KEYWORDS: *Fire – Preservation – Management – Gariwerd – Arnhem Land*

THE IMPACT OF BUSHFIRES AND FUEL REDUCTION BURNING ON THE PRESERVATION OF SHELTER ROCK ART

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Abstract. The observation of rock art shelters prior to and following bushfires and Fuel Reduction Burning has shown that generally there is little immediate deleterious impact on rock art and rock shelters. However, as with coal mining subsidence, when the impact is adverse it can be dramatic and catastrophic. It was apparent that there is accelerated soil erosion following fires, which can affect water flow patterns within rock shelters, both over the art and across the floor deposits. Case studies from the Grampians in western Victoria, and examples from other areas of Australia, are presented to support the conclusion.

Introduction

The role of bushfires, or wildfires, has long been recognised as a major agent in rock weathering (Blackwelder 1927; Emery 1944; Roth 1975; Twidale 1980; Twidale and Campbell 2005). The intense heat necessary to cause exfoliation appears to require burning vegetation to be either in direct contact or immediately adjacent to the rock surface (Lorblanchet 1975; Gunn 1999; Kelly and McCarthy 2001). While fire is often considered a threat to rockshelter artwork, there has been little specific study of the problem (Rosenfeld 1985; Lambert 1989). Given the frequency and extent of both bushfires and fuel reduction burning (also known as 'proscribed or controlled burns') in many rock art regions of Australia, does fire present the threat that we suppose?

Several large bushfires and fuel reduction burns (FRBs) in Gariwerd (Grampians National Park) and the adjacent Burrunj (Black Range State Park) in western Victoria (Fig. 1), from 1984 to 2006, have allowed the impacts to rock art sites following the fires to be assessed. Three aspects of the art sites were assessed: the artwork, the rock support, and the archaeological deposits. Evaluation was based on evidence of recent damage that could be attributed to the fire; such as recent exfoliation, smoke damage, burnt vegetation, ground litter, soil erosion, or the dispersion of ash. Additional field observations were undertaken in south-western Arnhem Land (Northern Territory) following numerous FRBs, and a single instance at Purnululu National Park (northern Western Australia) following a severe bushfire (Fig. 1). Through summarising these events the study draws some preliminary conclusions for the management of rock art sites in fire-prone areas. It is acknowledged, however, that there is a need for these conclusions to be verified by quantitative measurements and by further observational studies.

Bushfires and their behaviour

Pollen records demonstrate that fire has been a factor in the environment of south-eastern Australia since at least the late Tertiary (Kershaw et al. 2002). This parallels a reduction in rainfall, an increase in climatic variation and the development or expansion of sclerophyll forest and heathland. A notable increase in charcoal occurs around 40 000 BP, which these authors attribute to early Aboriginal burning. A plateau of burning was achieved around 11 000 BP, with the greatest peak coincident with European settlement. In recent decades the incidence

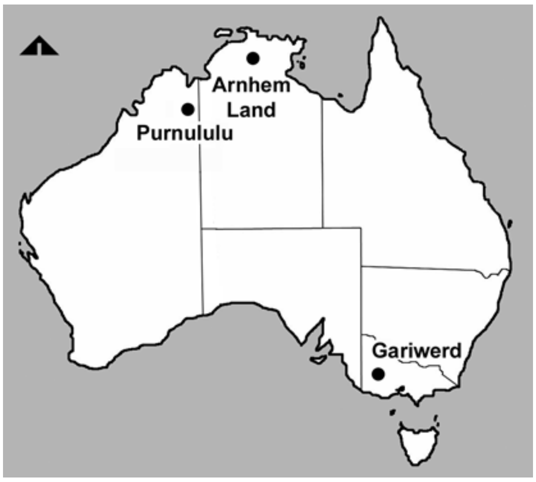

Figure 1. *Locations of the major study areas.*

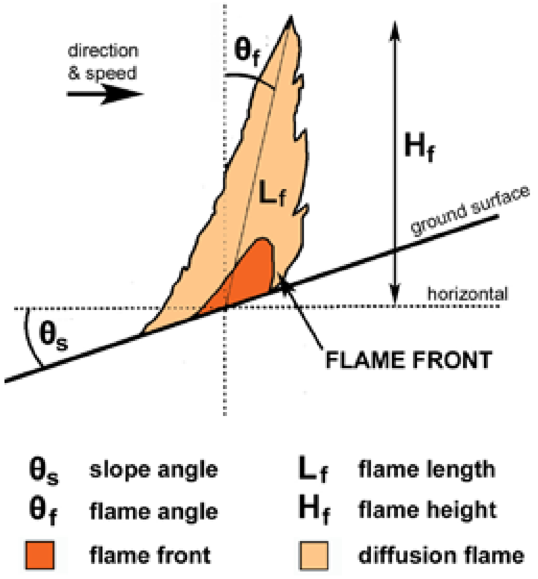

Figure 2. *The characteristics of bushfire flame (adapted from Weise and Biging 1996).*

Figure 3. *Victoria Range (Gariwerd) fuel reduction burning efficacy (redrawn from Forests Commission Victoria data 1985).*

of fires has dropped again to early Holocene levels (Kershaw et al. 2002). This suggests that, compared with the higher levels of the past 11 000 years, Australia's forests and woodlands are under-burnt, leading to a greater build up of fuels and a coincident increase in larger and hotter fires.

Bushfires are ignited by both natural and human agencies. In Victoria, there are over 600 bushfires on public land each year (McCarthy and Tolhurst 2001). Of these, 44% are caused by lightning, 14% by arson, 14% through 'public utilities' (unspecified), and 16% by inadvertent 'escapes' (Environment and Natural Resources Committee [ENRC] 2008). In Arnhem Land, while quantitative data is unavailable, lightning fires occur at the end of the dry season when fuels of tall dry grasses are at a maximum (Russell-Smith 1995a).

Fire, or combustion, occurs when fuels are ignited by heat in the presence of oxygen (Lang 1999). The chemical reaction produces large amounts of heat energy. In bushfires, the nature of the ecosystem will largely determine its frequency and magnitude. Fuel moisture, fuel size and spatial arrangement, temperature, humidity, wind speed and topography all contribute to the intensity of a fire. Fire movement is largely dependent on wind direction and wind speed (Lang 1999), although turbulent air currents, generated by the fire itself, cause its impact to be extremely variable within a burn area. Also, a longer burning fire has the potential to greatly increase its heat intensity due to internal convection drawing in 'air and heat not just from the fire-front, but also from burning fuels behind it' (Tolhurst 2010).

A fire undergoes three stages: preheating of fuels; combustion flaming with the front; and glowing combustion after the front has passed (Whelan 1995). Fine fuels (including leaf litter, twigs, bark and small branch-wood up to 6 mm diameter) ignite rapidly, while larger fuels, such as branches, are slower to ignite. Fine fuels, which are the major concern here, generally burn within the first 2–3 minutes and are characteristic of 'surface' fires (as opposed to 'crown' fires which involve tree-top burning). Fires are classified into low intensity burns (<500kW/m^2; such as prescribed or controlled burns) and high intensity burns (3000–7000 kW/m^2; such as severe forest fires). A severe bushfire or firestorm can have a 'very high' intensity up to 70 000 kW/m^2 (Cheney 1981: 156).

Following ignition, fire is induced ahead of the flame front through either heat conduction or diffusion. Diffusion flame is where the fuel and oxidants are brought together and the reaction takes place at the interface. The supply of air to the fire is sustained by the convection currents set up by the flame itself (Griffiths and Barnard 1995).

