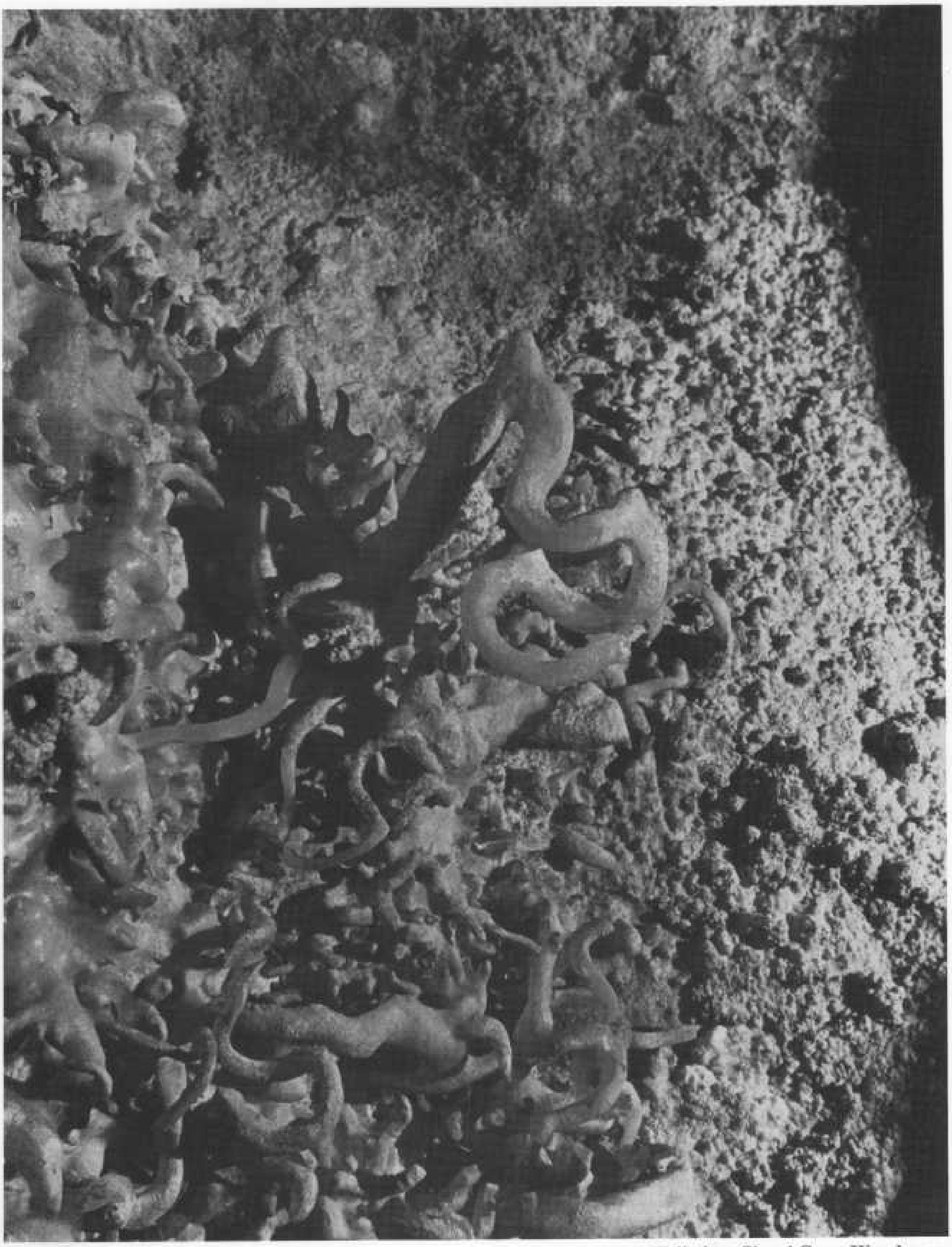
VOLUME 27 (2) 1989

Helictite

JOURNAL OF AUSTRALASIAN CAVE RESEARCH



D. J. Martin Helictites, Shawl Cave, Wombeyan

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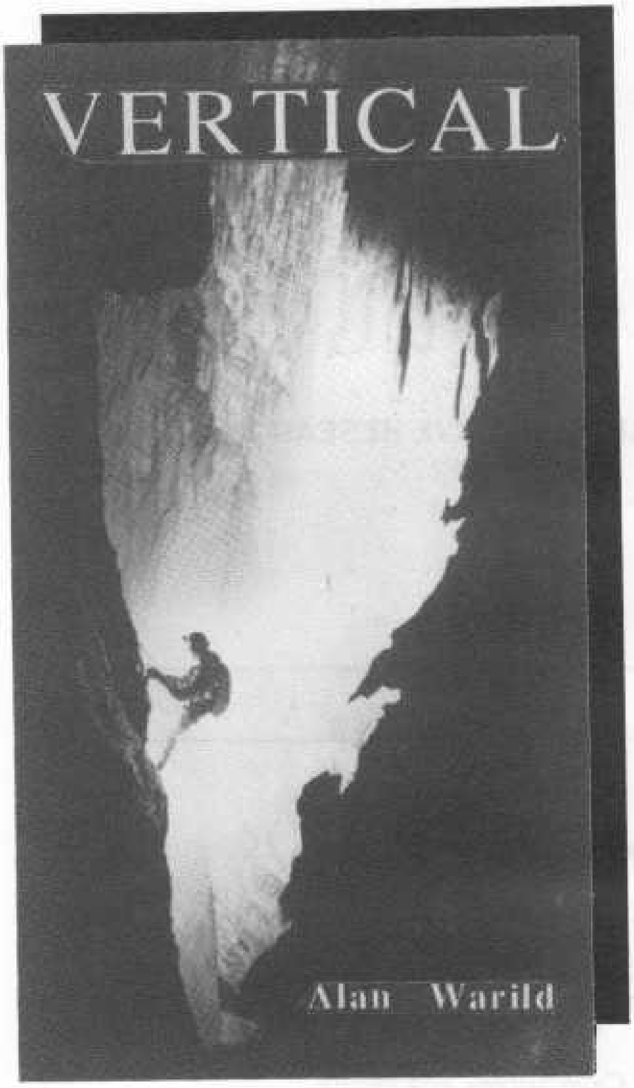

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KARST FEATURES IN PLEISTOCENE DUNES, BATS RIDGES, WESTERN VICTORIA

Susan White

Abstract

Karst features occur in Pleistocene aeolian calcarenite dunes at Bats Ridge near Portland, Victoria. The surficial and underground features show that the caves are sinuous shallow systems often with a number of entrances. Passage shape is often modified by collapse. Characteristic features such as speleothems, clastic sediments, solution pipes and foibes are described, especially "moonmilk". Syngenetic karst processes are briefly discussed.

INTRODUCTION

Although karst processes have been studied both in Australia and overseas, usually the theories developed have been applied to relatively pure, hard, compact and well-jointed limestones which approximate to Sweeting's ideal limestone (Sweeting,1973). There are particular problems of karstification in softer less compact limestones such as chalk (Reeve,1979), coral reefs (Ollier,1975; Francis,1977) and aeolian calcarenite (Jennings,1968). The particular issues of karst in indurated aeolian calcareous dunes can be understood within the context of controls on karst processes, especially those related to lithological variation. Aeolian calcarenites are limestones with diffuse permeability and high intergranular porosity. They show little or no jointing, although the cross bedding structures of the dune deposition are still obvious. The purity of the limestone is very variable, often as low as 50% $CaCO_3$. In southern Australia such dunes generally occur in areas of reliable rainfall which ensures sufficient water for solution processes to occur. However, karst in aeolian calcarenite is more extensive in Australia than on any other continent, and further study in Australia is likely to be rewarding (Williams,1978).

Karst evolution on indurated calcareous dune sands has previously been studied both in Australia (Bastion,1962, 1964; Bain,1962; Jennings,1968; Sexton,1965; Hill,1957) and overseas (Swinnerton, 1929, Bretz,1960, de Vaumas,1970). However the only previous attempt to synthesise the known data on the various areas of aeolian calcarenite has been by Jennings (1968). He proposed the term syngenetic karst development and developed a scheme around this to explain speleogenesis in such situations. This scheme describes and explains the formation of karst landscapes which have developed simultaneously with the lithification of the limestones concerned. Other karst schemes assume that the diagenesis of the limestones precedes the development of the karst landforms. The major importance of the scheme is that it presents a logical series of processes which explain the development of karst landforms including extensive cave systems in a limestone which is still undergoing diagenesis. However in 1968 many of the mechanisms of processes involved, especially the processes involving solution and precipitation of carbonate cements in aeolian dunes under sub-aerial conditions were not fully researched and the discussions of these processes by Jennings were not very conclusive. However since then other workers (Bathurst,1975, Dunham,1971) have detailed the processes involved in such diagenesis of limestones in sub-aerial conditions which support Jennings' hypotheses. The scheme is therefore incomplete but remains the only published speleogenetic scheme appropriate for testing in aeolian calcarenite karst.

Aeolian calcarenite karst has not been extensively described in Victoria but the karst province of south eastern South Australia (Marker,1975) extends into Victoria. Although the areas of aeolian calcarenite ridges in south western Victoria, described as Bridgewater Formation, have not attracted extensive speleological work, they provide an opportunity to look at the karst landforms and the processes of their development in this material. Bats Ridge in particular, is a site where extensive karst development in aeolian calcarenite is evident but was not included in Jenning's synthesis. Some limited description of the area has been published, (Coulson, 1940; Pierce & White, 1977; White & White, 1979), and analysis was carried out by White, (1984).

REGIONAL AND LOCAL SETTING

The area is one of calcareous dune ridges approximately 8 km north east of Cape Bridgewater and 8 km west of Portland (Fig.1) near the Portland aerodrome. The area of interest is approximately 700 hectares of dune ridges which includes 324 ha of wildlife reserve and some private land. It is typical of the Tertiary to Pleistocene calcareous ridge systems of the Otway Basin which were deposited as the sea retreated from the coast during the last major marine regression. Karst landforms are found in similar ridges to the north e.g. Mumbannar, but the dunes at Bats Ridge show more intensive karst development than these other sites.

Regional Geology

The study area lies within the structural unit known as the Otway Basin, a trough filled with a maximum of 7,500 m of Mesozoic and Tertiary sediments, which extends across the southern portion of eastern South Australia and south-western Victoria. It is separated from the similar Murray Basin to the north by the Palaeozoic rocks of the Dundas High (Kenley, 1976). The Tertiary sequence is characterized by a series of Miocene marine transgressions, and the distribution of the Quaternary sediments on the Normanby Platform is governed by the complex interaction between uplift along fault scarps, glacio-eustatic oscillations in sea level and local warping and faulting (Kenley, 1976).

Relics of a series of dune limestone ridges mark the positions of the shore stillstand between periods of epeirogenic movement and glacio-eustatic changes in sea level (Sprigg, 1952). Early discussions on the relative ages of such dune complexes are not conclusive (Kenley, 1971, p.132-135) but more recent work by Idnurm and Cook (1980) has resulted in more accurate dating of the Pleistocene sequences of an area to the north west of Portland. However the sequences of dunes to the west cannot be easily correlated with dunes to the east of the Kanawinka escarpment due to differential tectonic activity.

