CHARACTERIZATION OF EASTER ISLAND OBSIDIAN SOURCES

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INTRODUCTION

The question that has most attracted the attention of scholars looking at the prehistoric culture of Easter Island is the establishment of the complex technological and social organizational forms found there. The island is one of the most isolated and environmentally impoverished places in the South Pacific, yet it played host to an exceptionally rich and complex cultural tradition. Much of the attention given to the island's social and cultural development has focused on the architecture of *ahu* ceremonial centers, the associated carved stone statuary, burial goods, and the technology and craft specialization connected with carving and transporting the statues. But other related technological industries also contain the potential for making significant contributions to the reconstruction of the island's prehistoric social landscape, although until recently they have received little attention in the literature. Critical to answering questions about prehistoric social interaction patterns is information about territorial boundaries and their expansion and contraction through time (Métraux 1940; Beardsley 1990). Provenance studies on the stone used for tools and for construction offers one potential means of identifying the boundaries of territorial zones, as well as providing insights into the technological skills of the prehistoric islanders.

A first step in the advancement of provenance studies on Easter Island is the geochemical characterization of stone sources, in other words, determining the discrete fingerprint of each source. This paper reports on our recent efforts to characterize the four obsidian sources on the island. Obsidian - volcanic glass - was one of the primary tool materials used by the islanders during the prehistoric period. Differentiation of the sources provides a foundation for the analysis of archaeological specimens and enables us to begin tracing obsidian artifacts back to their raw material source, thereby developing a pattern of source utilization based on the distribution of the fingerprinted artifacts. Our goal in this analysis is the ultimate reconstruction of the prehistoric patterns of raw material use, control and trade, and the broader social and economic systems in which they are found. Specific aims are to define regional patterns of access to the obsidian

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sources and to determine the significance of such regional patterns for prehistoric social group boundaries and exchange patterns. For now, however, this goal is beyond the limits of the present research.

The source characterization study pursued three analytical tracks. First, the problem was to determine the discrete geochemical properties of each source. Prior research had established the unique geochemical fingerprint of only two of the four obsidian sources, while the remaining two were found to be indistinguishable from one another (Bird 1988). The second line of inquiry was to determine the level of chemical variation within the flow boundaries of each source; a task which, if successful, would promote better understanding of differential prehistoric use of the respective sources. Finally, our inquiry sought to determine the degree of similarity among the four sources.

PREVIOUS WORK

Other than geological studies (Chubb 1933; Bandy 1937; Baker *et al.* 1974; Bonatti *et al.* 1977; Hanan and Schilling 1989), the only research on the island's obsidian flows with respect to archaeological needs has focused on obsidian hydration. Evans (1965), among the first to study obsidian from archaeological sites on the island, attempted to apply obsidian hydration dating methods to archaeological specimens using a general tropical rate (Tropical Rate B); this prompted him to identify specific macroscopic features of the glass potentially affecting the rate of hydration. Michels and colleagues (n.d.) continued the obsidian hydration studies and included some analyses aimed at characterizing the obsidian to determine the chemical component impact on hydration rates. They concluded that two rates were needed, as opposed to the one tropical rate applied by Evans. Of the two rates, one was needed for the Motu Iti source (a small islet off the southwest coast of the island) and one was needed for both Rano Kau and Orito. Rano Kau is the volcano that forms the southwest corner of the island; Orito is a parasitic cone on the slopes of Rano Kau. The latter two sources, they found, were so chemically similar that only one rate need be applied. Other hydration studies, such as those by Stevenson (1984) and Stevenson *et al.* (1984), concentrated on refining the rate of hydration for the island. To date, Stevenson (personal communication) has determined that multiple rates are needed for archaeological specimens, each of which is dependent upon the specimen's history of deposition. The chemical characterizations of the obsidian sources to which these new hydration rates apply rest on the earlier conclusions of Michels and colleagues that there are two source pools on the island, one for Motu Iti and one for Rano Kau and Orito.

