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# Fission Track Dating of Obsidian Source Samples from the Willaumez Peninsula, Papua New Guinea and Eastern Australia

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ABSTRACT. Obsidian samples from several outcrops in Papua New Guinea and eastern Australia have been dated by the fission track method for the first time. The Papua New Guinea samples yielded young ages (≈25 Ka), whereas dates of 85.5 Ma to 92.3 Ma were obtained for the Australian samples after using the plateau age and track size methods to correct for track fading. The archaeological implications of the fission track dates are discussed.

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During the last two decades Fission track dating of obsidian has assisted provenance studies of prehistoric artifacts and the chronological study of related volcanic activity. For example, intense investigations have been carried out in the Mediterranean and nearby regions (Bigazzi *et al.*, 1982, 1990, 1993). This approach is applied here to Papua New Guinean and Australian obsidians to supplement archaeological studies of raw material sources and prehistoric trading patterns using trace element analysis (Bird *et al.*, 1987; David *et al.*, 1992; Torrence *et al.*, 1992, 1996; Summerhayes *et al.*, 1993, 1998). This paper aims to contribute to a more complete characterisation of sources and an improved understanding of their geological history by providing the first age determinations for some Papua New Guinean and Australian obsidians.

## Background

*Papua New Guinea Sources*. The widespread distribution of obsidian artifacts in archaeological sites in the Pacific region in places distant from known sources of the raw material has been interpreted as evidence for prehistoric trading systems (cf. review in White, 1996). As part of a wider investigation of prehistoric obsidian trade, the natural occurrence of obsidian has been studied for a number of areas, but the most detailed work has been carried out in the Willaumez Peninsula region of West New Britain province in Papua New Guinea where four source areas have been identified: Kutau/Bao, Gulu, Baki and Hamilton (Torrence *et al*., 1992, 1996; Summerhayes *et al*., 1998).

The known distribution of obsidian sources in the Willaumez Peninsula, including both rhyolitic flows and associated secondary contexts, is reported in Torrence *et al*., 1992. In addition to mapping the sources, a chemical analysis of obsidians from the four distinct source areas using the PIXE-PIGME technique has shown that they are distinctive (Bird *et al*., 1997; Torrence *et al*., 1992; Summerhayes *et al*., 1993, 1998).

Characterisation of artifacts from numerous archaeological contexts using PIXE-PIGME has shown that throughout prehistory the Kutau/Bao source was predominant both within the local area and in the wider Pacific region (Summerhayes *et al*., 1993, 1998). The presence of Kutau/Bao obsidian within levels dating between 18,000 and 20,000 B.P. at Matenbek cave in New Ireland is the earliest evidence for long-distance marine transport of material in prehistory (Summerhayes & Allen, 1993). Furthermore, the enormous spread of Kutau/Bao obsidian-extending from Sabah on the east to Samoa on the west-in the period between c. 3,500–2,000 B.P. is possibly the largest prehistoric distribution network known (Bellwood & Koon, 1989; Summerhayes *et al*., 1993, 1998).

In direct contrast to the Kutau/Bao obsidian, almost no material from the other three obsidian sources was exported out of the region; however, material derived from them was used at archaeological sites situated quite close to the outcrops (Summerhayes *et al*., 1993, 1998; Torrence & Summerhayes, 1997). Fission track analyses were carried out on one sample from the Kutau/Bao source (T6) and one from the Baki source (G002) (see map and descriptions in Torrence *et al*., 1992). These samples were chosen because, like the histories of their use as shown by archaeological research, it was suspected that their geological histories differed.

The aim of the analyses, therefore, was to broaden our knowledge of the volcanic history of the region as well as to resolve several archaeological questions. Firstly, because the Kutau/Bao obsidian occurs within a rhyolite dome showing relatively little erosion, a young age was suspected. It was important to determine the chronological relationship between the age of obsidian formation and its first occurrence in archaeological sites in New Ireland. Secondly, the Baki obsidian was suspected to be older than the Kutau/Bao obsidian because it was derived from a poorly preserved caldera (Bird *et al*., 1997). Dating the volcanic event which produced the Baki obsidian would help to determine the history of human settlement in the region in relation to volcanism.

