KEYWORDS: ***Murujuga – Petroglyph – Geology – Granophyre***

UNDERSTANDING THE ROCKS: ROCK ART AND THE GEOLOGY OF MURUJUGA (BURRUP PENINSULA)

Mike Donaldson

Abstract. The extensive rock art of Burrup Peninsula and Dampier Archipelago in the Pilbara region of Western Australia has been well documented over the past thirty years, yet there remains considerable confusion among rock art researchers about the rocks on which the art resides. Most of the art is on Neoarchean (2.7 billion years old) intrusive igneous rocks including granophyre, gabbro, dolerite and granite. Petroglyphs were produced by removing the outermost few millimetres of dark red-brown iron oxide to expose a pale-coloured 1-cm-thick weathered clay-rich rim above the dark grey-green, very hard fresh rock.

Introduction

The extensive rock art of Murujuga (Burrup Peninsula) and the adjacent Dampier Archipelago in Western Australia's Pilbara region is well known to rock art researchers through numerous technical publications over the last thirty years (e.g. Bevacqua 1974; Lorblanchet 1977; Virili 1977; Vinnicombe 1987, 2002; Bednarik 1979, 2002, 2006). The art complex is estimated to comprise over one million petroglyphs, but despite the huge archaeological endeavour in the region prior to clearing industrial sites for development (iron ore and salt shipping facilities; liquefied natural gas (LNG) and ammonia plants; and rock quarries and pipelines), there remains no complete inventory of this important heritage environment.

The geology of the peninsula has been well documented on a regional scale by the Geological Survey of Western Australia (GSWA) since the 1960s (Kriewalt 1964; De Laeter and Trendall 1971), and geological mapping at a scale of 1:100 000 was published in 2001 (Hickman 2001). However, this information has clearly not been widely accessed by rock art researchers who have continued to confuse the geological setting of the petroglyphs with erroneous statements about bedrock types, ages and weathering history of the rocks. For example Vinnicombe (1987) wrongly described Burrup rocks as '... ancient Pre-Cambrian extrusions of volcanic lavas and younger sedimentary deposits' although she did also refer to granophyre as the dominant rock type on the peninsula; and Bednarik (2007) incorrectly stated that 'most Dampier petroglyphs occur on relatively fine-grained Mesozoic rocks rather than the much older (Precambrian) porphyritic facies, and these are usually free of quartz, or very nearly so. Therefore they are most likely dolerites, diorites, basalts or gabbros.'

As the rocks may be considered the 'canvas' for the Burrup rock art, it is time to set the record straight and 'understand the rocks' of Burrup Peninsula.

Geology of Burrup Peninsula

There are several aspects of the geology of Burrup Peninsula and surrounding islands that are important in the study of the art: the *lithology*, or rock type, of the fresh bedrock; the nature of the *weathered surface* of the rocks; and the *geomorphic expression* of the various rock types — the different landforms that relate directly to the underlying geology.

Bedrock

Exposed bedrock geology is shown in Figure 1. The predominant rock types on the peninsula and the eastern islands are granophyre (a fine-grained igneous rock composed of quartz and alkali feldspar with a distinctive intergrowth texture) and gabbro (an intrusive rock composed of feldspar and pyroxene; the intrusive equivalent of basalt lava). On the outer islands basaltic lava is the main bedrock type with lesser exposures of sedimentary rocks derived from basaltic volcanoes, and some gabbro. The igneous rocks are of Neoarchean age, dated by radiogenic methods as 2725 ± 5 million years old (Wingate 1997). Although not directly spatially connected to the rocks of the Hamersley Basin to the south, they are of the same age and have many similar geological characteristics, and GSWA correlates them with the Hamersley Basin's