Flame can be measured in a variety of ways (Fig. 2). Ground slope and flame length and angle are the principal factors relevant to rock art preservation. Flame length is directly proportional to the intensity of the fire, and slope appears to significantly affect the angle of the flame (Weise and Biging 1996). Generally, a steeper slope will result in a faster moving and more intense fire, with longer flame lengths.

Grassland burns at around 300°C, grass-shrub at c. 550°C, and shrubs in excess of 1000°C (Whelan 1995: 14). The maximum temperature produced by the burning in air of gases generated from bushfires is thought to be 1925°–2200°C. Temperatures exceeding 1650°C have been measured in exceptionally intense fires. Such extremes are particularly unusual due to the considerable cooling effect of mixing with outside air (Countryman 1976). For bushfire applications, a flame temperature range of 725°C–1025°C (1000°K–1300°K) is generally expected (Midgley and Zhenxiang 2006).

Rockshelters, by their nature, are most often located on either steep slopes or in rocky terrain. This places them in a particularly threatened area, as flame speed doubles with every 10° rise in slope, and rocky topography creates wind turbulence that produces erratic fire behaviour (AFAC 1996).

In all but the worst scenarios, however, fire rarely burns all of the area within its perimeter, and usually only from 30%–70% of the available fuels (P. Billings, pers. comm., 1984). The size and location of burnt areas tends to relate to overall moisture and, in rocky areas, protection from the prevailing winds. In April 1984, an FRB in the Victoria Range of Gariwerd burnt over three days and under ideal conditions (see discussion below). Post-fire remote sensing photography in December 1984 indicated that the resultant burn produced an elaborate mosaic that was not restricted to the creek lines, but also included large areas along the crest of the range (Fig. 3). Hence, it is possible that individual sites within any burn area may not be subject to maximum heat, and may be completely bypassed by the fire front.

Fuel reduction burning (FRB)

Fuel reduction burning is a means of 'strategically reducing the fuel load' (leaf litter, grass, shrubs, elevated fuels, bark and living vegetation) in an effort to limit the spread and severity of any subsequent bushfire (McCarthy and Tolhurst 2001: 1). Other methods include mowing, raking and slashing; however, only burning is feasible for larger areas. While fire behaviour is determined by weather, topography and fuel levels, only the latter can be controlled to any extent. FRB involves 'the deliberate lighting of fires to burn within a predetermined intensity and in a predetermined time of year' (op. cit.: 2). In Victoria, FRB had been practiced for over 30 years and it has been found that 'the most obvious effects on subsequent bushfires are produced by FRB which are no more than two to four years old' (McCarthy and Tolhurst 2001: 22). There is a rapid decline in the probability of effectiveness after 7–8 years, and after 12–14 years the effect is almost negligible (op. cit.: 17). From an ecological perspective, the Foothill Heathy Woodland of Gariwerd (in which most rock art shelters occur) should have a low fire frequency of 10–20 years, with some areas remaining unburnt indefinitely (Wouters 1993: 12).

In the cases of particularly large areas, aerial ignition has the advantage of enabling large areas to be burned out in a reasonably short period, thus taking full advantage of any favourable weather conditions (Forests Commission Victoria n.d.: 102). Aerial ignition is the preferred method in Arnhem Land where ground access is extremely difficult (Ray Whear, pers. comm. 2005).

Fire damage

The principal threat to rock art from fire comes from exfoliation, of either surface pigment or the rock surface itself, caused by excessive heat directed onto the rock surface. However, fire also has the potential to create or exacerbate both the physical and chemical decay of the rock (McCabe et al. 2007). Fire creates a thermal shock by causing a sudden rise in surface temperature far greater than the substrate can accommodate. This causes a mechanical failure resulting in readily visible spalling (or exfoliation). It has been found that a rapid temperature increase of over 200°C is required to induce spalling (Roth 1975). Sandstone is particularly affected due to the high thermal expansion of quartz, requiring temperatures as low as 530°C to fracture quartz grains in quartz sandstones (Goudie et al. 1992).

Following a severe fire in the vegetation-rich Sydney-Hawkesbury region of New South Wales in 1979, an 8-m-high cliff suffered exfoliation up to 3–4 m above the ground (Selkirk and Adamson 1981). The spalls, around 20 mm thick, were thrown a distance of up to 2 m away from the face. Overall around 50% of the rock face was damaged with an average rock loss of 2–6 kg/m^2. Sandstone surfaces exposed by exfoliation are soft and friable for a depth of several millimetres, making them susceptible to rapid erosion by subsequent rainstorms or other agencies (Selkirk and Adamson 1981). Chemically, the heat can trigger changes in the rock matrix of the sandstone, which in turn can weaken the stone and make it more susceptible to physical weathering. Following the Sydney-Hawkesbury fire, the exposed friable surface continued eroding for 12 months before it stabilised.

Wood fire, such as bushfires, can also leave a waxy coating of soot on the rock surface (McCabe et al. 2007). This is not a permanent coating and is best left to natural weathering to remove. Attempting to wash soot off will result in simply smearing the soot, and cause further damage (Bjork 2009).

Spinifex fires, which are a principal concern in north-western Australia, can cause rock surface temperatures to rise rapidly to >800°C (Rosenfeld 1985: 33). To achieve these extremes, the rock would need to be within the 'flame zone' or 'flame front' (Fig. 2), the area in which there is sustained flame contact (NSWRFS 2006: 59).

Observation of extensive bushfire-induced exfoliation at Purnululu National Park, in northern Western Australia in 2008, supported the above findings. The area examined, on the southern side of the range, had supported a sandplain vegetation of open woodland with spinifex grassland (Fig. 4). The trees are low and sparse: Silverleaf Bloodwood (*E. collina*), Bauhinia (*Lysiphyllum cunninghamii*) and acacias; the understorey is dominated by grevilleas, Bunch

Figure 4. Purnululu bushfire showing burnt and unburnt sandplain vegetation.

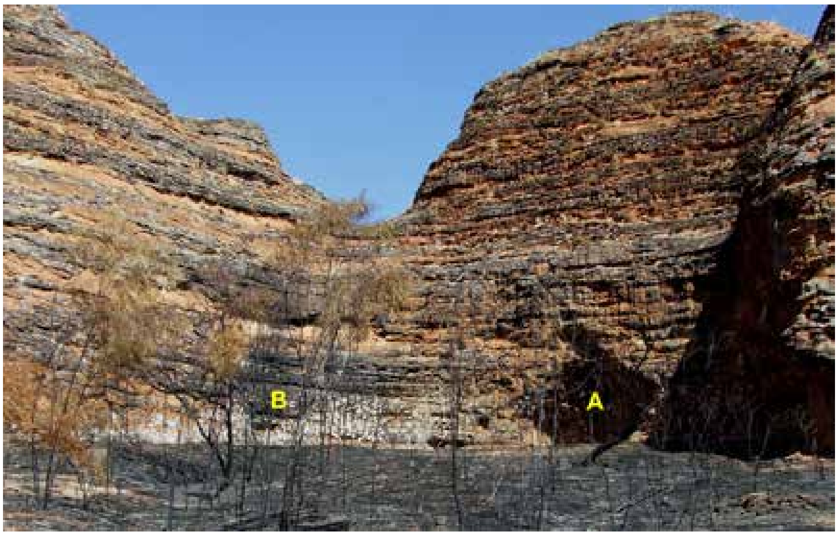

Figure 5. Purnululu showing alcove (A) and exfoliated wall (B).

