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A note on Dodgson's Rock platform, Elkington quarry, and the origin of bornhardts on north-western Eyre Peninsula, South Australia

Nota sobre la plataforma rocosa de Dodgson, la cantera de Elkington y el origen de los *bornhardts* en el noroeste de la Península de Eyre, Australia del Sur

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Abstract
The excavation of what was Dodgson's Rock, now Elkington quarry, exposed a domical bedrock form that can be construed as a stage in the development of incipient bornhardts. It confirmed the earlier interpretation of the domical inselberg known as Ucontitchie Hill as a structural feature initiated by the differential etching in the shallow subsurface of compartments of granitic rock of contrasted fracture density and exposed by the erosional lowering of the densely fractured and weathered surrounds. Stages in the excavation provided evidence concerning the nature of sheet fractures and structures as well as the origin of breached arches or A-tents. Other bornhardts in the district (Mt Wudinna, Polda Rock, Little Wudinna Hill) as well as sundry additional inselbergs, turrets, and elevated platforms may be of a similar origin.

Keywords: granite geomorphology, inselberg, residual relief, etched surface

Resumen
La excavación de lo que fue la Roca de Dodgson, ahora la cantera de Elkington, expuso una forma de lecho rocoso cupular que puede interpretarse como una etapa en el desarrollo de bornhardts incipientes. Esto confirmó la interpretación anterior del inselberg cupular conocido como Ucontitchie Hill como una característica estructural iniciada por alteración química diferencial en el subsuelo poco profundo de masas de roca granítica

con diferente densidad de fracturas, expuestos por la incisión erosiva del entorno densamente fracturado y meteorizado. Las etapas de la excavación han proporcionado argumentos para interpretar el origen de la estructura de exfoliación y otras estructuras, así como sobre el origen de arcos rotos o A-tents. Otros bornhardts en el distrito (Mt. Wudinna, Polda Rock, Little Wudinna Hill), así como otros inselbergs cercanos, tors y plataformas rocosas elevadas, pueden tener un origen similar.

Palabras clave: geomorfología granítica**,** inselberg, relieve residual, superficie grabada

1. INTRODUCTION: THE ‘BORNHARDT’ LANDFORM

The granitic terrain of northwestern Eyre Peninsula (Figure 1) includes four domical ‘island mounts’ or inselbergs (BORNHARDT, 1900; BAULIG, 1956, p. 173) in Mt Wudinna, Polda Rock, Little Wudinna Hill, and Ucontitchie Hill (e.g. Figure 2a). These isolated uplands are bare, rounded, steep-sided, and rise abruptly from the surrounding plains. Following the suggestion due to WILLIS (1934; 1936, p. 121), such domical inselbergs are frequently known eponymously as ‘bornhardts’ in honour of Wilhelm Bornhardt and his seminal research in what was German East Africa (now Tanzania).

