

## Research Report

### Characterising volcanic glass sources in the Banks Islands, Vanuatu

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#### Abstract

In 2006 volcanic glass deposits on Vanua Lava and Gaua Islands were re-visited and systematically sampled. Twenty-nine source samples were analysed using EDXA-SEM and LA-ICP-MS with a focus on detecting possible intrasource variation. The results show both Banks Islands deposits are readily distinguishable from each other and from other sources in the region and their chemical compositions are highly homogenous. Surface survey of other prospective areas established that these two are the only volcanic glass sources in the Banks Islands.

Due to its strategic location in the Western Pacific, Northern Vanuatu has acted as a crossroad between other archipelagos from the time of initial human colonisation. Although this island group is very important for the understanding of human colonisation of the Pacific, few archaeologists have visited it. Compared to the long successful history of volcanic glass provenance studies in the North-Western Pacific (Leach 1996; Ambrose 1978; Summerhayes 2003; Torrence *et al.* 1996), which identified and unambiguously distinguished major sources and their exchange systems (Bird *et al.* 1997; Duerden *et al.* 1987; Torrence 2004; Specht 2002; White 1996), little is known about the distribution of northern Vanuatu volcanic glasses (Ambrose 1976).

Initial research in the Northern islands of Vanuatu in the early 1970s indicated there were additional sources to the previously-located sources in Papua New Guinea and Western Polynesia (Ambrose 1976; Bird *et al.* 1981; Ward 1979). A small number of samples of Banks Islands material were analysed using XRF and PIXE-PIGME with characteristically high Al, Mn and Fe concentrations detected (Duerden *et al.* 1987).

Artefacts from the southern Solomon Islands and Fiji, which had similar elemental composition to these Vanuatu sources, were the basis for assuming there had been a regional exchange system (Kirch & Yen 1982; Hedrick

1980; Best 1984). This interpretation was complicated by the proposition that more than two sources of volcanic glass might be found in the Banks Islands (Smith *et al.* 1977). After analysis of geological maps (Ash *et al.* 1980; Mallick & Ash 1975) and field exploration with the help of local guides on six most likely islands of the Banks Islands group, two volcanic glass exposures were identified and sampled.

This paper describes the detailed chemical composition and intra-source variation of the Northern Vanuatu volcanic glass sources for future fingerprinting archaeological artefacts and discusses the comparison of these new data with the chemical composition of major volcanic glass sources of the Western Pacific using multivariate statistics.

#### Methods

##### *Geological background and sampling methods*

Following recommendations by previous scholars (Glascok *et al.* 1998; Ambrose pers. comm.; Ambrose 1976), a relatively large suite of samples (14 from Vanua Lava and 15 from Gaua) were collected from different locations once the source areas were identified.

The material analysed from Vanua Lava was collected from a geological formation (a 2 km ridge, which strikes in a roughly north-westerly direction and terminates at the top of a volcanic cone) approximately 3 km inland from the village of Ambek (Fig 1; S13 44.610, E167 25.624). In this general locality, volcanic glass of poor quality has been washed out by rain and caught between big boulders of mixed fine-grained types of andesitic rocks and iron-rich tuff. No volcanic glass outcrop was visible on the surface probably due to a landslide which occurred sometime in the last century. Surface collection from riverbeds and river profiles were instead used to systematically sample the whole area.

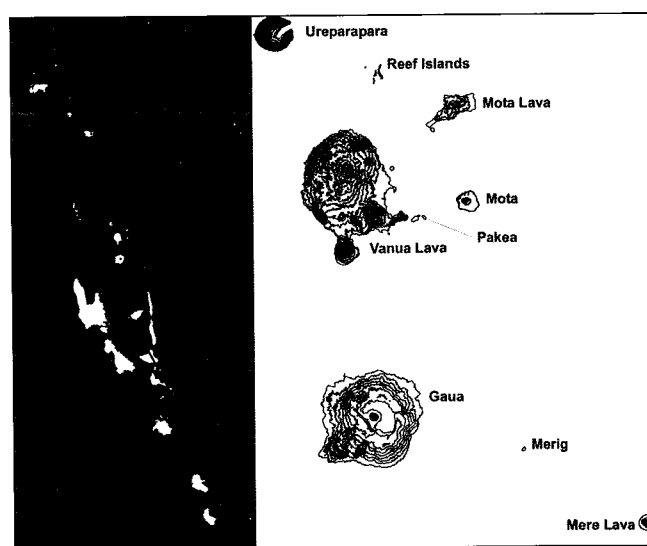


Figure 1. Western Remote Oceania and the Banks Islands group.

