KARST STYLES IN WESTERN AUSTRALIA

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Abstract

Western Australia contains several very different karst terrains. The differences can be related to contrasts in lithology, structure and climate. These three factors interact in complex ways so that often two or three of the factors are involved in the interpretation of each feature. The karst areas described are Devonian reef limestones of the West Kimberley; Tertiary open shelf limestone of the Nullarbor and Barrow Island; and Quaternary eolianite of the south-western coast.

INTRODUCTION

An outline of the different styles of karst that occur in Western Australia will serve as an introduction to speleologists visiting Western Australia for the first time. Traditionally geomorphic features have been interpreted as resulting from the interaction of three independent variables - lithology, tectonic history, and climate. Analysis of the origins of the various distinctive features of the regions shows that although lithology, tectonics and climate are the major factors determining the features, they are not independent variables but interact in complex ways. The areas discussed here are the Limestone Ranges of the West Kimberley, Barrow Island, the Nullarbor, and the South-western Coast.

SETTING AND CLIMATE

West Kimberley. The Devonian reef limestones in the West Kimberley form a belt 300 km long (Fig. 1). The climate is hot semi-arid with an average rainfall of about 500 mm. Most of the rain falls in the summer months with high intensity (10 to 20 mm per rain day, on annual averages).

Barrow Island. The island covers some 230 km^2, and lies 60 km offshore. According to West Australian Petroleum's records the average annual rainfall has been 200 mm. Onshore at Onslow the average rainfall is 265 mm with an average of 12 mm per rain day. Intense rainfall is associated with occasional summer cyclones (for example, 330 mm in 12 hours in March 1964) and whereas the West Kimberley rivers flow annually with the monsoon, river courses on Barrow Island only flood for a few days every five or ten years.

Nullarbor. Tertiary limestones of the Eucla Basin cover 130 000 km^2 in Western Australia, but only the higher rainfall area near the coast is described here. The climate is arid to semi-arid with rainfall (amounting to 200-300 mm annually) concentrated in the winter months. Average intensity is lower than in the preceding areas (3 mm per rain day at Eucla).

South-western Coast. The area considered here is a narrow belt of coastal dunes stretching from Cape Leeuwin in the extreme south-west to Dongara 600 km to the north. The belt of dune limestone extends much further north

