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Development of a Basin, Doughnut and Font Assemblage on a Sandstone Coast, Western Eyre Peninsula, South Australia

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ABSTRACT

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An assemblage of minor sandstone landforms, including rock basins, annular rims or doughnuts and miniature towers with crestal basins (fonts), is described from the Talia coast of western Eyre Peninsula, South Australia. The role of beach etching, the weathering of rock beneath moist beach material, in the sequential development of this assemblage is discussed. The possible role of beach etching in the development of some shore platforms, and in the shaping of angular unconformities and nonconformities covered by marine sediments, is also broached.

ADDITIONAL INDEX WORDS: *Rocky coast, shore platforms, plinth, beach etching, coastal erosion, unconformities, Talia coast.*

INTRODUCTION

This paper is concerned with the origin of an assemblage of minor landforms, namely doughnuts and fonts, which are associated with rock basins developed in sandstone exposed on the west coast of Eyre Peninsula, South Australia (Figure 1a). These minor forms are most commonly developed on platforms but they are also found on plinths, and the origin of these host forms is considered.

The west coast of Eyre Peninsula is characterised by alternations of rocky coasts, consisting of promontories with high cliffs, shore platforms and small bayhead beaches, with long sandy beaches behind which are developed extensive fields of foredunes. The cliffs are eroded predominantly in cross-bedded dune calcarenites of Late Pleistocene age (WILSON, 1991). The calcarenite rests unconformably on Precambrian rocks, mostly granite gneiss or granite, but in a 15 km long sector between Talia and Venus Bay the limestone overlies a Mesoproterozoic arenaceous sequence (FLINT, 1993).

The unconformity between the arenaceous beds and the overlying dune material is smooth but uneven, with a relief of at least 10 m in the study area, being below low tide level at Mt Camel Beach, but standing 10 m above high tide level between the Woolshed and the Monument (Figure 1b). A regolith up to a metre thick is preserved at the unconformity.

The Talia coast has a Mediterranean climate. Elliston, the nearest meteorological station, receives a mean annual rainfall of 429 mm, most of which is received in winter. The mean monthly maximum temperature ranges from 16.2° in July to 25.4° in January and the mean monthly minimum from 7.9° in July to 15.6° in February.

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The tidal regime on the Talia coast is similar to that of Thevenard, where the range is of the order of 2.3 m. This does not take account of meteorological tides coincident with strong onshore winds which, at Talia, from evidence of beach building, attain heights up to 4 m above normal high tide level.

MORPHOLOGY OF THE TALIA COAST

The Talia coast consists of two rocky sectors separated by Mt Camel Beach, which like the smaller ephemeral beaches accumulated in embayments on the rocky coast, is calcareous. The rocky coasts are essentially irregular serrated platforms cut in the arenaceous sediments and backed by limestone cliffs (Figure 2). The cliffs, 20 m high in places, have been undermined by wave attack and sapping by groundwater seepage. As a result, fallen calcarenite blocks up to 4 m diameter form a jumbled mass at the cliff base.

In some sectors the platform is characterised by an inner zone with numerous basins and an outer dominated by parallel ridges and gutters aligned perpendicular to the shoreline. This is similar to the zonation described by FOURNIER (1996) from a calcarenite coast near Streaky Bay.

Planate zones up to 60 m wide are found both at the outer edges of the platform and adjacent to the cliffs. Many are traversed by major joints, some of which give rise to linear clefts, but some are flanked by linear ridges up to a metre high due to goethitic impregnation of the bedrock on either side of the parting.

Basins are widely and abundantly developed all along this coast. Some consist of a smaller basin within a larger. Many are bordered by raised rims or doughnuts some of which are taller than they are wide and are termed fonts. Many of the