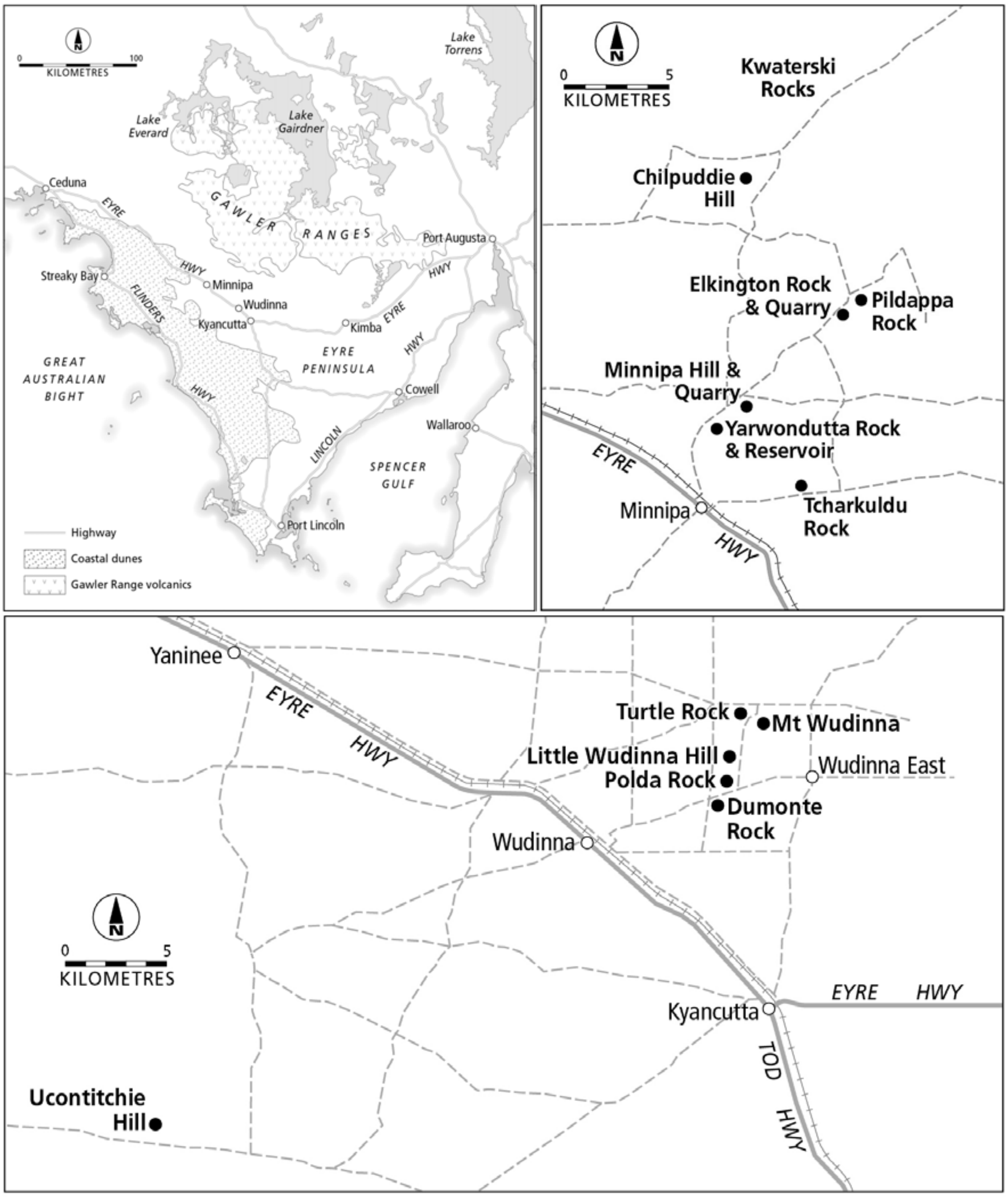

Figure 1. Location maps of Eyre Peninsula and the Minnipa and Wudinna districts.

2. POSTULATED ORIGIN

Many bornhardts, for example some of those located in the interior of the modern Tanzania, Bornhardt's type area, and the environs of Rio de Janeiro in southeastern Brazil, are eye-catching and their origin has long attracted the attention of geologists and geomorphologists. Bornhardts are arguably the basic form from which other inselbergs – block and boulder-strewn nubbins or knolls, castellated tors or *inselbergs de poches*, are derived, and the lesser residuals located on northwestern Eyre Peninsula can be construed as degraded bornhardts.

A few bornhardts are horst blocks thrust up along faults (e.g. BARBIER, 1957) but fault- and fault-line scarps frequently are difficult to differentiate. Many inselbergs examined in Africa south of the Sahara, in southeastern Brazil, in the western United States, and elsewhere appear to be based in structural advantage, either in composition, or in fracture density ('density' referring to fractures per unit volume rather than the more usual mass per unit volume). Several investigators have concluded that such residuals are of etch and two-stage origin, having been initiated by preferential weathering in the subsurface and later exposed by differential erosion (e.g. LOGAN, 1849; BRANNER, 1896; FALCONER, 1911, p. 246; WILLIS, 1936, pp. 113 *et seq*.; BOYÉ & FRITSCH, 1973). Shaped rock masses set in matrices of weathered rock and interpreted as potential or incipient inselbergs in the first stage of development, have been noted in various parts of the world (see TWIDALE & VIDAL ROMANÍ, 2005, pp. 109 *et seq.)*.

