UNIVERSITY OF UTAH ANTHROPOLOGICAL PAPERS

Number 121

NEWBERRY CRATER

A Ten-Thousand-Year Record of Human Occupation and Environmental Change in the Basin-Plateau Borderlands

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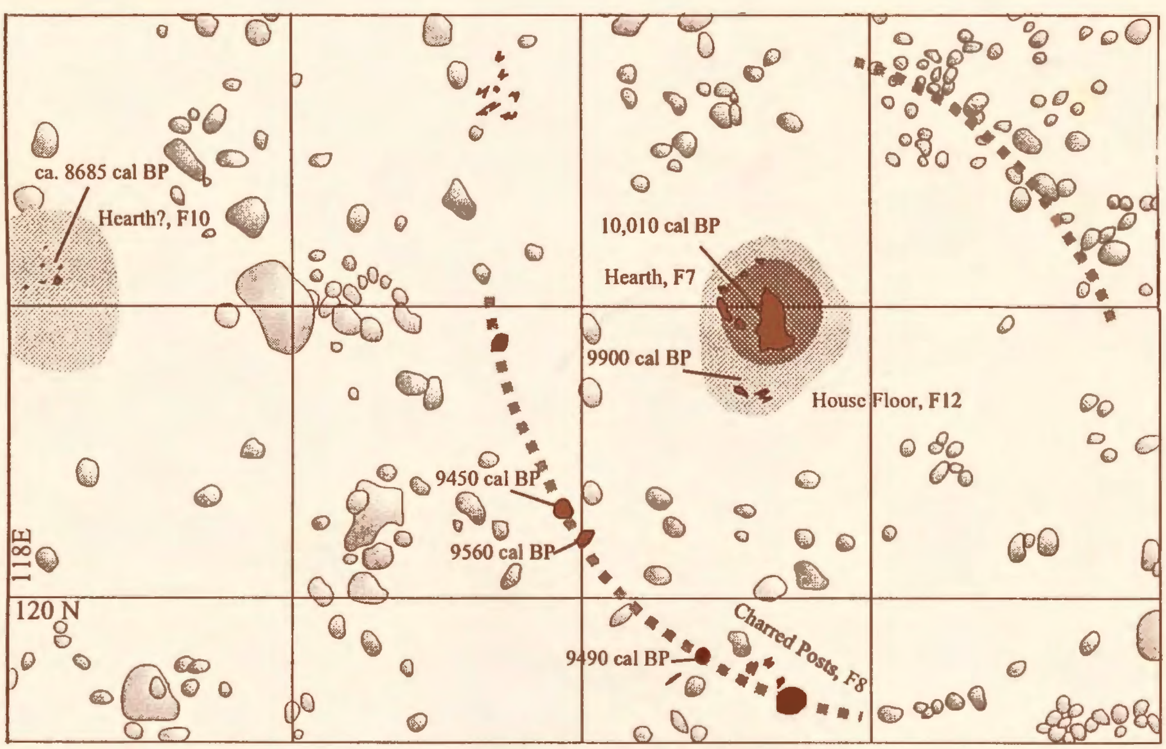

11

Geochemical Characterization of the Newberry Caldera Obsidian Flows

Thomas J. Connolly and Richard E. Hughes

A number of archaeological investigations have confirmed that Newberry Crater obsidian flows were systematically quarried for tool stone material throughout the Holocene (Connolly 1991a; Connolly and Musil 1994; Flenniken and Ozbun 1988, 1993; Ozbun 1991). By studying the geochemical profiles of obsidian artifacts recovered from archaeological sites, it has also been shown that Newberry obsidians were transported to distant locales including the Umpqua River basin, the Willamette Valley, the Klamath and Fort Rock Basins, the John Day River basin, and, especially, throughout the Deschutes River valley and to areas farther north along the spine of the Cascade Range (see chapter 13, this volume).

Volcanic activity has continued within the Newberry caldera throughout the Holocene, affecting the availability of various obsidian flows through time by burying older flows and producing new sources. The Buried Obsidian Flow (see Table 11.1, Figure 2.2), stretching from the south caldera wall to the shore of East Lake, may have been the most readily accessible caldera obsidian in early Holocene times. This flow spilled from a vent now marked by a dome near the south caldera wall and oozed north to the shore of East Lake. MacLeod and Sherrod (1988:10075) estimated its age "to be 8000–10,000 years old, based on relations to Mazama ash and degree of weathering." Linneman (1990) reports a radiocarbon date of 10,000 ± 500 years B.P. from a paleosol below a scoria-fall deposit from the East Rim Fissure (ERF), and he notes that ERF cinders also overlie the Buried Obsidian Flow. He suggests the flow may be more than 10,000 years old.

