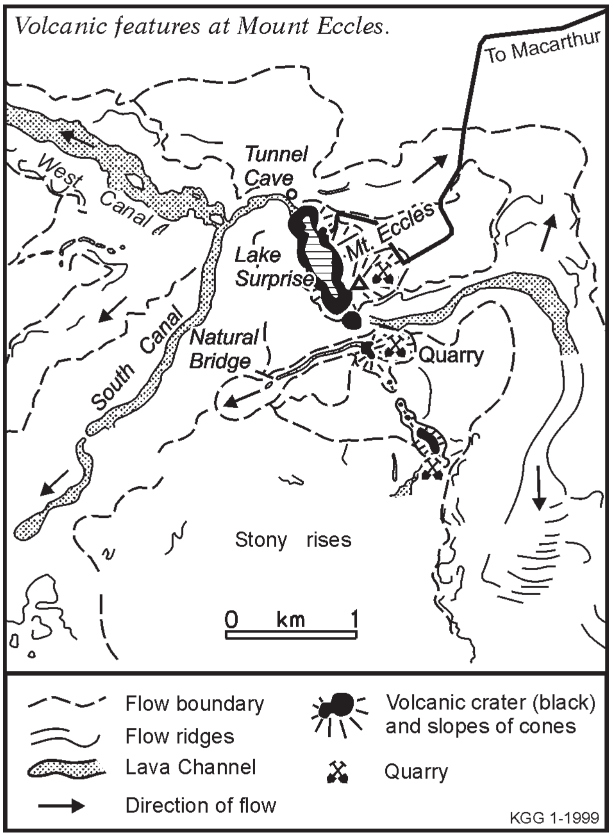


Figure 4.6: Mount Eccles area.

central group of cinder cones built up during the waning stage of the volcanism.

Twenty years ago the cones in the centre of the crater were bare of timber, and the detailed volcanic features were much easier to see. An intensive revegetation program has hidden much that would be of geological interest. Such programs should concider all heritage and conservation values of a site.

Site V-11: Tyrendarra Flow

Between Darlot Creek and the Fitzroy River, which are twin lateral streams, the highway crosses the Tyrendarra lava flow. This flow, which appears to be at least 27,000 years old, has come all the way from Mt. Eccles 25km to the north, and continues for 15 km out across the present ocean floor which was dry land at that time.

Site V-12: Stony Rises near Gorrie Swamp

The road crosses an area of black basaltic lava with many deep hollows which would have resulted from sagging of the still-plastic crust as liquid lava was partly drained from beneath.

Site V-13: Mount Eccles Area

This is a major stop, and visitors should allow several hours to visit the different sites (Figure 4.6). The area is infested with Koalas, and you will notice that the foliage on many of the trees is quite sparse. A control program is presently underway, which aims to sterilise up to 1,000 female animals from this site each year.

The main volcano has a deep steep-walled elongate crater which contains Lake Surprise. The crater wall has been breached at its north-western end by a large lava channel (or “canal” as they are called locally). A line of smaller spatter and scoria cones and craters extends to the southeast from the main crater (Figure 4.6).

A small but well-defined lava canal runs southwest from one of these smaller cones and ends at the Natural Bridge, which is a roofed over section of the canal.

The longer and more complicated caves known at Mount Eccles are beyond the reach of a quick visit. These caves are generally formed in the levee banks on the sides of the lava canals and would have fed small lateral lava lobes or sheets when the canal overflowed. Some are simple linear feeder tubes, but many have branching forms and complexes of low broad chambers which suggest draining from beneath the solidified roof of a series of flow lobes (see Figure 2.3 and Grimes, 1995, in press).

Main Lookout

Below you is the crater and present lake, which is about 14 m deep. The lake is at the level of the regional groundwater, and its level fluctuates by several metres. To the left is the small peak of Mount Eccles. At the time of the eruption the crater would have been filled with a lake of liquid lava, with a large roaring fountain of lava spurting up several hundred metres into the air. The lava droplets from the fountain would have frothed and partly solidified as they fell, and were also blown to the east by a westerly wind to build up the peak, which is composed of loose or partly-welded scoria (frothy lava fragments). The cliffs below you and visible on the far side are solidified lava that overflowed from the crater lake. The main overflow point was at the north-western end where a major lava channel runs away from the crater.

