



## IMPORTANCE OF SOURCE AVAILABILITY AND ACCESSIBILITY: A CASE STUDY FROM PAPUA NEW GUINEA

**ROBIN TORRENCE\***

*Anthropology, Australian Museum,  
 6 College Street, Sydney, NSW 2010, Australia*

**ROBERTO BONETTI, ALESSANDRA GUGLIEMMETTI,  
 ALBERTO MANZONI**

*Istituto di Fisica Generale Applicata,  
 Università di Milano, Via Celoria,  
 16 20133 Milano, Italy*

**MASSIMO ODDONE**

*Dipartimento di Chimica, Università di Pavia,  
 Via Tatamelli, 12 27100 Pavia, Italy*

Received: 19 - 2 - 2004

*e-mail: robint@austmus.gov.au*

Accepted: 30 - 5 - 2004

*\* to whom all correspondence should be addressed*

### ABSTRACT

The study of ancient trade and exchange would benefit from detailed analyses conducted at the level of the individual obsidian exposures. A useful method is to evaluate the null hypothesis that all potential sources were equally favourable to those who exploited, exchanged, and used the obsidian. Before deviations from the null hypothesis can be inferred as social behaviour, the physical characteristics of the obsidian exposures and their history in time and space should be studied. These points are illustrated by a case study from Papua New Guinea where volcanic activity during the time of occupation radically altered the availability and accessibility of obsidian sources. Having accounted for environmental factors, changes in the abundance of obsidian from various chemical groups is interpreted in terms of a highly flexible system of exchange that may have been adopted to help cope with the high risks created by volcanic activity.

**KEYWORDS:** Trade, Papua, New Guinea, obsidin, geology

### A NULL HYPOTHESIS

The study of ancient obsidian trade is generally based on inferences from archaeological data on how the resource was

acquired from the geological outcrops, manufactured into a product and/or consumed (Torrence 1986; Tykot 2002a). By far the majority of obsidian exchange studies focus

solely on patterns of consumption. These are typically represented by the spatial distribution of artefacts which have been determined by geochemical characterisation to have been derived from particular obsidian sources. Changes in the amount of obsidian consumed from various sources are frequently interpreted to mean differences in the way that exchange operated (e.g. Tykot 1998; 2002a; 2002b; Summerhayes *et al.* 1998; Specht 2002; White 1996; review in Torrence 1986, 4-7). Recent work, especially in Papua New Guinea (Ambrose *et al.* 1981; Torrence *et al.* 1992; Fredericksen 1997) and the western Mediterranean (Tykot 2002a; 2002b; Tykot *et al.* 2002), have shown that inferences about

the nature of exchange based on changes in the relative abundance of material from different sources are not accurate unless one has first considered the potential effects of the physical characteristics of the obsidian sources, the nature of their availability through time, and their accessibility in space.

A useful way to begin a study of obsidian trade or exchange is with a null hypothesis which states that all potential sources were equally favourable to those who acquired, produced and consumed obsidian. To evaluate this hypothesis, one first assesses the geological history of the outcrops both in terms of when they were formed and whether they have remained exposed on the surface.