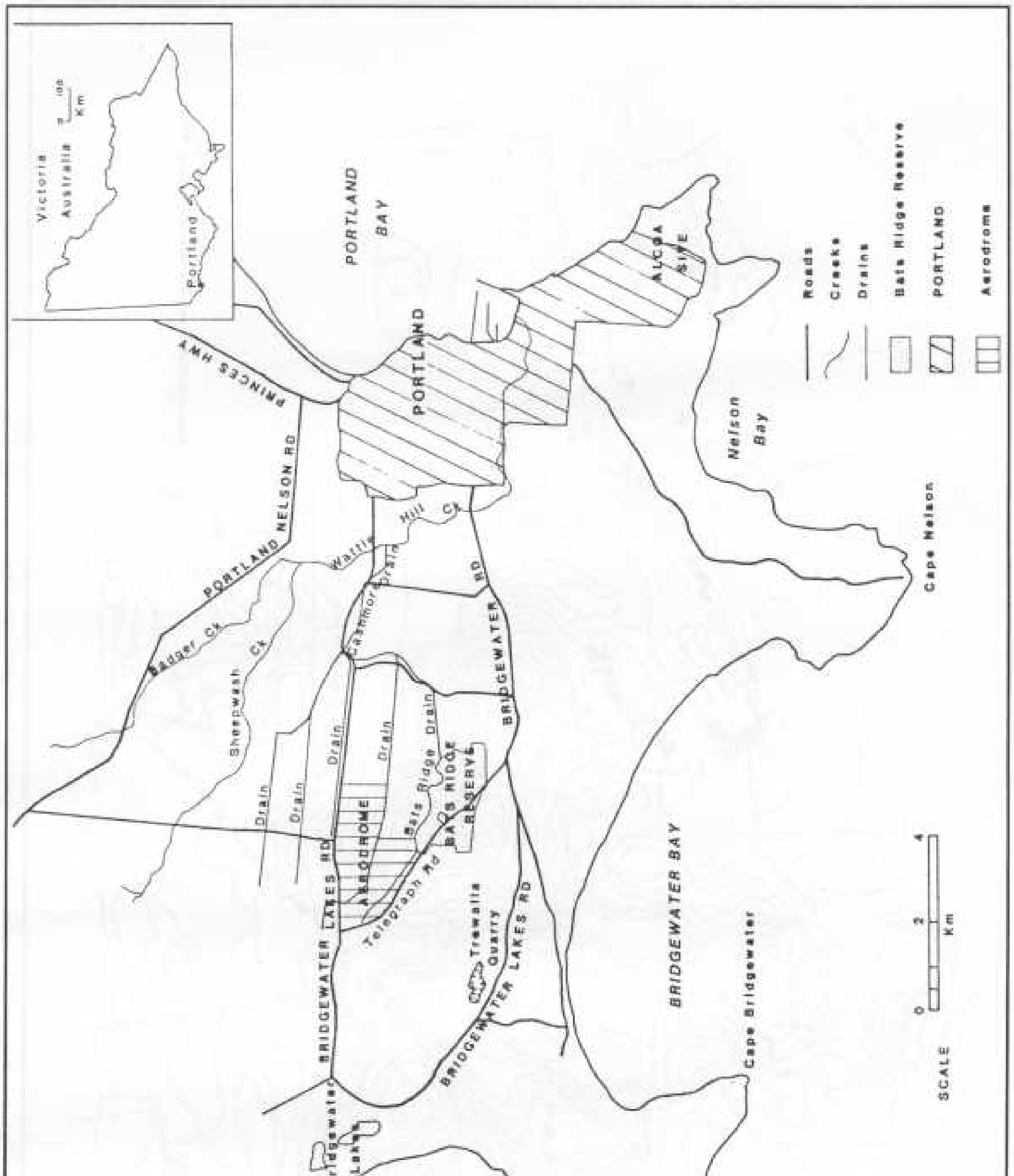

Figure 1. Location of Study Area

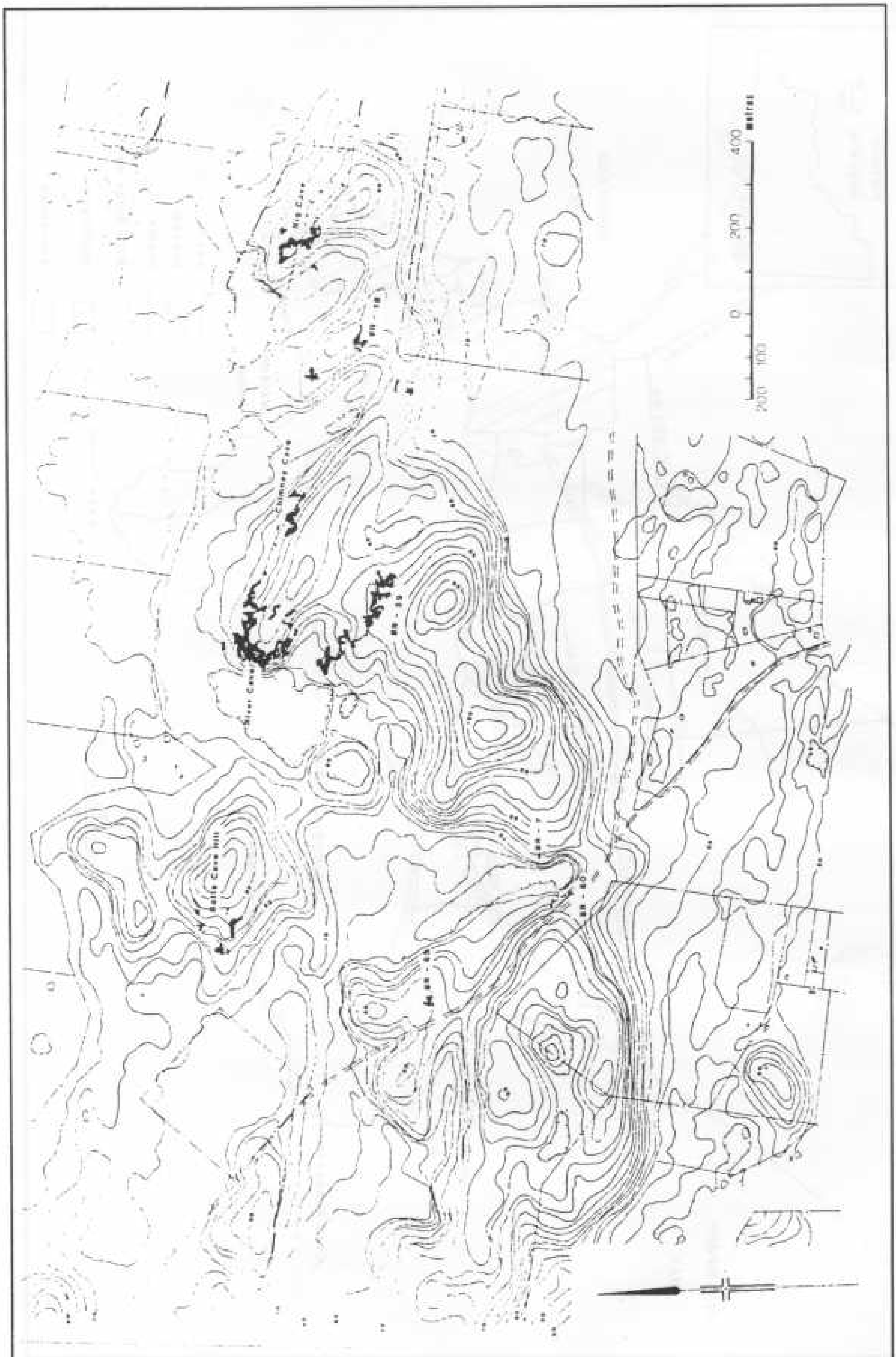

Figure 2. Ridge System and major caves

These dune ridges including the Bats Ridge system, are described as Bridgewater Formation (Boutakoff and Sprigg, 1953, Boutakoff, 1963). The rock is a well-sorted, fine to medium grained bioclastic carbonate sand which is commonly laminated and cemented by calcite. Cross-bedding is a prominent feature and fossil soil horizons are an integral part of the formation but at Bats Ridge the fossil soil horizons are absent. The rock is generally exposed or covered with thin calcrete and soil layers. At the coast it is often overlain by Holocene calcareous sand (e.g. at Bridgewater Bay and Discovery Bay), but inland it is sometimes covered by the grey to white siliceous sand of the Malanganee Formation, thought to be predominantly the residue of dune limestone eroded from deposits further south during terrestrial weathering periods (Kenley,1976).

The ridge has a general alignment north east- south west, with low spurs running north west-south east on the northern side (Fig. 2). These spurs are separated by swampy swales or hollows, some of which hold water in wet seasons. It is about100 m above present sea level and has a relative relief above the surrounding plain of 38 m. It is variable in width and assymetrical in cross section with a steep seaward slope facing south-east and a more gentle landward slope. There are peat swamps on both northern and southern sides of the dune. The swamps to the north are more complex and connect with swamps in the swales between the spurs. The ridge has the appearance of a longitudinal strandline dune which has been subjected to "blow outs" at right angles to the dune axis during periods of sand instability. Whether these enclosed depressions, such as the Bats Ridge lake, are purely swale lakes or at least partially solutional in origin is not clear.

Regional Geomorphology

The overall regional surface drainage pattern of the Normanby Platform is not fully developed. The Fitzroy and Surrey Rivers flow eastward, and Moleside Creek flows west into the Glenelg River. Johnstone's Creek flows south from Kentbruck over the Swan Lake-Bridgewater Fault Scarp into Swan Lake. The local surface drainage is part of a catchment draining eastwards via a system of artificial drains which flow into Wattle Hill Creek. These have been operative for many years and modifications have occurred, such as the diversion of water from the Bats Ridge Drain into the Bats Ridge lake in the early 1970's. This artificial drainage system now drains what was a series of swampy depressions between small calcareous sandy hills. Many depressions would have held water in wet seasons and still do, as despite the system of drains the water table remains quite high. However although the low flat area to the north of the ridge was swampy in the past, the dune ridges themselves are well drained. The lake at Bats Ridge now contains water in most wet seasons from a drain diversion but prior to main drain construction, the lake filled only infrequently.

The combination of this limited surface drainage, Pleistocene tectonic activity and the presence of suitable aquifer rocks has resulted in important ground water resources in the area. The major seaward drainage is as groundwater and important ground water aquifers occur under the Pleistocene sediments. There is seaward flow of ground water in the Bridgewater aquifer (Lawrence, 1976). Since the Pleistocene tectonic activity, drainage has been largely influenced by three factors: oscillation of sea level, climatic changes and volcanism. Sea level oscillations have influenced drainage by lowering the base level resulting in a lowering of the water table. Therefore the area was originally even more swampy than at present. The dissipation of drainage channels has also been important in the establishment of drainage patterns. Locally for the Bats Ridge area, the most important factors are those relating to the lowering of the water table in the immediate area.

Climate

The nearest meteorological stations are Cape Bridgewater and Cape Nelson, which show that the area has a temperate climate: warm summers, cool winters and winter maximum rainfall. Surface runoff and groundwater recharge are seasonal (Ceplecha,1971), and streams have a strongly seasonal regime and may cease to flow in the dry season for varying periods. This general picture can be seen in the surface runoff patterns in the Bats Ridge area. The only stream, Wattle Hill Creek, is strongly seasonal and ceases to flow during the summer months. Similarly the Bats Ridge Drain, which collects and drains surface water from west to east, flows only in the wet months and the high flows which are then diverted into the Bats Ridge lake occur only in the wettest period, usually August to October.

Climatic changes are more difficult to assess as most material is extrapolated from work done on the Murray Basin (Bowler,1975; Bowler et al.,1976), the Kosiousko area (Galloway, 1965), the volcanic lakes of the Western District of Victoria (Dodson, 1974) as well as summaries produced for the CLIMANZ conference (1981). However evidence for southern Australia indicates that conditions prior to 40,000 years B.P. were marginally drier than at present, and were followed by a cooler and wetter period. At 32,000 + 5000 years B.P., evidence for a wide variety of sites in southeastern Australia suggests that conditions were cooler than at present (CLIMANZ, 1981) but drier in S.E. South Australia (Dodson,1975). These conditions would probably apply to the Otway Basin (Bowler et al., 1976) and may help explain the hydrological conditions necessary for karst development. The first signs of drying out of these lakes and associated lunette building was at about 26,000 years B.P. and continues until about 15,000 years B.P. (Bowler,1975; Bowler et al.,1976; Dodson, 1974). Overall patterns indicate a change from warmer temperatures in the late Tertiary and very early Pleistocene to cooler and wetter conditions with high water tables in the late Pleistocene and as the ice retreated from the alpine areas by 10,000 B.P. After about 15,000 B.P. there is some evidence of rise in absolute precipitation, although the last 10,000 years have been relatively stable (Bowler et al.,1976). These climatic changes of the Pleistocene and their effects on regional water tables are important for karst development.

Vegetation

The dunes were fixed by vegetation in the past and a complex vegetation has developed which contains a mosaic of communities which include heath communities and low open forest communities. The heath may be primarily a result of infrequent firing of an otherwise open forest. The vegetation can be important in the development of karst landforms (e.g. caves, dolines) on such ridges as it affects the balances of water, carbon dioxide and humic acids in the soils and drainage water.

SURFACE KARST LANDFORMS.

The landforms include both underground features such as caves, and surface features e.g. karren and closed depressions. Other features such as soils play an important part in the understanding of the forms and processes of this karst area.