Samples up to >15 cm in diameter were collected. Most of the larger samples were heavily shattered and were unsuitable as raw material for tool production. However, smaller pieces (~10 cm diameter) of good quality were also observed and collected.

The material from Gaua derives from a similar geological situation to the one found on Vanua Lava (Fig 1; S14 15.158, E167 33.095 – S14 12.676, E167 34.068). The whole source area in northern Gaua is crisscrossed by several creeks which feed the Namasari River. These creeks cut through one extensive lava flow and unearth volcanic glass pebbles of different sizes in several locations. One primary deposit could be found where samples were collected in situ. Additionally, samples were collected along a transect starting from beach deposits, and moving south along the main riverbed and anabranches. Six test pits were excavated along the lava formation and in most cases small samples of volcanic glass were recovered below 1.5m.

Detailed description of the geology and sampling methods of both sources can be found in Reepmeyer (in prep.).

### Elemental analysis

In this study Laser Ablation – Inductively Coupled Plasma – Mass Spectrometry (LA-ICP-MS) was employed. This technique was developed in the late 1980s (Koppenaal *et al.* 2004) as a method to chemically characterise solid rocks. Its application has steadily increased since this time and it is now well established in Earth Sciences research (Falkner *et al.* 1995). LA-ICP-MS has also been successfully applied to several archaeological projects (Speakman & Neff 2005; Gratuze 1999; Bugoi *et al.* 2004), as it is a fast, reasonably inexpensive and almost non-destructive technique.

The samples were also analysed through a JEOL JSM6400 Scanning Electron Microscope with an Oxford ISIS Energy-Dispersive X-ray Analyser (SEM – EDXA) at the Australian National University (ANU) Electron Microscopy Unit (Reed 2005). Oxford instruments Link ISIS 3.3 software was employed.

Due to the inhomogeneity of the Vanua Lava source, the same area was excited with EDXA as used in LA-ICP-MS (~86 µm in diameter). Exciting an area of more than 200µm in diameter with EDXA can result in a loss of precision (Reed 2005, Ambrose pers. comm.). On the other hand analysing a smaller area using EDXA could produce different results to the ablated area with LA-ICP-MS (see below). This factor gets more important considering that the analysed area with PIXE-PIGME is significant larger (>1 mm<sup>2</sup>) than using EDXA and LA-ICP-MS (cf. Torrence *et al.* 1999) (see discussion below).

Calibration was conducted to the NIST612 standard and to an additional arbitrary ANU2000 standard, which is a silicate-rich, very homogenous volcanic glass from the Wekwok source on Lou, Admiralty Islands (Ambrose & Duerden 1982). The X-ray wavelengths were measured for 100 seconds. In total four runs were accomplished to limit possible variation in the analysis. Major elements analysed through this method were Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti,

Mn and Fe (Reed 2005). Inconsistent values in different runs were obtained for P, S and Mn, and therefore these elements were excluded from later analyses, in which a mean of four runs was used. The overall accuracy of the measurements is given in Table 1. For the crucial element of Si (see below for further discussion) the standard deviation was <0.43%.

Additionally, samples were analysed through an AGILENT 7500S Inductive Coupled Plasma – Mass Spectrometer combined with an EXIMER laser ablation system at the ANU Research School of Earth Sciences (for detailed description of experimental set-up, see Lee & Sneddon 1994). Detection limits are generally up to tens of parts per billion (ppb) for an ablation pit of 86 µm in diameter (Allen 2007). The pit diameter is controlled by the beam size, and only minimal residual melt occurs (Eggins *et al.* 1998). A laser diameter of 86 µm was chosen because it produced count-rates of 10<sup>3</sup>–10<sup>6</sup> units for most trace elements, allowing use of the same low count-rate part of the detector system (Allen pers. comm.).

Because all materials ablate somewhat differently, giving different counts per second per ppm for each material, the ANU2000 volcanic glass standard as compared to the synthetic standard NIST612 was used for an internal standard. The count rates for all elements were compared to silica, and the average of the element/Si ratio was multiplied by the SiO<sub>2</sub> content of the standard as determined by EDXA. Three ablations on each sample were conducted. Each sample was ablated for at least 40 seconds with a drilling depth of about 30µm (Longerich *et al.* 1996). After analysis of ten ablations (~15min.) the standard was re-measured to exclude possible variation in analysis conditions. Counts for 39 isotopes (major, trace and rare earth elements, as well as three Pb isotopes) were determined, by calculating the mean counts for each element from the three runs.