Provenance studies of the island's obsidian flows have been recently undertaken independently by Roger Bird (1988) of the Australian Nuclear Science and Technology Organisation and by us. Up to now, it has been generally accepted that there were only three sources of obsidian on the island - at Orito, Rano Kau, and the islet of Motu Iti - and that these represented two source pools which are chemically similar. Both Bird and we recognized that there are instead four sources, two of which are located on Rano Kau, where previously only one source had been identified (although soil maps and geological

maps of the island note two distinct outcrops, as does the *Atlas Arqueologico* [Cristino *et al.* 1981]), and the two located on Orito and Motu Iti (Fig. 1). The two sources on Rano Kau are identified here as Rano Kau I, located on the flanks of Rano Kau (identified by Bird as Te Manavai), and Rano Kau II, located on the rim of the Rano Kau caldera.

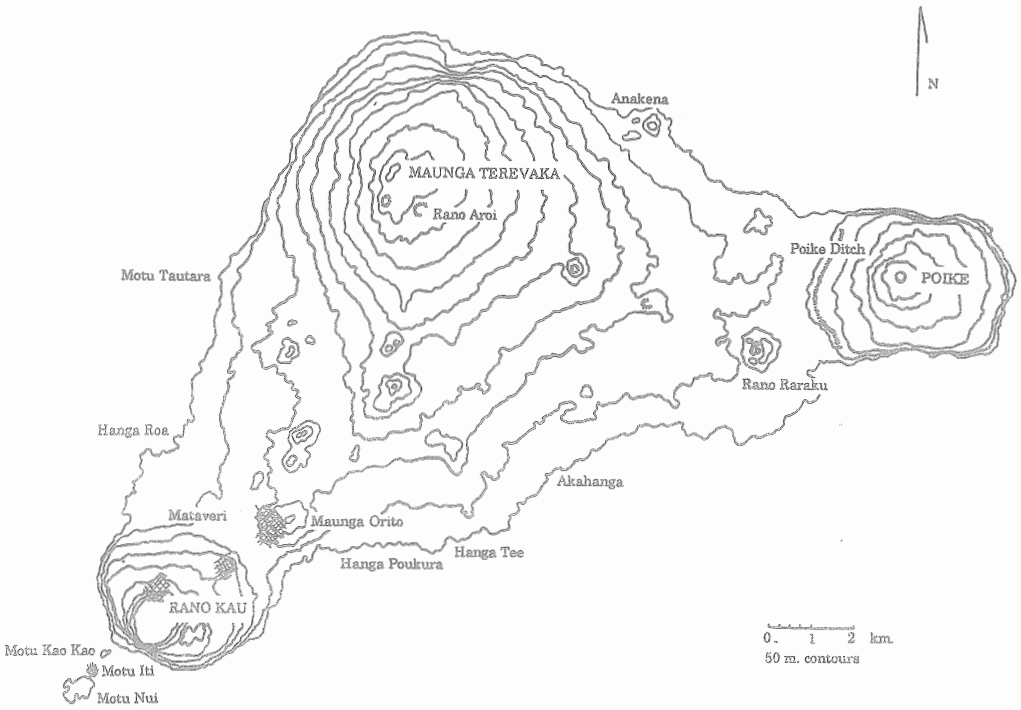

FIGURE 1: EASTER ISLAND (OBSIDIAN SOURCES SHADED)

In 1986, Bird collected a reference set of obsidian from each of the four sources and subjected them to PIXE-PIGME analysis (proton induced x-ray emission and proton induced gamma-ray emission). He found that two of the four sources (Motu Iti and Rano Kau II) could be distinguished on the basis of their chemical composition, that the remaining two sources (Orito and Rano Kau I) could not be distinguished from one another but that they exhibited chemical compositions distinct from those of both Motu Iti and Rano Kau II, and that all of the Easter Island obsidian can be distinguished from other known sources in the South Pacific.

Our study, like Bird's, began with a systematic collection of obsidian from the sources. The three largest sources - Orito, Rano Kau I and Rano Kau II - were visited by Beardsley in 1987, but Motu Iti was not sampled owing to rough seas which prevented access. We were able to obtain samples from Motu Iti from both Bird and Stevenson. A Department of Energy Reactor Use Sharing Grant from the Radiation Center at Oregon State

University (1988, 1989) provided the means to process nearly 40 samples using instrumental neutron activation analysis (INAA).