Karren

Small scale solutional features (karren) are present on exposed limestone surfaces and these are most common on the harder, more cemented limestone rather than the softer limestone exposures. The predominant types of karren are rillenkarren grooves 1-3 cm deep, 1-2 cm wide and of varying length with sharp crests; spike forms of similar dimensions; and irregular and uneven redeposition of calcite on exposed surfaces. Rillenkarren occur on inclined exposed surfaces such as cliffs, cave entrances or the crests of dunes where there is minimum soil cover and extensive exposed limestone. This karren forms on rocks exposed to runoff water, but does not occur under soil formation and vegetation cover. The spike forms occur more rarely than rillenkarren, but in similar situations. The irregular form is much more common than either of the other two types and is a result of irregular and uneven deposition of calcite on exposed surfaces combined with small solution hollows. No evidence of karren features was found on the exposures of softer less cemented limestones, from which it can be implied that karren does not form in such situations at Bats Ridge. Exposures of the less cemented limestones are common beneath the harder caprock and can be observed in many of the cave entrance collapse dolines. Similar sitations were observed on chalk by Bögli (1978) which is also a soft friable porous limestone. The smooth sides of solution pipes e.g. BR-58 do not exhibit karren forms despite the exposed limestone being well cemented.

Cave Entrances

There are two main types of cave entrances: collapse dolines and solution pipes. The cave entrance depressions (collapse dolines) tend to be small (1.5-5 m diameter) and approx-imately circular in plan. They are generally formed by a combination of solution and collapse. Many collapse entrances show evidence of a "roof beam" of stronger more cemented limestone which is interpreted as the result of "caprock" formation (Plate 1). Some collapse features are relatively small and tend to be on the side of the dune ridge e.g. BR-27. Others show bigger collapse areas of a more traditional collapse doline type (Sweeting, 1973), which have steep sides e.g. BR-2, BR-7. The other type of cave entrance is the solution pipe, the presence of which is characteristic of caves in aeolian calcarenite (Jennings, 1968). The solution pipes have a variety of forms: smooth sided straight solution type e.g. BR-58, solution tubes modified by collapse e.g. BR-76 and tubes modified by large tap roots e.g. BR-60, BR-35(Plate 2). In one case (BR-9 Bat Cave) there is a group of solution pipe entrances. The most spectacular example at Bats Ridge, is the chimney entrance (BR-58) to Chimney Cave. This is a cylindrical tube 6.5m. in length and about1 m in diameter, narrowing slightly downwards. The pipe is thinly lined with a secondary cemented calcite layer. There is a debris pile beneath the pipe, composed primarily of soil which

Plate 1. BR-9 showing caprock control of entrance shape. Photo: N.J. White

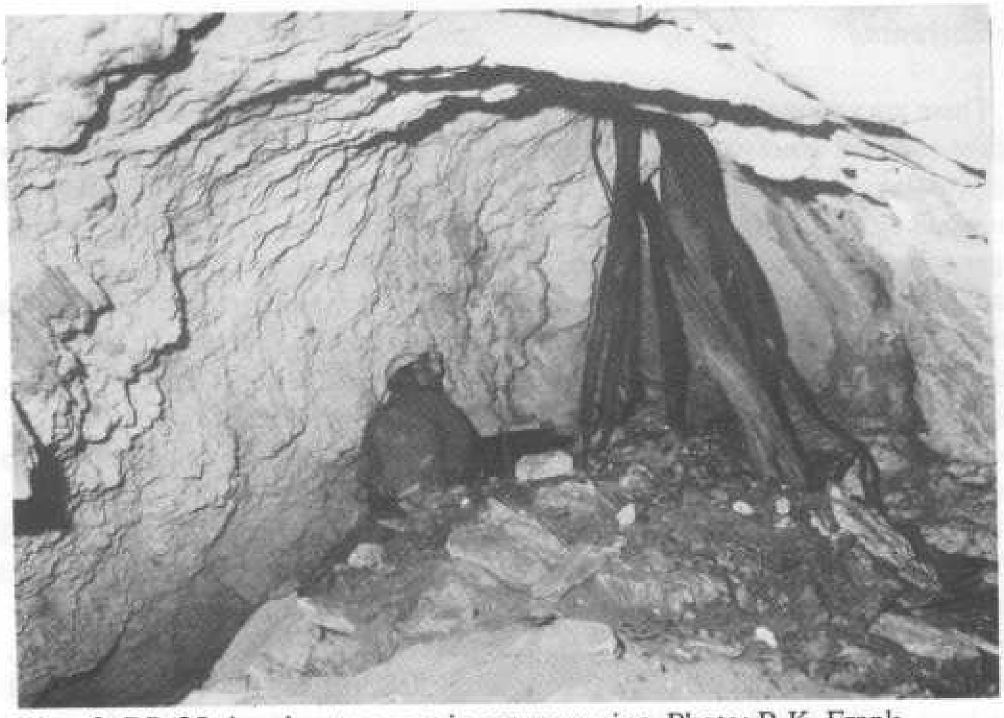

Plate 2. BR-35 showing tree root in entrance pipe. Photo: R.K. Frank

has been funnelled down the pipe. The pipe also forms a typical animal trap similar to those found in south- east South Australia (Sexton, 1965, Marker, 1975). Other examples can be seen in BR-9, BR-35 and BR-20. BR-35 is an interesting example of a small tube containing a tree root implying that vegetation roots may have some relation to the formation, at least in the early stages of such features.

Lakes and swamps

Small lakes and peaty swamps are found in low lying areas between ridges as seen in Figure 2. These depressions are irregular in shape and show shallow relative relief: about 5 m in depth from the highest point of the surrounding dune to the lowest point of the lake or swamp floor. Not all such depressions are closed depressions. The depressions may have been groundwater lakes in the past but there is little evidence for this being the case at present (White, 1984). The surface stream pattern relating to these lakes is obscure, however at least two are currently filled by the diversion of the Bats Ridge Drain. Generally they are not filled by natural or man-made streams. Even the lakes which receive water from the Bats Ridge Drain, contain water for only short periods of time. Where such depressions hold water, the edges of the dunes have been modified by solution. In some cases ephemeral lakes have eroded low cliffs into the calcarenite dune.

Karst features e.g. caves and dolines are found close to the lake edges. However most of the limestone in the areas close to the lake edges is relatively unconsolidated. South and south-west of the main lake, small caves have developed in the cliffs which are of very crumbly limestone with little secondary calcite cementation. There are some examples of collapse dolines which have collapsed as a result of solution underneath due to exceptionally high levels of lake water at an earlier time. However such levels of lake water occur only occasionally, although in the past they may have been more frequent. Similar features are found in the cliffs near Big Cave (BR-5) at the eastern end of the ridge. These lakes and depressions, although they are in the interdune swales may have been closed depressions, and have been further modified by solution. The modification of the dune slopes by occasional high lake levels is still occurring and shows the processes by which the swampy interdune swales are modified. However the landscape patterns of these interdune swales which have been modified by solutional processes on the calcarenite are a distinctive surface landform in the area.

Soils

The soils are predominantly sandy: sand, sandy loam or loamy sand, although a few profiles have developed clay horizons especially where more water is present, such as the interdune areas. There is some difference between the soils which have developed on the dunes and those developed on the interdune swales and lake bottoms. Much of the area of the main calcarenite ridges has thin terra rossa type soils varying from a few centimetres to two metres in depth, whereas the interdune swales and lake bottoms have at least one clay rich layer in an otherwise sandy soil. The sandy soils are well drained, friable soils developed from the residues of the calcarenite parent material. There are decreasing amounts of organic matter down profile.

UNDERGROUND FEATURES.

There are 70 known caves in the Bats Ridge area. These are the actual cave systems and in many cases include caves with more than one entrance. The accessible caves are predominantly to the east of Telegraph Road although a limited number of karst features, including caves, are to the west of the road. Detailed descriptions of most of the caves have been published in Nargun 17 (6) (1984).

Caves

The caves are generally shallow linear systems, often with more than one entrance e.g. Chimney Cave has four known entrances (BR-1, BR-54, BR-55, BR-58) and River Cave has nine (BR-4, BR-14, BR-16, BR-25, BR-26, BR-32, BR-67 and two unnumbered entrances). Caves rarely have more than one leveland in the few caves where this occurs, it is due to collapse partially filling a passage and a low passage is preserved under the rock pile (e.g. Big Cave BR-5).

Passages can show three types of cross-section shapes: wide horizontal low passages, tunnel shaped passages or domed chambers (Fig. 3). The low "flatteners" are characteristically wider than they are high, e.g. about 1 m high but up to 25 m wide such as in BR-1. Many of these appear to relate to changes in the dune bedding dip. The tunnel shaped passages are higher than they are wide and may have a flat or rock pile floor. Some are old stream passages e.g. BR-59. The domed passages often contain extensive rock pile e.g. BR-5 .

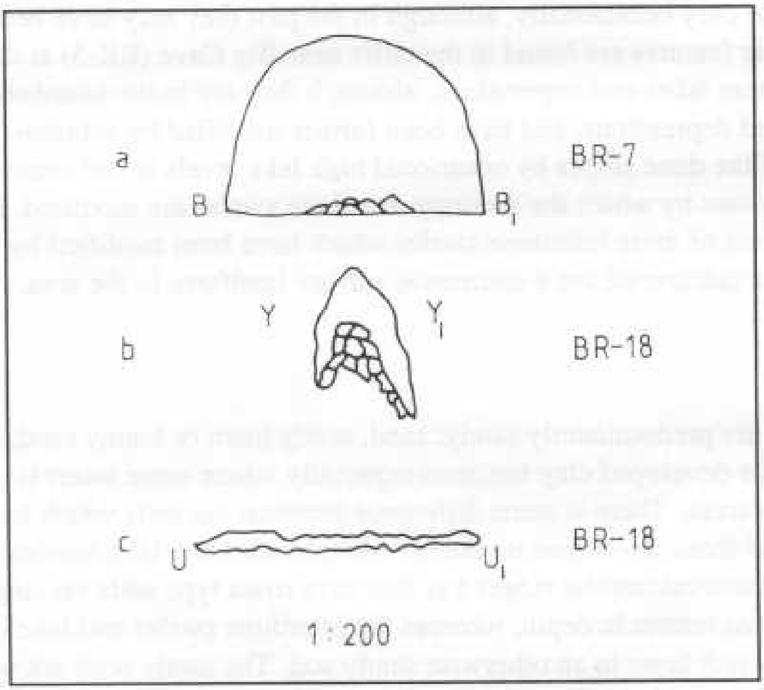

Figure 3. Passage cross section shape.