For statistical analysis the SPSS 14.0 package was employed. Of the 39 measured isotopes, only 34 (P<sup>31</sup>, Sc<sup>45</sup>, Ti<sup>49</sup>, V<sup>51</sup>, Mn<sup>55</sup>, Co<sup>59</sup>, As<sup>75</sup>, Rb<sup>85</sup>, Sr<sup>88</sup>, Y<sup>89</sup>, Zr<sup>90</sup>, Nb<sup>93</sup>, Mo<sup>95</sup>, Sn<sup>118</sup>, Cs<sup>133</sup>, Ba<sup>138</sup>, La<sup>139</sup>, Ce<sup>140</sup>, Pr<sup>141</sup>, Nd<sup>144</sup>, Sm<sup>147</sup>, Eu<sup>153</sup>, Gd<sup>158</sup>, Tb<sup>159</sup>, Dy<sup>162</sup>, Er<sup>166</sup>, Tm<sup>169</sup>, Yb<sup>174</sup>, Lu<sup>175</sup>, Ta<sup>181</sup>, W<sup>186</sup>, Pb<sup>208</sup>, Th<sup>232</sup>, and U<sup>238</sup>) gave consistent ppm counts and so only these were processed using logarithmic transformation and then analysed using Principal Component Analysis (PCA) and K-means clustering (Baxter 2006).

## Results

In total 29 samples directly collected from the source areas were analysed. The results are presented in Table 1.

The conclusions from earlier PIXE-PIGME analyses (Duerden *et al.* 1987) were confirmed: two sources are easily distinguished by their different Si, Al and Na content. Vanua Lava material has a consistent SiO<sub>2</sub> content of more than 70%, with 14% Al<sub>2</sub>O<sub>3</sub> and 4.5% Na<sub>2</sub>O; Gaua material ranges around 65% SiO<sub>2</sub>, 17% Al<sub>2</sub>O<sub>3</sub> and 5.6% Na<sub>2</sub>O. Both sources show high FeO concentrations of between 2.9% and 3.5%. Consistent with the basic difference between these

Element	Vanua Lava (n=14)			Gaua (n=15)			ANU2000 Standard (n=10)		
	Mean (ppm)	SD (ppm)	%	Mean (ppm)	SD (ppm)	%	Mean (ppm)	SD (ppm)	%
Na	33211.9	759.1	2.3	42000.0	490.7	1.2	35824.2	387.0	1.1
Mg	1395.24	336.8	24	3760.0	223.37	5.9	1814.88	1055.2	58
Al	73684.5	512.4	0.7	88455.0	259.	0.3	71689	1259.5	1.8
Si	331077.4	1559	0.5	301975.4	774.8	0.3	342859.5	1467.8	0.4
Cl	2742.86	314.9	11	4230.0	361.94	8.6	730.9	1098.4	150
K	42728.6	1938	4.5	48206.7	609.7	1.3	33422.6	978.7	2.9
Ca	8053.6	1139	14	11320.0	349.4	3.1	7930.52	333.7	4.2
FeTotal	23030.9	1572	6.8	27240	397.2	1.5	13745.2	201.9	1.5
P	284.5	12.5	4.4	765.8	19.6	2.6	189.1	3.8	2.0
Sc	9.9	0.3	2.7	6.1	0.1	1.0	6.5	0.7	10
Ti	1796.3	38.9	2.2	3452.1	15.2	0.4	1990.8	22.9	1.2
V	1.4	0.3	24	21.4	0.3	1.4	5.6	0.1	1.6
Cr	1.35	0.08	5.9	1.38	0.05	3.6	1.59	0.43	27
Mn	920.5	35.8	3.9	1078.6	5.70	0.5	450.6	12.6	2.8
Co	1.3	0.1	10	3.7	0.04	1.1	1.4	0.04	2.9
Ni	0.1	0.02	18	0.14	0.01	7.1	0.3	0.1	34
Cu	15.3	2.83	18	21.5	3.2	15	3.4	0.3	7.7
As	8.9	0.1	1.1	5.9	0.04	0.7	2.1	0.15	7.2
Rb	96.9	2.4	2.5	106.6	1.15	1.1	144.7	4.9	3.4
Sr	79.1	6.7	8.5	177	3.4	1.9	57.1	1.78	3.1
Y	39.23	0.5	1.2	24.7	0.1	0.4	31.3	0.8	2.7
Zr	261.8	1.9	0.7	189.9	0.7	0.4	277.2	6.7	2.4
Nb	5.9	0.05	0.8	4.9	0.03	0.6	42.34	0.23	0.5
Mo	5.12	0.06	1.2	4.23	0.03	0.7	3.5	0.07	2.0
Sn	2.0	0.02	1.0	1.34	0.02	1.4	3.1	0.09	2.9
Cs	2.2	0.02	0.9	1.6	0.01	0.6	1.9	0.07	3.6
Ba	657.1	7.6	1.2	916.2	12.6	1.4	619.8	30.3	4.9
La	20.23	0.15	0.7	26.1	0.1	0.3	34.8	1.2	3.5
Ce	45.5	0.4	0.9	52.7	0.25	0.5	69.7	2.6	3.7
Pr	5.81	0.06	1.0	6.1	0.03	0.5	7.2	0.3	4.5
Nd	23.1	0.26	1.1	22.12	0.10	0.5	23.34	0.8	3.5
Sm	6	0.06	1.0	4.9	0.04	0.8	5.0	0.15	3.0
Eu	0.87	0.03	3.4	1.09	0.01	0.9	0.85	0.03	3.5
Gd	6.01	0.08	1.3	4.26	0.03	0.7	5.03	0.16	3.2
Tb	1.0	0.01	1.0	0.6	0.01	1.6	0.8	0.03	3.8
Dy	6.7	0.08	1.2	4.2	0.04	1.0	5.3	0.14	2.7
Er	4.5	0.06	1.3	2.8	0.02	0.7	3.4	0.07	2.0
Tm	0.7	0.01	1.4	0.4	0.01	2.3	0.53	0.02	3.8
Yb	5.0	0.07	1.4	3.2	0.03	0.9	3.7	0.10	2.7
Lu	0.78	0.01	1.3	0.5	0.01	2.0	0.6	0.02	3.5
Ta	0.4	0.01	2.6	0.3	0.00	0.0	3	0.05	1.7
W	0.7	0.01	1.4	0.6	0.01	1.6	1.3	0.02	1.6
Pb	19.2	0.19	1.0	21.2	0.22	1.0	6.4	0.23	3.6
Th	5.0	0.04	0.8	6.9	0.03	0.4	10.4	0.80	7.7
U	2.6	0.02	0.	2.8	0.02	0.7	3.0	0.23	7.7
Pb <sub>208/206</sub>	2.082534	0.025	1.2	2.112671	0.007	0.3	2.081555	0.025	1.2
Pb <sub>207/206</sub>	0.848834	0.003	0.3	0.855615	0.005	0.6	0.831124	0.008	1.0

