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SOURCING RAPA NUI *MATA'A* FROM THE COLLECTIONS OF BISHOP MUSEUM USING NON-DESTRUCTIVE pXRF

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Obsidian and volcanic glass provided useful material for the manufacture of cutting implements throughout the Pacific during the period before European contact. Obsidian artefacts including flakes, cores and a variety of cutting tools are commonly encountered in archaeological deposits situated in both Near and Remote Oceania (e.g., Ambrose 1996; Kirch and Yen 1982; Sheppard *et al.* 2011; Torrence, Kelloway and White 2013; Vargas, Cristino and Izaurieta 2006). Advances in provenance methods since the early 1970s have resulted in a proliferation of studies that utilise techniques such as X-ray fluorescence (XRF) and instrumental neutron activation analysis (INAA) to accurately characterise the chemical properties of obsidian and other lithic materials (see Shackley 2005). Studies of obsidian characterisation in Oceania (e.g., Bird *et al.* 1978; Reepmeyer and Clark 2010; Sand and Sheppard 2000; Smith, Ward and Ambrose 1977; Specht 2002; Spriggs, Bird and Ambrose 2010; Torrence *et al.* 2013; Weisler 2012; Weisler and Clague 1998; White and Harris 1997) and more specifically in New Zealand (e.g., Green 1962, 1964; Green *et al.* 1967; Leach and Anderson 1978; McCoy *et al.* 2010; Mosley and McCoy 2010; Sheppard *et al.* 2011) and on Rapa Nui (e.g., Beardsley, Ayres and Goles 1991; Beardsley and Goles 1998, 2001; Bird 1988; Stevenson *et al.* 2013) have been widespread. These studies have been fundamental in providing insights into the dynamics of local and regional interaction spheres in a variety of contexts throughout the region.

Rapa Nui contains four sources of obsidian in the southwestern portion of the island (Fig. 1) that have been identified through intensive archaeological survey (McCoy 1976; Stevenson, Shaw and Cristino 1984; Vargas *et al.* 2006).

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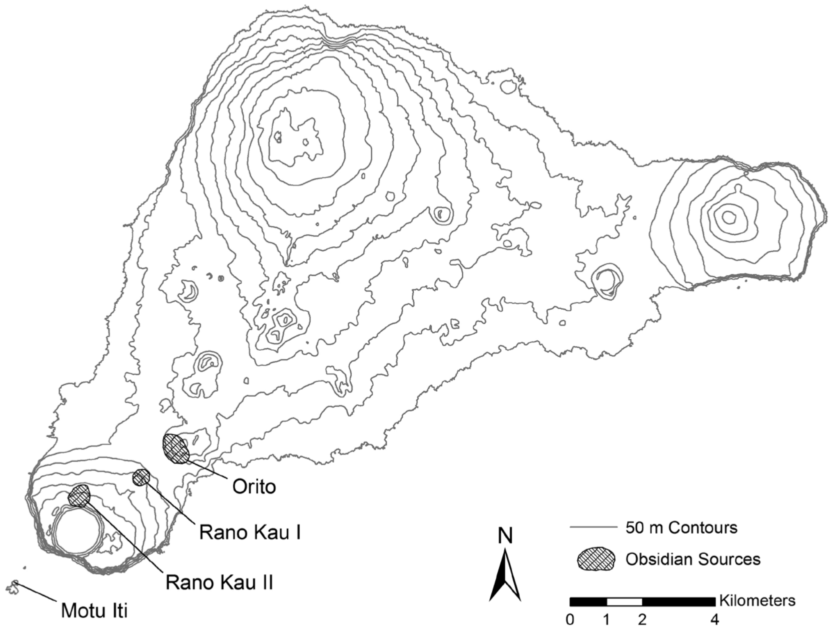

Figure 1. Obsidian source locations on Rapa Nui.

As the only large source of true obsidian outside of New Zealand in East Polynesia, this material would have been both a novel and valuable resource for the production of portable artefacts. Artefacts that were manufactured using obsidian are common across the island, and the assignment of geographical provenances using geochemical sourcing methods has provided insights into the exploitation of these source locations and social dynamics relating to access and exchange (e.g., Beardsley, Goles and Ayres 1996; Cristino *et al.* 1999; Stevenson *et al.* 2013).

The obsidian artefacts encountered on Rapa Nui are the product of a core-flake reduction technology (Stevenson *et al.* 1984) and include unretouched flakes, scrapers, small adzes and *mata‘a* (tanged obsidian tools). *Mata‘a* are reported to have “proliferated widely on Rapa Nui in late archaeological and surface contexts” (Van Tilburg 1994: 109) although chronometric data to substantiate this are lacking. Although typically described as spear points (e.g., Flenley and Bahn 2002: 152-53, Métraux 1940: 166-67), use-wear analyses carried out during the 1990s identified wear patterns and edge damage associated with the cutting of fibrous plants and wood, suggesting that *mata'a* were more likely used for crop harvesting and/or light woodworking (Church 1994, 1998; Church and Ellis 1996; Church and Rigney 1994). More recent analyses have identified the remains of sweet potato (*Ipomoea batatas*) on the cutting edges of these artefacts (Stevenson pers. comm. 2013), further suggesting that they were involved in food preparation. This empirical archaeological evidence is supported by the early observation of Bouman, a mariner onboard the first recorded European ship to visit the island in 1722 under the command of Jacob Roggeveen. Bouman observed that the Rapanui "cut their bananas with a sharp little black stone" (von Saher 1990: 52), but this observation may pertain to flakes rather than *mata'a.*

If *mata'a* did have an agricultural function, they would have been an important production tool for the chiefly economy, which was reliant on dryland agricultural practices which developed throughout the Rapa Nui cultural sequence (see Ladefoged *et al.* 2010, Stevenson 2002, Stevenson and Haoa 2008). However, the fact that hundreds of *mata'a* were surface-collected from ceremonial contexts, including 355 from the Vinapu area on the southwest coast and 287 from the Ahu Akivi-Ahu Vai Teka inland ceremonial complex (Mulloy 1961, Mulloy and Figueroa 1978) may suggest that they were not solely agricultural tools.

In the present study, we analyse a total of 332 artefacts, including 302 complete *mata'a* and 30 broken *mata'a*, from the Ethnology Collections of the Bishop Museum using pXRF (portable X-ray fluorescence) to assign geological provenances. This builds on the recent research of Stevenson *et al.* (2013), who used Discriminant Function Analysis (DFA) of laboratory-based EDXRF (energy dispersive X-ray fluorescence) data to source 331 obsidian flakes from various archaeological contexts across the island in an effort to explore regional exchange and use patterns. Stevenson *et al.* (2013) assigned the artefacts to the four geological sources that were exploited during Rapa Nui prehistory, and their findings suggested that quarries were differentially represented in ceremonial versus domestic contexts. Here, we apply a similar approach and utilise pXRF to non-destructively source the complete and incomplete *mata'a* from the collections at the Bishop Museum. Discriminant Function Analysis (DFA) and Support Vector Machines (SVM) source attribution studies were carried out to explore obsidian procurement activities and the results of these analyses are used to address the reasons for differential obsidian source exploitation and how elite personnel may have played a role in this process.

BACKGROUND

Mata'a *in the Collections of Bishop Museum*

In general, the *mata'a* curated by the Bishop Museum are ethnographic collections that lack specific provenance information. Along with a number of other cultural objects from Rapa Nui, a total of 232 complete and incomplete *mata'a* were purchased in 1920 from the private collector, J.L. Young. Young was a merchant who lived in French Polynesia and often travelled to Rapa Nui during the 1880s. Many of the *mata'a* from Young's collection have twine around the neck of the artefact, which suggests that they were likely purchased from the CEDIP (Compania Explotadora de Isla de Pascua) store on the island (historic photos of the company store show artefacts displayed on the wall using twine). Bishop Museum anthropologist Kenneth P. Emory collected 81 *mata'a* during a research expedition in 1929-1931, and these were accessioned in 1931. The remaining 20 artefacts were gifts to the museum: six *mata'a* from the Hawaiian National Museum in 1891, seven from J.L. Young in 1902, two from the Societe d'Etudes Oceaniennes in 1928, another two from ethnographer Alfred Métraux in 1936 and three from ethnobotanist Douglas Yen in 1964. Those donated by Yen are the only artefacts for which any provenance details are given. Yen indicated that these artefacts were collected near an *ahu* (ceremonial platform) in the northeastern area of the island. Aside from this very general description, there is no specific provenance information for any of the *mata'a* in the Bishop Museum collections. The argument made here is that despite limited provenance information, these artefacts can be used to explore general features of obsidian procurement.

Mata'a *Classifications*

Mata'a exhibit a wide range of morphological variation. Numerous classifications have been put forth, but they have generally been based on an intuitive or *ad hoc* selection of attributes. Ethnographic accounts from the late 19th and early 20th century (Routledge 1919, Thomson 1891) described these tools as weapons, and Thomson and Routledge both attempted to classify them based on overall shape. Thomson divided a collection of *mata'a*, which he purchased in 1886 from A.A. Salmon, an entrepreneur resident on Rapa Nui, into nine types and assigned each one a Rapanui name. Similarly, Routledge (1919: 223) was given 14 different descriptive names for *mata'a* by Rapanui informants, such as "tail of a fish", "backbone of a rat" and "leaf of a banana". It is, however, not certain if these names were used traditionally or relate to different functional types.

Since the early 20th century, a number of more formal classification schemes have been presented for *mata'a.* During the early 1920s, H.D. Skinner classified 194 artefacts from the collections of the Bishop Museum (as cited in Métraux

1940: 166-67). His classification was based on overall shape and consisted of six types (Fig. 2). In 1951, Bórmida studied 500 specimens from a museum collection in Chile and presented a classification consisting of four types, three of which had two subdivisions. He concluded that particular edge morphologies might have been employed for different woodworking functions. Bórmida's (1951) classification and Skinner's earlier one were built upon by Mulloy (1961), who analysed 355 surface-collected *mata'a* from the Vinapu area during the Norwegian Expedition to Rapa Nui in 1955-1956. A total of 219 of these were placed into Skinner's categories and "Type 2" specimens (distinguished by having a straight cutting edge) were more prevalent than the other types, with the most variation occurring in the blades of the artefacts, which were "almost infinitely varied" (Mulloy 1961: 152). Heyerdahl (1961: 399) added that "about two hundred additional surface specimens collected from most other sections on the island evince the same general characteristics…" and he thus concluded that Mulloy's study reflected island-wide variation in the morphology of these tools. In 1978, Mulloy and Figueroa expanded upon

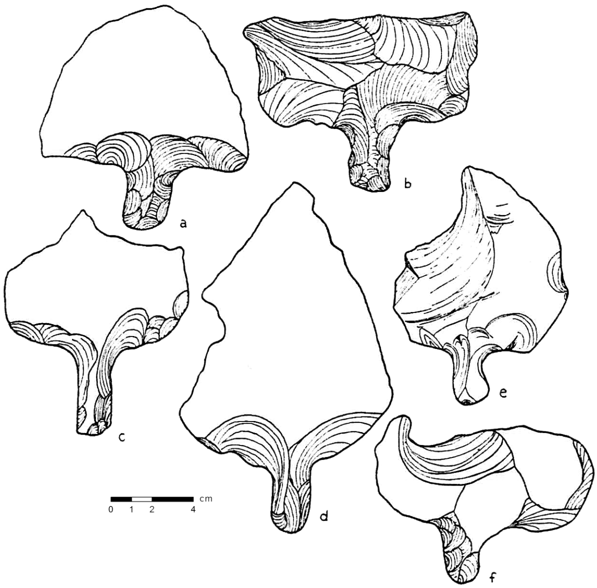

Figure 2. Examples of *mata'a* from the Bishop Museum collections showing Skinner's classification (drawings by H. D. Skinner; reproduced from Métraux 1940: 166, Fig. 3).

Mulloy’s previous analysis and compared the *mata‘a* assemblages from Vinapu and Ahu Akivi. Most recently, Lipo, Hunt and Hundtoft’s (2010) stylistic seriation of 447 artefacts from various areas of the island suggested localised patterns in *mata‘a* stylistic attributes. Overall, previous studies suggest that there is a wide range of variation, and that there is potential for the identification of some regional stylistic attributes in at least some areas of the island. In the present study, however, a stylistic seriation analysis was not undertaken due to a lack of geographic and temporal provenance for the artefacts under study.

Rapa Nui Geology and Obsidian Sourcing Studies

Rapa Nui’s four major obsidian sources are all associated with the final eruptive phase of the Rano Kau volcanic series (Vezzoli and Acocella 2009). These include: (i) the Motu Iti source, consisting of a massive dyke of obsidian located on the small (1.6 ha) offshore islet of Motu Iti, which is associated with a dense accumulation of flaking debris; (ii) the Orito source, situated on the vitrophyric dome of Maunga Orito, which contains expansive north and south flanking exposures of blocky material ~10-30 cm in length, which was extracted through open pit mining; (iii) the Rano Kau I source, located at the perlitic dome of Te Manavai, consisting of a light surface distribution of fragmentary obsidian on the northeast slopes of Rano Kau and (iv) the Rano Kau II source, which consists of small obsidian shards contained within a 20 m thick breccia along the northern edge of the Rano Kau caldera (see Fig. 1; see also McCoy 1976, Vezzoli and Acocella 2009: 874).