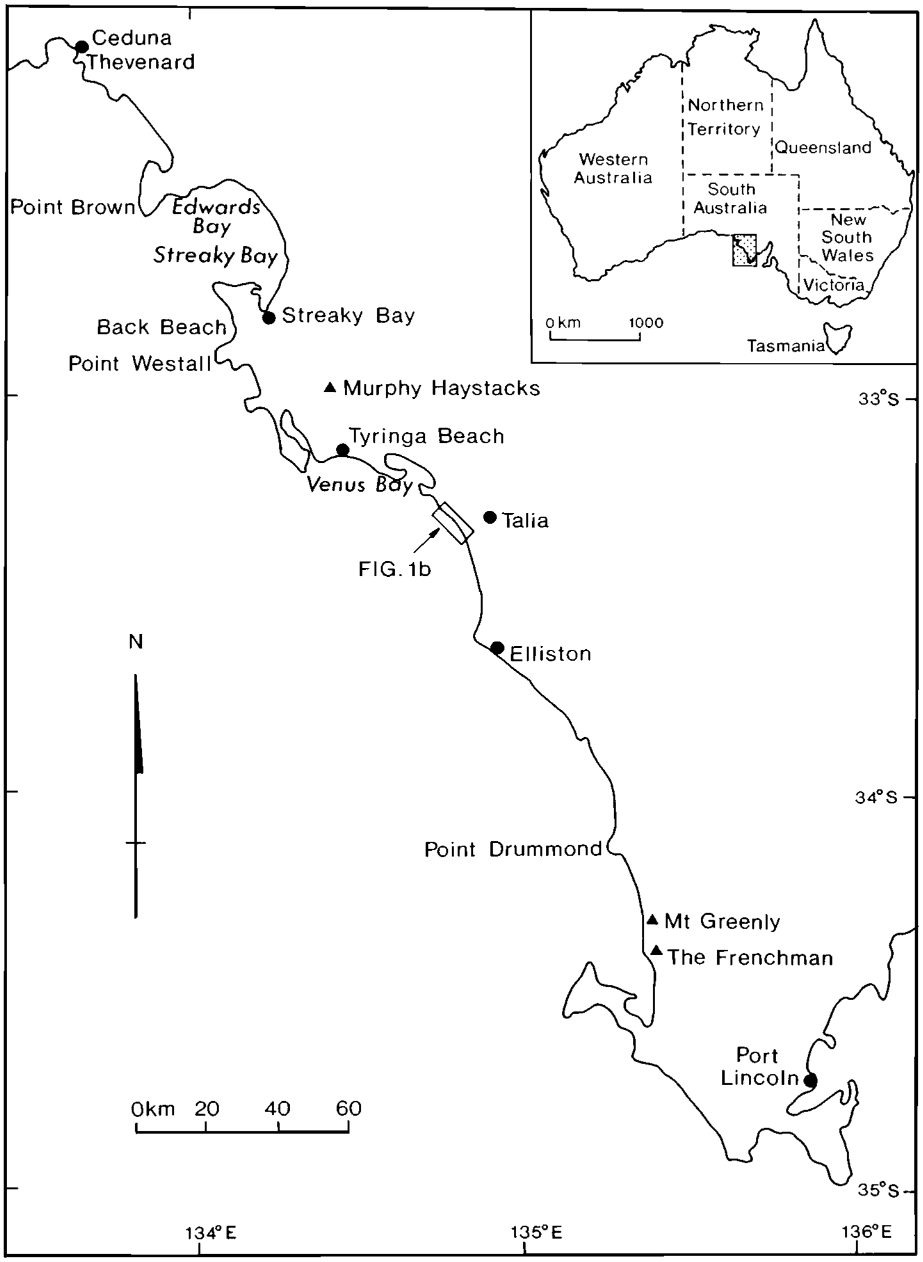

Figure 1. (a). Location map of the west coast of Eyre Peninsula.

gutters are guided by fractures but others follow the local slope. Of the other minor features found on the Talia coast, alveolar or honeycomb weathering is commonly developed on bedding planes and on exposed weathering fronts, as well as on the inner rims of some doughnuts. Pecking, the development of small (1–3 cm diameter), shallow scallops in the rock surface, is well displayed in some sectors. It may be due to salt weathering. It is not due to the impact of large rock fragments tossed about by waves, for it is neither restricted to, nor most pronounced on, seaward exposures.

ORIGIN OF SOME MINOR FORMS

Plinths

Many fallen calcarenite blocks now rest on miniature platforms, or plinths, which stand up to half a metre higher than the adjacent platform (Figure 3A). Basins and doughnuts, and at one site a font (Figure 3B), occur at the sandstone-calcarenite interface.

The calcarenite blocks protect the underlying sandstone from rainfall. They also divert both swash and backwash,

