X-Ray Fluorescence Analysis of Artifact Obsidian from the Orr Site, Western Cascades, Marion County, Oregon

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Introduction

One hundred and thirty-two obsidian artifacts from the Orr Site, Marion County, Oregon, were submitted for energy dispersive X-ray fluorescence trace element provenience analysis. The samples were prepared and analyzed at the Northwest Research Obsidian Studies Laboratory under the accession number 99-55.

Analytical Methods

X-Ray Fluorescence Analysis and Characterization Studies

Introduction. Although a variety of physical, optical, petrographic, and chemical attributes are used to characterize volcanic glasses, the use of trace element abundances to "fingerprint" obsidian sources and artifacts has shown the greatest overall success. X-ray fluorescence analytical methods, with their ability to nondestructively and accurately measure trace element concentrations in obsidian, have been widely adopted for this purpose (Harbottle 1982; Rapp 1985; Williams-Thorpe 1995; Glascock et al. 1998; Herz and Garrison 1998; Lambert 1998).

Most geologic sources of obsidian are quite homogeneous in their trace element composition, yet demonstrate adequate intersource variability so that individual sources of glass can be distinguished. Because obsidian can be widely dispersed from its primary geologic source due to a variety of geologic and geomorphic processes, specimens of chemically identical glass are sometimes recovered from outcrops spread over large geographic areas (Hughes 1986; Hughes and Smith 1993). These secondary source boundaries are often not as well documented as primary sources but must be carefully considered in obsidian procurement studies (Shackley 1998). Hughes (1986, 1998) points out that these chemically identical obsidian outcrops must be considered as a single chemical group or chemical type and his terminology is followed here.

From small scale (household and site) to large scale (regional and interregional) levels of analysis, the spatial source patterning of characterized obsidian artifacts is influenced by many different environmental and cultural factors. Interpretation of these patterns can provide valuable information about the prehistoric behavioral and environmental procurement variables responsible for observed artifact distributions. At the site level of analysis, patterns of source use may suggest the presence of specific activity areas, of single tool manufacturing events, or, in special cases, may point to differential access of goods and the existence of non-egalitarian social structures. At the intersite or regional level of investigation, the geographic patterning of artifacts can provide information about seasonal procurement ranges, territorial and ethnic boundaries, the location of trails and travel routes, the curational value of particular sources or formal artifact types, cultural preferences regarding glass quality and colors, the presence of trade and exchange systems, the existence of intergroup interaction, and the exchange of prestige items between elites of different groups (Hughes 1978, 1990; Ericson 1981; Hughes and Bettinger 1984). The effects of environmental influences such as the distance to source, the location of alternative or competing sources of lithic materials, the distribution of raw materials in secondary deposits, or the presence of potential barriers such as mountain ranges, must all be considered. Bias introduced during sampling by certain recovery methods, artifact size, and the use of small numbers of samples may also affect the reconstruction of the spatial patterning of analyzed artifacts.

Sample Preparation Methods. Obsidian samples selected for X-ray fluorescence analysis are typically restricted to clean artifacts (a wash with tap water and a brush will usually suffice) with a relatively flat surface at least 10 mm in diameter and at least 1.5 mm thick. Although it is possible to analyze slightly smaller samples (7-10 mm in diameter and 0.5-1.0 mm thick), these items will show some distortion in trace element values and may not be able to be reliably characterized. This is particularly true in areas with complex source use patterns. Source assignments of samples that do not meet the minimum reliable size criteria of 10 mm diameter and 1.5 mm thickness, and/or show distorted trace element values are indicated by an asterisk in the data tables that appear in the Appendix.

Analytical Methods. Analysis of the samples was completed using a Spectrace 5000 energy dispersive X-ray fluorescence spectrometer. The system is equipped with a Si(Li) detector with a resolution of 155 eV FHWM for 5.9 keV X-rays (at 1000 counts per second) in an area 30 mm^2. Signals from the spectrometer are amplified and filtered by a time variant pulse processor and sent to a 100 MHZ Wilkinson type analog-to-digital converter. The X-ray tube employed is a Bremsstrahlung type, with a rhodium target, and 5 mil Be window. The tube is driven by a 50 kV 1 mA high voltage power supply, providing a voltage range of 4 to 50 kV. The principles of X-ray fluorescence analytical methods are reviewed in detail by Norrish and Chappell (1967), Potts and Webb (1992), and Williams (1987). X-ray fluorescence analytical procedures used in the analysis of all obsidian samples were originally developed by M. Kathleen Davis (BioSystems Analysis and Northwest Research Obsidian Studies Laboratory).

For analysis of the elements zinc (Zn), lead (Pb), thorium (Th), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), and niobium (Nb), the X-ray tube is operated at 30 kV, 0.30 mA (pulsed), with a 0.127 mm Pd filter. Analytical lines used are Zn (K-alpha), Pb (L-alpha), Th (L-alpha), Rb (K-alpha), Sr (K-alpha), Y (K-alpha), Zr (K-alpha) and Nb (K-alpha). Samples are scanned for 200 seconds live-time in an air path.

Peak intensities for the above elements are calculated as ratios to the Compton scatter peak of rhodium, and converted to parts-per-million (ppm) by weight using linear regressions derived from the analysis of twenty rock standards from the U.S. Geological Survey, the Geologic Survey of Japan, and the National Bureau of Standards. The analyte to Compton scatter peak ratio is employed to correct for variation in sample size, surface irregularities, and variation in the sample matrix.