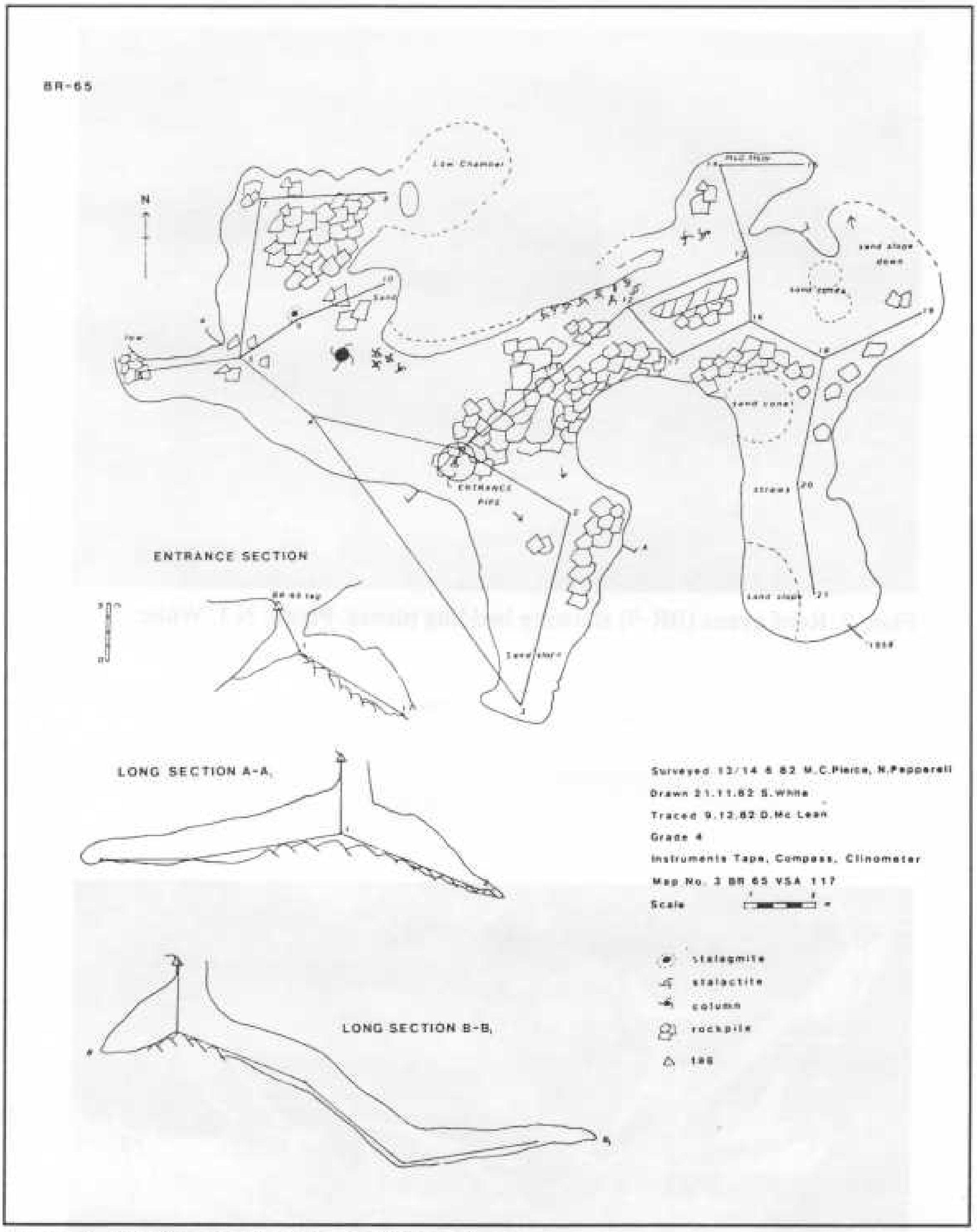

Figure 4. BR-65 cave showing sections and plan

Passages are ususally sinuous rather than straight in plan and give little indication of following joint lines e.g. BR-65 (Fig. 4). The virtual absence of any evidence of joints in the limestone itself implies that the caves develop using other lines of "weakness", such as dune bedding planes or vegetation roots, as initial channels for water. The presence of both solution pipes and roof avens or foibes is characteristic of caves in aeolian calcarenite (Jennings, 1968) and both are present at Bat Ridges. Roof avens (foibes) vary from very small features to those up to a couple of metres high. Bedding is often well displayed in them (Plate 3).

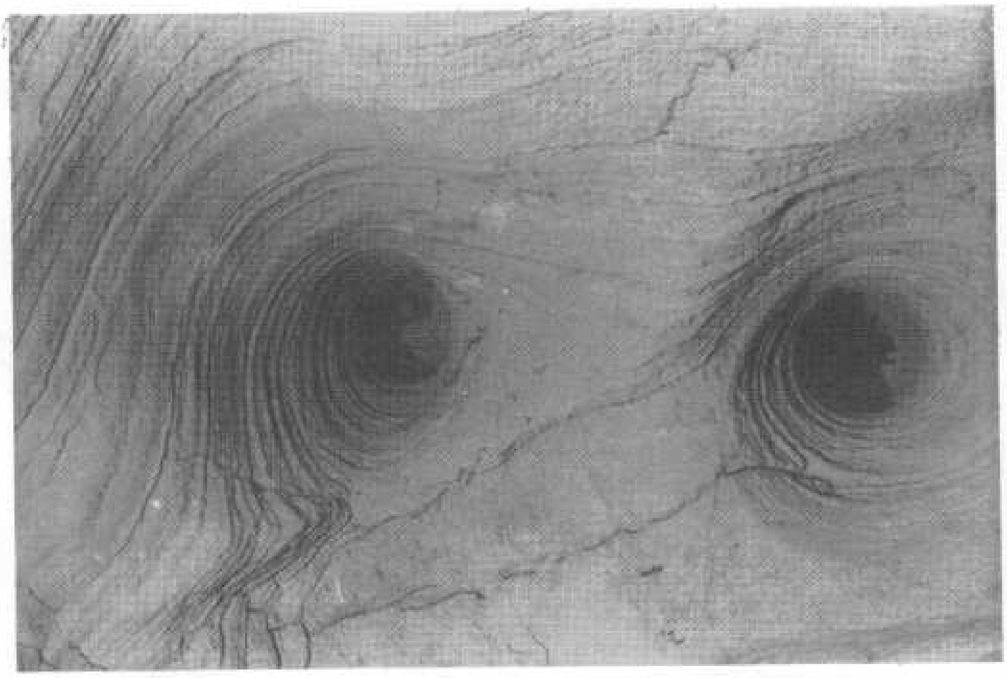

Plate 3. Roof avens (BR-9) showing bedding planes. Photo: N.J. White.

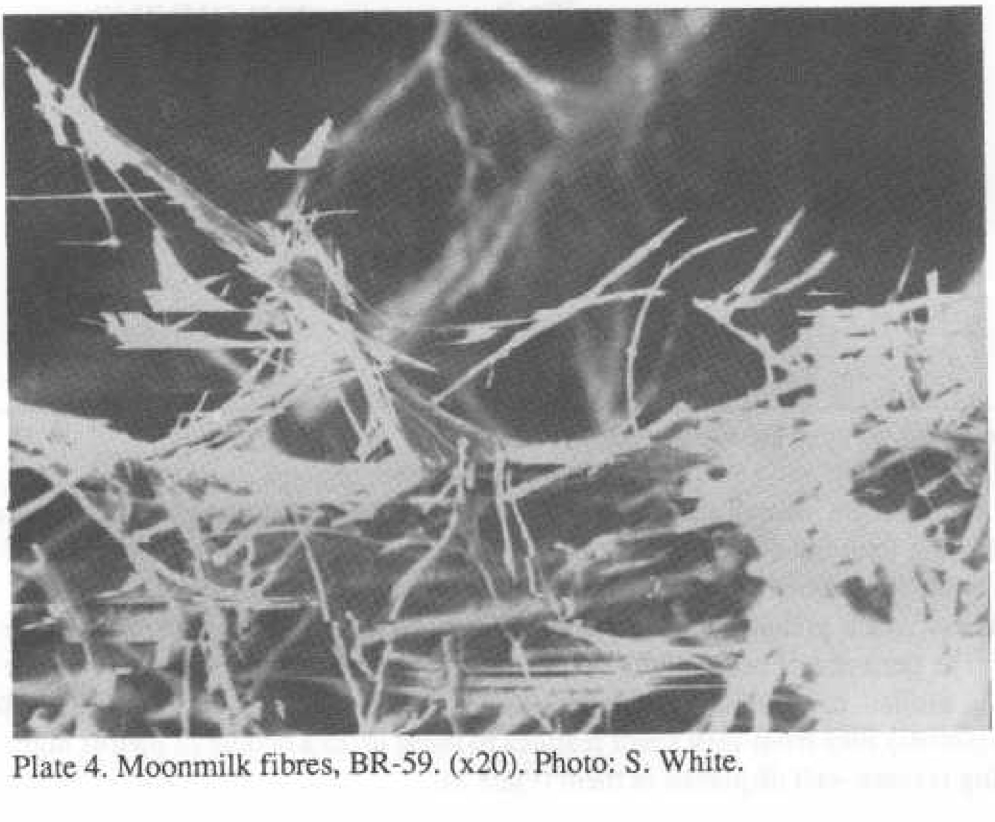

Plate 4. Moonmilk fibres, BR-59. (x20). Photo: S. White.

All caves are dependent for roof strength on the development of an indurated "cap rock" or kankar layer. This cap rock gives the otherwise relatively unconsolidated dune limestone sufficient strength for roof support (Plate 1). The caves show evidence of this cap rock in their entrances and also their passage shape. A particular variation of a collapse entrance and passage is also evident. This was recorded by Ollier in 1964 (McEachern Cave, Glenelg River) and is ascribed to the presence of relatively competent rocks, in this case probably kankar, near the surface in conjunction with either a very high or very low bedding dip. The best example at Bats Ridge is at BR-9 . Triangular passage cross sections can be seen in caves where there is intermediate bedding dip e.g. BR-60.

Collapse breakdown is a significant process in the development of most caves. Many passages are modified by collapse and many entrances to caves are through collapses e.g. BR-27. Rubble piles are therefore a common feature near entrances and in large chambers. However as collapse material has a greater bulk density than the original rock, prior removal of material is essential for collapse to take place. Many such collapse dominated passages show domes which remain almost full of collapse material (rock fall) e.g. BR-18. In others, much of the rock fall has been removed in solution e.g. BR-59, where the rock pile has well rounded clasts.

Speleothems

Speleothems are not the most prominent feature of many of the caves although they do commonly occur. Calcite speleothems occur in several major forms including massive columns, stalactites and stalagmites; fine straws and helictites; flowstone and rimstone pools; cave coral and moonmilk. The more massive columns, stalactites and stalagmites are generally no longer active but indicate a period of more active deposition of calcite in the past which is possibly related to a time of wetter climatic conditions. The currently active series of helictites, straws, flowstone and rimstone pools are generally restricted in distribution, smaller, and less extensive. In a few cases the finer straws are superimposed over older more massive formation. The precipitation of calcite is episodic and occurs only in wetter periods. This is demonstrated by speleothems such as straws which at times dry out and do not develop, and at other times are wet and growing.

The most spectacular speleothem in the caves is the abundant moonmilk on walls and ceilings. The moonmilk is composed of calcite crystals with high water content between the crystals and is generally rare in other limestone areas in the state. Overall large areas of cave walls are covered in either moonmilk or the dehydrated moonmilk. Examination of moonmilk under scanning electron microscope showed the crystals were fine fibres, and some variation in diameter and length of fibres was observed (Plate 4). X.R.D. analyses show that the fibres are calcite not aragonite. Chemical analyses show that the moonmilk at Bats Ridge can contain up to 82% water as well as up to 8% insoluble residues (silica, clays, etc.). Analyses for nitrate/nitrogen as an indication of organic material show a measurable nitrate content (White, 1984). Gèze (1961) and Bernasconi (1960) described in detail the chemistry of moonmilk and it can therefore be explained as the result of rock alteration under hydrated conditions.

Other workers (Caumartin and Renault, 1958) have maintained that this aqueous alteration of rock is assisted and developed by the presence of anaerobic bacteria. The presence of measurable quantities of nitrate indicates that bacterial action is at least possible, but much of this process is poorly understood.

Clastic Cave Sediments

The clastic sediments on the cave floors are generally massive, poorly bedded but moderately well sorted, medium to fine sand. The mean grain size of these sediments ranges from 2.05 ø to 3.0 ø which indicates that the medium to fine sand fraction is dominant. Samples show a negative skewness, indicating an excess of the coarse fraction, as could be expected from sediments deriving from aeolian dunes. Grain size frequency curves (Fig. 5) confirm these characteristics.

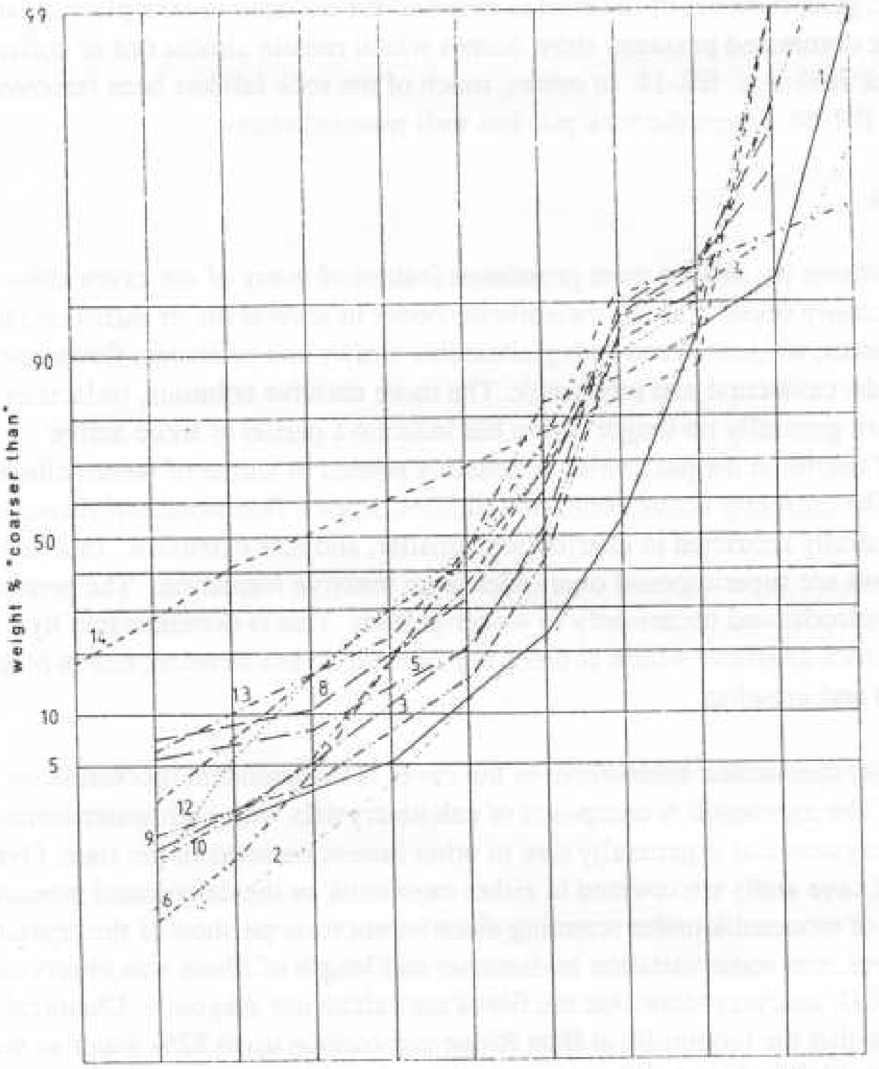

Figure 5. Grain size analysis frequency curves.