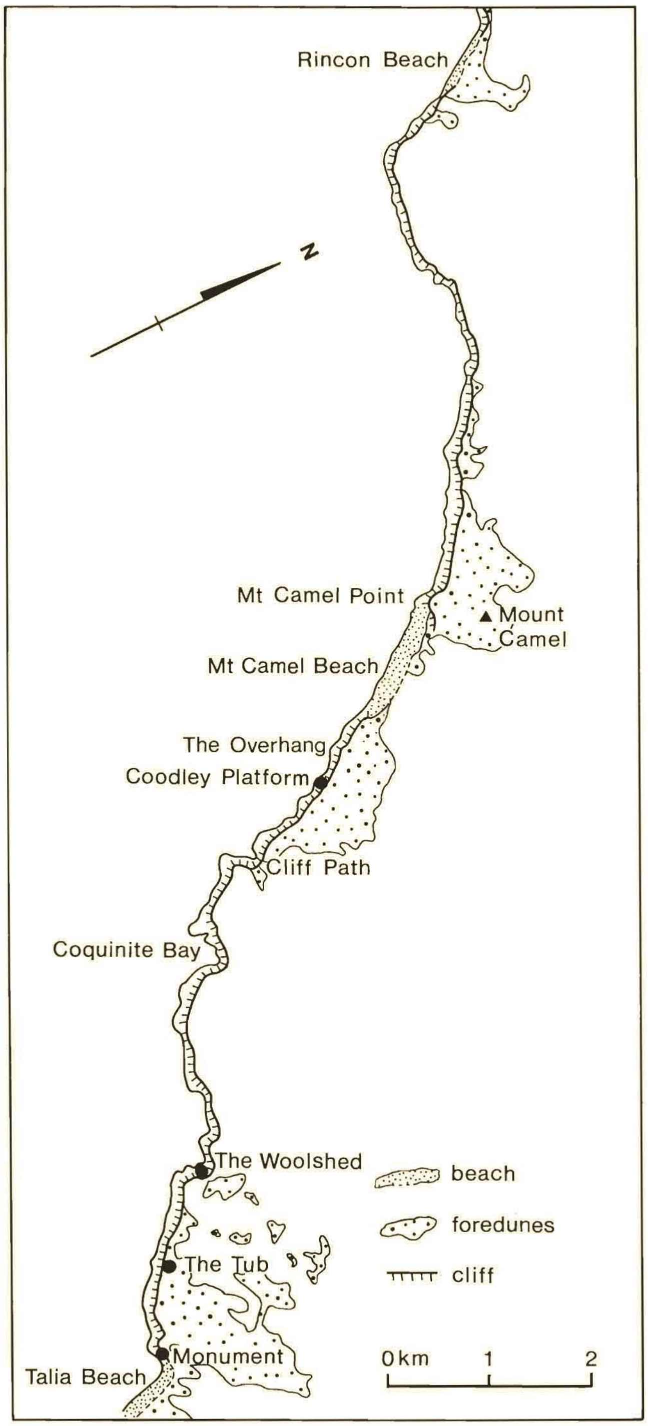

Figure 1. (b). Location map of the Talia coast. Some of the place names are informal.

causing increased turbulence and erosion of the exposed sandstone and initiating the formation of a plinth. Shallow and ill-defined, but definite, depressions have been formed around the plinths. Once developed, a plinth induces further diversion and erosion.

A few of the calcarenite blocks topping plinths have been displaced as a result of the blocks being thrown landwards by waves. The example illustrated in Figure 3a is about 9 cubic metres in volume and weighs some 2.2 tonnes. It has been moved 1.5 m toward the backing cliff. That (storm) waves are capable of moving even the largest of the fallen blocks is demonstrated also by the many large pieces of driftwood that are jammed between blocks and the sandstone platform or between blocks and plinths. Furthermore, fitted blocks (HILLS, 1970), due to waves moving the large blocks involved and grinding them against each other, producing smooth contacts, are common on the Talia coast.

THE BASIN-DOUGHNUT-FONT ASSEMBLAGE

Rock Basins

The sandstone basins of the Talia coast occur on exposed platforms and also on plinths beneath fallen blocks of calcarenite. They vary in shape and size. Most of the large basins found on the platforms are pits or hemispherical depressions. Some are flask-shaped. Some occur along lines of structural weakness or in a zone where wave turbulence is especially pronounced, for example, where backwash flows over low cliffs. Many are potholes, for cobbles or grinders remain in many of them. Once initiated, pits act as positive feedback systems, with retained water weathering the walls and floors of the depressions. In some deep pits located close to the cliff base, the cobbles are cemented to the walls and floors of the basins by calcium carbonate, suggesting that in these instances grinding is either weak or absent possibly because large waves rarely penetrate across the platform to the cliff base.

Other basins take the form of comparatively shallow flat-floored pans ranging from small depressions a few tens of centimetres in diameter and one or two centimetres deep, to basins several metres in diameter and up to a metre deep. Some have sidewalls which overhang by as much as 20 cm. These pans are probably due to water layer weathering (WENTWORTH, 1938; HILLS, 1949; KAYE, 1959), but most of the coastal basins, including pans, carry a rich flora and fauna (WOMERSLEY and EDMONDS, 1958; FORREST, 1993; FOURNIER, 1996) which may have contributed both physically and chemically to the weathering and enlargement of the depressions. Many of the pools frequently dry out and halite precipitates in the floors of the depressions, so that salt crystallisation may account in some measure not only for the enlargement of the basins, but also for the alveoles found on the inner rims of some basins.

The pans developed on plinths beneath calcarenite blocks are saucer-shaped depressions and may be due to seepage of water charged with calcium carbonate. Alkaline waters (pH 7–8) could weather the sandstone and produce a hollow in which further accessions of water could accumulate and continue the weathering. The pans developed on bedding planes between sandstone strata, like those developed at the southern limit of Coquinite Bay, could be of similar origin, for the outcrops were presumably formerly overlain by the calcarenite.

Figure 2. General view of the Talia coast looking south from Coodley Platform showing cliff, ramp and platform.(p—platform in sandstone; pc—platform with minor sandstone cuestas; r—ramp; cs—cliff in sandstone; ca—cliff in aeolianite/calcarenite).

Rock Doughnuts

Rock doughnuts are annular rims bordering basins. Coastal doughnuts have been reported in sandstone from Cape Paterson, Victoria (HILLS, 1971) and in caclarenite from Point Peron, Western Australia (FAIRBRIDGE, 1947–8). Calcarenite forms also occur at Edwards Bay. On the Talia coast, they are more numerous but smaller on the red grit and fewer but larger on outcrops of white and cream sandstone (Figure 4). Many are steepened on their seaward sides, presumably as a result of wave action. Some, though not all, annular rims carry a coating of blue-green algae (*Calothrix* sp., *Entophylis* sp.) which appear to protect the rock surface; though there is here the possibility of a circular argument: are they responsible for the rims or have the algae colonised the rims as preferred sites?