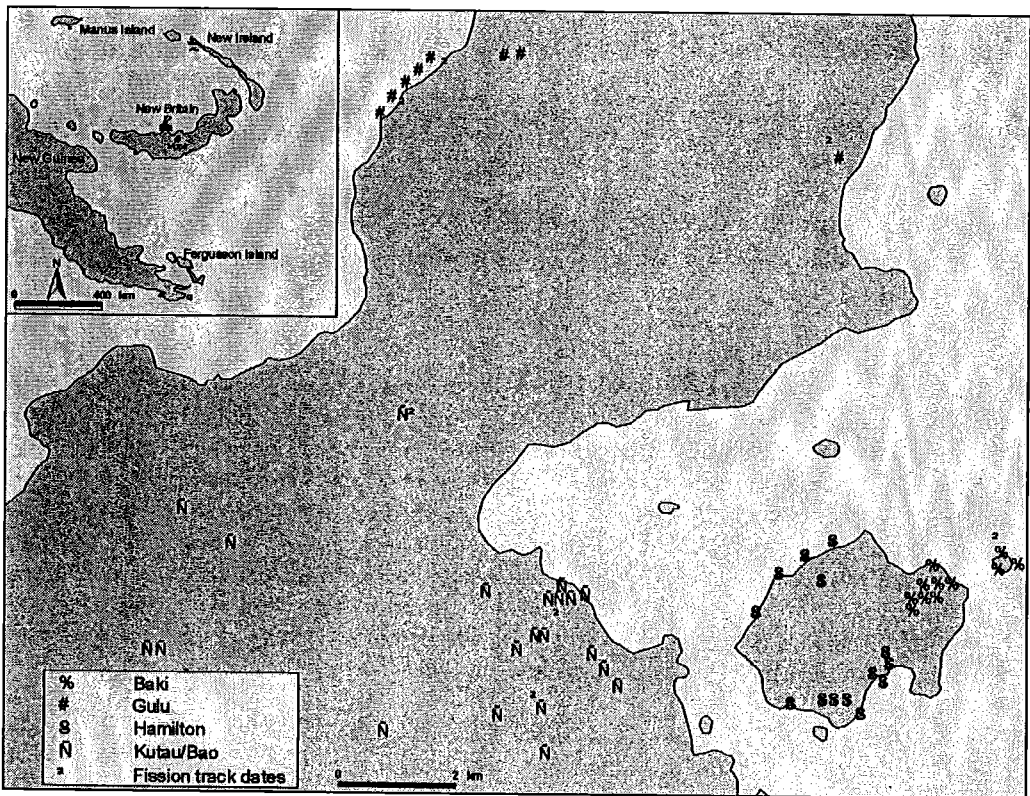


Fig. 1: The obsidian exposures which were evaluated and sampled for PIXE-PIGME analysis and locations for the samples dated by the fission track method. The major obsidian source areas within Papua New Guinea are identified in the inset map.

Secondly, the relative utility of the outcrops is measured in terms of physical qualities that would affect their desirability for the people who collected or quarried the material as well as to the producers and users. Relevant traits would include the ease of getting access to the sources, the relative cost of collecting or extracting the raw materials and the abundance, size, colour, and flaking properties, etc. of the obsidian within them (cf. Torrence 1986; Torrence *et al.* 1992, 85; Tykot *et al.* 2002; Eerkens and Rosenthal 2004). If the outcrops were not consistently available and accessible during the period when obsidian was exploited or they did not have equal utility or cultural value, then physical properties of the outcrops and/or the raw material may be a primary reason why all sources were not used equally in the past, rather than something related to the social nature of exchange.

To illustrate these points further, I turn to a case study from the Willaumez Peninsula in Papua New Guinea (Figures 1, 2). Obsidian found within this region was exploited from the time when humans first colonised the island at least 35,000 years ago (Torrence *et al.* in press) until very recently. The first evidence for long distance transport of obsidian is about 20,000 years ago. It continued to be widely distributed within Papua New Guinea until very recently, although the scale of movement was greatest in the period from about 3,000 to 2,000 BP (Summerhayes *et al.* 1998; White 1996; Specht 2002).

### FIELDWORK AT THE OBSIDIAN SOURCES

Fieldwork has been conducted at the obsidian sources within the Willaumez Peninsula over a number of years (Torrence *et al.* 1992; Fullagar *et al.* 1991; Summerhayes *et al.* 1998: 140-144). The study has been conducted with the 'exposure' as the minimal unit. An exposure is defined as any locality

where obsidian could be accessed and includes both in situ geological deposits as well as secondary sources such as beach cobbles or river gravels. Given the broad spread of obsidian flows in this region and the lack of access by road, it is clear that not every exposure has been studied, although an attempt has been made to sample across the known spatial distribution. The location of the studied exposures is presented in Figure 1.

With the exception of the exposures related to the Hamilton flows, which have abundant inclusions and are characterised by extremely poor fracturing properties, the majority of the exposures contain raw material of relatively good quality, although the size of the nodules can vary widely within and between exposures. Transport may have been an important factor for people in the past and it may be assumed that the inland exposures were harder to access than those closer to the beach. Overall, it was concluded that on the basis of physical attributes alone, the exposures in the Mopir and Kutau-Bao regions would have been slightly preferred over the Baki and Gulu flows because regular supplies of large nodules could have been acquired with less effort. The Baki and Gulu exposures were considered to be about equal thirds but not far behind.

In addition to the archaeological survey, a study of the recent volcanic history of the region and changes in sea level provide important evidence about when and where the different obsidian exposures could have been exploited. For instance, the lowering of sea level during the Pleistocene would have affected the conditions of access to the outcrops on the off shore islands such as Garua and Garala (Figure 2) since these would have become landlocked, along with the coastal exposures of the Kutau/Bao source (Torrence *et al.* 1996). Very little is known about volcanic activity during the Pleistocene and its potential effects on the distribution of obsidian

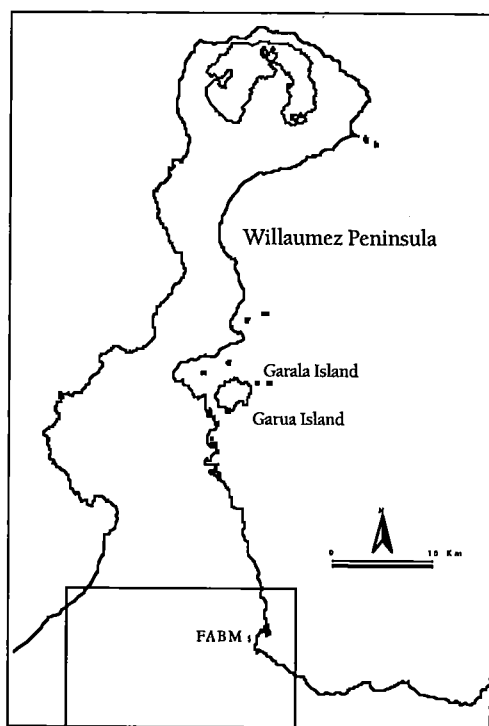


Fig. 2: The Willaumez Peninsula showing the area represented in Figure 4 and the location of the Kupona na Dari (FABM) Pleistocene site.

exposures. Long tephra sequences have been identified on Garua Island and in the southern part of the Willaumez Peninsula where artefacts are sealed below Pleistocene aged tephra at the site of Kupona na Dari (Torrence *et al.* 1999; FABM on Figure 2). In contrast, Holocene volcanic activity from several volcanoes has been well documented. Tephra derived from them blanket many areas where obsidian sources have been found (Machida *et al.* 1996; Torrence *et al.* 2000). It therefore seems likely that access to obsidian exposures was not stable through time and may have had an effect on the nature of exchange.