A plot of mean grain size against graphic standard deviation, used as a measure of sorting or the tendency of grains to cluster around "average" shows that the sediments are generally moderately well sorted. Visual inspection of sediments shows that they contain varying amounts of calcium carbonate and organic material. This is confirmed by chemical analysis which indicated between 0.25% and 38.94% calcium carbonate. The insoluble residue fraction ranges from10.99% to 97.68%. The organic component is quite low: ranging from1.78% to 7.03%. The insoluble residues consistently showed subrounded medium-grained fragments of quartz of the same type as found in the aeolian calcarenite itself. The levels were higher in the clastic sediments than in the rock but the quartz grains are the same subrounded recycled grains.

Sediments near the entrances of caves show evidence of some provenance from outside. Organic material such as sticks and leaves is found in the surface layers of these sediments, and the organic component is generally higher. These sediments are therefore seen as a distinct statistical population from those sampled well away from the entance areas and are significantly distinct with respect to the proportions of organic material, $CaCO_3$ and insoluble residues (White,1984). The major variable in the sediments is the percentage of organic material. Except where there is input from bat populations, much of the material is the result of input from outside the cave. Therefore there is more organic material in sediments near the entrances of caves rather than further into the cave system. This, combined with the lack of bedding structures in the deposits, implies that the clastic sediments are predominantly developed in situ and have not been influenced by extensive vadose water flow. The one cave subject to such water flow (River Cave), showed the same general trends as the other caves. Stratified deposits and other evidence of reworked material are not seen in any other situation except River Cave, and sediments are generally found in unstratified deposits of fine to medium sand sized grains.

The clastic sediments are therefore of rather uniform grain size but of slightly varying chemical composition as due to the effects of solution, organic inputs and mechanical breakdown of the calcareous host rock. Such clastic cave sediments are derived from fragments of pre-existing rocks which have undergone solution.

DISCUSSION

The characteristic landforms associated with the calcarenite strandline ridge at Bats Ridge are the result of karst processes. The dominant process is solution although collapse is very important. The characteristic caves are shallow, linear with horizontal development which have formed under a hardened cap rock or kankar layer in the calcarenite dune. This cap rock is a cemented relatively hard layer within the dune, formed as the result of solution and redeposition of calcium carbonate, under sub-aerial conditions. The cementation is primarily as meniscus cement which confirms that diagenesis has occurred under sub-aerial conditions. Solution pipes, roof avens and foibes are common, as in other areas of calcarenite karst in Australia. However no soil pipes were found at Bats Ridge, despite their presence in other areas of the same geological formation, Bridgewater Formation. Karren forms are not common on the exposed limestone but some examples, especially of an uneven form appear on areas of exposed cap rock. Exposures of the more cemented cap rock are generally restricted to the collapse cave entrances.

The karst features are concentrated on the spurs of the dune ridge (Fig. 2). These spurs are on the northern side of the ridge and the karst features, especially the caves, are grouped on these spurs. This concentration can be correlated to the effect that the small swampy depressions and lakes have had on the aggressivity of the ground water. The increased acidity of the ground water from humic acids also increased its aggressivity, which was essential for solution to occur. The caves show a common base level at about 90 m. above present sea level (Fig. 6). This level is between 5 to 8 m above the present water table. The caves therefore appear to have formed at the top of the water table when the water table was higher. The aggressive nature of the water at the top of the water table combined with the relative purity of the limestone compared to other areas of Bridgewater Formation resulted in suitable conditions for karst development. Thus Bats Ridge has more karst features, especially caves, than other such areas of Bridgewater Formation in south-east South Australia and south-western Victoria.

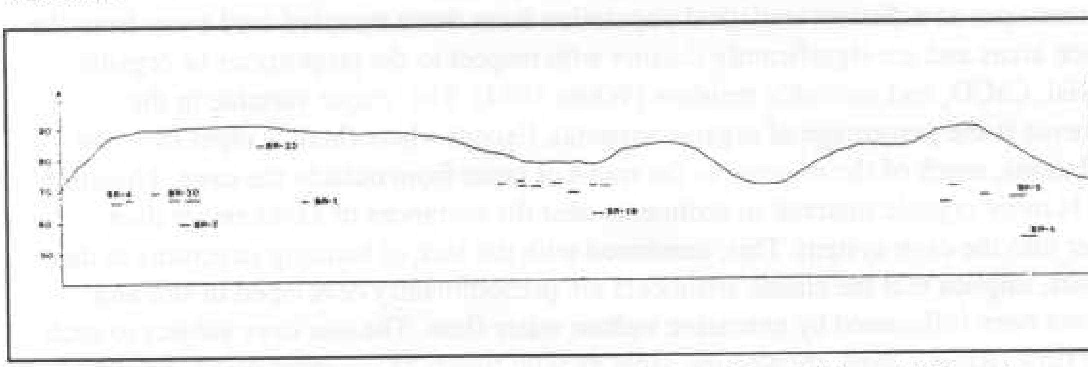

Figure 6. Relative cave base levels. All levels are below lake full level (70 m above present sea level), but at approximately lake base level.

As the dunes are of mid to late Pleistocene in age, the development of quite extensive cave systems and their features such as speleothems has occurred in quite a short period of geological time. The karst features appear therefore to have developed contemporaneously with the lithification of the dunes. Such karst development has been described elsewhere as syngenetic karst (Jennings, 1968). It is the most appropriate speleogenetic scheme to use in the description of the geomorphic evolution of karst features in relatively young limestones (Cainozoic) such as this Pleistocene calcarenite dune.

The limited period of time for the karst landforms to develop since the deposition of the dunes led Jennings to develop this scheme. Jennings saw the initiation of the processes of karst development occuring when the calcareous dunes were fixed by vegetation and soil development began. The processes of diagenesis which convert the loose dune sand to limestone began under the agency of downward percolation of rainwater. A hardened layer, termed a "caprock" or kankar layer developed below the surface as a result of the processes of dissolution and cementation. Once this caprock was sufficiently lithified, the development of karst landforms e.g. dolines, caves and solution pipes, continued to develop simultaneously with further diagenesis. This caprock was necessary for roof support in otherwise relatively unconsolidated dune sand. Caves in such conditions are generally well-developed linear systems which are explained as chiefly the result of lateral solution at the water table although Jennings considers the vertical development of solutional pipes as important.

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DATA HANDLING TECHNIQUES FOR CAVE SURVEY PROCESSING

Keir Vaughan-Taylor

Abstract

Survey processing programs require time consuming manual organisation of data, to ensure that processing takes place in a particular order. With appropriate data input techniques, data structures internal to a program and the use of recursive languages the need to order and pre-process data can be eliminated.

INTRODUCTION

This is achieved by building in computer memory a data structure representing survey locations and their linkages to other survey points. A traversal algorithm performs a processing operation on any subset of the structure as it traverses this memory representation. Such algorithms can be used to calculate xyz co-ordinates, output data, plotting commands or modify the data according to some desired purpose such as misclosure correction.

Cave Survey Programs and Data Handling

One of the best known cave mapping programs is SMAPS (Survey Manipulation Analysis and Plotting System) written by Douglas Dotson and popular in North America and Australia. This product runs under a variety of personal computer operating systems including CPM MS/DOS and Unix. Data input is achieved through the use of an inbuilt text editor and stored in a hierarchical set of directories similar to Unix.

The system provides features such as error correction on survey loops using a least squares method and allows output of scaled plans to a range of different printers. In SMAPS a sequence of survey legs is referred to as a shot run and the reduction of survey data is performed commanding the processing of shot runs under the control of the user. Processing of the shot runs must be performed in a logical order and likewise for error correction.

Spreadsheets lend themselves to the same task with the advantage that users can configure the package without having any explicit knowledge of programming. Numerous examples of how to use one of the major spreadsheet products appear in speleological literature. The spreadsheet offers a convenient data entry format and data storage mechanism associated with the package. Configuration of spreadsheets like programs can be passed on as a tool to other users. Depending upon how a spreadsheet handles recursive references there are various difficulties with interconnected systems (Rutherford and Amundsun, 1974).

Implementation

The programming techniques were all implemented under the unix system on a Vax 780, Mips M120 machine and a Mac 2 desktop computer under A/UX (unix). Control of graphics options such as scale options, rotations and labeling is under the command of a control file containing predefined keywords. Survey data is held in a directory in a format as close to the original as possible.

Modern microcomputers commonly boast large memory capacity and easily accommodate the programming techniques used. The system was originally written in Pascal but then re-implemented in C and the pseudo code used to illustrate a programming segment reflects the C Pascal background of this system. The software techniques employed in this system are well known, however speleology has yet to benefit from its general application.

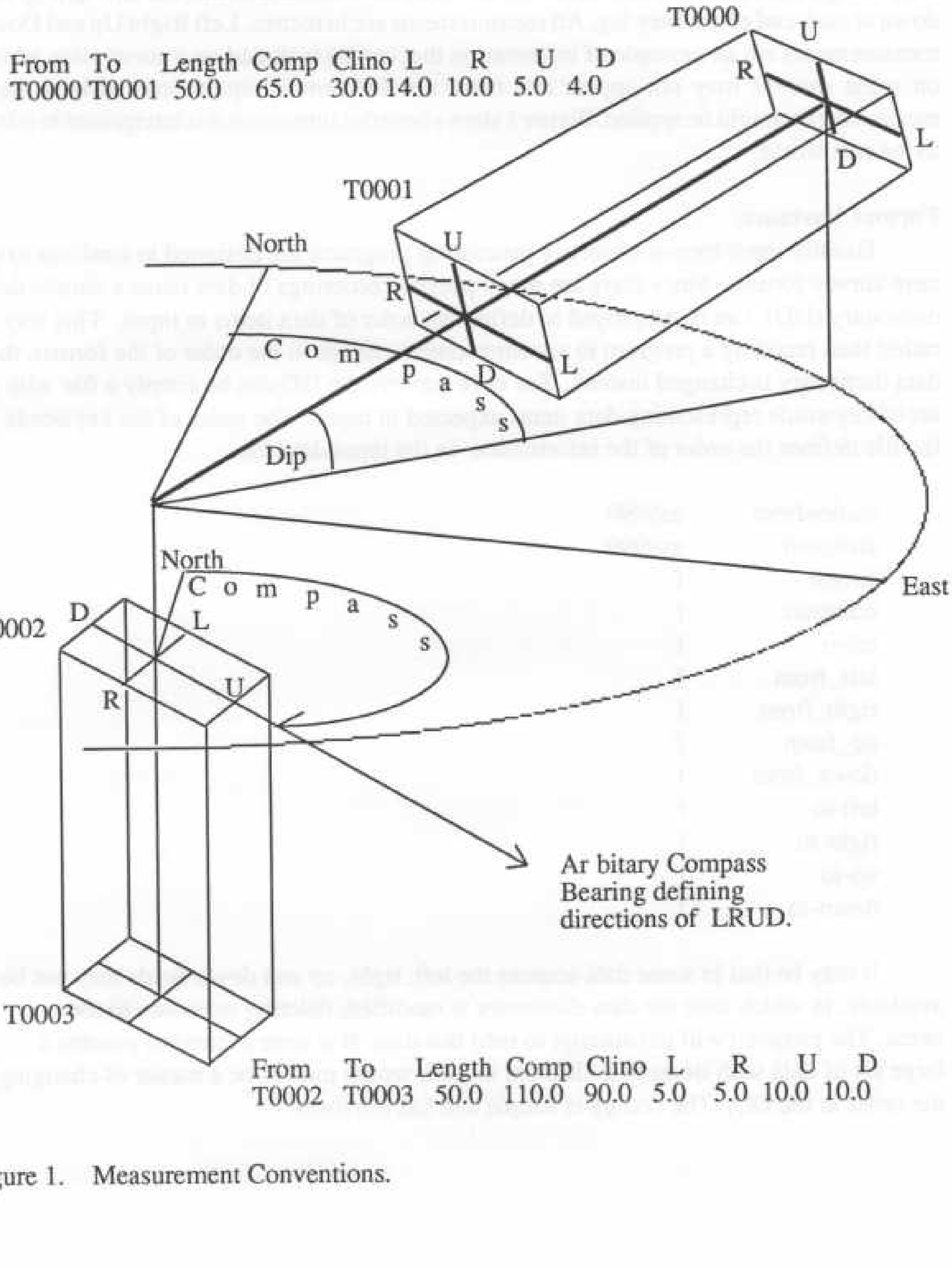


Figure 1. Measurement Conventions.