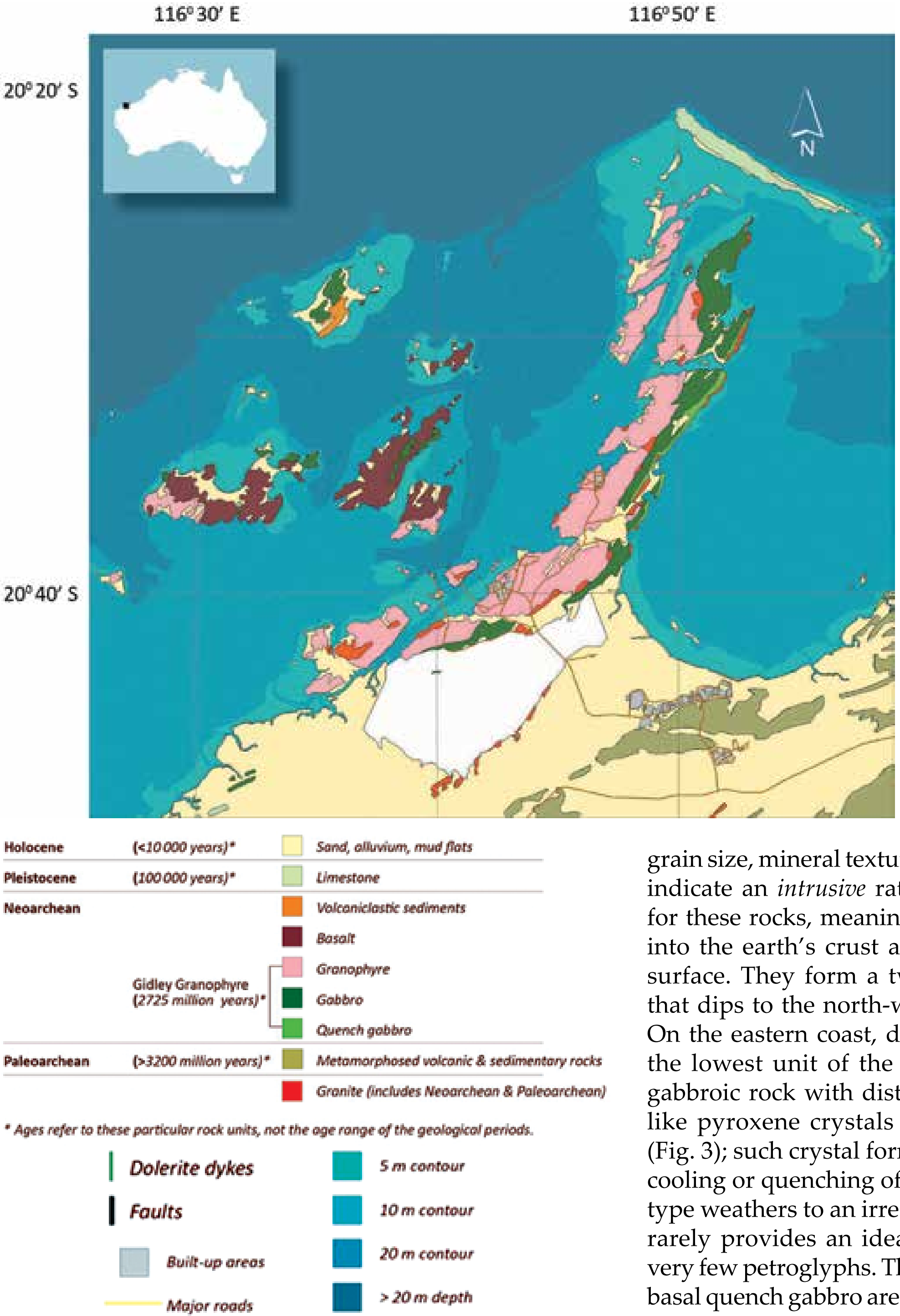

Figure 1. Simplified bedrock geological map of the Burrup Peninsula area (from Donaldson 2010, but after Hickman 2001).

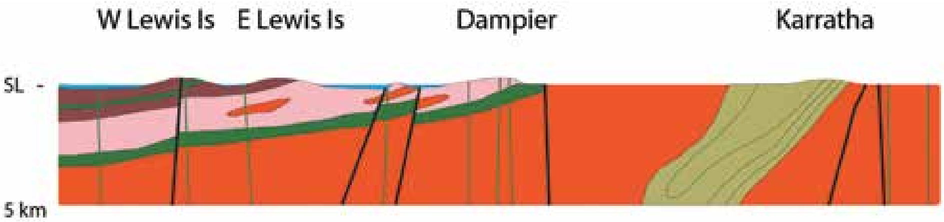

Figure 2. Geological cross-section of the Burrup Peninsula area (from Donaldson 2010, but after Hickman 2001).

Fortescue Group (e.g. Hickman et al. 2006). At 2.7 billion years old, these are ancient relics of the early Earth, but they are still some 500 million years younger than the Paleoarchean rocks behind Karratha, which comprise metamorphosed sedimentary and volcanic rocks and granites of the West Pilbara Superterrane. One of these 'granites' (the Karratha Granodiorite) has been dated as 3.27 billion years old (Hickman et al. 2006). So this part of Western Australia has some of the oldest rocks on Earth.