Various hypotheses have been devised in explanation of rock doughnuts in the terrestrial context (*e.g.* BLANK, 1953). One mechanism is based in the contrasted susceptibility to weathering of rocks in contact with moisture and in dry sites (TWIDALE, 1988; Figure 5). The mechanism was suggested by rock levees (SCOTT, 1967; LISTER, 1973), which are rims of rock bordering gutters. Whereas most of the regolith holds moisture, causing continuous weathering of the underlying rock surface, adjacent to basins the regolith drains into the depression. There is less weathering here beneath the drier regolith and rims develop around the basins. This interpretation can accomodate the suggestion due to WHITLOW and SHAKESBY (1988) that an opaline silica coating occurs on the rims of rock levees because silica may be precipitated at the margins of flows, just as siliceous rimstone occurs at the margins of trickles on flared slopes on granite, *e.g.* at Murphy Haystacks, northwestern Eyre Peninsula.

In the coastal setting the beach is the regolith. The water held in the calcareous sand is responsible for the weathering of the sandstone with which it is in contact in a process here termed beach etching. The products of weathering are removed, and the waters effecting alteration renewed, by the ebb and flow of the tide and, close to the cliff, by seasonal seepages and washes of water from the land. At various times, shelly beach material has been observed lapping against the low walls of several of the larger Talia doughnuts located on platforms. It is notable that the larger doughnuts are found on the inner platform where beach sediments are most frequent and widespread. Thus beach etching may be responsible for producing doughnuts around basins.

Most of the many small doughnuts developed in red grit and breccia, however, are not now associated with beaches, for the red grit forms the higher (+4 m) bevelled cuestas on the Talia coast. They could be associated with a higher stand of the sea or with beach materials accumulated during storms. Alternatively they could have formed beneath limestone blocks which were formerly strewn over this section of the platform.

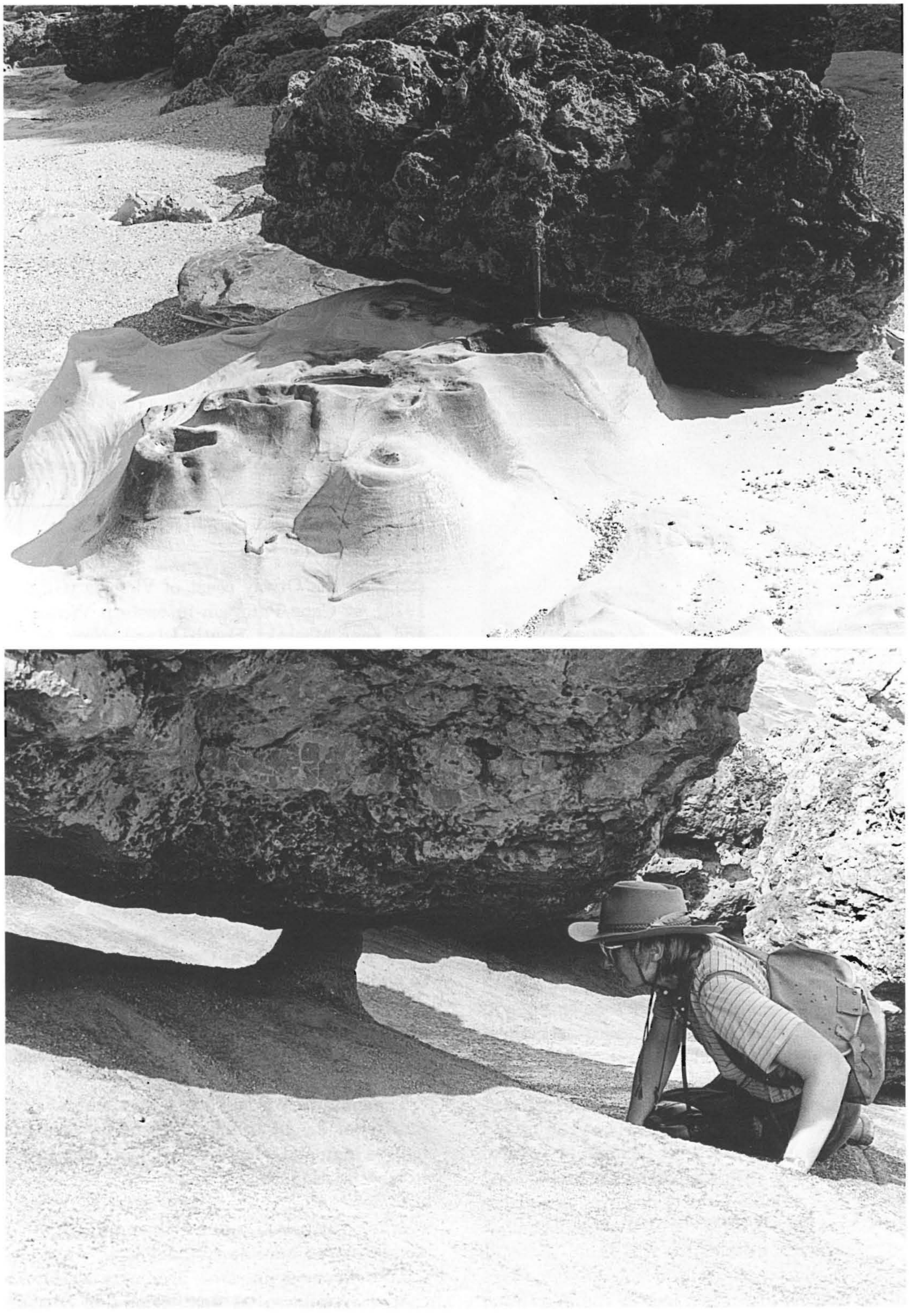

Figure 3. (a). Sandstone plinth at Coodley Platform, with several pans and doughnuts developed on the upper surface and exposed by wave translocation of the calcarenite block. (b). Font developed between sandstone plinth and calcarenite block fallen from the cliff betweeen Coodley Platform and the Cliff Path.