Figure 2. Ucontitchie Hill, seen from the southwest.

3. EVIDENCE FROM UCONTITCHIE HILL

The bornhardts and other residuals of the Eyre Peninsula granitic landscape appear to be of this *genre* but this conclusion is based on evidence from only one site, namely, Ucontitchie Hill (TWIDALE *et al*., 1985) which is developed on a massive compartment of rock with few open fractures, and which is thus protected against water penetration, weathering, and susceptibility to erosion and lowering. By contrast, the excavation of a water storage in the northwestern piedmont of the residual revealed a series of granite corestones (HASSENFRATZ, 1791; SCRIVENOR, 1913) set in a matrix of weathered country rock or *grus* (Figure 3). These features are developed on granitic rock that compositionally is the same as that exposed in the adjacent domical hill but is subdivided by a system of closely spaced orthogonal fractures (TWIDALE, 1964).

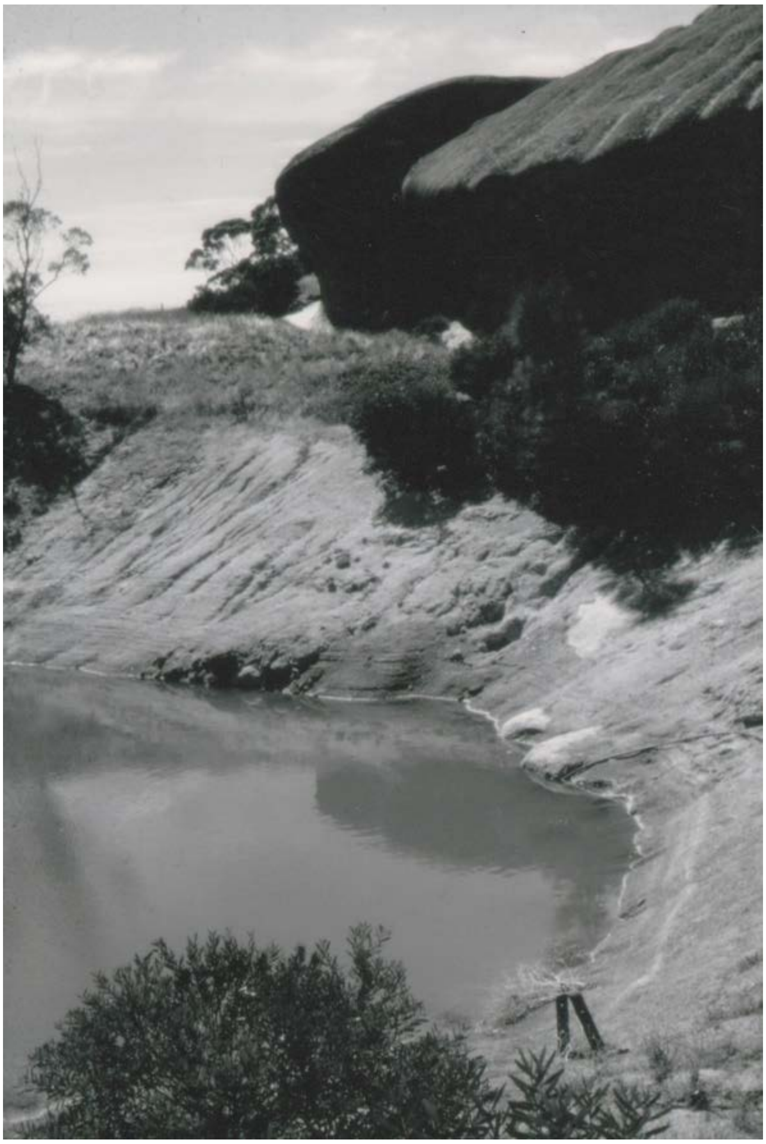

Figure 3. Water storage excavated in NW piedmont of Ucontitchie Hill and exposing corestones set in matrix of weathered granite or *grus.* Note overhanging flared wall in the background.