The material attributes of the Rapa Nui obsidian sources may have imposed some constraints on the production of *mata‘a*. The small and irregular shards of the Rano Kau II source preclude the production of large flakes and we would not expect any *mata‘a* to be made from this glass. Larger cobbles or fragments of obsidian are present at the Rano Kau I source, but they frequently contain perlite inclusions which likely made the material difficult to work (McCoy 1976: 329) and may have been visually undesirable. The Motu Iti source has a very suitable material for the production of large flakes, but with the practical drawback that it is located offshore. The Orito source contains large, easily acquired blocks of obsidian that are tabular in shape and are well-suited for the creation of large flakes from which *mata‘a* could be fashioned. We therefore predict that most of the *mata‘a* in the collections of Bishop Museum will be from the Orito source with significantly fewer *mata‘a* from Motu Iti and Rano Kau II.

Previous sourcing studies have had variable success in distinguishing between the four sources of obsidian on Rapa Nui. In 1974, Baker, Buckley and Holland utilised major, minor and trace element analysis on single samples to geochemically characterise the Orito, Motu Iti and Rano Kau I sources. Their analysis showed that the sources were broadly similar, and they were unable to distinguish among any of the sources completely. Bird (1988) performed a composition analysis using the PIXE/PIGME technique and, based on an analysis of 13 elements, found that the Te Manavai (Rano Kau I) source's geochemistry overlapped with the Orito and Rano Kau II sources.

In 1996, Beardsley *et al.* analysed 39 flakes from archaeological contexts and carried out a trace element analysis; they concluded that 82 percent of the samples (n = 32) came from the Orito source and 18 percent of the samples (n = 7) likely came from the Motu Iti source. They also assessed five obsidian samples from a site on the crater rim of Rano Kau (Site 1-193) and all five were assigned to the Orito source. As with Bird's previous study, their analysis could not distinguish between the Orito, Rano Kau I and Rano Kau II sources. Shortly thereafter, Cristino *et al.* (1999) utilised INAA and EDXRF to analyse 567 samples of source material in carrying out an extensive elemental characterisation of the four obsidian sources. Using DFA, which included 23 elements determined by INAA and seven major and minor oxides determined using EDXRF, they assessed 120 samples from Rano Kau II (identified simply as Rano Kau by Cristino *et al.*), 118 samples from Rano Kau I (identified as Te Manavai), 118 samples from Motu Iti and 211 samples from Orito. Their analysis was unable to fully partition the sources, with the Orito and Rano Kau I sources showing considerable overlap.

In 2007, Thomas, Neff and Lipo carried out an analysis of *mata'a* from nine parcels in the interior Te Miro O'one and Te Kahurea areas of the island and also analysed source material using TOF-LA-ICP-MS (Time of Flight-Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry). They used DFA to separate out the Rano Kau I (Te Manavai) and Orito sources and concluded that the vast majority of the *mata'a* under study came from the Orito source and a small number came from Motu Iti.

Most recently, Stevenson *et al.* (2013) processed 331 obsidian flakes from nine archaeological deposits and utilised a reference collection of 126 source material samples to assign provenance to the artefacts. They carried out a DFA of EDXRF data on seven elements and were able to accurately classify 89.6 percent of the 126 samples of source material analysed. They then compared archaeological samples to the geological sample distribution and showed that the sources were differentially represented in domestic versus ritual contexts (domestic: 47 percent Orito, 45 percent Rano Kau I, 2 percent Motu Iti, 5 percent Rano Kau II; ritual: 70 percent Orito, 16 percent Rano Kau I, 14 percent Motu Iti, 0 percent Rano Kau II). They also showed that the Rano Kau II source was rarely used. Here, we build on these previous sourcing analyses and use two methods (DFA and SVM) to assign geographic provenance to *mata'a* from the collections of Bishop Museum.

METHODS

The 332 *mata'a*, as well as a reference collection of 115 geological samples (Table 1), were analysed using a Bruker Tracer III SD pXRF instrument; the same reference collection was utilised by Stevenson *et al.* (2013). In the present study, these reference samples were re-analysed using the same pXRF instrument that was used to analyse the *mata'a*. Of the 115 geological samples, 31 came from the Maunga Orito source. Samples from the Orito pit mines on the northwest flanks were collected by Stevenson (Stevenson *et al.* 1984) and samples from across the site were collected by Beardsley during the course of a systematic survey of the entire dome (Beardsley and Goles 2001). Twenty-nine geologic samples came from the Rano Kau I and Rano Kau II sources. The former were collected by Stevenson from the Te Manavai exposure and the latter came from a road-cut adjacent to the road leading to the summit of Rano Kau. From Motu Iti, Stevenson collected 20 geologic surface samples and also obtained samples from an underwater area of cultural debris. Six additional geologic samples from Motu Iti were provided by Sonia Haoa.

All samples were processed in the Bishop Museum's Conservation Laboratory. Samples were placed on the instrument with a base covering mylar film and were exposed to 200 seconds of live counting time. Values for iron (Fe), gallium (Ga), manganese (Mn), niobium (Nb), rubidium (Rb), strontium (Sr), thorium (Th), yttrium (Y), zinc (Zn) and zirconium (Zr) were calculated as parts-per-million (ppm) concentrations using the S1CalProcess software provided with the Bruker instrument. The instrument was calibrated for analysing obsidian by the manufacturer before it was loaned to Bishop Museum and a supplied reference sample was run daily to check for analytical stability.

The resulting dataset was analysed using two techniques: Discriminant Function Analysis (DFA) and Support Vector Machines (SVM) classification. Discriminant Function Analysis is commonly used in archaeological studies (e.g., Sheppard *et al.* 2011) but SVM classification is a recently-developed technique (see Cortes and Vapnik 1995). The method is conceptually similar to DFA, in that it assigns unknown specimens to groups based on a reference set. However, it operates on non-parametric principles; instead of maximising the distance between group *means*, as is the case with DFA, this method maximises the distance between group *boundaries*, potentially making it less sensitive to departures from the assumptions of parametric techniques, such as normal group distributions and equality of group variance. Employing two methodologically different techniques provides a useful means of ensuring robust results.

Table 1. Means and standard deviations for the four Rapa Nui obsidian sources; all values are in parts-per-million (ppm).

Element	Rano Kau II (n=29)		Motu Iti (n=26)		Orito (n=31)		Rano Kau I (n=29)	
	µ	S.D.	µ	S.D.	µ	S.D.	µ	S.D.
Mn	440	55.3	644	88.3	555	54.2	622	66.7
Fe	20,732	1468.9	23,950	1508.5	22,367	1094.6	24,156	931.6
Zn	236	17.8	220	17.3	214	16.8	240	15.4
Rb	96	6.1	81	5.6	84	5.1	91	4.6
Sr	9	1.8	46	2.5	26	2.2	28	2
Y	160	8.3	139	7.5	143	7.6	154	5.7
Zr	837	45.3	751	110.7	837	114	880	65.7
Nb	132	5.3	122	5.3	124	5.4	130	4.5
Ga	31	3.2	29	4.2	28	2.6	31	2.9
Th	13	2.5	11	2	12	1.9	12	2.5

RESULTS

Discriminant Function Analysis

A DFA was carried out using the IBM SPSS statistics program (Version 20). Various combinations of elements were examined using standardised and log-transformed data, most of which gave similar results. It was found that using the same seven (untransformed) elements as in Stevenson *et al.*'s (2013) previous study (i.e., Mn, Fe, Zn, Rb, Sr, Y and Zr) produced results with the fewest misclassifications among the geological sample material. This DFA analysis placed the four sources into separate clusters, two of which overlapped slightly

Table 2. Predicted group assignments for obsidian source samples and artefacts as determined by Discriminant Function Analysis (DFA). The upper table shows the original results and the lower shows the results of Leave Out One Cross Validation (LOOCV).

Original	*Predicted Group*				
Actual Group	Rano Kau II	Motu Iti	Orito	Rano Kau I	*Correctly Classified*
Rano Kau II	29				1.000
Motu Iti		26			1.000
Orito			27	4	0.871
Rano Kau I			2	27	0.931
Artefacts		7	316	9	
Overall Correct Classification Rate					0.948

Original	*Predicted Group*				
Actual Group	Rano Kau II	Motu Iti	Orito	Rano Kau I	*Correctly Classified*
Rano Kau II	29				1.000
Motu Iti		26			1.000
Orito			26	5	0.839
Rano Kau I			4	25	0.862
Overall Correct Classification Rate					0.922

(Fig. 3). Overall, 94.8 percent of the source material samples were accurately classified, a figure which dropped slightly to 92.2 percent under Leave Out One Cross Validation (LOOCV) (Table 2). All misclassifications involved specimens from the Orito and Rano Kau I sources. The resulting discriminant functions were used to provide a geological provenance to the *mata'a* (n = 332). The vast majority of the artefacts (95.2 percent) were assigned to the Orito source (n = 317). Nine artefacts (2.7 percent) were assigned to the Rano Kau I (Te Manavai) source and seven (2.1 percent) to the Motu Iti source (see Appendix). No *mata'a* were assigned to the Rano Kau II source.

Table 3. Predicted group assignments for obsidian source samples and artefacts as determined by Support Vector Machines (SVM) classification. The upper table shows the original results and the lower shows the results of Leave Out One Cross Validation (LOOCV).

	Predicted Group				
Actual Group	Rano Kau II	Motu Iti	Orito	Rano Kau I	*Correctly Classified*
Rano Kau II	29				1.000
Motu Iti		26			1.000
Orito			26	5	0.839
Rano Kau I			2	27	0.931
Artefacts		8	319	5	n/a
Overall Correct Classification Rate					0.948

LOOCV	*Predicted Group*				
Actual Group	Rano Kau II	Motu Iti	Orito	Rano Kau I	*Correctly Classified*
Rano Kau II	29				1.000
Motu Iti		26			1.000
Orito			25	6	0.806
Rano Kau I			2	27	0.931
Overall Correct Classification Rate					0.930

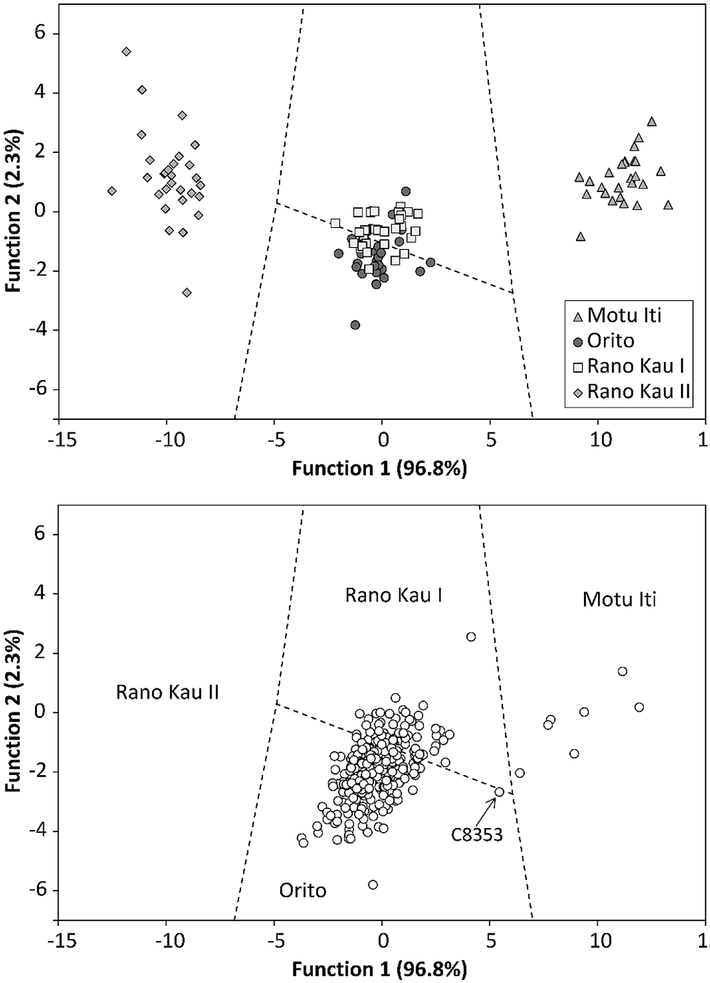

Figure 3. Plot of the first two Discriminant Functions of *mata'a* (n = 332) from the Bishop Museum collections and reference samples (n = 115). The upper plot shows the separation of the reference samples. The lower plot shows the assignment of *mata'a*. Dashed lines indicate the Discriminant Function group boundaries. Sample C8353 (labelled) was assigned to the Orito source by the DFA and to the Motu Iti source by the SVM classification.