Tunnel Cave, H-9

Tunnel Cave is an easily accessible cave, right next to the walking track where the big lava canal leaves the main crater. Lights are needed to see the far end of the cave. A detailed leaflet describing this cave can be obtained from the information centre.

It is a typical lava tube, with “railway tunnel” dimensions and shape. The flat floor is the top of a solidified lava pool. As you walk into the cave the roof becomes lower and eventually reaches the floor. The

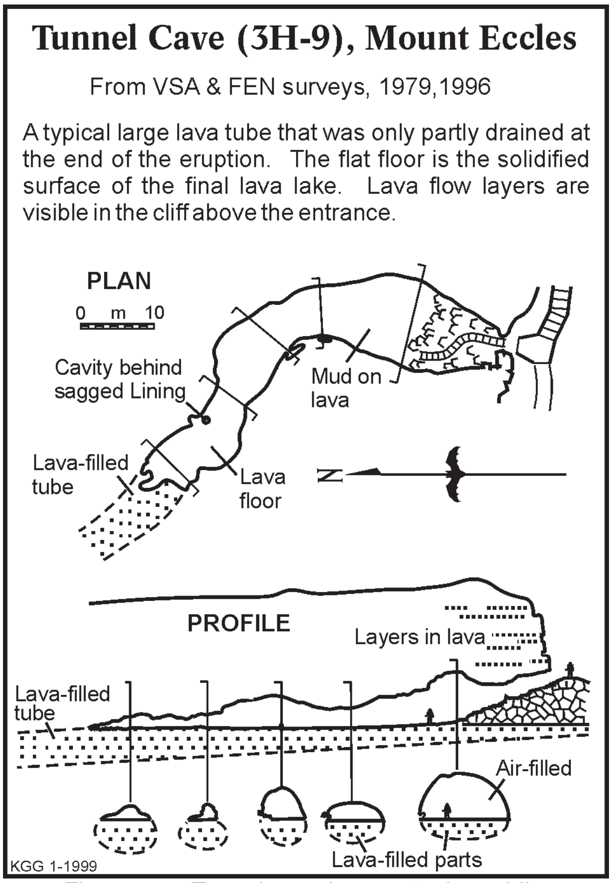


Figure 4.7: Tunnel cave is open to the public.

tube would originally have continued but is now blocked by solid lava (Figure 4.7). Features of interest are the lava bench on the left side near the entrance, and further in there are lava drips, a ropy lava floor and a sagged wall lining that has opened up a gap behind it.

Crater Rim Walk.

This walk passes Tunnel Cave and circles around the far side of the main crater. A turn-off leads to a smaller crater, the first of a chain of craters running off to the southeast. These may have formed along a fissure eruption. Another shallow lava channel runs off to the east from the dry crater (Figure 4.6).

Quarry

This scoria quarry is no longer operating, but there is a newer quarry about one kilometre to the southeast hidden behind and cut into another volcanic cone. A complete scoria cone has been removed here, what remains is just the small portion visible on the far side. Quarrying is a major problem for those who wish to preserve the volcanic landforms of the area. The scoria from the volcanic cones is a much-sought road-surfacing material. The only alternative over much of the volcanic plains is crushed basalt - which is more expensive to produce (Guerin, 1992).

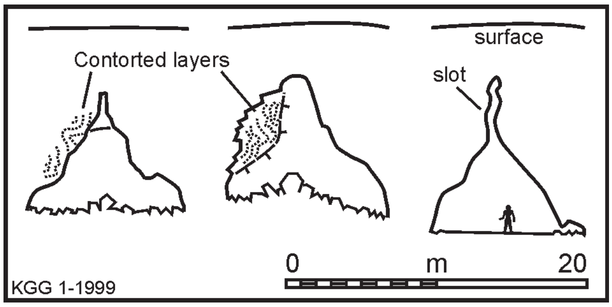


Figure 4.8: Cross-sections of Natural Bridge, showing the "gothic" roof and contorted layers.

Natural Bridge (Gothic Cave) H-10

From the crater near the quarry a small lava channel runs off to the south-west (Figure 4.6). At the end part of the lava channel has been roofed over to form a short section of cave (Figure 4.8). The pointed, 'gothic' roof of this cave suggests that it was roofed by levee overgrowth (Figure 2.3). The contorted layers visible in its walls would be linings that were built up and then slumped while still hot.

Site V-14: Wallacedale Tumuli.