The gabbros and granophyre of the eastern Dampier Archipelago collectively form the Gidley Granophyre as defined by Hickman (2001). Features such as grain size, mineral textures and field relationships indicate an *intrusive* rather than *extrusive* origin for these rocks, meaning that they were injected into the earth's crust and solidified beneath its surface. They form a two-kilometre-thick sheet that dips to the north-west at about 25° (Fig. 2). On the eastern coast, directly overlying granite, the lowest unit of the Gidley Granophyre is a gabbroic rock with distinctive branched needle-like pyroxene crystals up to a metre in length (Fig. 3); such crystal forms are indicative of rapid cooling or quenching of liquid magma. This rock type weathers to an irregular blocky outcrop that rarely provides an ideal art surface, so it hosts very few petroglyphs. The gabbros that overlie the basal quench gabbro are dark grey-green in colour and vary in grain size from about one millimetre to several centimetres. They are characterised by mineral layering (igneous lamination) on a scale of several centimetres (Fig. 4). The mineral textures and coarse grain size indicate the gabbros cooled very slowly. Gabbros outcrop as high hills of disaggregated blocks ranging in size from about one-to five-metre cubes. The coarser-grained varieties weather to a very rough

Figure 3. *Branching skeletal pyroxene crystals indicative of rapid cooling in quench gabbro at base of Gidley Granophyre, eastern Burrup Peninsula. Field of view is 15 cm.*

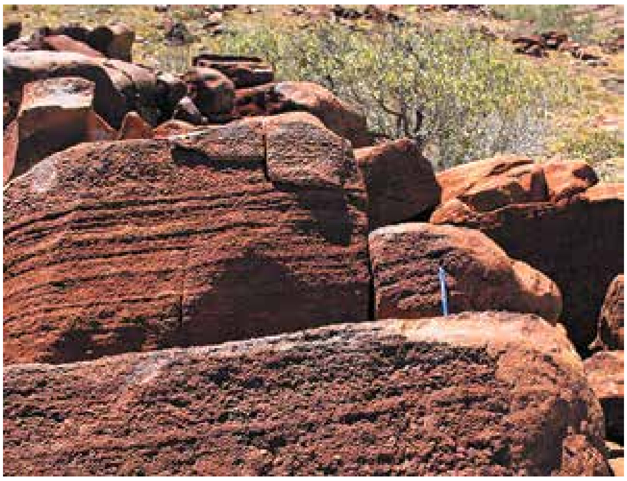

Figure 4. *Igneous lamination due to mineral layering during slow cooling of basal gabbro unit of Gidley Granophyre, eastern Burrup Peninsula. The layering dips gently to the north-west. Pen scale is 10 cm long.*

surface, again generally unsuitable as an art surface.

The Granophyre that overlies the gabbro is characterised by irregular sub-vertical pillars about fifty centimetres across (Fig. 5), caused by columnar jointing (cooling fractures) within the solidifying magma, similar to but less well defined than the famous Giants Causeway in Ireland. The granophyre is dark grey-green in colour and is generally very fine grained, with individual crystals not discernable to the naked eye. The distinctive microscopic granophyric texture of finely intergrown quartz and feldspar (Fig. 6) and the high quartz content give the rock its extreme hardness, and the fine grain size produces a smooth flat weathered surface that the Burrup artists preferred. Whole-rock chemical compositions of the gabbros and granophyre are given in Table 1; granophyre is much more siliceous, and has higher alkali (Na_20 and K_20) and lower magnesium and calcium contents than the gabbros. With approximately 4.5% iron (as Fe oxides), it has about half the iron content of the gabbros.

The Gidley Granophyre is overlain by Neoarchean basaltic rocks on East Lewis and Enderby Islands. The gabbros and granophyre are interpreted as sub-volcanic magma reservoirs beneath the volcanoes that erupted the overlying basalts, and rare exposures of the granophyre reveal structures formed by viscous flow within the magma chamber. Volcaniclastic sediments on Rosemary Island represent volcanic ash and debris that was deposited in adjacent submarine environments.

Legendre Island and some of the smaller outer islands are quite different, being composed of much younger limestone, at least in surface outcrop. These deposits represent calcareous sands composed largely

Figure 5. *Originally sub-vertical columns of granophyre formed by columnar jointing during cooling, Gidley Island. Individual columns are approximately 50 cm in diameter and in this outcrop columns have collapsed to be near horizontal due to tectonic movements and soil creep on a hill slope.*

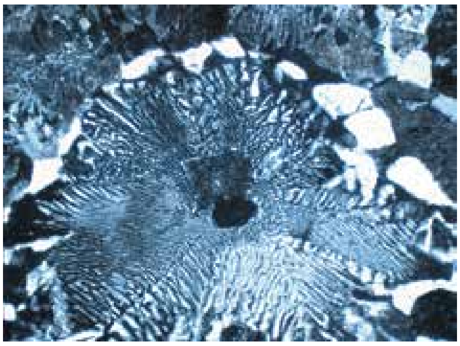

Figure 6. *Photomicrograph of granophyric texture comprising a micrographic intergrowth of quartz and alkali feldspar surrounding an equant feldspar crystal in granophyre. Field of view is 1 mm, photo taken with cross-polars in transmitted light.*