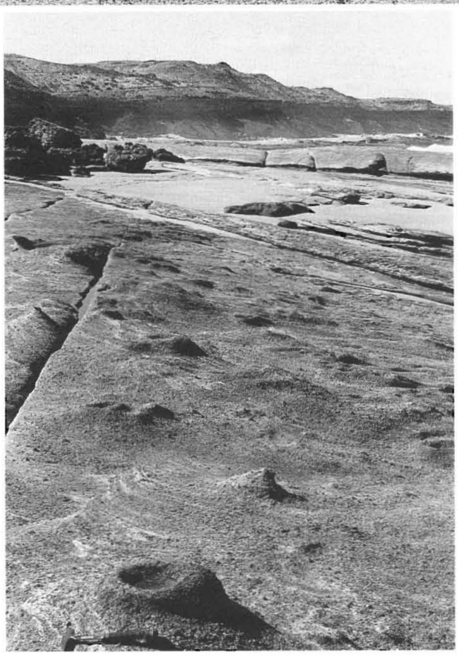

Figure 4. (a). Part of the block-strewn Coodley Platform with, in foreground, doughnuts in sugary sandstone, and beyond a conical font. Note beach sand around base of doughnuts. (b). Small doughnuts in red grit, north of Coodley Platform. Note joint cleft at left.

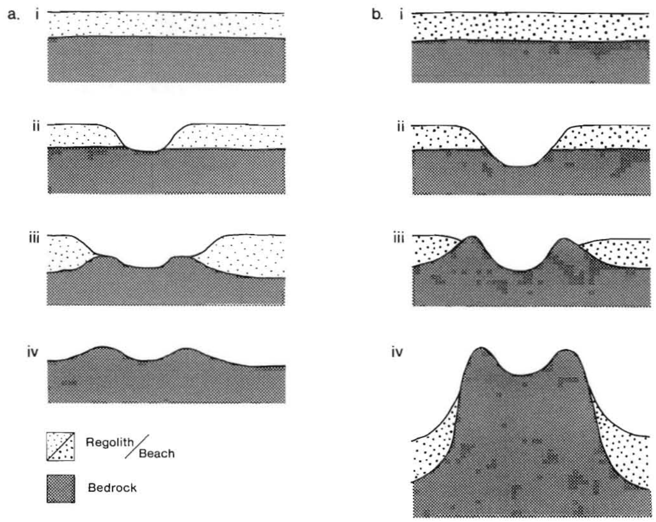

Figure 5. Diagrammatic sections illustrating proposed origin of doughnut and font.

Fonts

Fonts are small cones or towers, with inclined or vertical sides respectively, and each with a basin in the crest. They can be regarded as high annular rims or doughnuts, and, arbitrarily, the projecting form is termed a font where its height above the adjacent platform exceeds the maximum diameter of the crestal basin. In their turreted form they resemble baptismal fonts; hence their name, which follows the suggestion due to COUDÉ-GAUSSEN (1981), who referred to similar forms developed in granite in Portugal as *benitiers*.

Similar features, though with various given names, have been reported from other coastal settings, for instance in chalk on the north Norfolk coast (BURNABY, 1950), in sandstone on the Otway coast of Victoria (GILL and MCNEILL, 1973), at Cape Paterson in eastern Victoria (HILLS, 1971), and near Moeraki, South Island, New Zealand (TWIDALE, 1976, pp. 375 and 377); in basalt near North Cape, New Zealand (COTTON, 1963). Small examples are developed in sandstone near Wollongong in southern New South Wales (R.W. YOUNG, *pers. comm.*, December, 1993, R.A.L. WRAY, *pers. comm.*, 1996), in granite at Rose Bay, near Bowen, Queensland (E.C.F. BIRD, *pers. comm.*), and on the Falkland Islands (*The Guardian,* 24 September, 1994, p. 20).

Morphology and Composition

Fonts are widely distributed on the Talia coast, but there are concentrations of comparatively large forms at several sites, and especially at Coodley Platform (Figure 6 A and B) in white, sugary, well-sorted sandstone. Those few formed in grey grit are also large but those preserved in red grit are small (Figure 4B), presumably reflecting the relative resistance of this bedrock to locally operating weathering processes.

The fonts vary from 150 cm maximum diameter and 80 cm maximum height to small remnants several tens of centimetres high and wide. In plan, fonts are circular to oval and, in cross section, conical or turreted, but have a pan or pit in the crest (Figure 7A). Some turreted forms have concave overhanging sides (Figure 7B), and the strata on which some are developed have been undercut by wave abrasion and basin development. In some, bedding planes are slightly accentuated by differential weathering and erosion, and alveoles are developed high on the inner walls. The larger fonts contain water at most times, but the smaller ones frequently dry out leaving a residue of halite. Where water is retained, basins contain intertidal biota including tubeworms, barnacles, sea-grapes, limpets and *Littorina* (FORREST, 1993). Some of

