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The origin, age, and conservation, of an 'elevated platform', Yarwondutta Rock, north-western Eyre Peninsula, South Australia

Origen, edad y conservación de una "plataforma elevada", Yarwondutta Rock, Noroeste de la Península de Eyre, Australia Meridional

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Abstract

Yarwondutta Rock is a dimpled platform that was shaped at ground level by soil moisture but subsequently elevated, not because of local tectonism, but by the erosional lowering of the surrounding pedimented plains. Concave or flared slopes fashioned in the erstwhile piedmont were revealed during this erosional phase which took place in the earlier Pleistocene. The elevated platform is now buttressed against dissection by the calcreted surrounding pediments.

It is concluded that in technical terms, Yarwondutta Rock appropriately can be referred to as an 'elevated platform'.

'Criticism and testing are the essence of our work.' Remark by Herman Bondi on the occasion of Karl Popper's 90th birthday anniversary (But with a reminder that a 'criticism' is an assessment or evaluation, and is neither implicitly, nor of necessity, adverse. C.R.T.).

Keywords: granite geomorphology, etched surface, Australia, granite weathering

Resumen

Yarwondutta Rock es una plataforma pellizcada que fue modelada a nivel del suelo por la humedad del mismo, pero que posteriormente se elevó, no a causa de la tectónica local, sino por el descenso erosivo de las llanuras pedimentadas circundantes. Las laderas cóncavas o acampanadas formadas en el antiguo piedemonte quedaron al descubierto durante esta fase erosiva que tuvo lugar en el Pleistoceno más temprano. La plataforma elevada está ahora reforzada contra la erosión por los pedimentos circundantes de calcreta.

Se concluye que, en términos técnicos, la roca de Yarwondutta puede calificarse de "plataforma elevada".

La crítica y la comprobación son la esencia de nuestro trabajo". Comentario de Herman Bondi con motivo del 90 aniversario del nacimiento de Karl Popper (Pero con un recordatorio de que una 'crítica' es una valoración o evaluación, y no es implícitamente, ni por necesidad, adversa. C.R.T.).

Palabras clave: gemorfologia granítica, superficie grabada, Australia, meteorización granítica

1. INTRODUCTION AND PROBLEM

Yarwondutta Rock is a granitic outcrop located near Minnipa on north-western Eyre Peninsula (**Figures 1a & 2**). Originally there were adjacent granitic rises, Western and Eastern (**Figures 1b**), situated on a research and liaison farm established by the State Government in 1915 (Holloway 2015). The smaller Western residual was quarried for railway ballast in the late 1960s, but investigations conducted preliminary to the excavation have proved instructive as are the clean bedrock sections exposed during quarrying (**Figure 3a**; Tardyvas 1968a & b, 1969).

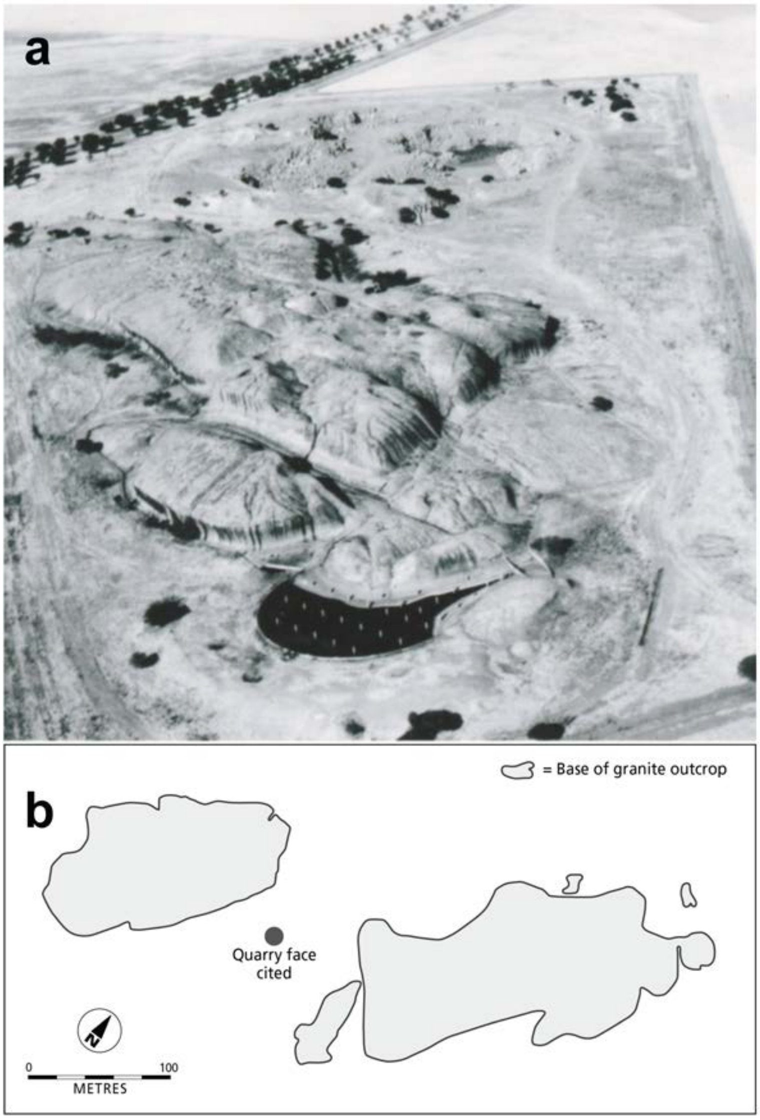


Figure 1. (a) Yarwondutta Rock from the air, from the NE. (b) Disposition of the two Yarwondutta Rocks, the Western and Eastern. The latter is the present Rock.

The larger or Eastern outcrop, the present Yarwondutta Rock, is host to several geomorphological features of interest and has been cited in scientific publications, but it has proved difficult to find an apposite technical name for the residual. 'Rock' is uninformative, having been applied to uplands of widely varied shapes and sizes. Here the origin and evolution of Yarwondutta Rock are analysed with a view to suggesting an appropriate descriptor. The problem is to identify, order, and explain, the disparate environmental events leading to its initiation and evolution.