Conventions

The term traversal is used in this paper to refer to a consecutive sequence of survey legs. A network traversal refers to the action by the computer of systematically consulting part or all of the interconnections in a cave survey.

The survey notation used as examples conform to the following conventions. Each station is given an identification string beginning with an alphabetic followed by four numerics. The basic unit of information is a link between two survey stations and any information that might be associated with that link is included in this basic survey record. In the given examples link records comprise two station names defining each end of a link, a tape length, compass and clinometer followed by four measurements, the left right up and down at each end of a survey leg. All measurements are in metres. Left Right Up and Down measurements are an example of information that can be included on a survey line which on some surveys may not appear and there are different interpretations of how these measurements might be applied. Figure 1 shows how this information is interpreted to relate to the real world.

Format Variance

Usually input format of survey processing programs are designed to conform to a cave survey format. Since there are many possible orderings of data items a simple data dictionary (DD) can be employed to define the order of data items in input. This way rather than recoding a program to accommodate a change in the order of the format, the data dictionary is changed instead. For cave surveys the DD can be simply a file with a set of keywords representing data items expected in input. The order of the keywords in the file defines the order of the information in the input data file.

```
stationfrom    aa9999
stationto      aa9999
length         f
compass        f
clino          f
left_from      f
right_from     f
up_from        f
down_from      f
left-to        f
right-to       f
up-to          f
down-to        f
```

It may be that in some data sources the left, right, up and down fields may not be available, in which case the data dictionary is modified, deleting reference to these items. The program will not attempt to read this data. If it were desired to process a large set of data with items in a different order it would merely be a matter of changing the order in the DD. The coding is simple and has the form:

```
for(keyword_number = 1 to number_of_keywords) {
  if(keyword_array[keyword_number]=="stationfrom" ) read(stationfrom);
  if (keyword_array[keyword_number] == "stationto" ) read(stationfrom);
  if (keyword_array[keyword_number] == "length" )    read(length);
  etc........
}
```

An optional feature that can be added is a grammar of the data item. In the above example the station from is defined to consist of two alpha characters (A-Z, a-z) and then four numerics. This is indicated by the a character and the 9 character borrowed from the COBOL format convention. The program can of course be tailored to classify a grammar character as any subset of the ASCII set. The input program reads the data until a string of characters is identified where each character in the string matches the set of characters defined by the grammar character. When this occurs the character string is read into the station name field. With this system the station identification code can be changed to suit any available data set.

The "f" after the other data items represents a real number input. A useful extension to this would be to incorporate expression parsing so data items matched with keywords could be used as parameters in a user function. This might be useful for metric conversion or error correction. Such a DD entry might appear as

length   f * 39.0 / 12.0 - 6.0

This expression converts a tape measure reading from feet to metres. The first 6 metres of tape were lost and the error is here corrected. In this implementation however the expression format was not developed.

Survey Procedure

The basic operation of a typical mapping program is to calculate the xyz co-ordinates of each survey station relative to some fixed point (usually the entrance) and then plot lines connecting each station. These lines represent the survey legs in three dimensional space. To do this, start with a point of known co-ordinates and calculate the next station point according to the transformation.

Z1 = Z0 + leglength * sin(clinometer)
displacement in xy plane = leglength * cos(clinometer)
X1 = X0 + displacement in xy plane * sin(450-compass)
Y1 =Y0 + displacement in xy plane * cos(450-compass)

Each new station position uses the xyz co-ordinates of the last station to calculate the position of the new station. To calculate any station co-ordinate, the station must be adjacent to a survey station of known position. A minor problem occurs when there are multiple exit junctions. Consider the following survey extract:

From	To	length	Compass	Clinometer	L	R	U	D
F0000	F0001	10	90	0.0	5.0	5.0	5.0	5.0
F0000	F0002	15	180	0.0	5.0	5.0	5.0	5.0
F0000	F0003	15	270	0.0	5.0	5.0	5.0	5.0

The from and to columns are arbitrary station labels that uniquely identify each station point. The first line defines a survey leg that joins F0000 and F0001. This can be thought of as link definition with the compass defining a direction of travel from one station to another. It is possible to process in the opposite direction but the compass bearing must be reversed and the clinometer sign changed.

F0000 is a junction with passages leading off in different directions to adjacent survey stations F0001 F0002, F0003. Calculations might typically read the first data line and determine the position of F0001. When the second data line is read F0000 must be recognised as a station that has previously been encountered and its xyz co-ordinates re-established as the reference point to determine other adjacent stations.

One typical solution is to maintain a list of all station names and their xyz co-ordinates in memory and as every station name is read from a data line this list is searched to see if the station has already been entered in the list. If it is not in the list then there is a problem and the program must halt printing an error message. The user must then check the data and discover why there is no previous reference to the trouble making record. If however the record is found in the list, the xyz co-ordinates associated with that station are then adopted as the reference position for further adjacent stations.

Another problem emerges if a survey team starts at an unknown place in the cave and surveys a route that eventually connects to a station point of known position. The ordering of such data is the reverse or what would be convenient for calculation. Since the known xyz position lies at the furthest reach of the traverse the known reference station is the last station in the data input. The calculation of the xyz co-ordinate of the first station in the sequential data lines can only be calculated with special treatment of this data set. The main survey is processed first and then for each unconnected traversal known to connect onto the main survey the xyz co-ordinates relative to an arbitrary point on the traversal are computed. There are two immediate solutions to this problem. The compass bearings can be reversed, the sign of the clinometer changed and the order of the survey records to the place where they join the main survey can be processed in reverse with the reference point at the point where traverse joins the main survey. Alternatively calculations can start from the unknown point proceed in the normal direction but when it connects onto the main survey these relative co-ordinates have to be adjusted again by adding on the co-ordinates of the known station connection from the main survey.

It is possible that a traversal from an unknown point is in turn connected by other such traversals and each such occurrence must be processed in correct order. The traversal connecting to the known reference point must be calculated first and then the traversals that connect into these first order traversals.

Traverse From an Unknown Point. (B0001)

Plan View:
Horozonal cave

From	To	length	Comp	Clino	L R U D
T0001	T0002	20.0	335	0	- - - -
T0002	T0003	22.0	040	0	etc
T0003	T0004				
B0001	B0002				
B0002	B0003				
B0003	T0003				

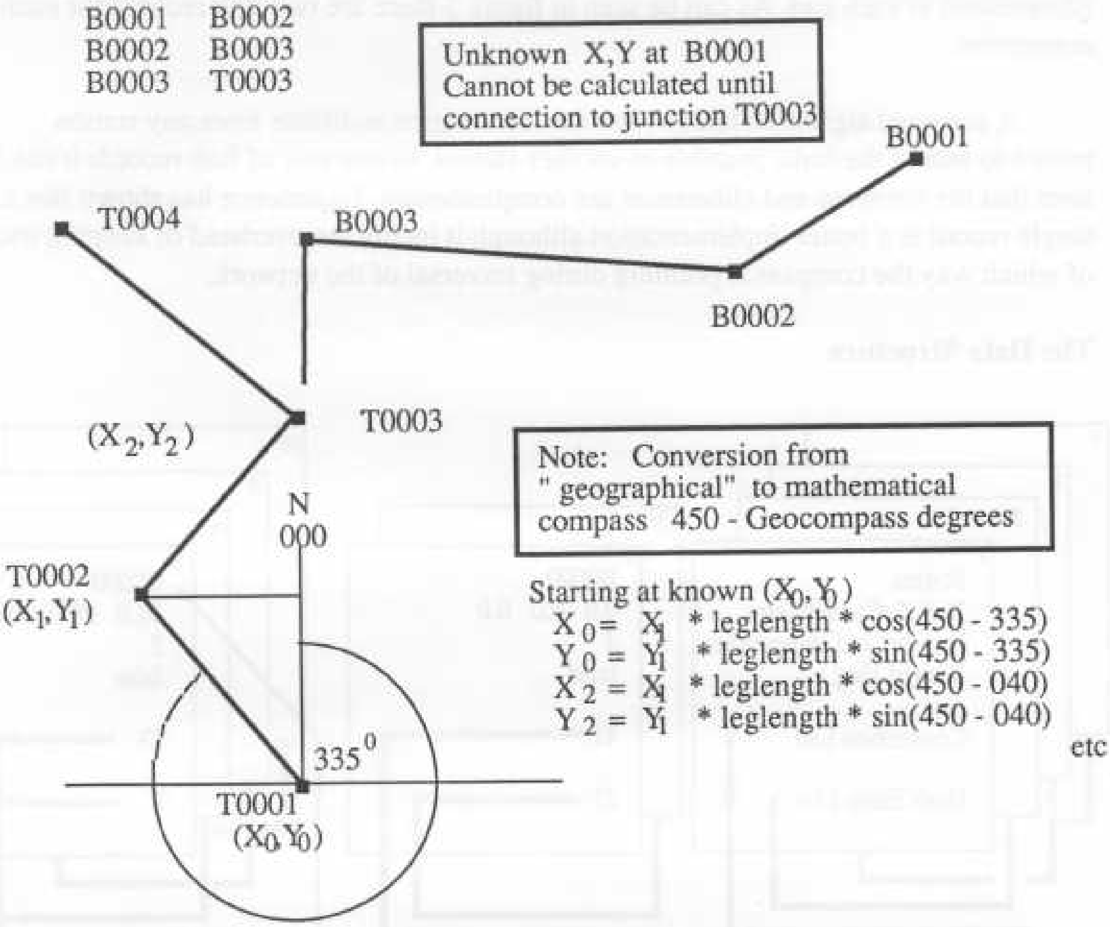


Figure 2 Traversal Calculations.

Surveying from an unknown point to a known point is a survey practice that is discouraged because of the nightmares it creates in data handling. Computer programs should easily handle this ordering. Joining disjoint survey work is important in order to place independent network systems in space relative to each other. Examples of such ordering would be

1. marrying two cave systems that are one day discovered to connect or
2. placement of caves with topographical and terrain information that might also be represented as a linked set of survey data.

Figure 3 shows a possible memory data structure representing a cave network. There are basically two types of record, those representing a station and those that represent a link with another station. Pointers are memory indexes that refer or point to another record in memory. Thus each station record contains a pointer to a link record.

In this record, information pertaining to a connection is kept and in turn the link record keeps pointers to where the link comes from and where it is going to. Here is the compass the length of the connection and also the magnitude of the connection (dimension) at each end. As can be seen in figure 3 there are two link records for each connection.

A traversal algorithm has to have the information available from any station record to access the links possible to another station. In one pair of link records it can be seen that the compass and clinometer are complemented. Experience has shown that a single record is a better implementation although it incurs the overhead of keeping track of which way the compass is pointing during traversal of the network.