For analysis of the elements titanium (Ti), manganese (Mn), and iron ($Fe_2O_3^T$), the X-ray tube is operated at 12 kV, 0.27 mA with a 0.127 mm aluminum filter. Samples are scanned for 200 seconds live-time in a vacuum path. Analytical lines used are Ti (K-alpha), Mn (K-alpha), and Fe (K-alpha).

Concentration values (parts per million for titanium and manganese, weight percent for iron) are calculated using linear regressions derived from the analysis of thirteen standards from the U.S. Geological Survey, the Geologic Survey of Japan and the National Bureau of Standards. However, these values are *not* corrected against the Compton scatter peak or other scatter regions, resulting in lower than normal trace element values for small samples that fall below the minimum size requirement.

Iron/titanium (Fe/Ti) and iron/manganese (Fe/Mn) peak ratios are supplied for use as corrected values. In order to ensure comparability among samples of different sizes, source assignments in all reports are based upon these ratios, and not on the absolute concentration values.

For analysis of the elements barium (Ba), lanthanum (La) and cerium (Ce), the X-ray tube is operated at 50 kV, 0.25 mA with a 0.63 mm copper filter in the X-ray path. Analytical lines used are Ba (K-alpha), La (K-alpha), and Ce (K-alpha). Samples are scanned in an air path for 100 to 600 seconds live-time, depending upon trace element concentration. Trace element intensities are calculated as ratios to the Bremsstrahlung region between 25.0 and 30.98 keV, and converted to parts-per-million by weight using a polynomial fit routine derived from the analysis of sixteen rock standards from the U.S. Geological Survey and the Geologic Survey of Japan. It should be noted that the Bremsstrahlung region corrects for sample mass only and does not account for matrix effects.

All samples are scanned as unmodified rock specimens. Reported errors represent counting and fitting error uncertainty only, and do not account for instrumental precision or effects related to the analysis of unmodified obsidian. When the latter effects are considered, relative analytical uncertainty is estimated to be between three and five percent.

In traditional X-ray fluorescence trace element studies, samples are powdered and pelletized before analysis (Norrish and Chappell 1967; Potts and Webb 1992). In theory, the irregular surfaces of most obsidian artifacts should induce measurement problems related to shifts in artifact-to-detector reflection geometry (Hughes 1986:35). Early experiments with intact obsidian flakes by Robert N. Jack, and later by Richard Hughes, however, indicate that analytical results from lenticular or biconvex obsidian surfaces are comparable to those from flat surfaces and pressed powder pellets, paving the way for the nondestructive analysis characterization of glass artifacts (Hughes 1986:35–37; Jack 1976). The minimum optimal sample size for analysis has been found to be approximately 10 mm in diameter and 1.5–2.0 mm thick. Later experimental studies conducted by Shackley and Hampel (1993) using samples with flat and slightly irregular surface geometries have corroborated Hughes' initial observations. In a similar experiment, Jackson and Hampel (1993) determined that for accurate results the minimum size of an artifact should be about 10 mm in diameter and 1.5 mm thick. Agreement between the U. S. Geological Survey standard RGM-1 (Glass Mountain obsidian) values and obsidian test samples was good at 1 mm thickness and improved markedly to a thickness of 3 mm. Details about the effects of sample size and surface geometry are discussed by Davis et al. (1998).

Correlation of Artifacts and Geologic Sources. The diagnostic trace element values used to characterize the samples are compared directly to those for known obsidian sources such as those reported in the literature and with unpublished trace element data collected through analysis of geologic source samples (Skinner 1999). Artifacts are correlated to a parent obsidian source or chemical source group if diagnostic trace element values fall within about two standard deviations of the analytical uncertainty of the known upper and lower limits of chemical variability recorded for the source. Occasionally, visual attributes are used to corroborate the source assignments although sources are never assigned on the basis of only megascopic characteristics.

Diagnostic trace elements, as the term is used here, refer to trace element abundances that show low intrasource variation and uncertainty along with distinguishable intersource variability. In addition, this refers to elements measured by X-ray fluorescence analysis with high precision and low analytical uncertainty. In short, diagnostic elements are those that allow the clearest geochemical distinction between sources. Trace elements generally refer to those elements that occur in abundances of less than about 1000 ppm in a sample. For simplicity in this report, we use the term synonymously with major and minor elements such as iron, titanium, and manganese, which may be present in somewhat larger quantities.

Nondestructive trace element analysis of the samples was completed using a Spectrace 5000 energy dispersive X-ray fluorescence spectrometer. The system is equipped with a Si(Li) detector with a resolution of 155 eV FHWM for 5.9 keV X-rays (at 1000 counts per second) in an area 30 mm^2. Signals from the spectrometer are amplified and filtered by a time variant pulse processor and sent to a 100 MHZ Wilkinson type analog-to-digital converter. The X-ray tube employed is a Bremsstrahlung type, with a rhodium target, and 5 mil Be window. The tube is driven by a 50 kV 1 mA high voltage power supply, providing a voltage range of 4 to 50 kV. Specific analytical conditions used for the analysis of the elements reported in Table A-1 are available at the Northwest Research Obsidian Studies Laboratory World Wide Web site at *www.obsidianlab.com.*

The diagnostic trace element values used to characterize the samples are compared directly to those for known obsidian sources reported in the literature and with unpublished trace element data collected through analysis of geologic source samples (Skinner 1999). Artifacts are correlated to a parent obsidian or basalt source or chemical source group if diagnostic trace element values fall within about two standard deviations of the analytical uncertainty of the known upper and lower limits of chemical variability recorded for the source. Occasionally, visual attributes are used to corroborate the source assignments although sources are never assigned solely on the basis of megascopic characteristics.

