Journal of the Royal Society of Western Australia, 87:123–133, 2004

Notes on the geomorphology of The Humps, near Hyden, Western Australia

C R Twidale & J A Bourne

School of Earth and Earth Sciences, Geology and Geophysics, University of Adelaide, Adelaide, SA 5005
✉ rowl.twidale@adelaide.edu.au

(Manuscript received May 2004; accepted October 2004)

Abstract

The domical inselberg or bornhardt known as The Humps is in many respects typical of the many granitic residuals of the Wheatbelt. Of great antiquity, it is a two-stage form which was initiated beneath a regolithic cover, and has been exposed in stages. Its minor forms (pitting, gnammas of various types, polygonal cracking, sheet structure) are also commonplace, though in some instances, such as the armchair-shaped hollows, they are especially well developed. But the evidence for its great age, for episodic exposure, and for the subsurface initiation of tafoni is noteworthy.

Keywords: bornhardt, multistage, tafoni, armchair-shaped hollow, mogote

Introduction

The Humps is a stepped bornhardt inselberg shaped in Late Archaean (2.55–2.75 Ga) granitic rocks and located some 20 km NNE of Hyden in the Western Gneiss Terrane of the Yilgarn Craton (Chin *et al.* 1984; Myers 1990). It stands more than 420 m above sea level and about 80 m above the surrounding plains (Fig 1). It displays several gross and minor features that are typical of other inselbergs in the region, and some that are peculiar to the site. For example, a perched block and plinth, an hourglass rock, split rocks and tafoni can be seen on the hill, which is characteristically bald and domical, but the evidence of great antiquity and of the subsurface initiation of tafoni are sufficiently rare to be noteworthy.

Origin of the bornhardt

The stepped morphology of The Humps (Figs 1 & 2) suggests that the residual was initiated in the subsurface and subsequently exposed as a result of periods of lowering of the surrounding plains, *i.e.* a two-stage or etch origin involving episodic exposure (Falconer 1911; Twidale 1964, 1982a, 1982b, 1982c; Twidale & Bourne 1975a). Such an interpretation implies differential subsurface weathering, and in particular the relative resistance to subsurface moisture attack of the compartment of rock that is The Humps. It might be argued that intrusive veins, which are particularly numerous on The Humps, as compared with, for example, King Rocks and Hyden Rock, have buttressed and strengthened the rock mass. First, however, the most common intrusions, namely pegmatites, are zones of weakness for they have been exploited to produce shallow linear depressions and steepened slopes (see also Bourne & Twidale 2002). Second, though density of intrusive sills and veins varies there is no reason to think that The Humps is more buttressed in this way than the immediately adjacent areas. To the contrary, in other areas such as the Pilbara, granite with numerous veins of aplite and quartz has been differentially weathered and eroded to produce an inselberg landscape, with veins exposed in both hill and plain.

The Humps, like other inselbergs in the vicinity, is massive. The few open fractures are widely spaced. A strong structural grain trending NW-SE or NNW-SSE (but locally variable) pervades the rocks of the Western Gneiss Terrane (*e.g.* Chin *et al.* 1984) and many of the more prominent outcrops (as indicated by their being named) occur in SE-NW corridors (Fig 3). Thus considering the Hyden area, Graham Rock, The Humps, Anderson Rocks and Mt Walker can be linked in this way, as can Gibb Rock, King Rocks, Bushfire Rock / Cockatoo Rock and a group of bornhardts in the Varley-Holt Rock district. Some of the bornhardts named also occur in roughly east-west (or ESE-WNW) alignments, as for instance Murray Rock, King Rocks, The Humps and Camel Peaks, and Cockatoo Rock / Bushfire Rock, Graham Rock, Hyden Rock, Captain Roe Rock / Mettam Knob and Karlgarin Hills. This suggests that the residuals may be preserved by virtue of compression associated with cross- or interference folding, first (and in terms of present orientations) NE-SW, and later roughly north-south; but whether as a result of direct compression or of shearing is not known, though persistent horizontal plate motions and evidence of conjugate *en echelon* fracture patterns favour the latter.

Episodic exposure and antiquity

As previously mentioned, the stepped morphology of The Humps (Figs 1 & 2) suggests episodic exposure. Four surfaces have been identified. Level I is of limited areal extent and is preserved in the highest crests. Level IV comprises the present plains and platforms (I *in* Fig 1). Level III takes the form of platforms preserved in spurs and perched some 30 m above present plain level. The most prominent planate surface remnants are referred to as Level II, 60–70 m above the surrounding plain. The