Table 1. Summary statistics and counts of EDXA and LA-ICP-MS abundances for two northern Vanuatu volcanic glass sources.

two sources, one silicate-richer (Vanua Lava) and one silicate-poorer (Gaua), the titanium contents differ by a factor of two, the silicate-richer source being Ti poor. In

addition the more compositionally evolved silicate-rich source has lower Rb as well as lesser Sr, but a distinctive higher Rb/Sr ratio.

Despite being a concern of other Pacific researchers including Ambrose (Smith *et al.* 1977), no significant intrasource variation was identified. The standard deviations of the major and trace elements, which are well above detection limits (cf. Table 1), are less than 5%. The Vanua Lava source shows a slightly higher internal variation than the Gaua source (average of 3.59% in contrast to 1.59% across all elements); as a comparison the elemental composition of the ANU2000 standard is given (Table 1).

Principle Components Analysis (PCA; conducted using covariance matrices) of the 34 diagnostic trace elements supports the detected differences in the major element composition (Fig 2). The first two components explain 95% of the variance, with the first component representing 92% of the total variance and the second component 3%. A clustering of the two sources is unambiguous.

A second observation in the data set is the variability of some elements in the samples from the Vanua Lava source, concentrating on the major elements analysed with the electron beam. Plagioclase phenocrysts (Ca-Na aluminosilicates) are visible or can be seen microscopically. In addition, microphenocrysts of titano-magnetite (Deer *et al.* 1992) have been identified by EDXA (Fig 3a). These are 5-100  $\mu\text{m}$  across. Clearly, different results in Na, K, Ca, Ti and Fe could be expected if differing volumes of glass, plagioclase and titano-magnetite are encountered in an ablation pit (Fig 3b and c), especially if the beam hit a large microphenocryst ( $\sim 100 \mu\text{m}$ ) (Table 2).

This indicates a difficulty in comparing these micro-analytical methods with true bulk analysis of rock specimens containing microphenocrysts, like XRF or solution ICP-MS data, where no detailed choice of the excited area exists and therefore the average of a much larger sample volume is analysed.