### OBSIDIAN CHARACTERISATION

Although a number of techniques have been used to differentiate among the known

obsidian outcrops (e.g. Summerhayes *et al.* 1998: 131-3; Green and Bird 1989; Torrence and Victor 1995), the majority of the research has utilised the PIXE-PIGME (Proton Induced X-ray Emission-Proton Induced Gamma-ray Emission) technique, following on from the pioneering efforts of Wal Ambrose and Roger Bird. Initial work discriminated among sources found in the major regions of Manus, New Britain and the Fergusson Islands (Figure 1). Following the archaeological studies of the outcrops in New Britain described above, an effort was made to discriminate on a much finer basis. Consequently, 5 main chemical groups were distinguished among the obsidian outcrops known in New Britain: Mopir, Kutau-Bao, Gulu, Hamilton, Baki (Bird *et al.* 1997; Summerhayes *et al.* 1998). As can be seen from Figure 1, the New Britain chemical groups cluster in space, suggesting that they may each be monitoring a single volcanic event. With the exception of the Baki chemical group, the composition of the exposures grouped together are quite homogeneous. In the case of the Baki group, it was suggested that the variability in chemical composition (which is notably less than the inter-group variation) was due to magma mixing within an ash-flow deposit (Bird *et al.* 1997, 66). Subsequently, a more detailed separation has also been achieved for obsidian sources in Manus province (Fredericksen 1997; Bird nd.).

### SPATIAL DISTRIBUTIONS

The spatial patterning of obsidian from the New Britain sources changes significantly through time (e.g. Specht 2002; Summerhayes *et al.* 1998; White 1996). To what extent do these changes reflect significant differences in exchange systems? I will address this question in terms of a recent study in which PIXE-PIGME was used to determine the chemical group of 327 obsidian artefacts derived from test excavations within a study area located at

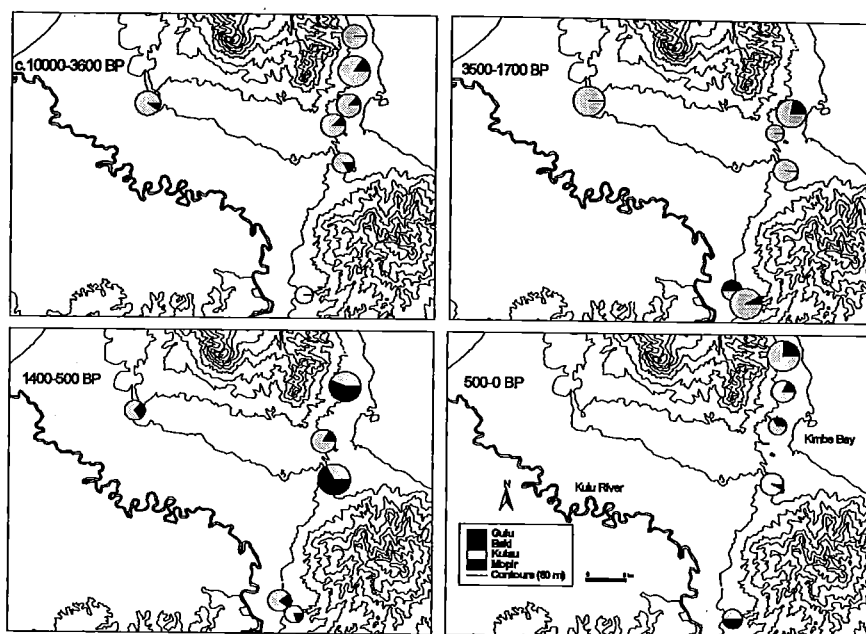


Fig. 3: Changes in the consumption of obsidian at the Kupona na Dari Pleistocene site. The location of the site is shown in Figure 2. The early period dates to before 20,000 bp and the late period is c. 20,000-6,000 bp.

the base of the Willaumez Peninsula (Figures 2). Given our assessments of the obsidian exposures, the null hypothesis would be that Kutau-Bao and Mopir should comprise the majority of the obsidian consumed in this region and temporal changes should reflect cultural processes. Note that the area is conveniently located approximately midway between these two source regions. As we shall see, the patterns of consumption that we have monitored do not conform to this prediction.

The late Pleistocene period (c. 40,000-10,000 BP), which represents the earliest colonisation of humans in this region, is represented in our data set by the single site of Kupona na Dari (Figure 2, FABM; Torrence *et al.* 1999; Torrence *et al. in press*). Almost 100 per cent of the 191 artefacts recovered from the site are composed of obsidian. The results of PIXE-PIGME characterisation of 60 artefacts are portrayed in Figure 3. The stratigraphy at

the site can be divided into an early (pre-20,000 BP) and a late (post-20,000 BP) period. The most important change in obsidian consumption is the absence of Kutau-Bao obsidian in the early period and its appearance in the late period when there is also a decrease in the amount of obsidian from the Mopir source. Given that the Kutau-Bao exposures were regarded along with Mopir as having the highest potential for sustained exploitation, the late arrival of Kutau-Bao obsidian, the decline in Mopir, and the relative stability in the proportion taken up by Baki and Gulu are surprising results.