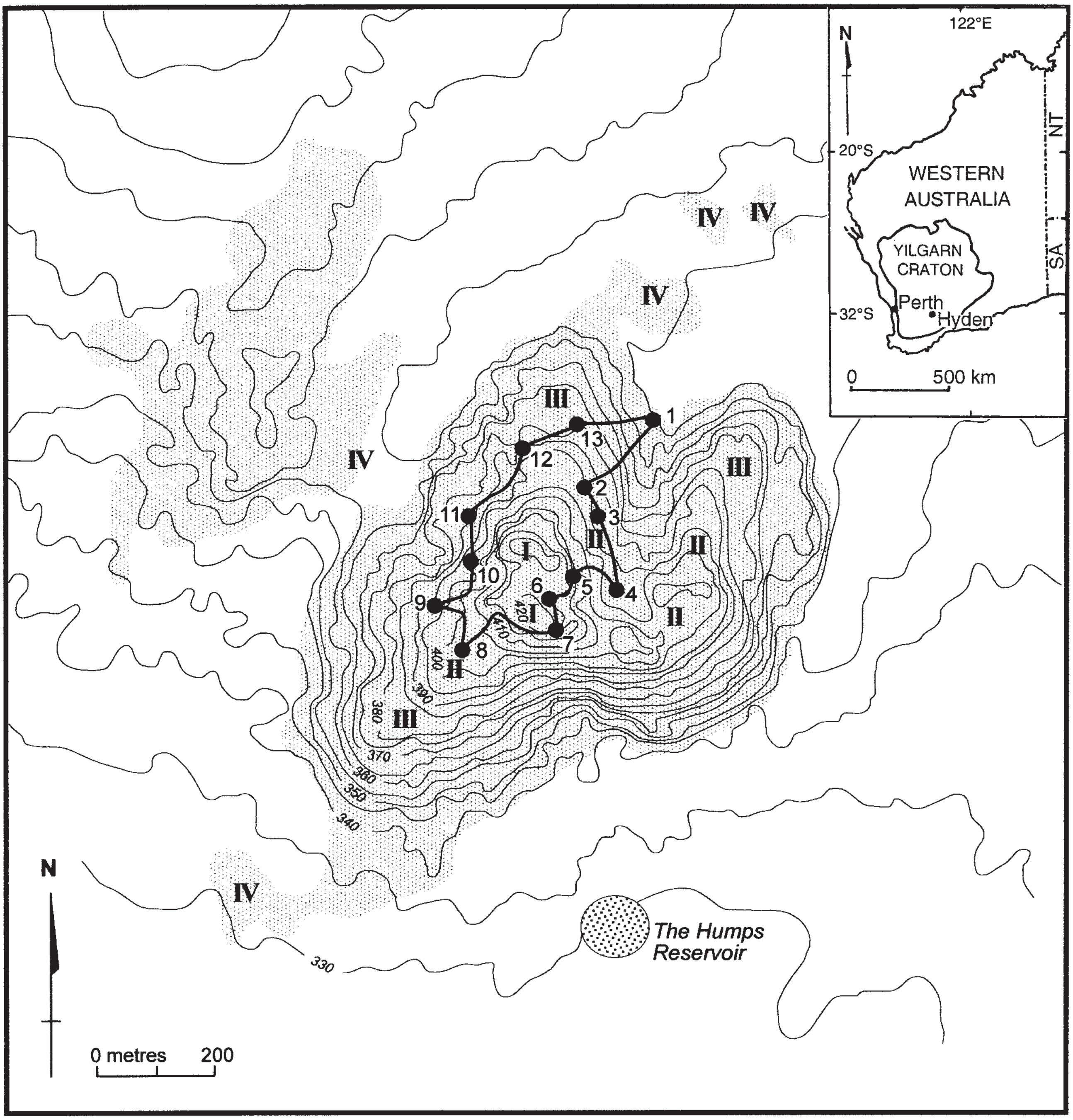


Figure 1. The Humps showing the outcrop (stippled), contours and levels I–IV. A suggested environmental walk, with thirteen sites exemplifying features of interest with reference to later Figures in this paper, viz. 1, platform (Fig 2); 2, joint clefts; 3, armchair-shaped hollow (Fig 8), pans and doughnuts; 4, flared slope, relic vegetation (Fig 6); 5, multiple flared slope (Fig 4); 6, joint cleft; 7, pans, pitting, boxwork, tramlines (Fig 9); 8, boulders on dome, polygonal cracking (Fig 11); 9, rock basins and buttressed slope (Fig 10); 10, sheet structure (Fig 7B); 11, boulders, tafoni, alveolar weathering, split rock, polygonal cracking; 12, boulders, perched, hourglass, split rock with tafone (Fig 12); 13, split boulder with window. Inset map of Western Australia showing location of Hyden. The Humps stands some 20 km NNE of the town of Hyden.

best developed flared slopes (Fig 4; 5 *in* Fig 1) are associated with this surface (Twidale 1962, 1968; Twidale & Bourne 1998a) as are large boulder fields which suggest prolonged and intense shallow subsurface weathering. Level II is readily correlated with the primary lateritic remnants of later Cretaceous age (Clarke 1994; Twidale & Bourne 1998b) preserved on adjacent plateaux and high plains (Fig 5). The pisolitic ironstone (or ferricrete: see Twidale 1976, pp. 196–197) exposed in shallow pits close to the northwestern base of the inselberg is interpreted as a secondary or derived deposit lacking the kaolinised mottled and pallid zones of a laterite profile. It accumulated in a scarp-foot depression which formed as a result of weathering and lowering by runoff from the hill and which is typical of inselberg landscapes (Thorbecke 1927; Clayton 1956; Dumanowski

Figure 2. Southwesterly view of The Humps showing the 'entrance' valley which drains the northern sector of the hill, and its stepped morphology. The prominent flared slope high on the hill is developed below Level I, a stand of trees, on the right skyline, amidst the weathered and fractured sheet structure marks Level II. Level III is not preserved in this sector of the hill so that a gentle incline leads down from Level II to Level IV, the dry grassed areas and rock platforms of the present plain level.