Element (as oxides)	Quench gabbro (n = 3)	Basal gabbro (n = 2)	Gabbro (n = 4)	Granophyre (n = 7)
SiO_2	54.73	53.84	52.10	71.44
TiO_2	0.83	0.78	0.48	0.52
Al_2O_3	11.47	9.29	16.72	12.40
Fe_2O_3	2.61	1.95	2.37	2.34
FeO	7.53	10.05	5.74	2.25
MnO	0.19	0.23	0.15	0.08
MgO	8.03	10.22	7.70	1.08
CaO	11.02	8.76	11.12	1.66
Na_2O	1.81	1.52	1.79	3.56
K_2O	0.70	0.65	0.69	3.75
P_2O_5	0.08	0.08	0.05	0.14
SO_3	0.05	0.07	0.05	0.03
LOI	0.79	2.47	0.92	0.56
Total	99.84	99.88	99.84	99.81

Table 1. *Average Burrup bulk rock chemical analyses (weight %). LOI = loss on ignition. Source: GSWA (*http://geochem.doir.wa.gov.au/geochem*). Analyses by Geoscience Australia.*

of marine shell fragments deposited as wind-blown dunes in a coastal environment in geologically recent Pleistocene times, 10000 to 100000 years ago. Other minor deposits of 'fresh water limestone' (travertine) occur as cream to white coloured creek deposits and flowstone resembling cave formations, typically at elevated heights in gabbro- and granophyre-dominated hilly areas. Although undated as yet, these are clearly very young deposits, and they may prove useful in dating some early human activity in the region (e.g. Bednarik 2007).

Of relevance to rock art distribution is the fact that limestone, basalt and volcaniclastic sediments do not form favourable surfaces for production or long-term preservation of petroglyphs. The limestone is soft and friable, whereas the basalts tend to weather easily and form rough surfaces unsuitable as an artistic canvas. A small number of petroglyphs have, however, been recorded on basalts and sedimentary rocks on the islands, as indicated in Figure 9.

Gabbro and granophyre outcrop strongly because they are hard and relatively resistant to chemical weathering. These ancient rocks are well-preserved (considering their age), but they have been subjected to the tectonic forces that have shaped the Earth's surface over many millions of years. They still have a gross layering reflecting their origin as sub-volcanic sills, but they also exhibit jointing and faulting in response to the massive forces they have been subjected to as continents have collided, split up, and collided again. Joints are regularly spaced cracks in the rock formed in response to these titanic stresses; they result in a tessellated outcrop pattern, in places curvilinear at a scale of several kilometres. Faults are similar cracks along which there has also been movement, horizontally or vertically or both.

Many joints and faults have been the locus for later intrusion of dolerite dykes — magmas of basaltic composition that used these conduits to reach the surface several kilometres above and erupt as lavas. There are many dolerite dykes that criss-cross the Burrup Peninsula and adjacent islands; some are tens of metres wide, others less than one metre. They are too numerous and generally too small to show on the geological map at this scale. Dolerite tends to weather more readily than the surrounding granophyre, so it outcrops poorly and commonly forms shallow valleys with minor rubbly outcrop. In some granitic areas dolerite occurs in more positive relief, and at Watering Cove on the eastern side of Burrup Peninsula a small dyke that outcrops strongly is the locus for many fine petroglyphs on the iron-rich weathered skin. Although not specifically dated by isotopic methods, all the dykes in this area are interpreted as Neoarchean, based on analogy with similar dykes throughout the Pilbara (Hickman 2001).

The secret to the preservation of gabbro and granophyre lies in the chemical composition and microscopic mineral textures of these rocks. Granophyre is a geological technical term for an intrusive rock of silica- and alkali-rich composition that has a distinctive (granophyric) intergrowth texture of quartz and feldspar: if the same magma erupted as lava it would be called rhyolite. This point is stressed because a large proportion of Burrup petroglyphs are on granophyre, and the historic literature (admittedly mainly by archaeologists rather than geologists) is quite confusing about what the host rock is.

Weathering

Rocks at the Earth's surface are subjected to chemical and physical processes that we collectively refer to as 'weathering'. The mineral assemblages that were stable at the time of formation of gabbro, granophyre and basalt in the volcanic environment at some 1100° C are not stable in the 20° – 30° C oxygen- and water-rich surficial environment where they break down to various clay minerals and oxides such as kaolinite and haematite. This process takes considerable time, and the rate of breakdown depends largely on the ease of access of groundwater to the constituent minerals in the rock. Gabbro and granophyre are extremely hard, compact rocks that are largely impervious to such weathering except along joints which are developed at various scales from a few tens of centimetres to several metres. The weathering process takes place over millions of years, and begins in the uppermost several hundred metres of the crust, where oxygen activity levels are highest. The proportion of fresh rock exposed at today's surface reflects the balance between rate of weathering and rate of erosion of the surface. In many parts of Western Australia where the erosion rate over the last several hundred million years has been minimal (such as Kalgoorlie), similar rocks