The data set from the Holocene period comprises 267 artefacts taken from test pits distributed across the base of the Willaumez Peninsula (Figure 4). The most important changes in obsidian use also involve the relative proportions of Kutau-Bao and Mopir obsidian. With the exception of the period c.

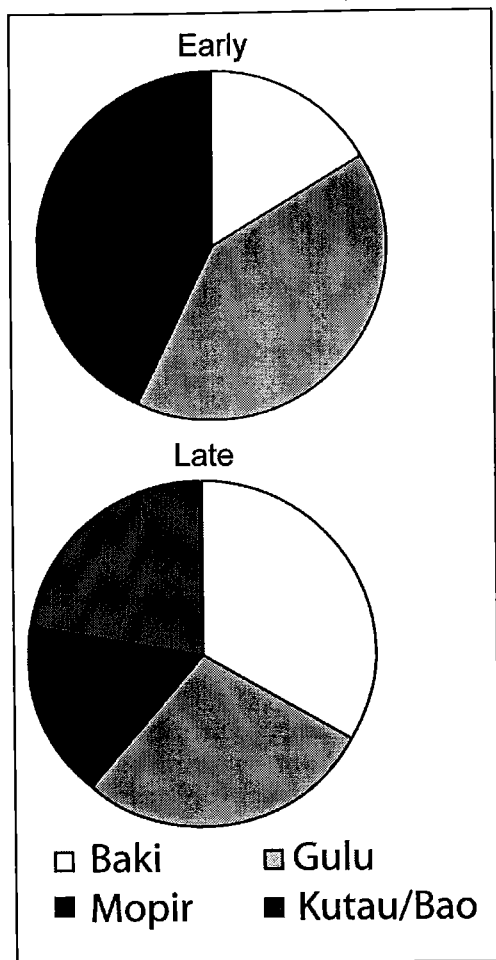


Fig. 4: Changes in the consumption of obsidian from different chemical groups based on PIXE-PIGME analysis. The variation in the size of the pie charts is related to the size of the sample that was analysed. The location of the study area is shown in Figure 2.

1400-500 BP, Kutau-Bao dominates the assemblages. Early on there is a small quantity of Mopir obsidian, but this disappears between 3600-1700 BP. At around 1700 BP Mopir obsidian is very popular for a short period before returning to a low percentage of the total obsidian consumed. Both Baki and Gulu, which were assessed as having lower quality exposures, were used in small

quantities throughout the Holocene, although there was a slight increase in the most recent period. Only a very few pieces from these two sources have been found outside the Willaumez Peninsula (Summerhayes *et al.* 1998).

#### CHANGES IN AVAILABILITY

Clearly the null hypothesis stating that the proportion of obsidian consumed should match the assessed quality of the exposures has not been met given the data presented in Figures 3 and 4. Furthermore, the relative amounts of obsidian appearing at the various locations are not stable through time as predicted. At this stage, however, we cannot conclude that the variations from expectations reflect different exchange processes. First, we need to determine whether the obsidian exposures were all available for use throughout the time periods in question. In particular, the absence of the high ranking Kutau-Bao source in the early part of the sequence at Kupona na Dari suggests that it may not have been present in the environment at this time.

To address this issue, we dated the outcrops directly using the technique of fission track dating. The results are presented in Table 1. A detailed discussion of the method used is presented in Bonetti *et al.* (1998) and Torrence *et al.* (in prep.). There are several important implications from these results. Firstly, it seems clear that Kutau-Bao obsidian is relatively young. There is some variability in the dates but they overlap at one standard deviation. The age of the emplacement of the obsidian accounts for its absence in the early levels at Kupona na Dari.

Secondly, the fission track dates indicate that the Baki and Gulu chemical groups are not homogeneous. This was already suspected for the Baki group where the mixing of several magmas was proposed to explain chemical differences among samples from the same outcrop (Bird *et al.* 1997: 66). The widely

Sample	Obsidian Outcrop	Chemical Group	Age (Ka)
1574	T6	Kutau/Bao	26.7 ± 7
1767	T1/H/III	Kutau/Bao	12.9 ± 9
396	Talasea airstrip	Kutau/Bao	11.8 ± 8
1573	G002	Baki	30.2 ± 9
381	Garala 2	Baki	232 ± 31
1576	V002	Gulu	21.1 ± 5
1577	V005	Gulu	26.3 ± 4
433	V008	Gulu	138 ± 22
1575	AIS-S2	Mopir	183.0 ± 40
	Ulip East S2	Mopir	180.4 ± 50

Table 1: Results from Fission Track Dating. See Figure 1 for sample locations. Information on locations and descriptions of outcrops is presented in Torrence *et al.* (1992: Figure 2, Table 1) and Fullagar *et al.* (1991).

differing ages for the Baki obsidians, however, indicate a rather complex situation for the source of the magmas. This problem deserves further geological study since it is possible that not all the current exposures were available for use when people first colonised the region at about 35-40,000 BP (Pavlidis and Gosden 1994).

