THE AUGUSTA AREA, SOUTH-WEST OF WESTERN AUSTRALIA: THE REASONS FOR ITS KARST MORPHOLOGY

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Abstract

Within several square kilometres of Tamala Limestone, south-east of Turner Brook, are found the only known extensive nothephreatic shallow watertable maze caves in the coastal limestone of Australia. The physiography, soils, vegetation and distribution of karst features in the area are described, and an hypothesis proposed to explain the occurrence of maze caves in this restricted area.

GEOLOGY AND PHYSIOGRAPHY

The Tamala Limestone of the Augusta area is underlain by hard igneous rocks of the Leeuwin Block. This block is separated from the Perth Basin to the east by a series of faults, the principal of which is the Dunsborough Fault (Lowry, 1967; Playford, Cockbain & Low, 1976). To the west there is no fault, the Precambrian rocks of the Leeuwin Block extending out into the Indian Ocean. The small section of this block which has not been eroded by wave action, corresponds to the Leeuwin-Naturaliste Ridge. The Precambrian in the Augusta area is granite-gneiss. Also in the Augusta area are anticlines in the granite-gneiss dipping roughly north-west.

There are three sets of joints in the granite-gneiss (Williamson, Loveday & Loveday, 1976) at roughly 180°, 240° and 270°. The 240° set is the most enlarged by wave action on the present coastline. This is also the dip of the axes of most synclines and anticlines in the block. The coastline south-west of the Augusta caves is relatively straight for about 10 km along the 270° joint orientation.

The Precambrian is overlain by a series of late to middle Pleistocene marine and aeolian deposits (see Fig. 1). The aeolian deposits visible on the surface generally increase in age from west to east. The older are podzolised silicious dunes which occur on the north-east edge of the limestone belt. These may represent fore dunes as do similar deposits at Capel (Playford *et al*, 1976). These dunes are now much reduced in relief, though still visible, sloping up from the laterite plains of the Blackwood Valley and down towards the limestone.

At the contact with the limestone, a marked sharpening of the slope of the aeolian calcarenite is evident. This is the result of greater leaching of carbonate where it overlies a silicious sediment.

On the surface, the next oldest bed is the oldest aeolian calcarenite but underlying this deposit and evident in Jewel Cave and Easter Cave is a beach ridge deposit which itself directly overlies a marine erosion surface developed on the granite-gneiss. This surface shows wave-cut gutters (along 240° and

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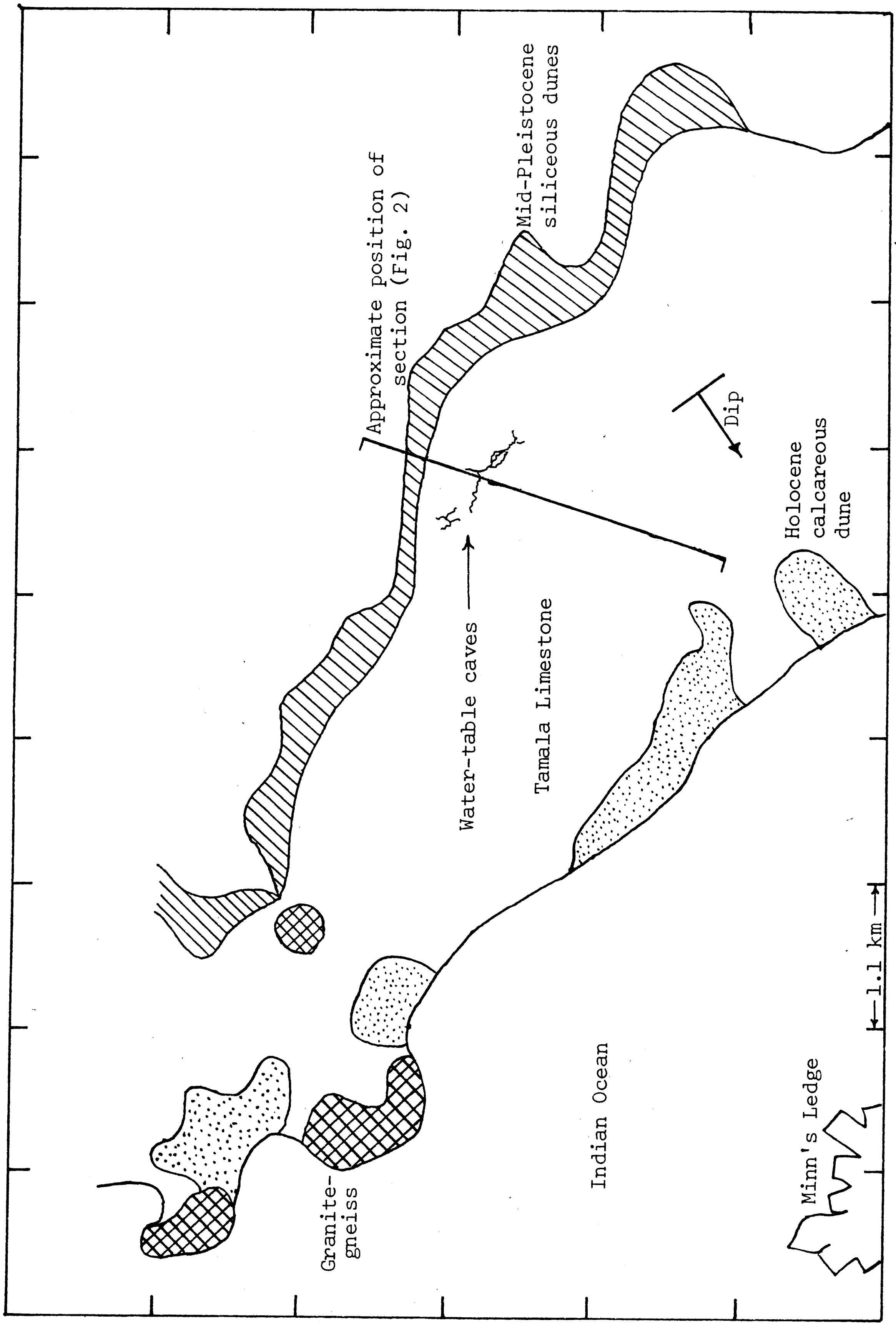