Figure 7. *Weathering 'skin' about 1 cm thick surrounds fresh, hard, fine-grained granophyre. The outer 1 mm comprises mainly iron oxides precipitated along former joint planes or accreted in the surficial environment from wind-blown material and/or organic activity, and the paler brown material beneath the outer rim is largely kaolinitic clays formed by break-down of feldspars, iron oxides and hydroxides formed by weathering of pyroxene, and fine grained quartz which is essentially impervious to the weathering process.*

Figure 8. *Petroglyphs of sea birds and an anthropomorphous figure on a 40-cm-diameter rock at Withnell Bay, Burrup Peninsula. The petroglyphs are light coloured as the artist has cut through the red-brown iron oxide outer coating on the rock to expose the clay-rich weathered rock beneath. The fresh rock which can be seen in the broken surface of the rock is extremely hard, grey-green in colour, and is not normally exposed in the petroglyphs; it is too hard for the artists to make much impression on it with the stone tools available to them, and it would in any case not provide such a vivid contrast to the dark surface material.*

are deeply weathered to depths of several hundred metres. In the Dampier region, the relatively rapid rate of erosion of perhaps five kilometres thickness of overlying rocks has been sufficient to enable many of these rocks to remain fresh at today's surface, with just a centimetre of weathered 'skin' along joint planes. Once the rocks are exposed on the surface, other physical processes such as exfoliation continue to breakdown the angular joint-controlled blocks. These processes particularly affect the edges and corners of angular blocks, resulting in a gradual trend towards more spherical shapes over time, in the process known as 'onion-skin weathering'. Bednarik (1979) highlighted the importance of this process (which he called 'boulder spalling') in any study of rock weathering and repatination of petroglyphs.

This weathered skin is important in the appreciation of the region's rock art, as this is the material that has been removed in the production of the rock art images. The fresh bedrock is far too hard to be significantly impacted by the materials available to the ancient artists, essentially just other hard rocks. The weathered skin of granophyre and gabbros is typically about one centimetre thick (Fig. 7), and consists of clay and iron oxide minerals with a thin (about a tenth of a millimetre) outer zone of dark-brown to almost black iron and manganese oxides. Most of the clay and iron oxide minerals result from the oxidation and hydrolysis of the original igneous minerals: feldspars alter to white kaolinite clays; pyroxenes and amphiboles alter to red and brown iron oxides (haematite and goethite) and magnesium-rich clay (montmorillonite). The quartz of the original rock is essentially unaffected by these weathering processes. Some of the oxides in the thin outer zone formed on the joint surfaces from percolating groundwater while the rock was still some tens to hundreds of metres below the surface, and some has formed at the surface by the oxidation of additional wind-blown materials, probably aided by microbial action. This is an on-going process that results in the repatination of petroglyphs over many thousands of years, as described by Bednarik (2007).

To produce an art work that stands out with high contrast from its surrounds, the Burrup artists pecked away the thin, dark, iron oxide-rich surface expose the light-coloured, kaolinite-rich weathered zone beneath. The dark grey-green colours of the fresh rock would not display such a contrast, and in fact the fresh rock is too hard for any such modification (Fig. 8).

Geomorphology

One of the distinctive features of the Burrup Peninsula and surrounding islands, and indeed the entire Pilbara region, is the massive barren rock piles composed of gabbro and dolerite that occur throughout the region. These high hills (up to 200 metres above the plains) stand high in the modern land surface because they are relatively resistant to