The Gulu results are not so clear cut since the younger outcrops may post-date the arrival of human in the region. This raises the question of whether the early Gulu material at Kupona na Dari came exclusively from the older source (the western most sample on Figure 1). The sampled exposure was found buried beneath a number of layers of tephra (volcanic material) within a modern quarry for road material, but it was exposed at some time in the past and it is likely that the overlying beds are derived from relatively recent eruptions from the nearby Dakataua volcano (Machida *et al.* 1996).

The fission track dates highlight the possibility of major changes in the landscape since the arrival of humans on New Britain

and the potential effects that these could have had on the availability of obsidian exposures. The importance of change in the occurrence of obsidian exposures on the proportions of the various sources that are recovered within archaeological excavations are obvious. What is especially important about the fission track dates for the New Britain obsidians, however, is that groups determined to be homogeneous in their chemical composition included obsidian which was formed at different times. Presumably the same source of magma erupted at different times. This is a well known phenomenon (e.g. Froggett 1983). It is therefore important to combine a program of dating with characterisation studies based solely on differences in elemental composition.

### CHANGES IN ACCESSIBILITY

In addition to changes in the *availability through time* of obsidian exposures, various forms of environmental change can alter their *accessibility in space*. In other words, the obsidian may have been formed, but through

later environmental processes, such as changes in relative sea level and subsequent volcanic activity, the exposures may have become more difficult to access or rendered completely out of the reach of human activity altogether. Changes through time in the accessibility of the obsidian exposures in New Britain illustrate both these processes.

Sea level change can radically alter the ease of access to resources. It has been proposed that, due to the local geography, the lowering of sea level during the last glaciation had a greater effect on access to the Willaumez Peninsula sources, particular Baki and Kutau-Bao, than to the Mopir exposures (Torrence *et al.* 1996). Volcanic activity, however, has probably played the most important role in altering access to obsidian exposures. One of the Baki obsidian exposures on Garua Island, which is adjacent to a series of thick piles of debitage from quarrying and tool manufacture (site FAP), was covered and effectively sealed by a thick layer of in situ airfall and reworked tephra derived from an eruption of the Witori volcano dated to c. 5900 BP (Torrence 1992; Torrence *et al.* 2000). At this location at least, the source material was completely buried until relatively recently when a stream eroded down through the layers and exposed it. To what extent and for how long other Baki exposures were seriously affected by this volcanic event is debateable, since Baki obsidian is plentiful within archaeological contexts on Garua Island (but not elsewhere) dating to the period following this volcanic event (Torrence and Summerhayes 1997). Tephra derived from the 5900 BP volcanic event has been observed in the vicinity of the Kutau-Bao outcrops, but there is no indication that they were sealed in the same manner as some of the Baki outcrops on Garua. The effects at this time of tephra falls on the Mopir source, which is located very close to the Witori volcano, are also unknown but are likely to have been considerable and may explain why such small quantities of Mopir

obsidian reached the study area in the early Holocene (Figure 4).

A great deal more information is available on the role of a further Witori eruption dated to 3600 BP. In addition to the Mopir region near the volcano, this sizeable volcanic event radically altered the entire landscape of the Willaumez Peninsula (Machida *et al.* 1996; Torrence *et al.* 1996). As a consequence of volcanic flows, the coastline was greatly extended so that the Mopir sources, previously obtainable from about 4 kilometres from the sea, would have become over 30 kilometres inland in a relatively short period of time, although some exposures may have been accessible by boat upriver from the sea. In addition, the massive pyroclastic flows and thick airfall tephra destroyed all the vegetation and made the region uninhabitable for many years. Consequently, Mopir obsidian disappears from the archaeological record in our sample (Figure 4) as well as from the Pacific region at large for almost 1000 years (Green 2003: 105-6; Summerhayes *et al.* 1998). Although obsidian from the Kutau-Bao chemical group continues to dominate assemblages in New Britain after this period, some of the Kutau-Bao exposures had become inaccessible as a consequence of the thick layer of air fall tephra in the region. For example, a major obsidian quarry at Bitokara Mission (site FAQ) was buried at this time and does not appear to have been reused in later periods (Torrence 1992; Specht *et al.* 1988). This example illustrates the complex relationship between the data obtained from a characterisation study of artefacts and the landscape of obsidian exposures from which they were originally acquired.

A third volcanic eruption, this time from the Dakataua volcano, located at the northern end of the Willaumez Peninsula, occurred at about 1400 BP<sup>1</sup>. The tephra from this event had its greatest impact on the local area and did not reach the Mopir region. The effect of the Dakataua eruption on the accessibility of



obsidian exposures in our study area is clear (Figure 4). Directly following the eruption, the proportion of Mopir obsidian in the assemblages increased dramatically, although this pattern did not maintain itself past 500 BP, possibly because another series of much smaller Witori eruptions probably contributed to its decrease.