Access to Buried Flow obsidian would have been severely restricted by ca. 7000 B.P. due to burial by Mazama and East Lake Tephras. At this time, a number of distinct vents produced the Interlake Obsidian Flow, Central Pumice Cone flow, and Game Hut Obsidian Flow. These lithic sources have been available for exploitation throughout the middle and late Holocene, but their importance may have been diminished after the eruption of the East Lake Obsidian Flows, which formed about 3,500 years ago, and the Big Obsidian Flow, which formed about 1,300 years ago (Friedman 1977; MacLeod et al. 1982; MacLeod and Sherrod 1988).

The reasonably precise chronology for Holocene-age obsidian flows within Newberry Crater has generated increasing interest among archaeologists for their potential use as horizon markers in archaeological sites (e.g., Matz 1991a; Scott et al. 1986; Thomas 1986:623–624). Recovery of obsidian from an archaeological context that is attributable to, say, the Big Obsidian Flow, would provide a maximum age (ca. 1300 B.P.) for the occupation with which it is associated. However, while there are many archaeologically important, and potentially chronologically distinct, obsidian flows in Newberry Crater, only two geochemical types have been recognized (Hughes 1988b). The Big Obsidian Flow has been consistently distinguished from most others on the basis of trace element profiles, but it is not distinguishable from the Buried Obsidian Flow. The East Lake Obsidian Flows, the Interlake Obsidian Flow, the North Obsidian Flow, and the Game Hut and Central Pumice Cone flows have not been shown to be sufficiently geochemically distinct to be reliably differentiated from the other middle Holocene Newberry obsidians using trace element profiles measured by x-ray fluorescence spectroscopy (Hughes 1988b; Jack and Carmichael 1969; Laidley and McKay 1971; MacLeod and Sherrod 1988).

The potential archaeological significance of the Buried Obsidian Flow is an important consideration in this sequence of obsidian flows. Linneman (1990:108) has noted the general similarity of this flow's chemical profile to the late Holocene Big Obsidian Flow, but this similarity has not been systematically explored. Skinner (1994b) has observed that anomalously thick obsidian hydration rims reported for artifacts correlated with the Big Obsidian Flow suggest that the artifacts are older than the flow from which they were thought to derive. Recent geochemical analysis of obsidian samples from the Buried Obsidian Flow, reported here, suggest that the chemical signature of this flow is sufficiently similar to the Big Obsidian Flow to account for the apparently anomalous attributions.

PRIOR GEOCHEMICAL CHARACTERIZATION STUDIES

Geochemical analyses of Newberry caldera obsidians (see Table 11.1) have been previously reported in a number of sources (Higgins 1973; Hughes 1988b, 1993b; Jack and Carmichael 1969; Laidley and McKay 1971; Linneman 1990; MacLeod et al. 1981; MacLeod and Sherrod 1988; Skinner 1983). However, because most of these investigators were exploring the general geologic history of the volcano,

Table 11.1.
Obsidian flow designations used in the present discussion, and cognates (ages are radiocarbon years, except where noted).

Current Designation	Designations in Literature	Reference	Estimated Age[a]	Age Reference
Buried Obsidian Flow	Buried Obsidian Flow	MacLeod et al. (1981)	8000–10,000 B.P.	MacLeod and Sherrod (1988)
		MacLeod and Sammel (1982)	>10,000 ± 500 B.P.	Linneman (1990)
		Skinner (1983, 1993)		
	South Obsidian Flow	MacLeod and Sherrod (1988)		
	Southeastern Obs. Flow	Linneman (1990)		
Interlake Obsidian Flow	Interlake Obsidian Flow	MacLeod et al. (1981)	6700 B.P.[b]	Friedman (1977)
		Friedman (1977)	6200 B.P.[b]	MacLeod and Sherrod (1988)
		MacLeod and Sherrod (1988)		
		Linneman (1990)		
		Skinner (1983)		
	North Obsidian Flow	Higgins (1973)		
		Hughes (1988, 1993b)		
	T Obsidian Flow	Laidley and McKay (1971)		
Central Pumice Cone flow	Central Pumice Cone flow	MacLeod et al. (1981)	6700, 4500 B.P.[b]	Friedman (1977)
		MacLeod and Sherrod (1988)	6200 B.P.[b]	MacLeod and Sherrod (1988)
		Skinner (1983)		
	Pumice Cone Obs. Flow	Higgins (1971)		
		Hughes (1988, 1993b)		
Game Hut Obsidian flow	Game Hut Obsidian Flow	Higgins (1973)	6700 B.P.[b]	Friedman (1977)
		Friedman (1977)		
		MacLeod and Sherrod (1988)		
East Lake Obsidian Flows	East Lake Obsidian Flows	Higgins (1973)	3500 B.P.[b]	Friedman (1977)
		Friedman (1977)		
		MacLeod and Sherrod (1988)		
		Linneman (1990)		
		MacLeod et al. (1981)		
	Middle and East Obs. Flows	Laidley and McKay (1971)		
	East Lake-A and East Lake-B	Skinner (1983)		
Big Obsidian Flow	Big Obsidian Flow	Higgins (1973)	1300 B.P.[b]	Friedman (1977)
		Laidley and McKay (1971)	1350–1300 B.P.	MacLeod and Sherrod (1988)
		MacLeod et al. (1981)	1270 ± 60	Pearson et al. (1966)
		MacLeod and Sherrod (1988)	1340 ± 60	MacLeod et al. (1982)
		Linneman (1990)	1390 ± 200	Peterson and Groh (1969)
		Hughes (1988, 1993b)	1540 ± 60	Connolly (1991b)
	Latest Obsidian Flow	Jack and Carmichael (1969)		