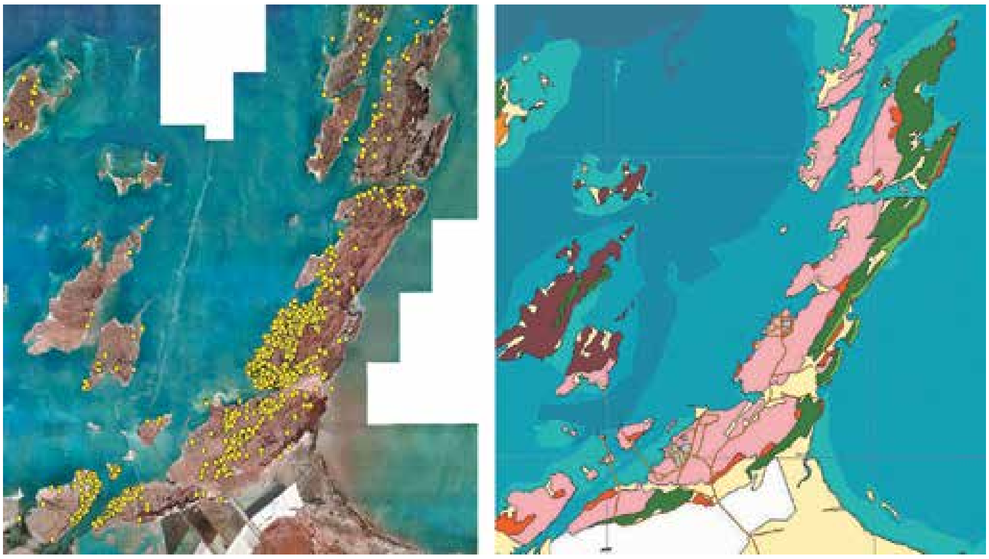

Figure 9. *Comparison of registered rock art sites (left, from Bird and Hallam 2006) with published geology (right, from Donaldson 2010) clearly shows that most sites occur on granophyre.*

weathering compared with the surrounding rocks. They comprise blocks of rock typically one to five metres square in a seemingly random pile with gaping crevices and hollows much valued by the many species of kangaroos, wallabies and other fauna for the protection they offer from the searing sun and predators. These rock piles present a formidable prospect to any would-be climber in search of game or rock art.

The rock piles have often been called 'scree slopes' but this implies that the rock material has tumbled down the hills from the upper levels. In fact, most of the rocks are essentially *in situ* and they represent the disaggregated layers of gabbro (or dolerite in some areas) broken up by fairly regular vertical and horizontal jointing. These 'blocks' are commonly erroneously referred to as 'boulders', but in a technical (geological) sense, the term boulder is reserved for 'a detached rock greater than 256 mm (10″), being somewhat rounded or otherwise distinctly shaped by abrasion in the course of transport' (Neuendorf et al. 2005). The term '*block*' is the preferred geological term for 'a large, angular rock fragment, showing little or no modification by transporting agents, its surface resulting from breaking of the parent mass, and having a diameter greater than 256 mm (10″) … it may be nearly in place or transported by gravity, ice, or other agents' (Neuendorf et al. 2005). Where a block has been modified by exfoliation or other processes (apart from transport) to be sub-angular or even sub-round in shape, it is still misleading to refer to it as a 'boulder'. The ancient artists have used the many rock surfaces produced by these processes as canvases in some of the most prolific art sites of the region.

The more subdued outcrop of granophyre has a similar joint-controlled aspect and, in addition, has the sometimes vaguely-defined columnar jointing pattern seen in Figure 5. The extensive outcrop areas of granophyre compared with gabbro distribution means there is more rock art on granophyre than gabbro (Fig. 9), but both rock types have similar surficial weathering skins and are, as such, equally chosen for this endeavour. Similarly, some dolerite outcrops have petroglyphs, but the relatively insignificant outcrop extent of the dykes compared to granophyre and gabbro means the proportion of art on dolerite is minimal. The similar depth of weathering and development of the dark red-brown surface layer on these lithologies indicates that these features are not strictly controlled by bedrock mineralogy and chemistry, but by the joint-controlled percolating groundwater that interacted with the rocks for many millions of years before they were eventually exposed at the surface, and by subsequent accretion of material on rock surfaces exposed at the surface as in the case of rock varnish formation.

Conclusion

Although, perhaps surprisingly, there have not been any definitive detailed geological studies on Burrup Peninsula or the surrounding islands, the region has been mapped at regional (1 : 250000) and more detailed (1 : 100 000) scales by GSWA over the last 45 years and there are geological maps, explanatory notes, and other publications that cover the area (e.g. Kriewalt 1964; De Laeter and Trendall 1971; Wingate 1997; Hickman 2001; Hickman et al. 2006). Despite this available data, rock art researchers have in general not accessed this information, or not understood it, and many incorrect statements have been made in archaeological publications concerning the rocks that host the Burrup rock art. Such problems are of course understandable and it is clearly not possible for professionals to be an authority in all related disciplines. However, it must surely be beneficial to consult with experts in appropriate related disciplines before going to print with technical statements that are, in some cases at least, grossly incorrect.

The problem is not confined to Burrup Peninsula and it is hoped that this paper encourages rock art researchers to delve a little deeper into the 'rock' aspects of rock art, particularly by taking advantage of government geological survey expertise and publications.

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COMMENT

Inherited vs recent accretions

By ROBERT G. BEDNARIK

I thank Donaldson for this additon to Bednarik (2007), which to a large degree is in agreement with my findings, and whilst I do support his contention that archaeologists need to take an interest in geology — not only but also when they work with petroglyphs — I have to respond to clarify some of Donaldson's apparent misconceptions. In the process I may need to defend archaeologists. My greatest concern is his claim that

> [t]he similar depth of weathering and development of the dark red-brown surface layer on both lithologies indicates that these features are not strictly controlled by bedrock mineralogy and chemistry, but by the joint-controlled percolating groundwater that interacted with the rocks for many millions of years before they were eventually exposed at the surface.

