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Lateral Variation in the Geomorphology of a Pleistocene Rocky Coastline at Kalbarri, Western Australia

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ABSTRACT

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The junction of the Indian Ocean with Kalbarri National Park and adjacent townsite of Kalbarri in Western Australia exhibits two spectacular rocky coastlines. One is the modern setting with its broad rock platforms and towering sea cliffs eroded in the red Tumblagooda Sandstone (Silurian) capped by pale sandstones and shales (Triassic, Cretaceous). The other is an approximately 100,000 year-old Pleistocene rocky shoreline with a wide variety of deposits preserved unconformably against the Silurian sandstone. Over a short distance of 8 km along the water front, five very different geomorphological features may be observed in a continuum associated with the same ancient rocky coastline. They include: river-mouth bar, cobble pocket beach, intertidal abrasion platform with tidal pools, drowned paleovalley, and neptunian dikes in massive sea cliffs. A typical intertidal fauna with turbinid and patellid gastropods is fossilized. These deposits richly illustrate a range of conditions through which rocky shores are incorporated into the geologic record. They are described herein as a new rock unit named the Chinaman's Rock Member, attributed to the basal Tamala Limestone.

ADDITIONAL INDEX WORDS: *Alongshore variability, unconformities, pocket beach, intertidal abrasion platform, neptunian dikes.*

INTRODUCTION

Continental cratons provide a stable core around which erosional unconformities may develop with accreted lithologies subject to further recycling. The cratonic regime is a complex reflection of several variables, including tectonism, eustatic sea-level change, as well as planation and fluvial dissection in the context of general climate (FAIRBRIDGE and FINKL, 1980). One of the earliest observers to gain a perspective on cratonic regime was Benoit de Maillet, who espoused a secular drop in sea level evidenced by an uncomformable progression of secondary and tertiary rocks around a core of primary rocks (DE MAILLET, 1748). Although it is a rifted cratonic margin with a tectonic history going back as far as Silurian time (FINKL and FAIRBRIDGE, 1979), the interior of Western Australia's Yilgarn Block has a long history of exposure with a steady rate of surface deflation. The serial emplacement of unconformable lithologies along the flanks of the Yilgarn Block creates a comparatively simple landscape in which De Maillet would have felt conceptually comfortable.

Rocky-shore deposits accumulate their debris from the erosion of sea cliffs and rocky headlands. Where preserved, such deposits constitute an unconformity with their parent rock. Much is known about the geomorphology of modern rocky shores (TRENHAILE, 1987), but the representation of rocky shores and their deposits in the geologic record is widely perceived as very poor due to sustained erosion and marine transport in nearshore settings. The bibliography on ancient rocky shores assembled by JOHNSON (1992) indicates this environment is better incorporated in the rock record than heretofore appreciated. Previous work in Western Australia has focused on Pleistocene rocky coasts eroded from carbonates and/or eolianites on Cape Range in the north (VAN DE GRAAFF *et al.*, 1976), in the Lake Macleod area (DENMAN and VAN DE GRAAFF, 1977), and at Perth in the south (SEMENIUK and JOHNSON, 1985). Not much investigation of this nature has been undertaken in the 1,000 km-long coastal zone between Perth and Lake MacLeod.

The purpose of this contribution is to describe a well preserved Pleistocene rocky shore along the shores of the Indian Ocean in Kalbarri National Park and the adjacent townsite of Kalbarri almost midway between Perth and the Cape Range. Based on research articles in the bibliography on ancient

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rocky shores (JOHNSON, 1992), most occurrences are extremely spotty due to poor exposure of unconformities. Thus, ancient rocky coastlines can seldom be traced for any distance. The Kalbarri example is worthy of study, not only because it may be followed over a modest distance of at least 8 km, but more so because it is characterized by a wide range in coastal geomorphological features and associated deposits. This rich variety, preserved in proximity to corresponding erosional and depositional settings, helps to demonstrate the many different pathways that rocky shores and their deposits enter the rock record. Some clasts being eroded under present conditions from the Pleistocene deposits originated from the Yilgarn Block. They are now going through their third stage of recycling relevant to the cratonic regime.

LOCATION AND GEOLOGIC SETTING

Kalbarri National Park is readily accessible by paved road 600 km north from Perth on the Brand and North West Coastal highways and another 70 km west on the Ajana–Kalbarri Road. The town of Kalbarri is the only significant settlement in the area and it is situated at the mouth of the Murchison River (Figure 1). The Ajana 1:250,000 geological map and explanatory notes cover the park area (HOCKING *et al.*, 1982). For the purposes of this research, three observations from the explanatory notes are very important.

First, the variable quartzose calcarenite of the Tamala Limestone is the major Pleistocene rock unit in the coastal area. "Two outcrops of shelly limestone, too small to show at the map scale, at the mouth of the Murchison River on the north and south banks, . . . are localized shallow-marine equivalents of parts of the Tamala Limestone" (HOCKING *et al.*, 1982, p. 15). The south-bank outcrop is at a locality known as Chinaman's Rock (Figure 1) and it is the thickest section of Pleistocene strata described and utilized in this project. Herein (Appendix 1), we propose to elevate the basal part of the Tamala Limestone to formal status as the Chinaman's Rock Member with its type locality designated as Chinaman's Rock.