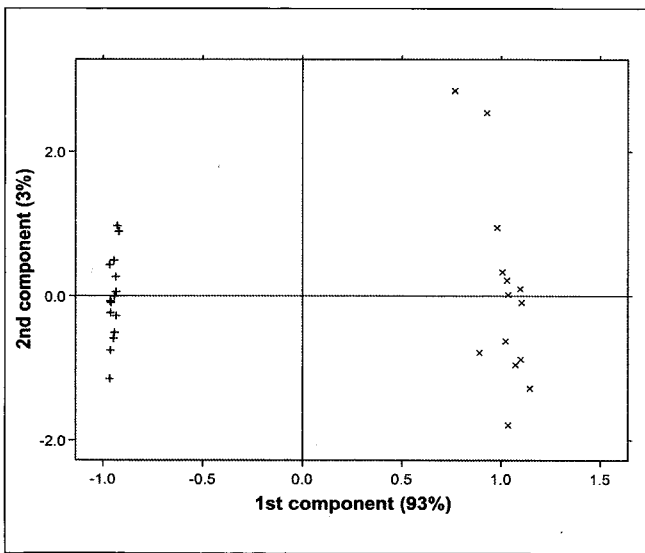


Figure 2. Principal Component Analysis of geochemical data for 29 samples from the two Banks Island sources. Displayed are the Gaua (+) and Vanua Lava (x) sources.

The first component represents 93% and the second 3% of the variance.

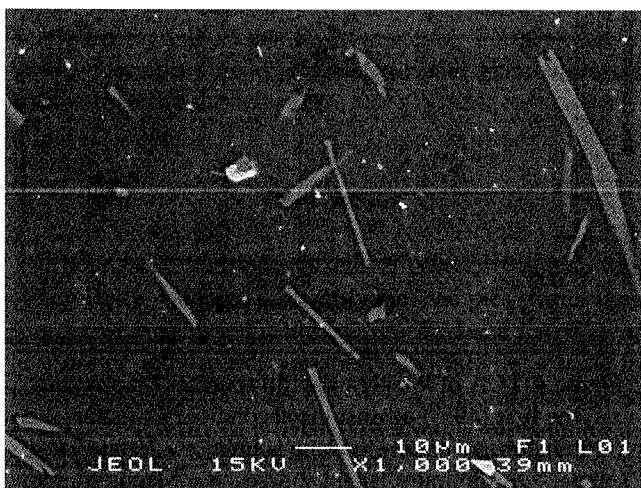
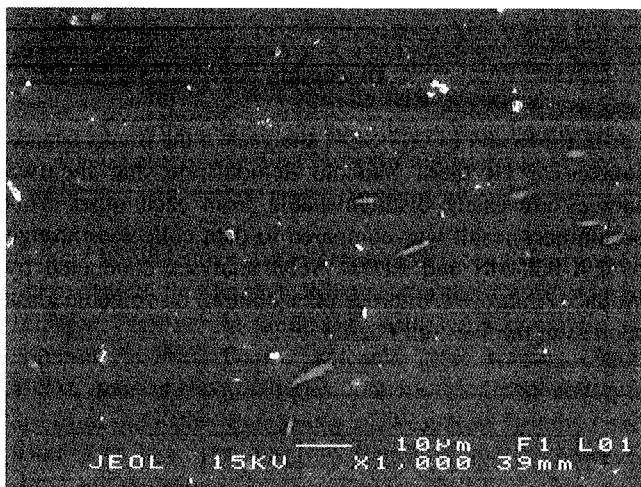
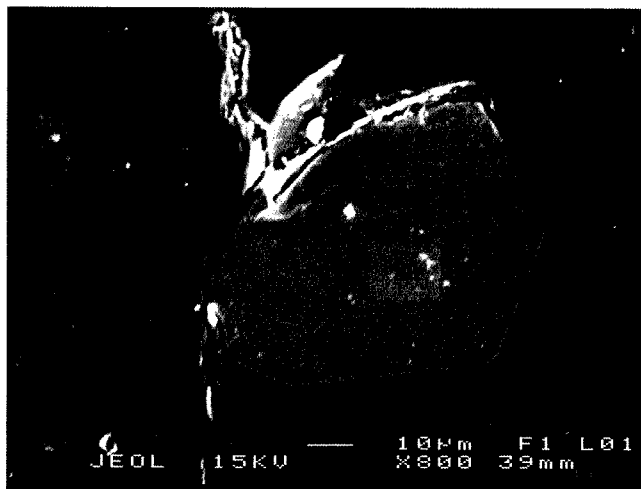


Figure 3. a: SE (secondary electron) Image of a large ( $\sim 100\mu\text{m}$ ) titano-magnetite microphenocrysts at x1000 magnification. b: SE Image of an area with a low count of microphenocrysts x1000 magnification. c: SE Image of an area with a high count of microphenocrysts x1000 resolution.