Runoff from the bare rock slopes flanking the upland penetrated along the many partings exposed in the excavation, altering the rock with which it came into contact. The corners and edges of the blocks were preferentially rotted leaving spheroidal cores that were gradually reduced in size and in many instances eliminated. The weathered compartment was susceptible to lowering, partly by the flushing of fines and solubles consequent on weathering, but mostly, baselevel permitting, by wash and abrasion (WILLIS, 1936; RUXTON, 1958; TRENDALL, 1962). Contrasts in weathering led to topographic differences.

Flares are two-stage forms and where exposed indicate relative elevation of the host residual (TWIDALE, 1962). At Ucontitchie Hill for instance the well-developed flare or concavity at the base of the slope adjacent to the water storage (see figure 3) and the shallow concavities shaped in the contiguous west-facing rampart together with the east-facing slope of the upland suggest that the lowering and exposure of the piedmont occurred in stages involving several alternations of subsurface weathering and erosional exposure. Like the residuals studied by Bornhardt, Ucontitchie Hill has come to stand higher in the local relief as a result of the episodic lowering of the surrounding plains and the consequent relative elevation of the residual (TWIDALE & BOURNE, 1975), or what WILLIS (1936, p. 120), with reference to the multistage character of the original bornhardts, described as uplift *per saltum*.

This interpretation of Ucontitchie Hill is based not only on the juxtaposition of massive and densely fractured compartments that differ in their susceptibility to weathering and erosion, but also on an assumption, namely, that a more closely fractured compartment similar to that below the present piedmont and exposed in the storage excavation, formerly stood alongside, and at the same level as, the massive compartment. It was a reasonable assumption for which it is difficult to visualise an alternative, but nevertheless an assumption. Fortunately, the work of BLÈS & BLANCHIN (1986) offers justification. Charged with finding a repository in his native France for liquid nuclear waste, he demonstrated that fracture patterns in granite outcrops are indicative of patterns in the rock at depth and from this it can be taken to imply that the fracture patterns exposed in the piedmont excavation reflect those of the suprajacent, but now eroded, mass (TWIDALE, 1987).

Thus, observations, and arguments based on them, point to Ucontitchie Hill being a structural feature, but how typical is it of the other granitic bornhardts and residuals that constitute the granitic landscape of northwestern Eyre Peninsula? How far can the evidence and argument concerning Ucontitchie Hill be extrapolated? Additional local evidence germane to the question was not forthcoming for some thirty years, with the quarrying of Dodgson's Rock, but it was telling.

4. DODGSON'S ROCK BECOMES ELKINGTON QUARRY AND ROCK

Dodgson's Rock, situated 25 km NNE of Minnipa, consisted of a platform, grey in colour, some 10 m diameter, and scored by shallow flat-floored, irregularly shaped, basins. It stood flush with the surrounds and was one of many similar features exposed in the district near outcrops such as Pildappa Rock (Figure 4). Dodgson's platform was examined in connection with the possible origin of the flared or concave bedrock slopes that are well developed in the district.

Figure 4. Flared wall of western spur of Pildappa Rock with platform at ground level.