The second important aspect of the geological survey's map is the local prominence of the Silurian Tumblagooda Sandstone which crops out along much of the Murchison River and along the National Park coastline. This formation was mapped and described in more detail by HOCKING (1991). It is the Tumblagooda Sandstone which

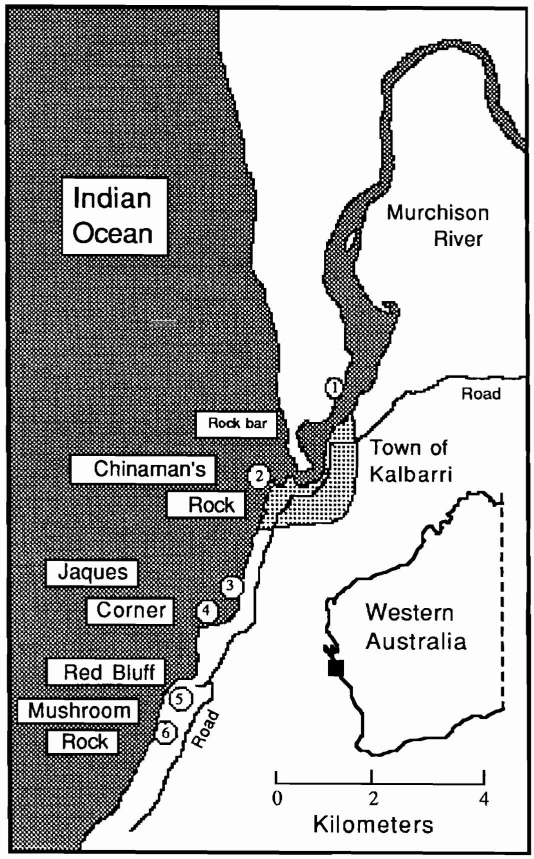

Figure 1. Map of study sites: Inset shows Western Australia; detailed map is for coastal area near the townsite of Kalbarri on the edge of Kalbarri National Park.

sits unconformably beneath outcrops of Pleistocene conglomerate and sandstone. The contact between the Pleistocene and Silurian rock layers is traceable discontinuously for at least 8 km along the shores of the Indian Ocean. Clasts from the Silurian formation are commonly found reworked in the basal Pleistocene rocks we assign to the Chinaman's Rock Member.

The Tumblagooda Sandstone is well exposed in the gorge of the Murchison River where it attains a composite thickness of 1,200 m, and in the coastal cliffs of the national park. Various fluvial and coastal environments are represented by these Silurian strata in which HOCKING (1991) recognized four distinct facies associations (FA1–FA4) based on grain-size variation and sedimentological structures. The associations tend to be stratigraphically segregated and laterally persistent. An especially distinctive marker bed occurs in Facies Association 3 as a pebbly sandstone less than 1.5 m thick. Named the Gabba Gabba Member of the Tumblagooda Sandstone (HOCKING, 1991), this unique marker bed is rich in small quartz pebbles. It divides FA3 into an essentially unbioturbated lower sequence and a commonly bioturbated upper sequence. On the whole, the depositional environment of this facies is interpreted as a high-energy fluvial system located close to the coast and accessible by marine waters at times of low clastic influx. An overlying association (FA4) contains much finer sediment and more extensive bioturbation, interpreted as characteristic of a low-energy protected bay. From a geomorphological point of view, it is notable that each facies weathers differently and that they dip about 5° to the northwest for several kilometers along the coastal cliffs of the National Park as stratigraphically segregated packages.

Finally, the third important aspect revealed by the Ajana sheet (HOCKING *et al.*, 1982) is the proximity of Precambrian basement rocks from the Yilgarn Block and associated Northampton Complex. The Silurian strata were derived from the Yilgarn Block but are locally faulted against the small Northampton Complex.

METHODS

Following standard practice, a series of stratigraphic sections was measured and described for six outcrops of the Pleistocene Chinaman's Rock Member exposed along the shores of the Murchison River and the coast of Kalbarri National Park. Particular attention was paid to both the sedimentological and paleontological aspects of the conglomerate at the base of the Chinaman's Rock Member. Variation in clast size, composition, and dominance was analyzed using a standard quarter-m^2 quadrate divided into 10 cm × 10 cm squares. Fossil mollusks preserved in the matrix were identified with respect to extant forms illustrated in the shell guide by WELLS and BRYCE (1988).

LATERAL VARIABILITY OF PLEISTOCENE DEPOSITS

Exposures of the shell-rich, orangish-tan sandstone belonging to the Chinaman's Rock Member of the Tamala Limestone are easily observed at several sites stretching intermittently for 8 km along the coastal area, numbered from 1 in the north to 6 in the south (Figure 1). In each case, the Pleistocene rocks are physically nearby modern environments which reflect corresponding depositional environments. The six sites are described in the following passages, clustered into five depositional environments.

River-Mouth Sand Bar

Section 1 (Figure 2) was measured at a low bluff on the north bank of the Murchison River across from the Kalbarri townsite (Figure 1). The contact with the Silurian Tumbgooda Sandstone is not exposed at this site, although it can not be far below the surface judging from scattered red clasts observed in bedrock free of sand dunes on the open-ocean side of the narrow peninsula. The river section begins with laminar sandstone beds and abruptly changes to high-planar crossbeds. Succeeding layers are composed of massive sandstone with minor burrowing and a few marine shells. The interval with high-planar crossbeds shows a surprisingly wide distribution as exposed nearby on the rocky bar blocking the mouth of the Murchison River (Figure 1). Although a generally transgressive sequence is indicated from higher-energy to lower-energy environments, the unique cross-bedded interval reflects the Pleistocene development of a river-mouth sand bar with primary orientation of beds dipping oceanward. The gorges of the lower Murchison River have a long history of entrenchment. It seems reasonable that this area was the mouth of the paleoriver, given the restriction of other possible outlets by Silurian outcrops.