## SOCIAL FACTORS

In an area with so much recent volcanic activity, it is not surprising that obsidian exposures have not been a stable resource. Both changes in the existence of certain obsidian sources as well as their relative accessibility have had profound effects on how and when they were exploited in the past. In turn, the consumption of obsidian (measured in terms of the relative proportion of different chemical groups represented in archaeological contexts) was dependent on what could have been obtained by direct procurement or through exchange. Clearly, for the New Britain obsidian sources our null hypothesis must be rejected. Environmental factors had a profound effect on changes in the relative abundance of different source groups at archaeological sites.

Having accounted for changes in source availability and accessibility, there are still a number of unexplained deviations from the null hypothesis. For example, the dominance of Kutau-Bao obsidian in the assemblages in our case study (Figure 4) (as well as elsewhere in the Pacific from the beginning of the Holocene cf. Summerhayes *et al.* 1998; Torrence and Summerhayes 1997) cannot be explained solely in terms of the physical properties of the exposures or the obsidian within them. In this case it can be inferred that some form of social exchange took place.

Gaining access to a resource is an inherently social process. Although people may have acquired obsidian directly from the exposures themselves, direct access still would have involved social factors. Firstly, the

recognition that some people were 'owners' is a social definition. Secondly, others would have had to negotiate access in order to obtain the material directly. With the exception of the very first colonisers, the acquisition of obsidian from the sources would have always required some form of social process.

The evidence about the dominance of the Kutau-Bao obsidian points to either strict control over the access to sources and/or cultural preference for this particular obsidian or to the people who were exchanging it. Furthermore, the degree of monopoly of Kutau-Bao is less strong before and after the period c. 3600-1700 BP. Given that there is a different mix of sources within each sample pit shown in Figure 4, it seems more likely that individual persons or families within a community obtained their supplies of obsidian through personal exchange relationships with a trade partner and that these links were rather fluid (cf. Winter and Pires-Ferreira 1976; Torrence 1986, 32-35). During 3600-1700 BP, when there is much less variation among places, it is possible that the region was involved in a more formal system of exchange involving Kutau-Bao obsidian.

Information about how social systems might have operated in the past can be gleaned from changes in the consumption of obsidian from different sources. For example, the rapid switch to Mopir obsidian following 1400 BP indicates a great deal of flexibility in social relationships. It seems to have been remarkably easy for people to alter their source of supply from primarily Kutau-Bao to primarily Mopir either by travelling to the sources direct and negotiating access with the owners, through establishing new exchange relationships, or perhaps by negotiating to exchange a different product with established exchange partners. Fluidity in social relations, especially over long distance, would have been quite an asset for people inhabiting a region prone to volcanic disasters.

Possibly the need to establish social ties over a large area in order to offset the high environmental risks of this region is one reason why, with the exception of the poor quality material from the Hamilton source, obsidian from all the chemical groups was circulated around the Willaumez Peninsula as soon as the various sources were formed and when they were accessible (cf. Kirch 1988). The only exception to this general pattern is the dominance of Kutau-Bao between 3600-1700 BP, when a different type of exchange system may have been operating. Torrence and Summerhayes (1997) proposed that in this period exchange was characterised by intra-regional exchange of a limited set of products, of which Kutau-Bao obsidian was one. Whatever system was operating, small amounts of Baki and Gulu obsidian continued to be moved, perhaps because some people were maximizing their options, and by implication their social ties, or were not integrated into a larger system.

### SIGNIFICANCE OF THE RESULTS

The key finding of this study is that the social networks created through the exchange of obsidian in the Willaumez Peninsula have varied through time but have maintained their flexibility. This strategy may have been an important mechanism for coping with an environment characterised by the serious risks of volcanic disasters (Torrence 2002). The results of this study have implications beyond the study region, particularly in terms of the methodology. Our understanding of the role of exchange in prehistoric societies in this region could only be reached after a detailed study of the history of the obsidian exposures themselves. We have demonstrated that a reconstruction of the availability and accessibility of obsidian sources should be an essential component of all studies of obsidian exchange.

The inferences about social networks and

exchange were made following a thorough study of the basic resource: the obsidian exposures. Rather than be guided by the chemical groups obtained by clustering determinations from a characterisation study, it is important to operate at the base level of the obsidian exposures because it is relevant to what we are trying to understand: why people chose or favoured particular resources and not other ones. To begin with, it is important to understand what the chemical groups mean in terms of the physical world. In the case presented here, fission track dating demonstrated that exposures grouped together had been formed at different times in the past, despite the similarity in their chemical makeup. Unfortunately, dating exposures has not usually been seen to be an important aspect in studying the potential for human exploitation of obsidian sources, perhaps because in many parts of the world the time scales over which they were used is quite short. In our case, the dating has produced important results and has substantially enriched our interpretations of the PIXE-PIGME characterisation studies.

Secondly, it is important to evaluate a representative range of exposures in terms of variables relevant to human exploitation. For example, not all chemical groups will be comprised of exposures that are conducive to sustained quarrying, have nodules of the appropriate sizes or shapes, are the desired colour, etc. (cf. Eerkens and Rosenthal 2004). This procedure also enables one to determine rank orderings of the chemical groups in terms of their potential value to people exploiting them.

