# Karst in recent dunes, Codrington, Victoria

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## Introduction

Aeolian calcarenite is formed when calcareous fine sand size particles are mobilised by wind action and deposited as dunes, when then undergo diagenesis and lithification. We have examined the formation of karst features in aeolian calcarenite dune limestone at Codrington and the relative base level positions in the landscape of surface and subsurface features. By examining the spatial relationships between the karst features and the dunes it can be determined whether or not terrain in the study area has been influenced by solutional processes. The swamps between the dunes are primary dune swales which show evidence of solutional modification, eg. notches and cliffs. The lithified dunes contain caves which show solutional features at the same levels as the notches and the base of the swamps.

## The Codrington karst landscape

The area is situated on farming land used for cattle grazing at Codrington, south-west Victoria. Codrington is approximately 30 km from Port Fairy and approximately 35 km from Portland. The study area is 3 $km^2$, approximately 1 km inland and the strandline dune ridges represent a former coastline. Within the study area there are three distinct calcarenite dunes. These dunes have been identified as Dune A, B and C for convenience of discussion. Swamps are present in the interdune swales between the dunes, and the Eumeralla River flows through the study area. The area studied does not cover the entire outcrop of aeolian calcarenite dune ridges in Codrington which extend for at least 20 to 30 km along the coast. The dunes in the study area were assumed to be representative of those found throughout Codrington and nearby areas. The area was chosen due to its accessibility, minimal previous study, numerous karst features in a relatively small area and because it complements similar studies of karst on the calcareous dunes in south-west Victoria.

The aeolian calcarenite limestone dune ridges at Codrington are mainly composed of calcareous sand which was derived from the calcareous Tertiary sediments of the Port Campbell limestone. These sediments were mobilised and redeposited in strandline dunes during the higher sea levels of the Pleistocene. As the sea retreated from the region during the Pleistocene the exposed sand fragments were carried by the wind and deposited as dunes.

This series of dune limestone ridges has been described as the Bridgewater Group (Orth, 1988). The preservation of the dune ridges was due to rapid 'case-hardening' of the calcareous sands by calcrete development. Calcrete development began when the sand became stabilised by vegetation (von der Borsch et al., 1980; White, 1984, 1989, 1994; Grimes, 1992).

Syngenetic caves and karst features are predominant in these partly consolidated Bridgewater Group calcarenite dunes. The karst features were developed as the sands were being cemented into limestone (Kenley, 1988; Grimes, 1992; White, 1984, 1989, 1994). The Bridgewater Group calcareous dune ridges at Codrington contain an interesting series of caves and karst features and the dunes are separated by interdune swales which are presently swamp hollows (Bonwick, 1858; Kenley, 1988). The large swamps in the interdune flats are most likely to be the remains of primary coastal lagoons and swamp features (Grimes, 1992).

## Caves of the study area

The existence of caves in the dunes at Codrington have been known for over 100 years. Bonwick (1858, p.88) mentions seeing caves in the district in 1857, ie. "several rises of limestone appear amidst the swamps of Eumeralla, and contain interesting caves". Systematic exploration and documentation of the caves by VSA was not started until 1990.

The location of the caves in the study area is dependent on the drainage direction in the area, ie. north to south. The caves are generally down drainage, especially where swamp water has increased the aggressivity of groundwater. The caves were formed at the top of the water table by solution in conditions of mixing corrosion and evidence of solution by slow moving water can be found in rock pendants protruding from cave walls near the ceiling in CD-13. These pendants were of varying dimensions smoothed by solutional activity but evidence of dynamic phreatic water was absent in the caves studied. Evidence of past vadose flows was present in mud deposits on the extensive collapse rockfalls in the cave passages, eg. CD-13. Lateral solution at or near the water table along lines of weaknesses in the rock, eg. cross bedding planes resulted in roof collapse. However, the caprock has enabled caves to have some structural support and therefore entire collapse of the caves has not occurred.