Speargrass (*Heteropogan contortus*) and Soft Spinifex (*Triodia pungens*) (Hoatson et al. 2004: 21, 27). In the affected area, the sandstone outcrops in vertical-walled 'beehives' of Devonian sandstone and conglomerate, which is generally poorly cemented (pers. obs.). The fire caused massive exfoliation of the wall surfaces, mostly in a band up to 1.5 m high, but extending up to 5 m above the ground in some areas (Figs 5 and 6). The distribution of exfoliation around and within a shallow alcove in the wall, 2.5 × 2.5 × 1 m, was concentrated around the outer rim of the alcove and underside of the ceiling verandah (Figs 7 and 8). This suggests that the depth of the alcove, although very shallow, was sufficient to prevent the heat from damaging the rear wall and, had there been any rock art here, it is unlikely that it would be damaged (cf. Gunn and Whear 2009).

Similar patterns of exfoliation within rockshelters have been observed elsewhere at small shelters that had been screened by vegetation prior to burning (Fig. 9).

Hough (1987) observed only a minor area of exfoliation on the outer perimeter of a granite rockshelter in NE Victoria as a result of FRB. This was attributed to the burning of a dead tree that fell against the shelter wall at this point.

Fire greatly reduces soil moisture and can destroy soil-binding organic material to a depth of 25 mm below the surface (Clinnick 1984; Humphreys and Craig 1981: 181). (Increases in soil temperature are rarely noted below 50 mm.) This, combined with the opening of the canopy, exposes the soil to exceptional erosion by wind and water. These threats to the landscape generally have long been recognised (e.g. Brown 1972; Butzer 1974) as fire lowers the erosional threshold and amplifies the subsequent erosional response to rainfall for up to four years after the fire (Moody and Martin 2001). Hughes and Sullivan (1982) have suggested that Aboriginal firing

Figure 6. Purnululu wall exfoliation detail.

Figure 7. *Purnululu alcove profile.*

of the landscape during the Late Holocene was a major factor in the stripping of hill slope soils and, in some instances, in a dramatic increase in valley fill (alluvium). The duration of soil loss is dependent on the vegetation recovery rate (Clinnick 1984: 9).

In the Grampians and western Arnhem Land, rainfall runoff is the greatest cause of soil erosion through 'gully erosion'. Taking the form of dendritic rills near the top of the ranges and deep channels on the lower slopes, gully erosion is most commonly induced by heavy rainstorms following fires. The funnelling effect of rock outcrops most likely exacerbates the situation and the passage of such a redirected water-path through a rockshelter could displace large quantities of its deposit, reducing its archaeological potential within a few hours (pers. obs.).

Similarly, in California, following a major fire in 2005 which burnt out some 29 000 ha, an assessment of 871 petroglyphs, 502 pictograms and 149 cupules within 26 sites found that only two elements were destroyed but that another 42 pictograms and 34 petroglyphs were smudged by soot deposits (Christensen et al. 2005). They found that the indirect impacts from major flooding, sheetwash and rilling, which were a direct result of the fire, were present at ten of the sites. They therefore concluded that post-fire erosion may be the most serious impairment to the rock art.

Figure 8. *Purnululu exfoliation around and within the alcove.*

Aborigines and fire

As a background, it is essential to consider the role and impact of Aboriginal fire use in relation to both landscape and rockshelters. Palaeoecological data suggest that fire has been a constant factor of the Australian landscape for the last 7 million years (Lang 1999). Humans have been using fire for at least 750 000 years and so it is likely that the first people into the continent had a good understanding of its management. In support of this is the dramatic increase in fire frequency concurrent with their presumed arrival (Lang 1999). Prior to the cessation of traditional Aboriginal lifestyles, throughout the mainland and Tasmania fire was used as a tool

Figure 9. *Gariwerd small alcove showing a similar pattern of exfoliation.*

in hunting and gathering as well as domestically for warmth and cooking (Jones 1969; Gould 1971; Hallam 1979; Gott 1983, 2002; Latz 1995). Curr described how the Aborigines of the Echuca region were constantly setting fire to the bush, both accidentally and systematically for hunting purposes, and that the fire-stick was an instrument 'which must be credited with results which it would be difficult to overestimate' (cited in Barr and Cary 1992: 12). However, the reliability of historical records and dendrochronology and other scientific methods must still be treated with caution (Miller et al. 2007) and a parliamentary report concluded that a lack of uniformity in fire use by Aboriginal societies was due to: variations in vegetation types; different cultural reasons; and the fact that some areas were not regularly occupied by people and therefore were not required to be managed or stimulated by fire (Esplin et al. 2003). It is generally acknowledged that traditional Aboriginal firing of the landscape was considerably more frequent than is the current situation.

Fire also had ceremonial uses and featured prominently in the mythology of much of Australia (Spencer and Gillen 1899; Maddock 1970; Mountford 1956: 208–211; Chaloupka 1993: 56–59).

In western Victoria the myth of the acquisition of fire by the Aborigines is tied specifically with Gariwerd (Dawson 1881: 53–54). In this myth the wedge-tailed eagle, who is equated with Creator Being *Bunjil*, gives fire from Gariwerd to the Aboriginal people. Lightning fires, which have been common in Gariwerd for at least the past 3000 years, were called 'supernatural fires belonging to thunder'. As thunder was the voice of *Bunjil* (Dawson 1881: 49), such fires could be the fires referred to in the above myth. However, lightning was one of the forms of *Muuruup*, a bad spirit of whom the Aboriginals had a great dread, especially at night (ibid: 49). Fire caused by lightning was therefore superstitiously avoided because the lightning 'hangs around the spot and would kill anyone going near it' (Dawson 1881: 53). The high frequency of lightning fires, 'up to ten such fires may occur almost simultaneously' (Forests Commission Victoria 1977: 10) suggests that the mythological references to the crows 'throwing fire sticks about' (Dawson 1881: 54) had a factual basis.

It is therefore probable that the Grampians were fired, by either the Aborigines or lightning, on a regular basis. As a result the vegetation here, as in Western Australia, would have consisted of 'tall straight, mature trees, all frequently scorched but clear of undergrowth and easy to move through' (Hallam 1979: 17; note also Haglund 1984). This was certainly the case for the foothills of the Grampians, which Mitchell described as being 'grassy forests' (Mitchell 1839: 171–3). Similarly, Hallam's ethnographic accounts from south-west of Western Australia in the early nineteenth century was probably true for most parts of Australia, namely that

> most of our virgin bush is fire climax vegetation and that Aboriginal firing of the bush must have been an important factor in the establishment and maintenance of this vegetation pattern (Hallam 1979: 7).

Hallam also concluded that this firing was mostly carried out around early spring (ibid). Such a time strategy would coincide with the archaeological evidence for the seasonal use of the Grampians (Coutts and Lorblanchet 1982: 95). To date, however, no studies have been undertaken on this aspect of Aboriginal use in the Grampians, despite its significance to the archaeological record and despite the fact that it may have been a major factor in determining the status of the present flora and fauna of the area.

In a contrasting paper, Horton (1982) argues that the Aborigines had no significant effect on the country's flora and fauna. He suggests that fire has been, at least throughout the Pleistocene, as much a part of the natural scene as drought and flood (1982: 249) as the Aborigines, after noting the natural succession, only provided an alternative source of ignition and in such a way that they did not alter the natural fire regime (ibid). In forested areas (such as the Grampians and Arnhem Land) he claims that there was no need for artificial firing as these areas already had sufficient ignition (from lightning) to achieve their fire potential (op. cit.: 247).

In the Sydney basin, Hughes (1978: 41) proposed that the traditional Aboriginal use of rockshelters was a major factor in accelerating their deterioration (and enlargement). This was promoted by, among other things, 'influencing the shelter environments through changes in temperature and humidity, particularly by the lighting of fires' (ibid). Hughes also suggested that this factor could apply to the art sites within Kakadu National Park, western Arnhem Land (Hughes and Watchman 1983: 51). In both cases, however, he seems to be considering only 'camp fires' within the shelters rather than the broader range of fire types used by Aborigines (cf. Jones 1969) and in neither case is wildfire discussed.