Element	Samples with microphenocrysts smaller <10µm (n=8)		Samples with large microphenocrysts ~100µm (n=5)	
	Mean (ppm)	SD (ppm)	Mean (ppm)	SD (ppm)
Na	33227.9	3349.6	20699.0	10047.6
Mg	3045.3	2136.9	14907.1	27198.4
Al	75094.1	5589.3	44965.2	19862.9
Si	324036.7	6263.4	211563.9	28264.7
K	38871.6	5075.0	18396.1	10745.0
Ca	12909.23	5524.2	23513.6	41399.0
Ti	2135.7	1056.5	32109.2	17543.5
Mn	1094.0	586.1	5049.7	3023.7
Fe	29055.5	8566.7	229813.7	61440.1

Table 2. Summary statistics and counts of EDXA abundances of samples with a high count of microphenocrysts.

### Discussion

LA-ICP-MS and EDXA-SEM analyses of the Banks Islands sources of Northern Vanuatu demonstrate that the two sources are easily distinguishable from each other. This preliminary result was compared to data collected through 59 LA-ICP-MS and EDXA-SEM analyses conducted by Wallace Ambrose (Ambrose pers. comm.) on volcanic glass sources in the Western Pacific.

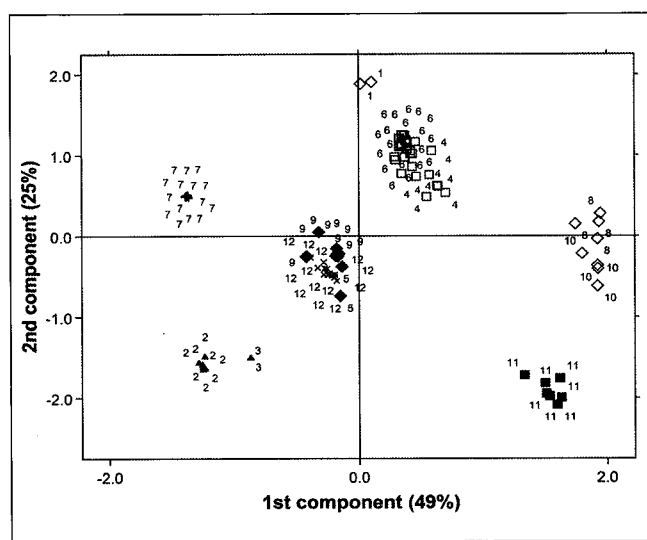


Figure 4. PCA of Western Pacific sources. Displayed is the first (49%) against the second (25%) factor (lg transformed data; + = Gaua source; x = Vanua Lava source; □ = Admiralty Island sources; ■ = Manus source; ◆ = West Ferguson sources; ◇ = East Ferguson sources; ▲ = West New Britain sources). Additional K-means cluster numbering are plotted (2, 3 = West New Britain sources; 9 and 5 = West Ferguson sources; 1, 8 and 10 = East Ferguson sources; 7 = Gaua source; 12 = Vanua Lava source; 4 and 6 = Admiralty Island sources; 11 = Manus source)

Combined PCA analysis of selected elements from the Banks Islands results and Ambrose's original data shows the Gaua sourced samples are significantly different from all other sources (Fig 4).

To control the arbitrary grouping of the PCA, additional numbering on the diagram refers to clusters produced with the K-means procedure. For the analysis the number of identified sources plus the assumed two northern Vanuatu sources were used (n=12). Clustering of the samples from the two Banks Islands sources are distinct from the other sources as well as from each other. Both clusters reflect the above-mentioned low standard deviation. Euclidian distances of 0.07 to 0.57 show a reasonably well-defined cluster for the Vanua Lava source (Cluster 12). The Gaua samples (Cluster 7) cluster even closer together. No sample is further from the centre than 0.17.

Distinguishing the Vanua Lava samples is still problematic as on the first component they are relatively similar to the West Fergusson sourced volcanic glass. However, by focussing on single trace elements rather than case centroids (PCA results), the two source areas can be unambiguously separated. Figure 5 plotting Sr/Rb ratio against V, and Fig 6 plotting Y against Ta allow the Vanua Lava samples to be distinguished from the West Fergusson ones.