Results

Eight geochemical obsidian sources, six of which were correlated with known or previously recognized sources, were identified among the 132 obsidian artifacts that were characterized by X-ray fluorescence analysis (Table 1). The locations of the site and the identified obsidian sources are shown in Figure 1 while descriptive information about the identified obsidian source is presented in Table 2. Analytical results are summarized in Figure 2 and are presented in Table A-1 in the Appendix.

Two of the geochemical groups, the Butte Creek and Clackamas River sources, have been previously identified among characterized artifact collections. The primary source locations for both these groups, however, remains unknown at the present time. In the current investigation, 30 of the 47 artifacts correlated with the Butte Creek source retained at least a trace of original surface cortex. The cortex on all specimens was angular and mechanically unmodified by transport processes, suggesting procurement at or very near the primary source of the material. This evidence, when combined with the large proportion of material from the Butte Creek source found at the Orr Site, suggests that the parent source lies within a relatively short distance of the site.

Table 1. Summary of results of trace element analysis.

Geologic Source	N =	Percentage
Butte Creek	48	36.4
Clackamas River	1	0.8
Devil Point	4	3.0
Inman Creek B	1	0.8
Newberry Volcano	1	0.8
Obsidian Cliffs	75	56.8
Unknown 1	1	0.8
Unknown 2	1	0.8
Total	132	100.2

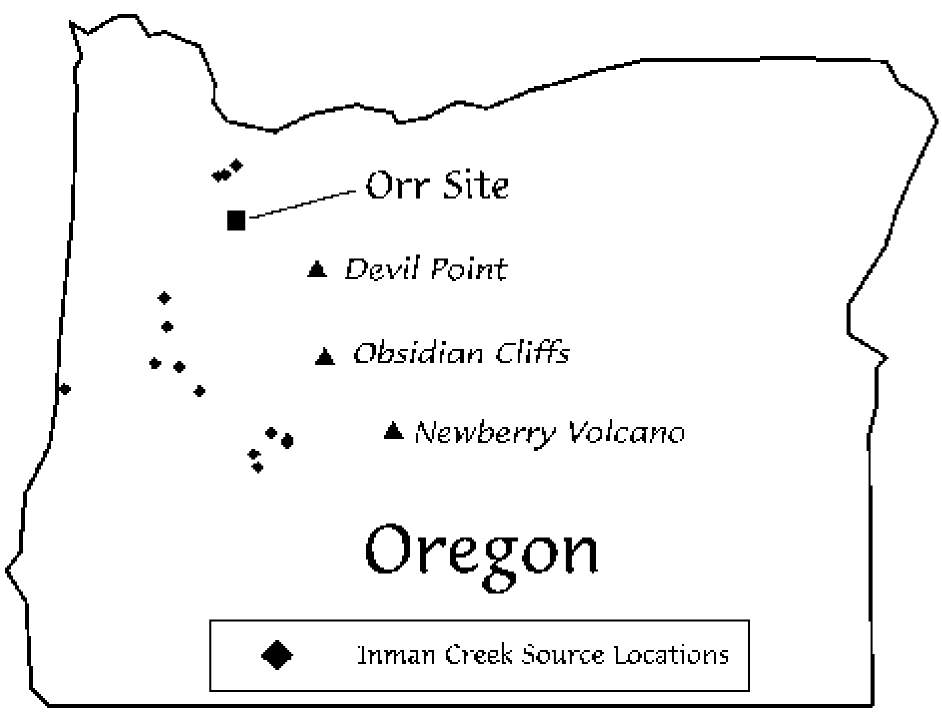

Figure 1. Locations of archaeological site and obsidian sources identified by trace element analysis.

Table 2. Description of obsidian sources identified in the current investigation. Summary includes results of unpublished field and geochemical source research conducted by Northwest Research. Continued on following page.

Geologic Source	Location	Description	References
Butte Creek	Western Cascades?	The primary source location of the Butte Creek source is currently unknown, although it is likely that it lies somewhere in the northern portion of the Western or High Cascades in Oregon. The glass is often a uniform black to dark gray color and sometimes exhibits distinct black and dark gray banding. Surface luster varies from vitreous to earthy with a smooth to matte surface texture. Light transmittance qualities range from transparent to opaque. Prehistoric use of the obsidian appears to be restricted to a limited geographic area – prior to the current investigation, only two characterized artifacts correlated with the Butte Creek source have been identified (at 35-MA-141 and 35-CL-148).	Roulette et al. 1996
Clackamas River	Western or High Cascades, Oregon?	The primary source location of the Clackamas River source is currently unknown, although it is likely that it lies somewhere in the northern portion of the Western or High Cascades in Oregon. In early trace element investigations by BioSystems Analysis, this visually distinctive source was designated Unknown C. The glass is dark gray to black in color and exhibits a smooth to matte surface texture and vitreous to earthy surface luster. Prehistoric use of the Clackamas River source appears largely restricted to the Clackamas River drainage of the Western Cascades, the eastern margin of the Willamette Valley, and to archaeological sites within the Mt. Hood National Forest. Artifacts of a gray glassy rhyolite (probably the Clackamas River source) at Clackamas River sites were first mentioned by Woodward (1974:194–195); later geochemical studies reported by Roulette et al. (1996) corroborated the prehistoric utilization of this source.	Roulette et al. 1996 Skinner and Davis 1997a, 1997b Skinner and Thatcher 1998 Woodward 1974
Devil Point	High Cascades, Marion County, Oregon	Prehistoric use of this minor source of obsidian, located about 8 km (5 mi) northwest of Mt. Jefferson in the Western Cascades, is typically limited to Cascades and central Oregon archaeological sites located relatively short distances from the source.	Skinner 1997 Skinner and Winkler 1991, 1994
Newberry Volcano	Newberry Caldera, Newberry National Volcanic Monument, Deschutes County, Oregon	A composite chemical source consisting of several geochemically indistinguishable Holocene obsidian flows (Central Pumice Cone, East Lake, Game Hut, and Interlake flows) located within Newberry Caldera (Newberry National Volcanic Monument). All of the flows making up this geochemical group erupted after the Mazama ashfall of about 6,850 ^{14}C years ago, providing a unique temporal window for the prehistoric use of the glass. The rapid and widespread prehistoric use of Newberry Volcano obsidian in the period following the eruption of the flows is well documented in central and northcentral Oregon. Glass from this source is occasionally encountered at sites in the Western Cascades, southwest Oregon, northwest Oregon, and Washington, and has been reported from as far north as British Columbia, Canada.	Carlson 1994 Connolly 1995 Connolly et al. 1995 Flenniken and Ozbun 1988 Friedman 1977 Friedman and Obradovich 1981 Hughes 1992 Linneman 1990 MacLeod et al. 1995 Musil and O'Neill 1997 Skinner 1983, 1995a, 1995b Skinner and Winkler 1991, 1994 Williams 1935