The results of the analysis indicated firstly that all four sources could be geochemically distinguished through trace element analysis. Secondly, variation within each source could not be spatially defined because all sampling locations analyzed within a single source provided overlapping chemical compositions. Each source is thus sufficiently homogeneous to be treated as a single unit. Finally, inter-source variability was reliably characterized by differing amounts of three trace elements - scandium, zinc, and selenium. All other element abundance ranges overlap.

METHODS

The procedures for sampling each obsidian source on Easter Island required a clear definition of the surface extent of the respective flows. For the two sources on Rano Kau this entailed a re-examination of the boundaries published in the *Atlas Arqueologico*. On Orito, no surface boundaries of the obsidian source had been recorded prior to Beardsley's field study. The boundaries of the Motu Iti source have yet to be examined but the islet itself is very small. According to both Bird and Stevenson, Motu Iti is nearly a solid block of obsidian.

Using topographic base maps from the *Atlas Arqueologico*, the sources at Orito, Rano Kau I and Rano Kau II were examined on foot. During this survey, samples of obsidian were collected from the surface at various points across the flows along transects which were surveyed to establish the outcrop limits. The extent of the surface distribution of each source was recorded on topographic maps and the positions of all sampling locations triangulated. Multiple samples of obsidian were randomly collected from each sampling location, which was defined as an area one metre in radius. The source boundaries on Rano Kau varied somewhat from those published in the *Atlas Arqueologico*, but the differences were not dramatic. The source at Orito covers a large area, approximately 90 hectares, and is confined to the western peak and flanks of the double-peak land form. Fifty locations were sampled across all three sources.

Thirty-eight samples were selected for analysis: seven from Rano Kau I, seven from Rano Kau II, fifteen from Orito and nine from the Motu Iti specimens sent by Bird and Stevenson. Altogether the samples represent a cross section of the four obsidian sources. Each sample was ground to a fine powder, of which about 0.5 gram was encapsulated for irradiation; the exact quantity of powder used was measured to the nearest 0.1 milligram. Samples from the same powder prepared for two of the locations (Orito CC and Motu Iti 1) were included in every set irradiated as a means of control for comparative purposes. As a further control measure within the experiment all samples were irradiated with and measured against a reference set of standard rock powders and liquid monitors, the geochemical properties of which have been published by the Bureau of Standards, the Radiation Center at Oregon State University and the Center for Volcanology at the University of Oregon (Goles 1978).

The samples, together with the standard rocks and monitors, were irradiated in the nuclear reactor at Oregon State University. The relative abundances of diverse trace elements, including rare earths, within each sample, standard and monitor were then calculated at various points in the radioactive decay process - from a few days after irradiation (short counts) to many weeks after (long counts). By observing the gamma emissions of induced radionuclides at different intervals after irradiation, we were better able to sort through energy interferences as well as to compare results obtained from each counting episode and from each laboratory. The Radiation Center at OSU calculated results from both the short counts and the intermediate counts. We, at the Center for Volcanology at UO, calculated results from the intermediate and long counts.

In both laboratories a gamma spectrometer was used to detect the gamma emissions. The spectrometer at the Center for Volcanology is a Ge(Li) detector. Output signals from the gamma emissions were fed into a preamplifier and then into the main amplifier. The output pulses from the main amplifier were then fed into a multichannel analyzer. The raw data are displayed as a spectrum with a number of photopeaks, which looks like a continuous line of peaks, valleys, and plateaux spread across the 4096 channels within the multichannel analyzer. Each peak represents a specific series of constant-energy events from the gamma emission of a specific radionuclide (some peaks are composite, but these instances are well known and corrections are routinely made for this kind of spectral interference). The Radiation Center uses a computerized program to select and analyze specific channels. At the Center for Volcanology, we select individual photopeaks based on observation of the spectral features displayed on a microcomputer interfaced with the multichannel analyzer.

The area within each photopeak was calculated, and that calculation then translated into a relative abundance for the corresponding element, commonly expressed in parts per million (ppm). All abundances within the samples were determined through comparisons with the known element abundances of the standard rocks that were irradiated with them.

RESULTS

The INAA results are presented in Tables 1 and 2, which list the relative abundances of non-rare-earth trace elements and rare earth elements respectively for all obsidian samples used in this experiment. The similarity in nearly all of the element concentrations between the four sources is overwhelming. Only three trace elements - scandium, zinc, and selenium - exhibited differences in concentrations which could be considered unique to each source. In other words, all four sources could be geochemically identified and distinguished through the relative abundances of these three trace elements. None of the rare earth elements was useful in distinguishing one source from another because the relative concentrations of each element within each source overlapped.