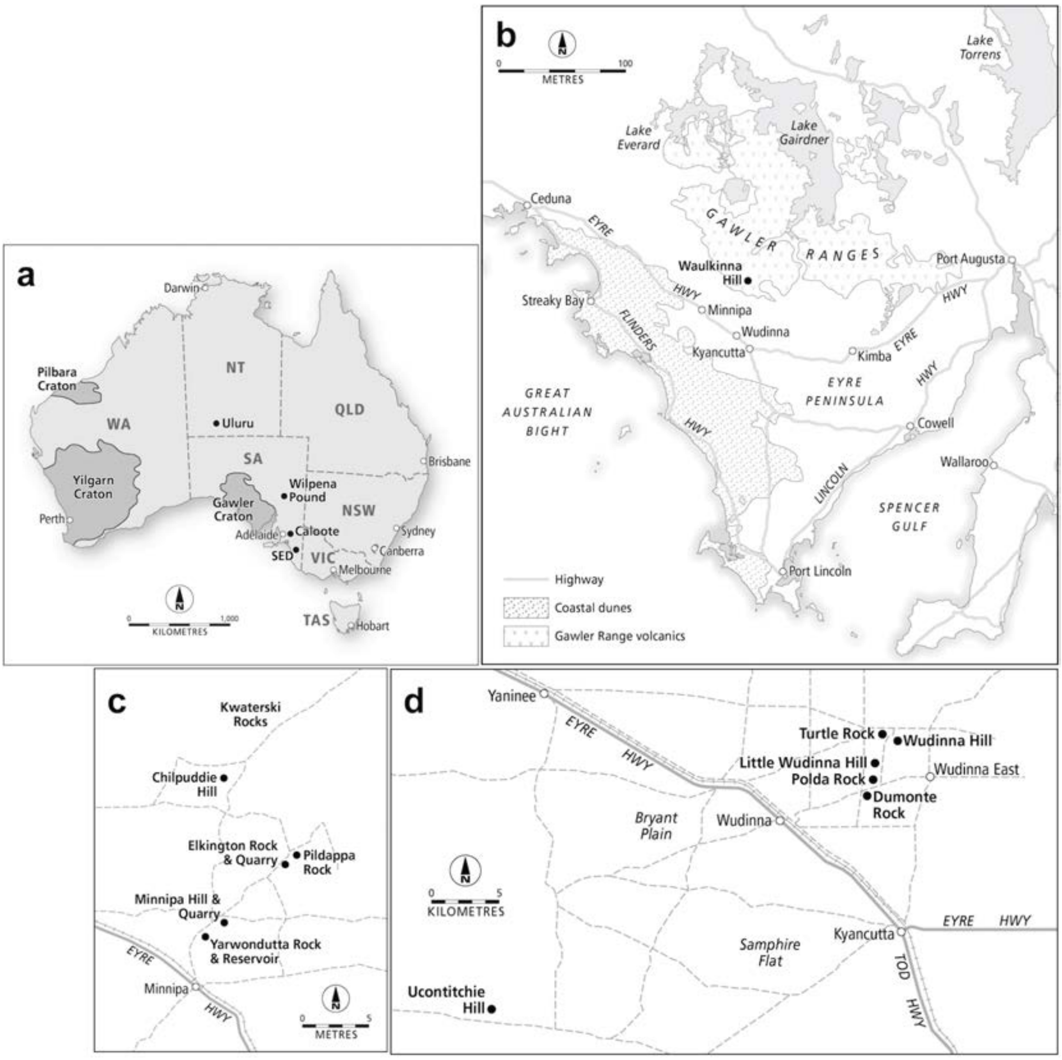


Figure 2. Location maps (a) Australia. (b) Eyre Peninsula, with details of (c) Minnipa and (d) Wudinna districts. The location of the South East District (SED) is shown on (a).

2. BACKGROUND

The Yarwondutta Rocks were shaped in rocks of the Mesoproterozoic Hiltaba Suite. It consists of 20% quartz, 60% K feldspar, plagioclase 10 -15%, and minor biotite and for the sake of simplicity will be referred to as granitic (Flint 1993; Ferris et al. 1998). The low rises are situated in a climatic zone characterised by cool wet winters and hot dry summers, but remnants of laterite and silcrete show that the area has been affected by humid warm climates in the past (Twidale 1983). The plains of north-western and central Eyre Peninsula carry a carapace of calcrete (caliche, kunkar, kankar) formed from carbonate dust produced by the weathering of the stack of calcarenitic coastal foredunes constructed behind the west coast of the Peninsula during the Middle and

Late Pleistocene (Wilson 1991; Belperio 1993; **Figure 2b**). The fines were distributed by westerly winds and spread over the land surface where they were illuviated and reprecipitated to form a massive duricrust (**Figure 3b)** rendering the erstwhile riverine plains karstic, streamless, and essentially static or unchanging. During the Middle and Late Pleistocene, during the period of calcrete formation, they were traversed by longitudinal desert dunes that advanced across the area from NW to SE as shown by the encroachment of sand ridges on the north-western shores of salinas and the north-west facing slopes of granitic outcrops. The mid Holocene saw a renewal of dune activity, but all the sand ridges are now stabilised by vegetation and calcrete accumulations (Hilgers et al. 2011).

Figure 3. (a) Quarry section of regolith on granite, but with substantial protective capping of calcrete derived from airborne carbonate dust. (Explanatory notes. (S. M. Kraemers, pers. comm. 1983) Surface *0-10cm red sandy soil;10-20 cm nodular calcrete with granite fragments and quartz grains*;*20- 24 cm massive calcrete;24-30 cm nodular calcrete;30-60 cm grus and clay, lenses of calcrete;60-90 cm laminated grus and clay;90-91 cm bleached rock; 91-92 cm fresh graniet;92-93 cm iron -enriched granite;93cm- fresh granite) (b)* massive duricrust.

3. ESSENTIAL MORPHOLOGY OF YARWONDUTTA ROCK

(1) Yarwondutta Rock is shaped in massive compartments of granite **(Figure 4)** the plan shape of which, like the prominent clefts or *Kluftkarren* within it, is determined by the weathering and erosion of major passive fractures or joints trending NNE-SSW and E-W (**Figure 5a &b**).

Figure 4. Vertical air photograph of Yarwondutta Rock showing massive compartments, major fracture zones, and quarry (South Australian Lands Department).

(2) The residual is stepped in profile and the main platform stands some 10 metres above the surrounding pedimented plains. Its present dimpled appearance is due to the formation of numerous flat-floored rock basins or pans (Twidale & Corbin 1963). On the north-west aspect a platform with a large residual boulder *tafone* intervenes between the summit surface and the plain (**Figure 5c**). To the north a slightly higher area is scored by bowls some two metres in plan diameter and height.

(3) The walls forming the perimeter of the feature are steeply flared as is that separating the summit and an intermediate platform, and flanking the major clefts (**Figures 1 & 5b & d**. Those on the northern extremity are not only overhanging but the gutters that once scored the surface are now inverted and form ribs (Twidale and Bourne 2003). A shallow scarp foot depression has formed at the base of the flared wall (**Figures 5d & e**).