Cave passages are sinuous rather than straight in plan, eg. CD-13 (Figure 1). The shape of the passage is dependent on the dune bedding planes in conjunction with the geometry of the water table. Collapsed roofs show cross bedding influences, eg. CD-4. The cave passages are flat with only slightly arched roofs and a few domed chambers and consist of a caprock with weaker material below. The cave passage cross sections were generally either low in height and wide horizontally, or were as wide as they were high in the domed chambers (Figure 2). Passage shape is often modified by collapse. Passages can be increased in size by collapse, eg. in CD-13 collapse has resulted in a large domed chamber approximately 15 m high and 20 m wide. In other cases, eg. CD-4, passages are blocked by extensive collapse material. The extended profile of CD-28 shows clearly the flat cave passage and the low horizontal roof with minimal collapsed domes. The domes in CD-28 were very small (1.5 m high) in comparison to CD-4 and CD-13 (6 - 8 m high). The extended cave profiles of CD-4 and CD-13 were similar, ie. both cave passages comprise of high dome chamber ceilings and low horizontal ceilings.

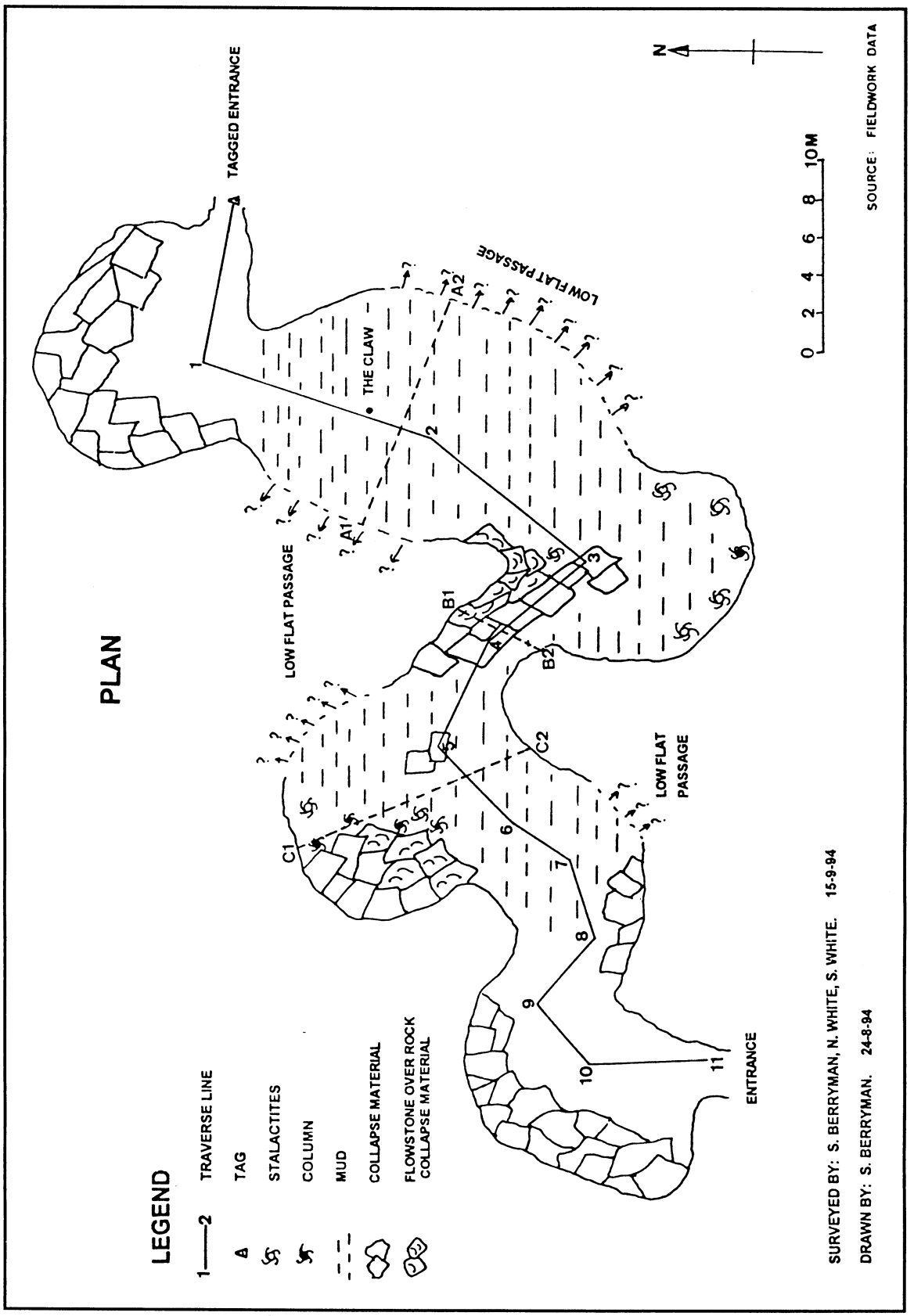


**Figure 1: Plan map of Claw Cave (CD-13)**

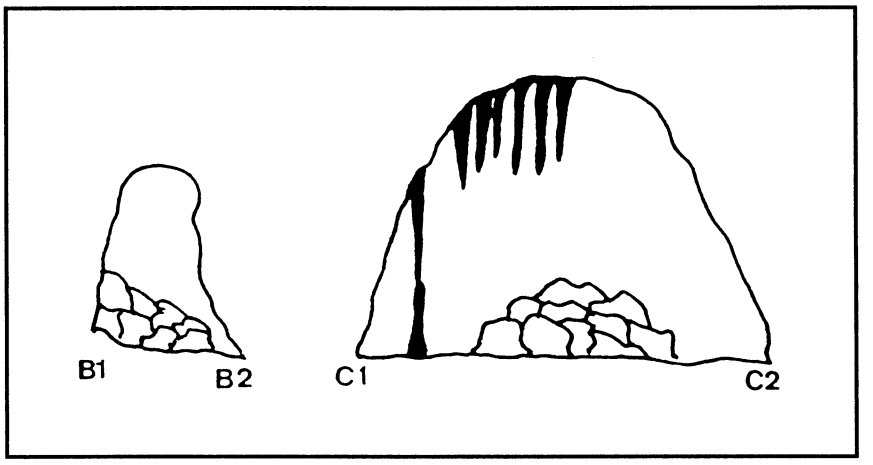


**Figure 2: Cross sections of Claw Cave (CD-13) illustrating collapse**

All of the caves studied had multiple entrances. The tagged cave entrance to CD-13 is an example of a modified smooth sided solution pipe. The pipe has been modified by some collapse and there is debris funnelling at the entrance composed primarily of soil. The other entrance to CD-13 and the multiple cave entrances to CD-4 and CD-28 have formed through roof collapse.

## Diagenesis of Calcarenite

Changes in the mineralogy, geochemistry, texture and fabric of a sediment after deposition are known as diagenesis (McLaren, 1993). Diagenesis of the host rock plays a very important role in the development of karst features, eg. caprock.

Before diagenesis occurs the unlithified calcareous sediments in the dunes are free-draining in the vadose zone. A supply of water rapidly moving through this vadose zone results in water concentrating at points of grain contact allowing meniscus cements to precipitate (McLaren, 1993). Any water between the grains is held within the pores by capillary forces. As the pores become smaller and less well connected in the course of diagenesis, the capacity for more water to remain longer within the primary pores is likely to increase. In most cases, porosity decreases over time with carbonate diagenesis until it is finally occluded, or remains stable at low levels (Gardner & McLaren, 1993). In the initial stages of diagenesis meniscus cements develop. In the next stage magnesium is lost from high-Mg calcites before the dissolution of aragonite. As a result of the re-precipitation of the dissolved aragonite, pore-filling cement occurs. Pore-filling is when cement fills the small pores and spaces within the calcareous sediments. The identification of these separate stages suggests that local variability is low (Gardner & McLaren, 1993).