The similarities and differences in element compositions were reviewed in two stages. The first comparison was between samples from within the same source; the second was

Quarry	Na2O %	FeO %	Co	Sc	Cr
Orito	5.49 - 6.02	2.63 - 2.91	0.297 - 0.464	0.50 - 0.52	6 - 19
Rano Kau I	5.61 - 5.86	2.70 - 2.82	0.401	0.50	7 - 11
Rano Kau II	5.15 - 5.52	2.20 - 2.59	0.312	0.20 - 0.30	8 -14
Motu Iti	5.58 - 6.24	2.71 - 4.52	0.418 - 0.826	0.70 - 0.80	7 - 33

Quarry	Hf	Ta	Th	Rb	Cs
Orito	22.8 - 26.7	6.8 - 8.4	10.3 - 11.5	54 - 84	0.7 - 1.0
Rano Kau I	22.0 - 24.6	6.7 - 7.9	10.4 - 11.3	66 - 105	0.8 - 0.9
Rano Kau II	21.0 - 24.3	6.8 - 7.6	11.1 - 12.1	69 - 83	0.8 - 0.9
Motu Iti	19.0 - 38.1	6.5 - 9.1	9.8 - 11.1	49 - 92	0.5 - 1.0

Quarry	Sb	Zn	Se
Orito	0.3 - 0.8	137 - 154	8.2 - 11.1
Rano Kau I	0.3 - 0.5	337 - 357	n v
Rano Kau II	0.3 - 0.4	311 - 343	n v
Motu Iti	0.3 - 0.5	330 - 331	n v

TABLE 1: RANGES OF MEAN VALUES FOR TRACE ELEMENTS (PPM)

Quarry	La	Ce	Nd	Sm
Orito	82 - 92	193 - 215	85 - 108	20.14 - 23.50
Rano Kau I	86 - 90	184 - 214	90 - 100	20.35 - 22.70
Rano Kau II	78 - 91	174 - 222	79 - 105	20.15 - 24.00
Motu Iti	81 - 90	177 - 211	85 - 104	19.66 - 23.50

Quarry	Eu	Tb	Yb	Lu
Orito	3.14 - 3.78	3.47 - 3.81	12.10 - 13.36	1.65 - 2.01
Rano Kau I	3.16 - 3.47	3.30 - 3.74	12.37 - 13.13	1.73 - 2.00
Rano Kau II	2.41 - 2.86	3.35 - 3.83	12.65 - 13.36	1.76 - 2.02
Motu Iti	3.41 - 3.80	3.25 - 3.77	11.95 - 13.02	1.65 - 1.89

TABLE 2: RANGES OF MEAN VALUES FOR RARE EARTH ELEMENTS (PPM)

between samples from the different sources. Each comparison was facilitated through graphic plots of the element abundances and tables of element ratios. Fourteen element ratios were tested as another comparative measure (Hf/Ta, Hf/Th, Th/Ta, Cs/Th, Cs/Ta, Cs/Hf, Ce/La, La/Sm, La/Lu, Eu/Sm, Eu/Ce, Sc/Cr, Sc/Co, Co/Sc). However, only the ratios with scandium were of any assistance in differentiating of sources. Graphic plots of the three critical elements proved more useful in displaying the differences between sources (Fig. 2). The similarity in the element composition of a single source, as well as the differences between sources, was immediately apparent. Within a single source the results indicated that discrete areas could not be differentiated, and that in fact a source is homogeneous across the extent of its outcrop. All sampling areas examined within a single source displayed relative abundances in element concentrations that were consistent between samples, with little variation present.