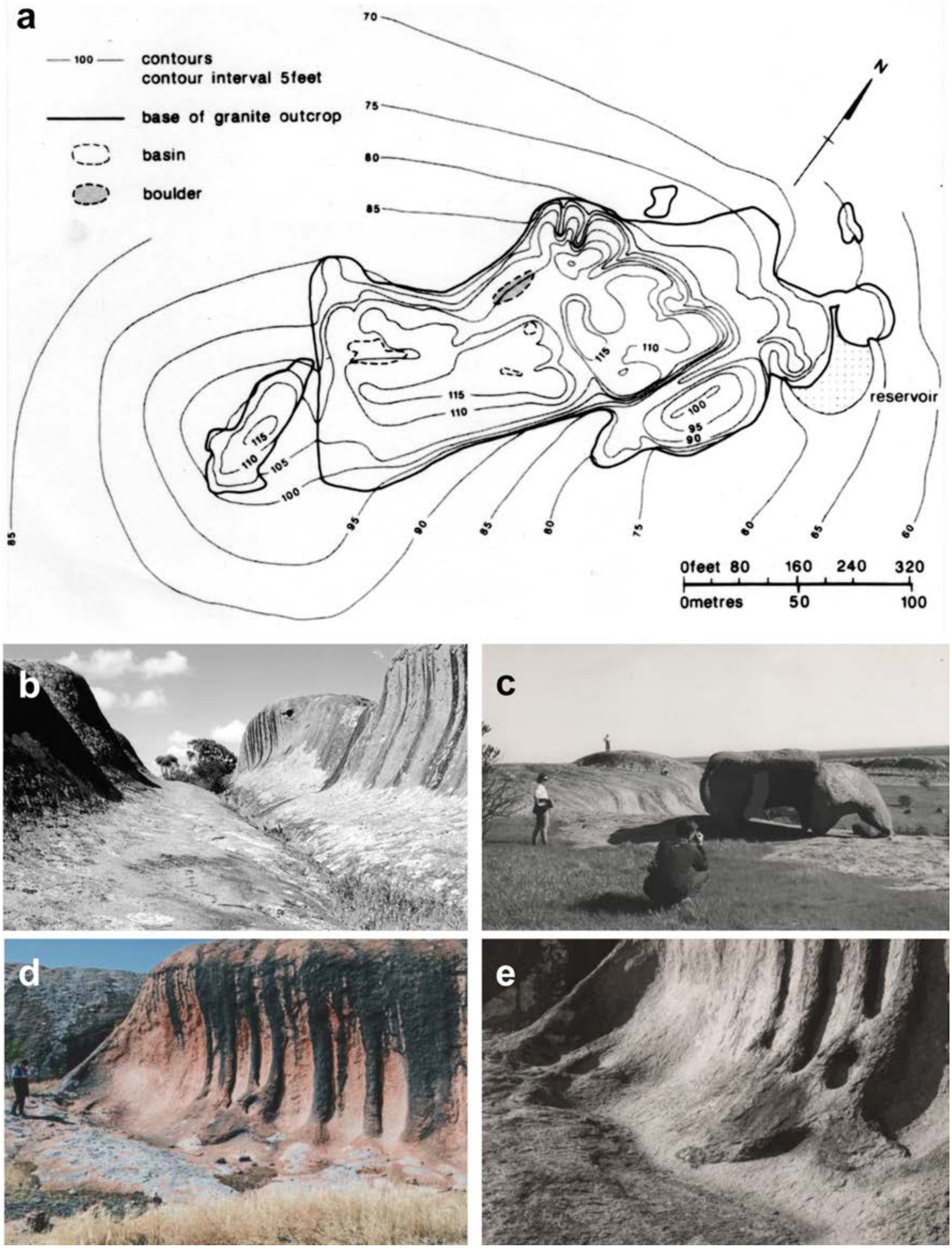


Figure 5. (a) Plan of present Yarwondutta Rock (b) Main cleft or *Kluftkarren.* (c) Part of north-western intermediate platform with residual boulder *tafone* and distant view of part of the western residual. (d) Northern slope some two metres high with overhanging flare and inverted gutters or *Rillen.* (e) Scarp foot depression at base of slope.

4. TERMINOLOGY

Yarwondutta Rock stands higher than the surrounding plain yet is neither hill nor plain. There appears to be no agreed form or lower limit of relative height for an upland to qualify as a 'mount', the term invoked by many early travellers and explorers for an upland or mountain perceived to be significant. Also, all is relative. Mt Fort Bowen, for instance, projects only 45 m or so above the general level of the Carpentaria Plains of north -west Queensland yet is known as a mount as is indicated on official maps (Twidale 1966). But the Sugar Loaf of Rio de Janeiro rises some 390 m from sea level, and Ayers Rock/Uluru some 330m above the surrounding plains, whereas, and by contrast, the eastern Yarwondutta Rock, with a bevelled crest standing about 10 m above plain level, clearly does not qualify as a mount, as an *inselberg* or 'island mountain' (Bornhardt 1900; Baulig 1956, p. 53) of any type - domical bornhardt, boulder-strewn nubbin or knoll, castellated koppie - and not even, in French terminology, as an *inselberg de poche*.

5. ORIGIN OF A GRANITOID RESIDUAL.

Inselbergs are convergent features for they have originated in various ways (e.g. Vidal Romani & Twidale 1998, pp 151 et seq.; Twidale & Vidal Romani 2005, pp. 109 et seq.) but some, and perhaps most, of those located on north-west Eyre Peninsula appear to be of structural origin. Although sheared, that is differentially dislocated and stressed (e.g. Endersbee, 2005, pp, 142-143) there is no evidence to suggest that the fracture defined compartments on which Yarwondutta Rock is based (**Figure** 4) have, and by contrast with for instance, the Pic Parana of south- eastern Brazil (Barbier 1957), been upthrust along faults. Rather has fracture propagation and the exploitation of tensional partings by etching or physicochemical weathering[1] generated a differentiated relief.

The corners and edges of the massive compartments have been preferentially weathered, converting angular orthogonal blocks into compact rounded masses that were set first in a matrix of grus with corestones but later of grus and eventually of a puggy or stiff clay. Domical masses of granite, some represented by crestal platforms, have been revealed by excavations at several sites in Africa (Boyé & Fritsch 1973;Vidal Romani & Twidale 1998; Twidale & Vidal Romani 2005, pp. 131 et seq.). Such exposures can be construed either as the end-product of the long-continued weathering and erosion of a granitoid mass, or as the initial exposure of a massive compartment that has been shaped in the shallow subsurface.

5.1. Platforms

Emergence of domical residual. A crest is the first sector of such a rounded compartment to be exposed, and when the author first saw what became the dome known as Elkington Rock (**Figures 6a &** b), it was a platform etched in the country rock and about 10 m diameter, scored by shallow and irregularly shaped basins and

[1] *Contact with water causes the alteration of feldspar and mica to clays. Some are hydrophilic and expand, causing physical rupture, readier access for water, and further weathering. Eventually, even quartz is dissolved.*

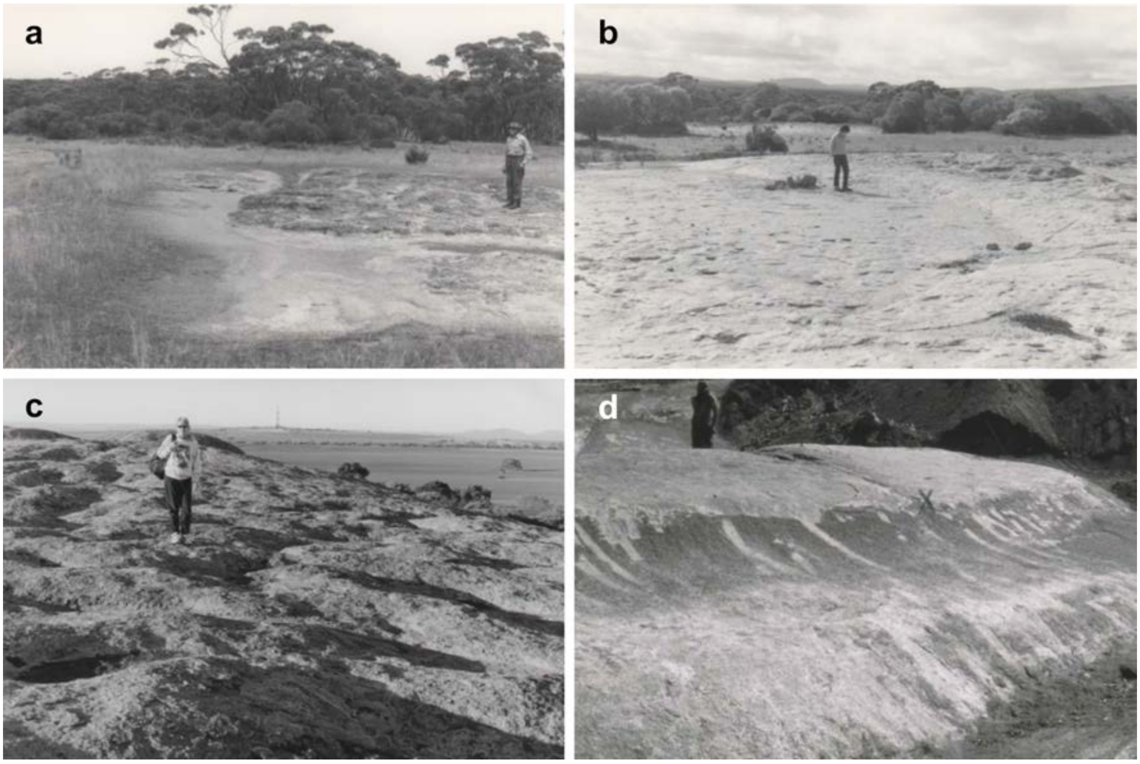
standing flush with the surrounding soil-covered pediments. Stripping of the weathered mantle[2],** as well as at least three broken and marginally altered sheet structures (Dale 1923 pp. 26 et seq), revealed the present large-radius dome which is about 70 m diameter. The initial overburden consisted of a thin soil and weathered mantle or saprolith the thickness of which increased with distance from the crest of the dome. At the exposed eastern edge of the dome it is 7-8 m thick (**Figure 6c &d)**, and around both of the Yarwondutta Rocks the regolith is between one and 7 metres thick (Tardyvas 1968a), observations that stand in denial of the assertion due to (Buckman et al. 2021, p. 2) that there is no evidence of 'weathered saprolite '(*sic*)' beneath the thin soil cover on the rock platforms marginal to the inselbergs.