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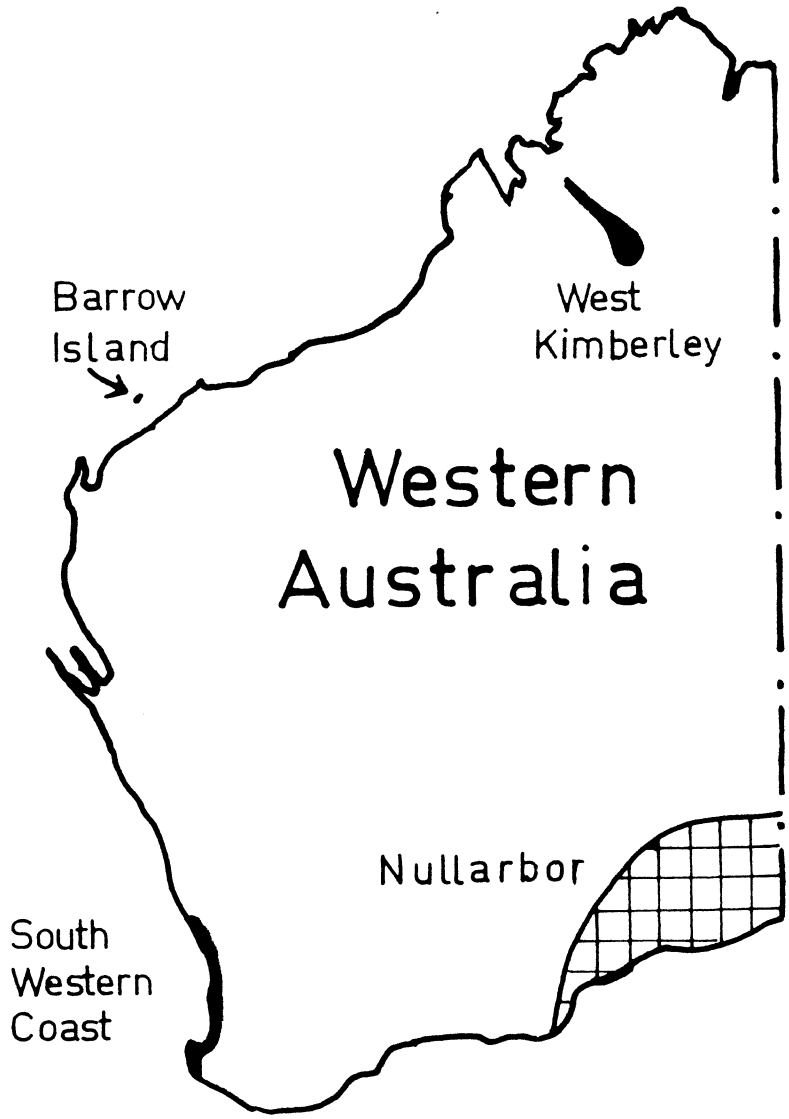
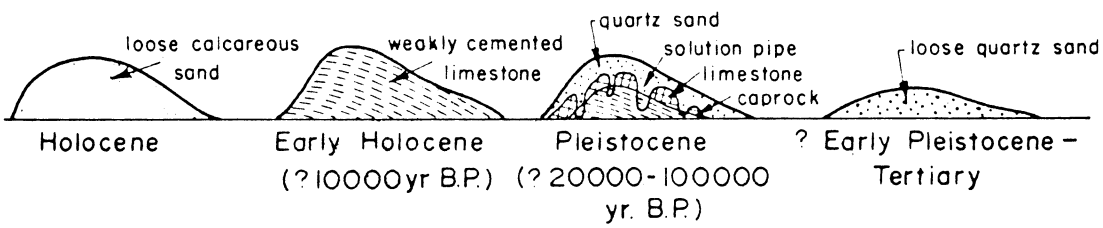


Figure 1 Location map

Figure 2

WEATHERING SEQUENCE OF CALCAREOUS DUNE SAND



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but karst features and knowledge of them are sparse. Rainfall varies from 1000 mm annually in the extreme south through 880 mm at Perth to 600 mm in the north. It is largely restricted to the winter months - at Perth 80% of the rain falls in the six months May to September.

LITHOLOGY

West Kimberley. The Limestone Ranges are the remnants of a reef complex developed along the northern margin of the Canning Basin 350 million years ago. The reef presumably grew in tropical waters and thus the lithology was partly climatically determined. The complex includes a barrier reef (for example, Napier Range) and several atolls (for example, Laidlaw Range). Limestone platforms were built up in horizontal layers of coral, algal and stromatoporoids together with their debris. The platforms were mostly rimmed by a reef margin of similar organisms in front of which was a steep talus slope leading down into deep water between the reefs. The fore-reef limestone tends to be impure and to pass downslope into siltstone brought in by rivers from the north.

Subsequent burial caused stylolitisation, recrystallisation and cementation of the limestone, resulting in a very hard limestone with negligible intergranular porosity.

Barrow Island. The island consists of Tertiary foraminiferal limestones that were laid down on a broad stable continental shelf.

Nullarbor. Limestone on the Nullarbor Plain consists of Tertiary foraminiferal, algal, and bryozoan shelf limestone similar to that of Barrow Island. The general absence of terrigenous material suggests that there were no major rivers flowing from the continental interior, as a result of low relief and low rainfall (that is, tectonic history and climate). Much of the limestone retains its high intergranular porosity, presumably because of a lack of later burial (tectonics) and the slight amount of groundwater movement (climate).