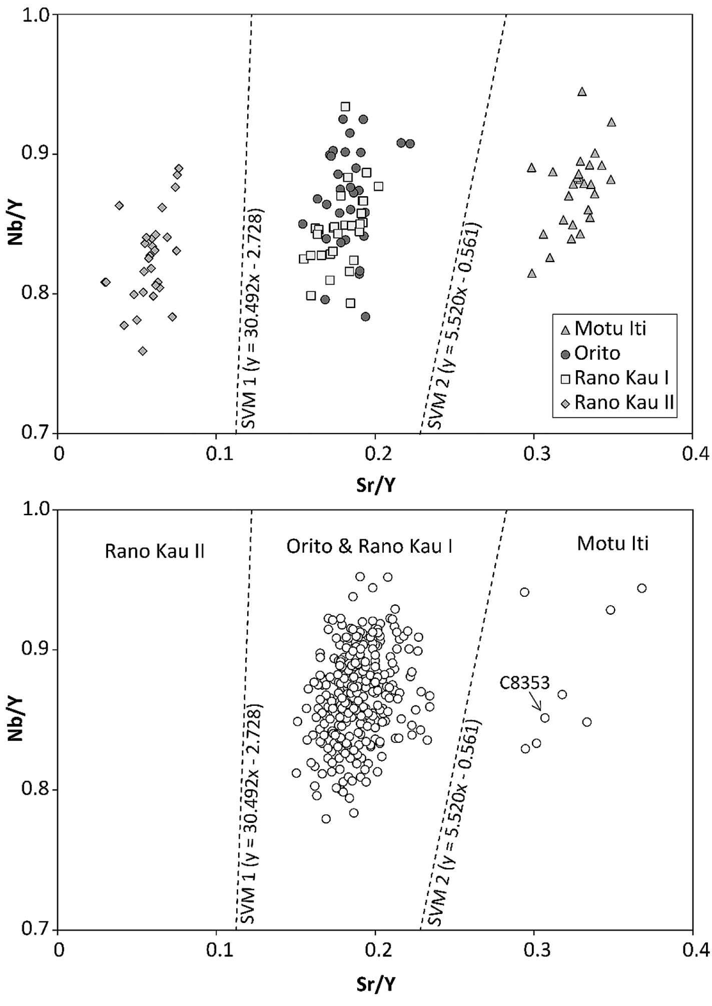

Figure 4. Stage 1 of the Support Vector Machines classification. The upper plot shows the separation of the Motu Iti and Rano Kau II reference samples from the other two sources. The lower plot shows the assignment of *mata'a*. Data are the same as in Figure 3. Sample C8353 (labelled) was assigned to Orito by the DFA and to Motu Iti sources by the SVM classification.

Support Vector Machine (SVM) Classification

The SVM analysis was carried out using the *ksvm* implementation in the Kernlab package for R (Karatzoglou, Smola and Hornik 2013: 54-61). The *vanilladot* kernel was selected to produce a linear classification function and all other settings were left at their default values. An initial assessment of the reference data suggested that different combinations of elements would be required to separate the four sources. Accordingly, a nested approach was used for the analysis; first, a pair of mid-Z element ratios (Sr/Y against Nb/Y) was used to discriminate the two most distinct sources, Motu Iti and Rano Kau II (Fig. 4). This combination produced a clear separation for these sources but resulted in considerable overlap among the Orito and Rano Kau I samples.

For the second stage of the analysis, all paired combinations of elements and element ratios were examined and the pair that best visually separated Orito from Rano Kau I (Y against Zn) was used to generate an SVM classification function (Fig. 5). This resulted in seven misclassifications for the reference samples; five samples from the Orito source were assigned to Rano Kau I, while two Rano Kau I samples were assigned to Orito. Overall, 93.9 percent of the geological reference samples were classified correctly using SVM and 93.0 percent under LOOCV (Table 3), a result almost identical to the DFA. The SVM classification functions were then applied to the artefacts. Eight were assigned to the Motu Iti source and the remainder (n = 324) were assigned to either the Orito or Rano Kau I sources (Fig. 4). No artefacts were assigned to the Rano Kau II source. For the second stage of the SVM classification, five artefacts were assigned to Rano Kau I, and the remaining 319 to Orito (Fig. 5).

Comparison of Results

Overall, both methods gave very similar results; the Motu Iti and Rano Kau II sources each possess distinct chemical compositions and were completely separated using either method. The same seven *mata'a* (2.4 percent) were assigned to the Motu Iti source by both methods, but the SVM assigned one additional artefact (Accession Number C8353) to Motu Iti, which was assigned to Orito in the DFA. The scatterplot of the DFA classification shows that this specimen plots close to the junctions of three DFA grouping boundaries (Orito, Rano Kau II and Motu Iti) and appears to be more closely associated with the cluster of artefacts assigned to the Motu Iti source than to the Orito artefact cluster (Fig. 3). This artefact (Accession Number C8353) also plotted close to group boundaries when log-transformed data were used in a DFA. In contrast, the SVM analysis shows the specimen to be clearly associated with the Motu Iti reference samples and artefacts assigned to that

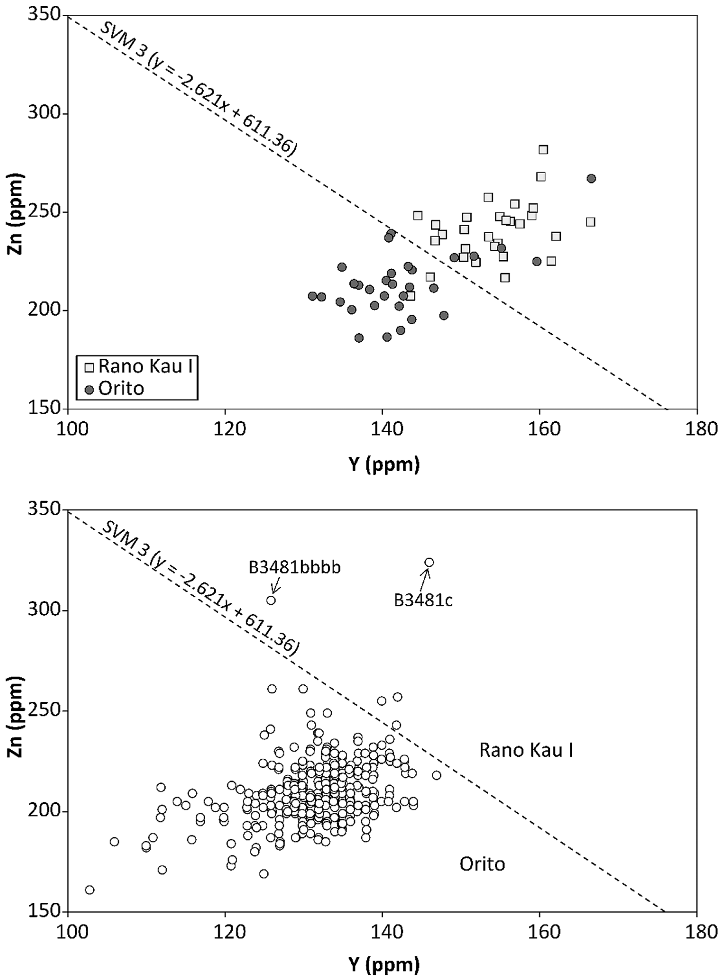

Figure 5. Stage 2 of the Support Vector Machines classification. The upper plot shows the separation of the Orito and Rano Kau I reference samples. The lower plot shows the assignment of *mata'a* assigned to those two sources in Figure 4.

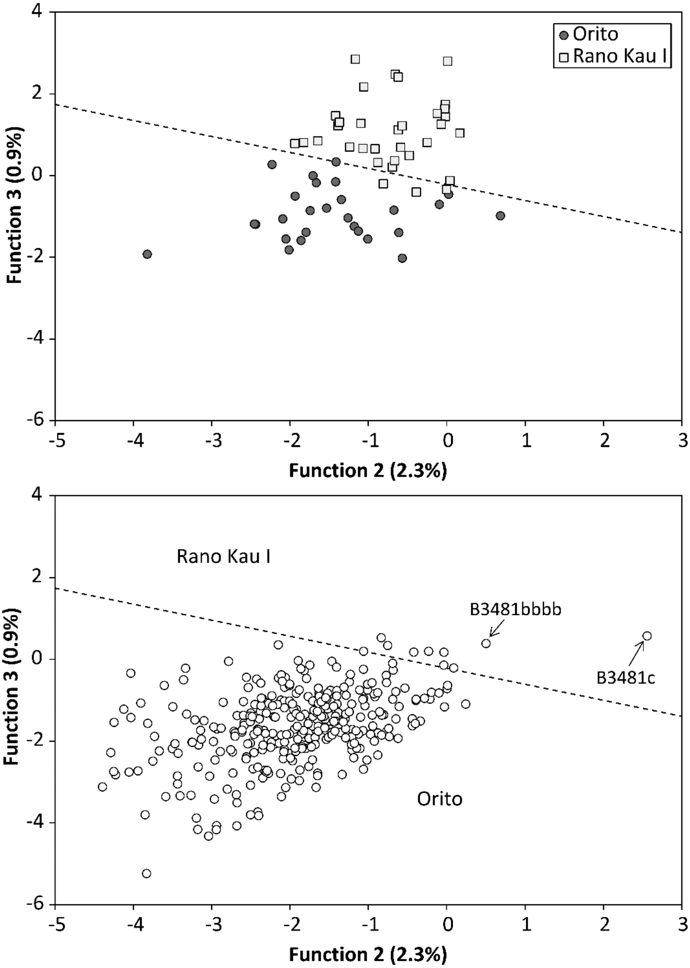

Figure 6. Plot of the second and third functions from the DFA, showing the separation of the Orito and Rano Kau I sources. The Motu Iti and Rano Kau II source materials and associated artefacts are omitted for clarity. The upper plot shows the separation of the reference samples. The lower plot shows the assignment of *mata‘a*. The dashed line indicates the Discriminant Function group boundary.

source (Fig. 6). On balance, these results suggest that the artefact is more likely derived from the Motu Iti source. It is noteworthy that Sample C8353 has the lowest values for Zr (523 ppm) and Nb (86 ppm) of all of the artefacts, so it may represent the extreme range of the Motu Iti source.

The other two sources, Rano Kau I and Orito, could not be completely separated using either method. Six reference samples were misclassified by DFA and seven by the SVM analysis. Our results concur with previous analyses (e.g., Stevenson *et al.* 2013) and indicate that the Rano Kau I and Orito sources are too similar to be completely separated by geochemical means alone. However, with the exception of two specimens (B3481c and B3481bbbb), which appear to be clearly associated with the Rano Kau I source, the remainder of these artefacts form a single homogenous cluster that is more closely associated with the Orito reference samples than those from Rano Kau I. The virtually identical results obtained using two methodologically different (i.e., parametric and non-parametric) techniques (see Figs 5 and 6) suggests that Orito is the most likely source for this cluster.

Comparison of Mata‘a *Metric Data by Obsidian Source*

Upon completion of the source discrimination, we measured *mata‘a* length, width and calculated length/width ratio metrics. The primary aim was to determine if material source might have limited or constrained *mata‘a* shape or dimensions. Consequently, if significant metric differences exist between *mata‘a* items sourced to various quarry locales, future hypotheses linking tool function, raw material quality and ultimately resource extraction and procurement may be addressed. However, these results should be viewed with some caution due to the small sample size for *mata‘a* from sources outside Orito.

In carrying out this analysis, the maximum length and width of each *mata‘a* was measured and each artefact was weighed. Length was measured from the base of the stem to the top of the tool, and maximum width measurements were taken perpendicular to the stem. Incomplete *mata‘a* were not included in the analysis. A total of 302 *mata‘a* were measured. This included 288 that were assigned to the Orito source by both DFA and SVM, seven assigned to the Motu Iti source by DFA and SVM and seven that were assigned to the Rano Kau source by DFA.

Comparison of the width for *mata‘a* from the three obsidian sources suggests that the mean width of *mata‘a* from each source group is similar (Table 4, Fig. 7). Although samples sizes for the Rano Kau source (n = 7) and the Motu Iti source (n = 7) are relatively small when compared to Orito (n = 288), a Kruskal-Wallis non-parametric comparison of mean width returned a value of $X^2 = 2.168$ (sig. = 0.338) which indicates that the mean

Table 4. Descriptive statistics for width for *mata'a* from Orito, Motu Iti and Rano Kau I.

Source	N	Min	Max	Mean	S.D
Orito	288	29.5	169.2	85.84	24.39
Motu Iti	7	63.2	122.8	92.71	23.86
Rano Kau I	7	54.0	126.5	98.17	28.36

Table 5. Descriptive statistics for length for *mata'a* from Orito, Motu Iti and Rano Kau I.