Cobble Beaches

The 7-m-high outcrop in Section 2 (Figure 2) is the site of Chinaman's Rock, described in detail in Appendix 1. The local landmark is a promontory on the south side of the river mouth (Figure 1), but also open to the Indian Ocean. The basal unit of this sequence sits on the unconformity with the Tumblagooda Sandstone as observed at low tide. It is a thick layer of conglomerate composed of Tumblagooda-derived cobbles, pebbles, quartz grains, and interbedded fossils. The contact was the surface of transgression for the Chinaman's Rock Member of the Tamala Limestone across the rocky shore eroded from Silurian bedrock. Looking south from a point near Chinaman's Rock towards Red Bluff, the density of Tumblagooda-derived clasts in the Pleistocene sandstone

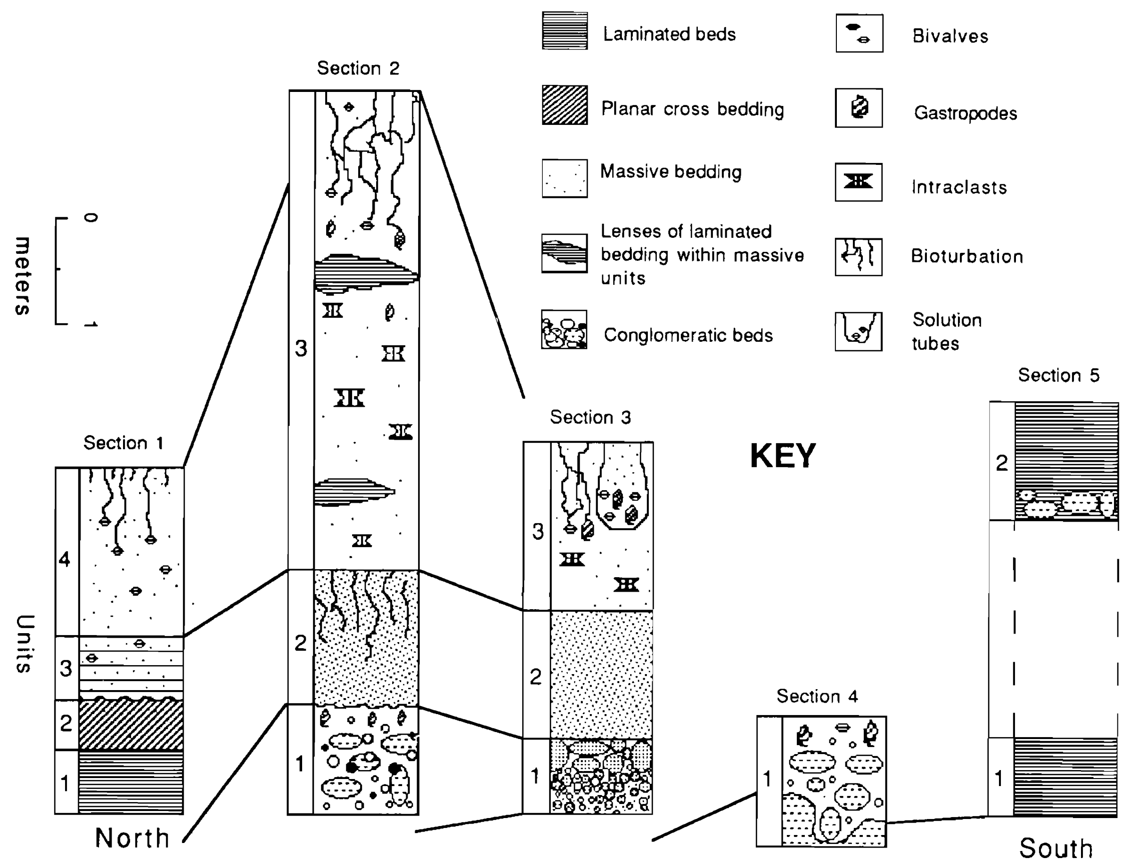

Figure 2. Stratigraphic sections showing the development and correlation of the Pleistocene Chinaman's Rock Member (Tamala Limestone) at six sites marked on the map in Figure 1. Section 2 is the type locality of the member at Chinaman's Rock.

about a half meter above the contact is apparent at low tide (Figure 3A).

The basal unit is overlain by a well-sorted, massive sandstone with rare burrow traces, which in turn is succeeded by a thick sequence of fossil-rich strata riddled with reworked lenses of laminated sediment, intraclasts, and localized burrows. Most of the molluscan fauna from this upper unit are found today in rocky-shore to nearshore settings, although some gastropods like *Thais orbita* and *Lepsiella vinosa* are typical of offshore, reefal settings (WELLS and BRYCE, 1988). As in Section 1, the overall effect of Section 2 is that of a transgressive sequence passing from a high-energy onshore environment to a lower-energy offshore environment.