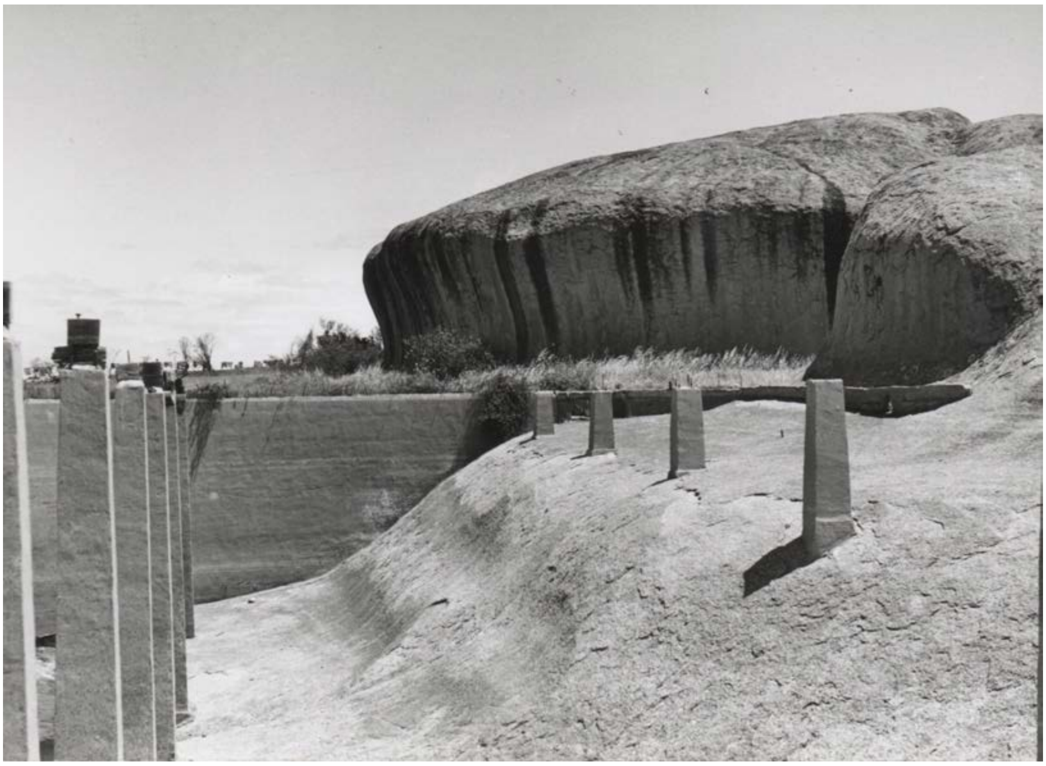

Figure 5. Water storage excavated at northern extremity of Yarwondutta Rock with bedrock concavity or flare exposed. Note concave bedrock slope beyond excavation. (Photo February 1960).

Evidence from Chilpuddie Hill, but especially Yarwondutta Rocks, noted and recorded in 1960 and 1961 pointed to an etch and two-stage origin for the flares (Figure 5, TWIDALE, 1962), Evidence was sought at other sites. In particular, the steep plunge of the bedrock surface beyond the ’toes’ or lower limit of flares at sites in the Minnipa area and elsewhere was construed as possibly indicating deep weathering below the piedmont. Unfortunately, the widespread development of calcrete just beneath the surface throughout the district (see Figure 6, also TARVYDAS, 1969) was discouraging, and at Dodgson’s Rock drilling with a hand auger demonstrated only the shallow extension of the platform for a few metres to the east and south of the outcrop.

Figure 6. Calcrete (a) exposed in quarry wall, Yarwondutta Rock (Photo K-H Seelig) and (b) exposed in piedmont of Tcharkuldu Rock.

In the 1990s however, the Dodgson site was selected for investigation by a mining company seeking ornamental stone, possibly the variety known as 'Minnipa Red' (see FERRIS *et al*., 1998). Drill holes obtained with a power take off penetrated through the calcrete and a weathered granitic mantle indicating a domical bedrock surface with sheet fractures and structures, and quarrying proceeded.

Dr Jennifer Bourne and the author had over the years investigated several aspects of granite landform morphology on northwestern Eyre Peninsula and had incidentally monitored sites such as working quarries. We were on hand for example, to record and map changes wrought during the January 1999 earthquake (estimated to measure 2.3 on the Richter Scale) at the Minnipa Hill quarry (TWIDALE & BOURNE, 2000). The changes included the formation of reverse fault scarps, several A-tents or breached arches (CUSHING *et al*., 1910; JENNINGS & TWIDALE, 1971) and other displacements. Flaking along pre-existing partings, displaced slabs, and rock bursts and associated flyrocks (the threat of which caused the quarry to be abandoned) were recorded and previous interpretations of these features as of tectonic origin confirmed (TWIDALE & SVED, 1978).

The bedrock forms, including shallow bedrock concavities, revealed by the westerly extension of the Wudinna quarry were also noted. In addition, changes attributed either to continued stress adjustments or to recurrent tectonism were noted in the months following the main seismic episode at Minnipa Hill. They included a plate that developed into a breached arch or A-tent in the quarry floor, a fracture parallel with the quarry face, a large A-tent on the surface of Hill, and the development of series of minor reverse faults the pattern of which, on opposite flanks of a divide, was taken as possibly defining a series of small concave sheet fractures (see also DALE, 1923; MARTEL, 2006).