Source	N	Min	Max	Mean	S.D
Orito	288	43.8	202.4	94.52	22.66
Motu Iti	7	90.1	151.8	113.27	21.68
Rano Kau I	7	14.5	308.8	118.29	97.33

Table 6. Descriptive statistics for length/ratio for *mata'a* from Orito, Motu Iti and Rano Kau I.

Source	N	Min	Max	Mean	S.D
Orito	288	0.47	2.72	1.15	0.3012
Motu Iti	7	0.96	1.58	1.26	0.2386
Rano Kau I	7	0.27	2.5	1.11	0.7486

width differences between sources is not statistically significant at a 90 percent confidence level.

Mata'a length was also compared between the obsidian source groups (Table 5, Fig. 8). The Kruskal-Wallis non-parametric comparison of group means indicates that *mata'a* made from different source material are significantly different in mean length at a 90 percent confidence level ($X^2 = 5.1773$, sig. = 0.075). To determine if there were significant differences between the three quarry groups, we ran a set of Mann-Whitney U t-tests comparing the groups pairwise. The results indicate that the only difference

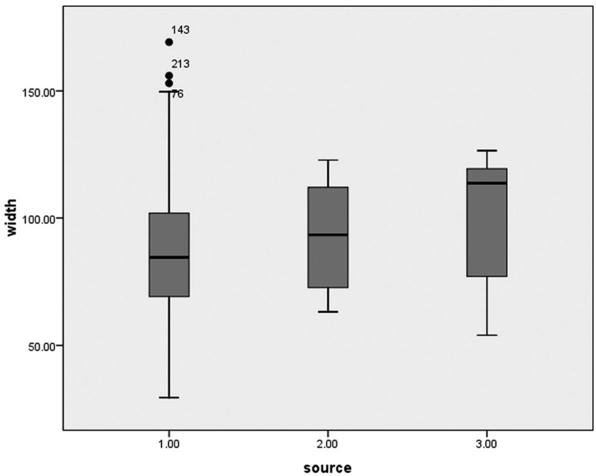

Figure 7. Box-plots of *mata'a* width values by obsidian source: 1.00 = Orito, 2.00 = Motu Iti and 3.00 = Rano Kau I.

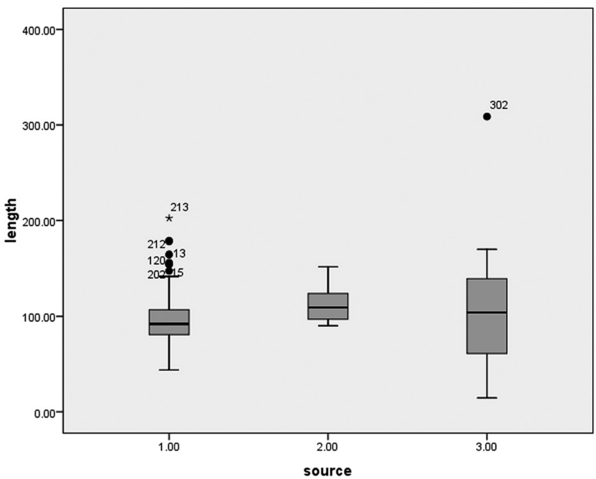

Figure 8. Box-plots of *mata'a* length values by obsidian source: 1.00 = Orito, 2.00 = Motu Iti and 3.00 = Rano Kau I.

between *mata'a* mean length is found when comparing Orito *mata'a* to the Motu Iti samples (z = -2.26, sig. = 0.02). Inspection of the group mean values and the sign of the z score indicate that the Orito source was associated with smaller mean length *mata'a* in comparison to *mata'a* from the Motu Iti source. Additional Mann-Whitney U t-tests did not identify any differences between Orito and Rano Kau assemblages (z = -0.130, sig. = 0.0897) or Motu Iti and Rano Kau assemblages (z = -0.575, sig. = 0.620).

The length/width ratio of *mata'a* from the three different sources was also compared using the Kruskal-Wallis non-parametric test (Fig. 9). The results demonstrate that *mata'a* from different sources are not significantly different in mean length/width ratios (X^2 = 2.120, sig. = 0.346). Descriptive statistics for the length/width ratios for three quarry sources are presented in Table 6.

Overall, the mean dimensions of artefacts from all three identified sources were similar. The only significant difference identified was that of *mata'a* from Orito, which were on average 21 mm shorter than those from the other sources. This may be due to differences in raw material form or, given the non-significant differences in width, more intense resharpening of *mata'a* from Orito. However, the dimensional ranges of *mata'a* from all three sources overlap, suggesting functional similarities across all sources. Additionally, we note more variability in the lengths of the artefacts sourced to Rano Kau I (see Table 5), which might reflect difficulties in flaking due to perlite inclusions.

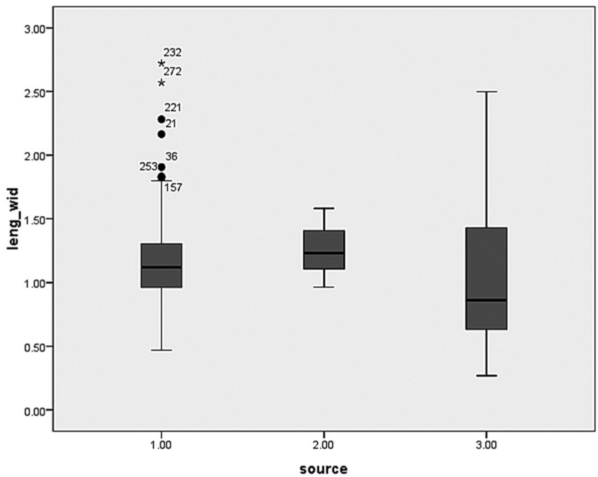

Figure 9. Box-plots of *mata'a* length/width values by obsidian source: 1.00 = Orito, 2.00 = Motu Iti and 3.00 = Rano Kau I.

DISCUSSION

With the exception of very recent analyses (e.g., Stevenson *et al.* 2013), most previous provenance studies on Rapa Nui have relied on destructive methods of analysis. As shown by this study, which employed two separate analytical methods, the use of non-destructive pXRF analysis results in source discrimination with levels of accuracy similar to those obtained using destructive techniques. Museum collections, like the one examined herein, sometimes lack well controlled artefact provenances when compared with assemblages from excavated contexts. However, because museum collections are often from a variety of contexts, they might provide a useful space and time-averaged overview of "typical" resource exploitation for a region. This can provide a baseline for comparing to individual site assemblages, associations which may have had different functions (i.e., domestic vs. ritual) or status.

Another advantage of the present study was analysis of complete tools as opposed to flakes. This may provide better quantitative insights into obsidian tool production, because several dozen flakes could potentially represent the manufacturing process involved in making a single tool. Therefore, even though this collection is not from secure archaeological contexts, it does provide general insights into resource exploitation on Rapa Nui.

Both of the sourcing methods used here indicate that a very low proportion of artefacts were manufactured using obsidian from the Motu Iti (n = 7) and Rano Kau I (n = 7) sources, and no artefacts in our sample were fashioned using obsidian from the Rano Kau II source. The absence of obsidian from Rano Kau II in this study (which contains artefacts that may represent variable time periods and/or geographical areas) suggests that this source was never intensively exploited. We suggest that this past use pattern may stem from the fact that the Orito and Motu Iti obsidians are of a better quality than the Rano Kau II material, which has unfavourable fracture properties (Baker *et al.* 1974, McCoy 1976, Thomas *et al.* 2007).

The results of the present analysis also are in general agreement with the findings of Stevenson *et al.* (2013) in relation to the extraction of obsidian from the Motu Iti source, especially in the case of the assemblages they analysed from inland habitation contexts. In those contexts, Stevenson *et al.*'s study suggested that only two percent of flakes were sourced to Motu Iti (versus coastal ritual contexts, where 14 percent of flakes are from the Motu Iti source). Both of the analytical methods employed in the present study suggest that approximately two percent of the Museum's collections were made using obsidian from the Motu Iti source.

With respect to the Rano Kau I source, the number of *mata'a* made from this material constitute two to three percent of the Museum assemblage (in six out of ten cases, the DFA and SVM were not in agreement in assigning tools to either the Rano Kau I or Orito sources). This is considerably lower than the 45 percent reported by Stevenson *et al.* (2013) for the occurrence of Rano Kau I obsidian in their flake assemblage. This may suggest that the material size, or quality, of this obsidian was not desirable for the production of *mata'a*, or that some of the tools in the present study that were assigned to the Orito source could have come from a portion of the Rano Kau I source that overlaps considerably with Orito. However, the high proportion of Rano Kau I obsidian identified by Stevenson *et al.* might also indicate that this material was commonly used for informal flake tools.

The vast majority of the *mata'a* analysed in this study were quarried from Orito, the largest source on Rapa Nui, suggesting that the ancient Rapanui may have chosen geographical ease of access and abundance of raw materials, as well as performance characteristics of the raw material, when manufacturing these tools. The very low proportion of artefacts manufactured using the less accessible offshore Motu Iti source, coupled with the possibility that more controlled distribution may have been enforced by elites, as has been suggested by Stevenson *et al.* (2013:119), may indicate that Orito became the preferred option. However, an elite presence in the immediate vicinity of Orito in the form of a chiefly dwelling (*hare paenga*), as noted by Stevenson *et al.* (2013), raises the possibility that access to the quarry may also have been controlled. Instead of restriction, as appears to have been the case for Motu Iti, chiefly control at Orito may instead have involved encouraging access to this source of high-quality obsidian as a means of building and maintaining prestige. Indeed, the ubiquity of *mata'a* on Rapa Nui raises the question as to whether or not they were used exclusively in subsistence activities. The possibility of elite intervention in their production hints at an ideological component for this object which is reinforced by the prolific occurrence of these items at ceremonial centres.

* * *

In the current study, a Discriminant Function Analysis and Support Vector Machines classification produced almost identical results. However, neither method could completely separate the Orito and Rano Kau I sources. In this respect, our analyses agree with previous research, suggesting that the compositions of the sources are too similar to allow complete separation using the suite of major and trace elements commonly quantified with XRF instruments. While it is likely that more precise analytical techniques, such as radiogenic isotope analysis (Woodhead and Weisler 1997), could provide better source discrimination, these methods tend to be at least partially destructive, which might preclude their use on artefacts, especially those from museum collections.

Overall, each of the methods outlined here appears to be effective in assigning geographical provenances to source materials and artefacts, as indicated by the fact that each method correctly assigned geologic sample materials to source over 90 percent of the time. Even when we take into account the small amount of overlap between the Orito and Rano Kau I sources, the results of both analyses suggest the ancient Rapanui preferentially accessed the Orito source in manufacturing these tools. These findings are in line with previous studies of both *mata'a* tools (Thomas *et al.* 2007) and simple obsidian flakes (Stevenson *et al.* 2013). The discovery that the overwhelming majority of these island *mata'a* were manufactured at the Orito quarry adds another indication of possible chiefly involvement in the activities at the quarry, as initially identified on the basis of residential architecture. Future sourcing studies on securely-provenanced *mata'a* may lend further insights into lithic extraction and exchange patterns across the island and the elite management entailed therein.

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APPENDIX

The following table shows pXRF data and source determinations for *mata'a* in the Bishop Museum collections by Support Vector Machines (SVM) classification and Discriminant Function Analysis (DFA).