Figure 6. Elkington Rock (a) Aerial view of granitic dome exposed in quarry, from the south. (b) Exposed dome. (c) Eastern part of dome and exposed saprolith, Pildappa

[2] *As used here, soil is a surficial cover with an organic component. A regolith is a horizon of mixed disintegrated and decomposed country rock in situ plus any introduced material such as colluvium, alluvium, wind- blown debris; a saprolith is dominated by chemically altered material and a weathered mantle is a general term for a cover the nature and origins of which have not been ascertained.*

Rock on skyline. (d) Saprolith up to10 m thick to east of dome, with surficially altered block, part of a disintegrated sheet structure in foreground.

Platform extension. Elkington Rock has been artificially exposed but local evidence suggests that bedrock platforms have been extended laterally beneath a thin soil cover (**Figures 7a & b**), and, it is suggested, Yarwondutta Rock was similarly initiated and developed. Soil is occasionally moist because it receives direct rainfall or run off. In addition, water attracts plants and insects and hence organic waste. Like standing pools, even thin soil layers weather the rock and in time generate smooth, level, or gently inclined, bedrock extensions to platform surfaces. The exposed platforms were smooth or were scored by shallow depressions of irregular plan shape that held water and time developed into pans; hence the overall dimpled appearance (**Figure 7c**). In addition, and in most instances because of steeply inclined joints run off from platforms soaked into the piedmont and steeper slopes were initiated in the immediate subsurface **(Figure 7d**).



7. (a) & (b) Extensions of platforms, at Kwaterski Rocks. The smooth recently exposed platforms stand in contrast with the adjacent rough and dimpled surfaces. (c) Dimpled main platform of Yarwondutta Rock. (d) Steep lowering of rock surface at hill-plain junction (X) at Calca quarry, some 38 km southeast of Streaky Bay.

5.2. Concave or flared bedrock slopes

Fortuitous discovery. In an effort to ensure a reliable supply of water for the horses that worked the fields on the Government Farm, a conservation scheme was constructed inn1915 on the Eastern or present Rock, which offered the greater catchment. Test holes were drilled at the proposed site of a storage basin in the northern piedmont of the residual. The excavation penetrated through more than two metres of regolith but bottomed on bedrock with ‘breaks’ (Cook 1916) or fractures, that allowed leakage and necessitated the construction of a concrete retaining wall (**Figures 1a& 8a)**. However the excavation also exposed a weathered mantle abutting a bedrock concavity that is similar in shape to the nearby sidewalls. This wholly fortuitous discovery provided crucial evidence pointing to the subsurface initiation of at least some flared slopes, though it was not sighted by the writer until early in 1960 when, as it transpired, toward the end of a severe drought. the basin was dry.

Origin of bedrock flares. This serendipitous exposure showed that that flared bedrock surfaces have been shaped in the shallow subsurface by moisture retained in soils and weathered mantles. Curved fractures were noted in the country rocks but none was associated with concave slopes, and external processes were considered, When flares were first noted on Eyre Peninsula, in 1959, the regional environment suggested sand blasting, and running water as possible causative agencies (Twidale 1962,1967). But the excavation at Yarwondutta Rock, supporting similar though less well-defined evidence from the nearby Chilpuddie Hill (**Figure 9**; Twidale 1962) effectively precluded any epigene or ’subaerial’ process as a general agency responsible for all flared slopes. How typical was the evidence pointing to a subsurface initiation and later exposure of flared slopes, was yet to be ascertained, but that some flared walls are of subsurface derivation was certain.

Later, the subsurface origin of the Yarwondutta Rock flare was confirmed by the recognition, on the upper shoulder of the weathered slope, of pitting, due to differential weathering at the crystal scale, in the hill-plain junction by soil water rendered especially aggressive by frequency of wetting and biota attracted by the moisture (Twidale & Bourne 1976; **Figure 8b**). The subsurface flared surfaces have been exposed as landforms by the erosional lowering of the piedmont the reason for which, bearing in mind the chronology of geological events reconstructed for the particular area, calls for comment (see below).

Flared slopes vary in height between a few centimetres (e.g. **Figure 7d**) and roughly 14 metres (in Wave Rock - **Figure 10a**). The degree of concavity varies between shallow (large radius of curvature) and deep to overhanging (small radius), and according to the volume and chemistry of runoff, fluctuations of water table, and the duration of weathering. As the geometry of a given flare varies with degree of weathering and recession, the deepest arcs are regarded as more advanced than the shallow. The height of the concavity reflects the depth of earlier weathering and multiflared slopes record past shifts of mean seasonal water tables (**Figure 10b**). At the Yarwondutta Rocks water storage site (**Figure 1a, 8a)**) the juxtaposition of this subsurface feature and the adjacent concave walls of the residual suggested that the latter are exposed versions of the former, and that flares are of two-stage origin, having been initiated by etching in the shallow subsurface but later exposed as concave rock surfaces. In broader view, the flared bedrock profiles exposed in the water storage at Yarwondutta Rock and elsewhere can be regarded as local deviations and variations in the weathering front ,or lower level of effective weathering (Büdel 1957; Mabbutt 1961; Bourne et al. 2002).

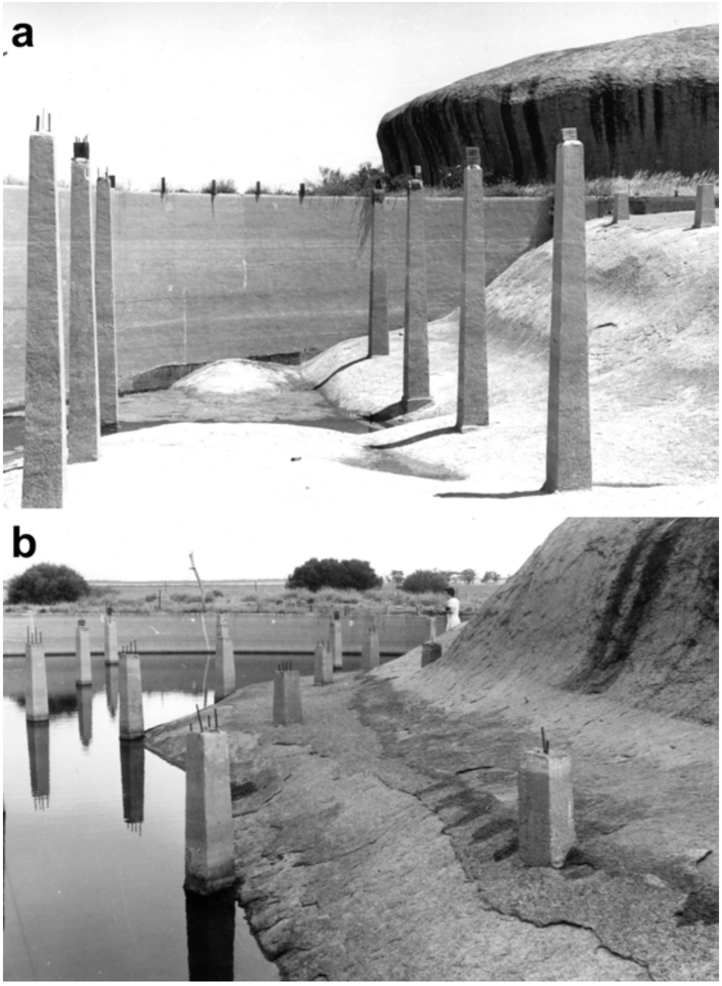


Figure 8. (a) Yarwondutta Rock water storage, dry and just over two metres deep. (b) Pitted surface on shoulder of flared bedrock slope.