A Tumulus is a steep-sided mound of lava crust that has been pushed up above the lava surface. The solidified crust above the liquid core of a lava flow generally forms irregular mounded surfaces known as Stony Rises. However, in a few places, the movement is localised


A tumulus at Wallacedale - the lava crust has been pushed up by pressure from below.

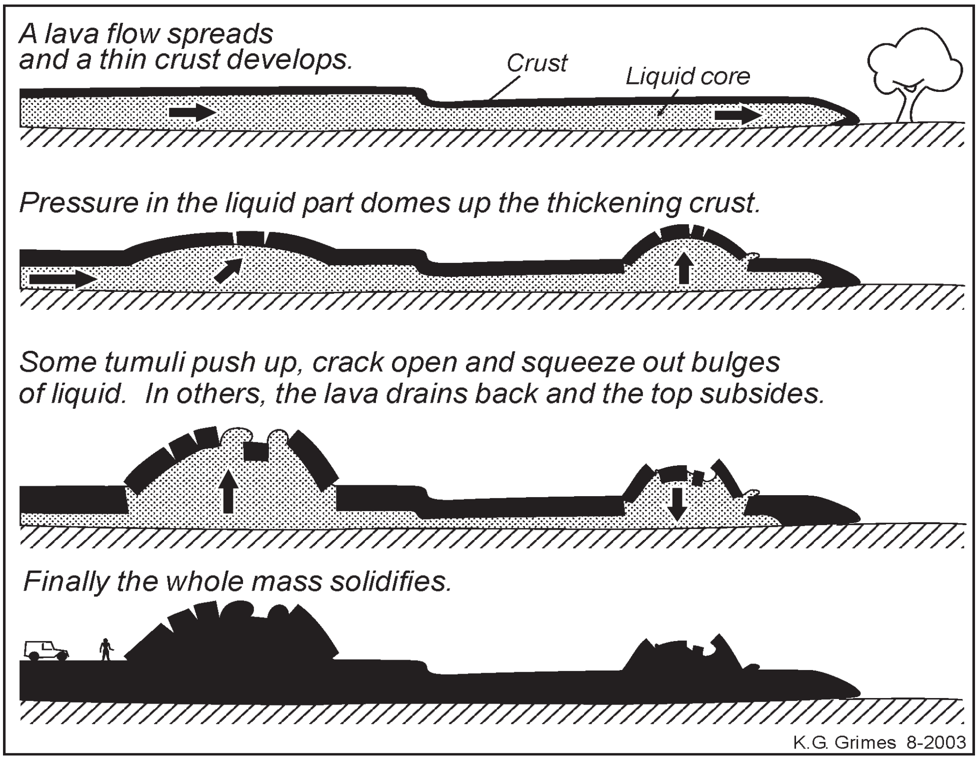


Figure 4.9: Development of tumuli on the surface of a crusted lava flow

to small "soft spots" in the crust which are pushed up to form discrete steep-sided mounds the size of a house rising above a relatively flat surface (Figure 4.9). A close look shows tilted remnants of the original crust's surface split apart by gaping cracks on the sides and top of the mounds and in places small tongues of liquid lava have been squeezed out through the cracks. Even more rarely one finds that the liquid core has drained back down to leave a central hollow and a "donut" ring, or perhaps a small cave within the tumulus.

While Stony Rises are a common feature, steep-sided tumuli are rare, and the tumuli seen in the Harman Valley flow are the best examples in Australia.

Site V-15: Harman Valley Viewpoint

A good view point on the Hamilton - Port Fairy Road looks up the Harman Valley towards the volcano of Mount Napier. The mountain is a composite volcano with a broad, timbered, lava shield capped by a steeper, bare, scoria cone formed by explosive activity at the end of the eruption. Below the lookout one can see the lava flow (about 32,000 years old, Stone and others, 1997) that came down the valley from the mountain. This flow was fed by lava tubes, some of which can be entered at the Byaduk Caves (Site V-16). One can see a lava channel below and to the right of the lookout.