The visits to the Dodgson's Rock quarry were not as frequent as we wished but several significant features were observed and recorded. One immediate effect of the intervention by the mining company was for the site to become known locally as the Elkington quarry after the family name of the company geologist who drilled and demonstrated the subsurface geometry and structure of the rock mass. It had been the habit to name sites after the family that had cleared and first farmed the land, and the Dodgson family is mentioned for example in HEATH and FRANKLIN (1986), but the farm had changed hands and somehow the site of both quarry and exposed rock instantly became 'Elkington's' or 'Elkington'.

The final domical bedrock surface was formed on a massive compartment of granite that was uncovered by the removal of altered overburden up to 7-8 m thick on the eastern flank (Figure 7a). Imbrication demonstrating compressive stress with the upper side moving over the lower was revealed along an arcuate sheet fracture in fresh granitic rock exposed during the excavation (Figures 7b and c), as were disparities between the intended quarry extension and the patterns dictated by imposed stress (Figure 7d).

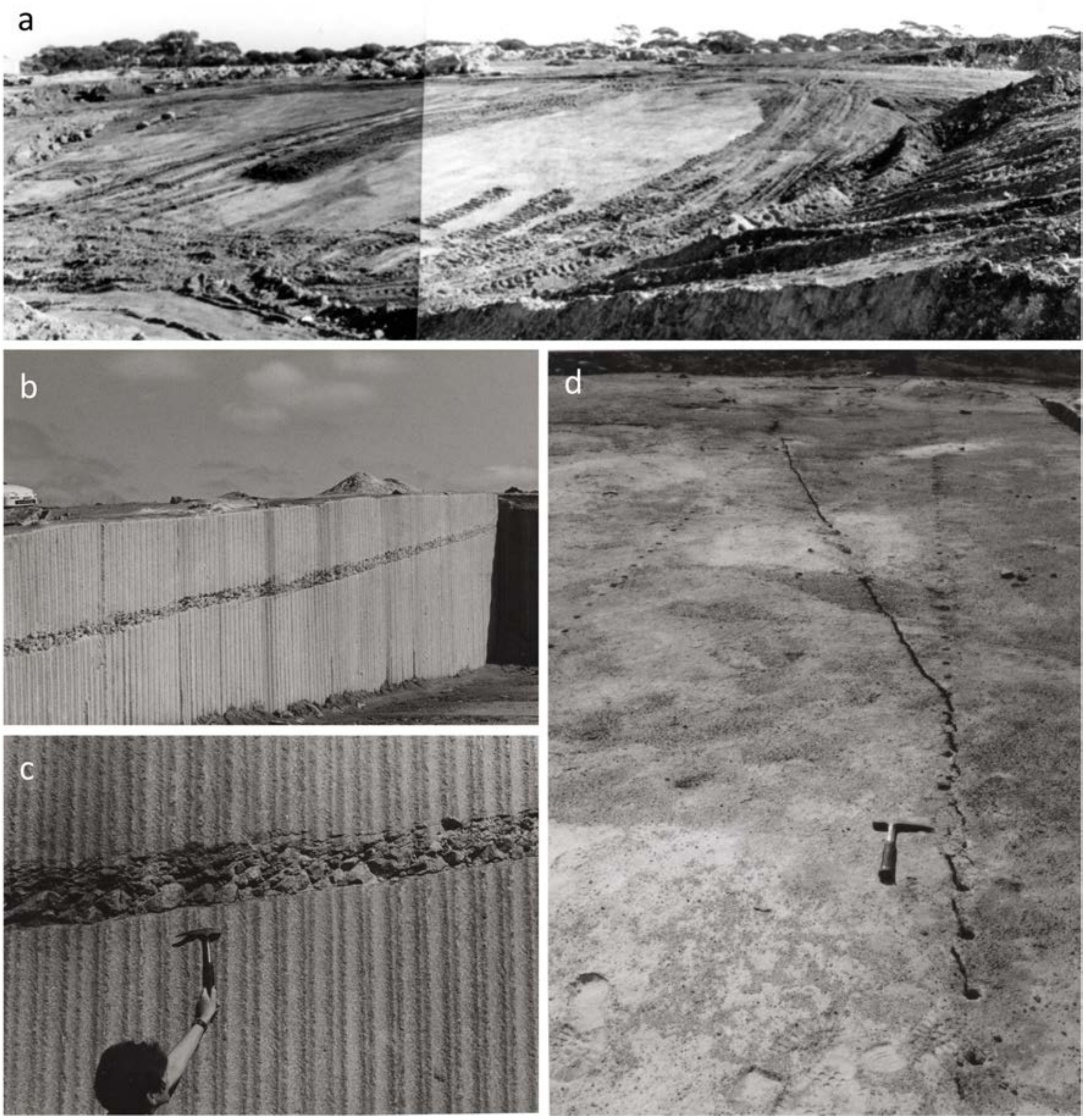

Figure 7. Elkington Rock (a) bedrock dome (b and **c**) general view and detail of imbrication developed along sheet structure which is a fault, or slippage plane associated with compressive stress. (d) Divergence of intended fracture indicated by line of drill holes and natural split imposed by pattern of strain and evacuation of overburden.

The cover removed included at least three sheet structures, each about a metre thick and separated by convex upward sheet fractures, each of which was broken into quadrangular slabs with thin weathered skins or rinds formed prior to exposure. They are attributed to compressive stress that found expression within the compartment as fractures as overburden and vertical loading were reduced prior to quarrying.

During the removal of overburden several A-tents or breached arches were observed on the mid slopes of the domical feature (Figure 8a) at different times and stages in the exposure of the core of the rock mass. They presumably were caused by compressive stress taking effect as overburden was stripped and the vertical load decreased.

Some months after the quarry was abandoned the upper slope of the exposed dome was disrupted with the formation of thin A-tents (Figure 8b), but whether as a delayed result of unloading, or a separate low level seismic event, is not known (TWIDALE & BOURNE, 2003).