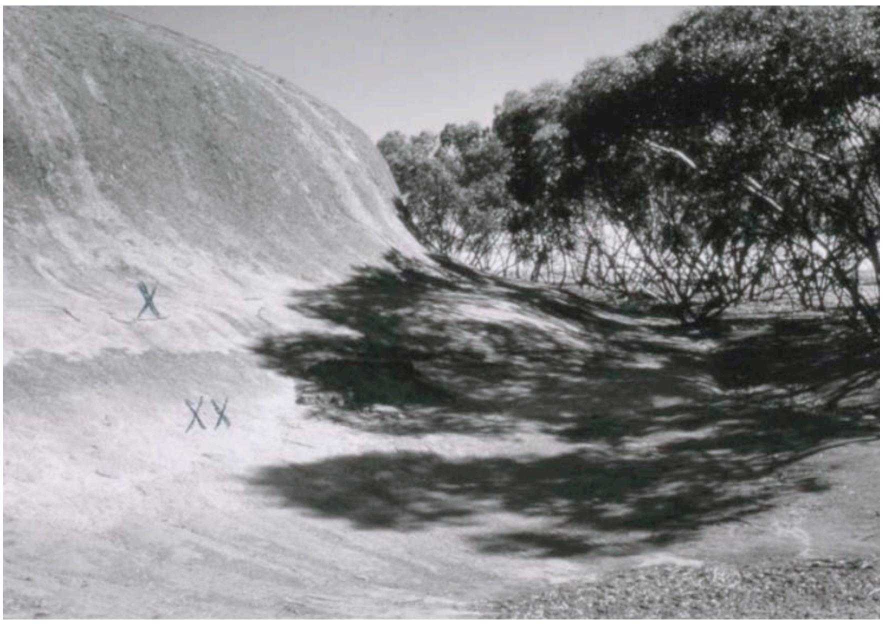


Figure 9. Shallow flares exposed in water storage at Chilpuddie Hill - X exposed, XX revealed by excavation.

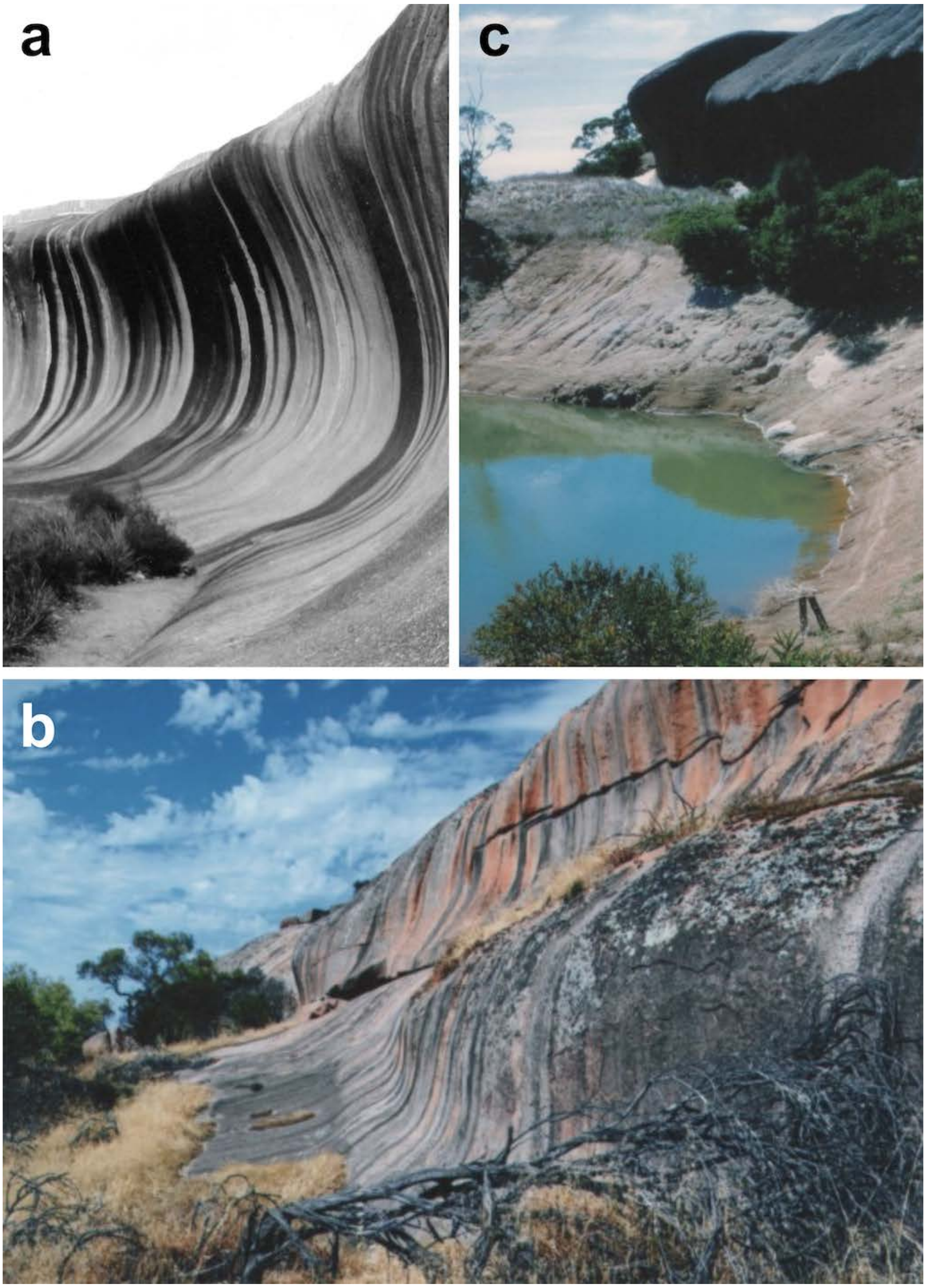


Figure 10. (a) Steep plunge of bedrock surface at base or 'toe', of the spectacular but misleadingly named, Wave Rock, part of the perimeter wall of Hyden Rock some 350 km SSE of Perth, WA. (b) Multiflared east-facing slope of Ucontitchie Hill. (c) Water storage excavated in NW piedmont of Ucontitchie Hill exposing a weathered mantle comprising grus and corestones. The granitic backwall plunges steeply from fringing

platform to a depth of some 15 metres, bottoming on massive corestones (R. Schmucker, pers.com.).