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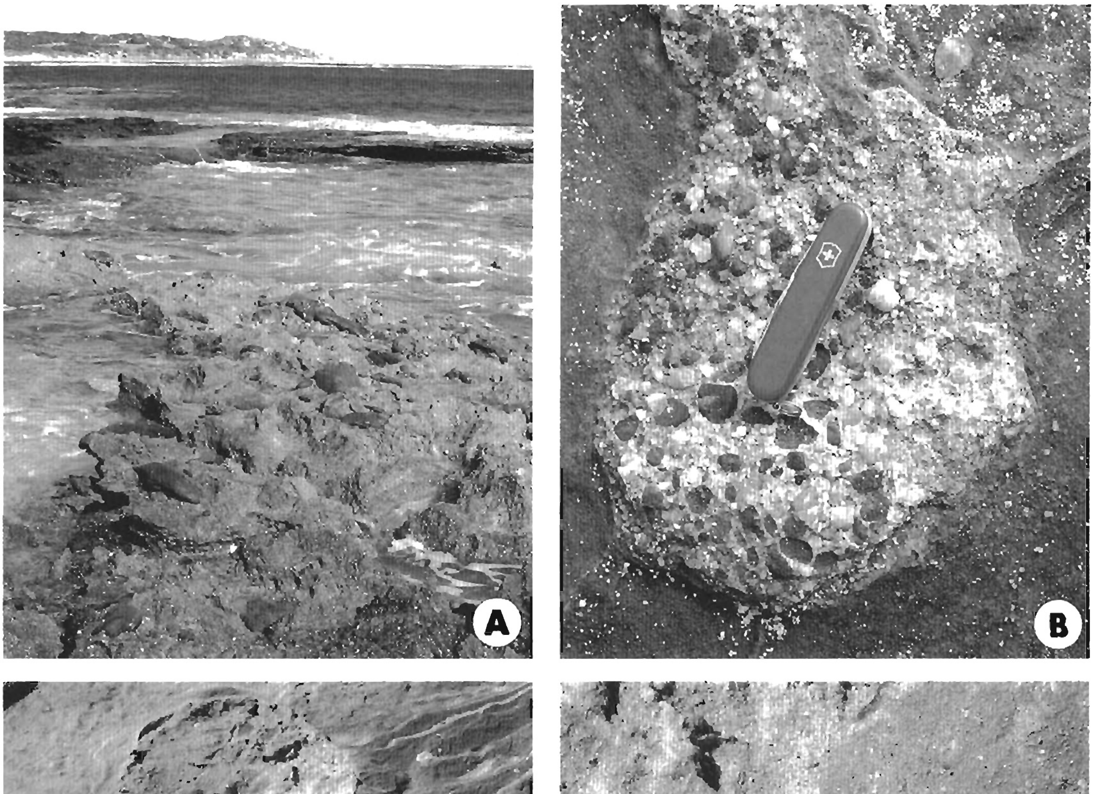
Figure 3. A. View of Pleistocene Chinaman's Rock Member looking south from a point near Chinaman's Rock toward Red Bluff, showing reworked clasts of Silurian Tumblagooda Sandstone about a half meter above the unconformity with the Tumblagooda Sandstone. 3B. Close-up view of a 1 cm-thick pod of Pleistocene conglomerate sitting directly on the Silurian Tumblagooda Sandstone at Jaques Corner. Dark clasts are lithologically Silurian sandstone. White clasts are quartz pebbles last derived from the Silurian sandstone but originating on the Yilgarn Block. 3C. Outline of a 30 cm × 90 cm Pleistocene tidal pool sitting on an intertidal abrasion platform south of Jaques Corner (9 cm pocket knife for scale). 3D. Close-up view of tidal-pool margin, showing a fossil specimen of the gastropod *Turbo intercostalis* (9 cm pocket knife for scale).


A
B
C
D

Sections 3 and 4 (Figure 2) are located about 2 km south of Chinaman's Rock on opposite sides of Jaques Corner (Figure 1). The Pleistocene outcrops here straddle an exhumed promontory and rock platform in the Tumblagooda Sandstone, as shown in detail by a compass and tape map of the area (Figure 4). Section 3 on the north side of Jaques Corner correlates very well, unit-by-unit, with the Chinaman's Rock section (Figure 2). Section 4 on the south side of Jaques Corner exposes only the Pleistocene basal conglomerate. A spot in the present intertidal zone near Section 3 is especially suited to illustrate the locally peculiar nature of the basal conglomerate (Station 10, Figure 4). Three different conglomeratic intervals fill a large crevice eroded in the margin of the Tumblagooda platform. Each has its own specific elevation above the unconformity and each yields distinct results with regard to clast composition, diversity, and size.

Data quantifying these differences were collected from bedding surfaces using a quadrate in which only five 10 cm × 10 cm grids were randomly selected as targets. This was done in order to reasonably limit the number of clast identifications and measurements in the quarter-m^2 quadrate; an estimate of data for any full quadrate is a simple multiplication problem based on the five grids. All of the clastic material was derived from the Tumblagooda Sandstone with populations composed primarily of small quartz pebbles and sandstone pebbles and cobbles. The matrices are limey with a high content of fossil fragments intermixed with sand-size particles of quartz.

Calculations given in Tables 1–3 show that a substantial proportion of the clasts at each level are quartz in composition. The source of these clasts is the Gabba Gabba Member of the Tumblagooda Sandstone. Following regional dip, this bed reaches present mean sea level at Jaques Corner where some horizons are exposed in the surface of the exhumed rock platform. Figure 3B illustrates a pod of Pleistocene conglomerate only 1 cm thick still intact directly on the unconformity surface. The darker rock framing the pod is the Tumblagooda Sandstone and the darker pebbles within the pod are reworked clasts of Silurian sandstone. The small white pebbles are milky quartz, reworked from the Gabba Gabba Member. A larger patch of nearby conglomerate was used to generate the data summarized in Table 1. A comparable surface 10 cm above the unconformity provided the data summarized in Table 2 and the third conglomerate surface was sampled at a level 55 cm above the unconformity (Table 3).

It may be observed from the data in these tables that the raw number of small quartz pebbles steadily grows up section in proportion to the raw number of ordinary sandstone clasts, from 69% to 76% to a high of 94%. In terms of cross-sectional area, however, the ratio of quartz pebbles to sandstone clasts decreases. This is because the sandstone clasts become progressively larger up section, beginning with an average cross-sectional area of 0.76 cm^2, then 5.83 cm^2, and finally areas representative of boulders. While the quartz clasts show no particular trends, the sandstone clasts contributed to an upward coarsening sequence over a short stratigraphic span of little more than a half meter.