Sample No.	MnKa1	FeKa1	ZnKa1	RbKa1	SrKa1	Y Ka1	ZrKa1	NbKa1	GaKa1	ThLa1	Source (SVM)	Source (DFA)	Description
2013.057.001	569	22256	236	84	27	141	988	116	28	11	Orito	Orito	*mata'a* (incomplete)
2013.057.002	558	22023	215	83	26	130	759	114	26	8	Orito	Orito	*mata'a* (incomplete)
2013.057.003	591	20964	217	79	25	135	790	116	27	8	Orito	Orito	*mata'a* (incomplete)
5962	483	21634	255	79	25	140	865	119	28	12	Rano Kau 1	Orito	*mata'a* (complete)
5963	495	21221	208	80	24	135	700	122	25	12	Orito	Orito	*mata'a* (complete)
5964	587	21540	232	79	24	129	796	110	26	13	Orito	Orito	*mata'a* (complete)
5965	479	19668	208	71	21	124	703	109	27	11	Orito	Orito	*mata'a* (complete)
5966	543	20080	203	79	21	127	866	114	22	9	Orito	Orito	*mata'a* (complete)
5967	694	22322	195	77	44	132	662	112	24	12	Motu Iti	Motu Iti	*mata'a* (complete)
6714	632	21938	215	90	23	132	770	118	23	12	Orito	Orito	*mata'a* (complete)
6715	438	18605	182	62	22	110	603	92	20	9	Orito	Orito	*mata'a* (complete)
6716	543	20978	213	80	21	133	726	116	29	13	Orito	Orito	*mata'a* (complete)
6717	570	21357	199	82	24	139	800	117	26	12	Orito	Orito	*mata'a* (complete)
6718	470	21144	206	78	25	133	901	120	28	12	Orito	Orito	*mata'a* (broken stem)
6719	513	18178	187	69	23	111	737	97	25	7	Orito	Orito	*mata'a* (complete)
B3481a	557	21557	211	80	30	141	1078	118	21	12	Orito	Orito	*mata'a* (complete)
B3481a_6	671	20989	214	77	27	128	703	112	27	10	Orito	Orito	*mata'a* (complete)
B3481a_7	457	21123	218	77	25	133	739	114	28	8	Orito	Orito	*mata'a* (complete)
B3481a_8	447	19681	200	70	23	136	779	106	23	15	Orito	Orito	*mata'a* (complete)
B3481a_9	628	21740	209	79	24	139	804	115	26	10	Orito	Orito	*mata'a* (complete)
B3481aa	582	20290	209	72	25	131	844	112	23	12	Orito	Orito	*mata'a* (complete)
B3481aaa	664	20835	225	83	25	137	883	120	24	12	Orito	Orito	*mata'a* (complete)
B3481aaaa	579	21082	207	70	39	112	605	104	22	13	Motu Iti	Motu Iti	*mata'a* (complete)
B3481aaaaa	512	20369	261	80	24	130	731	111	26	14	Orito	Orito	*mata'a* (complete)
B3481b	489	21340	207	83	25	136	763	114	24	13	Orito	Orito	*mata'a* (complete)
B3481b_6	503	21265	213	80	26	128	715	116	25	10	Orito	Orito	*mata'a* (complete)
B3481b_7	485	21352	214	81	25	135	791	115	24	13	Orito	Orito	*mata'a* (complete)
B3481b_8	531	19432	196	75	24	120	658	102	26	11	Orito	Orito	*mata'a* (complete)
B3481b_9	537	19110	195	73	22	117	650	104	30	9	Orito	Orito	*mata'a* (complete)

B3481bb	597	22112	205	83	26	133	758	121	24	11	Orito	Orito	*mata'a* (complete)
B3481bbb	510	21151	209	81	27	132	713	116	27	15	Orito	Orito	*mata'a* (complete)
B3481bbbb	556	20957	305	80	26	126	712	107	29	13	Rano Kau 1	Rano Kau 1	*mata'a* (complete)
B3481bbbbb	505	19202	186	71	22	116	682	106	25	9	Orito	Orito	*mata'a* (complete)
B3481c	569	21781	324	82	34	146	968	122	24	13	Rano Kau 1	Rano Kau 1	*mata'a* (complete)
B3481c_6	572	21556	225	80	30	133	761	114	24	10	Orito	Orito	*mata'a* (complete)
B3481c_7	542	21085	223	79	23	131	822	119	28	11	Orito	Orito	*mata'a* (complete)
B3481c_8	470	19129	195	68	20	120	667	105	23	11	Orito	Orito	*mata'a* (complete)
B3481c_9	513	21041	205	82	24	134	807	117	27	14	Orito	Orito	*mata'a* (complete)
B3481cc	548	21077	205	83	25	136	746	117	27	8	Orito	Orito	*mata'a* (complete)
B3481ccc	568	20834	197	76	29	130	729	110	25	10	Orito	Orito	*mata'a* (complete)
B3481cccc	448	22115	205	79	28	139	881	113	26	10	Orito	Orito	*mata'a* (complete)
B3481ccccc	433	21086	216	78	23	128	753	110	22	14	Orito	Orito	*mata'a* (complete)
B3481d	580	21272	187	83	28	138	966	115	25	14	Orito	Orito	*mata'a* (complete)
B3481d_6	538	21844	210	82	26	135	780	122	27	15	Orito	Orito	*mata'a* (complete)
B3481d_7	512	17397	185	64	21	106	603	94	23	9	Orito	Orito	*mata'a* (complete)
B3481d_8	515	21047	204	78	26	124	689	111	27	10	Orito	Orito	*mata'a* (complete)
B3481d_9	652	20497	200	78	23	126	788	110	24	12	Orito	Orito	*mata'a* (complete)
B3481dd	532	22092	205	83	24	134	773	123	24	13	Orito	Orito	*mata'a* (complete)
B3481ddd	617	21163	207	83	26	132	826	120	20	14	Orito	Orito	*mata'a* (complete)
B3481dddd	463	19105	209	70	22	116	683	100	24	7	Orito	Orito	*mata'a* (broken stem)
B3481ddddd	589	21543	208	75	24	126	772	112	29	12	Orito	Orito	*mata'a* (complete)
B3481e	535	21382	226	83	25	140	940	112	23	10	Orito	Orito	*mata'a* (complete)
B3481e_6	633	21065	229	84	22	133	778	119	24	7	Orito	Orito	*mata'a* (complete)
B3481e_7	571	20884	230	81	23	127	744	109	29	15	Orito	Orito	*mata'a* (complete)
B3481e_8	518	21059	205	74	27	133	710	111	23	11	Orito	Orito	*mata'a* (complete)
B3481e_9	518	20747	210	74	25	139	944	112	19	11	Orito	Orito	*mata'a* (complete)
B3481ee	394	21520	219	79	26	135	813	115	25	10	Orito	Orito	*mata'a* (complete)
B3481eee	552	20081	209	77	24	133	705	113	28	11	Orito	Orito	*mata'a* (broken stem)
B3481eeee	618	21446	227	82	25	135	848	121	24	9	Orito	Orito	*mata'a* (complete)
B3481eeeee	530	21629	228	89	27	135	992	120	24	14	Orito	Orito	*mata'a* (complete)
B3481f	638	21720	209	77	27	134	771	121	28	15	Orito	Orito	*mata'a* (complete)

Sample No.	MnKa1	FeKa1	ZnKa1	RbKa1	SrKa1	Y Ka1	ZrKa1	NbKa1	GaKa1	ThLa1	Source (SVM)	Source (DFA)	Description
B3481f_6	652	22183	206	82	26	135	806	118	25	12	Orito	Orito	*mata‘a* (complete)
B3481f_7	542	21438	227	83	24	133	765	115	27	12	Orito	Orito	*mata‘a* (complete)
B3481f_8	469	18991	197	73	24	117	739	100	26	12	Orito	Orito	*mata‘a* (complete)
B3481f_9	559	18926	197	66	20	112	634	99	28	5	Orito	Orito	*mata‘a* (complete)
B3481ff	599	22704	257	83	28	142	836	118	26	9	Rano Kau 1	Rano Kau 1	*mata‘a* (complete)
B3481fff	574	20854	203	77	27	137	792	114	20	11	Orito	Orito	*mata‘a* (complete)
B3481ffff	429	18064	171	68	20	112	620	100	22	13	Orito	Orito	*mata‘a* (complete)
B3481fffff	597	21209	214	81	24	129	718	113	30	12	Orito	Orito	*mata‘a* (complete)
B3481g	592	20672	209	80	27	138	984	113	22	14	Orito	Orito	*mata‘a* (complete)
B3481g_6	613	21519	207	76	24	126	720	120	26	14	Orito	Orito	*mata‘a* (complete)
B3481g_7	545	21864	197	77	24	133	770	119	30	10	Orito	Orito	*mata‘a* (complete)
B3481g_8	623	21508	243	77	29	131	725	118	25	11	Orito	Orito	*mata‘a* (complete)
B3481g_9	565	21825	218	83	25	137	809	119	23	12	Orito	Orito	*mata‘a* (complete)
B3481gg	499	21193	225	77	24	141	767	116	25	11	Orito	Orito	*mata‘a* (complete)
B3481ggg	591	20294	217	79	23	134	693	114	28	10	Orito	Orito	*mata‘a* (complete)
B3481gggg	566	20958	198	76	24	133	726	113	23	9	Orito	Orito	*mata‘a* (complete)
B3481ggggg	608	21909	215	80	27	135	797	122	27	13	Orito	Orito	*mata‘a* (complete)
B3481h	644	21066	212	80	24	130	747	119	24	14	Orito	Orito	*mata‘a* (complete)
B3481h_6	521	20655	224	72	24	125	711	114	25	11	Orito	Orito	*mata‘a* (complete)
B3481h_7	495	20745	198	83	23	136	734	116	24	12	Orito	Orito	*mata‘a* (complete)
B3481h_8	645	21525	196	81	27	135	778	118	26	13	Orito	Orito	*mata‘a* (complete)
B3481h_9	600	21152	229	83	26	134	726	118	27	15	Orito	Orito	*mata‘a* (complete)
B3481hh	544	21054	211	79	24	126	801	115	27	10	Orito	Orito	*mata‘a* (complete)
B3481hhh	571	20974	212	77	27	137	731	117	27	11	Orito	Orito	*mata‘a* (complete)
B3481hhhh	625	20974	261	79	23	126	735	114	25	14	Orito	Orito	*mata‘a* (complete)
B3481hhhhh	633	22339	204	75	41	129	681	112	26	8	Motu Iti	Motu Iti	*mata‘a* (complete)
B3481i	674	21634	225	83	26	143	729	119	27	10	Orito	Rano Kau 1	*mata‘a* (complete)
B3481i_6	454	18425	212	63	25	112	626	94	26	8	Orito	Orito	*mata‘a* (complete)
B3481i_7	546	19853	202	74	24	131	712	106	24	14	Orito	Orito	*mata‘a* (complete)

B3481i_8	420	21601	205	78	27	143	1139	118	27	17	Orito	Orito	*mata‘a* (complete)
B3481i_9	604	23562	214	84	25	133	758	118	28	10	Orito	Orito	*mata‘a* (complete)
B3481ii	444	21182	219	79	23	143	1234	120	22	15	Orito	Orito	*mata‘a* (complete)
B3481iii	650	21097	209	78	26	125	715	119	25	12	Orito	Orito	*mata‘a* (incomplete)
B3481iiii	480	19867	197	73	24	120	645	102	26	11	Orito	Orito	*mata‘a* (complete)
B3481iiiii	507	18892	193	71	23	124	658	100	28	10	Orito	Orito	*mata‘a* (complete)
B3481j	625	21780	215	74	26	130	858	113	26	11	Orito	Orito	*mata‘a* (complete)
B3481j_6	549	20146	206	76	22	132	750	110	22	9	Orito	Orito	*mata‘a* (complete)
B3481j_7	609	20700	210	77	23	128	729	106	25	10	Orito	Orito	*mata‘a* (complete)
B3481j_8	606	20579	196	72	27	132	726	112	20	10	Orito	Orito	*mata‘a* (complete)
B3481j_9	559	20819	216	82	25	133	952	118	24	13	Orito	Orito	*mata‘a* (complete)
B3481jj	514	20690	195	78	23	130	727	110	26	11	Orito	Orito	*mata‘a* (complete)
B3481jjj	563	21355	224	79	23	139	771	116	28	11	Orito	Orito	*mata‘a* (broken stem)
B3481jjjj	550	20737	214	75	26	134	865	115	27	13	Orito	Orito	*mata‘a* (broken stem)
B3481jjjjj	530	19631	201	73	23	123	697	110	25	13	Orito	Orito	*mata‘a* (broken stem)
B3481k	702	21510	235	76	28	132	768	117	27	9	Orito	Orito	*mata‘a* (complete)
B3481k_6	548	20833	187	81	28	126	743	111	25	11	Orito	Orito	*mata‘a* (complete)
B3481k_7	383	21507	218	79	24	147	1309	117	20	13	Orito	Orito	*mata‘a* (complete)
B3481k_8	660	21003	212	81	26	130	752	116	23	12	Orito	Orito	*mata‘a* (complete)
B3481k_9	517	20302	198	75	22	131	710	111	25	8	Orito	Orito	*mata‘a* (complete)
B3481kk	629	21247	225	77	26	137	741	114	23	12	Orito	Orito	*mata‘a* (complete)
B3481kkk	369	18710	205	70	21	118	696	101	28	11	Orito	Orito	*mata‘a* (complete)
B3481kkkk	532	20634	215	77	23	128	754	110	21	9	Orito	Orito	*mata‘a* (complete)
B3481kkkkk	618	21511	219	77	28	132	735	115	23	10	Orito	Orito	*mata‘a* (complete)
B3481l	508	20544	223	76	25	126	724	116	24	13	Orito	Orito	*mata‘a* (complete)
B3481l_6	638	20073	187	71	23	132	1014	110	22	12	Orito	Orito	*mata‘a* (complete)
B3481l_7	615	20580	199	76	27	129	914	114	22	12	Orito	Orito	*mata‘a* (complete)
B3481l_8	504	20740	219	75	23	136	889	118	25	10	Orito	Orito	*mata‘a* (complete)
B3481l_9	498	20796	202	79	24	126	684	109	23	10	Orito	Orito	*mata‘a* (complete)
B3481ll	441	20411	191	76	25	135	733	115	26	13	Orito	Orito	*mata‘a* (complete)
B3481lll	652	21559	233	78	32	140	985	118	27	11	Orito	Orito	*mata‘a* (complete)
B3481llll	584	20361	189	73	23	130	755	116	22	13	Orito	Orito	*mata‘a* (complete)