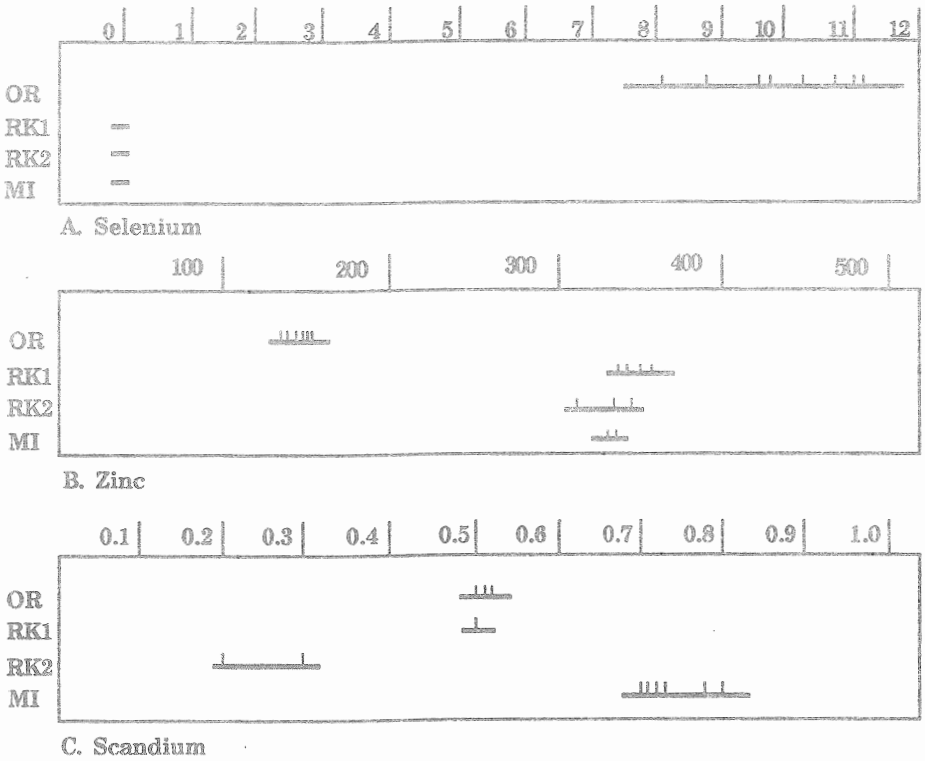

FIGURE 2: RANGE OF CRITICAL ELEMENT ABUNDANCES BY SOURCE
A) Selenium, B) Zinc, C) Scandium

Among the four sources, the relative abundances for the three trace elements of scandium, zinc, and selenium are sufficient to illustrate differences, however slight, among the sources and to set the foundation for future provenance studies of obsidian artifacts. Of the three elements, scandium was used as the first discriminant between the sources.

It is relatively easy to obtain highly accurate values for it using INAA. Scandium allowed us to separate three source areas - Motu Iti, Rano Kau II, and the combined Orito and Rano Kau I. These are the same source pools Bird recognized in his analysis (Bird 1988). From this point, we used zinc and selenium to differentiate Orito from Rano Kau I and vice versa. Either zinc or selenium can be used separately to distinguish the two sources; we found that one element reinforces the results for the other. Unfortunately, both elements (Zn, Se) are difficult to obtain and require intermediate and/or long count episodes. Scandium, on the other hand, can easily be obtained from any counting episode whether short, intermediate, or long.

In short, INAA has proved a successful technique for provenance studies of the island's obsidian resources. Through its application we found that we could determine the geochemical properties unique to each source; that intra-source variation was not measurable - instead a single source proved to be homogeneous in its chemical composition across the extent of its outcrop; and that inter-source variability was present and could be recognized through the relative abundances of three trace elements.

CONCLUSIONS

Until our study only three source pools for the four obsidian sources had been identified on Easter Island. Our work illustrates that all four sources can be distinguished from one another through INAA. The process, however, is time consuming, demanding, and expensive. As we have used it, it is also a destructive technique requiring the object studied to be ground to a fine powder. This is not a major concern when debitage is used as the focus of study; however, it presents a major drawback when considering its application to rare artifacts such as the obsidian pieces in statue eyes. We believe this can be circumvented in future studies.

Through our work, we have established the foundation for provenance studies on the island, as well as demonstrated that a source is homogeneous across its outcrop. INAA has proven a successful technique in differentiating the four sources, unlike the other techniques employed to date (XRF, Atomic Absorption, PIXE, PIGME).

The next step is to begin examining archaeological obsidian specimens from sites around the island, and then to trace these artifacts to their raw material source. This application will enable us to gain some insight into the social interaction patterns within the prehistoric landscape, as well as to define raw material access and cultural prescriptions for obsidian use. We have just begun this task.

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