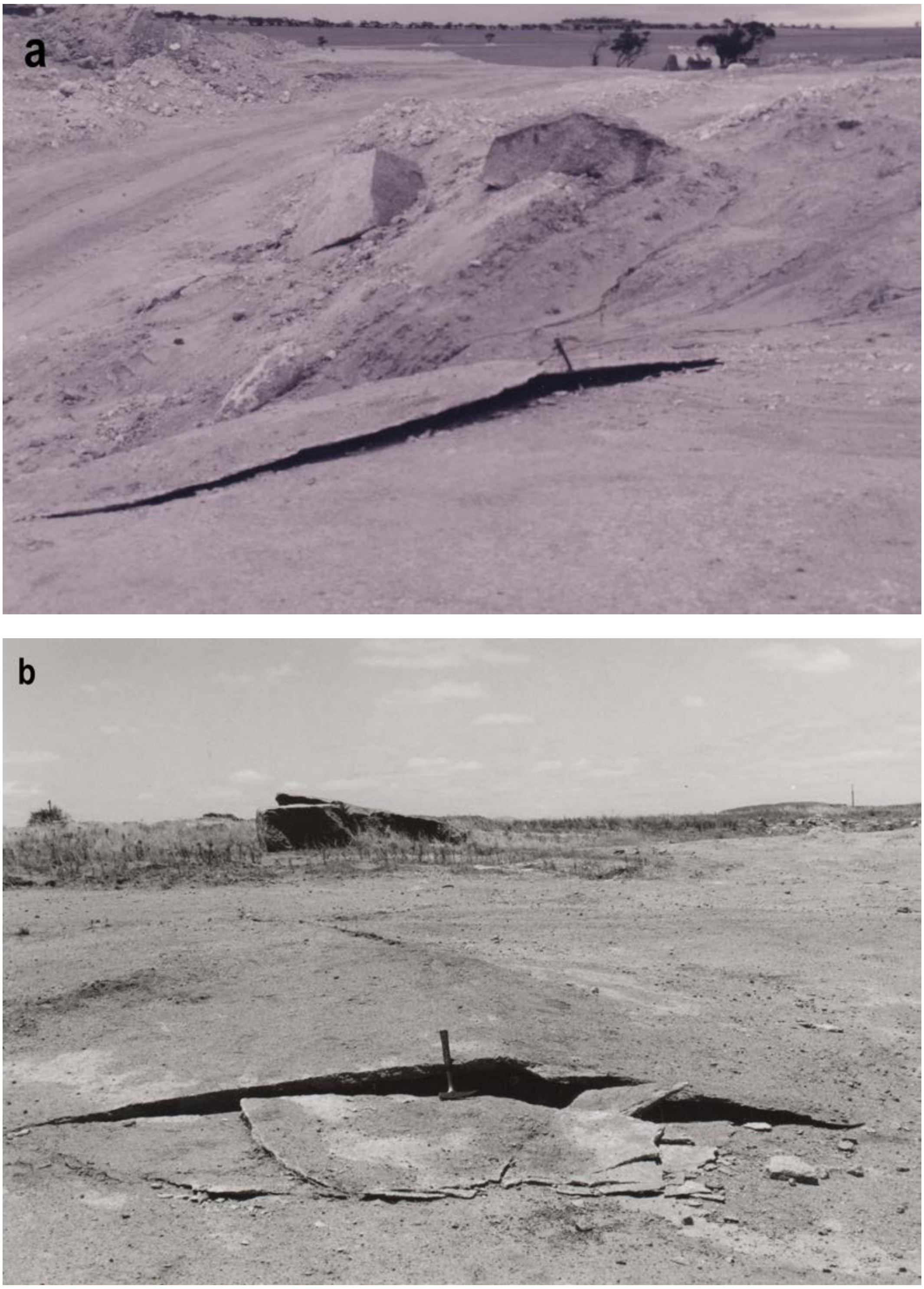

Figure 8. A-tents (a) formed on flank of dome during excavation of quarry, and (b) formed on crest of Elkington Rock several months after quarrying abandoned (TWIDALE & BOURNE, 2003)

Local anecdotal information strongly suggests that similar flattish plates formed in the Minnipa and Elkington excavations and were collected as useful rockery items or souvenirs before they could be recorded. Low level seismicity of an order of magnitude estimated to have been involved in the 1999 Minnipa Hill event that caused rock bursts, flyrocks, cracks minor scarps, and the displacement and buckling of slabs and plates, recalls the experience of the late Dr David Sutton (pers comm., early-mid nineteen sixties) of the Department of Physics in the University of Adelaide, who, seeking a site for a permanent seismic recording station, camped at the base of Mt Wudinna, placed a portable seismic recorder at midslope, and registered two minor but definite events overnight (also SUTTON & WHITE 1968, also TWIDALE 1986). Although situated on a supposedly stable craton (e.g. TEICHERT 1947), northwestern Eyre Peninsula is seismically active, albeit at a low level, as is attested by the abundance of minor neotectonic forms such as A-tents and lateral and vertical wedges developed on outcrops throughout the district (e.g. TWIDALE & SVED 1978; TWIDALE & BOURNE 2009).