Table 2 (continued). Description of obsidian sources identified in the current investigation.

Geologic Source	Location	Description	References
Obsidian Cliffs	High Cascades, Three Sisters Wilderness Area, Lane County, Oregon	This large 95,000 yr-old glaciated obsidian-rhyolite flow is located in the central High Cascades near North Sister Volcano. Obsidian nodules from the source can be found in deposits of glacial till to the west of the source and are occasionally found in the gravels of the McKenzie and Willamette rivers in northwestern Oregon. Obsidian artifact manufacturing debris covers a large portion of the Obsidian Cliffs plateau and it is likely that this important source was used throughout much of the post-glacial period. Characterized artifacts from Obsidian Cliffs have been found at many archaeological sites in western Oregon, central and northcentral Oregon, and Washington. Artifacts from the source have been reported from as far north as British Columbia, Canada. See Figure 3.	Anttonen 1972 Carlson 1994 Hill 1992 Hughes 1992, 1993 Hughes, S. 1983 Musil and O'Neill 1997 Skinner 1983, 1986, 1995a, 1995b Skinner and Winkler 1991, 1994 Taylor 1968 Taylor et al. 1987 White 1974, 1975 Williams 1944

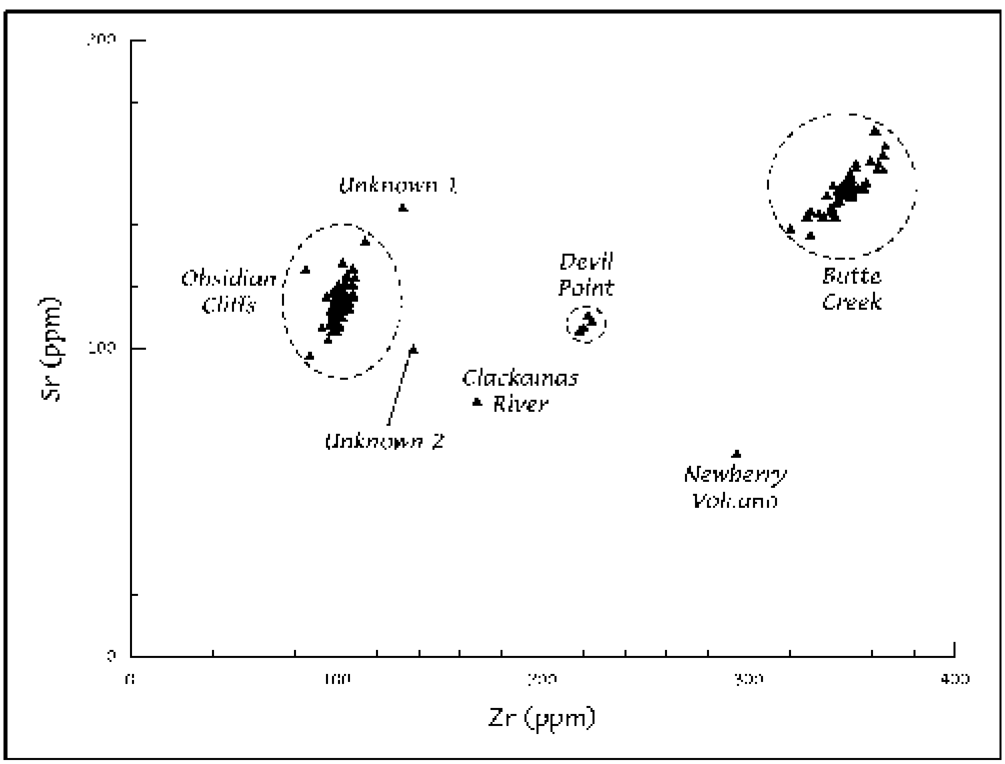

Figure 2. Scatterplot of strontium (Sr) plotted versus zirconium (Zr) for all analyzed artifacts.

Figure 3. Obsidian Cliffs Plateau as seen from the summit of the Middle Sister. Taken facing west.