NOTES:
a Radiocarbon (uncalibrated) years ago.
b Obsidian hydration age estimate, based on uncorrected radiocarbon years (Friedman 1977).

rather than determining the precise nature and degree of interflow and intraflow variability, most of these studies are of limited use for geochemical "fingerprinting" of the various caldera flows (compare Hughes 1984). The studies by Laidley and McKay (1971), Skinner (1983), and Hughes (1988b, 1993b) are notable exceptions.

Laidley and McKay (1971) sampled five Newberry caldera obsidian flows for the purposes of investigating differences among flows and testing the intraflow variability of the Big Obsidian Flow. Using a combination of x-ray fluorescence (XRF), atomic absorption analysis, and gamma spectroscopy to determine trace element values, they found that chemical variation within the Big Obsidian Flow was so low that "a sample taken from any point in the flow would be representative of the entire flow" (Laidley and McKay 1971:341). They further reported that all the tested flows (the Central Pumice Cone flow, Interlake Obsidian Flow, and two East Lake Flows) are "sufficiently similar chemically to indicate a common source. However, real differences do exist" (Laidley and McKay 1971:340). They

Table 11.2.
Trace element composition data[a] for six Newberry caldera obsidian flows.
Concentration estimates for obsidian from the Buried Flow appear here for the first time,
as do barium (Ba) values for all six flows; other data from Hughes (1993b, Table 2);
five samples analyzed from each flow.

Element		Big Obs. Flow	Buried Obs. Flow	Game Hut Obs. Flow	Central Pumice Cone Flow	Interlake[b] Obs. Flow	East Lake Obs. Flows
Ti	$\bar{x}$	1350	1337	1385	1416	1358	1475
	s.d.	52	61	55	66	65	70
	CV%	4	5	4	5	5	5
Mn	$\bar{x}$	589	480	455	466	447	466
	s.d.	12	24	18	11	24	12
	CV%	2	5	4	2	5	3
$Fe_2O_3^T$	$\bar{x}$	2.60	2.27	2.25	2.29	2.23	2.36
	s.d.	.05	.05	.06	.05	.09	.05
	CV%	2	2	3	2	4	2
Rb	$\bar{x}$	117	125	127	126	129	126
	s.d.	1	3	6	3	7	4
	CV%	1	3	5	3	6	4
Sr	$\bar{x}$	53	56	60	59	59	62
	s.d.	2	3	3	4	3	3
	CV%	4	6	5	6	5	4
Y	$\bar{x}$	42	46	38	39	37	36
	s.d.	1	2	3	3	3	2
	CV%	3	3	8	6	7	6
Zr	$\bar{x}$	349	314	277	275	274	275
	s.d.	3	4	7	7	6	8
	CV%	1	1	3	2	2	3
Ba	$\bar{x}$	851	786	869	830	843	855
	s.d.	26	32	32	17	15	9
	CV%	3	4	4	2	2	1

NOTES:
[a] All values in parts per million (ppm), except iron expressed as total $Fe_2O_3^T$ weight percent (from Hughes 1993b).
[b] Identified as the North Flow in Hughes (1993b); see Table 11.1.

reported significant differences between the Big Obsidian Flow and several of the other flows, but they don't specifically address the nature or magnitude of the "real differences" they mention.