A model for this pattern is illustrated in Figure 5. As intertidal erosion scours away at the sides of a major joint in the Tumblagooda Sandstone, fine sediment and small quartz pebbles from the Gabba Gabba Member are plucked out and redeposited in Pleistocene sediment. With continued widening of the joint zone, a small pocket beach gradually develops. Sandstone cobbles and boulders are added to the Pleistocene deposit, not as reworked clasts but due to the collapse of overhanging side walls along the former joint zone. Horizons near or just above the top of the Silurian Gabba Gabba Member may be more prone to disaggregation into large pieces, which subsequently are rounded in the surf. The end result is a pocket cobble beach with a upward coarsening history.

Intertidal Abrasion Platform

The present promontory just 100 m farther south of Jaques Corner, well before Red Bluff (Figure 1), reveals a large Pleistocene abrasion platform cut in the Tumblagooda Sandstone. No measurable stratigraphic section of the Pleistocene is available, as such. The unconformity between the Silurian and the Pleistocene is uniquely present, however, in the form of fossil tidal-pool fillings. Most of the tidal pools are circular in shape, but an oblong tidal pool with dimensions 30 cm × 90 cm is preserved (Figure 3C). A close view of one margin of this pool (Figure 3D) shows a specimen of the gastropod *Turbo intercostalis* cemented in the deposit. Present-day storm waves wash this rock platform, but the fossil tidal pools indicate that the feature was an intertidal abrasion platform during Pleistocene time.

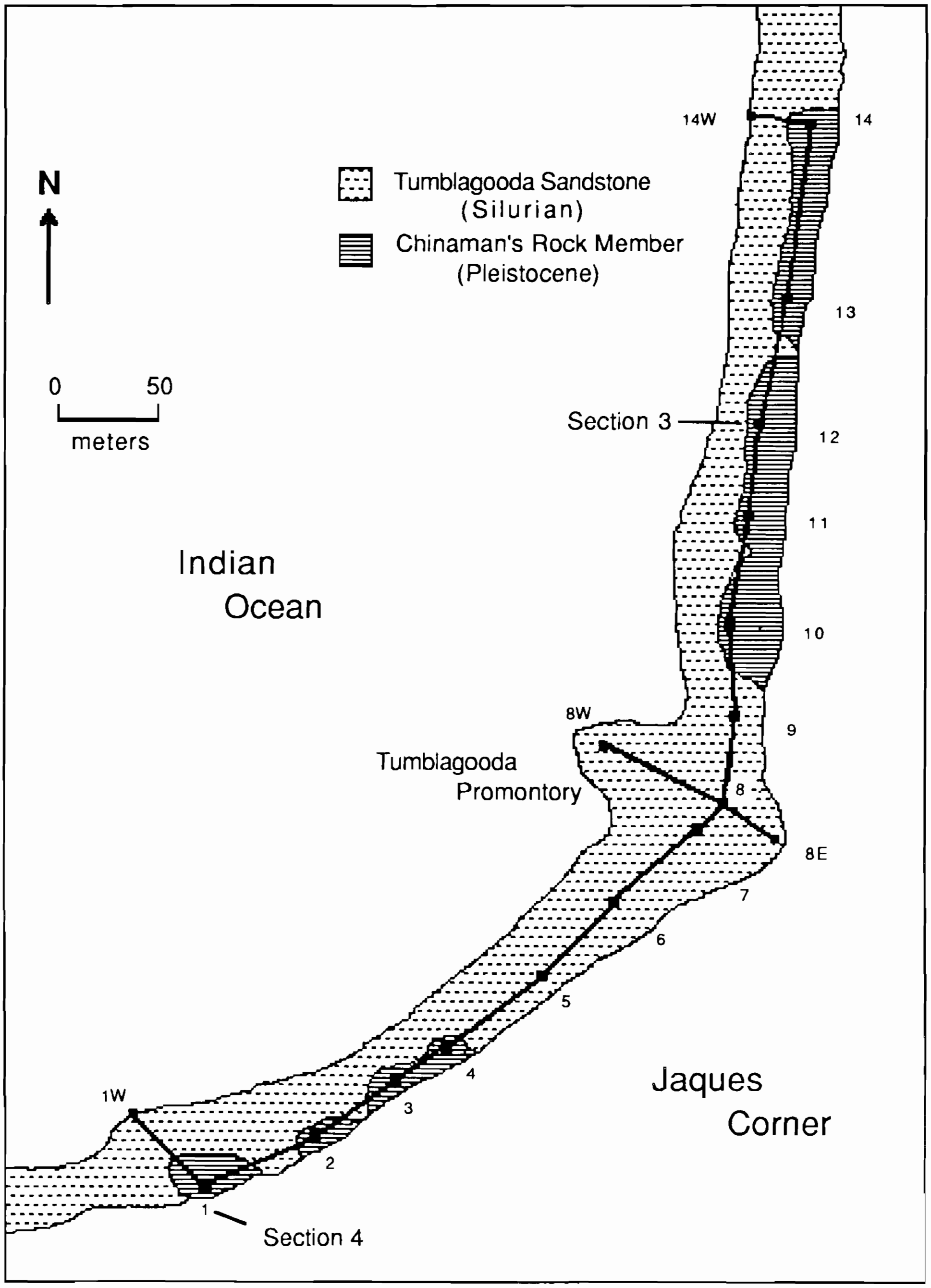


Figure 4. Map of Jaques Corner, showing disposition of Pleistocene deposits on the flanks of a promontory eroded in the Silurian Tumblagooda Sandstone.