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Appendix

Results of X-Ray Fluorescence Analysis

Northwest Research Obsidian Studies Laboratory

Table A-1. Results of XRF Studies: Orr Site, Western Cascades, Marion County, Oregon

Site	Specimen No.	Catalog No.		Trace Element Concentrations											Ratios		Artifact Source
				Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	
Orr	4	ORR-1		35	13	84	146	19	132	9	636	269	920	0.94	38.0	48.9	Unknown 1
			±	7	3	3	7	3	7	2	96	47	13	0.11			
Orr	5	ORR-2		45	25	123	153	34	349	11	1559	228	730	1.52	72.4	31.7	Butte Creek
			±	8	3	3	7	3	7	2	97	47	13	0.11			
Orr	6	ORR-3		49	27	146	66	44	294	18	1039	293	886	1.59	55.7	49.2	Newberry Volcano
			±	7	3	3	7	3	7	2	97	47	15	0.11			
Orr	7	ORR-4		38	13	84	114	16	102	8	498	267	NM	0.93	37.7	61.0	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	8	ORR-5		29	11	78	112	15	101	10	664	295	NM	1.05	37.5	51.8	Obsidian Cliffs
			±	7	2	3	7	3	7	2	96	47	NM	0.11			
Orr	9	ORR-6		57	24	123	158	40	365	12	1707	252	709	1.55	65.2	29.5	Butte Creek
			±	7	3	3	7	3	7	2	97	47	14	0.11			
Orr	10	ORR-7		59	20	114	150	37	346	15	2439	342	719	2.39	68.7	31.2	Butte Creek
			±	7	2	3	7	3	7	2	98	47	13	0.11			
Orr	11	ORR-8		54	18	124	155	35	350	12	1926	272	724	1.85	70.3	30.9	Butte Creek
			±	7	3	3	7	3	7	2	98	47	14	0.11			
Orr	12	ORR-9		46	17	78	113	15	99	7	657	302	NM	1.01	35.4	50.6	Obsidian Cliffs
			±	6	2	3	7	3	7	2	96	47	NM	0.11			
Orr	13	ORR-10		58	27	118	152	38	349	16	1956	297	700	2.16	73.3	35.3	Butte Creek
			±	7	2	3	7	3	7	2	98	47	14	0.11			
Orr	14	ORR-11		48	23	113	143	35	342	13	2116	306	NM	2.27	74.3	34.2	Butte Creek
			±	7	2	3	7	3	7	2	98	47	NM	0.11			
Orr	15	ORR-12		57	24	118	152	36	349	16	1998	248	NM	1.85	78.4	29.8	Butte Creek
			±	7	3	3	7	3	7	2	98	47	NM	0.11			
Orr	16	ORR-13		59	20	120	154	38	348	18	1614	230	NM	1.60	74.8	32.0	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	17	ORR-14		65	19	123	150	37	350	12	2038	294	902	2.06	71.1	32.4	Butte Creek
			±	7	3	3	7	3	7	2	98	47	14	0.11			
Orr	18	ORR-15		63	29	119	157	38	349	16	1984	292	NM	2.08	72.2	33.5	Butte Creek
			±	7	3	3	7	3	7	2	98	47	NM	0.11			

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Table A-1. Results of XRF Studies: Orr Site, Western Cascades, Marion County, Oregon

Site	Specimen No.	Catalog No.		Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Artifact Source
				Trace Element Concentrations											Ratios		
Orr	19	ORR-16		49	22	116	149	39	350	12	2266	309	NM	2.28	73.7	32.1	Butte Creek
			±	7	3	3	7	3	7	2	98	47	NM	0.11			
Orr	20	ORR-17		57	21	114	151	38	343	12	1894	266	NM	1.84	71.8	31.2	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	21	ORR-18		54	25	119	156	36	349	16	1207	189	NM	1.20	73.4	32.6	Butte Creek
			±	7	3	4	7	3	7	2	96	47	NM	0.11			
Orr	22	ORR-19		60	25	105	143	33	336	14	1483	241	NM	1.62	71.6	35.3	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	23	ORR-20		57	27	116	151	38	350	15	1996	298	NM	2.08	70.7	33.4	Butte Creek
			±	7	2	3	7	3	7	2	98	47	NM	0.11			
Orr	24	ORR-21		57	25	115	152	38	345	14	1628	250	NM	1.71	71.9	33.8	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	25	ORR-22		51	17	88	107	23	220	15	1122	283	NM	1.49	54.6	42.9	Devil Point
			±	7	2	3	7	3	7	2	97	47	NM	0.11			
Orr	26	ORR-23		54	22	124	154	39	357	14	1952	278	849	2.07	75.9	33.9	Butte Creek
			±	7	2	3	7	3	7	2	98	47	14	0.11			
Orr	27	ORR-24		50	29	111	144	39	341	15	1403	217	886	1.45	73.4	33.6	Butte Creek
			±	7	3	3	7	3	7	2	97	47	14	0.11			
Orr	28	ORR-25		56	34	123	161	41	359	15	1748	251	910	1.83	76.7	33.8	Butte Creek
			±	7	3	3	7	3	7	2	97	47	14	0.11			
Orr	29	ORR-26		53	21	118	152	39	356	13	1610	230	913	1.62	75.6	32.5	Butte Creek
			±	7	3	3	7	3	7	2	97	47	14	0.11			
Orr	30	ORR-27		52	16	93	106	23	218	13	929	244	NM	1.34	58.9	46.6	Devil Point
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	31	ORR-28		67	26	108	150	38	344	15	1534	208	NM	1.40	74.8	29.7	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	32	ORR-29		51	16	86	117	17	102	9	569	277	NM	0.84	32.9	48.9	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	33	ORR-30		68	28	121	149	39	349	13	1691	257	NM	1.76	71.4	33.5	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			