South-western Coast. A belt of limestone is formed along the western coast by the lithification of the carbonate-rich Quaternary coastal dunes. A few thousand years after the dunes accumulate they become weakly lithified. The sand commonly contains abundant quartz grains so that after some tens of thousands of years of weathering the surface of the dune develops a soil of leached quartz sand. Below the sand a layer of limestone becomes indurated and recrystallised. This "cap rock" is perforated by solution pipes and with prolonged weathering the limestone is reduced to pinnacles and finally to a heap of quartz sand (Fig. 2). Again, the very existence of carbonate-rich sand on the continental shelf is partly controlled by the low relief and low rainfall of the continent. The weathering progression described here is not well understood but the development of a cap rock with its rinds of secondary calcium carbonate ("kankar", "caliche" or "calcrete") is probably controlled by the rainfall being concentrated in a few months of the year, thus giving an annual wetting and drying.

TECTONIC HISTORY

West Kimberley. The reefs lie on a basin margin that remained tectonically active in the Carboniferous and Permian, resulting in the burial, faulting,

tilting and jointing of the limestone. The area was planed by erosion. Rejuvenation of the drainage in the Tertiary exhumed the reef limestone by eroding the soft inter-reef siltstone, so that the carbonate platforms now stand above the modern valleys almost as if the Devonian sea had just drained away.

Barrow Island. This is the crest of an anticline whose growth has continued intermittently into the late Tertiary or Quaternary.

Nullarbor. The Nullarbor Plain is an emerged sea bed that has been modified by very minor faulting and by minor stripping. Air photos indicate a regional joint pattern but the rocks are relatively soft and regular joints are not obvious in outcrop.

South-western Coast. The dune limestone is geologically very young and has not undergone any recognisable tectonic deformation.

MAJOR SURFACE FEATURES

West Kimberley. The overall trend of the reef complex is controlled by the tectonic structure of the basin margin, and in some cases the shape of individual ranges is controlled by faulting. However some features are related to the shape of the growing reef (for example, the spine at the southern end of the Laidlaw Range, and the cliffs along the front of the Napier Range which mark approximately the limit of reef growth).

The ranges are flat-topped, standing some 50-100 m above the plain, and these flat tops are the remnants of an earlier erosion surface.

Barrow Island. Most of Barrow Island displays a gently-domed planation surface that is presently being dissected. At the southern end is a low-lying down-faulted area. Coastal cliffs are developed around much of the island, particularly on the exposed western coast.

Nullarbor. The area consists of a plateau rising gently northwards from about 60 m above sea level to about 250 m inland. Coastal cliffs (in places modern; in places emerged) form an abrupt southern margin. Inland, the arid climate has developed a deep calcareous clay soil with a layer of secondary concretionary calcium carbonate ("kankar") but nearer the coast the soil has been blown eastwards leaving a stony plain. The plain is gently sculptured by solution: in some areas into circular "dongas" 1-2 km across and 2-5 m deep; in other areas into subdued parallel ridges with a relief of 5-8 m spaced 0.2-1 km apart and separated by flat clay-floored valleys.

These features probably result from a combination of low rainfall and low initial tectonic relief - runoff ponds locally and does not develop an integrated surface drainage system.

South-western Coast. The topography of the eolianite belt is basically dune topography.

DRAINAGE

West Kimberley. The intense summer rainfall has developed a fairly well integrated surface drainage system, but some goes underground to emerge in springs at the margins of the ranges. A few major rivers flowing from the Kimberley Plateau to the north have been superimposed on the limestone and

now flow in steep-sided gorges (for example, Windjana Gorge) or have suffered underground capture (for example, Tunnel Creek, Cave Spring). Much of the drainage pattern is strongly joint-controlled.

Barrow Island. Apart from the area south of the fault, Barrow Island has a well developed radial drainage pattern dissecting the domed old land surface (Fig. 3). There is no sign of drainage going underground. This is largely a climatic feature. Rainfall sufficient to cause runoff occurs only rarely and on those occasions it does, it is usually associated with a cyclone and very intense. Thus the rainfall pattern results in extensive fluvial erosion and very little solution of the limestone.