A recent threat to this view, and to our recent lava flows in general, has arisen from the development of heavy machinery which can crush the rocky surfaces of the "stony rises" - allowing its use for improved pasture, but destroying the surface lava features, and potentially collapsing any shallow lava caves. Several areas in the

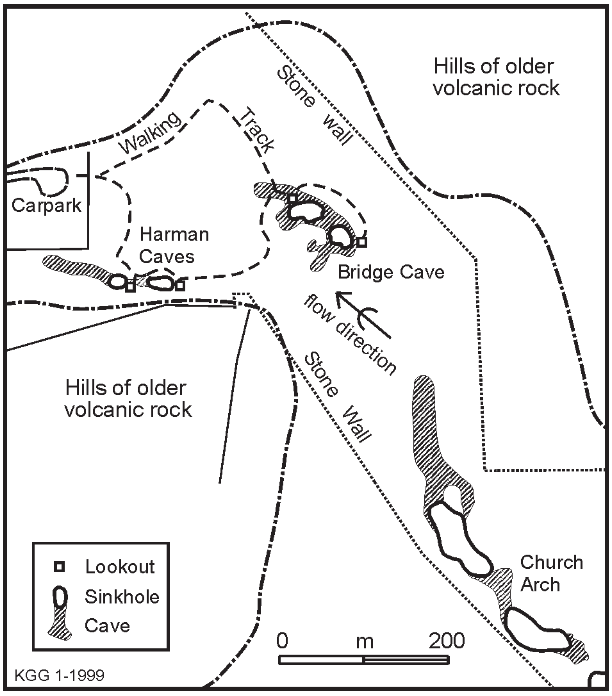


Figure 4.10: The Byaduk Caves are a line of large partly-collapsed lava tubes.

valley below you have been crushed and "smoothed" in this manner, but the major features are still visible.

Site V-16: Byaduk Caves

This lava flow, which came from Mount Napier, is the same one as that seen at Sites V-14 and V-15. It was fed by large lava tubes which would have formed by the roofing of lava channels (c.f. Figure 2.2). In the Byaduk Caves area collapse of parts of the main feeder tube has exposed the largest and most spectacular lava tubes, arches and collapse dolines in the region (Ollier & Brown, 1964, Grimes & Watson, 1995). The largest tunnels are up to 18 m wide and 10 m high. There are also some smaller but more complicated caves, and a multilevel system which has a shallow surface maze, and two lower levels connected by lava cascades and chutes where the lava drained downward to the lowest level. A walking track and viewing platforms with interpretation signs have recently been constructed.

Harman Cave, H-11

This large lava tube has been extensively modified by collapse, but some relicts of the original form can still be seen (Figure 4.11). In addition, the small "blister" near the western lookout, called Turtle Cave, is a shallow "drained-lobe" cave on the surface of the flow (c.f. Figure 2.3).

Bridge Dolines, H-13, H-14

The walking track leads to a pair of connected large collapse dolines over what would have been a large lava tube. Little of the original tube remains.

Church Arch, H-16

This is a spectacular arch connecting two long sections of collapsed tunnel. The tunnel is about 12m high, 25m wide and 60m long. One can see thin lava benches on the wall in places, and elsewhere the lining has broken away to reveal layers of lava that would have overflowed from the original open lava channel as the valley filled up. The cave has not been included in the walking trail at this stage as any track would have to go past another obvious cave that is important for bat habitat.

Site V-17: Wannon Falls

This stop is on the Wannon River, west of Hamilton (Figure 4.12). This is a classic hard-bed-over-soft style of waterfall (Figure 4.13). A hard, early Quaternary(?), basalt flow overlies soft Tertiary sediments. The water falls vertically for 30 metres and scours out a plunge pool in the soft rock and undermines the overlying hard rock to form a vertical undercut waterfall. The falls have migrated upstream for several kilometres to leave a narrow gorge.

Contrast this form with the Nigretta Falls, 10km upstream, that are in an older, massive, but jointed, rock (Figure 4.14).

The lava flow appears to have run **up** the river valley! It originated from a volcano to the east, and ran down a tributary valley to enter the Wannon valley 4km to the south of here. Most of the lava flow continued down the Wannon valley, but the flow was quite thick and confined by the valley so that some of the lava backed up the Wannon to this spot (see map, Figure 4.12)