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NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

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Table A-1. Results of XRF Studies: Orr Site, Western Cascades, Marion County, Oregon

				Trace Element Concentrations											Ratios		
Site	Specimen No.	Catalog No.		Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Artifact Source
Orr	34	ORR-31		62	22	118	154	35	347	11	1606	225	NM	1.67	80.4	33.6	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	35	ORR-32		58	27	123	153	38	355	11	1771	243	NM	1.81	78.8	32.8	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	36	ORR-33		62	24	115	150	39	338	16	1244	185	NM	1.20	75.5	31.7	Butte Creek
			±	7	3	4	7	3	7	2	96	47	NM	0.11			
Orr	37	ORR-34		65	24	104	139	35	320	10	1319	194	NM	1.33	78.3	33.0	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	38	ORR-35		75	25	117	144	30	334	14	875	151	NM	0.91	77.3	34.8	Butte Creek
			±	8	4	4	7	3	7	2	96	47	NM	0.11			
Orr	39	ORR-36		59	29	118	153	38	341	13	1104	184	NM	1.20	75.5	35.5	Butte Creek
			±	7	3	4	7	3	7	2	96	47	NM	0.11			
Orr	40	ORR-37		55	15	83	118	17	99	5	668	283	NM	0.87	33.3	43.4	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	41	ORR-38		39	13	84	121	16	101	10	642	276	NM	0.90	35.2	46.4	Obsidian Cliffs
			±	6	3	3	7	3	7	2	96	47	NM	0.11			
Orr	42	ORR-39		42	9	83	114	16	102	7	692	275	NM	0.95	37.1	45.2	Obsidian Cliffs
			±	6	3	3	7	3	7	2	96	47	NM	0.11			
Orr	43	ORR-40		44	12	79	113	19	105	8	685	285	NM	1.00	37.5	48.1	Obsidian Cliffs
			±	6	2	3	7	3	7	2	96	47	NM	0.11			
Orr	44	ORR-41		39	15	80	110	15	103	7	745	283	NM	1.01	38.1	44.7	Obsidian Cliffs
			±	6	2	3	7	3	7	2	96	47	NM	0.11			
Orr	45	ORR-42		36	14	81	109	16	100	11	496	194	NM	0.62	39.5	43.1	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	46	ORR-43		30	15	84	107	17	101	9	607	317	NM	1.06	34.7	56.7	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	47	ORR-44		37	13	82	114	18	99	8	745	333	NM	0.92	28.9	41.0	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	48	ORR-45		40	13	80	107	16	93	5	517	234	NM	0.75	36.8	48.8	Obsidian Cliffs
			±	6	3	3	7	3	7	2	96	47	NM	0.11			

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NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

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Table A-1. Results of XRF Studies: Orr Site, Western Cascades, Marion County, Oregon

Site	Specimen No.	Catalog No.		Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Artifact Source
				Trace Element Concentrations											Ratios		
Orr	49	ORR-46		41	16	86	115	17	106	9	579	302	NM	0.99	34.7	56.2	Obsidian Cliffs
			±	6	2	3	7	3	7	2	96	47	NM	0.11			
Orr	50	ORR-47		50	12	81	113	16	102	8	586	223	NM	0.67	35.3	39.1	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	51	ORR-48		29	18	81	112	19	97	11	887	308	NM	1.05	35.7	38.9	Obsidian Cliffs
			±	7	2	3	7	3	7	2	96	47	NM	0.11			
Orr	52	ORR-49		38	13	80	110	18	100	10	485	268	NM	0.87	35.5	59.2	Obsidian Cliffs
			±	6	2	3	7	3	7	2	96	47	NM	0.11			
Orr	53	ORR-50		38	15	80	114	18	99	9	636	323	NM	0.98	31.8	50.9	Obsidian Cliffs
			±	6	2	3	7	3	7	2	96	47	NM	0.11			
Orr	54	ORR-51		37	11	78	109	18	98	7	579	237	NM	0.83	39.6	47.8	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	55	ORR-52		40	14	81	112	17	97	11	563	280	NM	0.94	35.9	54.7	Obsidian Cliffs
			±	6	2	3	7	3	7	2	96	47	NM	0.11			
Orr	56	ORR-53		44	16	85	110	16	102	11	403	194	NM	0.61	38.7	51.7	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	57	ORR-54		54	15	99	109	25	224	13	1013	282	NM	1.48	54.5	47.1	Devil Point
			±	6	3	3	7	3	7	2	97	47	NM	0.11			
Orr	58	ORR-55		34	10	82	116	16	99	12	576	284	NM	0.96	36.1	54.7	Obsidian Cliffs
			±	6	3	3	7	3	7	2	96	47	NM	0.11			
Orr	59	ORR-56		39	18	81	115	18	101	9	460	253	NM	0.81	35.5	58.0	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	60	ORR-57		55	26	118	146	38	340	14	2108	289	NM	2.20	77.2	33.3	Butte Creek
			±	7	2	3	7	3	7	2	98	47	NM	0.11			
Orr	61	ORR-58		39	11	90	117	14	100	9	493	248	NM	0.80	36.1	53.9	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	62	ORR-59		50	14	80	110	16	102	11	488	239	NM	0.63	30.7	44.3	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	63	ORR-60		45	13	83	117	19	107	7	394	203	NM	0.63	37.4	53.9	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			