The earliest date for human presence in West New Britain (c. 35,600 B.P.) is from the site of Yombon in the interior of the island. It is significant that obsidian does not occur in Pleistocene levels at this site (Pavlides & Gosden, 1994). If the Willaumez Peninsula was undergoing major volcanic activity during the period of initial settlement, it might explain why obsidian was not distributed from the region until much later.

*Australian Sources*. Although rare, outcrops of silicic volcanic glass are scattered through eastern Australia. They are variously referred to as obsidian, pitchstone, perlite, or vitrophyre depending on individual characteristics such as extent of devitrification and hydration, abundance of crystals, and presence or absence of conchoidal fracture or perlitic cracks. The glassy rocks are generally of limited extent and are collectively referred to as "obsidian" here for the sake of simplicity. The rapidly chilled margins of some high-level silicic intrusives and dykes also consist of obsidian in places, for example, west of Eidsvold (Burnett region of central Queensland, in a tributary of Morrow Creek, at GR 930 876, Rawbelle 1:100 000 Sheet area), in the Peak Range area (Emerald region of central Queensland, e.g., Knutson, 1989: 101), and in the Mitchell River area of far north Queensland (Bultitude *et al*., 1996: 43).

Obsidian is most common in relatively young (Cainozoic) deposits. However, extensive outcrops of glassy dacitic ignimbrite of early Carboniferous age (332±4 Ma) from the Port Stephens area (near Newcastle) on the central coast of New South Wales have been described by Hamilton (1992) as the oldest abundant glass on Earth. He also listed other occurrences of relatively old (pre-Tertiary) volcanic glass (both silicic and basic varieties) in Australia and overseas. Subsequently, small outcrops of older obsidian were located west of Emerald in central Queensland in the Silver Hills Volcanics (Withnall *et al*., 1995: 85) which is Late Devonian/early Carboniferous in age (≈370 to ≈340 Ma; Henderson *et al*., in press).

Obsidian is relatively common in some late Palaeozoic (mainly Permian) volcanic sequences of north Queensland (e.g., see Hamilton, 1992; Mackenzie, 1993; Bultitude *et al*., 1995, 1996). The samples of obsidian from far north Queensland (FNQ) dated here are from two rhyolite lava flows in the Early Permian Nychum Volcanics (Nolan Creek sample locality at GR 101397, Elizabeth Creek sample locality at GR 184423, Bellevue 1:100 000 Sheet area; cf. David *et al*., 1992; Fig. 1). This geological formation contains extensive zones of obsidian in places. Samples AU602, AU603, and AU662 from outcrops in the headwaters of Nolan Creek and sample AU612 from Elizabeth Creek were analysed by the fission track method.

Obsidian artefacts have been found more than 30 km south of the Nolan Creek and Elizabeth Creek localities at an archaeological site called Echidna's Rest. PIXE/PIGME analyses performed at the Australian Nuclear Science and Technology Organization (David *et al*., 1992) have shown the artefacts to be very different in composition to the widely studied Melanesian sources but chemically similar