Table 1. *Clast analysis from selected grids in a quadrate 1 cm above the Silurian-Pleistocene unconformity at Jaques Corner (Station 10).*

Grid	# Quartz Clasts	# Sandstone Clasts	Total Clasts	Average Size Qtz. (cm²)	Average Size Ss. (cm²)
3	90	30	120	0.30	0.96
10	128	31	159	0.34	0.69
15	73	32	105	0.32	0.46
19	70	39	109	0.31	0.74
24	25	43	68	0.74	0.93
Total:	386	175	561	av: 0.40	0.76
×5:	1,930	875	2,805		
Ratio of quartz to sandstone clasts in raw numbers:					
	69%	31%			
Ratio of quartz to sandstone clasts in cross-sectional area (cm²):					
				54%	46%

Drowned Paleovalley

The south side of Red Bluff (Figure 1) reveals the last measurable section of Pleistocene sandstone to the south (Section 5, Figure 2). This site represents a major fracture zone in the Silurian Tumblagooda Sandstone, where the Indian Ocean is currently depositing sand at the mouth of a gully set in a narrow valley. The horizonal strata overhanging the interval with steeply dipping beds (Figure 6A) suggest how large pieces of Silurian rock are prone to break off and become reintroduced to the sedimentary cycle under vigorous tidal action. Another view of the same site looks up the gully from the direction of the ocean during high tide (Figure 6B).

Pleistocene strata almost a meter thick, bearing laminations, are preserved in place along the gully. The two intervals shown for Section 5 (Figure 2) are in separate down-stream and up-stream positions, with elevations 2 m apart vertically. Both segments, however, are in an unconformable relationship with the Silurian Tumblagooda Sandstone. Remains of the Chinaman's Rock Member at this locality demonstrate that Pleistocene coastal sediments transgressed the narrow paleovalley and filled it to a depth of at least 4 m.

Neptunian Dikes

Fillings of cracks, joints, crevices, or fissures in any host rock by sedimentary rocks deposited under water are called neptunian dikes. Much attention has been paid to the origin of neptunian dikes in submarine settings including caverns (Smart *et al.*, 1987). Indeed, the glossary definition of a neptunian dike (Bates and Jackson,

Table 2. *Clast analysis from selected grids in a quadrate 10 cm above the Silurian-Pleistocene unconformity at Jaques Corner (Station 10).*

Grid	# Quartz Clasts	# Sandstone Clasts	Total Clasts	Average Size Qtz. (cm²)	Average Size Ss. (cm²)
3	40	9	49	0.88	6.40
10	7	6	13	1.10	0.30
15	21	4	25	0.31	2.01
19	6	3	9	0.35	15.20
24	13	5	18	0.46	5.26
Total:	87	27	114	av: 0.62	5.83
×5	435	135	570		
Ratio of quartz to sandstone clasts in raw numbers:					
	76%	24%			
Ratio of quartz to sandstone clasts in cross-sectional area (cm²):					
				26%	74%

Table 3. *Clast analysis from selected grids in a quadrate 55 cm above the Silurian-Pleistocene unconformity at Jaques Corner (Station 10).*

Grid	# Quartz Clasts	# Sandstone Clasts	Total Clasts	Average Size Qtz. (cm^2)	Average Size Ss. (cm^2)
3	81	8	89	0.34	0.72
10	77	6	83	0.34	1.84
15	54	5	59	0.42	1.10
19	72	3	75	0.35	1.75
24	80	3	83	0.39	0.41
Total	364	25	389	0.37	1.16
×5	1,820	125	1,945		
Ratio of quartz to sandstone clasts in raw numbers:					
	94%	6%			
Ratio of quartz to sandstone clasts in cross-sectional area (cm^2):					
				82%	18%
NOTE: Six boulders excluded from the above analysis fall within the sample quadrate at this level; their combined cross-sectional area is 2,115 cm^2. Taking these clasts into account the ratio in raw numbers is negligibly affected but the ratio in terms of cross-sectional area changes to:					
				23%	77%

1987, p. 446) explicitly mentions their "undersea" origin. Such features also originate in an intertidal setting on rocky shores that are extensively jointed or otherwise fractured. The term neptunian dike should be extended to include this specific depositional environment.

The most southerly trace of the Pleistocene Chinaman's Rock Member in Kalbarri National Park occurs at Bluff Point (HOCKING, *personal communication,* 1992) at the southwest corner of the park, but the most southerly site described herein occurs near present mean sea level in the gorge below a local landmark called Mushroom Rock (Figure 1). A vertical 6 cm-wide crack extends over several meters in the Silurian Tumblagooda Sandstone and it is filled with Pleistocene sandstone (Figure 6C).

The dike contains the tell-tale white quartz pebbles, some small red sandstone pebbles of Tumblagooda lithology, and some surprisingly well preserved fossils. Most abundant among the fossils is the rocky-shore limpet, *Petella peroni* (Figure 6D). Other rocky-shore mollusks present include the gastropod, *Pyrene bidentata,* and mytilid bivalve, *Brachidontes ustulatus.* The filling of this long crack far back from the ocean front must have required tremendous wave energy. During Pleistocene time, as today, this part of the coastline was dominated by durable sea cliffs in an interval of the Tumblagooda Sandstone well below the Gabba Gabba Member. The neptunian dikes are the only remaining witness to the Pleistocene intertidal zone at this locality.

Mushroom Rock (Figure 1) is a block of resistant Tumblagooda Sandstone still attached to a pedestal of softer strata in the sea cliffs well above the neptunian dikes and at a horizon above the Gabba Gabba Member. This kind of differential erosion in the Tumblagooda Sandstone is characteristic of the way the intertidal rock platforms at Jaques Corner developed. They formed because the softer strata above the Gabba Gabba Member of the Tumblagooda Sandstone gave way to intertidal abrasion. The neptunian dikes formed where they did because the more resistant sandstone below the Gabba Gabba Member did not give way so readily to intertidal abrasion.