Sample No.	MnKa1	FeKa1	ZnKa1	RbKa1	SrKa1	Y Ka1	ZrKa1	NbKa1	GaKa1	ThLa1	Source (SVM)	Source (DFA)	Description
B3481lllll	514	21520	212	82	26	130	721	119	25	10	Orito	Orito	*mata‘a* (complete)
B3481m	582	21106	211	79	24	130	774	115	25	12	Orito	Orito	*mata‘a* (complete)
B3481m_6	542	20283	237	74	24	137	738	115	26	12	Orito	Orito	*mata‘a* (complete)
B3481m_7	602	21734	213	80	24	137	783	117	28	12	Orito	Orito	*mata‘a* (complete)
B3481m_8	514	21530	229	84	25	137	736	119	27	13	Orito	Orito	*mata‘a* (complete)
B3481m_9	558	21065	191	81	26	138	791	119	27	11	Orito	Orito	*mata‘a* (complete)
B3481mm	563	20285	209	76	24	123	702	105	29	10	Orito	Orito	*mata‘a* (complete)
B3481mmm	584	21238	210	82	25	134	730	119	28	11	Orito	Orito	*mata‘a* (complete)
B3481mmmm	542	21416	206	82	27	133	858	121	24	12	Orito	Orito	*mata‘a* (complete)
B3481mmmmm	559	21758	204	75	38	126	660	105	25	8	Motu Iti	Motu Iti	*mata‘a* (complete)
B3481n	573	20754	215	76	30	128	727	110	24	14	Orito	Orito	*mata‘a* (complete)
B3481n_6	602	21021	211	75	23	122	727	106	26	12	Orito	Orito	*mata‘a* (broken stem)
B3481n_7	703	21410	222	79	27	139	745	116	26	11	Orito	Rano Kau 1	*mata‘a* (complete)
B3481n_8	576	21476	223	76	26	130	771	113	28	14	Orito	Orito	*mata‘a* (complete)
B3481n_9	632	21241	216	74	21	134	841	115	27	9	Orito	Orito	*mata‘a* (complete)
B3481nn	562	22425	203	81	28	144	869	122	25	15	Orito	Orito	*mata‘a* (complete)
B3481nnn	596	20797	185	74	26	127	764	109	24	10	Orito	Orito	*mata‘a* (complete)
B3481nnnn	501	21639	210	79	25	126	733	119	27	12	Orito	Orito	*mata‘a* (complete)
B3481nnnnn	558	22366	202	76	38	129	655	107	27	8	Motu Iti	Motu Iti	*mata‘a* (complete)
B3481o	644	21590	220	79	26	137	749	121	27	11	Orito	Orito	*mata‘a* (complete)
B3481o_6	640	22234	229	87	26	141	727	116	29	9	Orito	Rano Kau 1	*mata‘a* (broken stem)
B3481o_7	550	21487	189	80	22	131	803	115	24	12	Orito	Orito	*mata‘a* (complete)
B3481o_8	607	21386	225	74	26	130	708	113	28	12	Orito	Orito	*mata‘a* (complete)
B3481o_9	548	21469	239	81	26	132	744	112	28	9	Orito	Orito	*mata‘a* (complete)
B3481oo	531	21794	231	82	26	131	729	112	29	12	Orito	Orito	*mata‘a* (complete)
B3481ooo	507	21192	208	81	24	125	729	115	28	12	Orito	Orito	*mata‘a* (complete)
B3481oooo	597	21214	200	77	25	137	784	114	25	11	Orito	Orito	*mata‘a* (complete)
B3481ooooo	392	21059	200	78	24	132	730	119	29	14	Orito	Orito	*mata‘a* (complete)
B3481p	489	21292	209	80	26	135	781	116	24	14	Orito	Orito	*mata‘a* (complete)
B3481p_6	512	21431	223	81	25	136	846	108	20	11	Orito	Orito	*mata‘a* (complete)

B3481p_7	583	20865	193	75	25	123	714	113	24	12	Orito	Orito	*mata‘a* (complete)
B3481p_8	562	21715	239	75	25	132	733	120	29	13	Orito	Orito	*mata‘a* (complete)
B3481p_9	613	21170	207	81	23	134	843	116	25	13	Orito	Orito	*mata‘a* (complete)
B3481pp	590	19284	203	74	19	115	742	97	23	11	Orito	Orito	*mata‘a* (complete)
B3481ppp	642	22285	235	81	27	137	733	120	27	12	Orito	Rano Kau 1	*mata‘a* (broken stem)
B3481pppp	607	20542	201	79	25	131	817	110	27	11	Orito	Orito	*mata‘a* (incomplete)
B3481ppppp	501	21879	218	81	25	139	879	111	21	14	Orito	Orito	*mata‘a* (complete)
B3481q	514	21007	196	82	23	136	766	119	24	13	Orito	Orito	*mata‘a* (complete)
B3481q_6	595	20335	232	74	25	133	1005	116	25	13	Orito	Orito	*mata‘a* (complete)
B3481q_7	568	20288	197	77	24	132	732	112	19	11	Orito	Orito	*mata‘a* (complete)
B3481q_8	504	18855	183	73	25	110	684	100	19	6	Orito	Orito	*mata‘a* (complete)
B3481q_9	543	19517	202	77	23	120	685	107	26	11	Orito	Orito	*mata‘a* (complete)
B3481qq	454	21351	215	81	28	130	742	113	24	10	Orito	Orito	*mata‘a* (complete)
B3481qqq	539	21077	203	76	27	133	794	114	27	14	Orito	Orito	*mata‘a* (broken stem)
B3481qqqq	502	20628	221	77	26	129	739	114	22	12	Orito	Orito	*mata‘a* (complete)
B3481qqqqq	508	21593	222	76	26	129	818	118	26	13	Orito	Orito	*mata‘a* (complete)
B3481r	566	21453	206	79	24	131	753	119	29	12	Orito	Orito	*mata‘a* (complete)
B3481r_6	696	20164	213	74	27	121	704	107	27	14	Orito	Orito	*mata‘a* (complete)
B3481r_7	581	20864	221	75	27	127	726	118	26	12	Orito	Orito	*mata‘a* (complete)
B3481r_8	478	18612	197	78	25	134	1397	105	24	11	Orito	Orito	*mata‘a* (complete)
B3481r_9	541	20189	201	73	21	128	716	112	23	17	Orito	Orito	*mata‘a* (complete)
B3481rr	612	21125	207	76	26	130	739	114	30	9	Orito	Orito	*mata‘a* (complete)
B3481rrr	456	20547	183	85	23	127	821	112	26	12	Orito	Orito	*mata‘a* (broken stem)
B3481rrrr	569	21701	227	78	25	141	806	116	26	13	Orito	Orito	*mata‘a* (complete)
B3481rrrrr	625	19125	173	74	22	121	699	103	23	9	Orito	Orito	*mata‘a* (complete)
B3481s	691	21555	224	79	24	134	751	115	25	9	Orito	Orito	*mata‘a* (complete)
B3481s_6	394	18945	205	70	23	114	652	104	21	9	Orito	Orito	*mata‘a* (complete)
B3481s_7	579	21155	186	84	23	132	697	116	29	9	Orito	Orito	*mata‘a* (complete)
B3481s_8	567	20153	200	79	23	129	779	119	24	10	Orito	Orito	*mata‘a* (complete)
B3481ss	371	20206	182	77	23	124	773	109	23	9	Orito	Orito	*mata‘a* (complete)
B3481sss	540	21892	249	79	23	131	702	110	25	12	Orito	Orito	*mata‘a* (complete)
B3481ssss	639	19786	193	71	23	125	808	107	21	11	Orito	Orito	*mata‘a* (complete)

Sample No.	MnKa1	FeKa1	ZnKa1	RbKa1	SrKa1	Y Ka1	ZrKa1	NbKa1	GaKa1	ThLa1	Source (SVM)	Source (DFA)	Description
B3481sssss	463	18795	201	68	20	112	625	100	24	8	Orito	Orito	*mata‘a* (complete)
B3481t	504	21681	218	80	28	130	728	118	21	13	Orito	Orito	*mata‘a* (complete)
B3481t_6	572	21118	217	82	26	135	802	120	26	11	Orito	Orito	*mata‘a* (complete)
B3481t_7	621	21356	206	80	23	134	765	114	30	15	Orito	Orito	*mata‘a* (complete)
B3481t_8	633	21059	209	77	25	126	788	114	24	15	Orito	Orito	*mata‘a* (complete)
B3481tt	602	20785	213	76	23	129	712	111	24	11	Orito	Orito	*mata‘a* (complete)
B3481ttt	490	21309	212	78	25	135	1027	117	22	10	Orito	Orito	*mata‘a* (complete)
B3481tttt	520	19393	184	75	22	121	703	110	25	12	Orito	Orito	*mata‘a* (complete)
B3481ttttt	612	21497	195	80	23	138	809	112	27	10	Orito	Orito	*mata‘a* (complete)
B3481u	571	20996	214	80	22	129	807	119	23	13	Orito	Orito	*mata‘a* (complete)
B3481u_6	515	20030	201	79	25	126	817	111	26	12	Orito	Orito	*mata‘a* (complete)
B3481u_7	472	20966	205	75	22	131	730	111	26	9	Orito	Orito	*mata‘a* (complete)
B3481u_8	663	23310	221	85	27	136	855	116	23	13	Orito	Orito	*mata‘a* (complete)
B3481uu	621	21024	205	80	23	136	820	118	25	14	Orito	Orito	*mata‘a* (complete)
B3481uuu	642	21780	220	84	25	131	742	111	23	9	Orito	Orito	*mata‘a* (complete)
B3481uuuu	490	21421	224	81	23	135	762	116	25	9	Orito	Orito	*mata‘a* (complete)
B3481uuuuu	523	19790	196	76	24	127	810	113	21	8	Orito	Orito	*mata‘a* (complete)
B3481v	613	21187	199	84	28	132	709	121	25	10	Orito	Orito	*mata‘a* (complete)
B3481v_6	571	19927	198	71	22	124	684	107	24	10	Orito	Orito	*mata‘a* (complete)
B3481v_7	391	19793	188	69	24	123	692	104	24	11	Orito	Orito	*mata‘a* (complete)
B3481v_8	495	21246	204	79	26	131	795	114	23	14	Orito	Orito	*mata‘a* (complete)
B3481vv	526	20702	203	77	27	138	790	118	23	10	Orito	Orito	*mata‘a* (complete)
B3481vvv	585	20723	193	76	29	135	922	113	26	14	Orito	Orito	*mata‘a* (complete)
B3481vvvv	568	22992	205	85	22	140	804	117	22	11	Orito	Orito	*mata‘a* (complete)
B3481w	666	21083	216	78	22	134	725	115	26	7	Orito	Orito	*mata‘a* (complete)
B3481w_6	497	20592	195	77	22	133	784	115	26	14	Orito	Orito	*mata‘a* (complete)
B3481w_7	536	21481	201	85	26	132	758	120	23	11	Orito	Orito	*mata‘a* (complete)
B3481w_8	581	21076	205	87	24	131	897	116	22	12	Orito	Orito	*mata‘a* (complete)
B3481ww	635	21667	243	79	23	142	776	116	27	11	Rano Kau 1	Rano Kau 1	*mata‘a* (complete)