Testing and corroboration. The exposure at Yarwondutta Rock is significant because it is one of only a few known concave rock walls already fashioned in the subsurface. Its subsurface origin is confirmed by morphological as well as documented or historical evidence. As at Chilpuddie Hill there was no sign of its being exhumed, that is, of its having been shaped, say, by some subaerial or epigene process, then buried, and later disinterred. The Chilpuddie Hill and Yarwondutta Rock concavities were *in situ*. The concave forms had formed below ground and been exposed incidentally to the implementation of water conservation schemes. The setting was such that to associate water flowing from the adjacent bare bedrock slope with the weathered rock revealed in piedmont excavations was credible and plausible.

But demonstrated examples of flared bedrock surfaces *in situ* in the subsurface are few and have been located only by the monitoring of working quarries and other excavations. In addition to the bedrock profiles already cited, examples of two-stage flared slopes already fashioned below natural ground level have been noted in the Calca and Wudinna quarries, and in exposures eroded in corridors at the Grant County City of Rocks, New Mexico (Mueller & Twidale 1988a; see **Figures 7d & 11**).

However, that bedrock concavities similar to that revealed in the Yarwondutta Rock water storage may occur at several sites in the district, as well as on the Yilgarn Block of the south-west of Western Australia, is suggested by the steep plunge of the 'toes' of flares and the occurrence of deep weathering beneath the piedmont close to the outcrops as indicated by drilling and excavation (**Figures 10a & c;** Twidale 1968, Tardyvas 1969).

Primacy of water. The weathering that mainly responsible for flared bedrock forms is driven by water as is indicated by their piedmont locations that most frequently receive runoff additional to direct rainfall. Standing water has produced parallel and horizontal notches that are miniature flares or the forerunners of flares in the western Wichita Mountains of southwestern Oklahoma, where the sets of horizonal concavities appear to have formed at the contact between a sequence of flat-lying Permian arenaceous and argillitic beds with the Cambrian granite in which the uplands are fashioned **(**Harrell & Twidale 1989, **Figure 12)**. The sandstone beds are porous and retain water and that has generated the eye-catching decorations.

Thus the etch and two-stage hypothesis appears to be compatible with field evidence not only from north-western Eyre Peninsula, but also from sites overseas. Nevertheless, other processes have been entertained and indeed favoured. Given its prominence in any discussion concerning the origin and nature of Yarwondutta Rock, as well as other residuals and landscapes, any contrary arguments involving the formation of concave bedrock forms by running water and by bushfires must needs be considered.

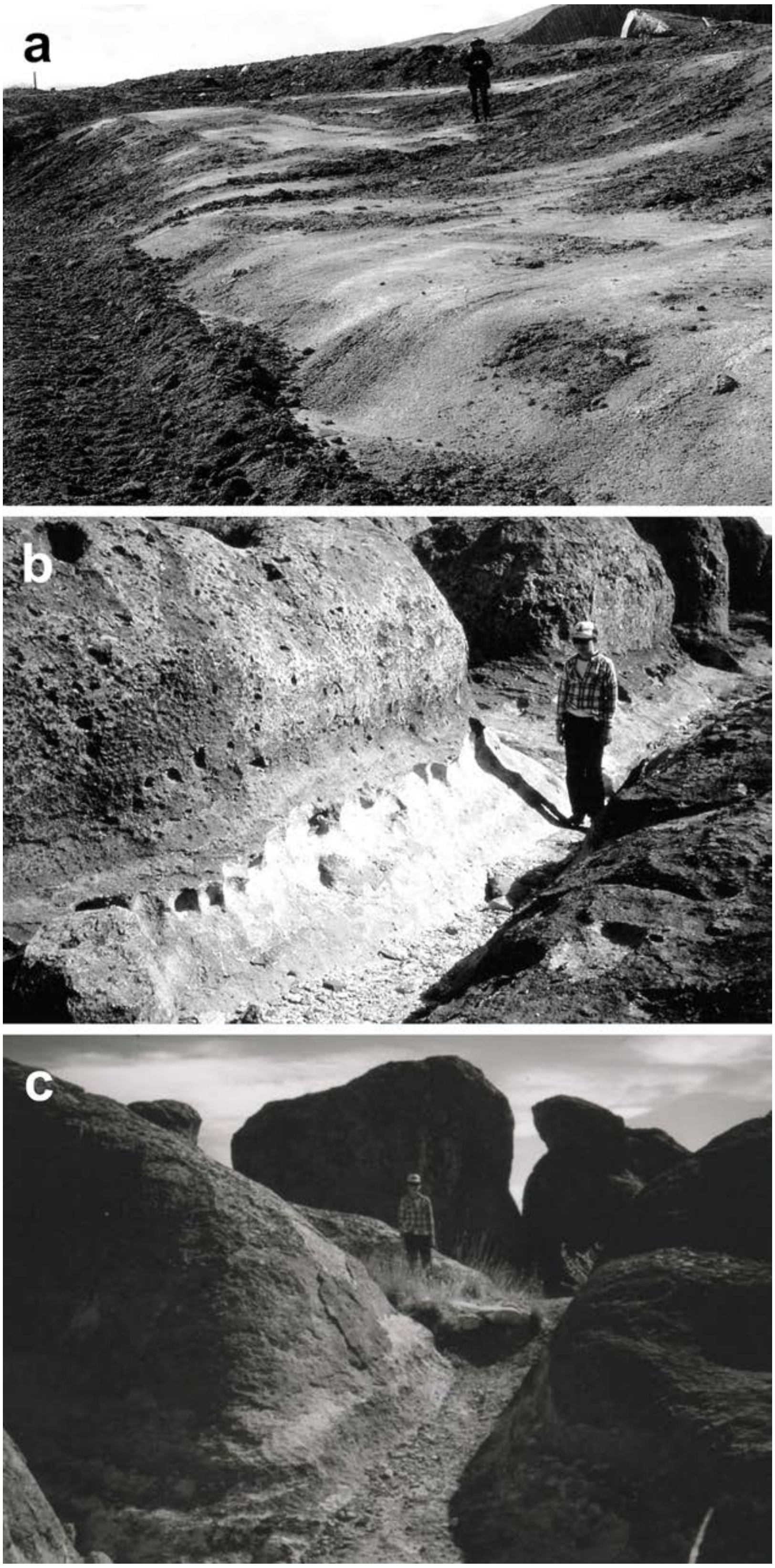


Figure 11. (a) Shallow concavities exposed in extension of Wudinna quarry (b)) Crenate weathering and concavity exposed in eroded floor of corridor between columns of rhyolitic tuff in the Grant County City of Rocks, southern New Mexico. (c) Small flare as base of column in the same complex. (Photos 11b & c, courtesy Dr J.E. Mueller)

Figure 12. (a) and (b) Horizontal grooves in granite, Wichita Mountains, SW Oklahoma. (Photos courtesy Prof. J.R. Harrell)

5.3. Alternative working hypotheses.

Running water and fire spalling, have been suggested as alternative causes of flared slope development. Both are epigene or subaerial and the certain initiation of some flares in the subsurface rules them out as all-embracing causative agencies.

Second, regarding running water (Ollier & Bourman 2002; Bourman et al. 2015), surface tension allows wash and seepage to effect weathering, but such flows do not carry large volumes of grit, the tools of abrasion (e.g. Willis, 1936, p. 120). Accordingly they are of low erosive potential. Separation of rivulets and even seepages rule them out of consideration as influencing the many steeply inclined and overhanging flares formed and preserved in the field. On Little Wudinna Hill (**Figure 2d)** rivulets are estimated to have separated at van inclination of about 23 degrees). Rivulets create and flow in gutters separated from each other by divides (**Figure 13a**) a pattern incompatible with the continuous and consistently concave surfaces that constitute the flared walls developed not only on Yarwondutta Rock, for example, but also at other sites (e.g. Bourne & Twidale 2002). Flares occur on isolated columns, blocks, and other surfaces fed by limited catchments that generate limited wash, which however is retained as soil moisture and rots the rock with which it is in contact (e.g. Logan 1851, p. 326 (**Figures 13b &** c).