COMPARISON WITH SOME OTHER EXAMPLES

Examples of ancient rocky shores and their associated deposits are generally limited by the constraints of exposure around geological unconformities. Most unconformities are not exhumed in three-dimensional relief, but typically appear in cross section. There are very few published examples of unconformities diagnostic of ancient rocky shores which have been traced laterally for any considerable distance. A very well preserved segment of rocky-shore coastline dating from the Late Ordovician was mapped in detail over a distance of 350 m in Hudson Bay, Canada (JOHNSON

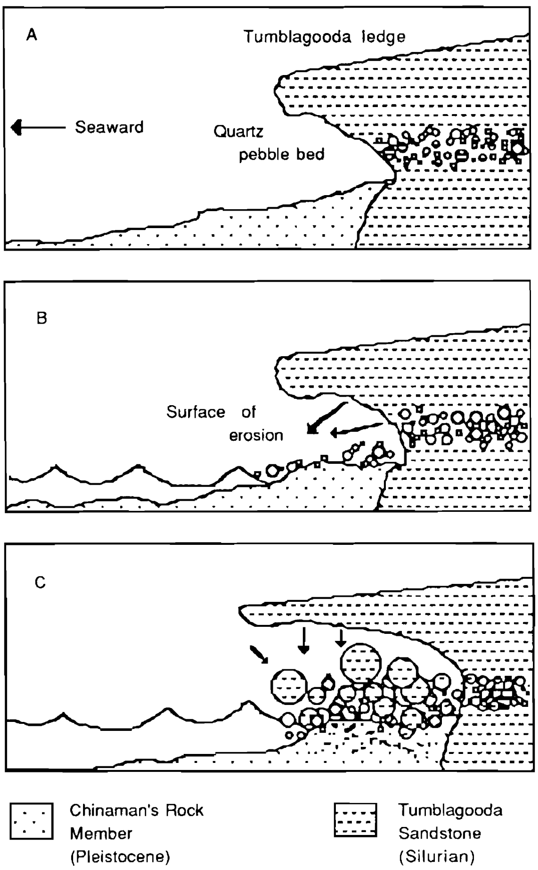


Figure 5. Model showing progression of events (A, B, and C) in the development of a stratigraphically coarsening-upward deposit in Pleistocene strata at Jaques Corner.

et al., 1988), but the results yielded no geomorphological or ecological variability alongshore. Variations in clast size around a Cambrian archipelago composed of Precambrian quartzite in Wisconsin were employed by DOTT (1974) to differentiate prevailing winds. No faunal or geomorphological consequences of such wind and storm patterns were detected in his study, however. Perhaps the most detailed mapping of an ancient rocky shoreline is available in the work of RADWANSKI (1970, Figure 1) in southern Poland, showing features of a complicated Miocene coastline with bays, inlets, and well-defined straits between small islands. Some faunal variation is observable in the range of littoral boring fauna which colonized the Polish carbonate coast. In comparison, the insight provided by the Kalbarri example described in this paper is significant as a survey of geomorphological variation conveniently represented in a single stretch of ancient rocky coastline.

CONCLUSIONS

Stratigraphic variability in the lithology and weathering properties of sedimentary rocks which form the basis for unconformity surfaces play a profound role in the local development of rocky coastlines. The same variation in coastal morphology observed today has been preserved in the geologic record through the burial of ancient rocky shores. Where coastal strata also are deformed or tilted, major variations in coastal morphology may occur over rather short distances. A wide range of Pleistocene depositional environments are observed within a distance of 8 km along the present coast of the Indian Ocean in and around Kalbarri National Park in Western Australia. These include a river-mouth bar, cobble beaches (some developed as pocket beaches), intertidal abrasion platforms with intact tidal pools, a drowned paleovalley, and neptunian dikes in massive sea cliffs. All are related to unconformities with the Silurian Tumblagooda Sandstone, all reflect variations in coastal dynamics controlled to a great extent by the differential resistance of the strata in this thick formation, and all include diagnostic rocky-shore fossils.

The Silurian sandstone was a major contributor of reworked clasts to the Pleistocene Chinaman's Rock Member (Tamala Limestone) which accumulated in the several coastal environments. Small quartz pebbles are the most durable elements in the Tumblagooda Sandstone. They were transported down to the Silurian coastline in rivers from the Yilgarn Block and deposited first in the