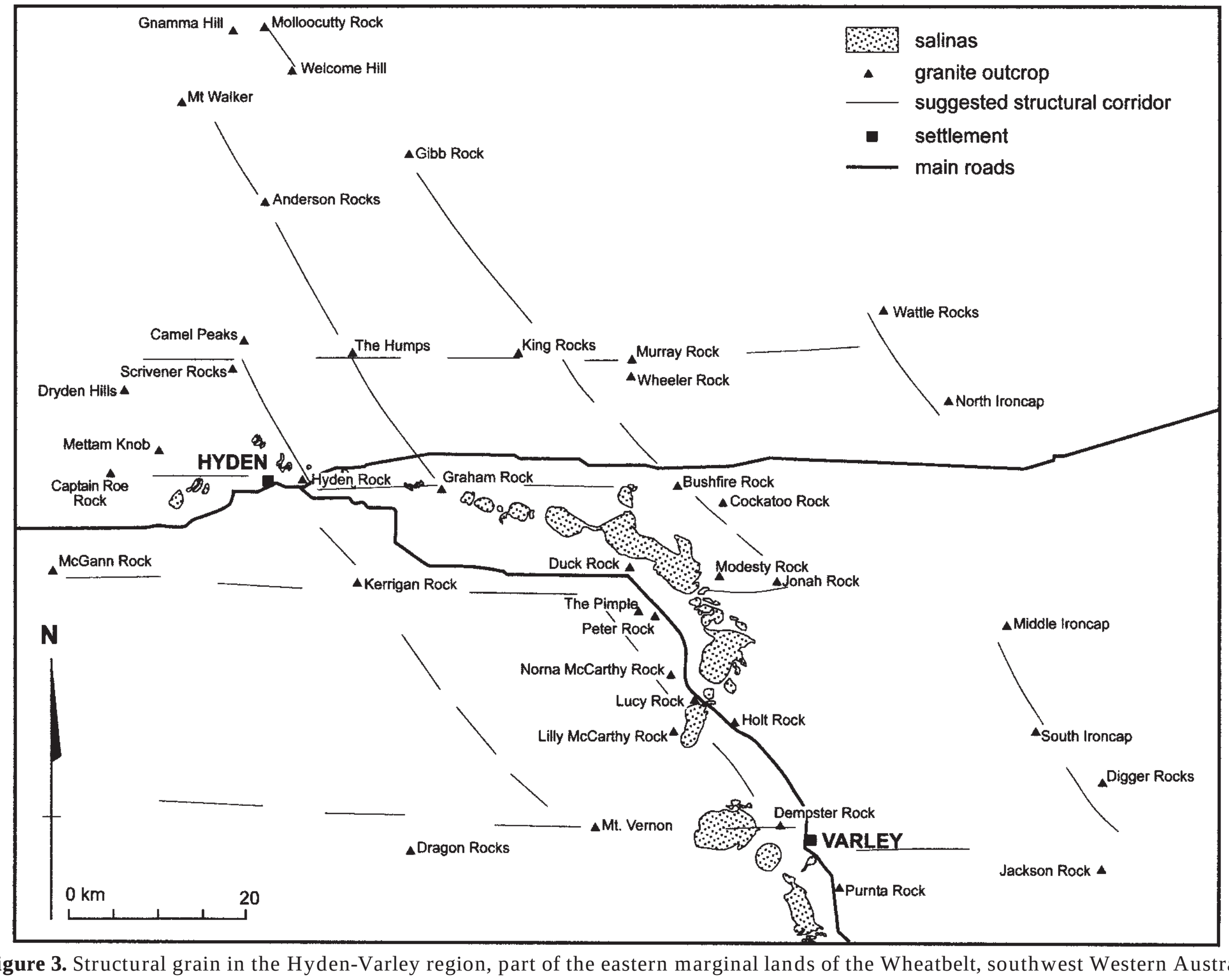


Figure 3. Structural grain in the Hyden-Varley region, part of the eastern marginal lands of the Wheatbelt, southwest Western Australia.

Figure 4. The northern end of the multiple flared slope is developed along a fracture zone, seen at right base of flare. Note the gently inclined fracture exposed in the slope in the middle distance, and in the foreground the flared back- and sidewalls of an armchair-shaped hollow floored with soil and vegetation.

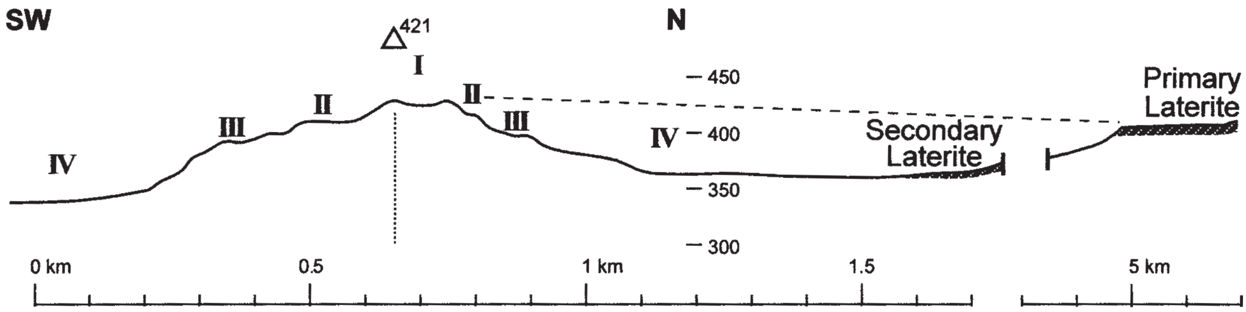
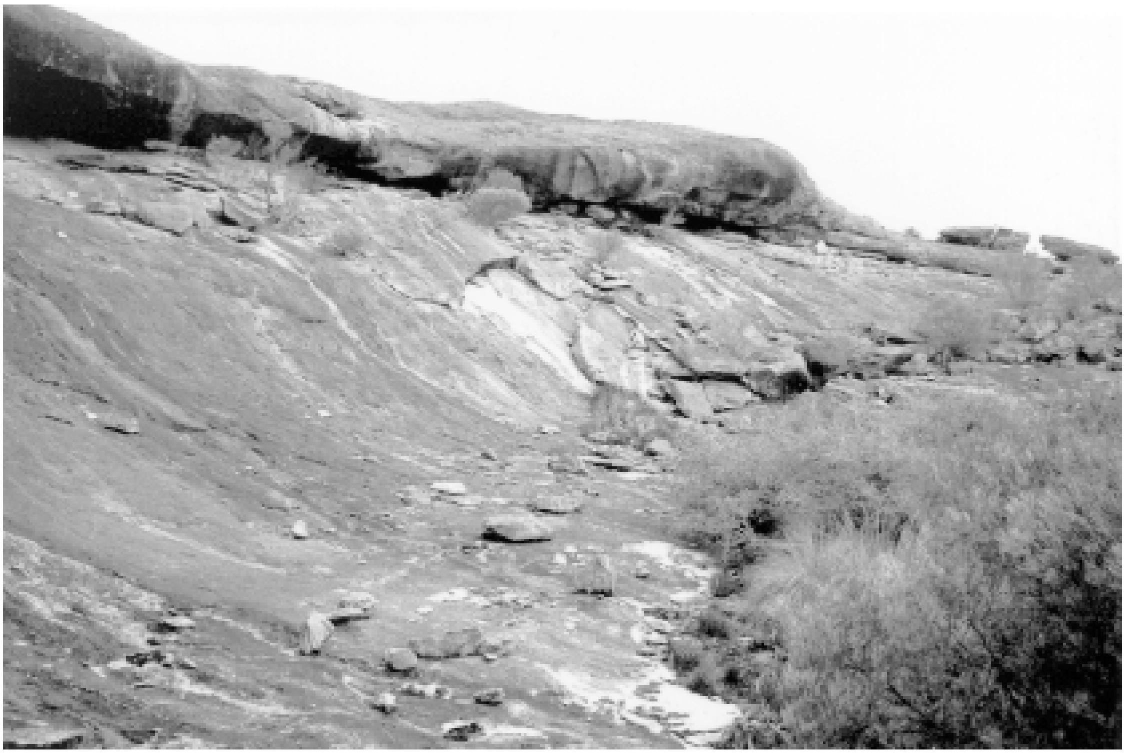