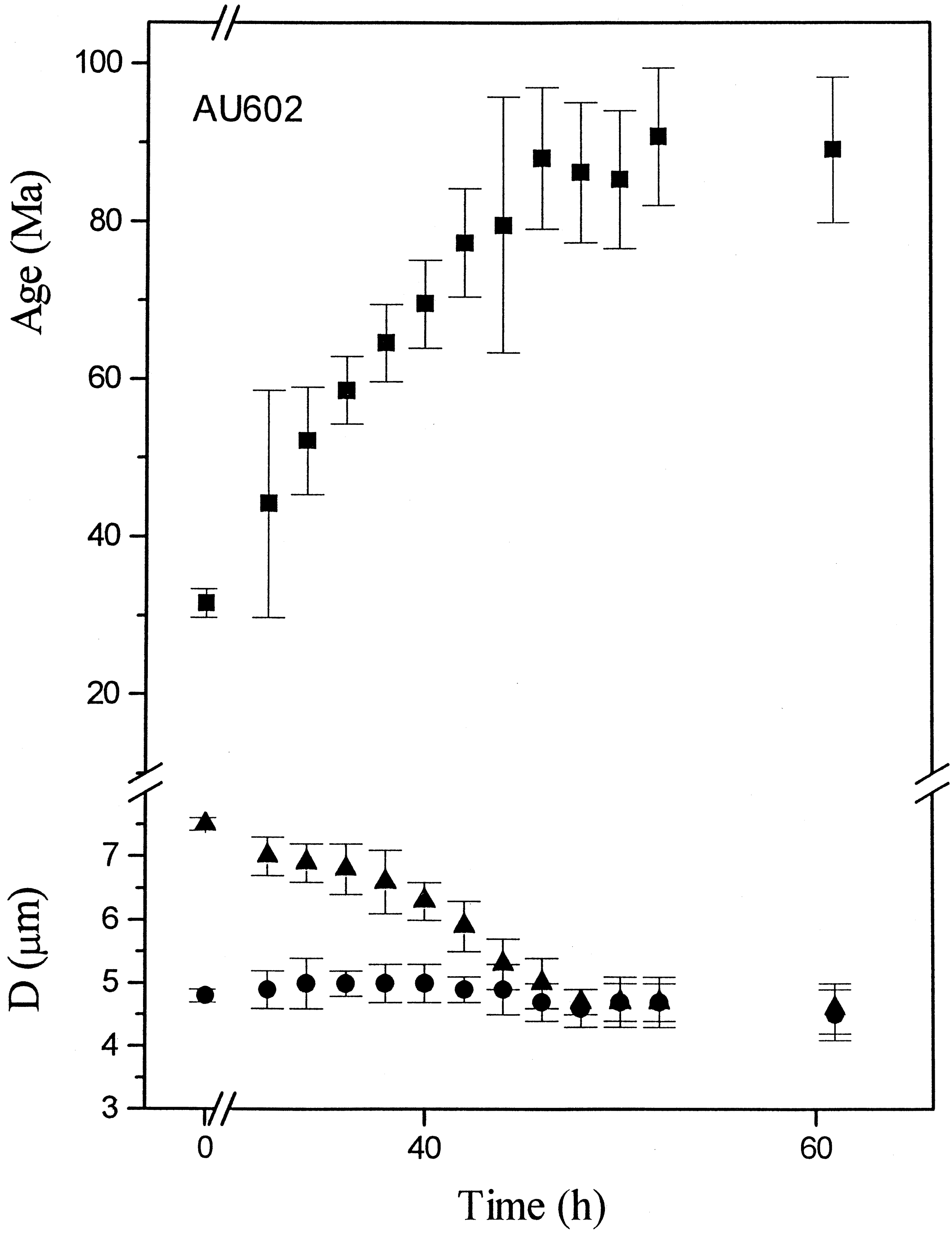


**Figure 1**. Plateau age for Australian obsidian AU602 obtained by using isothermal treatment (upper represented by squares). Induced (pyramids) and spontaneous (circles) fission-track diameters at each step of thermal treatment (lower).

to the Nolan Creek obsidian. Since the Nolan Creek source area extends over several square kilometres, whereas the Elizabeth Creek obsidian is very restricted because it is the chilled margin of a large rhyolite lava flow, it seems likely that the the former is the main source for the glassy artifacts.

Obsidian samples AU101 and AU102 were collected as isolated cobbles in streams in the Mount Warning area, in northern New South Wales (NSW). The late Oligocene/ early Miocene (≈24 to ≈21 Ma) Mount Warning volcanic sequence is much younger than the Nychum Volcanics. It also contains rhyolite lava flows, some with glassy bases and tops up to ≈10 m thick (Ewart *et al.*, 1987; Stevens *et al.*, 1989). PIXE-PIGME analyses have shown that this obsidian forms a well-defined compositional group, distinct from the other analysed sources in the southern Pacific (Bird *et al.*, 1987). No confirmed artefacts have been identified, probably because of the badly weathered nature of most of this obsidian, which is also commonly extensively devitrified.

Several obsidian artifacts have also been found in south-eastern Australian, but PIXE-PIGME analyses have been unsuccessful in linking them to known outcrops (Duerden *et al.*, 1987).

## Fission track methods

The obsidian samples were divided in two fractions, one of which was irradiated at the Lazy Susan facility (Cd ratios 6.5 for gold and 48 for cobalt) of the Triga Mark II Reactor of the LENA Laboratory of the University of Pavia, Italy. Metallic monitors and CN1 and CN2 standard glasses, together with calibrated mica and Makrofol foils acting as external detectors were also irradiated for thermal neutron fluence determination; results are shown in Table 1.