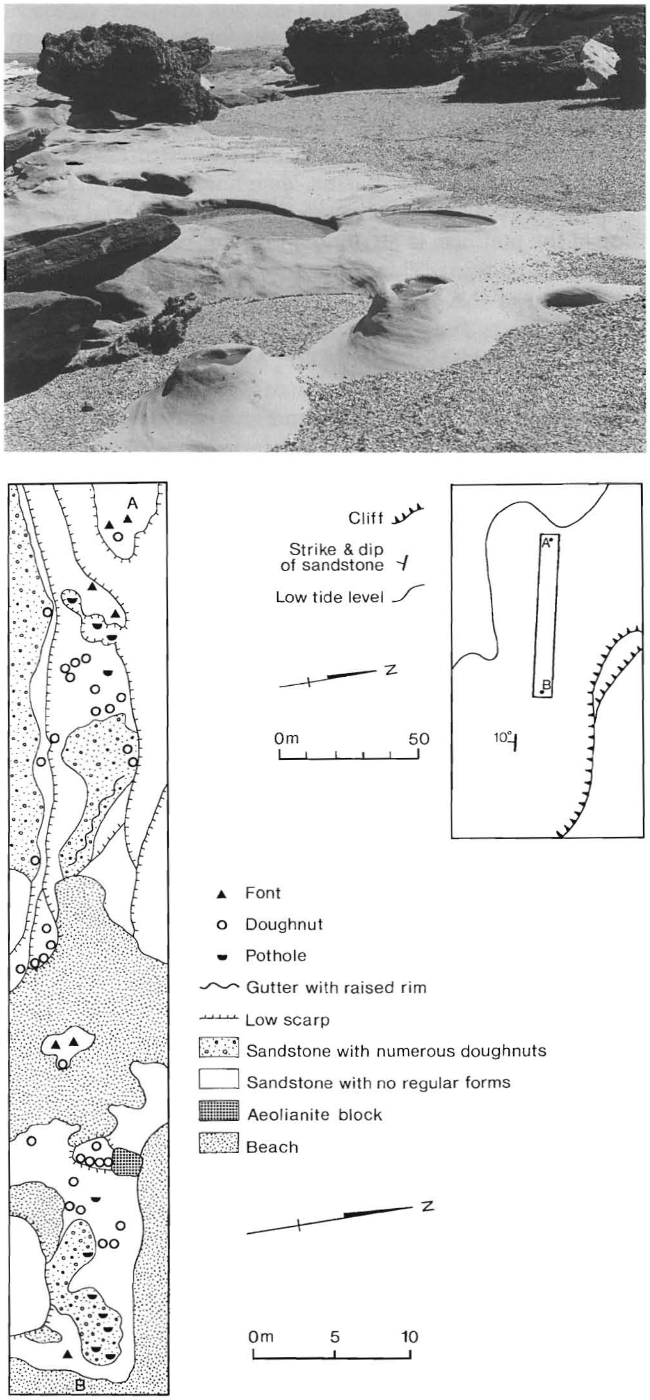

Figure 6. (Top). Basins and conical fonts in sandstone at Coodley Platform. Note beach sand. (Bottom). Plan of assemblage of basins, doughnuts and fonts, Coodley Platform.

the larger font basins contain rounded cobbles and pebbles of sandstone and/or calcarenite and sand and shellgrit.

The composition of the fonts in hand specimen appears the same as that of the adjacent platform, and cross-bedding extends through font and adjacent platform. Microscopic and cathodoluminescent analyses, however, reveal small differences between font and platform. The font rock is a compact sericitic sandstone consisting of tightly packed quartz (>90%), some feldspar and a small amount (<5%) of microcrystalline sericitic cement. The cement is black under cathodoluminescence. When stained with potassium ferricyanide, some of the cement is blue, indicating ferroan calcite. In contrast, a sample of the platform material collected along strike from the font readily crumbles to sand and, in thin section, shows no cement.

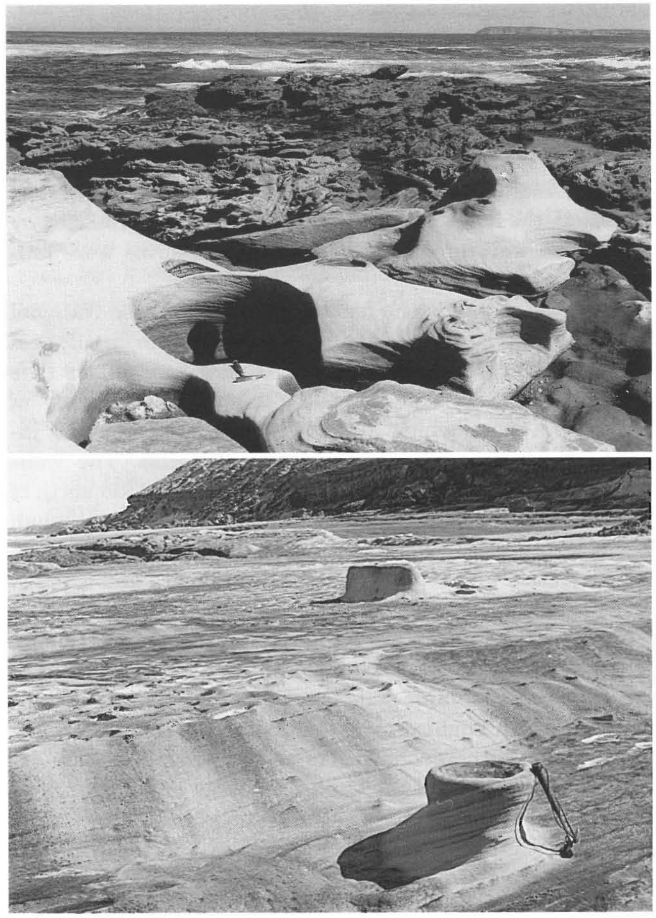

Figure 7. (Top). Potholes and conical font in sandstone, Coodley Platform. The larger font is undercut on the landward (right) side. (Bottom). Font in cross-bedded sandstone, near The Overhang.