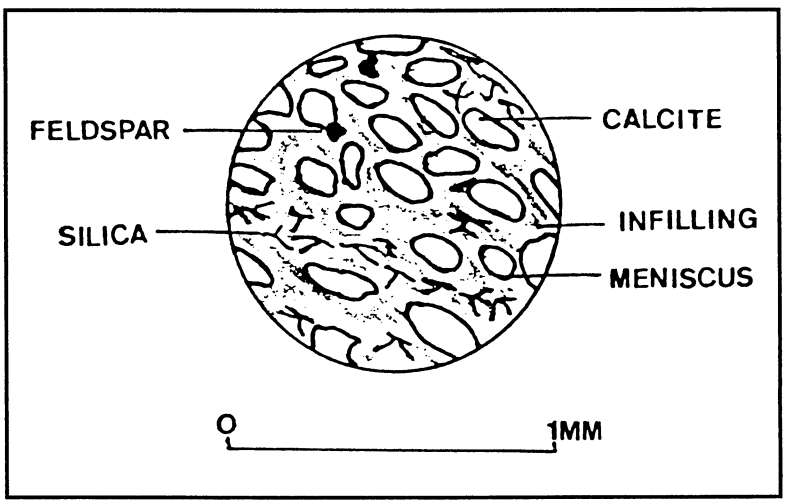


**Figure 3: CD-5 Thin Section**

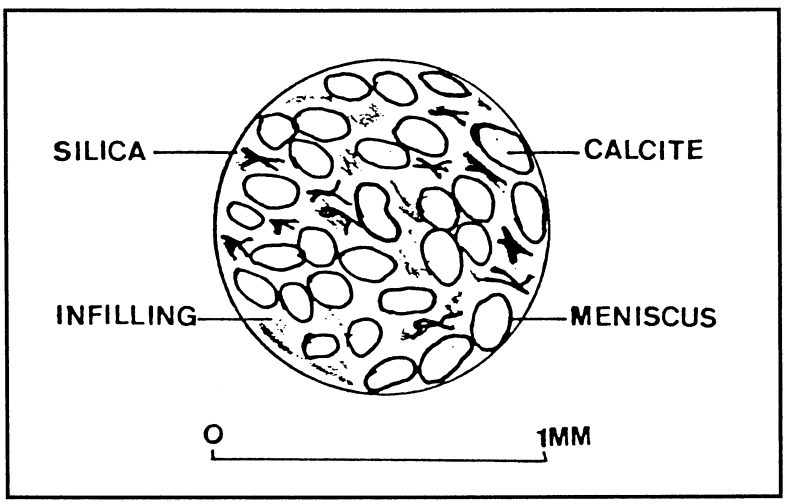


**Figure 4: CD-13 Thin Section**

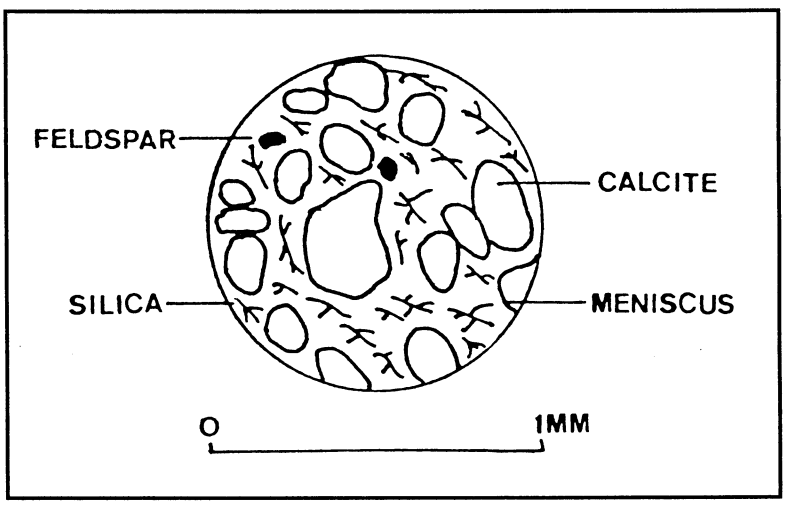


**Figure 5: CD-28 Thin Section**

Hand specimens of the Bridgewater Group rock were taken from the caprock at CD-5, CD-13 and CD-28 cave entrances. Of the thin sections studied, the rocks showed low diagenetic development, ie. pore-filling cement was low and restricted to the finer-grained laminations, eg. CD-5. The thin section of CD-5 showed that meniscus cement surrounded some of the grains in the sample however the grains were well cemented with abundant pore-filling cement. Small-rounded calcite and silica grains were easily identified under the microscope and a few fragments of feldspar. There were more calcite grains than silica grains (Figure 3). The thin section of CD-13 was very similar to that of CD-5 however pore-filling was less abundant and meniscus cement was the main cement. The rounded grains of calcite and silica were slightly larger than CD-5 (Figure 4). The thin section of the rock sample taken at CD-28 showed that the rock was comprised of large rounded calcite and silica grains with a predominantly meniscus cement at grain contacts. This thin section displayed a lot more silica than the other two samples. Minor fragments of feldspar were also present in the thin section (Figure 5).

The silica compositions and grain size in the thin sections of CD-5 and CD-13 were less than that of CD-28. These characteristics are related to deposition conditions; perhaps Dune C was deposited at a different time to Dunes A and B and is of a different age, however more research is required to determine this.

The analyses shows that there is evidence of diagenesis still occurring in the calcareous dunes at Codrington. The first stage of diagenesis, the meniscus cement formation, was clearly seen in all of the thin sections. The pore-filling cement seen in the CD-5 sample illustrates the beginning of the second stage of diagenesis. This evidence indicates diagenesis is occurring at the same time as cave formation.