Thirdly, the history of when and in what ways the obsidian exposures were accessible for human use needs to be reconstructed. Some environments are inherently more stable than others and will require less research along these lines. As illustrated by our case study, environmental reconstruction is critical

to understanding changes in the consumption of different sources in situations where volcanic activity was ongoing. Some sources that were used in the past may no longer be accessible, as in the case of one of the Manus obsidians that dominated the Pleistocene record and appears to have been drowned since (Ambrose *et al.* 1981; Fredericksen 1997) and others may only have been formed recently, as demonstrated for the Kutau-Bao source and possibly also in Manus (Ambrose *et al.* 1981). Furthermore, very old sources can be buried by volcanic tephra and later be re-exposed by erosion.

## CONCLUSIONS

Although the main points of this paper should be blatantly obvious, they have not been given adequate attention by scholars studying changes in the history of obsidian distribution and exchange. Generally, inferences about exchange have been based entirely on the results of characterisation studies on artefacts recovered from

archaeological contexts. Although these have produced very important results, additional data is needed to fully understand the operation of past exchange systems.

The physical properties of the resource must have played an important role in how different obsidians were conceptualised, utilised, and exchanged in the past. Among these availability and accessibility were especially critical. What has not been appreciated enough is that these attributes may not have been stable throughout the entire period when obsidian was exploited and exchanged. Future research on obsidian exchange should incorporate a historical study of the exposures. Direct dating of the obsidian or the geological deposits in which it occurs may be required, as well as additional analyses of the actual and potential coverbeds and local sequences or erosion. Combining detailed studies of the obsidian exposures themselves with characterisation analyses will provide a much richer account of the nature of past systems of exchange.

## ACKNOWLEDGEMENTS

Fieldwork was funded by Australian Research Council grants to Torrence, who was also supported by Australian Research Council Fellowships, and by the Australian Museum, Pacific Biological Foundation and New Britain Palm Oil, Ltd. The PIXE-PIGME analyses were funded by AINSE grants to White and Torrence and assisted by Peter White, Glenn Summerhayes, Pip Rath, Ivo Orlic, Rainer Siegele, and Ed Stelcer. Fieldwork was greatly assisted by the following bodies as well as by local and international volunteers: Papua New Guinea National Museum and Art Gallery; National Research Institute; West New Britain Provincial Government and Cultural Centre; New Britain Palm Oil Ltd.; Walindi Plantation; Mahonia Na Dari Research Station; Kimbe Bay Shipping Agencies. We are also grateful to Trudy Doelman for assistance with analyses and preparing the figures and to Peter White, Jim Specht and Vince Neall for useful additions and criticisms to the original manuscript.

## ENDNOTES

1. The date for the Dakataua eruption was previously reported at c. 1100 BP (Machida *et al.* 1996; Torrence *et al.* 2000), but new fieldwork has yielded a more accurate date of 1400 BP.

## REFERENCES

- Ambrose, W. R., Bird, J. R. & Duerden, P. (1981) The impermanence of obsidian sources in Melanesia. In F. Leach & J. Davidson *Archaeological Studies of Pacific Stone Resources*, eds.
- Bird, J. R. nd. *Pacific Obsidian Studies*. Manuscript filed at the Australian Nuclear Sciences and Technology Organisation, Lucas Heights, Australia.
- Bird, J. R., Torrence, R., Summerhayes, G., Bailey, G. (1997) New Britain obsidian sources. *Archaeology in Oceania*, vol. 32, 61-67.
- Bonetti, R., Di Cesare, P., Guglielmetti, A., Malerba, F., Migliorini, E., Oddone, M., Bird, J. R., Torrence, R. & Bultitude, R. J. (1998) Fission track dating of obsidian source samples from the Willaumez Peninsula, Papua New Guinea and North Queensland and Eastern Australia. *Records of the Australian Museum*, vol. 50, 277-84.
- Eerkens, J. W. & Rosenthal, J. S. (2004) Are obsidian subsources meaningful units of analysis?: temporal and spatial patterning of subsources in the Coso Volcanic Field, southeastern California. *Journal of Archaeological Science*, vol. 31, 21-29.
- Fredericksen, C. (1997) Changes in Admiralty Islands obsidian source use: the view from Pamwak. *Archaeology in Oceania*, vol. 32, 68-73.
- Froggatt, P. C. (1983) Towards a comprehensive Upper Quaternary tephra and ignimbrite stratigraphy in New Zealand using electron microprobe analysis of glass shards. *Quaternary Research*, vol. 19, 188 - 200.
- Fullagar, R., Summerhayes, G., Ivuyo, B. & Specht, J. (1991) Obsidian sources at Mopir, West New Britain Province, Papua New Guinea. *Archaeology in Oceania*, vol. 26, 110-14.
- Green, R. C. (2003) The Lapita horizon and traditions - Signature for one set of oceanic migration, in *Pacific Archaeology: Assessments and Prospects*, ed. C. Sand (Les Cahiers de l'Archéologie en Nouvelle Calédonie 15). Service des Musées et du Patrimoine: Noumea, New Caledonia
- Green, R. C. & Bird, J. R. Fergusson Island obsidian from the D'Entrecasteaux Group in a Reef Islands Lapita site from the Santa Cruz group. *New Zealand Journal of Archaeology*, vol. 11, 87-99.
- Kirch, P. V. (1988) Long-distance exchange and island colonisation: the Lapita case. *Norwegian Archaeological Review*, vol. 21, 103-117.
- Machida, H., Blong, R. J., Specht, J., Moriwaki, H., Hayakawa, Y., Talai, B., Lolok, D., Torrence, R. & Pain, C. F. (1996) Holocene explosive eruptions of Witori and Dakataua caldera volcanoes in West New Britain, Papua New Guinea. *Quaternary International*, vol. 34-36, 65-78.
- Pavlidis, C. & Gosden, C. (1994) 35,000-year-old sites in the rainforests of West New Britain, Papua New Guinea. *Antiquity*, vol. 68, 604-610.
- Specht, J. (2002) Obsidian, colonising and exchange. In eds. S. Bedford, C. Sand, & D. Burley *Fifty Years in the Field. Essays in Honour and Celebration of Richard Shutler Jr's Archaeological Career*, Dunedin: New Zealand Archaeological Association.
- Specht, J., Fullagar, R., Torrence, R. & Baker, N. (1988) Prehistoric obsidian exchange in Melanesia: a perspective from the Talasea sources. *Australian Archaeology*, vol. 27, 3-16.
- Summerhayes, G. R., Bird, J. R., Fullagar, R., Gosden, C., Specht, J. & Torrence, R. (1998) Application of PIXE-PIGME to archaeological analysis of changing patterns of obsidian use in West New Britain, Papua New Guinea. In ed. M. S. Shackley. *Archaeological Obsidian Studies*, New York.