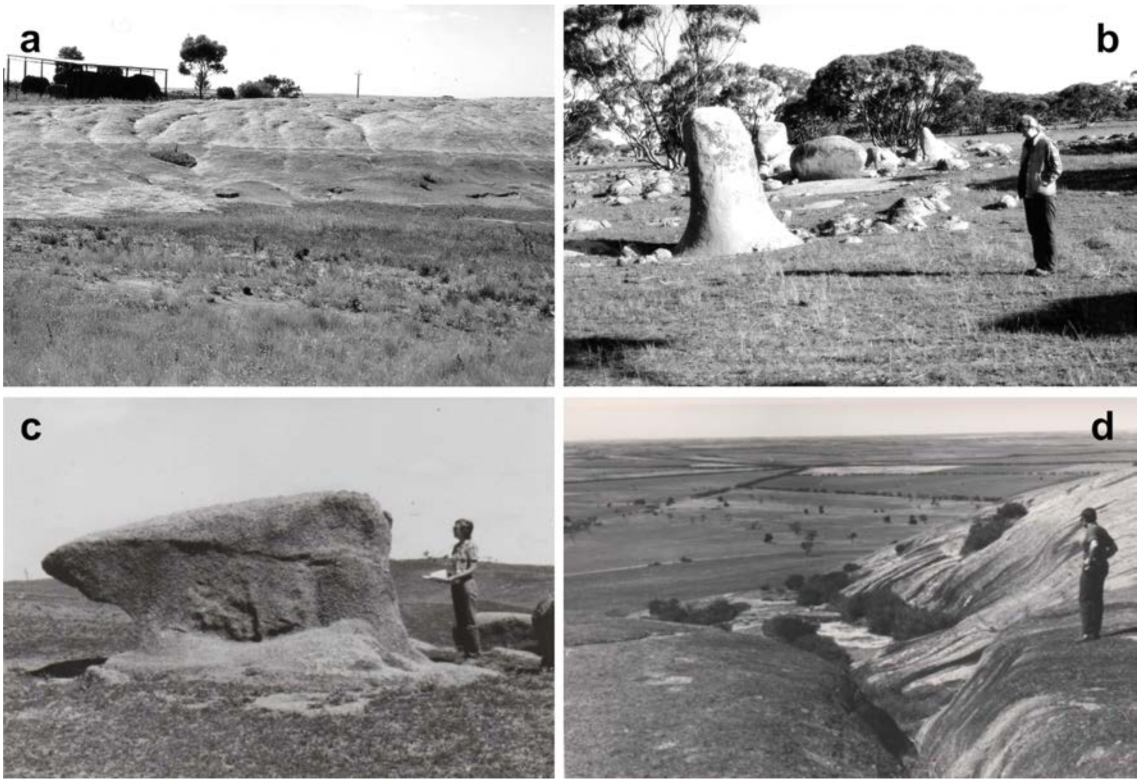


Figure 13. (a) Flank of shallow water storage at DuMonte Rock, north of Wudinna, showing gutters separated by smooth 'interfluves' shaped by soil moisture .(b) Granite column with flared sides, northern piedmont of Waulkinna Hill southern piedmont of Gawler Ranges (c) Anvil-shaped residual block of coarse granite, near Caloote, eastern piedmont of Mt Lofty Ranges, South Australia,

Flared granite slopes flanking high level valleys, multiflared steep slopes, and, of course, subsurface concavities (**Figures 11)** are readily accounted for as the work of soils moisture, of water. The continued localised weathering of Wave Rock by seepages is not denied, but it produces very minor modifications (including localised inversions of gutters withing seepage lines (Twidale & Bourne 2003) of a major form shaped in the subsurface,

Third, that fire is an agent of physical weathering has long been recognised (e.g. Collins 1893; Warth 1895; Tarr 1915; Blackwelder 1927; Dragovich 1993, Weisgerber & Willies 2002) but it was not entertained during the initial analysis of the problem posed by flared slopes in the early 1960s and concerning the inselberg landscape of north-western Eyre Peninsula, (Twidale 1962) for the same reason that glaciation, wave action, and Indigenous culture for example were not contemplated: there was no suggestion, no evidence in the field, of the intervention or involvement of such agencies. It is noted that fire as an agent of weathering is not formally discussed in the Scott et al. (2014) text on fire..

Furthermore, though it is demonstrated that bedrock concavities have been shaped in the subsurface and probably are still being fashioned underground by water-related processes, none manifestly shaped by fires have been identified. That Buckman et al. (2021) assert otherwise does not make it so. They describe the flares as being 'poorly understood' and consider the etch and two-stage hypothesis driven by water as 'enigmatic' (Buckman et al. 2021), yet it is in accord with, and more firmly based in, the actual field realities than the proposed alternatives.

5.4. Exposure and age of Yarwondutta Rock

The significance of etch and two-stage mechanism extends beyond the understanding of the flared slopes *per se*. As a granite landform of etch origin (e.g. Mueller & Twidale 1988b; Twidale 2002) they are in some measure exempt from climatic control (e.g. Twidale & Lageat 1994). In addition, repeated alternations of subsurface weathering and subsequent erosional exposure, implies a topographical sequence sufficient to explain the stepped topography that has been recognised in many parts of the world (but especially on shields and cratons) both at the local scale (see below) and regionally (Jessen 1936, Willis 1936, King 1962; Bourne & Twidale 2000). And embodied in the concept of episodic exposure, the etch and two-stage model of flared slope development has provided a critical test for competing theories of inselberg evolution (King 1966; Twidale & Bourne 1975); Twidale 1982). The temporal aspect implicit in flared slope development also contributes to the understanding of Yarwondutta Rock.

The morphology of the Rock reflects a demonstrable sequence of events. First the compartments that form the present Yarwondutta Rock were isolated as the surrounding, presumably more densely[3] fractured rock, was rotted. Second,

the main upper surface was developed as an incipient platform scored by shallow irregularities at the weathering front. Third, this surface was later exposed as a landform that began to become dimpled as pans evolved on the sites of shallow depressions (**Figure 7c**). Also at this stage runoff from the platform caused deep weathering beneath the piedmont pediments and the initiation of concave bedrock surfaces. Fourth the platform was relatively uplifted as the adjacent pediments were eroded and the concavities beneath the outlines of the outcrop were exposed as the flared slopes that define the Rock. Fifth, drilling and exposures in the quarry (**Figure 3a)** show that a substantial calcrete caprock has been superimposed on the granitoid regolith. And sixth, a new generation of flares is being fashioned in the subsurface beneath the piedmonts all around the perimeter of Yarwondutta Rock, and in all likelihood beneath the bases or around other outcrops.

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[3] '*density' in the sense of number of fractures (or stream channels) per unit volume or country rock rather that the more general definition of density as mass per unit volume.*

The capping is part of sheet of calcrete that is protective and has stabilised the surfaces on which it formed. But how the surrounds of the Yarwondutta platform were lowered and the flared wall revealed as postulated in stage four above calls for explanation.

The stack of calcarenitic coastal dune formed behind the west coast of Eyre Peninsula beginning in the Middle Pleistocene, roughly 630,000-180,000 years ago (Wilson 1991; Belperio 1993, p. 219 et seq.). Weathering of the dunes produced carbonate dust that was spread on the wind over north-western and central Eyre Peninsula where it was illuviated and reprecipitated to form a protective capping to the land surface which can be no older that the earliest of the dunes that are the source of the dust.