Figure 5. Diagrammatic section through The Humps showing relationship with primary laterite and secondary or derived laterite or ferricrete.

Figure 6. View southeast along the flared slope behind the stand of *Eucalyptus caesia.* Note the fractures in parallel scoring the upper and mid slopes of the dome.

A



B

Figure 7. (A) View of west-facing valley-side slope where shadows emphasise major fracture lines and numerous rock basins. The wooded area of sheet remnants on the left skyline and boulders to the right mark Level II. The roughness of the granitic surface in the foreground is typical of The Humps. (B) Sheet structure exposed in a large alcove or armchair-shaped hollow on the northwestern basal slope of The Humps. Tafoni and triangular wedges occur at the base of the leading edge of the sheet structure. Note sheet remnants on right skyline, and slipped slabs near the figure. The black coating in left foreground is due to blue-green algae which favour the shallow channels carrying runoff from the slopes above. The vegetation to right has colonised the sand and clay accumulated in the floor of the alcove.

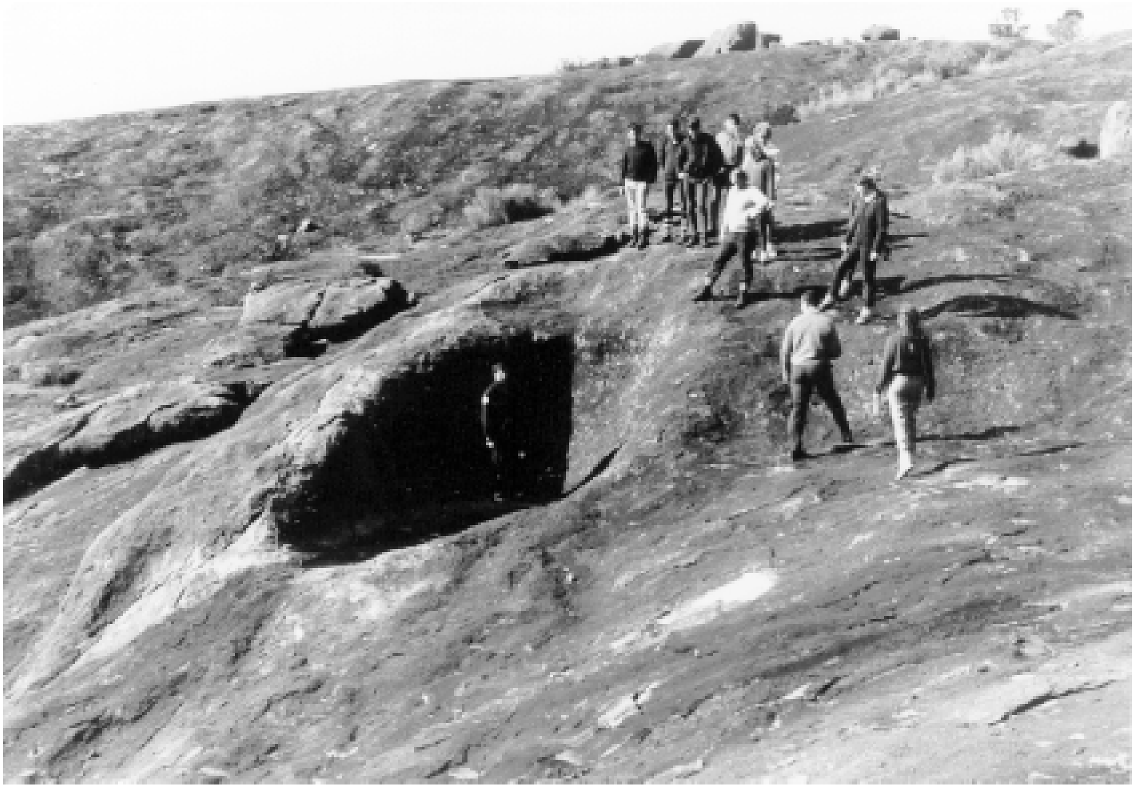


Figure 8. An unusually deep armchair-shaped hollow developed high on the midslope near the head of the entrance valley.

1960; Mabbutt 1967; Bocquier *et al.* 1977; also Ruxton 1958).

If this interpretation is correct, the dome surmounting Level II was in existence during the later Cretaceous 70–100 m.y. ago. Level I is even older, though there is no suggestion that it predates the Late Palaeozoic glaciation which affected all of what is now southern Australia (B M R Palaeogeographic Group 1992). The antiquity of levels I and II finds support in the survival in a broad joint cleft high on the eastern slope of the bornhardt (Fig 6; 4 *in* Fig 1) of *Granitites intangendus*, a monotypic genus which is at least of Middle–Late Tertiary age (Fay *et al.* 2001). Also in this cleft is a geographically isolated and genetically divergent population of *Eucalyptus caesia* (Hopper & Burgman 1983).