The Data Structure

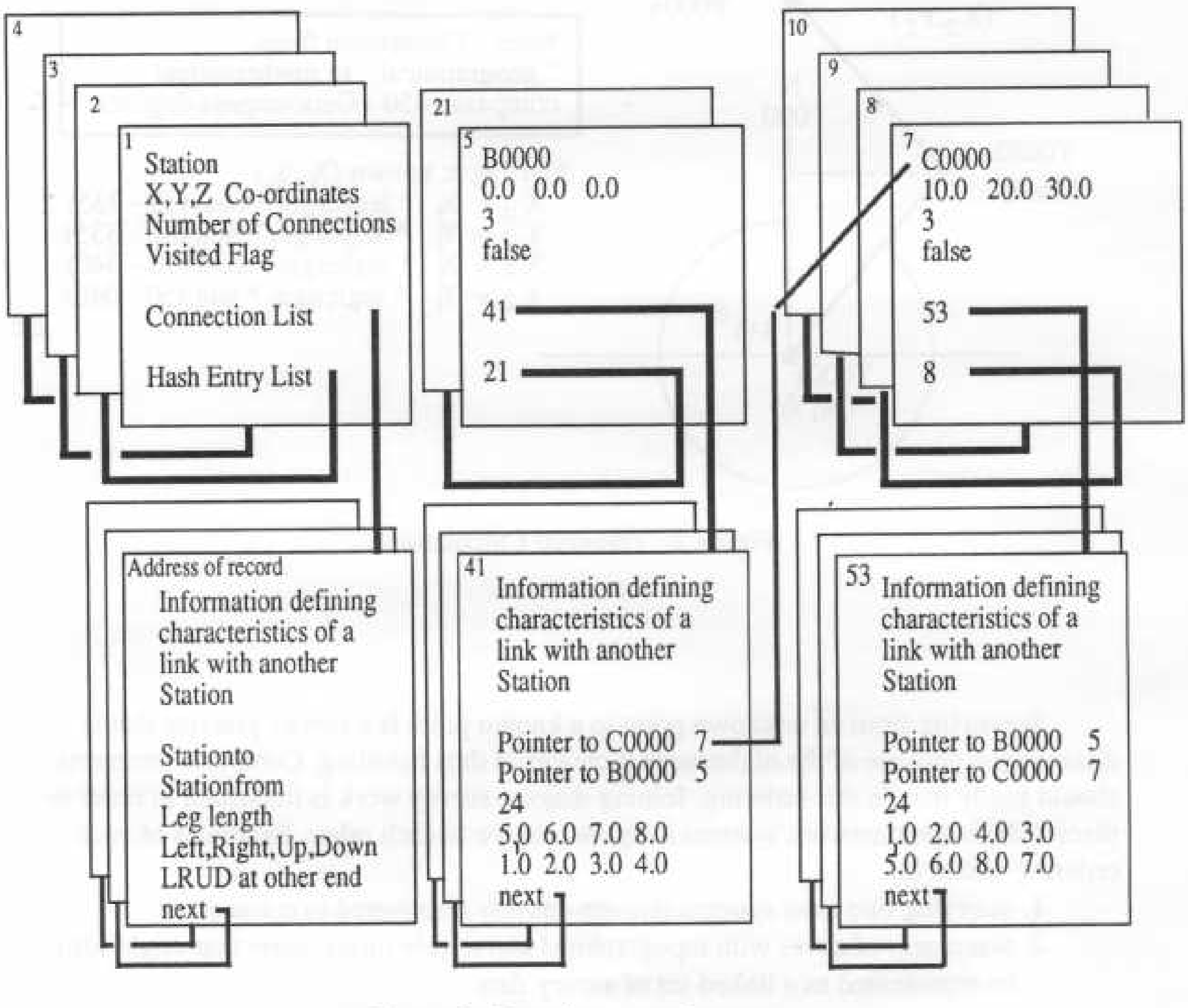


Figure 3 Data Structure Layout.

Often it is necessary to obtain a station record using the station identification code as the key. For this reason station records are stored in an array using a hashing function. It could easily have been stored sequentially in an array or in a linked list but searches for stations by identification code are much slower. In figure 3 the squares in the top row represent records relating to a station stored in a hash table. As can be seen the top left hand square: 1 points to 2 which points to 3. (Pointer values are illustrative and entirely arbitrary.) This is a linked list of hash entries belonging to the first position in the hash table. Location of any particular station is derived from a hash entry generated with the alphabetic station name. This provides an index to a hash table position which may contain multiple entries. These multiple hash entries are stored in a linked list which is then searched for the appropriate entry. (Barbara, Mann, and Zlotnick, 1987)

The second and third squares in the hash table are illustrated with an example. B0000 is the name of the station and is located at xyz co-ordinate (0.0, 0.0, 0.0.) It is connected to three other stations. These connections can be derived by following through the connection list. The first entry in B0000's connection list is pointing to station C0000. The LRUD at this end of the connection is shown in the connection list. It can be seen that the connection list of C0000 also shows its connection to B0000 but notice that the left and right measurements are reversed.

Building the Data Structure in Memory

Each line contains a station name that a leg is starting from and another name that the leg is going to. As each link record is read, the hash table must be consulted to see if these station names already exists in the hash table. If a name exists then a new link record is added to this station. If it doesn't exist then memory for a new station record is allocated and then memory for a link record attached to the station record. There is a link record allocated for each station; one in the defined direction and one with the compass reverse and the sign of the clinometer changed. Initially all semaphores are initialised to zero.

Traversal Algorithm

The first operation to perform is the calculation of the xyz co-ordinates of each station position. There are many possible network traversal algorithms possible (Knuth, 1987). A depth first search method was chosen because of its further application to misclosure correction, this traversal method is now briefly outlined.

It is necessary to assign some starting place, an initial xyz position and branch out from there eventually "visiting" all other stations in the network. Each station record references a list of links to other stations. By starting at a known point and traversing the list of links to all adjacent stations the xyz co-ordinates of the adjacent stations can be calculated and inserted into their records. For each one of those adjacent records the same process is applied with the proviso that stations already processed are not re-processed. This is checked by setting a semaphore in each station record. A semaphore can also be located in the link records to check if a link has been traversed. This prevents retracing a link back to a previous station before discovering this link has been travelled before.

As an analogy consider a speleologist exploring a labyrinth marking each encountered junction with chalk. If upon entering a chamber already marked then the semaphore reveals that this chamber has been visited before and it is necessary to return to a previous junction with uninvestigated passages to continue exploration.

This algorithm lends itself to a recursive implementation. The method of recursively traversing networks is well documented. For appropriate problems recursive programming allows the programmer to perform tasks with a very small amount programming code. While more expensive with machine memory and processing time, code maintenance and development cost is greatly reduced.

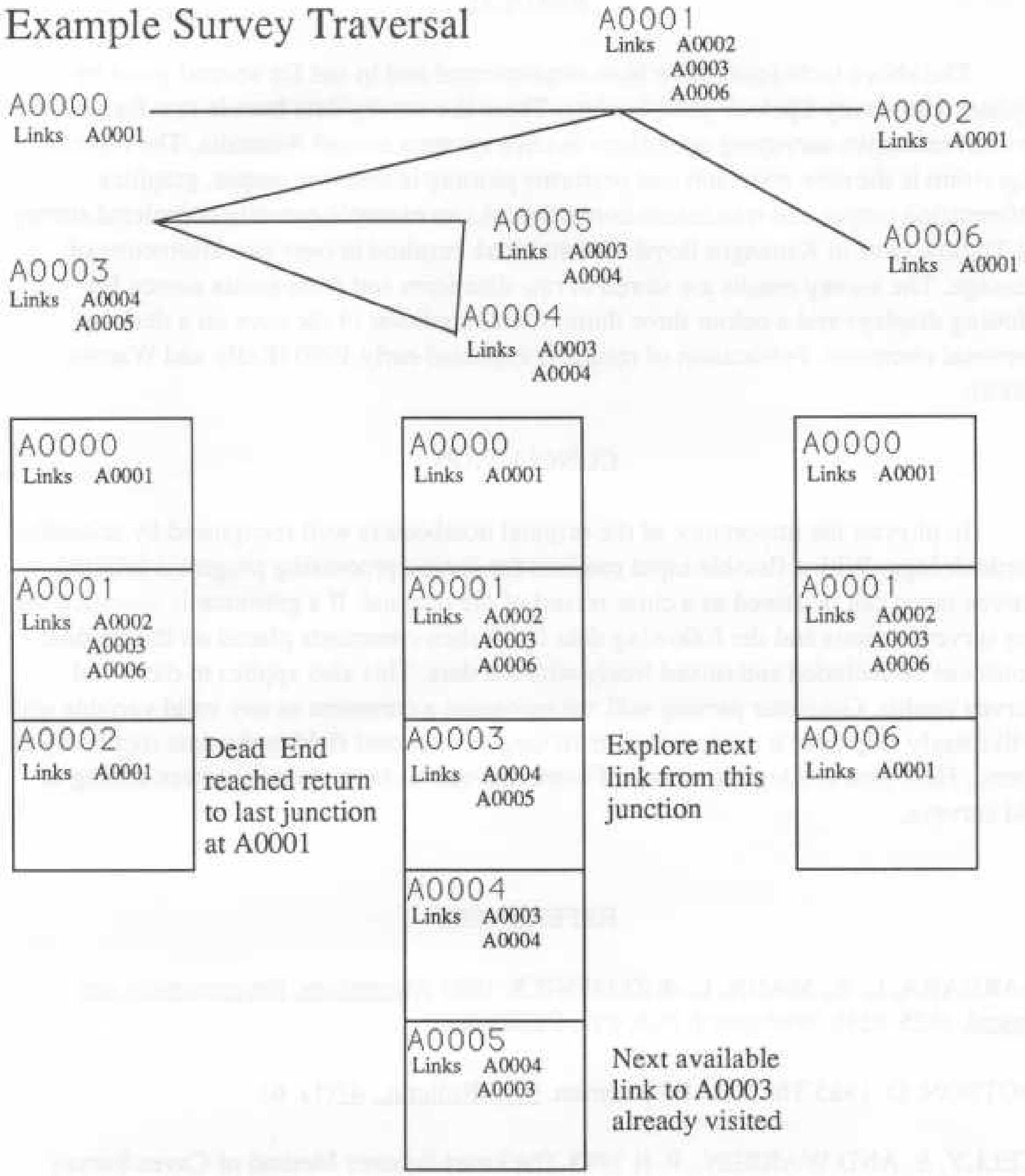
A recursive routine allows the routine to execute itself. All the variables within the routine are personal to that level of execution. The called routine has no access to variables from the calling routine except for variables that are specifically passed to the next level of execution. At the termination of the routine it returns to the calling routine and all the variables that were active at the time of calling are restored. This property of recursion serves as the memory capable of retracing the path back through any network that has been explored. Each recursive call passes the address of the next station travelling through the network exploring the station data structure. If a routine calls itself, then unless there is a conditional statement within the routine that terminates execution, it would continually call itself forever. The terminating condition in this example is either encountering a dead end in a survey line, encountering a survey record or link record that has already been visited. As the routine calls itself, it passes on to the called routine the memory location of next station that it is about to "explore" and the calculated xyz co-ordinates for that station.

The following pseudo code summarises the routine.

```
procedure traverse(station_pointer, x, y, z)
  if  station referenced by station_pointer not visited {
     set visited flag
     set xyz co-ordinates of the station pointed to by station_pointer
     for(each link_record referenced by station record) {
        calculate new xyz position based on x,y,z and link information
        enter the new xyz into the adjacent station record
        call traverse(link_record_station_pointer, newx, newy, newz)
     }
  }
}
```

This routine is the basis for any processing that might be performed on the data. The processing in this example is to set the xyz co-ordinates of each station record but it can equally be any other processing task. A recursive call can be represented as a stack of boxes. Each box represent a recursive call to a routine with the information relevant to that level of execution in each box. When a recursive call terminates it removes a box and execution returns to the box underneath. Below is an example survey and the links that would be represented in some memory structure. The three stacks show the memory structure upon encountering the main junctions of the network.

Example Survey Traversal



Error Handling

In large survey operations involving multiple survey teams some conventions regarding naming of survey station is required. Obviously it is undesirable for two groups to use the same name for two different stations. If a survey data set is connected into another block the name of the connecting survey point must be agreed upon or changed later so that the known point is the same on both surveys. If this is not done correctly there will be sections of survey data that are not connected to the start point. This should be apparent since there will be a section missing on the final plot. The missing survey information can be output to an error file by first applying the traversal algorithm to calculate xyz co-ordinates then running a sequential search through the hash table checking for station records that do not have the visited flag set. These must be station records that were missed by the traversal algorithm. It is then up to the survey organiser to discover where the missing station should be linked in.

RESULTS

The above techniques have been implemented and in use for several years by Sydney University Speleological Society. There is a survey data base in raw form from several extensive surveying operations in cave systems around Australia. The traversal algorithm is the core code unit and performs plotting instruction output, graphics information output and misclosure correction. As an example recently completed survey of Tuglow cave in Kanangra Boyd National Park resulted in over two kilometres of passage. The survey results are stored in raw data form and form a data source for plotting displays and a colour three dimensional rendition of the cave on a desktop personal computer. Publication of results is expected early 1990 (Kelly and Warren, 1988).

CONCLUSION

In physics the importance of the original notebook is well recognised by scientific methodology. With a flexible input routines for survey processing programs original survey notes can be stored as a close record of the original. If a grammar is specified for the survey stations and the following data fields then comments placed on the original notes can be included and mixed freely with the data. This also applies to dates and survey credits. Grammar parsing will not recognise a comment as any valid variable and will merely skip over it until an item matching an expected field in the data dictionary is found. Here then is a legible record of work that can be built upon by others adding to old surveys.