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Table A-1. Results of XRF Studies: Orr Site, Western Cascades, Marion County, Oregon

Site	Specimen No.	Catalog No.		Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	Artifact Source
				Trace Element Concentrations											Ratios		
Orr	64	ORR-61		36	16	76	107	17	99	11	627	250	NM	0.90	39.6	47.4	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	65	ORR-62		62	28	116	152	36	351	14	1916	274	NM	2.06	77.0	34.4	Butte Creek
			±	7	3	3	7	3	7	2	98	47	NM	0.11			
Orr	66	ORR-63		29	11	90	116	16	101	11	451	237	NM	0.73	35.0	53.9	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	67	ORR-64		48	26	114	147	37	342	13	1802	267	NM	1.94	75.2	34.5	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	68	ORR-65		53	19	110	143	32	328	16	1701	264	NM	1.76	69.3	33.3	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	69	ORR-66		37	11	80	110	19	98	13	502	244	NM	0.79	36.2	52.2	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	70	ORR-67		66	25	132	166	39	366	14	1480	213	NM	1.43	73.9	31.4	Butte Creek
			±	7	3	4	7	3	7	2	97	47	NM	0.11			
Orr	71	ORR-68		33	13	81	106	16	100	10	476	274	NM	0.87	34.6	60.1	Obsidian Cliffs
			±	7	2	3	7	3	7	2	96	47	NM	0.11			
Orr	72	ORR-69		58	13	90	111	21	222	15	855	247	NM	1.30	56.5	49.2	Devil Point
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	73	ORR-70		44	18	82	109	15	99	9	690	277	NM	0.94	36.6	45.2	Obsidian Cliffs
			±	6	2	3	7	3	7	2	96	47	NM	0.11			
Orr	74	ORR-71		43	23	115	152	40	353	18	1509	239	NM	1.55	69.5	33.3	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	75	ORR-72		45	10	86	112	13	98	7	497	240	NM	0.81	37.8	53.9	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	76	ORR-73		47	13	81	113	16	106	11	519	251	NM	0.84	37.4	53.9	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	77	ORR-74		52	18	93	128	15	103	6	498	206	NM	0.64	37.2	43.7	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	78	ORR-75		47	14	86	115	13	99	11	406	212	NM	0.67	37.6	55.7	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			

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Table A-1. Results of XRF Studies: Orr Site, Western Cascades, Marion County, Oregon

Site	Specimen No.	Catalog No.		Trace Element Concentrations Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Ratios Fe:Mn	Fe:Ti	Artifact Source
Orr	79	ORR-76		50	16	88	123	19	109	10	433	253	NM	0.80	35.0	60.8	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	80	ORR-77		42	20	111	145	33	340	14	1520	240	NM	1.60	70.8	33.9	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	81	ORR-78		42	11	80	114	17	101	8	405	241	NM	0.79	36.7	63.9	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	82	ORR-79		35	14	92	126	19	108	8	427	227	NM	0.75	37.9	58.5	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	83	ORR-80		62	29	114	152	35	349	14	1296	189	NM	1.30	78.6	32.7	Butte Creek
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	84	ORR-81		43	14	91	118	18	108	9	413	226	NM	0.73	37.1	58.7	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	85	ORR-82		55	21	96	126	23	85	9	140	289	NM	0.76	28.8	166.2	Inman Creek B
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	86	ORR-83		46	19	139	100	28	137	10	505	171	885	0.60	45.1	41.1	Unknown 2
			±	7	3	4	7	3	7	2	96	47	16	0.11			
Orr	87	ORR-84		45	20	92	121	17	105	8	444	288	NM	0.87	32.6	64.4	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	88	ORR-85		33	14	78	108	17	101	9	339	206	NM	0.65	38.0	64.4	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	89	ORR-86		31	16	81	112	16	103	6	390	193	NM	0.54	35.1	47.9	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	90	ORR-87		46	12	92	116	17	99	13	360	211	NM	0.60	34.0	56.1	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	91	ORR-88		38	26	112	137	39	330	15	1771	251	NM	1.78	74.6	32.4	Butte Creek
			±	8	3	3	7	3	7	2	97	47	NM	0.11			
Orr	92	ORR-89		40	17	80	114	17	98	11	430	234	NM	0.68	33.4	53.0	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	93	ORR-90		40	18	70	98	17	87	11	292	159	NM	0.40	35.0	48.6	Obsidian Cliffs
			±	8	3	3	7	3	7	2	95	47	NM	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table A-1. Results of XRF Studies: Orr Site, Western Cascades, Marion County, Oregon

Site	Specimen No.	Catalog No.		Trace Element Concentrations Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Ratios Fe:Mn	Fe:Ti	Artifact Source
Orr	94	ORR-91		29	13	89	119	13	103	14	379	212	NM	0.59	33.3	52.6	Obsidian Cliffs
			±	8	3	3	7	3	7	2	95	47	NM	0.11			
Orr	95	ORR-92		43	12	85	115	16	99	12	337	206	NM	0.60	35.3	60.2	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	96	ORR-93		38	15	87	116	17	103	8	483	244	NM	0.79	36.5	54.4	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	97	ORR-94		44	11	80	114	18	101	8	492	222	NM	0.74	38.5	50.4	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	98	ORR-95		36	15	84	115	15	102	11	413	239	NM	0.72	34.4	58.0	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	99	ORR-96		69	23	113	150	41	347	16	1768	266	NM	1.83	71.2	33.2	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	100	ORR-97		48	10	77	106	18	98	7	451	227	NM	0.72	36.5	53.3	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	101	ORR-98		36	16	79	112	18	98	8	335	210	NM	0.60	34.4	60.3	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	102	ORR-99		60	29	124	163	38	365	16	1750	262	NM	1.78	70.8	32.8	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	103	ORR-100		64	24	122	158	36	362	14	1655	234	NM	1.65	75.4	32.2	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	104	ORR-101		49	14	78	111	16	98	10	478	217	NM	0.68	36.9	48.2	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	105	ORR-102		35	15	90	116	20	102	11	579	214	NM	0.61	34.1	36.4	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	106	ORR-103		31	15	83	116	16	105	8	600	261	NM	0.94	39.1	51.5	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	107	ORR-104		48	14	80	103	15	96	9	399	208	NM	0.62	35.8	52.5	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	108	ORR-105		57	27	121	150	39	348	13	1674	263	NM	1.76	69.7	33.9	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