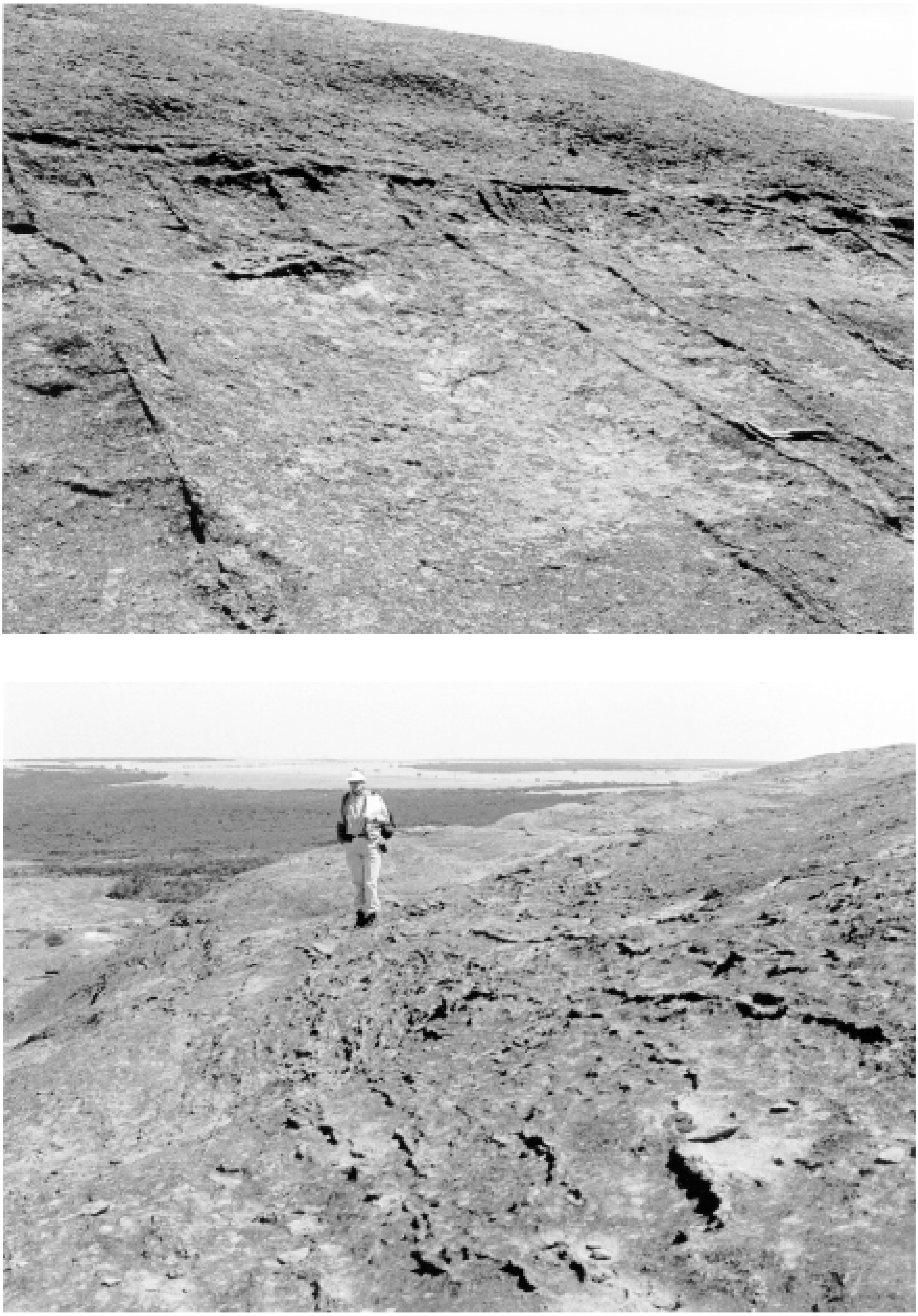
Structural effects and multistage development

The granitic rocks of The Humps are commonly porphyritic, and large feldspar crystals project a few millimetres, providing a pitted or rough surface (Twidale & Bourne 1976; 7 *in* Fig 1). The rocks have been sheared and fractured, resulting in prominent partings aligned roughly 130º, 140º and 160º (Fig 7A). The rock has also been intruded by veins and pods of aplite, quartz and pegmatite. Many of the veins of which the pegmatite is the youngest are aligned along fractures but there are many cross-cutting veins and numerous complex intersections are exposed, especially on the southern slopes of the residual. These fractures and intrusions have had a profound effect on the morphology of the inselberg both in gross and in detail.

Fractures strongly influence the detailed morphology of the residual, being responsible for several prominent clefts and for the deep valley on the northern flank of the residual (Fig 7A; 2 *in* Fig 1), but such features are widely spaced. Many have flared sidewalls. Sheet fractures and structures (Figs 4 & 7B) are exposed on the slopes of the residual and notably in a large alcove or armchair-shaped hollow (*q.v.*) near the western base of the hill (Fig 7B).

Linear shallow depressions are associated with steeply-dipping pegmatite sills and some locally steep slopes can be explained in terms of the preferential weathering and erosion of such gently inclined bodies (*cf* Bourne & Twidale 2002). Aplite sills have given rise to eye-catching 'boxwork patterns' (Fig 9A) as well as 'tramlines' or parallel projecting veins and irregular or wavy miniature ridges (Fig 9B; 7 *in* Fig 1). Preferential weathering and erosion of country rock infested by sills of relatively weak rock has caused them to the eroded, leaving rounded linear or gently sinuous ramparts or low ridges in relief. Zones buttressed by massive pods and veins of quartz (9 *in* Fig 1), combined with preferential weathering and erosion of pegmatitic areas have produced a cascade of basins and linking channels on the western midslope of The Humps (Fig 10).

Clearly, though The Humps and associated minor forms are two-stage developments, the origin of numerous minor features can be traced to the Archaean and to several magmatic episodes during which intrusion of various composition and textures were introduced. Considered both in gross and in detail the residual is a multistage feature (Twidale & Vidal Romani 1994).



A

B

Figure 9. (A) Boxwork pattern due to greater resistance to weathering and erosion of intrusive veins, south of crestal area. Note rough surface of slope above, and porphyritic texture of rock seen in foreground. Hammer gives scale. (B) Wavy 'tramlines' to south of crestal area.