This view of the origins of the ferromanganeous thin surface skins in arid regions (cf. also Donaldson 2009: 508) conflicts dramatically with the view that this crucial feature is a *largely* accretionary deposit that formed for the greater part *at the surface*. This conflict needs to be resolved. I reject the view that any significant part of the surface patina is inherited from 'many millions of years before [the rocks] were exposed at the surface'. Like rock varnish (Engel and Sharp 1958), the same patination can occur on rock types that contain virtually no iron, and on some petroglyphs the iron-rich coating is as thick as it is on the adjacent surface. Moreover, I have shown that, far from being 'similar', the depth of weathering ranges from about 2 mm to 21 mm in a sample of nineteen sections from Murujuga (Bednarik 2007: Fig. 18), which implies that these surface facets (Bednarik 1979) became exposed to weathering at different times. As shown by Trendall (1964) and confirmed by Černohouz and Solč (1966), a weathering depth of 5 mm per one million years is a reasonable age estimate.

The regolith piles at Murujuga and elsewhere in the region do comprise a small minority of large blocks bearing ancestral joint surfaces, but smaller clasts dominate numerically, mostly of <1 m grainsize. Like any rock, these are subjected to breakdown and mass-exfoliation, in a progressive process described in Bednarik (1979: 19) as 'boulder spalling'. This may involve diurnal temperature changes, kernsprung, mechanical impact, brush fires, lightning strikes, and especially insolation (Fig. 1).

Therefore the various facets on each block or boulder are all of different ages, and anyone with an open mind can stroll around the island and find thousands of such fracture surfaces that are relatively young. Some of them have very little accretion covering a fracture surface. The relative thickness of the weathering rind is probably a good indicator of the relative age of each fracture facet on each clast. Very few facets are former joint surfaces, formed 'tens to hundreds of metres below the surface'. This proposition can be tested easily: Donaldson can show us which facet on each rock is a joint surface. I predict that he cannot in almost all cases, and even if he could it would leave him with the problem of having to explain why all other facets on the clast in question have similar iron coatings (except those that were broken in recent centuries).

One of these forms of accretionary deposits is called rock varnish, which has been demonstrated to form in as little as 60 years (Engel and Sharp 1958). The dark-brown deposit of iron oxides and hydroxides is largely a result of such deposition, although it is perfectly possible that some of its cations were recycled from inherited, much earlier weathering products. The repatination process of petroglyphs has been calibrated against time, and we know that it takes between roughly 2000 and 5000 years, depending on known ambient variables, for a fresh surface to patinate to a colour matching the adjacent old surface (e.g. Bednarik 2009).

There are several other issues in Donaldson's text

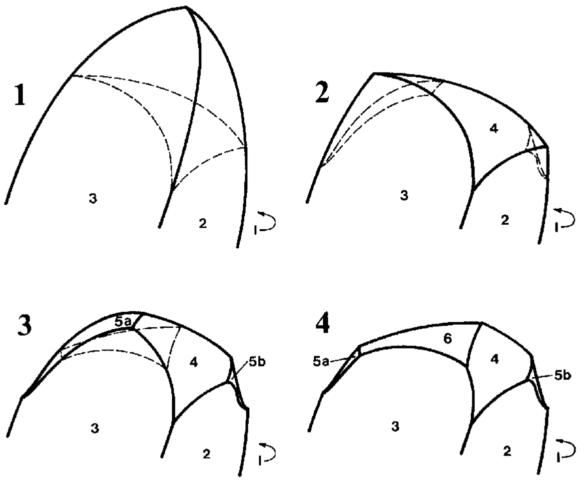

Figure 1. *Schematic depiction of the spalling process affecting rocks at Dampier (from Bednarik 1979).*

that would need clarification, but I will raise just two more. His repudiation of my claim that most Dampier petroglyphs occur on specific rock types is interesting but to refute the claim he needs to present quantified statistics of numbers of motifs on the various rock types. He has not presented such proof, nor have I; either one of us may be right, and I will return to this subject in the second part of my paper on the science of Dampier rock art, as well as to other points Donaldson raises. It may be that Donaldson actually agrees with my statement, but only rejects the notion that there are any post-Neoarchaean rocks in the archipelago. That, too, can be tested, and again he provides no evidence to support his view. At this stage I ask Donaldson to take another look at the rock he illustrates in his Figure 7 and identifies as granophyre, a felsic rock, and to find in it the large quartz and feldspar crystals that characterise granophyre. I predict that he will find mostly small mafic mineral crystals: pyroxenes, olivine or amphiboles.