After irradiation, the irradiated and non-irradiated fractions were prepared for etching and microscope observation. The standard technique consisting of mounting samples in epoxy resin, followed by grinding and polishing did not work for the NSW samples due to their almost completely crystallised condition. In this case, an appropriate technique had to be developed. Thin slices were cut with a diamond wheel, glued onto microscope slides and finally the cut surface was carefully polished Subsequently, etching was performed with 20% HF at T = 40°C for 70–120 seconds, and then spontaneous and induced fission tracks were observed and counted at 500× magnification.

## Results

The Papua New Guinea results are shown in Table 2. Their young age caused no appreciable fading effect but, as a kind of perverse compensation for the experimentalist, fossil tracks were extremely scarce due to the very small (≈1 ppm) uranium content of the obsidians. The quoted uncertainty (≈30%) therefore reflects the relatively small number (11–15) of fossil tracks measured.

The Australian results are presented in Table 3. It is important to point out that the spontaneous to induced track size ratio, Ds/Di, is generally smaller than unity. This indicates considerable fading, producing lowered fission track ages. Standard thermal based correction techniques have therefore been applied. However, the conditions of the samples (crystallisation and devitrification for NSW samples and evidence for hydration for FNQ ones) imposed restrictions and concern. Subsequent experimentation at different temperatures and times has shown that only a low-temperature isothermal treatment was tolerable for the FNQ samples, while the NSW samples could not allow any temperature increase.

**Table 1**. Measurement of thermal neutron fluence.[1]

| monitor | external detector | B ($10^9$ n $t^{-1}$) | track density on ext. detector ($10^5$ t $cm^{-2}$) | thermal neutron fluence ($10^{15}$ n $cm^{-2}$) |
|---|---|---|---|---|
| Au wire | – | – | – | 2.399 ± 0.034 |
| Co wire | – | – | – | 2.392 ± 0.025 |
| CN1 glass | mica | 1.873 ± 0.025 | 13.43 ± 0.26 | 2.515 ± 0.036 |
| | makrofol | 1.863 ± 0.023 | 13.24 ± 0.26 | 2.468 ± 0.058 |
| CN2 glass | mica | 1.985 ± 0.007 | 12.34 ± 0.25 | 2.449 ± 0.051 |
| | makrofol | 2.016 ± 0.041 | 12.31 ± 0.25 | 2.482 ± 0.072 |

1 Calibration of glass dosimeters (B value measurement) was performed by using cobalt and gold monitors (Bonetti *et al.*, 1994). The thermal neutron fluence value used in the age measurements has been obtained as a weighted mean of the values listed in the last column.

**Table 2**. Results for fission track dating of Papua New Guinean obsidians.[1]

| sample | $n_s$ (t) | spontaneous track density (t $cm^{-2}$) | $n_i$ (t) | induced track density ($\times 10^4$ t $cm^{-2}$) | neutron fluence ($\times 10^{15}$ n $cm^{-2}$) | age ± (a) |
|---|---|---|---|---|---|---|
| Baki | 11 | 17 | 2933 | 5.54 | 1.644 ± 0.014 | 30198 ± 8906 |
| Kutau | 15 | 14 | 7094 | 5.16 | 1.644 ± 0.014 | 26707 ± 7688 |

1 $n_s$ and $n_i$ represent the number of spontaneous and induced tracks counted, respectively. The induced track density has been evaluated by means of the population subtraction method. Ages are calculated by using the following constants ($\lambda_\alpha = 1.551 \times 10^{-10} a^{-1}$, ${}^{238}U/{}^{235}U = 137.88$, $\sigma_f = 580.2$ b, $\lambda_f = 7.03 \times 10^{-17} a^{-1}$). The thermal neutron fluence is determined from both two calibrated mica and Makrofol detectors in contact with glass dosimeters (Corning CN1, CN2) and two metallic monitors (Co, Au). All corrected ages are weighted means of values in the plateau region.

Both the "plateau" technique and the "correction curve" technique (Storzer & Wagner, 1969; Storzer & Poupeau, 1973; Arias *et al.*, 1981) have been applied to the FNQ samples. The results of the isothermal treatment at from 10–60 h is shown in Fig. 1. As can be clearly seen, the plateau age of 85 Ma is reached at 50 h, this time consistently corresponding to the attainment of the condition Ds/Di = 1 (lower part of Fig. 1), which indicates that thermal history of the fossil tracks has been reproduced for those induced in the laboratory. Corrected ages are shown in the last column of Table 3.