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Table A-1. Results of XRF Studies: Orr Site, Western Cascades, Marion County, Oregon

Site	Specimen No.	Catalog No.		Trace Element Concentrations											Ratios		Artifact Source
				Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	
Orr	109	ORR-106		38	7	82	114	11	101	10	267	168	NM	0.44	35.6	58.0	Obsidian Cliffs
			±	8	4	3	7	3	7	2	95	47	NM	0.11			
Orr	110	ORR-107		38	13	85	135	18	114	13	639	263	NM	0.85	35.3	44.1	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	111	ORR-108		63	27	125	160	43	363	14	1550	225	NM	1.56	75.2	32.7	Butte Creek
			±	7	3	4	7	3	7	2	97	47	NM	0.11			
Orr	112	ORR-109		46	15	88	117	18	108	6	512	259	NM	0.84	36.0	54.5	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	113	ORR-110		55	15	98	124	19	105	12	466	255	NM	0.80	35.0	57.1	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	114	ORR-111		35	16	83	117	18	105	12	393	210	NM	0.66	37.5	56.5	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	115	ORR-112		32	15	82	110	16	101	10	363	213	NM	0.62	34.7	57.7	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	116	ORR-113		47	16	89	116	18	105	7	391	228	NM	0.69	34.9	58.8	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	117	ORR-114		43	13	88	121	18	108	8	375	211	NM	0.63	35.5	56.5	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	118	ORR-115		50	15	93	123	16	105	9	468	232	NM	0.72	35.6	51.7	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	119	ORR-116		76	23	145	83	47	168	32	276	209	NM	0.83	45.7	95.9	Clackamas River
			±	8	3	4	7	3	7	2	95	47	NM	0.11			
Orr	120	ORR-117		50	20	118	148	34	344	15	1530	233	NM	1.59	72.9	33.5	Butte Creek
			±	7	3	3	7	3	7	2	97	47	NM	0.11			
Orr	121	ORR-118		43	18	89	115	18	102	8	452	224	NM	0.69	36.0	51.4	Obsidian Cliffs
			±	8	3	3	7	3	7	2	96	47	NM	0.11			
Orr	122	ORR-119		40	14	77	108	13	97	13	395	192	NM	0.59	38.1	51.0	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	123	ORR-120		54	22	111	145	38	330	7	1091	180	NM	1.05	69.4	32.0	Butte Creek
			±	8	3	4	7	3	7	2	96	47	NM	0.11			

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Table A-1. Results of XRF Studies: Orr Site, Western Cascades, Marion County, Oregon

Site	Specimen No.	Catalog No.		Trace Element Concentrations											Ratios		Artifact Source
				Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	
Orr	124	ORR-121		43	22	86	117	14	95	8	386	179	NM	0.52	37.3	46.5	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	125	ORR-122		39	15	92	121	17	104	8	378	204	NM	0.58	34.9	52.7	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	126	ORR-123		52	15	85	119	15	99	9	505	213	NM	0.61	34.4	41.5	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	127	ORR-124		49	11	88	115	17	104	10	511	207	NM	0.62	36.1	41.8	Obsidian Cliffs
			±	7	3	3	7	3	7	2	96	47	NM	0.11			
Orr	128	ORR-125		59	20	87	119	21	102	5	385	199	NM	0.58	35.8	51.5	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	129	ORR-126		45	11	85	118	17	99	10	411	200	NM	0.54	33.5	45.7	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	130	ORR-127		67	15	114	153	36	345	13	1291	193	NM	1.22	72.7	31.0	Butte Creek
			±	7	3	4	7	3	7	2	96	47	NM	0.11			
Orr	131	ORR-128		42	16	81	110	16	100	12	323	182	NM	0.53	37.2	56.4	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	132	ORR-129		45	13	84	118	15	98	11	332	185	NM	0.50	34.3	51.7	Obsidian Cliffs
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
Orr	133	ORR-130		70	27	124	159	35	352	12	1084	176	NM	1.08	72.7	32.8	Butte Creek
			±	8	4	4	7	3	7	2	96	47	NM	0.11			
Orr	134	ORR-131		41	27	134	171	37	361	16	1189	183	NM	1.23	78.0	33.8	Butte Creek
			±	9	3	4	7	3	7	2	96	47	NM	0.11			
Orr	135	ORR-132		55	28	124	160	39	352	14	954	155	NM	0.86	70.7	30.2	Butte Creek
			±	9	4	4	7	3	7	2	96	47	NM	0.11			
NA	RGM-1	RGM-1		35	23	150	104	25	215	13	1558	270	772	1.79	68.8	37.0	RGM-1 Reference Standard
			±	6	2	3	7	3	7	1	97	47	13	0.11			

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NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.