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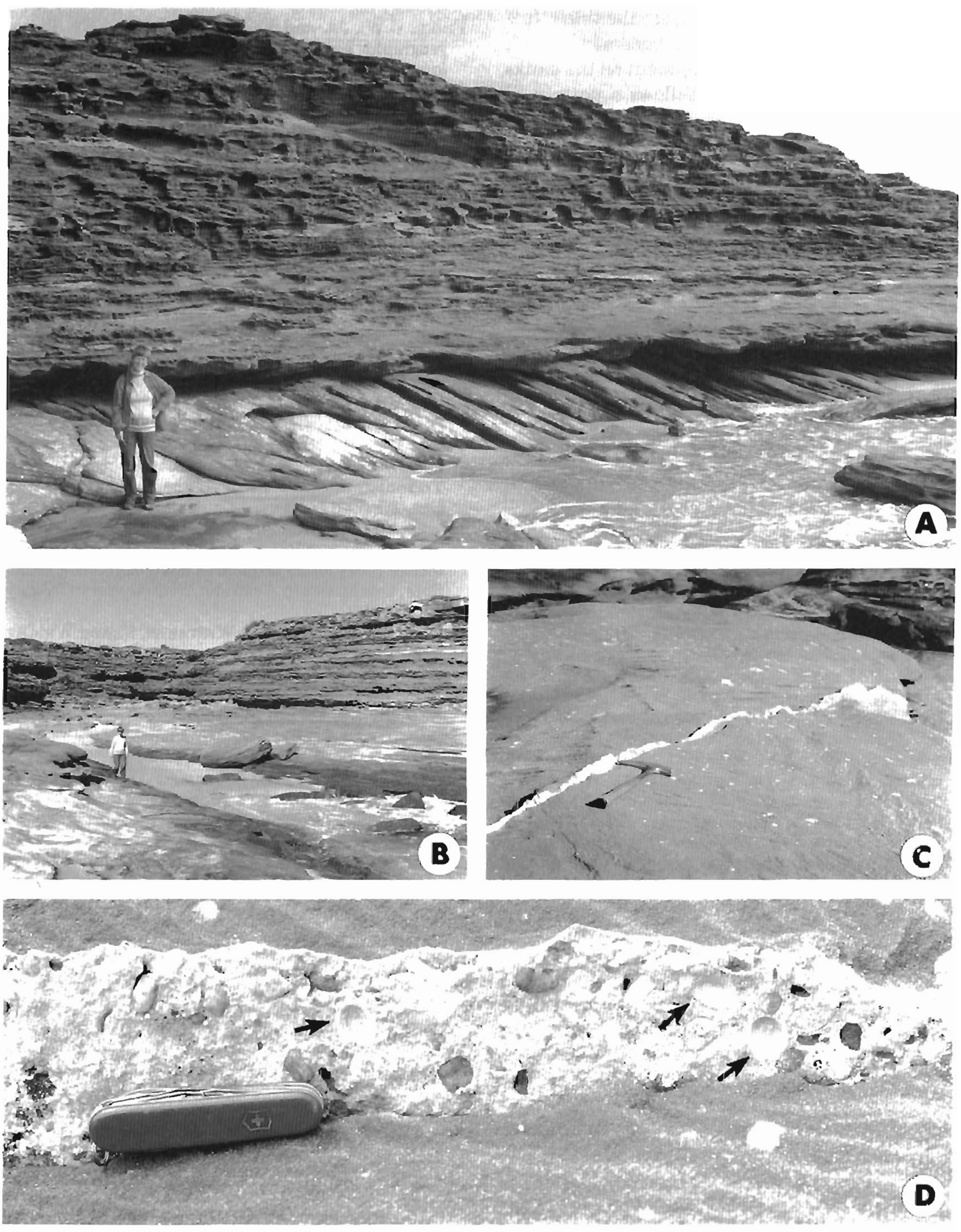
Figure 6. A. Narrow inlet on the south side of Red Bluff following a major fracture zone in the Silurian sandstone. Ledge overhanging the dipping beds (foreground) suggest how clastic debris derived from the Silurian is introduced to the sedimentary cycle by vigorous tidal activity. 6B. Another view of the same inlet during high tide from the ocean looking inland. 6C. Neptunian dike of Pleistocene sandstone within the Silurian Tumblagooda Sandstone near Mushroom Rock (hammer for scale). Figure 6D. Close-up of neptunian dike: Arrows point to fossil limpets *Patella peroni*; dark clasts of Silurian lithology also visible (9 cm pocket knife for scale).



Tumblagooda Sandstone. Present day erosion of the Chinaman's Rock Member by wave abrasion is recycling these clasts for at least the third time in their long history. This sequence of primary, secondary, and tertiary development on the flanks of the Australian continent follows a pattern in cratonic regime partly understood by observers as early as DE MAILLET (1748). We hope this contribution on a young rocky coastline will help convince skeptics that rocky-shore deposits are and have been incorporated into a geologic record demonstrative of all natural environments.

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APPENDIX I

Type section of the Chinaman's Rock Member (Tamala Limestone) as measured at Chinaman's Rock on the south promontory of the mouth to the Murchison River in the townsite of Kalbarri, Western Australia.

Unit	Description	Thickness
3	Sandstone, orangish-tan, buff colored, massive with intraclasts of cobble to pebble size (largest: 20 cm × 14 cm × 12 cm); intraclast grain size: 3.0 to 2.5 phi, subrounded; matrix grain size: between −0.5 to −1.0 phi and 2.5 to 2.0 phi, subrounded; pockets with small interconnected burrows; lenses of laminated sediment (1.46 m × 2.6 m); lower boundary irregular; fossils include *Collisella onychitis, Turbo torquatus, T. intercostalis, Rhinoclavis fasciatus, Thais orbita, Vexillum maleopunctum, Lepsiella vinosa,* and *Patella laticostata* (gastropods) and *Brachidontes ustulatus, Trisdos semitorta,* and *Natica* sp. (bivalves)	4.60 m
2	Sandstone, orange-ish tan, massive, grain size: 2.0 to 1.5 phi, well sorted and rounded, rare vertical burrows (with spreiten), sharp base	1.25 m
1	Conglomerate, main clasts consisting of red Silurian sandstone (generally flat cobbles and rounded pebbles) and milky white quartz pebbles; matrix consisting of an orange-ish tan sandstone with a wide range of grain sizes between 1.0 to 0.5 phi and −0.5 to −1.0 phi, rounded to subrounded and very poorly sorted; between 10 to 20% of the quartz grains are stained red, unconformable contact with Tumblagooda Sandstone, fossils: *Patella laticostata, Turbo intercostalis, T. torquatus, Thais orbita,* and *Vexillum maleopunctum* (gastropods)	1.20 m
	Total:	7.05 m