## Discussion

*Papua New Guinea Sources*. The fission track dates presented in Table 1 not only provide new information about the volcanic history of the region, but also shed light on the nature of prehistoric human settlement in West New Britain and obsidian trade in the wider region. Although the Baki source is relatively old as suspected, at one standard deviation the dates for both obsidians significantly overlap with the earliest date for settlement in the region and with the earliest known use of obsidian in New Ireland. It seems likely that the absence of obsidian at Yombon during the Pleistocene may be explained by the absence of obsidian in the Willaumez Peninsula region until a later date and/or the difficulty of obtaining access to a highly active volcanic region. If the Willaumez Peninsula was undergoing major volcanic activity, as is evidenced by the caldera forming event which introduced Baki obsidian, then humans may have avoided the area until it was safe to explore. The initiation of obsidian movement at c. 20,000 B.P. may simply reflect the period when access to the sources became feasible. The beginning of marine transport of obsidian may therefore merely indicate when obsidian was first available to be exploited, and not a major change in social organisation/trading patterns or in boat technology

**Table 3**. Results of fission track dating of Australian obsidian samples; $n_s$, $n_{i+s}$ represent the number of spontaneous and induced+spontaneous tracks being counted, respectively. See Table 2 for constants. (*) In this case the corrected age is determined by using the correction curve of sample AU602.

| sample | $n_s$ (t) | spontaneous track density ($\times 10^4$ t $cm^{-2}$) | $n_{i+s}$ (t) | induced track density ($\times 10^5$ t $cm^{-2}$) | neutron fluence ($\times 10^{15}$ n $cm^{-2}$) | Ds/Di | apparent age ± σ (Ma) | heating hours at 140°C | corrected age ± σ (Ma) |
|---|---|---|---|---|---|---|---|---|---|
| **Far North Queensland (FNQ)** | | | | | | | | | |
| AU602 | 2533 | 8.17 ± 0.16 | 3736 | 3.51 ± 0.07 | 2.431 ± 0.016 | 0.63 ± 0.06 | 33.9 ± 1.1 | 60 | 86.9 ± 3.8 |
| AU603 | 1390 | 7.25 ± 0.19 | 3666 | 3.23 ± 0.07 | 2.431 ± 0.016 | 0.54 ± 0.05 | 32.7 ± 1.3 | (*) | 88.5 ± 9.0 |
| AU612 | 278 | 10.86 ± 0.65 | 1002 | 4.13 ± 0.15 | 2.431 ± 0.016 | 0.68 ± 0.07 | 38.2 ± 3.2 | (*) | 92.3 ± 10.6 |
| AU662 | 122 | 4.24 ± 0.38 | 608 | 1.69 ± 0.09 | 1.644 ± 0.014 | 0.53 ± 0.10 | 24.7 ± 3.1 | 70 | 85.5 ± 5.9 |
| **New South Wales (NSW)** | | | | | | | | | |
| AU101 | 273 | 2.32 ± 0.14 | 898 | 2.57 ± 0.09 | 2.431 ± 0.016 | 0.79 ± 0.06 | 13.1 ± 1.0 | – | – |
| AU102 | 95 | 1.48 ± 0.15 | 760 | 2.23 ± 0.09 | 2.431 ± 0.016 | – | 9.7 ± 1.1 | – | – |

as previously postulated (Summerhayes & Allen, 1993).

Fission track dating of two obsidian sources in the Willaumez Peninsula, Papua New Guinea therefore raises very important questions concerning the cause for the earliest long distance transport of raw material in world prehistory. Before the reasons for the inception of this transport can be fully understood, the distribution and nature of the obsidian sources themselves must be known. As several Pacific archaeologists have noted (Ambrose *et al.*, 1981; Torrence *et al.*, 1996), obsidian sources are impermanent; they are created at different times and are not always accessible due to sea level changes and volcanic activity. If the Willaumez Peninsula sources were unavailable for human exploitation until c. 20,000 B.P., then obsidian movement may not be the earliest evidence for human transport of raw materials over long distances. It may only represent the first archaeological signature of what was a much older phenomenon.