B3481www	553	21369	211	80	23	130	733	114	25	13	Orito	Orito	*mata‘a* (broken stem)
B3481wwww	487	20707	230	78	25	131	765	106	26	11	Orito	Orito	*mata‘a* (complete)
B3481wwwww	610	21237	210	78	26	138	779	113	28	11	Orito	Orito	*mata‘a* (complete)
B3481x	530	21533	207	86	27	139	805	112	23	13	Orito	Orito	*mata‘a* (complete)
B3481x_6	486	21357	222	78	25	138	832	114	25	7	Orito	Orito	*mata‘a* (complete)
B3481x_7	585	20311	193	77	21	130	742	114	24	14	Orito	Orito	*mata‘a* (complete)
B3481x_8	610	21625	212	86	28	136	971	120	23	14	Orito	Orito	*mata‘a* (complete)
B3481xx	615	19748	180	75	25	124	718	108	26	7	Orito	Orito	*mata‘a* (complete)
B3481xxx	607	21438	232	78	25	139	753	119	24	12	Orito	Orito	*mata‘a* (complete)
B3481xxxxx	559	20631	208	78	24	129	773	113	26	11	Orito	Orito	*mata‘a* (complete)
B3481y	583	20039	192	72	24	124	698	101	23	11	Orito	Orito	*mata‘a* (complete)
B3481y_6	724	20816	213	81	25	130	743	115	25	14	Orito	Orito	*mata‘a* (complete)
B3481y_7	507	21573	213	88	26	132	729	116	26	11	Orito	Orito	*mata‘a* (complete)
B3481y_8	574	20915	202	74	25	130	759	116	25	13	Orito	Orito	*mata‘a* (complete)
B3481yy	457	20268	205	77	23	131	701	105	20	9	Orito	Orito	*mata‘a* (complete)
B3481yyy	665	21194	213	78	27	128	777	114	26	12	Orito	Orito	*mata‘a* (complete)
B3481yyyy	604	21367	223	77	29	134	727	114	25	13	Orito	Orito	*mata‘a* (complete)
B3481yyyyy	491	21938	190	80	26	134	752	119	27	10	Orito	Orito	*mata‘a* (complete)
B3481z	674	21504	203	85	26	136	851	116	27	12	Orito	Orito	*mata‘a* (complete)
B3481z_6	547	21105	208	78	23	130	786	113	25	12	Orito	Orito	*mata‘a* (complete)
B3481z_7	528	20527	194	79	24	133	705	115	27	7	Orito	Orito	*mata‘a* (complete)
B3481z_8	490	19909	187	79	23	129	790	111	24	11	Orito	Orito	*mata‘a* (complete)
B3481zz	587	21251	198	83	24	139	950	113	25	11	Orito	Orito	*mata‘a* (complete)
B3481zzz	535	21256	203	79	24	126	792	113	27	12	Orito	Orito	*mata‘a* (complete)
B3481zzzz	540	19489	200	78	23	129	766	115	24	10	Orito	Orito	*mata‘a* (complete)
B3481zzzzz	527	19820	185	75	20	133	686	108	20	10	Orito	Orito	*mata‘a* (complete)
B3482a	541	21174	206	75	30	128	744	111	24	11	Orito	Orito	*mata‘a* (incomplete)
B3482b	540	21398	204	79	24	132	726	110	28	10	Orito	Orito	*mata‘a* stem
B3482c	582	21553	249	78	29	133	879	121	25	13	Orito	Orito	*mata‘a* stem
B3482d	687	21644	205	72	35	119	640	112	26	6	Motu Iti	Motu Iti	*mata‘a* (incomplete)
B611	571	21060	222	77	23	134	828	118	26	12	Orito	Orito	*mata‘a* (complete)
C4120	558	18505	161	61	22	103	659	94	19	10	Orito	Orito	*mata‘a* (complete)

Sample No.	MnKa1	FeKa1	ZnKa1	RbKa1	SrKa1	Y Ka1	ZrKa1	NbKa1	GaKa1	ThLa1	Source (SVM)	Source (DFA)	Description
C4121a	531	21479	221	83	25	134	764	116	27	9	Orito	Orito	*mata‘a* (complete)
C4121aa	597	21595	209	81	25	136	770	117	30	10	Orito	Orito	*mata‘a* (complete)
C4121aaa	570	19573	176	70	25	121	703	105	20	10	Orito	Orito	*mata‘a* (complete)
C4121aaaa	460	19886	238	75	23	125	706	112	21	10	Orito	Orito	*mata‘a* (complete)
C4121b	616	20794	214	81	28	134	721	116	22	11	Orito	Orito	*mata‘a* (complete)
C4121bb	548	21722	218	85	26	134	833	117	28	13	Orito	Orito	*mata‘a* (complete)
C4121bbb	664	22067	219	76	25	133	740	121	28	10	Orito	Orito	*mata‘a* (complete)
C4121bbbb	606	21849	208	79	24	141	743	117	26	12	Orito	Orito	*mata‘a* (complete)
C4121c	580	21207	201	80	23	138	776	118	23	10	Orito	Orito	*mata‘a* (complete)
C4121cc	649	21059	222	80	25	133	736	116	26	10	Orito	Orito	*mata‘a* (incomplete)
C4121ccc	449	21072	199	81	24	135	1004	110	28	9	Orito	Orito	*mata‘a* (complete)
C4121d	542	20835	208	78	26	131	736	118	23	12	Orito	Orito	*mata‘a* (complete)
C4121dd	552	20565	241	76	27	126	706	109	26	11	Orito	Orito	*mata‘a* (broken stem)
C4121ddd	428	20736	191	77	24	130	750	113	26	12	Orito	Orito	*mata‘a* (complete)
C4121e	604	21385	216	82	27	139	745	122	26	13	Orito	Orito	*mata‘a* (complete)
C4121ee	586	20966	201	76	24	136	711	113	21	9	Orito	Orito	*mata‘a* (complete)
C4121eee	691	21687	228	86	24	139	747	120	22	13	Orito	Rano Kau 1	*mata‘a* (complete)
C4121f	463	21110	231	77	25	133	791	114	25	13	Orito	Orito	*mata‘a* (complete)
C4121ff	682	22172	194	88	25	135	836	120	26	11	Orito	Orito	*mata‘a* (complete)
C4121fff	530	19762	202	74	25	125	974	111	28	8	Orito	Orito	*mata‘a* (complete)
C4121g	553	20001	208	73	23	129	678	111	21	8	Orito	Orito	*mata‘a* (complete)
C4121gg	548	20908	199	82	25	126	710	115	28	11	Orito	Orito	*mata‘a* (broken stem)
C4121ggg	542	22115	201	79	23	129	776	113	26	10	Orito	Orito	*mata‘a* (complete)
C4121h	444	20157	187	78	25	129	770	115	27	8	Orito	Orito	*mata‘a* (complete)
C4121hh	586	22335	220	80	25	137	998	118	25	12	Orito	Orito	*mata‘a* (complete)
C4121hhh	618	22884	218	86	26	138	741	120	29	13	Orito	Orito	*mata‘a* (incomplete)
C4121i	494	20385	169	77	26	125	789	107	24	13	Orito	Orito	*mata‘a* (complete)
C4121ii	470	19524	202	72	22	123	702	104	24	9	Orito	Orito	*mata‘a* (complete)
C4121iii	528	21294	203	81	25	137	935	120	30	11	Orito	Orito	*mata‘a* (complete)

C4121j	628	21589	202	77	23	142	859	114	30	12	Orito	Orito	*mata'a* (complete)
C4121jj	554	20729	197	79	24	134	783	115	26	9	Orito	Orito	*mata'a* (complete)
C4121jjj	640	20747	222	78	22	127	724	117	24	13	Orito	Orito	*mata'a* (complete)
C4121k	512	20677	234	75	25	134	703	118	24	10	Orito	Orito	*mata'a* (complete)
C4121kk	629	21072	207	81	25	131	757	118	23	7	Orito	Orito	*mata'a* (complete)
C4121kkk	553	21576	199	76	28	131	794	118	24	10	Orito	Orito	*mata'a* (complete)
C4121l	529	21181	213	81	22	129	851	118	26	14	Orito	Orito	*mata'a* (complete)
C4121ll	654	20904	209	79	24	134	699	119	27	11	Orito	Orito	*mata'a* stem
C4121lll	633	23674	225	81	46	125	651	118	27	11	Motu Iti	Motu Iti	*mata'a* (complete)
C4121m	585	20401	214	78	23	133	786	112	27	8	Orito	Orito	*mata'a* (complete)
C4121mm	439	20945	194	79	24	131	781	112	25	12	Orito	Orito	*mata'a* (complete)
C4121mmm	593	21382	190	82	24	135	699	115	25	11	Orito	Orito	*mata'a* (complete)
C4121n	534	20897	211	82	25	133	954	121	26	10	Orito	Orito	*mata'a* (complete)
C4121nn	557	20797	199	77	24	128	856	114	25	11	Orito	Orito	*mata'a* (complete)
C4121nnn	578	22747	219	76	25	144	771	121	25	13	Orito	Orito	*mata'a* (complete)
C4121o	579	21594	205	80	25	141	738	118	25	11	Orito	Orito	*mata'a* (complete)
C4121oo	553	20962	229	76	28	127	737	116	22	8	Orito	Orito	*mata'a* (complete)
C4121ooo	524	21035	204	78	25	135	838	118	23	9	Orito	Orito	*mata'a* (complete)
C4121p	517	21738	214	82	27	135	789	114	28	12	Orito	Orito	*mata'a* (complete)
C4121pp	401	21986	203	80	24	129	845	121	24	12	Orito	Orito	*mata'a* (complete)
C4121ppp	617	20616	200	87	27	129	845	119	24	14	Orito	Orito	*mata'a* (broken stem)
C4121q	445	20122	189	76	25	127	674	112	21	12	Orito	Orito	*mata'a* (complete)
C4121qq	520	20217	202	79	23	129	692	108	23	13	Orito	Orito	*mata'a* (complete)
C4121qqq	564	21239	229	78	23	134	740	114	28	12	Orito	Orito	*mata'a* (complete)
C4121r	538	22986	229	87	25	138	781	119	26	10	Orito	Orito	*mata'a* (complete)
C4121rr	539	21392	222	82	25	143	979	120	25	12	Orito	Orito	*mata'a* (incomplete)
C4121rrr	604	21100	203	75	21	139	789	118	26	9	Orito	Orito	*mata'a* (complete)
C4121s	449	20018	193	76	24	127	710	111	24	11	Orito	Orito	*mata'a* (complete)
C4121ss	491	21258	220	78	25	132	768	111	25	11	Orito	Orito	*mata'a* (complete)
C4121sss	566	21316	223	81	25	134	740	117	26	11	Orito	Orito	*mata'a* (complete)
C4121t	509	20297	219	79	25	134	806	115	25	8	Orito	Orito	*mata'a* (complete)
C4121tt	530	22155	224	84	29	142	802	117	27	10	Orito	Orito	*mata'a* (complete)

Sample No.	MnKa1	FeKa1	ZnKa1	RbKa1	SrKa1	Y Ka1	ZrKa1	NbKa1	GaKa1	ThLa1	Source (SVM)	Source (DFA)	Description
C4121ttt	542	21284	217	81	22	135	839	115	23	10	Orito	Orito	*mata'a* (complete)
C4121u	638	21192	212	81	26	135	756	117	25	11	Orito	Orito	*mata'a* (complete)
C4121uu	501	21347	222	77	25	132	714	114	25	10	Orito	Orito	*mata'a* (complete)
C4121uuu	617	19971	193	76	24	133	804	117	22	10	Orito	Orito	*mata'a* (complete)
C4121v	509	20596	230	76	23	133	748	109	24	12	Orito	Orito	*mata'a* (complete)
C4121vv	550	21447	214	78	24	135	705	115	22	9	Orito	Orito	*mata'a* (complete)
C4121vvv	580	21135	211	80	27	134	756	118	22	10	Orito	Orito	*mata'a* (complete)
C4121w	523	20526	195	78	24	136	840	120	25	11	Orito	Orito	*mata'a* (complete)
C4121ww	483	20178	202	77	27	119	701	107	25	10	Orito	Orito	*mata'a* (complete)
C4121www	593	21596	212	77	28	134	744	117	24	11	Orito	Orito	*mata'a* (complete)
C4121x	551	20203	184	72	21	127	770	112	25	10	Orito	Orito	*mata'a* (complete)
C4121xx	556	21069	202	81	25	134	787	111	28	9	Orito	Orito	*mata'a* (complete)
C4121xxx	529	19228	205	73	22	123	694	104	25	13	Orito	Orito	*mata'a* (complete)
C4121y	638	21082	205	81	23	144	740	118	23	12	Orito	Orito	*mata'a* (complete)
C4121yy	638	21737	226	80	24	143	912	120	21	14	Orito	Orito	*mata'a* (complete)
C4121yyy	516	20919	205	83	24	129	740	118	26	11	Orito	Orito	*mata'a* (complete)
C4121z	464	20722	199	77	26	130	824	114	27	12	Orito	Orito	*mata'a* (complete)
C4121zz	582	21111	200	81	27	128	759	118	24	12	Orito	Orito	*mata'a* (complete)
C4121zzz	663	21704	205	78	24	134	751	116	25	13	Orito	Orito	*mata'a* (broken stem)
C602	550	20725	211	83	26	129	742	111	21	11	Orito	Orito	*mata'a* (complete)
C603	580	21082	211	78	22	127	751	109	26	9	Orito	Orito	*mata'a* (complete)
C8353	541	18501	174	61	31	101	523	86	21	9	Motu Iti	Orito	*mata'a* (complete)
C8354	643	21101	194	80	24	135	738	120	24	13	Orito	Orito	*mata'a* (complete)
D2969	575	21737	217	84	27	135	729	121	24	12	Orito	Orito	*mata'a* (complete)
D2970	533	21286	219	79	30	131	821	114	24	14	Orito	Orito	*mata'a* (complete)
D2971	492	21038	204	82	24	129	750	116	23	7	Orito	Orito	*mata'a* (broken stem)

REFERENCES

Ambrose, W.R., 1996. Obsidian hydration dating of the Reef/Santa Cruz Lapita sites. In J.M. Davidson, G. Irwin, B.F. Leach, A. Pawley and D. Brown (eds), *Oceanic Culture History: Essays in Honour of Roger Green*. Dunedin: New Zealand Journal of Archaeology Special Publication, pp. 245-55.