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DROUGHT DAMAGE IN A TASMANIAN FOREST ON LIMESTONE

Fred Duncan and Kevin Kiernan

Abstract

Widespread but patchily distributed drought death of forest trees occurred in early 1988 on a limestone ridge at Mole Creek in Tasmania. A close juxtaposition of damaged and undamaged vegetation probably reflects differences in the speed of soil moisture decline down the length of individual soil-filled solution tubes in which the trees are rooted. Possible palaeoecological, geomorphological and silvicultural implications are briefly reviewed.

INTRODUCTION

Severe drought damage occurred in a forest at Mole Creek in central northern Tasmania in early 1988. The forest area is situated at ~360-400 m above sea level on a limestone ridge that extends northwards from the Great Western Tiers. The ridge separates the Mayberry polje to the west from the Sassafras Creek Valley to the east. It supports mainly a wet sclerophyll forest, but some dry sclerophyll species are also present.

Nature of the damage

The drought damage and death affected both overstorey and understorey species. They were widespread but patchily distributed. Moderate to severe symptoms of drought stress were observed in *Eucalyptus delegatensis, Eucalyptus obliqua, Eucalyptus viminalis, Pomaderris apetala, Olearia argophylla, Olearia lirata, Cassinia aculeata, Pultenaea juniperina* and *Senecio linearifolius*. On the other hand, *Bursaria spinosa* exhibited no drought symptoms and *Acacia melanoxylon* seemed to be only slightly drought affected. Samples taken from shrubs and trees exhibited classic symptoms of droughting (T. Wardlaw, pers. comm.) with some secondary fungal infections also being evident.

Canopy die-back of varying severity was widespread in eucalypt saplings ranging in height from 2 m to 12 m. Some older trees in the area exhibit thin crowns, presumably due to leaf abscission. Numerous stags are present, hinting that the current drought death may not be an isolated phenomenon on the limestone ridge.

Relative interspecific damage was broadly similar to that recorded from southern Tasmania by Kirkpatrick and Marks (1985). However, at a more detailed level the comparative degree of drought damage to individuals of these various species was sometimes intriguing. For instance, severe damage was occasioned to some specimens of *Pultenaea juniperina*, the most xerophytic in character of the shrubs present. This occurred side by side with healthy specimens of *Pomaderris apetala*, a wet sclerophyll species that might have been expected to be more sensitive to drought.

The most severely drought affected patches were generally associated with slight rises in the topography, but this was not always the case. Vegetation around sinkholes showed no sign of drought damage. In many instances dead trees stood side by side with healthy ones. Comparable damage to the vegetation was not observed in non-karst areas with the same general topographic setting, which suggests that the karst itself contributed in a critical way to the deaths.

Rainfall deficit and damage recovery

The damage to the forest followed severe drought conditions. The nearest comparable station for which reliable rainfall figures are available is Meander. Although Meander lies 22 km further ESE it is in a very comparable situation with respect to the Great Western Tiers, which exert a major influence on the distribution of rainfall in this part of Tasmania. The mean annual rainfall for Meander is 1105 mm. The drought damage at Mole Creek was first noted on 21 April 1987. During the preceeding six months the rainfall at Meander totalled only 73% of the long term mean for that period. Probably more significantly, the months July-September, normally the wettest time of the year, saw only 47% of the usual rainfall with total falls since midwinter 1987 having reached only 56% of the long term mean. During the three normally driest months, January, February and March, rainfall in 1988 totalled respectively only 78%, 27% and 6% of the long term mean.

Heavier rain fell in northern Tasmania in April 1988, the total received at Meander being 57mm or 67% of the long term mean for that month. Most of the drought affected plants at Mole Creek were observed to be shooting subsequent to these rains. This included many plants on which no green leaves or shoots previously remained. However, not all survived. When the site was revisited in January 1989 the most visibly conspicuous damage in the long term was to *Pomaderris apetala*, with only one out of a dozen drought-stressed specimens marked during the previous April having survived.

DISCUSSION

It is the geographical pattern of the damage at Mole Creek, as much as the development of intense drought stress specifically on the karst, that is of interest. The area of drought damage is characterised by thin residual soils developed from limestone that protrudes through in many places. Similar drought damage was not observed in adjacent areas where the soils were developed from thick allogenic colluvial or glacial sediments that had been deposited on the limestone surface.

Within the drought affected area many of the joint systems in the limestone have been weathered open to produce rifts, clefts, natural shafts and sinkholes. In terrain such as this the rain that falls on the ground is quickly evacuated down solution pipes and channels in the limestone. Soil materials extend down into these solution pipes. Hence, there is a system of discrete soil-filled compartments. There is likely to be only limited lateral migration of moisture from one compartment to another unless they are formed on the same joint system. Exploration of one shaft showed that it maintained a diameter of little more than 1m to a depth of 15 m at which point it was blocked by sediment washed into it from the adjacent slopes.

In such terrain plant roots are probably concentrated within the soil in the karren and solution pipes rather than on the adjoining thinly soil-covered or bare limestone outcrops. Under drought conditions soil moisture will progressively diminish in the pipes due to transpiration by the plants. Where pipes are connected to deeper karst drainage systems, moisture will fall down the length of the pipes. Some pipes will lose their moisture more rapidly than others, depending on the transpiration demands of the plants and the inter-connectedness of the cracks and voids. With severe drought such as that which occurred at Mole Creek during the 1987-88 summer, soil moisture conditions are able to diminish below those needed to sustain some plants. In at least a few cases this is probably because drainage via pipes lowers the zone of moist soil below the level reached by the roots of some of the trees and shrubs. The result is that intolerable drought stress can arise very suddenly and with a finality that may not generally be the case in most non-karstic situations.

These facts probably underlie the patchy distribution of drought damage and death. Groups of trees were either affected or unaffected, and in some cases individual trees growing in one soil compartment died while others immediately beside them rooted in different compartments remained healthy. Monocotyledons lack a deep tap root and so are not dependant upon soil filled pipes and continue to flourish on the outcrops.

Implications

The drought damage observed at Mole Creek offers useful insight into understanding the likely vegetational and geomorphic response of similar karst areas to the climatic changes that occurred during the Pleistocene. Depressions such as grikes and sinkholes generally provide damp refugia where some plants are protected from increasing aridity, fire and grazing pressures (Ward and Evans, 1976). However, with the onset of colder and more arid conditions there is likely to be very rapid vegetation change from trees to grasses in well drained areas immediately beside these refugia. Under such circumstances pollen records may not show clear dominance of either forest or grassland communities. The geomorphic response is likely to be quite complex because weathering and erosion tend to be strongly influenced by the vegetation cover. Areas that experience a marked increase in mechanical weathering and slope instability due to a loss of tree cover may be closely juxtaposed with others where the ground surface remains comparatively stable or aggradational and where chemical weathering processes continue to predominate.

Potential karst drought may also need to be considered in the context of forestry planning in karst areas. In particular, in a soil/ bedrock context such as this one, episodes of drought stress may pose considerably greater risk to regeneration after clearfalling than is the case in most other types of forest terrain. The result may be regrowth that is very patchy and uneven and, hence, considerable economic loss. Moreover, the potential problems of karst drought that already exist in areas such as Mole Creek are likely to be further aggravated should soil erosion accompany logging. In various parts of the world soil erosion caused by humans has led to the development of virtual karst deserts (Kermode, 1974; Drew, 1983; Goldie, 1986). Erosion of the soils on the limestone ridge beneath the Mole Creek forest, or in other areas like it, could easily initiate rapid site decline that could prove irreversible.

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CAVERNICOLOUS SPIDERS (ARANCAE) FROM UNDARA, QUEENSLAND AND CAPE RANGE, WESTERN AUSTRALIA

M.R. Gray

Abstract

Two small collections of cavernicolous spiders from Undara, N.E. Queensland and Cape Range, W.A. are compared and their relationships are discussed. Cave adapted species are recorded for the families Ctenidae, Zodariidae, Nesticidae, Mysmenidae, Anapidae and Desidae.

INTRODUCTION

This report deals with two collections of spiders from caves at Undara, north-east Queensland and Cape Range, Western Australia. Both faunas contain highly cave adapted species and share related groups. The Undara spiders come from Bayliss Cave, the largest of the Undara lava tunnels. The Cape Range roglobitic spiders were collected from the deep, vertically developed caves. Ongoing biological work at both of these cave regions is revealing rich and diverse cavernicolous faunas. Howarth (1987) has recorded 24 troglobitic invertebrates from Bayliss Cave alone.

Table 1. List of Species

Undara, Qld. - Bayliss Cave (U-30)

Family Ctenidae: *Janusia* sp. 1 (Tb)
Nesticidae: *Nesticella* sp. 1 and 2 (Tb and Tp)
Zodariidae: *Storena* sp. (Tb)

Cape Range, W.A.	Cave
Family Ctenidae: *Janusia* sp. 2 (Tb)	C167, C126, C106
Nesticidae:*Nesticella* sp. 3 (Tp)	C18
Mysmenidae: *Mysmenopsis* sp. (Tb)	C126, C167
Anapidae: Undetermined (Tb)	C18, C167
Desidae:*Forsterina* sp.	C18, C94, C167
:Undetermined (Tb)	C18
Filistatidae: *Pritha* sp.	C94
Pholcidae: *?Pholcus* sp.	C18, C94

Relationships

The faunas listed in Table 1 share two genera, *Janusia,* whose members are vagrant hunters, and *Nesticella*, small 'tangle' web builders. *Janusia* Gray was erected for a troglobitic spider from the Nullarbor Plain, *J. muiri* Gray, 1973. The two species listed here are more closely related to each other than to *J. muiri*. *J. muiri* was placed in the family Miturgidae (Gray, 1973) but examination of surface relatives from forest litter in N.E. Queensland suggests that their affinities are with the Ctenidae. The current relictual distribution pattern of the genus is indicative of an ancestral continental distribution.

Both *Janusia* species are blind and depigmented troglobites. Males and females from Cape Range are fairly similar in size, but males from Undara are much smaller than females. This is unusual as hunting spiders, including ctenids, typically show little size dimorphism. In this case the dimorphism observed may reflect both a neotenic response to a low energy environment and a strategy to maximise outbreeding in a small, isolated population. Thus, males may take fewer moults to mature to small adults, so minimising their lifetime food needs; and, maturation in a shorter time than females may promote mating by males with females of a different generation (assuming females are long lived as seems common in many cave adapted species).

The family Nesticidae (Nesticini) has mainly cave associated species in the northern hemisphere. Its tropical representatives in the Nesticellini are less common in caves than in forest litter. The only Australian representative (an undescribed surface species from Iron Range in north Queensland) is placed in the east Asian genus *Nesticella* Lehtinen and Saaristo (Davies, 1985). The cavernicolous nesticids recorded here also belong to this genus. The male and female specimens from Bayliss Cave have been placed in separate species on the basis of the markedly more advanced state of troglobionty in the male and their disjunct distribution in the cave.

Nesticella has also been recorded from Papua New Guinea (Lehtinen and Saaristo 1980), but not from caves. Bourne (1980) attributed 2 species from P.N.G. caves and dolines to the northern genus *Nesticus*. His diagrams, however, indicate that one (*N. renatus*) belongs to *Nesticella*, the other (*N.utuensis*) to the east Asian-Pacific genus *Howaia* Lehtinen and Saaristo. Zodariid spiders are ground dwelling hunters that are widely distributed in Australia. The Undara species is depigmented and shows marked eye regression including loss of the posterior median eyes. Typically it is the anterior median eyes that are the first to regress or be lost in troglobiontic spiders). The placement of this spider in the genus '*Storena*' is provisional pending a review of the taxonomy of the family.

The mysmenid species from Cape Range, a tiny unpigmented web builder is placed in the genus *Mysmenopsis* Simon. This diagnosis is based on female specimens which have a characteristic small apophysis on the proximal femur of each first leg. This is an interesting record as *Mysmenopsis* has been previously noted only from the southern Nearctic -northern Neotropical Americas. Cavernicolous mysmenid spiders are proving also to be of interest in eastern Australia where spiders closely allied to the northern hemisphere genus *Trogloneta* (from caves in France and North America) has been found at Kutikina Cave, Tasmania (Gray, 1988) and Jenolan Caves.

The desid and anapid troglobites are represented by single females only and their generic placement is uncertain. The remaining species are more or less troglophilic spiders belonging to widely distributed genera.

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