Previous Theories and Critique

COTTON (1963, p.101, and citing BARTRUM 1935) illustrated conical residuals with a crestal depression which he termed miniature inselbergs, formed in basalt near North Cape, New Zealand. He considered them to be residuals remaining after planation due to water-level weathering. HILLS (1971) attributed similar forms at Cape Paterson, Victoria, which he called elevated pits, to the bedrock exposed in the walls and floors of the pools being continuously wet, and thus not subject to slaking. GILL and MCNEILL (1973) described the basins in small fonts on the Otway coast of Victoria as the site of spherical calcium carbonate concretions, later removed by wave action, but which protected the surrounding rock (the font) from erosion. TWIDALE (1976, p. 375) noted that the conical fonts he observed near Moeraki, in New Zealand, carry a coating of, and are impregnated by, limonite. Indurated spheres also occur on the platform, but they are much smaller than the crestal basins of the fonts. He invoked inversion, the floors and walls of the pools being protected by continuous wetting while the adjacent platforms were lowered.

Huge conical sandstone fonts in the Glen Canyon National Recreation Area, Utah, have been attributed to lithological differentiation (NETOFF and SHROBA, 1997). A similar type of explanation was adduced for the tubular chalk "stacks" of the Norfolk coast, which BURNABY (1950) interpreted as infilled solution pipes lithified by organic acids. The well-known pillars of the Pinnacles Desert, about 180 km north of Perth, Western Australia, may be of a similar origin, though it has also been suggested that they are tap roots replaced by dissolution and reprecipitation of carbonate and exposed by deflation of the adjacent dune sand (MCNAMARA, 1986).

Many of these ideas are either irrelevant, or inadequate, in the Talia context. For example, the sandstone exposed in the Talia coast contains neither concretions of more resistant material which might protect the underlying rock from wave erosion. Nor is there evidence of clastic pipes like those described as the basis of the Utah megafonts or structural infillings comparable to those of the Norfolk coast. Concerning rhizoliths, suitable organisms did not exist in Mesoproterozoic times, and there is no evidence of appropriate lithological differentiation as might be anticipated were the fonts due to solution and replacement. On the contrary, structures such as cross bedding carry through from font to platform (see Figure 7B). It can be suggested that basins, and hence doughnuts and fonts, develop along fractures, and at fracture intersections. But these are usually lines of weakness, and where there has been induration this results in linear ridges, not localised areas of more resistant rock which could give rise to doughnuts and fonts. The sericitic cement found in one of the fonts at Talia, may be construed as the reason for the font, but it can equally be interpreted as the result of water seeping into the host rock from the basin in the already-formed font.

Water level weathering (WENTWORTH, 1938, 1939) or water layer weathering (HILLS, 1949), invoked by COTTON (1963) in explanation of basaltic residuals on a shore platform is undoubtedly important in the formation of basins where water is retained, and hence of platforms, but fonts are not surrounded by pools and the process seems irrelevant to their development. Such weathering in the crestal pool may indeed contribute to the destruction of the font.

If the fonts are preserved by being continuously wet and thus not subject to fretting or slaking (HILLS 1971) they ought to be well developed on the middle and outer zones of the platform, yet they are best developed close to the cliff line. Their absence distant from the cliff base can be accounted for by the more effective and continuous wave erosion.

Working Hypothesis

It is suggested that most of the Talia fonts are formed from basins and doughnuts by the continued lowering of the adjacent platform as a result of beach etching. In these terms, fonts are merely tall doughnuts, or rock rims that have grown in relief amplitude as a result of the continued lowering of the adjacent platforms. Basins, doughnuts and fonts thus constitute a developmental sequence. The preferential weathering of the platform is attributed to water retained in shelly beach sand and grit. This explanation is consistent with the distribution of the assemblage of minor forms (plinths, basins, doughnuts and fonts) on the inner platform within 60 m, and mostly within 20 m of the base of the cliff. This is where beach sediment most frequently occurs. It is wetted by groundwater seepage from the land and twice a day at high tide, as well as during rains and by storm waves. A few basins are found on the outer platforms, but there are few sediment accumulations, plinths, doughnuts and fonts. The increasing age of the platform from the cliff seawards is commensurate with the observed tendency to an increase in height of font away from the cliff.

Conical fonts are the basic form. The inclined flanks may reflect the greater frequency of wetting and drying and hence weathering (solution, slaking, salt crystallisation) near the surface of beach detritus than at depth. The turreted forms are due to wave attack and steepening of the basic cones, especially at the inner edge of the platform where abrasive tools (sand particles and cobbles) are most commonly available. This is why turreted forms and some higher doughnuts are asymmetrical, with the steeper, in places overhanging, sidewall facing the direction of wave attack. Once formed, fonts are self-enhancing, for once the rim is in positive relief it sheds water while the sand around the base remains moist and aggressive.