Nullarbor. On the Nullarbor plateau there is a very limited development of a drainage system and it is mostly relict. When rain is sufficiently intense to develop runoff, there is mostly local ponding followed by evaporation and some infiltration. Most of the infiltrating water is absorbed by the clay soil and later lost by evaporation, concentrating salts carried by the wind and rain. Thus a small, saline proportion of the rainfall reaches the water table. In the Madura area, the combination of low recharge and highly permeable limestone results in caves having lakes of saline (10 000 ppm) water within a few metres of sea level as much as 60 km from the coast.

Some major allogenic rivers (for example, Ponton Creek draining 70 000 km^2) pond on the edge of the plateau and probably have done so since the Miocene emergence.

South-western Coast. No surface drainage occurs on the dune limestone. The permeability of both the original dune and of the quartz sand soil that develops later is sufficient to cause complete absorption of rainfall. In a few areas the limestone belt is broken by major rivers that have maintained their course to the sea, but because of the generally low rainfall inland, many rivers have had their courses blocked by the belt of dunes, and the water seeps through, dissolving caves.

MINOR SURFACE FEATURES

West Kimberley. Where the margin of a limestone range has a few tens of metres of relief there is a lateral progression from the old undissected soil-covered land surface in the interior, to areas of bare limestone with joint openings, to areas of karst corridors where the joints are several metres wide and have flat floors, to areas of box valleys with level floors connected with the alluvial plain, to areas of marginal amphitheatres and isolated limestone towers at the edge of the range. This erosional sequence is strongly joint controlled and the near-vertical limestone surfaces are spectacularly fluted (Rillenkarren). This type of karst has commonly been thought to be the product of tropical weathering but recently it has been argued that such features can develop in any climate and the requirement is an impermeable limestone with extensive jointing; that is, the control is lithologic and tectonic rather than climatic. Nevertheless, the solutional sculpturing of outcrops points to surface solution of limestone as being a major process in the West Kimberley, despite the modest rainfall, and this may be due to the association of the rainfall with high summer temperatures.

A minor weathering agent is the spalling of crystalline limestone due to fires. The semi-arid climate restricts vegetation to spinifex (*Triodia*) which burns every few years during the dry season. The intense heat from the