Previous extensive research on chemical fingerprinting volcanic glass sources in the Pacific has usually used PIXE-PIGME analyses (Bird 1996; Duerden *et al.* 1987; Bird *et al.* 1997; Summerhayes *et al.* 1998), and the results are not directly comparable with the newly collected LA-ICP-MS data. Nevertheless, the comparison is important, and has been attempted here despite the previously mentioned difficulty in comparing data from micro-analytical techniques and bulk analysis and the consideration that, if results of two different methods of chemical characterisation are compared, a slight variation can be expected (Bellot-Gurlet *et al.* 2005; Bugoi *et al.* 2004).

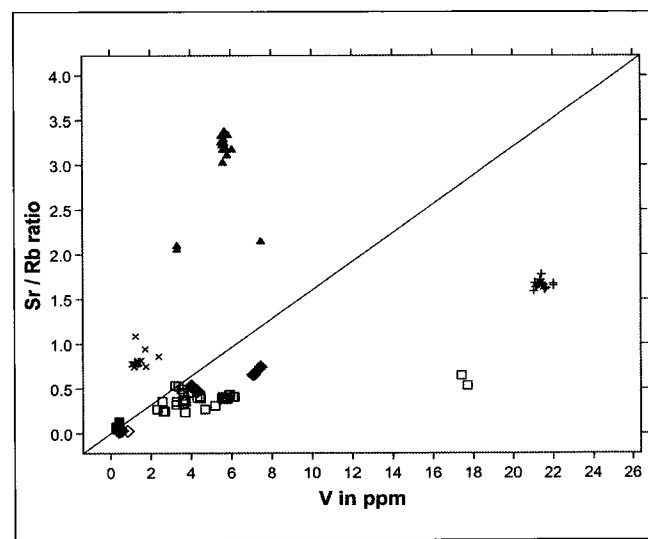


Figure 5. Vanadium contents and Sr/Rb ratio (+ = Gaua source; x = Vanua Lava source; □ = Admiralty Island sources; ◇ = D'Entrecasteaux sources; filled = West Ferguson sources; ▲ = West New Britain sources).

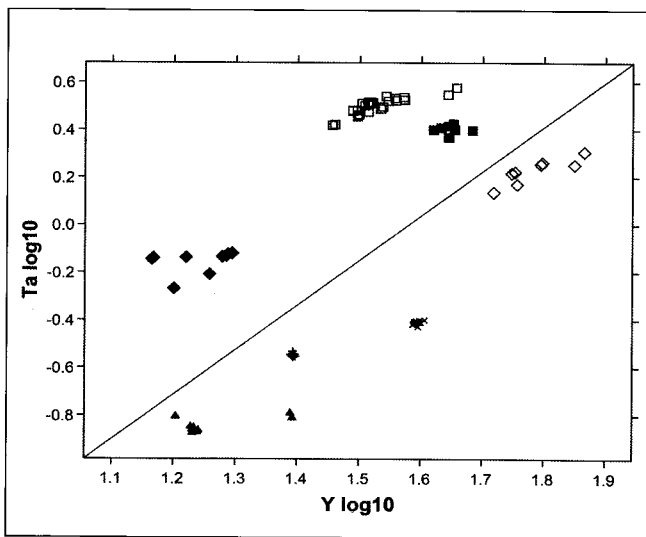


Figure 6. Yttrium and Tantalum contents (logarithmic transformed; + = Gaua source; x = Vanua Lava source; □ = Admiralty Island sources; ◇ = East Fergusson sources; filled = West Fergusson sources; ▲ = West New Britain sources).

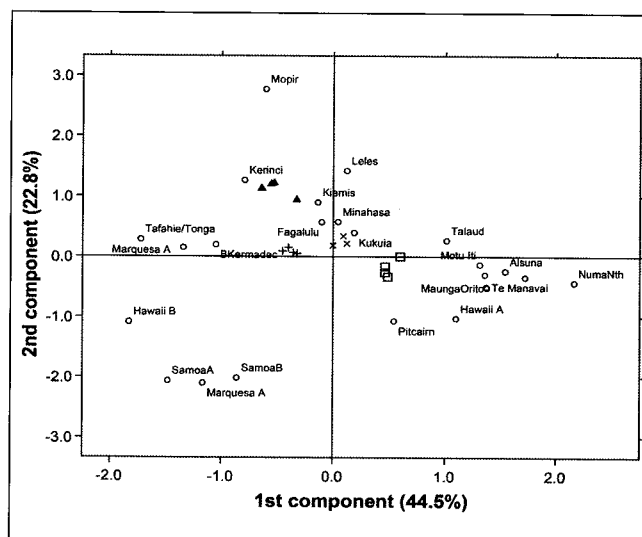


Figure 7. Correlation of XRF, PIXE-PIGME and ICP data of Vanuatu sources (+ = Gaua source; x = Vanua Lava sources) with means of other Pacific volcanic glass sources (□ = Admiralty Island sources; ◇ = D'Entrecasteaux group, filled = West Fergusson source; ▲ = West New Britain sources).