Finally, there is the issue of the terms 'block' vs 'boulder'. I raised this after Donaldson's presentation in Broken Hill, but he repeats his bold claim that archaeologists are wrong in calling large rocks boulders, because to be boulders they must have been *rounded by transport*. Quite apart from the fact that rounded rocks form by other processes as well, the overriding factor is that archaeologists refer not to formation process of boulders; they leave that to geologists to squabble over. They are much more interested in defining the size of the rock with this term, and in so doing they use the technically (sedimentologically) correct term for a rock larger than 25 cm (see IFRAO's *Rock Art Glossary*). In other words, archaeologists correctly use the term in its granulometric sense. Besides, what would Donaldson call a rock that is intermediate between angular and spherical? We can argue whether the spherical tors at Devil's Marbles (Northern Territory) are blocks or not, but granulometrically, they most certainly are *boulders*.

Conversely, Murujuga is not a peninsula; the construction of a causeway to connect an island to a mainland does not result in a peninsula, and the name 'Burrup' only applies to the island's part north of the King Bay isthmus — which is indeed a peninsula. Therefore when Donaldson writes of the 'Burrup Peninsula', he effectively refers only to the northern part of Murujuga.

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REPLY

Geological processes and semantics

By MIKE DONALDSON

Bednarik's comments on *inherited vs recent accretions* in the formation of the thin iron-rich surface layer of Burrup rocks indicate that he has misunderstood the processes and timing involved in the geological weathering process. Contrary to Bednarik's claim, I do not regard this thin (0.1 mm) surficial feature as 'inherited' (his term) and I agree with him that it is, at least in part, an accretionary product. Note that this thin surficial layer is distinct from the weathered rind that is typically about 10 mm thick, as shown in my Figure 7; this is demonstrably a product of weathering of the bedrock. The difference between us would seem to be that I attribute some of this accretion to precipitation from ground waters in the shallow sub-surface environment, as well as a demonstrable component formed at the surface, whereas he suggests it is largely formed above ground similar to the way 'desert varnish' forms. I do not regard these iron-rich surficial skins as 'desert varnish' although there may be a component of that in some cases. There are many examples of such iron-rich coatings on joint planes in weathered rocks down to depths of about 100 metres exposed in open-pit mines throughout the country.

Bednarik is quite correct in pointing out that there are many other processes involved in the weathering and break down of rocks at or near the earth's surface, and his term 'boulder spalling' refers to the physical processes that impact on angular (originally joint controlled) blocks of rock, resulting in the corners being progressively broken away to form sub-angular and eventually sub-round rocks such as the Devil's Marbles. This process commences below the surface and continues (more slowly) in the drier environment above the surface. Such 'spherical' rocks have certainly not formed by transport, and they are not 'boulders' in any technical *geological* sense, even if they are larger than 256 mm. Such rocks are commonly called 'tors' and they are typically outcrops shaped by weathering processes rather than boulders caused by transport as by a river.

My issue with Bednarik's (2007) statement that

> most Dampier petroglyphs occur on relatively fine-grained Mesozoic rocks rather than the much older (Precambrian) porphyritic facies

is simply that this is just not correct. There are no Mesozoic rocks in the area at all, and almost all petroglyphs are on granophyre, gabbro or dolerite which are all of Neoarchaean age (i.e. Precambrian). The evidence for this is in published geological literature as quoted in my paper, and summarised in my Figure 9.

The rock shown in my Figure 7 is indeed a granophyre, but as with many Burrup granophyres, it is very fine grained as illustrated in my Figure 6, and the individual quartz and feldspar crystals are not always visible to the naked eye, and are even difficult to see with a 10× hand lens.

Clearly there is room for more detailed research on the origin of these surficial deposits.

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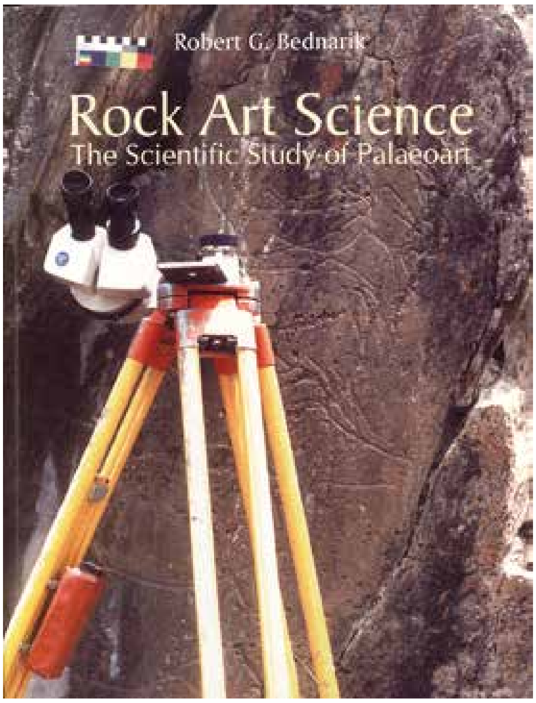

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