Fig. 1 Augusta area - surface geology and location of water-table caves.

(After Lowry 1967.)

270° joints) and large rounded boulders. All is very weathered and kaolinised. The beach ridge is a well laminated calcarenite with no obvious fossils on an admittedly cursory investigation. The lamination is enhanced in corrosion passages. Dips are small (10° to 12°) with in places overlying cross bedded deposits which may represent storm ridges.

The aeolian calcarenite overlies these deposits and shows the wide-spaced bedding, soil horizons, *Bothriembryon* (native terrestrial gastropod) beds of aeolianite. A terra rosa soil with bands of ferricrete is developed above the limestone. In places this ferricrete has fallen through solution pipes into caves, for example, the Gravel Grovel in Easter Cave.

Overlying and to the west of this older calcarenite is a younger aeolianite. This aeolianite has cavern collapse up into it, for example, Old Kudardup Cave, but no development of water table maze caves has been found. Similarly, there has been no development of the caves extending under the youngest aeolianite. This aeolianite is poorly vegetated, unconsolidated sand. It has a poorly developed alkaline soil. In some places down slope of the dunes, this soil has become cave fill. The large size of the calcited drip pools in Old Kudardup Cave is probably the result of the calcareous nature of the fill.

Each aeolianite has its characteristic soil and faunal association. Bain (1962) distinguished several stages in the formation of these dunes. Bain also suggested that drainage was mainly off the younger dunes and aeolianites and to the north-east. There is evidence that this is not entirely the case. Recent experiments have shown that the direction of flow in the Flat-roofed Chamber lake in Jewel Cave is to the south-west (R. Webb, pers. comm.).

At the contact of the younger aeolianite and the old aeolianite is a steep slope, almost a karst pavement, developed on the cap rock of the younger aeolianite. At the base of the slope are areas of karst pavement with very small solution shafts formed from runoff.

THE CAVES

The Augusta area is characterised by extensive shallow nothephreatic maze cave systems. Three reach down to extensive tracts of water-table development: Labyrinth (AU-16), Jewel (AU-13), and Easter (AU-14) Caves. A fourth, Moondyne (AU-11) Cave, has developed just above the present water table with some areas of maze. Other caves in the area are interpreted as collapses down onto such mazes.

Easter Cave is no doubt the most extensive with possibly 10 km of passages. Labyrinth Cave is the next most extensive with 4 km, followed by Jewel Cave with 3 km of mapped passages. Each cave is different in character. Labyrinth is characterised by a profusion of tubes along dip and strike, a relative absence of helictites and generally small passages. Corrosion passages in Labyrinth show a greater range in altitude. Jewel, near the edge of the limestone (north-east Flat-roofed section) and the Gneiss Extension of Easter Cave are characterised by wide sandy-floored flattener passages. Jewel has more tubes than Easter while Easter has massive wide corrosion chambers and collapse chambers. Also common in sections are networks of tubes and rifts, that is, tubes which have become rifts due to dropping watertable, for example, the CEGSA Extension in Easter Cave. Similar cross-sections of the same origin are seen in Nurina Cave, Nullarbor (Lowry & Jennings, 1974). Easter Cave shows a greater profusion of spongework than Jewel or Labyrinth Caves. There is also a north-east to south-west increase in spongework within Easter Cave.