The PIXE-PIGME procedures (using absolute ppm counts of Ti, Mn, Rb, Sr, Y, Nb, F, Zn, Zr and ratios of Al/Na, F/Na, K/Fe, Ca/Fe, Mn/Fe, Rb/Fe, Sr/Fe, Y/Fe, Zr/Fe, (cf. Bird 1996)) were successfully used in the past to distinguish sources in the Pacific, and of these, Fluorine (F) is particularly important (Bird 1996; Bird *et al.* 1981; Bird *et al.* 1997). Unfortunately, analysing F and Zinc (Zn) with LA-ICP-MS is problematic, because the ionisation potential of F exceeds both that of the carrier gas Argon (Jarvis *et al.* 1992), which means that F can't be effectively ionised (Falkner *et al.* 1995, 412), and of an overlapping of the atomic weight of  $Zn^{64}/Zn^{70}$  with isotopes of  $Ni^{64}$  and  $Ge^{70}$ . PCA on covariance matrices using log transformed data with a reduced dataset of two major (Ti, Mn) and five trace elements (Rb, Sr, Y, Zr, Nb) as well as eight ratios (F/Na was missing due to the mentioned F incompatibility), show a high correlation ( $r > 0.98$ ) with the means of PIXE-PIGME and XRF analyses (Bird 1996). Displayed in Figure 7 are the first against the second component for all new results, representing 62% of the variance. Open circles represent the means of other Pacific volcanic glass sources (Bird 1996). Due to the variability in comparing three analytical methods, a spread in the Vanua Lava material is observed which results in an overlapping between the Vanuatu sources with the West Fergusson sources (although see earlier discussion of the use of single trace elements to rectify this problem).

The high count of crystallisations in the Vanua Lava material suggested the idea of using these microphenocrysts in fingerprinting Pacific volcanic glass sources. Acquafredda and Paglionico (2004) have already successfully applied the analysis of microphenocrysts in provenance studies in the Mediterranean. In all Vanua Lava material these microphenocrysts can be observed. The Gaua material

is more homogenous and microphenocrysts can be found in only ~20% of the samples. Whereas the occurrence of larger feldspar, orthoclase and plagioclase phenocrysts are common in West Pacific volcanic glass sources (Smith 1974), none of those samples containing microphenocrysts are from the Kutao/Bao source of West New Britain. Other sources in this area, like the Hamilton source, however, show microphenocrysts (Torrence *et al.* 1992). One piece from Wekwok, Admiralty Islands, has small amounts of titano-magnetite microphenocrysts. At this stage it seems that there is potential for fingerprinting Vanuatu sources by analysing crystallisations in the material. Further research on a wider spectrum of Pacific volcanic glass sources is needed to verify these results.

## Conclusions

Two sources in the Banks Islands of northern Vanuatu were systematically sampled. Twenty-nine samples from these sources were analysed using EDXA-SEM and LA-ICP-MS to examine intra-source variability and provide a basis for further provenance studies of volcanic glass in the Western Pacific. Both methods proved to be a very useful tool for the chemical analyses of volcanic glass.

The analysis of the samples showed a high intrasource homogeneity for both sources. The previous finding of high Fe, Al and Na content was confirmed. However, the hypothesised degree of intrasource variability was not confirmed.

Multivariate statistical analyses revealed good discrimination from other volcanic glass sources in the Western Pacific region. By combining PIXE-PIGME and

LA-ICP-MS data variance in the elemental composition can be detected, but the correlation was higher than presumed. Therefore, it can be stated that this variance is not large enough to seriously compromise the distinction of Vanuatu sources from other sources in the Pacific. Based on a series of trace elements in combination with a focus on Y, V, Ta content and Sr/Rb ratio, the sources in Northern Vanuatu are easy to identify.

Analytical problems were caused by the large amount of microphenocrysts in the Vanua Lava material. The development of microphenocrysts in the material can substantially alter the overall elemental composition of a sample. This issue has to be taken into account, especially in analyses where an average of a large area (>1 mm<sup>2</sup>) is used to identify the elemental composition of artefacts, such as PIXE-PIGME. The content of Fe and Ti, particularly, varies to a considerable extent due to the microphenocrysts. Therefore the use of Ti and Fe is not recommended for provenance studies to identify Banks Islands' volcanic glasses.

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