In northern Australia, fire is well recorded as having been a regular and regulated occurrence, both through traditional burning practices and lightning strikes (Jones 1969; Haynes 1985; Russell-Smith 1995a; Thompson 2003). On account of the general annual division of a wet and dry season, the burning-off of tall grasses is traditionally done during April-May at the beginning of the dry season when the grass begins to cure. At this time the burn is usually cool and extinguishes overnight, creating a natural mosaic pattern across the landscape. If left to later in the dry season (July-August), fires will be much hotter and can run unchecked for days, destroying hundreds of kilometres of much valued vegetable foods (Russell-Smith 1995a; Wiynjorrotj et al. 2005).

Gariwerd and Burrunj

Gariwerd is an isolated range of quartzose sandstone and contains the highest and most visually prominent ranges in central western Victoria (Fig.

Figure 10. *Gariwerd ranges showing their rugged relief amidst the surrounding plain.*

10) which, today, are mostly encompassed within the Grampians National Park. The ranges consist principally of north-south trending strike-ridges, with broad intervening valleys and heavily dissected gullies. The peak, Mt William in the central ranges, is 1160 m above sea level (just into the snow line) and 800 m above the surrounding plains (Day et al. 1984; Calder 1987; Twidale and Campbell 2005: 125). The northern ranges are considerably lower, reaching 500m at Mt Stapylton at the extreme northern end.

At the time of European settlement, Gariwerd was subdivided between the country of Jardwadjali and Tjap wurrung people (Clark 1990). Evidence indicates that Gariwerd was initially occupied over 22 000 years ago (Bird and Frankel 1998; Bird et al. 1998). The Gariwerd ranges have the highest concentration of rock art in the State, and over half of these occur in the Victoria Range (Gunn 1984a, 1987b). These comprise three separate periods of artwork: an early phase of well-permeated red painting; an intermediary phase of dry pigment drawings in red, white and charcoal; and a more recent phase of surface crusted white paintings (Gunn 1987b, 2005, 2008). No ages are available for any of the phases. However, the deteriorated state of many of the red paintings suggests they have considerable antiquity, while the crusted pigment of the many of the white paintings suggests a relatively recent production. Hence the rockshelters and evidence of their occupation, if not necessarily the artwork, has been subject to bushfires of varying intensity and frequency for at least 22 000 years.

Burrunj (the Black Range and outliers) lies immediately west of Gariwerd and is of the same geological formation with a contiguous flora and fauna. The main range is now within the Black Range State Park and also contains a concentration of rock art consistent with that in the body of Gariwerd (Gunn 1987b).

The climate is generally mild with highest maximum and lowest minimum temperatures in the order of 44°C and -2°C (February and July respectively; Bureau of Meteorology, Australia: web-site for Stawell). Summers are generally hot and dry, but with occasional lightning-bearing thunderstorms, while winters are normally cold and wet. Severe frosts are common on the plains around Gariwerd and occasional heavy snow settles on the higher peaks (Day et al. 1984: 8). The average annual rainfall of the central ranges is around 750–1000 mm, but it is significantly lower in the northern ranges where it drops to around 550–650 mm (op. cit.: 6–7). While this parallels a change in vegetation from south to north, due to the nature of its eucalypt woodland and differences in altitude, both areas are equally fire prone.

The dominant rocky woodland is composed principally of Brown Stringybark (*E. baxteri*) and Oyster Bay pine (*Callitris rhomboidea*), with a diverse shrubby and carpet understorey (Day et al. 1984: 40 and 57). The intervening valleys and surrounding plains are dominated by heathland. The vegetation is highly flammable over the dry summers and, as the area is prone to lightning strikes, bushfires are common (op. cit.: 64). Over the years this has doubtless had an effect on the survival of scarred trees and other organic artefacts (Gunn 2009). Those caused by lightning and arson are usually in the hottest and driest times of the year and are likely to be the most devastating. However, regeneration from fires in the Grampians is rapid, with regrowth 'softening' the landscape after the first 12 months (Wouters 1993: 6).

From 1872 to 1984, the area was managed by Forests Commission Victoria as a State Forest (Day et al. 1984). In 1984, 168 000 ha was included within the Grampians National Park, which has since become one the State's premier tourist destinations, catering for over one million visitors annually. As mentioned above, lightning strikes are the greatest cause of bushfires on Public Land in Victoria (44%; ENRC 2008: 22), which is where 99% of all shelter rock art is located. Fire, in the form of bushfires and controlled burns, is therefore an ever-present feature of Gariwerd and an ongoing factor in rock art management.

The fire history of Gariwerd

Documentation of the fire history of Gariwerd was begun in 1918 (Day et al. 1984: 64), but systematic records have only been maintained since the devastating bushfires of 1939 (Parks Victoria files). These records detail both bushfires and FRB. As the impact of both