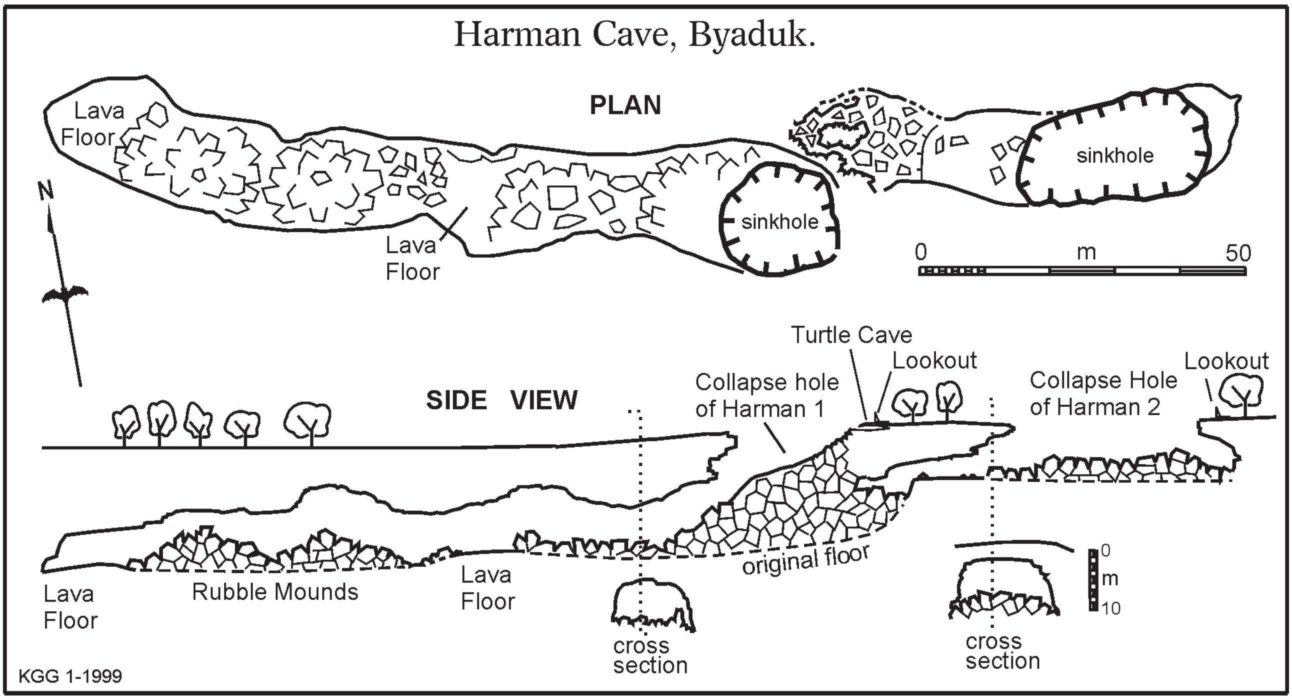


Figure 4.11: Harman cave, Byaduk, is a large lava tube modified by collapse.