Skinner (1983) conducted XRF analyses for major and trace elements on four samples each from the Big Obsidian Flow and both lobes of the East Lake Obsidian Flows. He reported that the two East Lake flows "are indistinguishable in their major and trace element composition" (Skinner 1983:114, trace elements measured included Rb, Sr, Y, Zr, and Nb). He also reported that the "Big Obsidian Flow and East Lake obsidian flows were easily differentiated using their trace element composition" (Skinner 1983:166).

Hughes (1988b:D3) later compared the Game Hut Obsidian Flow, Central Pumice Cone flow, East Lake Obsidian Flows, and North Obsidian Flow, and he concluded that "no statistically significant composition differences were observed between any of the four sources within the Volcano" based on Ti, Mn, Fe, Rb, Sr, Y, and Zr values.

ADDITIONAL GEOCHEMICAL ANALYSES

The purpose of the present analysis is to further explore the potential to discriminate among the archaeologically important Newberry Crater obsidian flows, and in particular to evaluate the potential for discriminating the geochemical signature of the Buried Obsidian Flow from other archaeologically significant obsidian sources within the caldera. Table 11.2 presents trace element profiles for Newberry caldera flows determined by x-ray fluorescence (XRF), the analytic technique on which prior studies primarily rely (e.g., Hughes 1988b, 1993b; Jack and Carmichael 1969; Laidley and McKay 1971). We also explore the feasibility of instrumental neutron activation analysis (INAA) for determining diagnostic interflow trace element values, because this technique is sensitive to an array of additional elements not easily measured by XRF.

Although the Buried Obsidian Flow is largely buried by a thick mantle of later tephra deposits, an eroding exposure is visible at the East Lake shoreline. For both INAA and XRF analyses, obsidian was taken from this exposure, as well as from a test probe (trench Q locality, see chapter 4) excavated in a roadcut above and immediately west of the U.S. Forest Service's East Lake Campground. Samples for INAA analysis were collected from surface exposures of the other flows. Some of the data in Table 11.2 is derived from Hughes (1988b, 1993b).

To be useful for artifact-to-source attributions, a source must exhibit a trace element profile that can be accurately measured, shows low intrasource variability, and has unambiguous variability between sources (compare Hughes 1993b). For the present discussion, (following Hughes 1993b), differences are considered significant if demonstrable to 2-sigma at the 0.05 level, using the larger of either the calculated sample standard deviation or the measurement uncertainty value, as described below.

ANALYTICAL RESULTS

X-ray Fluorescence Analysis

The laboratory methods employed in the present XRF analysis are summarized in Hughes (1993b). The XRF-determined trace element profiles for five Newberry caldera obsidians are presented in Table 11.2. With the exception of the Buried Obsidian Flow, these values have been previously reported by Hughes (1988b, 1993b). Note also that the coefficient of variation (CV%) is calculated. This value measures the size of the standard deviation relative to the mean; a low CV% means a particular element can be measured with precision (compare Hughes 1984). In cases where the computed standard deviation for a source-specific set of samples was less than the lower detection limits of the measurement device, a value reflecting the element-specific detection limit (i.e., measurement uncertainty) is substituted. Measurement uncertainty values are as follows: 0.1% for Fe; 2 ppm for Y; 3 ppm for Sr; 4 ppm for Rb; 5 ppm for Zr; 6 ppm for Zn; 14 ppm for Ba; 20 ppm for Mn; and 30 ppm for Ti.

A series of difference of means tests was conducted to compare sample means of paired sources for each element. As expected, no significant differences were detected for any element among the Game Hut Obsidian Flow, Central Pumice Cone flow, Interlake Obsidian Flow, and East Lake Obsidian Flows, a set of flows that have been collectively referred to as the "Newberry Volcano" geochemical type (compare Hughes 1988b). By contrast, significant differences in mean values are seen in values for Mn, Fe, and Zr between the Big Obsidian Flow and the Newberry geochemical group. The Buried Obsidian Flow also exhibits significant differences in Y and Zr values between each of the Newberry geochemical group flows.