The caves contain a profusion of secondary calcite forms. Forms characteristic of highly supersaturated groundwater occur in Moondyne (Lux Flakes), Jewel (Pendulites and volcanoes) and the Gondolin-Crystal Labyrinth sections of Easter Cave (Pendulites and volcanoes). The relative scarcity of helictites from Labyrinth Cave may have a lithological reason.

The passage orientations are along dip and strike (Bain & Lowry, 1964). The major overall trend of both Easter and Labyrinth is along the strike. Overall the systems are found in a narrow generally strike-orientated band between the youngest aeolianite and the old silicious dunes. Gneiss and beach-derived sediments show a south-west slope in Jewel Cave.

GEOLOGICAL HISTORY, HYDROLOGY AND SPELEOGENESIS

The following series of events is postulated to explain the existence of these large complex caves in such a restricted belt.

The first event would be a marine transgression resulting at its height in a beach plus foredunes at the edge of the present limestone belt. Such a transgression would have destroyed its own foredune and beach deposits as it progressed inland. This transgression in such a high wave-energy area would have removed most of the soft sediments in its path - foredunes, soil and laterite profiles and kaolinised gneiss - and produced wave-cut gutters in the underlying gneiss.

The regressive phase would have resulted in a strip of beach sediments overlain by beach storm ridges, foredunes and more extensive dune belts (Fig. 2). The regressive beach strip would have been laid down on a gently sloping south-west surface of gneiss with wave-cut gutters. The beach deposits would have a higher proportion of silica and molluscan carbonate fragments left behind as a lag deposit when the more platey and light fragments (for example, red algae) were winnowed out by wind action on the beach. Its dip would parallel the gneiss surface beneath. Due to the action of prevailing winds, the aeolian deposits would dip north-east and strike north-west at much steeper angles (up to 30°) than the beach sediments.

Water would move down off the silicious dunes along the slope of the gneiss basement until the present water table was reached. Initially, this movement would be down the dip of the beach sediments (south-west). Water movement would also be channelled along the paths of the buried wave-cut gutters. Such gutters are visible in the Gneiss Extension of Easter Cave and the Flat-roofed Chamber section of Jewel Cave (Bell, 1978).

To the south-west the gneiss and the overlying beach rock would eventually dip below the water table. At this stage water movement, which occurs mainly at the water table surface would be across the dip of the aeolian beds if it were to move south-west. This would result in a 90° switch in the direction of water movement, the water following along the strike of the aeolian beds - north-west to south-east. Movement in this zone would be much slower.

In the section of the limestone where water moves down the dip of the beach sediments following the path of wave-cut gutters in the gneiss, wide low sandy passages occur, oriented in Jewel mainly along the 240 joint set of the granite-gneiss and the Gneiss Extension of Easter along the 270 joint set. Further downslope strike tubes and passages start appearing at different levels reflecting different water table levels.

The greater number of tubes and greater altitudes in corrosion forms in Labyrinth compared to the two other caves to the south-west, suggest that