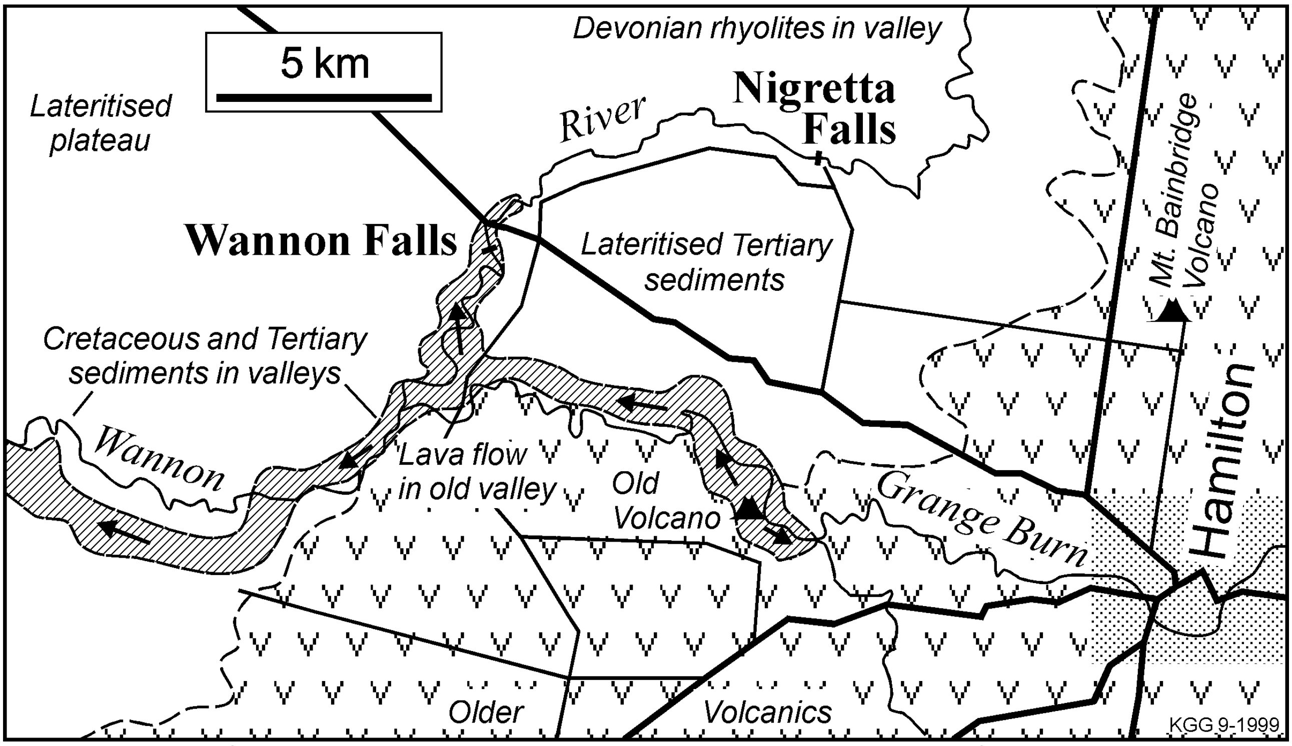


Figure 4.12: Map of the Wannon area showing older volcanics (VV) and the younger lava flow (shaded) that ran down the Grange Burn and backed up the Wannon River valley. Arrows indicate lava flow directions.

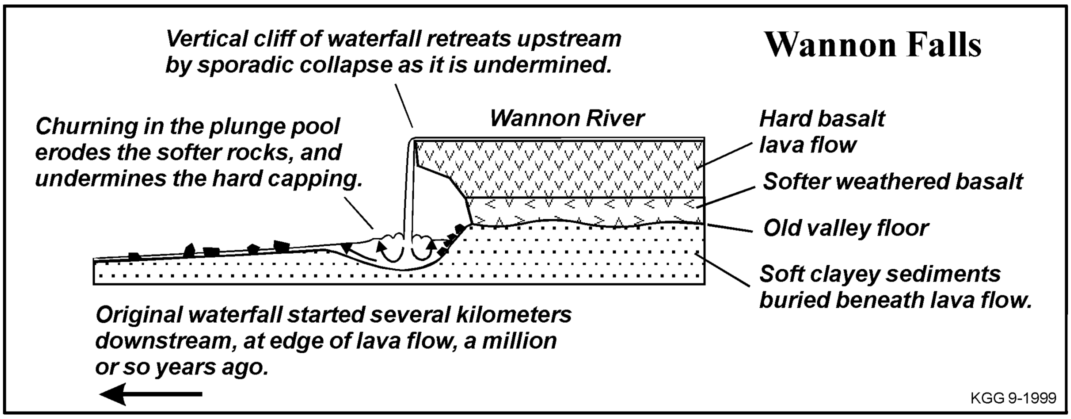


Figure 4.13: Section through the Wannon Falls, showing geological structure.

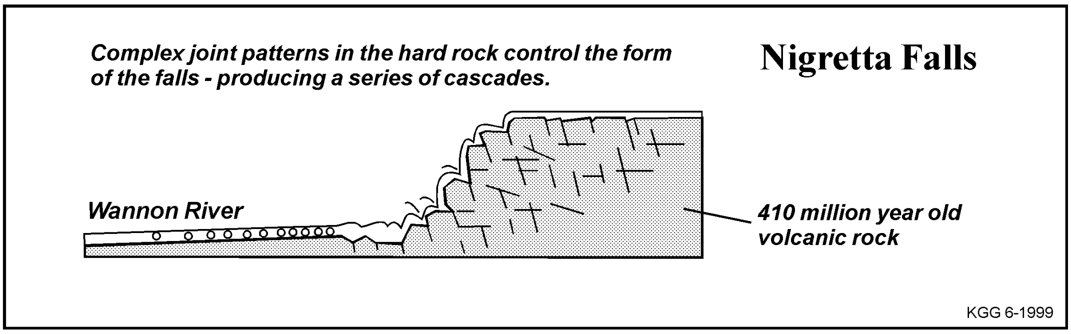


Figure 4.14: Section through the Nigretta Falls, showing geological structure.

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