Baker, P.E., F. Buckley and J.G. Holland, 1974. Petrology and geochemistry of Easter Island. *Contributions to Mineralogy and Petrology* 44: 85-100.

Beardsley, Felicia R., William S. Ayres and Gordon G. Goles, 1991. Characterization of Easter Island obsidian sources. *Indo-Pacific Prehistory Association Bulletin* 11: 179-87.

Beardsley, Felicia R. and Gordon G. Goles, 1998. Sampling the field: Provenance studies on prospective rock sources. In C.M. Stevenson, G. Lee and F.J. Morin (eds), *Easter Island in Pacific Context South Seas Symposium: Proceedings of the Fourth International Conference on Easter Island and East Polynesia*. Los Osos: Easter Island Foundation, pp. 284-91.

——2001. Sampling for provenance: Tailings from prehistoric stone quarries in the South Pacific. *Journal of Archaeological Science* 28: 587-95.

Beardsley, F.R., G.G. Goles and W.S. Ayres, 1996. Provenance studies on Easter Island obsidian: An archaeological application. In M.V. Orna (ed.), *Archaeological Chemistry: Organic, Inorganic, and Biochemical Analysis*. American Chemical Society Symposium Series No. 625. Washington, D.C.: American Chemical Society, pp. 47-63.

Bird, J.R., 1988. Isla de Pascua Obsidian. In J.R. Prescott (ed.), *Archaeometry: Australasian Studies 1988*. Adelaide: Department of Physics and Mathematical Physics, University of Adelaide, pp. 115-20.

Bird, J.R., L.H. Russell, M.D. Scott and W.R. Ambrose, 1978. Obsidian characterization with elemental analysis by proton induced gamma ray emission. *Analytical Chemistry* 50 (14): 2082-84.

Bórmida, M., 1951. Formas y funciones del 'mata', el mas conocido artefacto de la arqueologia de Pascua. *Runa* 4: 396-408.

Church, Flora, 1994. A microwear analysis of tools from Site 10-241, Easter Island – An inland processing site. *Rapa Nui Journal* 8 (4): 101-4.

——1998. Upland, lowland, citizen, chief: Patterns of use-wear from five Easter Island sites. In C.M. Stevenson, G. Lee and F.J. Morin (eds), *Easter Island in Pacific Context: South Seas Symposium; Proceedings of the Fourth International Conference on Easter Island and East Polynesia.* Los Osos: The Easter Island Foundation, pp. 312-15.

Church, Flora and J. Grace Ellis, 1996. A use-wear analysis of obsidian tools from an *Ana Kionga*. *Rapa Nui Journal* 10 (4): 81-88.

Church, F. and J. Rigney, 1994. A microwear analysis of tools from Site 10-241, Easter Island—an inland processing site. *Rapa Nui Journal* 8 (4): 101-5.

Cortes, Corinna and Vladimir Vapnik, 1995. Support-vector networks. *Machine Learning* 20 (3): 273-97.

Cristino, Claudio, Y. Enomoto, M. Kumagai, S. Ninomiya, C.M. Stevenson, M. Suzuki, M. Teshirogi and K. Tomura, 1999. *Analytical Data of Rapa Nui Geologic Obsidians by INAA and EDXRF.* Report 9901. Tokyo: Institute for Atomic Energy, Rikkyo University.

Flenley, John and Paul Bahn, 2002. *The Enigmas of Easter Island: Island on the Edge*. New York: Oxford University Press.

Green, Roger C., 1962. Obsidian, its application to archaeology. *New Zealand Archaeological Association Newsletter* 5: 8-16.

——1964. Sources, ages and exploitation of New Zealand obsidian. *New Zealand Archaeological Association Newsletter* 7 (3):134-43.

Green, Roger C., Kaye Green, Roy A. Rappaport, Ann Rappaport and Janet Davidson, 1967. *Archaeology on the Island of Mo'orea, French Polynesia*. Anthropological Papers of the American Museum of Natural History 51 (2). New York: American Museum of Natural History.

Heyerdahl, Thor, 1961. Surface artifacts. In T. Heyerdahl and E.N. Ferdon Jr (eds), *Reports of the Norwegian Archaeological Expedition to Easter Island and the Pacific. Volume 1: Archaeology of Easter Island*. London: George Allen and Unwin, pp. 397-489.

Karatzoglou, A., A. Smola and K. Hornik, 2013. *Package 'kernlab'*. Available at: http://cran.r-project.org/web/packages/kernlab/index.html

Kirch, Patrick V. and Douglas E. Yen, 1982. *Tikopia: The Prehistory and Ecology of a Polynesian Outlier.* Bernice P. Bishop Museum Bulletin 238. Honolulu: Bishop Museum Press.

Ladefoged, Thegn N., Christopher M. Stevenson, Sonia Haoa, Mara Mulrooney, Cedric Puleston, Peter M. Vitousek and Oliver A. Chadwick, 2010. Soil nutrient analysis and Rapa Nui gardening. *Archaeology in Oceania* 45: 80-85.

Leach, Bryan Foss and Atholl J. Anderson, 1978. The prehistoric sources of Palliser Bay obsidian. *Journal of Archaeological Science* 5: 301-7.

Lipo, Carl P., Terry L. Hunt and Brooke Hundtoft, 2010. Stylistic variability of stemmed obsidian tools (*mata'a*), frequency seriation, and the scale of social interaction on Rapa Nui (Easter Island). *Journal of Archaeological Science* 37: 2551-61.

McCoy, Mark D., Thegn N. Ladefoged, Andrew Blanshard and Alexander Jorgensen, 2010. Reconstructing lithic supply zones and procurement areas: An example from the Bay of Islands, Northland, New Zealand. *Journal of Pacific Archaeology* 1 (2): 174-83.

McCoy, Patrick C., 1976. *Easter Island Settlement Patterns in Late Prehistoric and Protohistoric Periods*. Bulletin No. 5. New York: International Fund for Monuments, Inc.

Métraux, Alfred, 1940. *Ethnology of Easter Island.* Bernice P. Bishop Museum Bulletin 160. Honolulu.

Mosley, Brigit and Mark D. McCoy, 2010. Sourcing obsidian and pitchstone from the Wakanui Site, Canterbury, New Zealand. *Rapa Nui Journal* 24 (2): 6-15.

Mulloy, William, 1961. The ceremonial center of Vinapu. In T. Heyerdahl and E.N. Ferdon Jr (eds), *Reports of the Norwegian Archaeological Expedition to Easter Island and the Pacific. Volume 1: Archaeology of Easter Island*. London: George Allen and Unwin, pp. 93-180.

Mulloy, William and Gonzalo Figueroa, 1978. *The A Kivi - Vai Teka Complex and Its Relationship to Easter Island Architectural Prehistory*. Asian and Pacific Archaeology Series 8. Honolulu: Social Science Research Institute, University of Hawaii at Mānoa.

Reepmeyer, Christian and Geoffrey Clark, 2010. Post-colonization interaction between Vanuatu and Fiji rediscovered: the re-analysis of obsidian from Lakeba Island, Fiji. *Archaeometry* 52 (1): 1-18.

Routledge, Katherine, 1919. *The Mystery of Easter Island.* London: Hazell, Watson and Viney.

Sand, Christophe and Peter J. Sheppard, 2000. Long distance prehistoric obsidian imports in New Caledonia: Characteristics and meaning. *Earth and Planetary Sciences* 331: 235-43.

Shackley, Steven (ed.), 2005. *Obsidian: Geology and Archaeology in the North American Southwest*. Tucson: University of Arizona Press.

Sheppard, Peter J., Geoffrey J. Irwin, Sam C. Lin and Cameron P. McCaffrey, 2011. Characterization of New Zealand obsidian using PXRF. *Journal of Archaeological Science* 38: 45-56.

Smith, Ian, Gerome Ward and Wallace Ambrose, 1977. Geographic distribution and the characterization of volcanic glasses in Oceania. *Archaeology and Physical Anthropology in Oceania* 12: 173-201.

Specht, Jim, 2002. Obsidian, colonising and exchange. In S. Bedford, C. Sand and D. Burley (eds), *Fifty Years in the Field. Essays in Honour and Celebration of Richard Shutler Jr's Archaeological Career*. Monograph 25. Auckland: New Zealand Archaeological Association, pp. 37-49.

Spriggs, Matthew, Roger Bird and Wallace Ambrose. 2010. A reanalysis of the Tikopia obsidians. *Archaeology in Oceania*, 45: 31-38.

Stevenson, Christopher M., 2002. Territorial divisions on Easter Island in the 16th Century: Evidence from the distribution of ceremonial architecture. In M.W. Graves and T.N. Ladefoged (eds), *Pacific Landscapes: Archaeological Approaches*. Los Osos: Bearsville Press, pp. 211-30.

Stevenson, Christopher M. and Sonia Haoa (eds), 2008. *Prehistoric Rapa Nui: Landscape and Settlement Archaeology at Hanga Ho'onu*. Los Osos: Bearsville Press.

Stevenson, Christopher M., Thegn N. Ladefoged, Sonia Haoa, Oliver Chadwick and Cedric Puleston, 2013. Prehistoric obsidian exchange on Rapa Nui. *Journal of Island and Coastal Archaeology* 8 (1): 108-21.

Stevenson, Christopher M., Leslie Shaw and Claudio Cristino, 1984. Obsidian procurement and consumption on Easter Island. *Archaeology in Oceania* 19: 120-24.

Thomas, Roberta, Hector Neff and Carl P. Lipo. 2007. The Sourcing of Stemmed Obsidian Bifaces on Easter Island. Poster (and printed handout) presented at the 72nd Annual Society for American Archaeology Meetings, Austin, Texas, USA.

Thomson, William J., 1891. Te Pito te Henua, or Easter Island. Report of the United States National Museum for the year ending June 30, 1889. *Annual Reports of the Smithsonian Institution for 1889.* Washington: Smithsonian Institution, pp. 447-552.

Torrence, Robin, Sarah Kelloway and Peter White, 2013. Stemmed tools, social interaction, and voyaging in early mid-Holocene Papua New Guinea. *The Journal of Island and Coastal Archaeology* 8 (2): 278-310.

Van Tilburg, Jo Anne, 1994. *Easter Island: Archaeology, Ecology and Culture*. London: British Museum Press.

Vargas, Patricia, Claudio Cristino and Roberto Izaurieta, 2006. *1000 Años en* Rapa Nui*: Arqueología del asentamiento*. Santiago: Editorial Universitaria, S.A.

Vezzoli, Luigina and Valerio Acocella, 2009. Easter Island, SE Pacific: An end-member type of hotspot volcanism. *Geological Society of America Bulletin* 121 (5/6): 869-86.

von Saher, Herbert, 1990. Some details from the journal of Captain Bouman on the discovery of Easter Island. *Rapa Nui Journal* 4: 49-52.

Weisler, Marshall, 2012. Polynesian volcanic glass: Uses, sourcing, and distribution. In I. Liritzis and C.M. Stevenson (eds), *Obsidian and Ancient Manufactured Glasses*. Albuquerque: University of New Mexico Press, pp. 130-42.

Weisler, Marshall I. and D.A. Clague, 1998. Characterization of archaeological volcanic glass from Oceania: The utility of three techniques. In M.S. Shackley (ed.), *Archaeological Obsidian Studies: Method and Theory*. New York: Plenum Press, pp. 103-28.

White, J. Peter and Mary-Noel Harris, 1997. Changing sources: Early Lapita period obsidian in the Bismarck Archipelago. *Archaeology in Oceania* 32: 97-107.

Woodhead, Jon D. and Marshall I. Weisler, 1997. Accurate sourcing of basaltic artefacts by radiogenic isotope analysis. In M. I. Weisler (ed.), *Prehistoric Long-Distance Interaction in Oceania: An Interdisciplinary Approach*. Monograph 21. Auckland: New Zealand Archaeological Association, pp. 212-23.

ABSTRACT

On Rapa Nui (Easter Island), four geological sources of rhyolitic obsidian were utilised to manufacture obsidian artefacts, including tanged implements known as *mata'a*. In the present study, a total of 332 *mata'a* from the collections of Bishop Museum were analysed using portable X-ray fluorescence (pXRF). Two analytical methods, Discriminant Function Analysis and Support Vector Machines Classification, were used to assign geographical provenance to these artefacts. These appear to be manufactured using obsidians predominantly from Orito, one of four geological sources on the island. This study demonstrates how non-destructive analyses of museum collections can contribute to our understanding of obsidian procurement and production on Rapa Nui.

Keywords: obsidian, museum collections, geochemical sourcing, portable X-ray flourescence, Rapa Nui, Easter Island

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