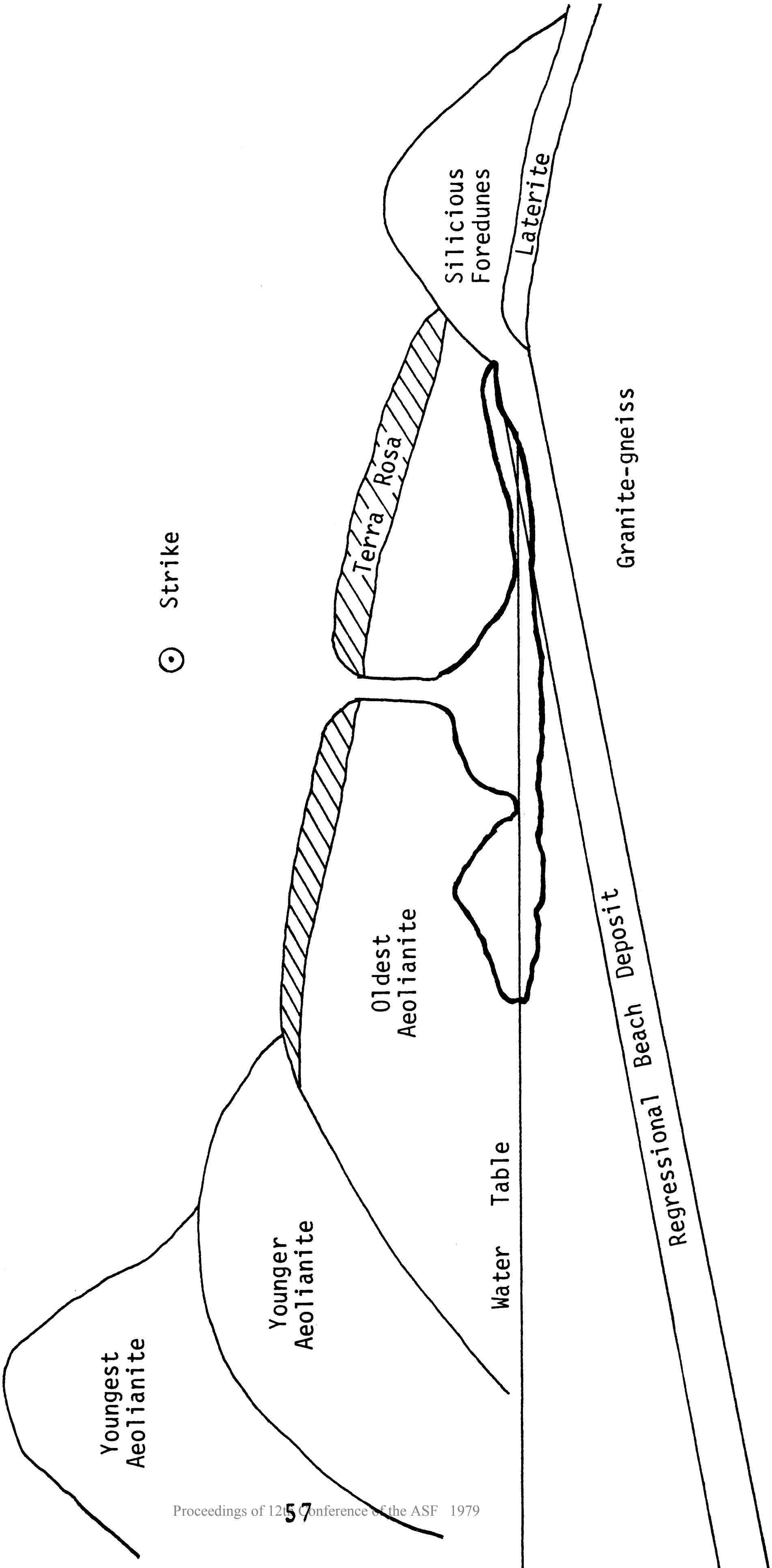

Fig. 2. Augusta caving area - north-east to south-west cross section

the slope of the water table along the strike is north-west to south-east. Tubes are typical of a fairly fast phreatic situation as postulated by Ford (1971). A reduction in the rate of movement of water would result in large spongework mazes. This is the situation in the south-west sections of Easter Cave, where movement is slow and along the direction of slope to the south-east. A rise in water table may reduce the rate of movement of water in a particular area and hence the resulting passage morphology to spongework mazes. Similiarly a drop in water table may result in tubes. In the Y Junction area of Easter, a large collapse block has a mini-cave system in it. This shows the only well-developed one level tubes in the area. In the upper sections of the water table thalweg, rises and falls in the water table will not greatly affect the flow rate and down cut tubes, as in the CEGSA Extension mazes, will occur.

It is the widening resulting from slow-flow conditions that causes over widening and resultant collapse. It is in these sections that entrances are likely to occur.

This model invokes water movement through the silicious dunes to the north-east into the limestone belt in the formation of water table caves. Water movement, from the vegetated calcareous dunes to the west of the limestone, no doubt occurs and is quite major in terms of volume. However, it seems to play no part in cave formation, probably because its waters are saturated in carbonate and low in humic and carbonic acids due to the poorly developed soil. This is supported by the abrupt truncation of caves at the edge of the new dune.

The importance of downward percolating water in the region of the old and younger aeolianites and the beach sediments, is problematic. Sections of cave such as the north end of the Flat-roofed Chamber section in Jewel are devoid of formation and virtually raining with presumably aggressive drip water in early spring. This water then moves rapidly down slope over sand covered gneiss slopes to the lakes below. It is probably only coming through a thin covering of limestone, overlain by silicious dunes. Percolation water in saturated carbon dioxide/carbonate equilibrium can be aggressive on mixing with ground water (Bogli, 1971). With low ground water levels drip water may on losing carbon dioxide to cave air, deposit carbonate, for example, calcite crystal films just past the Gravel Grovel. With high levels when water is right up to the roof, mixing of the waters will corrode the roof into nondirectional scallops and spongework.

The continuation of the Easter and Labyrinth mapping, more accurate levelling within and between the caves, geological mapping following on from the cave mapping, water sampling and analysis, air tracing and specific experiments should in the next decade subject the above hypothesis to a thorough test and no doubt modify it considerably. We have tendered it here as an incentive to such projects. In few places in the world are there maze caves of such an extent as to give access to large areas of a karst system in rocks with high intergranular porosity.

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