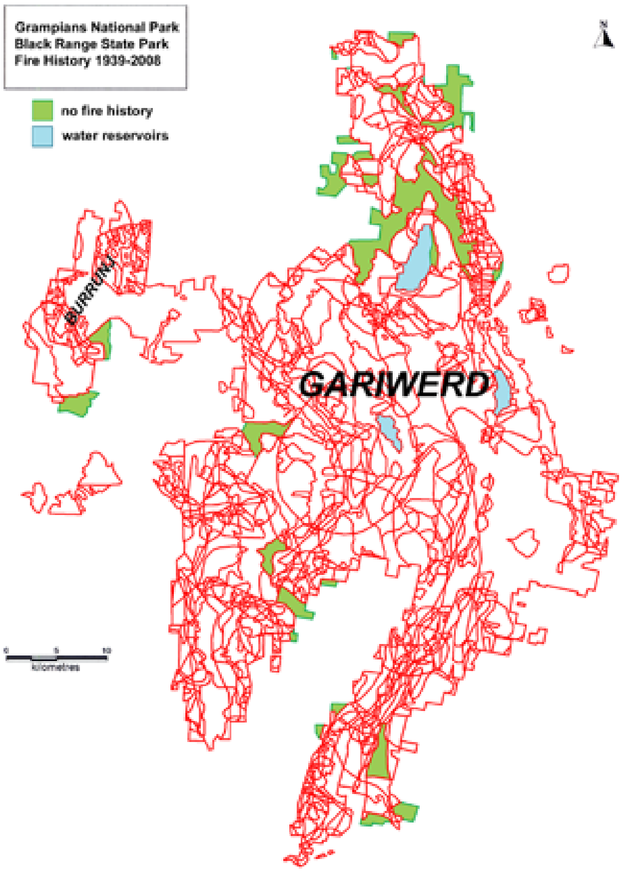

***Figure 11.** Gariwerd-Burrunj fire history map 1939–2008 (courtesy Parks Victoria).*

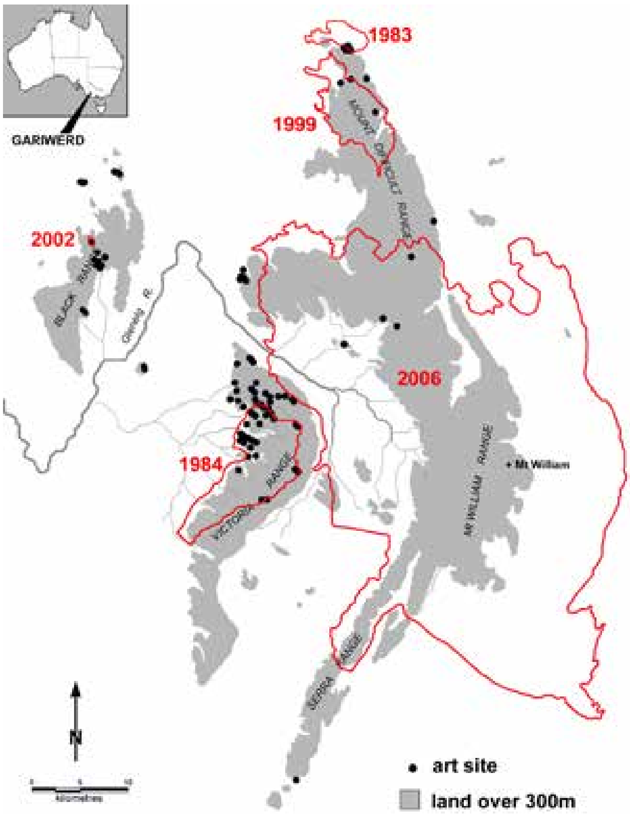

***Figure 12.** The five study areas within Gariwerd-Burrunj.*

types of fire is similar on rock surfaces, a combined map of both types (Fig. 11) indicates that very few areas of the Park have not been burnt in the past 70 years. Although even the hottest fires will produce a mosaic effect of heavily and lightly burnt patches, it can be expected that over this time, most areas with rock art sites will have been highly impacted. A number of studies of the effect of fires on rock art sites have been undertaken since 1983 (Gunn 1984b, 1987a, 1999, 2002), and each of these will be summarised below.

1983 Stapylton bushfire

A bushfire, on the 22 February 1983, burnt some 1200 hectares of the Mt Stapylton-Mt Zero range, at the northern end of the Park (Fig. 12). This area included three rock art sites. The larger art site, Gulgurn Manya, then known as FR-1 (VAHR 7374-013), was a promoted visitor destination but its only management infrastructure at the time was a cyclone mesh grille. The other two shelters were small with little artwork and had no active management. The intensity of the fire was rated as extreme by Forests Commission Victoria (P. Billings, pers. comm. 1983). The vegetation around the Gulgurn Manya art shelter consisted of Oyster Bay pine, Brown Stringybark, grass-tree (*Xanthorrhoea australis*), and an encompassing dense understorey of tall heathy plants. The pre-fire fuel load in front of the shelter was estimated at 12–15 tonnes/hectare, and unlikely to have been burnt for at least 45 years (P. Billings, pers. com., 1983). The fire reduced shrubs with stems up to 30 mm in diameter to ash, and left only the charred trunks of larger shrubs and trees (Fig. 13; Gunn 1987a).

Rock exfoliation and fire blackening, which were obvious throughout the burn area, were not detected inside the dripline of any of the shelters. The only visible impact at any of the three sites was a dusting of fine ash on the shelter floor and on top of the large block within FR-3. None was observed on the art panels, which are either overhanging or vertical. In contrast, outside the shelters, the ash formed a carpet up to 50 mm deep. Rock exfoliation outside the shelter was most intense on surfaces that had been in direct contact with vegetation. While irregular in size and shape, most exfoliated spalls were around 80 × 50 mm in area and penetrated to a depth of up to 5 mm.

1984 Victoria Range fuel reduction burning

Fuel reduction burning was carried out by Forests Commission Victoria (FCV) in the Victoria Range over three days in April 1984. Prior to the FRB, the fuel load of the area (primarily ground litter) was in the order of 70–120 tonne/ha (FCV quoted in the *Stawell Times-News* 19/4/84). This was well in excess of the normal range for FRB of around 15 tonnes/ha. The threshold of floor fuel for site safety is unknown, though a level of 5 tonne/ha was considered reasonable (P. Billings, pers. comm., 1984).

Previously, the three largest fires, which together burnt most of the western half of the Victoria Range, all predate existing records (hence pre-1965). It is believed that these fires all occurred around 1900, concurrent with the development of the area for grazing (P. Billings, FCV, pers. comm. 1984). At that time it is likely that these fires would have been of a lower intensity than similar fires today because of the more open vegetation structure. Other smaller fires that may have affected art sites occurred in 1962, 1966, 1967, 1970 and 1977. As a consequence, none of the art sites within the 1984 FRB area had been burned for at least 15 years and possibly for most it was around 80 years. This would account for the surrounding vegetation being at a maximum and the fuel load being so exceptionally high.

Figure 13. *Gulgurn Manya shelter post-fire 1983.*

Of the 23 art sites recorded within the area prior to the burn, 12 were noted to have vegetation within their overhangs (Gunn 1981). Five of these were considered particularly vulnerable to the effects of fire due to their inclined rear wall and the close proximity of the vegetation (pers. obs.). Despite Ministerial pronouncements (*Ararat Advertiser* 14/4/84), however, no special measures were instigated to protect the art sites.

The days were forecast to be almost windless and with temperatures in the low twenties (Celsius). After back-burning the perimeter of the area, aerial incendiaries were used to fire large tracts of the range simultaneously so that full advantage could be taken of favourable weather conditions. This method produces parallel rows of dotted fires about 500 m wide and 100 m apart. In theory, these fires remain small as they burn out when they reach an adjoining fired area. The pattern was laid from the south-west, along the base of the range and burnt uphill in a north-easterly direction. The operation was essentially completed in the three days and was followed by a series of rainstorms. Despite these heavy rains however, large logs with cores of glowing coals were observed two weeks later, and smouldering stumps were still to be found in June, two months after the firing. On the ground it was clear that the fire had burned with varying intensity, as in some areas only light ground litter had burned, while elsewhere, only the skeletal stalks of the larger shrubs and trees remained. In general, the fire was much more intense around the crest of the range where the upper tree canopy was burnt and many large trees were felled and incinerated. Unlike in the 1983 wildfire, exfoliation was not widespread but, where it did occur, was often extensive.

Satellite photographs (Landsat 4, colour image, 29.4.84) taken two weeks after the burn, showed that within the designated burn area there was a patchwork of lightly (<50%) and heavily burnt (>50%) burnt areas (cf. Fig. 3). The photographs also showed a large (1600 ha) breakaway had occurred in the south-east, and revealed a serious problem in FRB management in relation to the unexpected impact on other art sites.

The post-fire survey found that no artwork had been damaged but that rock surfaces had been damaged in two shelters and the floor deposit had been damaged in another (Gunn 1984b: 11).

Two shelters were found to have recent exfoliation most probably due to the fire: CC-13 (VAHR 7323-047) and HSC-4 (7323-005). CC-13, on the crest of the range, had two areas of exfoliation. One was on the same rock panel and two metres to the east of the recorded paintings. This area was 1.0–1.5 m above the ground and at the same level as the artwork. The exfoliation was likely caused by heat from burning shrubs that leant into the shelter. Further expansion of this area was seen as a potential threat to the paintings. The other area consisted of several small spalls along the base of the rear wall, up to 20 cm above the ground. This was clearly caused by the combustion of grasses growing along the interface. As this exfoliation was within a different rock layer to the artwork, it was considered unlikely to prove any future threat to the paintings.