## Spatial relationships of karst landforms and dunes

The spatial relationships between the dunes, notches, Eumeralla River, swamp water, swamp base levels and cave base levels in the study area have been influenced by solutional processes (Figure 6).

The notches located at the dune/swamp interface are associated with the episodic high swamp levels. The notches are prominent at the southern end of the swamps where swamps drain towards and into the dunes. The cave base level near one of the multiple entrances to CD-4 (tagged with a screw) correlates to that of the base of a notch on Dune A. This relationship indicates that the cave floor and notch probably formed at the same water table height.

The water table level under areas of higher relief is normally higher than under low relief areas. Figure 6 shows that the water table height under the dunes is higher than under the swamps. CD-4 and CD-13 cave base levels exist above the present water table level in the dunes. However CD-28 base level is at the same height as the present wet winter water table level. The Eumeralla River water level is the local base level for the area and correlates to the depths of the water table measured under the swamps.

The caves are only located in the dunes, they do not extend under the swamps. The swamp material has insufficient strength to form the roof beam required for cave passages. The caves appear to be confined to parts of the dunes, especially on Dunes A and B (Figure 6). The caves are generally on the northern side of the dunes in close proximity to the swamps. Only a few caves are known to exist on the south side of the dunes. This spatial pattern of the caves indicates that cave formation is dependant on the drainage of the water table through the swamps which is a southerly direction towards the sea.