- Torrence, R. (1986) *Production and Exchange of Stone Tools*. Cambridge.
- Torrence, R. (1992) What is Lapita about obsidian? A view from the Talasea sources. In J-C Galipaud (ed.), *Lapita et Peuplement*. Noumea, 111-126.
- Torrence, R. (2002) What makes a disaster? A long-term view of volcanic eruptions and human responses in Papua New Guinea. In eds R. Torrence & J. Grattan. *Natural Disasters, Catastrophism and Culture Change*, London, 292-312.
- Torrence, R., Doelman, T., Neall, V., Rhodes, E., McKee, C., Parr, J., Bonetti, R. Guglielmetti, A., Manzoni, A., Oddone, M., Wallace, C. in prep. Variability in the Pleistocene colonisation of the Bismarck Archipelago.
- Torrence, R., Pavlides, C., Jackson, P. & Webb, J. (2000) Volcanic disasters and cultural discontinuities in the Holocene of West New Britain, Papua New Guinea. In eds B. McGuire, D. Griffiths, & I. Stewart. *The Archaeology of Geological Catastrophes*, (Geological Society Special Publications 171). London, 225-44.
- Torrence, R., Specht, J., Davies, H., Ainge, P. & White, P. (1999) A Pleistocene landscape in West New Britain. *Australian Archaeology*, vol. 49, 44-5.
- Torrence, R., Specht, J., Fullagar, R. & Bird, R. (1992) From Pleistocene to present: obsidian sources in West New Britain, Papua New Guinea. *Records of the Australian Museum, Supplement*, vol. 15, 83-98.
- Torrence, R., Specht, J., Fullagar, R. & Summerhayes, G. R. (1996) Which obsidian is worth it? In eds., J. M. Davidson, G. Irwin, B. F. Leach, A. Pawley, & D. Brown. *Oceanic Culture History: Essays in Honour of Roger Green*, New Zealand Archaeological Association, 211-24.
- Torrence, R. & Summerhayes, G. R. (1997) Sociality and the short distance trader: intra-regional obsidian exchange in the Willaumez region, Papua New Guinea. *Archaeology in Oceania*, vol. 32, 74-84.
- Torrence, R. & Victor, K. L. (1995) The relativity of density. *Archaeology in Oceania*, vol. 30, 121-31.
- Tykot, R.H. (2002a) New approaches to the characterisation and interpretation of obsidian from the Mediterranean island sources. In eds. P.B. Vandiver, M. Goodway, J. R. Druzik & J. L. Mass. Warrendale. *Material Issues in Art and Archaeology VI*, PA: Materials Research Society Proceedings, 712: II4.6.1-II4.6.14.
- Tykot, R. H. (2002b) Determining the source of lithic artefacts and reconstructing trade in the ancient world. In eds P.N. Kardulian & R. Yerkes. *Written in Stone: The Multiple Dimensions of Lithic Analysis*. Maryland, 59-85.
- Tykot, R. H., Beyer, L., Setzer, T., Vargo, B., Bernal, J. & Bliss, J. (2002) Geoarchaeological survey and characterization of the central Mediterranean obsidian sources: new approaches to an old problem. *American Journal of Archaeology*, vol. 106, 254.
- White, J. P. (1996) Rocks in the head: thinking about the distribution of obsidian in Near Oceania. In eds., J. M. Davidson, G. Irwin, B. F. Leach, A. Pawley, & D. Brown. *Oceanic Culture History: Essays in Honour of Roger Green*. Dunedin, 199-209.
- Winter, M. C. & Pires-Ferreira, J. W. (1976) Distribution of obsidian among households in two Oaxacan villages. In ed. K.V. Flannery. *The Early Mesoamerican Village*, New York (NY), 306-11.