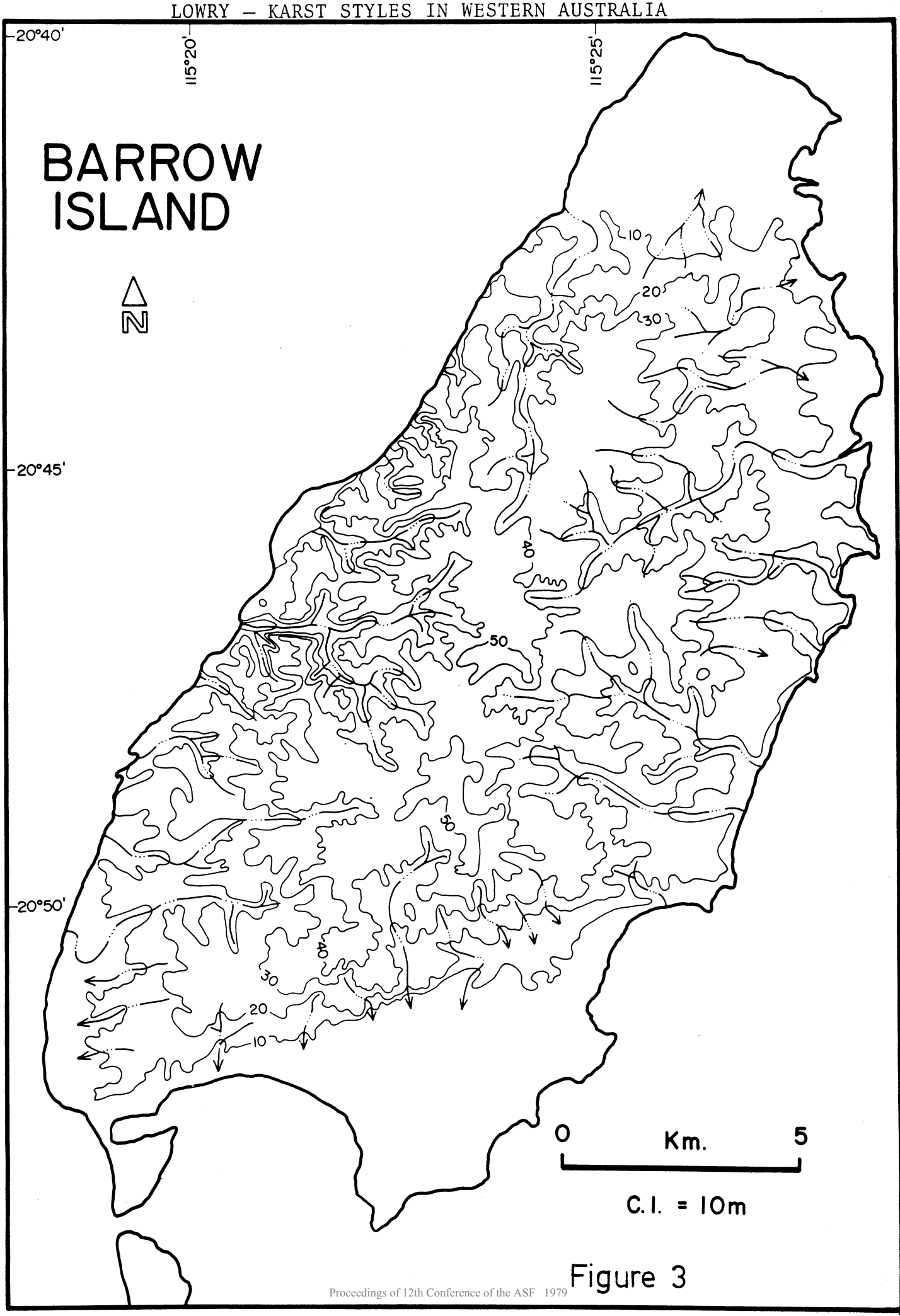
20°40'
115°20'
115°25'
BARROW ISLAND
N
20°45'
10
20
30
40
50
50
40
30
20
10
20°50'
0
Km.
5
C.I. = 10m

Figure 3

the fire causes spalling around the base of outcrops.

Barrow Island. Much of Barrow Island is soil covered. The scattered outcrops show minor solutional fluting, together with sculpturing that may have developed while covered with soil. Vertical rock faces along the coast and along some river valleys have minor rock shelters at the base. These appear to be formed by salt-wedging of flakes and grains of the porous limestone and are thus partly related to the low rainfall.

Nullarbor. Much of the Nullarbor is covered by residual and colluvial clay and silt. Limestone pavements are smooth or show only small scale solution pans. In a few places, large unjointed pavements have developed rock holes about 1 m across and 1 m deep. They hold water for several months after rain and their enlargement is probably speeded up by the biological activity of algae and decaying animal carcasses.

South-western Coast. Where limestone is exposed by deflation or coastal erosion, solutional pitting is comon but fluting is rather minor. In the northern part, smooth crusts of caliche are common.

CAVES AND DOLINES

West Kimberley. There are relatively few major caves known in the Limestone Ranges although there are a large number of short cliff-foot caves and overhangs of anthropological interest. Upper Cave Spring System with more than 2 km of passages is the most extensive mapped system. It is a striking example of a cave system developed by the opening up of a grid of joints. The Tunnel is a spacious cave developed by underground capture of a river superimposed on the Napier Range. There is a collapse doline in the centre of the cave, but in general roof collapse is not an important process in West Kimberley caves because of the hardness of the rock. Calcite cave decoration is moderately well developed. A feature of Cave Spring Middle System and of Old Napier Downs Cave is floating calcite which forms on pools that are left by the summer flood and that evaporate throughout the dry season.