HSC-4 lies near the base of the range and, as predicted by Lorblanchet (1975: 41), suffered considerable exfoliation on its rear wall up to 1 m above the ground. This was caused by the burning of small shrubs and grasses that were growing within the shelter. As this area was some five metres to the east of the artwork it was not considered a potential threat to the long-term

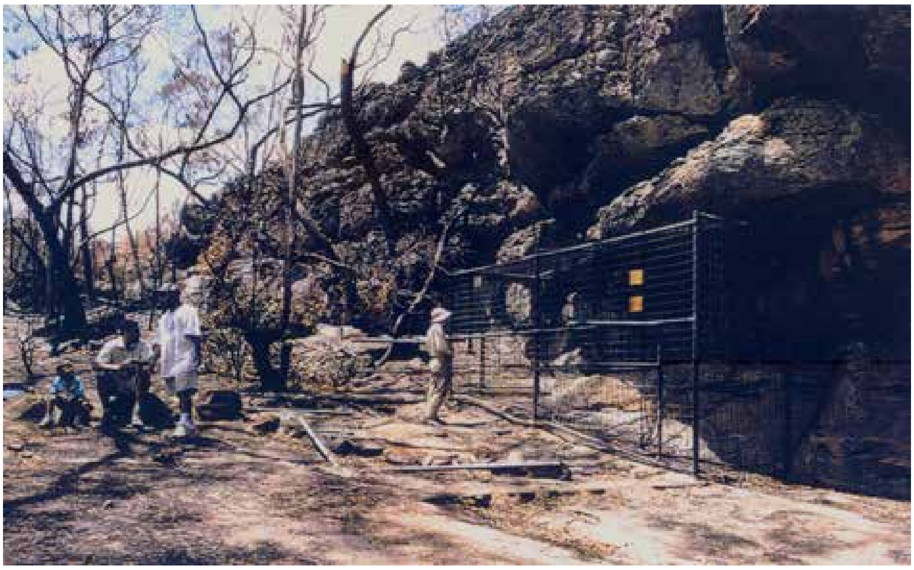

Figure 14. Ngamadjidj shelter showing destroyed boardwalk and heat-buckled grille.

preservation of the paintings.

At CC-15b (VAHR 7323-0058), the stump and root system of an old tree (diameter c. 25cm) that had grown from the deposits, were completely burnt out. This produced a depression some two metres in diameter and 40 cm deep. Although the initial growth of the root system would have considerably disturbed these deposits, the roots did bind the soil against erosion to which they then became exposed. The combustion of the roots system of the tree also introduced heat, air and modern charcoal into the deposits and further reduced their archaeological integrity.

The deposits at three other sites also appear to have suffered minor disturbance through the burning of small shrubs and reedy grasses. Again, this burn appears only to have exacerbated what was most probably previously disturbed material.

It can be concluded that all of the sites within the Victoria Range have been previously affected by bushfires and/or FRB (Tables 1 and 2). It is clear, however, that fire damage can still occur to rockshelters although there is no evidence of damage to any existing artwork. It was also concluded that soil erosion was a particular threat prior to the floor deposits restabilising. Further, as a number of bark and wooden artefacts had been located within these shelters as surface finds (Gunn 2009), the more often the shelters are exposed to high intensity fires, the more likely that any as yet undiscovered organic artefacts may be destroyed by fire.

No. of fires	No. of sites
Three	8
Two	28
One	14
Nil	3
Unknown	3
TOTAL	**56**

Table 1. Victoria Range sites: fire subjection frequency as at 1985.

1999 Mt Difficult bushfire

On the 5–7 January 1999, a lightning-sparked wildfire burnt approximately 5500 ha in the northern section of the Grampians National Park and around 500 ha of adjacent freehold land (Fig. 12; Gunn 1999). Eight recorded archaeological sites were within the fire area, including three rock art sites. One of the art sites, Ngamadjidj (VAHR 7423-016; Gunn 1983a, 2003a), had been extensively developed and was promoted as a tourist attraction that included a large wooden boardwalk in front of the shelter.

The fire was started by lightning and was fanned by high wind gusts of around 30–40 kph (Gunn 1999). At its peak the fire travelled very rapidly for a forest fire, at 2–3 kph on the ground. Daytime temperatures were extreme over the period (35°–38° C). Most of the area had not been burnt for around 30–40 years and so the fuel rating was heavy. The intensity of the fire was similar to that of the 1983 Stapylton fire.

Ngamadjidj shelter is an open shallow recess with an elevated vertical panel of white pigment paintings. The fire burnt the area around the shelter, incinerating the site's wooden boardwalk, installed in 1993, and the weldmesh grille was heat-buckled, presumably as a result of the burning boardwalk (Fig. 14). The interpretative signs affixed to the grille were also destroyed. Amazingly, the visitor book and stand 50 m in front of the shelter were untouched, although the Stapylton Campground beyond was also guttered.

Despite the obvious intense heat, and the burning of the low vegetation within the grille, the artwork showed no signs of heat damage, although a light and patchy ash layer covered the rock bench in front of the art panel. The art panel had acquired a light coating of pinkish dust, which is most likely to have come from the adjacent car park, developed in 1992.

Year	Pre-1955	1962	1966	1967	1971	1970	1977	1981	1984	No burn
No. of sites	44	3	6	3	3	1	1	2	31	3

Table 2. Victoria Range sites: fire subjection by year as at 1985.

Consequently it is likely to have accumulated over a prolonged period and is not attributed to the impact of the fire or fire-fighting activities. This would now be difficult to prove (see also Thorn 1999).

Following a detailed assessment of the artwork, Thorn (1999) concluded that the bushfire had had no impact on the painted area.

Pohlners Track Cave (VAHR 7323-053) is a low but deep cave (4 × 8 × 2 m) with a flat floor and a suite of thick white paintings on its vaulted ceiling (Gunn 1981). The vegetation around the shelter was heavily burnt by the fire and the leaf litter on the floor burnt two metres into the cave, and partially under the art panel. The shelter had not been monitored since its initial recording in 1980.

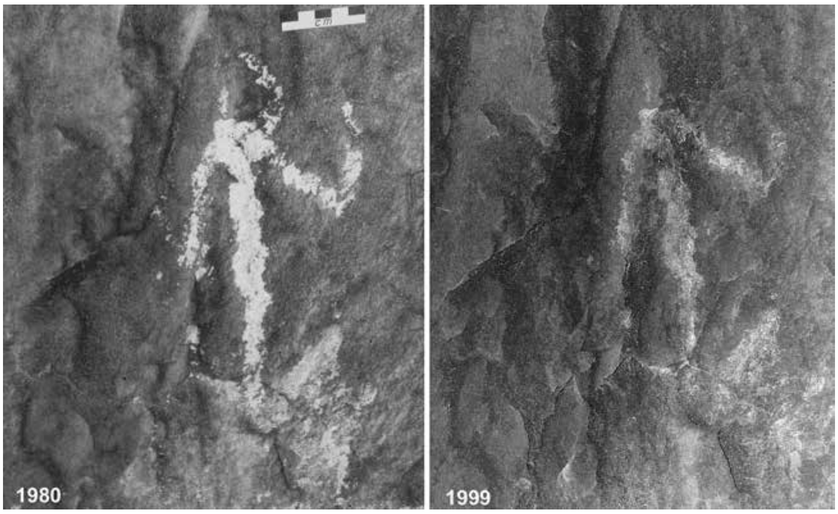

Figure 15. *Pohlner's Track Cave motif 1 in 1980 and 1999.*

The immediate observation was that the fire had smoke-blackened the entire painted wall section including all of the motifs (Gunn 1999). The head of the largest human figure motif had exfoliated (Figs 15 and 16), and many of the previously recorded motifs to the lower left and lower right could not be relocated. It was unclear whether they had been destroyed or simply covered by the ash. Cleaning tests were unable to improve the brightness of the pigment suggesting that it was not coated. Thorn was therefore unable to confirm that the pigment had in fact been brighter in the past (Thorn 1999). This result reinforces the need for regular photographic monitoring of art sites. Also, and despite the burning of the leaf litter, an inverted grindstone bearing white pigment within the shelter was not damaged.