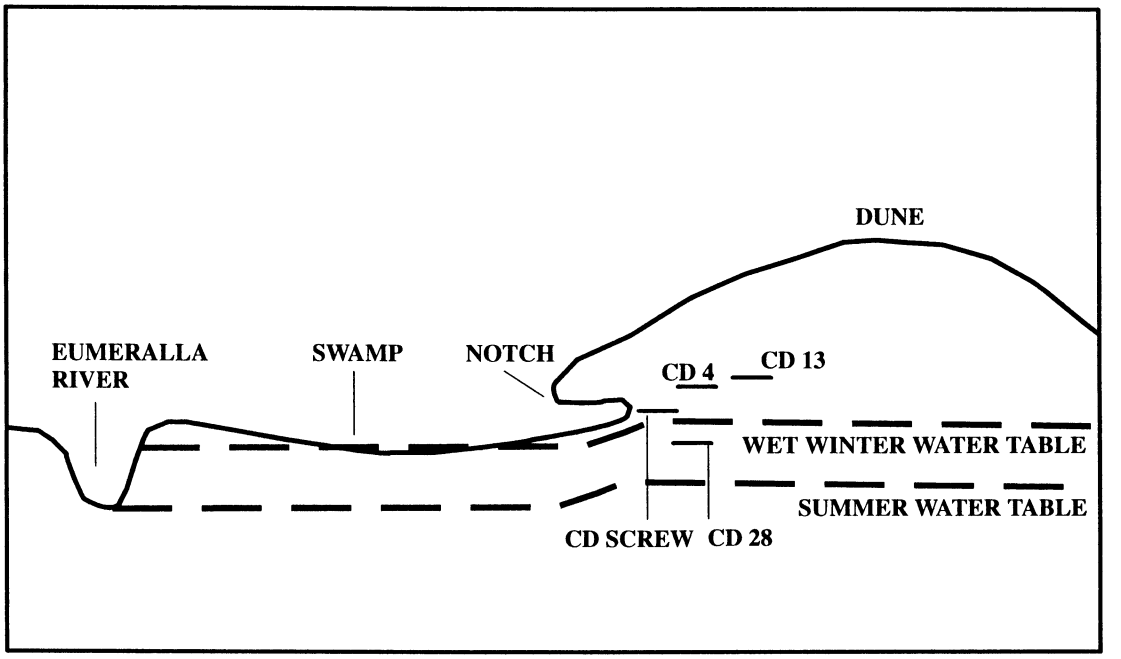


**Figure 6: Schematic representation of Spatial Relationships**

## Speleogenesis at Codrington

Although no absolute dating has occurred at Codrington it is known that the calcareous dunes at Bats Ridge, Portland (White, 1984) and Warrnambool (B. Oysten, pers. comm.) date from the Mid to Late Pleistocene. Therefore it can be assumed that the calcareous dunes at Codrington would be of a similar age. The dunes are geologically young and insufficient time has lapsed for diagenesis of the dunes to occur first, then subsequent development of karst features.

Speleogenesis in aeolian calcarenite dunes occurs concurrently with diagenesis. Evidence of this process is the limestone dune bedrock thin sections displaying only the first stage of diagenesis completed. Therefore the dunes at Codrington contain syngenetic karst.

Syngenetic karst may also be recognised by its characteristic features due to the variable degrees of consolidation and lithification of aeolian calcarenite, eg. linear caves and collapse dolines. These characteristic features were observed at Codrington. The caves have formed where there is lateral solution at the water table resulting in the linear cave system. Collapse dolines have resulted due to weaknesses in cave roofs.

The notches in the study area appear to have formed when water table levels were slightly higher and the swamps had high water levels. Figure 6 shows notch levels to be near and/or at the same level as cave base levels in the dunes. This relationship indicates that the notches have probably formed at the same time as the caves and supports the argument that syngenetic karst processes are occurring at Codrington.

# Conclusions

This study, whilst describing the karst landforms and their geomorphic evolution, raised many unanswered questions which could be answered if a more detailed study were carried out. In particular, the question of 'what is the time involved for karst development?' remains unanswered. As noted previously, if it is assumed the dunes at Codrington represent the same sequence as those at Warrnambool, it can only be assumed that the karst landforms at Codrington are younger than 400,000 years old.

These assumptions form the major limitations of this thesis, and if proved wrong would have a major impact on the conclusions reached. To eliminate these assumptions a major integrated study of the entire aeolian calcarenite dune ridges at Codrington and nearby areas would be necessary.

Evidence that the karst landforms have developed simultaneously with the lithification of the dunes is found in the cementation of the dunes. Only the first of the four stages involved in dune limestone diagenesis is strongly evident in the area, although evidence of the start of the second phase is present. This shows clearly that syngenetic karst processes are operational at Codrington.

The area shows strong similarities to other areas of karst in aeolian calcarenite in southern Australia, in particular Bats Ridge near Portland. Although there are some differences (Bats Ridge is further inland, is basically uncleared Eucalyptus woodland and is on a ridge of higher altitude above sea level), the relationships to the swamps, the linear horizontal cave systems, and the prominence of collapse features are similar. Codrington is another area which adds to our knowledge of karst processes in dune limestone.

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