Barrow Island. Just as climate and tectonics have inhibited the development of surface karst, so there is very little cave development. The largest known cave occurs in a headland on the west coast about 20 m above sea level. It appears to be an ancient cave unrelated to the present erosion processes, and to have been breached accidentally by the retreat of coastal cliffs. The cave is about 100 m long; it has a flat earth floor and massive calcite decorations. Another small cave occurs near the Barrow Fault where it has been opened by solution along a fracture parallel with the fault. The doline is about 3 m by 1 m at the surface, and the cave extends horizontally for 3 m at a depth of 5 m.

Nullarbor. On the Nullarbor there are two main styles of cave. The "deep caves" of large dimensions are developed close to the level of the present water table some 70-110 m below the plateau. The caves have stoped their way upwards by roof collapse and in places have breached the surface to form spectacular collapse dolines. There are also "shallow caves" developed in the upper 5-15 m of the plateau. This rock is often rubbly and perforated by small tubes and cavities, and this may be a weathering response of a fairly porous poorly-jointed limestone to an arid to semi-arid climate. The shallow caves often connect with the surface by way of circular blow-

holes that have probably developed by upward stoping by granular disintegration at the top of cave roof domes. Many caves are modified by granular disintegration of the roof and walls. The Dune in Mullamullang is a spectacular example. This occurs where saline water seeping through the porous rock evaporates as it reaches a cave wall. The dissolved salts are precipitated in the pore spaces and crystal growth wedges off fragments of rock. In a few caves halite crystals are extruded from the walls. Thus the presence of this rare speleothem is due to a combination of climate and lithology. Gypsum occurs in several caves but calcite speleothems are relatively uncommon.

South-western Coast. Most caves are associated with allogenic drainage that has been blocked by the dune belt. The water ponds against the dunes and seeps through, developing caves with flowing streams. Roof collapse is usually extensive and may extend to the surface, forming a collapse doline. Many dolines have overhanging lips caused by the hard cap rock. If the cap rock fails to collapse, the soil may fall through the solution pipes to give a chimney-like entrance above a soil cone.

In many caves, collapsed rock hides the stream and blocks the passage so that only short segments of dry cave are accessible. Near Augusta there are a few caves developed by solution at a water table with no perceptible gradient, and the cave consists of low anastomosing lake-filled passages of variable width. Calcite decoration is abundant in the high rainfall area in the south where thick sandy soil with dense vegetation results in aggressive water percolating into porous limestone - ideal conditions for getting calcium carbonate into solution. At the northern end of the belt, rainfall is lower, and as a result the soil is thinner and the vegetation sparser. Not surprisingly the northern caves are mostly sparsely decorated.

DISCUSSION

In a paper of this length it has been possible only to bring out the contrasting highlights of the four areas, and an attempt has been made to interpret the contrasts in terms of the complex interaction of differences in lithology, structure and climate. There is one other important influence on the morphology of the West Kimberley and Barrow Island areas - that is the dissection of a Tertiary planation surface. This has not been stressed because there is no comparable feature on the Nullarbor (the surface is still essentially that of the sea bed) or on the South-western Coast (the limestone is too young and soluble).

An attempt could have been made to extend the cause-and-effect arguments a step further by relating lithology, structure and climate to the plate tectonic history of each area and the general circulation of the hydrosphere and atmosphere, but at this level the generalisations become rather too great too be useful. For example, it could be pointed out that in the Devonian the West Kimberley was near the Equator and was therefore likely to develop reefs, but the perfection of preservation and of present exposure could not have been predicted. Similarly, the Nullarbor is tectonically undisturbed because the basin is on an Atlantic-type continental margin, yet Barrow Island is in a comparable position on the plate but is tectonically active.

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In a paper as brief as this it is not possible to document previously published ideas and argue new ones. Instead, key publications are listed here to enable the interested reader to explore the subject further.

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