At Briggs Creek 1 (VAHR 7325-067), the fire burned around and within the western half of the shelter, including the felling and incineration of a 20-cm-diameter tree. A steep area of vegetation at the eastern end of the shelter was not burnt. The fire caused areas of exfoliation on the floor rocks, particularly around the felled tree. A 50-cm-diameter spall was dislodged from the rear wall during the fire, as it was found overlying burnt vegetation. A second large spall (50 cm) had been dislodged from the rear wall but this predated the burning of the shelter floor. It is not clear whether the fire induced this fall or whether it was a result of earlier natural processes. The fire burnt to within 5 m of the art panel but small, twiggy shrubs growing beneath the artwork were unaffected. Had these shrubs burnt, some damage to the motifs could have been expected.

It was also concluded that open artefact scatter sites exposed along roadways within the fire area would have been disturbed to a considerable extent by fire-fighting vehicles.

2002 Graham's Rocks bushfire

In March 2002, a lighting strike caused a fire that burnt 350 ha in the Graham's Rocks area of Burrunj (the Black Range), 20 km west of Gariwerd (Gunn 2002). Graham's Rocks is a low sandstone outcrop immediately adjacent to the Black Range State Park that had been largely hidden from sight by dense vegetation. Although small, the fire was intense with many large areas of exfoliation on exposed rock faces. Prior to the fire, no archaeological sites were known from the outcrop. The incineration of the vegetation and a subsequent rainstorm, however, made a thorough survey possible. Two rock art sites and three open surface scatters were located (Gunn 2003a), giving the outcrop a similar archaeological significance to other outcrops in the vicinity (such as Mt Talbot 4 km to the north; Bird 1995). No signs of fire damage were located within either of the shelters but erosion of the now exposed surface scatters was considered a potential problem.

2006 Mt Lubra bushfire

In January 2006, a lightning strike began a fire on the slopes of Mt Lubra. It burnt for eight days in a spiral pattern, destroyed 130 000 hectares of bush and farmland, and was the largest in the region for many years.

A summary tabulation of a site inspection carried out by staff from Parks Victoria and Aboriginal Affairs Victoria (Table 3) found no damage to the seven art sites within the burn area. Two scarred trees were burnt, one partially and the other totally. The extent of three open artefact sites was expanded due to greater visibility.

Arnhem Land

Recent rock art surveys in the Jawoyn lands of central and southern areas of the Arnhem Land plateau (Fig. 16) have recorded many art site complexes, both

SITE TYPE	No damage	Not located	More detail	Damaged
Isolated artefacts	14	13	1	
Artefact scatter	6	1	2	
Art shelter	7			
Stone quarry	1			
Scarred tree	2			2

Table 3. *Summary of 2006 post-fire assessments.*

prior to and following bushfires and FRB (e.g. Gunn and Whear 2007). The area consists of an elevated and deeply dissected sandstone plateau rising to 400 m above sea level and 200 m above the surrounding plains. The western margin is an almost continuous cliff line. To the south and east the plateau grades into rounded hills. The plateau is composed of horizontally bedded quartz sandstone with varying degrees of cementation and case hardening (Russell-Smith et al. 1995). The region contains one of the densest concentrations of rock art in Australia and most probably in the world (cf. Edwards 1979; Chaloupka 1993), with the older artwork considered to be in excess of 10 000 years old (Chippindale and Taçon 1998).

Unlike Gariwerd, the plateau climate is dry monsoonal with a distinct bi-seasonal division between the wet season and the dry season (Russell-Smith et al. 1995; Wiynjorrotj et al. 2005). Temperatures are high throughout the year, with a daytime average of 34°C. Night-time temperatures vary from warm in the wet season (25°C) when humidity is high (70–90%) to cool in the dry (10°C) when humidity is low. The annual rainfall on the plateau is around 1300 mm, with the bulk of this falling during the wet season between November and April, but in most years evaporation exceeds rainfall.

Figure 16. *Arnhem Land plateau landscape showing rock art complex and surrounding vegetation.*

Figure 17. *Typical flame height of fuel reduction burning within the plateau.*

The soils on the plateau are skeletal sands and the vegetation is dominated by eucalypt low open woodland (*E. tetrodonta, E. miniata, E. ferruginea*) with a tall grass understorey (*Heteropogon triticeus, Sorghum plumosum*) (Russell-Smith 1995b). Within the gorges and around springs there are pockets of escarpment rainforest (dominated by *Allosyncarpia ternata*) which is mostly fire-tolerant. Fires throughout the region are typically low intensity grass fires, with crown fires almost unknown (Russell-Smith 1995a). Typically, flame height is around 1–2 m (Fig. 17; Gunn and Whear 2009). Traditionally, the Jawoyn would burn the country in Pangkarrang, at the beginning of the dry season, to promote green growth (Wiynjorrotj et al. 2005).

Evidence from rockshelter excavations has shown that sites around the plateau were occupied at least 40 000 years ago (see discussion in Hiscock 2008: 34–37). The rock art within the plateau and outliers appears to date to at least the terminal Pleistocene-early Holocene (c. 10 000 BP). Following the Second World War, Aboriginal people drifted away from the plateau and traditional burning was discontinued. In recent years, the current land managers, the Jawoyn Association, in collaboration with the North Australian Fire Information

Service (NAFI), has begun a systematic program of early dry season aerial burning. Consequently, as in Gariwerd, fire in the form of either bushfires or FRB has been and continues to be an ever-present feature of the plateau environment.

Few studies of fire and rock art have been undertaken in the region. In Kakadu National Park on the north-west corner of the plateau, lightning struck a tree which then fell against the wall of a large shelter (Thorn 1999: 2). Spalling of the rock face extended up to a metre from the tree itself. In this case, Thorn noted that the tree would have burned for 'several hours and that the rock would have had a good deal of heating time' (Thorn 1999: 2).

Following a bushfire in the Nitmiluk National Park in 2008 an assessment was made of three site complexes that had been affected. No deleterious impacts were observed, with the fire in most cases stopping at the dripline where the vegetation thinned out. In the only case where fire entered a shelter, the burning vegetation did not cause any damage to the artwork.

Since 1995, the Jawoyn Cultural Heritage Project has recorded 103 rock art complexes with 560 art sites. It is expected that all of these sites will have survived fires in the past. Also, while about a quarter of the complexes recorded were recorded within days or weeks of FRB, no definite examples of fire-induced damage have been noted in any of the shelters, even though exfoliation of exposed rock surfaces elsewhere is common.

As with fires in Gariwerd, it was concluded that

- fires rarely enter a shelter due to a break in the vegetation at the dripline (Fig. 18); and
- fires rarely cause exfoliation within rockshelters.

It was also found that the field surveys greatly benefit from pre-burning, through both higher quality results, due to increased visibility, and greater time efficiency (Fig. 19).

Discussion

Although the evidence to date suggests that burning vegetation due to bushfires or FRB is not a major threat to shelter rock art sites, should fire encroach upon a shelter, the damage would be irreparable and the loss disastrous. The threat to rock surfaces from fire is essentially related to five factors:

- Quantity of adjacent fuel
- Type and arrangement of fuel
- Topographic situation of the outcrop
- Temperature
- Wind direction and velocity

The first two of these, which includes management infrastructure as well as vegetation, can be and should be controlled.