Figure 10. Cascade of rock basins draining north (away from the camera) and located between a rampart buttressed by quartz (left) and slope of the hill (right). Low rise or platform, devoid of trees, in middle distance (see separate outcrop NW of hill on Fig 1).

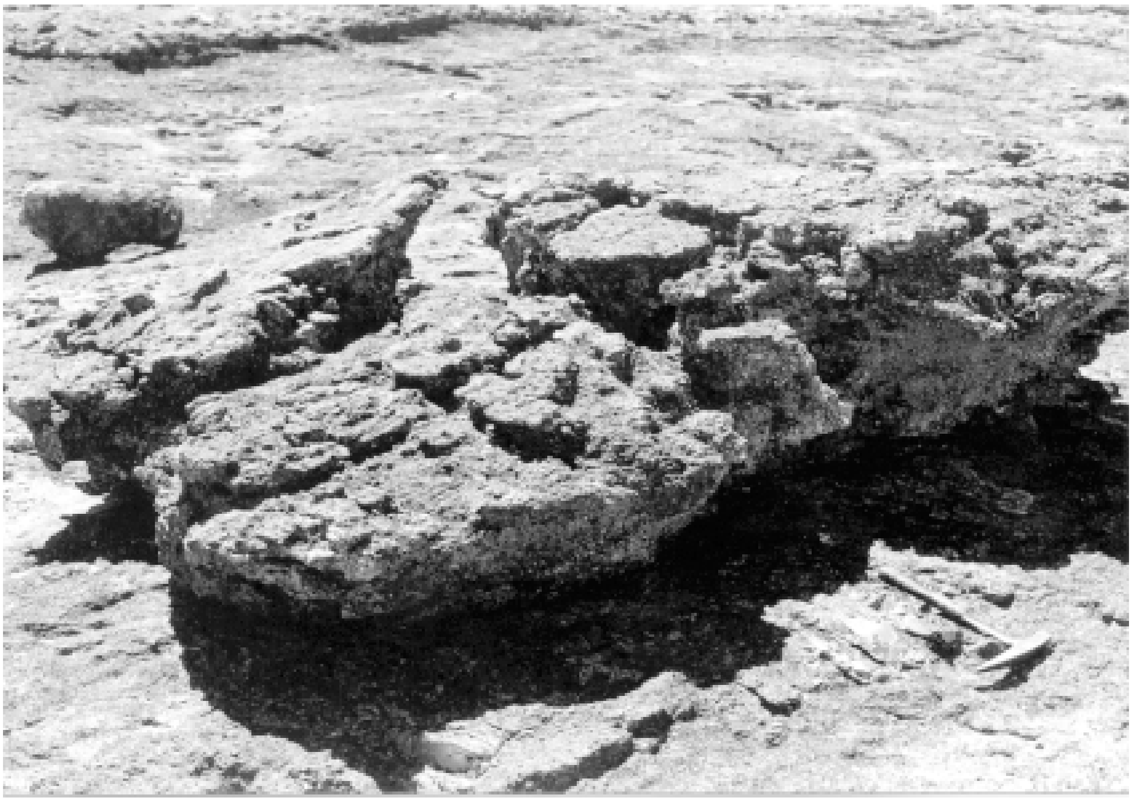


Figure 11. Weathered sheet remnant on Level II in the southwestern sector of The Humps. Polygonal cracking has been exploited and plates weathered away, leaving some polygonal remnants upstanding as 'mogotes'.

Impacts of seismic events

Though seismically stable by comparison with some parts of the world, the southwest of Western Australia is one of three relatively active sectors within the continent (*e.g.* Gordon & Lewis 1980, pp. 209–214). The formation of new fault scarps is reported from several sites from Mt Narryer in the northwest to Lort River in the southeast. The impacts of the Meckering earthquake of October 1968 are well known, evidence of active warping (as opposed to faulting has been detected in the Northam area and two periods of activity on the Hyden Fault have been identified (Thom 1972; Williams 1979; Gordon & Lewis 1980; Wellman & Tracy 1987; Twidale & Bourne 2003; Crone *et al.* 2003). Thus, it is not surprising that, like

A

B

Figure 12. (A) Elongate boulder with tafone at left end, and undercut lower margins. (B) Detail of tafone with markedly mamillated surface, shown in Fig 12A. The granite is weathered and crumbles to the touch. The feldspars are altered to kaolin. Hammer provides scale.

many other massive outcrops in the vicinity, The Humps has been affected by earth movements. Evidence takes the form of an A-tent (have others been disturbed and used as small animal traps?), blisters or arches not yet with cracked crests, and several groups of slipped slabs and low angle fractures slicing though the crests of domical rises (*cf* Twidale & Sved 1978; Twidale & Bourne 2000). The formation of split rocks may have been hastened by seismic shaking.

Other specific features

Polygonal cracking and mogotes

Spectacular groups of miniature mesas, or *mogotes*, capped by iron oxide indurations occur low on the western slope of King Rocks, some 20 km east of The Humps (Twidale *et al.* 1999). It has been suggested that they are remnants of indurated polygonally-cracked surfaces which originated at the weathering front, where a concentration of iron and other oxides created a space problem, which in turn produced cracking and arching of some of the plates (Twidale 1982a, pp 315–317).

Evidence from the southern slopes of The Humps sustains this interpretation for some components of the polygonally-cracked heavily indurated surface of some residual blocks have been eroded. This can be construed as an early stage in the development of mogotes from a cracked surface (Fig 11; 8 *in* Fig 1). The encrustation is, however, not iron-rich but mainly organic. Lichens, for instance, protect the surface but also they introduce the possibility that they may have caused expansion, for instance, sufficient to buckle pre-existing thin plates as their hyphae (or rootlets) penetrated between crystals exposed in the surface layer of rock.