There are, however, some difficulties. One concerns the regional distribution of fonts. No comparable forms have been identified on granitic coasts on the west coast of Eyre Peninsula, yet they are developed in such materials elsewhere, in both terrestrial and coastal settings. Most, though not all, of the beaches of the granitic sectors of the Eyre Peninsula west coast are predominantly calcareous, though with minor quartz and feldspar. Whether minor compositional variations influences the rate of beach etching is not known.

Second, many flat-floored basins or pans, some with bordering rims or doughnuts, the suggested precursors of fonts, are found on plinths beneath calcarenite blocks (Figure 3b). How, if at all, are they related to fonts? At the northern end of Coquinite Bay rims bordering both pools and gutters in sandstone, and located beneath limestone blocks, are lined on their inner faces by algae (*Cladophora* sp. which are shade-loving and intolerant of direct sunlight) suggesting that the sequence may be initiated on the plinths; though here again,the biotic input can be construed in terms of either cause or effect. On the other hand, on many plinths basins and doughnuts occur at the interface between sandstone and calcarenite. This is particularly well demonstrated where calcarenite blocks have been dislodged by wave action. In neither instance are algae present.

Finally, and as mentioned previously, at one site between Coodley Platform and the Cliff Path, a small font occurs beneath a large calcarenite block (Figure 3B). It is unlikely to predate the fall of the block and have survived the impact; it must have formed by the preferential lowering of the surface of the plinth, implying that the font sandstone is in some way harder than the rock which originally surrounded it.

DISCUSSION AND CONCLUSIONS

The thesis advanced here is that although some of the minor, as well as the major, forms described from the Talia coast are due to wave attack, plinths, doughnuts and fonts owe their origin to the preferential weathering of the platforms surrounding the basins, doughnuts and fonts by water retained in shelly beach sand and grit. Such beach etching has implications for several aspects of the development of shore platforms and features associated with them.

First, beach etching may be partly responsible for the remarkably smooth overall morphology of some platforms, and for sectors of others. On the Talia coast smooth platforms are developed near low tide level at the outer margin of the rocky coast, primarily by wave action but doubtless with biochemical contributions. Others, just as featureless, occur near the cliff base, and though swept by waves at high tide, commonly carry beach sediment.

Some platforms developed in calcarenite, like those illustrated from the Victorian coast by HILLS (1949) have been described as being as smooth as a billiard table. At Edwards Bay, between Streaky Bay and Ceduna, a platform some 300 m wide is formed in Late Pleistocene calcarenite. There are a few stacks near the seaward margin but in detail the platform carries a discontinuous veneer of seagrapes (*Hormosira* sp.) which trap sand and water in shallow pools, so that even at very low tides the platform is moist. Even on serrated platforms, such as that developed at Hallett Cove, south of Adelaide, there are areas of quite remarkable smoothness. Etching by waters retained in beach materials offers an explanation for these remarkably smooth platforms.

Beaches are ephemeral, and platforms are at times exposed, at others covered. For example, at various times along the west coast of Eyre Peninsula platforms in granitic gneiss and amphibolite (Mt Greenly), quartzite (The Frenchman), granite (Tyringa Beach) and calcarenite (Back Beach), have been observed covered by beach materials in summer (Figure 1a). Similarly, the distribution and thickness of shelly beaches on the Talia coast varies according to season and storm.

Second, the platform, ramp and cliff assemblages have formed in relation to present sealevel, plus or minus one metre, during the last ~7000 years (MÖRNER, 1971; CLARK and LINGLE 1979; TRENHAILE, 1987, pp. 135 *et seq.*; BELPERIO, 1995). Those fonts found on the platform can, even on a simple calculation based on position on the platform against total age of the feature, and making no allowance for negative feedback mechanisms, be no more than 1000 years old. Those located in the cliff foot zone can be only a few hundreds of years old. A very rapid rate of formation of plinths, basins, doughnuts and fonts is indicated. This is consistent with evidence of the rapid development of platforms in other parts of Eyre Peninsula and in other areas. For example, on the west coast of Eyre Peninsula, platforms eroded in Late Pleistocene calcarenite have extended at a rate of 3.0–4.5 cm/year (TWIDALE 1997), and similar rates are evident on sandstone, granitic and amphibolitic coasts in the same area, in argillite near Adelaide, and on the Victorian coast (e.g. GILL, 1973; TWIDALE, 1997; see also HODGKIN, 1964; GUILCHER, 1989).

At Talia the width of the platform and the disposition of the calcarenite-sandstone unconformity indicate that a considerable volume of sandstone, as well as cemented dune rock, has been eroded in this period. Rapid cliff retreat, and the evacuation of large volumes of detritus, are implied.

Rapid development can plausibly be explained partly by the study area being on an exposed coast, but partly also by beach etching. This process continues as long as a beach is present, the water supply being replenished and the products of weathering evacuated, during and following winter rains, at high tide and during winter storms.

Third, etching in a coastal setting may account for the smoothness of many unconformities that have been buried beneath marine sediments. Water weathering, as in pool or water-level weathering, in the context of beach etching, provides a plausible contributary explanation for such a morphology.

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