The evidence of existing sites suggests that art within rockshelters with a low ceiling and concave plan (types formed by cavity erosion of the bedrock) that enclose or partially enclose their floor area, will not be seriously damaged by wildfire (Gunn and

Figure 18. *Fire limit at the shelter dripline despite dry fuel within the alcove.*

Figure 19. *Rock art survey following fuel reduction burning.*

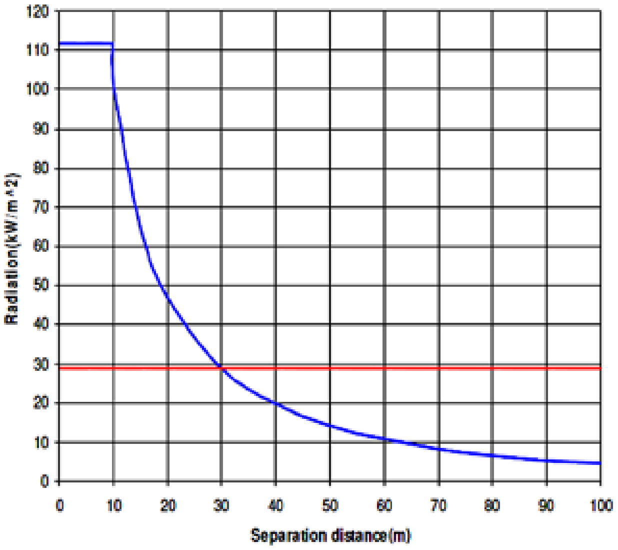

Figure 20. *Radiant heat flux-distance profile (from Midgley and Zhenxiang 2006).*

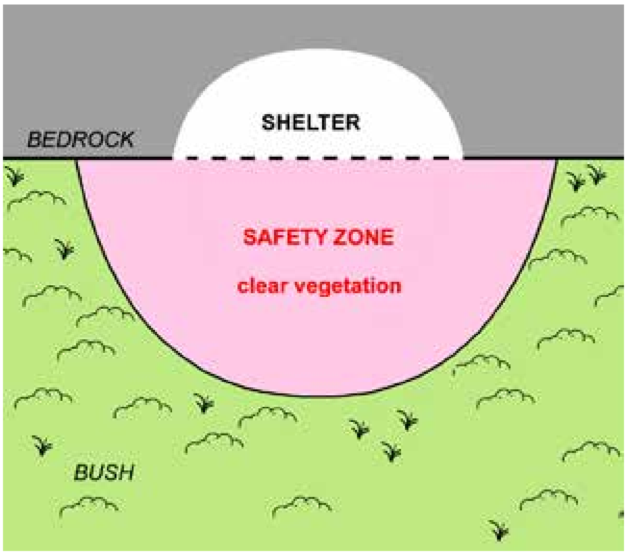

Figure 21. *Vegetation clearance area.*

Whear 2009). In contrast, sites where the rear wall is inclined at a steep angle and that have an essentially straight plan (types formed by the undercutting of the bedding plane) are much more prone to damage as they are more likely to have vegetation in close proximity to the rock surface.

However, while rock art was doubtless painted on exposed surfaces, either out from or adjacent to rockshelters throughout Australia (cf. Gunn 2003b), these images are likely to have been destroyed by the more frequent rain wash than by periodic fire. Hence, the artwork that we record today is only likely to be found in the more protected places, such as behind bare living floors. These archaeological floors support little in the way of vegetation as, being 'living areas', they were used primarily because they are the driest areas of the shelter. Consequently, the use of emergency 'shields', such as proposed for the United States (Loubser 2002: 24), is unwarranted here.

A factor that has not been incorporated into these observations, however, is that of 'climate change'. If the change does bring about more frequent and hotter fires throughout Australia, as the recent spate of catastrophic fires in SE Australia suggests, then the effect on rock art and other cultural sites may be substantially greater than the past fire histories indicate.

Site defence

The primary management zone for a rockshelter is that area directly to its front. The well-established management recommendations for the protection of rock art sites involve vegetation clearing or frequent low-intensity firing in the vicinity of the sites (Rosenfeld 1985: 34; Lambert 1989: 22). From a radiant heat flux-distance profile (Fig. 20), to prevent rock art from being within the flame zone, vegetation on flat ground should be cleared for a minimum of 20 m in front of the shelter (Fig. 21). However, from the observations presented above where exfoliation has only been observed in instances where vegetation is in direct contact with the rock surface, it is recommended that such a distance is unnecessary, even on sloping ground where the flame threat is greater. In Gariwerd, for instance, a minimum distance of 10 m should suffice, while in Arnhem Land a five meter buffer would be sufficient in all but the most extreme fire events. In north-east Victoria where the forest is taller and slopes steeper, however, a zone of 20 m is probably appropriate for site safety. This zone will require the thinning of trees, the pruning of lower branches and the removal of all shrubs, tall grasses, loose bark, leaf litter and other fuels. Tree removal, however, should only be undertaken following an assessment of the effects of solar impact, which may be greater than that of a fire (Thorn 2005).

Also, while FRB removes or reduces fuel loads from around rockshelters, it needs to be reiterated that the maximum 'period of usefulness' of such burns decreases rapidly after five years, due to vegetation regrowth, and that after 10 years the effects of an FRB become negligible (McCarthy and Tolhurst 2001: 25).

Conclusion

From these results it appears that neither bushfires nor FRB pose a major threat to existent rock art or other archaeological sites in these study areas. Such fires, however, can cause irreparable damage to particular sites as a result of local and untimely factors such as heavy vegetation or fuel loads, wind direction or drainage. In most cases damage can be avoided by the implementation of suitable pre-fire management programs.

Bushfire and FRB open up unique opportunities for additional site survey work, particularly the more uncommon types such as stone arrangements, water sources (rock-holes and springs), and scarred trees which are generally more obscured by vegetation. (The threat of fires to scarred trees is equivocal).

Hence it is concluded that bushfires do not pose a threat to shelter rock art sites and, effectively managed, fuel reduction burning should prove beneficial in the management of rock art and other archaeological sites.

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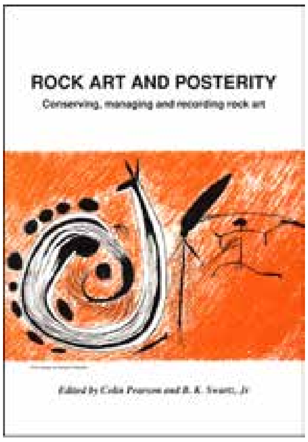

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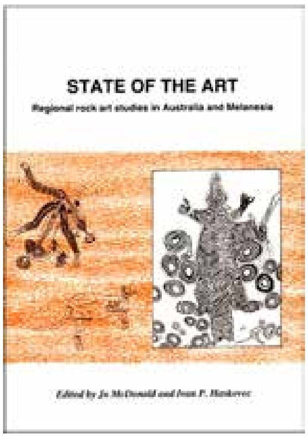

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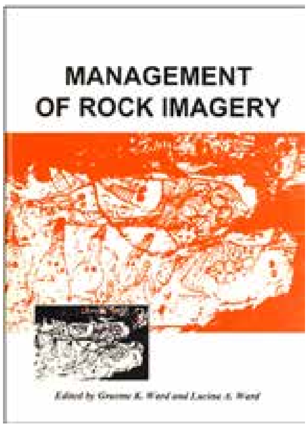

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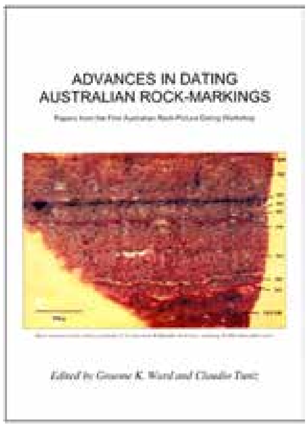

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