Subsurface initiation of tafoni and alveoles

Though many familiar major and minor granite landforms are demonstrably of two-stage or etch type and are of subsurface origin (see e.g. Twidale 1962; Twidale & Bourne 1975b, 1976) the provenance of alveoles and tafoni (Fig 12A) has remained enigmatic. On the one hand, the enlargement of the hollows is clearly due to salt crystallisation or haloclasty (Evans 1969; Winkler 1975; Bradley *et al.* 1978). Growth takes place from the base upwards in exposed blocks, boulders and sheet structures. Evidence of subsurface initiation is lacking, though the lateral merging of tafoni with flared slopes, as for example at Ayers Rock (Uluru) and at Kokerbin Hill (Twidale 1978; 1982a, p 257), suggests that some have been initiated within the regolith.

This conclusion finds support on the northwestern spur of The Humps just below but associated with Level II. There, several large residual boulders display tafoni developed in rock that is rotten due to chemical weathering of the basal zones (Fig 12B). It is suggested that the bases of the boulders, resting on an impermeable rock-base – an intact sheet of rock – were altered as a result of contact with water. The feldspars have been altered to kaolin. Limonite is concentrated in the marginal zones or visors. This chemical alteration contrasts with the haloclasty which is a physical or mechanical process and which, exploiting the already weakened host rock, is, with gravity, responsible for the formation and enlargement of the hollows.

Preservation of sheet structure and boulders on crests

The smooth outlines of the bornhardt are at several sites interrupted by isolated blocks or boulders, or by groups of such residuals preserved on crests or upper slopes (Figs 2 & 7A). The reasons for the survival of these remnants of sheet structures (10 *in* Fig 1) are twofold. First, that the volume of runoff increases downslope, so that crestal zones are less weathered and eroded than downslope areas. Downslope wash removes the *grus* which otherwise would retain moisture and thus ensure the continuation of weathering and the eventual disintegration of the blocks and boulders. Second, the lower zones have been subjected to successive phases of subsurface scarp-foot weathering. Any remnant blocks and boulders on lower slopes either have survived because they are especially large and therefore persistent, or they have fallen to their present position.

Large gnammas on crests

In the sense of areal extent, and as on many other granite hills in the district, most of the largest gnammas, in the form of shallow, flat-floored pans (Twidale & Corbin 1963), are found on the crests of hills. Some on the crest of King Rocks, for instance, are more than 15 m diameter. As runoff increases downslope (see above), it might be thought that the largest gnammas ought to be developed on lower slopes. But there, heavy runoff ensures that the basins are filled to overflowing. Egress channels are eroded, so that lateral extension by solution, hydration and hydrolysis of the rock-forming minerals by standing water is limited. On hill crests, however, only direct rainfall which stands in basins is received. Moreover, the crests are the oldest, and longest exposed, parts of the outcrops; there has been time for pans to extend laterally by moisture-related weathering.

Alcoves: armchair-shaped hollows and embayments

Several armchair-shaped hollows are developed high on the midslope of the valley which drains the northern sector of The Humps (Figs 4, 7A & 8). One is as deep as it is long and wide (Fig 8; 3 *in* Fig 1), but they are typically much wider than they are in plan dimensions.

How have they formed? Grus is washed into the floors of clefts (or slots) and valleys. There, the patches of detritus become vegetated and a soil develops. Thus a depression – an incipient alcove? – filled with enough soil to nurture small trees has formed in the floor of the cleft with *Eucalyptus caesia.* Vegetated soil patches retain moisture which aggressively react with the granite with which it is in contact by virtue of chemicals released by weathering and organic acids derived from rotting organisms. In addition, lichens favour wetter surfaces such as are found in valleys and even otherwise bare rock surfaces are attacked by the hyphae of lichens and by the roots of trees and shrubs. In these ways weathering causes vertical rotting and thickening of soil patches. They also effect lateral extension. Headward extension takes place causing steepening of the valley headwalls but lateral growth – what Mabbutt (1966) called mantle-controlled planation – takes place at both margins so that the depression widens twice as rapidly as it extends headwards. This produces alcoves or armchair-shaped hollows, some of them many tens of metres across. The side- and head-walls are commonly flared (as on Hyden Rock: Twidale & Bourne 2001) though the largest such alcove located on the western side of The Humps is bounded by slightly overhanging bluffs in which sheet fractures and structures are exposed (10 *in* Fig 1). These fractures attract weathering, so preventing any tendency for the development of a smooth convexity.

Conclusion

The Humps displays many morphological features in common with other Wheatbelt inselbergs: it is of etch origin and has survived by virtue of its massive structure, its crestal area is of great antiquity, it has been exposed in stages, and it displays many familiar minor forms including some due to contemporary seismicity. Yet it offers enough different forms and lines of evidence to make it interesting. A subsurface initiation for tafoni is suggested, the survival of the inselberg can be construed as tectonic, and the origin of several minor structural features can be traced back more than 2.5 billion years to the origin of the rock of which the inselberg is composed.

Acknowledgements: The authors thank the Hyden-Karlgarin and District Landcare group for facilitating their most recent work on The Humps and environs, and those several local enthusiasts, and notably Russel and Val Mouritz, who have actively promoted the natural features of the Hyden district for tourist and educational purposes.

References

B M R Palaeogeographic Group 1992 Australia: Evolution of a Continent. Australian Government Publishing Service, Commonwealth of Australia, Canberra.

Bocquier G, Rognon P, Paquet H & Millot G 1977 Geochimie de la surface et formes du relief. II. Interprétation pédologiques des dépressions annulaires entourant certains inselbergs. Sciences Géologiques Bulletin 30: 245–253.

Bourne J A & Twidale C R 2002 Morphology and origin of three bornhardt inselbergs near Lake Johnston, Western Australia. Journal of the Royal Society of Western Australia 85: 83–102.

Bradley W C, Hutton J T & Twidale C R 1978 Role of salts in the development of granitic tafoni, South Australia. The Journal of Geology 86: 647–654.

Chin R J, Hickman A H & Thom R 1984 Hyden, Western Australia, SI/50-4 International Index. 1:250,000 Geological Series – Explanatory Notes. Geological Survey of Western Australia, Perth.