Additional dates on the two remaining Willaumez Peninsula sources, Gulu and Hamilton, as well as the very important source at Mopir (artifacts from there also occur in the early New Ireland sites), will provide very useful additional information about the nature of raw material availability during prehistory. It is against this background that archaeology can better understand the cultural history of obsidian trade (Torrence *et al.*, 1996).

*Australian Sources*. As Table 3 shows, the fading correction considerably increases the apparent fission track ages and also decreases their apparent spread. As a result, the three age-corrected FNQ samples exhibit a common value in the order of 85–90 Ma years, although derived from two physically different sources (AU612 from Elizabeth Creek, and AU602 and AU662 from Nolan Creek) that have different uranium contents (see Table 3).

The apparent fission track (AFT) ages of the obsidian samples from north Queensland are significantly younger than their stratigraphic age. The rhyolite lava flows from which the samples were obtained form part of the Nychum Volcanics of Early Permian age (Bultitude *et al.*, 1995). Another sample from the lava flow from which sample AU612 was collected recently yielded a U-Pb zircon ion probe (SHRIMP) age of 277±4 Ma (Bultitude *et al.*, 1996). This date represents the time of lava eruption and is consistent with the local stratigraphy. The Nychum Volcanics are unconformably overlain in places by latest Jurassic?/Early Cretaceous (Neocomian—late Albian; Smart *et al.*, 1980) sedimentary rocks of the Carpentaria Basin succession.

The AFT ages therefore reflect post-depositional heating and subsequent cooling in the Late Cretaceous. Significantly, several AFT ages in the range from ≈80 to ≈95 Ma have also been obtained from other pre-Late Cretaceous rock units in the Cairns hinterland (unpublished data of RJB). The elevated palaeotemperatures may have resulted from heating due to burial beneath the sediments of the Carpentaria Basin.

The cooling episode in the Late Cretaceous probably followed significant uplift, heating, and subsequent erosion of the region. Major changes in base levels and associated large-scale denudation between ≈110 Ma and ≈80 Ma have been recorded over much of southern, eastern and northeastern Australia, as well as in Papua New Guinea (e.g., Veevers *et al.*, 1991; O'Sullivan *et al.*, 1996; Raza *et al.*, 1996; Symonds *et al.*, 1996). These changes resulted from the onset of extensional thermal rifting on the eastern and southern margins of the Australian continent (Veevers *et al.*, 1991) related to the breakup of eastern Gondwanaland.

## Conclusions

The fission track dating of Papua New Guinean and Australian obsidian sources has yielded valuable insights into the geological histories of these two regions. The New South Wales results demonstrate the importance of using suitable obsidian for studying older materials and the necessity of applying corrections for fission track fading in older obsidians.

In terms of archaeological implications, it is important to note that extremely old sources of obsidian, such as those in Australia, may still produce some workable material which may have been used in the past. Most Australian obsidians are not suitable for manufacturing tools, but some were exploited on a limited basis (David *et al.*, 1992). The fission track dating method did not yield the age the obsidians were formed, but the younger dates may indicate periods of reheating due to burial, magmatic activity, tectonism or a combination of these processes. As such, fission track dating may assist in unravelling the geological history of the region.

In contrast, the fission track dates of Papua New Guinean obsidians raise important implications about the history of trading systems and sea travel in this region. If obsidians from the Willaumez Peninsula were not formed until after the region was first settled, then their absence in the oldest archaeological levels is not indicative of the movements of people and raw materials at that time. In other words, the subsequent introduction of obsidian into archaeological sites could simply be a product of its availability rather than a change in human technology and/or social systems. Fission track dating of other Pacific obsidian sources could also help clarify the relationship between supply and demand within prehistoric economic systems.

Fission track dating also has potential as another technique for characterising obsidian outcrops and matching artefacts with their sources, as has been done successfully in the Mediterranean (e.g., Bigazzi *et al.*, 1990). With more work to apply an age correction to the NSW samples, it may be possible to use fission track dating to characterise Australian obsidian sources since the Ds/Di ratios in Table 3 indicate that the dates for the two areas would be distinctive. This would not be the case, however, for the two Papua New Guinean obsidians since the dates overlap at one standard deviation. These results provide further evidence that fission track dating has a potentially important role to play in geological and archaeological research.

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