Calcrete did not form on the bare and higher granite surfaces, presumably because the carbonate dust that settled on them was blown away or washed on to the piedmonts and fringing pediments, where thick accumulations of calcrete occur, and that as shown in quarry exposures and drilling were underlain by a weathered mantle formed by run off from the platform. The latter thus had been relatively elevated prior to the period of calcrete formation for the latter would have protected the vulnerable regolith and prevented its evacuation. The exposure of the flared sidewalls implies the relative elevation of the main platform and the formation of a new generation of fringing pediments before the onset of calcrete development which, however then stabilised the platform-flare-pediment assemblage.

In summary, the main and dimpled platform surface of Yarwondutta Rock was in existence prior to the formation of the flared walls that define it. Indeed runoff from the platform initiated them. Both the concave perimeter walls of Yarwondutta Rock and the fringing pediments around the platforms predate the formation of the calcrete sheets. The latter however must post-date the deposition of the earliest coastal dunes from which the carbonate dust is derived. Thus the platform, flare, pediment assemblage has formed by some 630,000 years ago or the beginning of the Middle Pleistocene: it may be of later Early Pleistocene age. A new generation of flared bedrock surfaces is in train beneath a land surface stabilised and preserved by calcrete..

5.5. Elevation of Yarwondutta platform

The agency responsible for the stripping of the weathered mantle remains to be identified. Relatively minor and localised features like the scarp foot depression located at the northern extremity of Yarwondutta Rock (**Figure 5e**) and more extensive piedmont depressions have been attributed to volume decrease during weathering or to flushing following heavy rains and run-off (Ruxton 1958; Trendall 1962, see also Thorbecke 1927; Clayton1956; Pugh 1956; Bocquier et al, 1977), or to both processes, and some such depressions have been enlarged by streams. This mechanism produces ,or has contributed to, piedmont depressions at scales ranging from the local to the regional and functions by subsurface volume decrease. It would operate at sites protected by a surficial capping such as calcrete. The stripping of a weathered mantle at regional scale by the shrinkage of a weathered mantle however calls for a considerable runoff, and a more widely effective agency. In the context of Yarwondutta Rock it must also predate the development of the widely distributed calcrete carapace that protected and stabilised the plain surfaces.

The stack of coastal dunes constructed along the west coast of Eyre Peninsula during the Middle and Late Pleistocene affected a wide area and in several ways. It generated the calcrete crust, and river systems that had from Pliocene times drained the south-western Gawler Ranges, the Corrobinnie Depression (Bourne et al. 1974; Binks & Hooper 1984; see also Benbow et al. 1993, p. 179) and what is now north- western Eyre Peninsula, were blocked and buried by the calcareous duricrust. In the Minnipa district farmers drilling for water reported rounded cobbles that attest to a former river system beneath the calcrete horizon, which they clearly predated (B. Holloway, pers. comm.). These rivers reached, and were graded to, the shoreline of the Great Australian Bight that existed at that time. Any lowering of river baselevel either through tectonism or a lowering of sea level during a glacial phase prior to the deposition of the stack of coastal dunes and the formation of the calcrete crust, would have initiated a phase of river rejuvenation, valley incision, and landscape revival.

A channel associated with the Minnipa area paleodrainage reached the ocean in the Smoky Bay area and incised a canyon now preserved in the continental shelf (Binks & Hooper1984). The Waterwitch channel, shown on some official maps as scoured in the sea bed in Smoky Bay, probably is of similar or related origin. Any lowering of regional baselevel would have provided a window, a period, during which a wave of erosion preceded the stabilisation of plain surfaces by surficial accumulations of calcrete, stripping weathered mantles developed around granite platforms and along *Kluftkarren.* Marginal flares and clefts would be revealed as well as a new generation of fringing pediments eroded around the freshly exposed residual and weathered before and also following their stabilisation by the formation of the calcrete crust.

The platform surface of Yarwondutta Rock predated the subsurface initiation and exposure of the present flared margins and fringing pediments which in turn predated the accumulation of calcrete following the formation of the coastal dunes, probably in the early Middle Pleistocene. Some desert dunes were diverted around granite hills such as Pildappa Rock but some abut against NW- facing steepened, possibly flared, basal slopes of granite residuals that clearly were already in existence when the dunes, which are most likely of later Pleistocene rather than mid Holocene age, became active (Figure 14; Hilgers et al. 2011; Twidale, Bourne & Hilgers 2018).

5.6. The Yarwondutta 'elevated' platform

The purpose of this analysis was to suggest an appropriate geomorphological or technical name for the low dimpled platform developed on massive compartments of granite band ordered by flared slopes that is the Yarwondutta Rock. Its main surface is a platform that became dimpled after exposure. It is flanked by flared walls that imply relative uplift. Accordingly the name '*elevated' platform* is suggested. It is appropriate, its being understood that the descriptor 'elevated' pertains not to localised uplift but to the lowering of plains leaving the outcrop *relatively* higher. The residual may date from the Early, or more probably the early Middle Pleistocene, some 630,000 years ago.

Since that time the elevated platform has persisted as a local topographic feature, but it has been changed in detail. Pool waters converted initial shallow platform depressions into pans or dimples. Some gutters have been inverted and the boulder t*afone* standing on the intermediate platform doubtless has been enlarged. But the platform has remained locally prominent and distinctive. Meantime, however, and judging from the water storage excavation, beneath all the piedmont pediments surrounding the elevated platform, moisture derived mostly from runoff is preparing another generation of concave bedrock surfaces or flared slopes.

Figure 14. Dune sand covering part of a steepened basal granite slope on an unnamed granite hill located 4 km east of Yarwondutta Rock.

6. CONCLUSION

The current Yarwondutta elevated platform is the outcome of a concatenation of events, aeolian as well as hydrological, and regional as well as local, over a period of many millions of years if the emplacement and shearing of the granitic mass is taken into account.

The shaping of the granite mass is due to differential weathering by groundwaters acting in on structurally contrasted compartments of granite in the shallow subsurface. The future Yarwondutta Rocks were massive and survived with only marginal alteration. The flattish crest of what became the eastern mass and the surviving Yarwondutta Rock probably was a domical mass. It was extended by soil moisture attack. Water draining from the platform generated a moat of weathered rock around the margin of the platform and forming concave surfaces in the inner sides of the moat. The surrounding plains were shaped by rivers graded to sea level in the forerunner of the Great Australian Bight. A lowering of baselevel initiated river rejuvenation and landscape revival. In particular, the weathered surrounds of the Yarwondutta platform were eroded, exposing the flared walls developed along prominent *Kluftkarren* as well as the margins of the platform. This effectively elevated the platform.

Weathering of the new pedimented foot slopes began prior to a radical environmental change that swept over the region beginning with the formation of a calcrete carapace that stabilised the landscape including the then recently formed pediment fringe around the elevated platform.

Similar but smaller scale low granite platforms standing a metre or less above the level of the surrounding flats, and of limited area, occur in the South East District of South Australia, but elevated platforms comparable in size and complexity to Yarwondutta Rock are limited in number and distribution. They call for a particular environment and chronology of geological events. Yet it can be argued that all the varied granitic outcrops of north-western Eyre Peninsula , whether bornhardts, obviously stepped residuals, or what appear to be partly disintegrated domes, are protected and preserved by the calcrete that not only stabilises the plains and pediments around the outcrops but also constitutes a local time marker. It buttresses the granite outcrops and forms, including the elevated platform known as Yarwondutta Rock that has stood essentially unchanged since it attained its essential morphology in the early Middle Pleistocene some 680,000 years ago

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