The excavation of the Elkington quarry not only revealed convincing evidence of the first of two stages in the evolution of a bornhardt - though given its location below ground level, stage two cannot be anticipated in the foreseeable future - but also provided data on the state of stress in the near surface compartments of rock and thus on the origin of various structures and forms such as sheet fractures and structures, and A-tents or breached arches. Like the covered granitic dome reported from the Ebaka quarry in Cameroon (BOYÉ & FRITSCH, 1973) the Elkington quarry excavation offers a clear example of rock compartment already partly rounded in the shallow subsurface by the preferential weathering of corners and edges of the compressed rock mass. It is an undeniable example of a nascent bornhardt in the first stage of evolution. As such it too has been, and will be, cited in the geomorphological literature.

In a more immediate sense the quarrying of the Dodgson platform and the revelation of the associated domical mass strengthens the suggestion arising from studies of Ucontitchie Hill, that the inselbergs of northwestern Eyre Peninsula, including bornhardts, are etch and two -stage forms, as apparently are turrets like the Murphy Haystacks and elevated platforms such as Yarwondutta Rock (TWIDALE & CAMPBELL, 1984; TWIDALE, 2023). In addition, the excavation of Elkington Rock has surely changed in the way platforms will be viewed.

Appropriately linked with the name of its discoverer, it is suggested that Elkington Rock merits registration as a Geological Monument.

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