Clarke J D A 1994 Evolution of the Lefroy and Cowan palaeodrainage channels, Western Australia. Australian Journal of Earth Sciences 41: 55–68.

Clayton R W 1956 Linear depressions (*Bergfussniederungen*) in savannah landscapes. Geographical Studies 3: 102–126.

Crone A J, Martini P M, De Machette M N, Okumura K & Prescott J R 2003 Palaeoseismicity of two historically quiescent faults in Australia: implications for fault behaviour in stable continental regions. Bulletin of the Seismological Society of America 93: 1913–1934.

Dumanowski B 1960 Comment on origin of depressions surrounding granite massifs in the eastern desert of Egypt. Bulletin de l'Academie Polonaise des Sciences 8: 305–312.

Evans I S 1969 Salt crystallization and rock weathering: a review. Revue de Géomorphologie Dynamique 19: 155–177.

Falconer J D 1911 The Geology and Geography of Northern Nigeria. Macmillan, London.

Fay M F, Lledo M D, Richardson J E, Rye B L & Hopper S D 2001 Molecular data confirm the affinities of the south-west Australian endemic *Granitites* with *Alphitonia* (*Rhamnaceae*). Kew Bulletin 56: 669–675.

Gordon F R & Lewis J D 1980 The Meckering and Calingiri earthquakes October 1968 and March 1970. Bulletin 126. Geological Survey of Western Australia, Perth.

Hopper S D & Burgman M A 1983 Cladistic and phenetic analyses of phylogenetic relationships among populations of *Eucalyptus caesia*. Australian Journal of Botany 31: 35–49.

Mabbutt J A 1966 Mantle-controlled planation of pediments. American Journal of Science 264: 78–91.

Mabbutt J A 1967 Denudation chronology in central Australia. Structure, climate and landform inheritance in the Alice Springs area. In: Landform Studies from Australia and New Guinea (eds. J N Jennings & J A Mabbutt). Australian National University Press, Canberra.

Myers J S 1990 Western Gneiss Terrane. In: Geological Survey of Western Australia. Geological and Mineral Resources of Western Australia. Memoir 3. Geological Survey of Western Australia, Perth.

Ruxton B P 1958 Weathering and subsurface erosion in granite at the piedmont angle, Balos, Sudan. Geological Magazine 45: 353–377.

Thom R 1972 A recent fault scarp in the Lort River area, Ravensthorpe 1:250,000 sheet. Annual Report of the Geological Survey of Western Australia 1971. Geological Survey of Western Australia, Perth, 58–59.

Thorbecke F 1927 Der Formenschatz im periodisch trockenen Tropenklima mit überwwiegender Regenzeit. Dusseldorfer Geographische Vorträge 3: 10–17.

Twidale C R 1962 Steepened margins of inselbergs from north-western Eyre Peninsula, South Australia. Zeitschrift für Geomorphologie 6: 51–69.

Twidale C R 1964 A contribution to the general theory of domed inselbergs. Conclusions derived from observations in South Australia. Transactions and Papers of the Institute of British Geographers 34: 91–113.

Twidale C R 1968 Origin of Wave Rock, Hyden, Western Australia. Transactions of the Royal Society of South Australia 92: 115–123.

Twidale C R 1976 Analysis of Landforms. Wiley/Jacaranda, Brisbane.

Twidale C R 1978 On the origin of Ayers Rock, central Australia. Zeitschrift für Geomorphologie SupplementBand 31: 177–206.

Twidale C R 1982a Granite Landforms. Elsevier, Amsterdam.

Twidale C R 1982b The evolution of bornhardts. American Scientist 70: 268–276.

Twidale C R 1982c Les inselbergs à gradins et leur signification: l'exemple de l'Australie. Annales de Géographie 91: 657–678.

Twidale C R & Bourne J A 1975a Episodic exposure of inselbergs. Geological Society of America Bulletin 86: 1473–1481.

Twidale C R & Bourne J A 1975b The subsurface initiation of some minor granite landforms. Journal of the Geological Society of Australia 22: 477–484.

Twidale C R & Bourne J A 1976 Origin and significance of pitting on granitic rocks. Zeitschrift für Geomorphologie 20: 405–416.

Twidale C R & Bourne J A 1998a Flared slopes revisited. Physical Geography 19: 110–133.

Twidale C R & Bourne J A 1998b Origin and age of bornhardts, southwest Western Australia. Australian Journal of Earth Sciences 45: 903–914.

Twidale C R & Bourne J A 2000 Rock bursts and associated neotectonic forms at Minnipa Hill, northwestern Eyre Peninsula, South Australia. Environmental and Engineering Geoscience 6: 129–140.

Twidale C R & Bourne J A 2001 Field Guide to Hyden Rock. Including Wave Rock. Wave Rock Management P/L., Hyden, W.A.

Twidale C R & Bourne J A 2003 Active dislocations in granitic terrains of the Gawler and Yilgarn cratons, Australia, and some implications. South African Journal of Geology 106: 71–84.

Twidale C R, Bourne J A & Vidal Romani J R 1999 Origin of miniature mogotes in granite, King Rocks, southern Yilgarn Block, Western Australia. Cuaternario y Geomorfologia 13: 33–43.

Twidale C R & Corbin E M 1963 Gnammas. Revue de Géomorphologie Dynamique 14: 1–20.

Twidale C R & Sved G 1978 Minor granite landforms associated with the release of compressive stress. Australian Geographical Studies 16: 161–174.

Twidale C R & Vidal Romani J R 1994 On the multistage development of etch forms. Geomorphology 11: 107–124.

Wellman P & Tracey R 1987 Southwest seismic zone of Western Australia: a measurement of vertical ground movements by repeat levelling and gravity surveys. Bureau of Mineral Resources Journal of Australian Geology & Geophysics 10: 225–232.

Williams I R 1979 Recent fault scarps in the Mount Narryer area, Byro 1: 250,000 sheet: Annual Report of the Geological Survey of Western Australia 1978. Geological Survey of Western Australia, Perth, 51–55.

Winkler E M 1975 Stone: Properties, Durability in Man's Environment. Springer, New York.