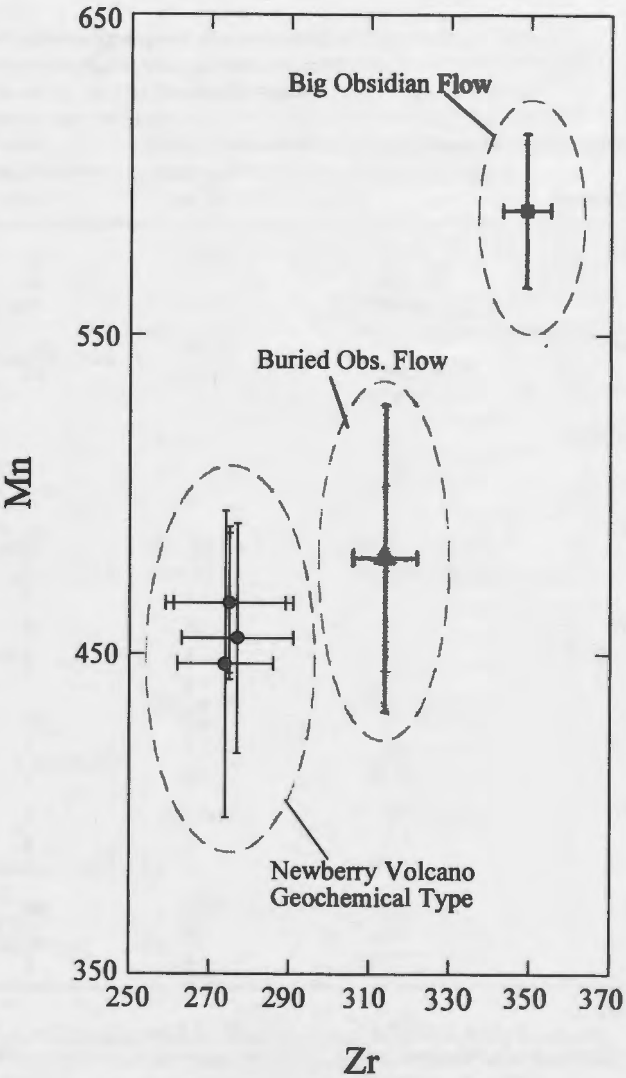

Figure 11.1. Plot of mean Mn and Zr values for Newberry caldera flows with 2 standard deviation error bars, measured by x-ray fluorescence; Big Obsidian Flow and Buried Obsidian Flow values based on five measured samples from each flow, Newberry Volcano values based on five samples each from the Game Hut, East Lake, Interlake, and Central Pumice Cone flows.

Both the Buried and Big Obsidian Flows are chemically distinct from the Newberry Volcano group of flows, but they are less clearly distinguishable from one another. Importantly, while there is no difference in Mn between the Buried Obsidian Flow and each of the Newberry Volcano geochemical group flows, our small sample shows a significant difference for Mn between the Buried and Big Obsidian Flow samples means (Figure 11.1). However, because of the small number of samples considered in this analysis, it is premature to know whether this difference in Mn values will be maintained to a sufficient degree in additional sample runs. Values for Y are also quite disparate in the present sample, but the difference is not significant at the specified level to be considered a diagnostic element.

Instrumental Neutron Activation Analysis
Craig E. Skinner and Thomas J. Connolly

Trace element profiles for seven flows are presented in Table 11.3. Because the samples were ground in a tungsten-carbide mill, the measured values for W (tungsten), and possibly for Co (cobalt) and Ta (tantalum), are not considered reliable due to possible contamination from the mill and are not reported here. The two East Lake lobes were tested independently, with the western lobe identified as East Lake-A and the eastern lobe as East Lake-B (compare Skinner 1983:113). As discussed above, the calculated standard deviation for a particular set of samples may be unrealistically low, particularly considering the small number of samples submitted to characterize each source. Therefore, a relative standard deviation value was also calculated based on the measurement accuracy for an element based on one standard deviation calculated on repeated counts of appropriate elemental standards. These percent uncertainty values are as follows: 3% for Sc and La; 5% for FeO, Cs, Sm, Yb, Hf, and Th; 7% for Ce; 10% for Rb and Ba; 12% for Nd; and 15% for Zn.

Possibly due in part to the small number of specimens in each of our source samples, which necessitates greater differences to establish significance, the INAA analysis was less useful than the XRF data for discerning differences. These data may be more refined, and potentially more useful, with additional sampling. On the whole, it appears that the Mn, Zr, and Fe values measured by XRF remain the most useful diagnostic elements in distinguishing the Big Obsidian Flow from the other Newberry flows. The INAA data suggest, however, that these flows might also be distinguished by Sc. The Buried Obsidian Flow consistently exhibits the highest Hf values of all the flows, but the difference is significant only for the Buried Obsidian Flow relative to the Central Pumice Cone and Interlake sources. A significant difference is also noted between the Buried and Interlake flows for Hf.

DISCUSSION

Not surprisingly, no significant differences emerged for any element in either analysis among the Game Hut Obsidian Flow, Interlake Obsidian Flow, Central Pumice Cone flow, or East Lake Obsidian Flows. This group of middle Holocene flows constitute what has been previously identified as the Newberry Volcano geochemical type (compare Hughes 1988b). The Big Obsidian Flow has been known to be distinguishable from this group, and it now appears that the Buried Obsidian Flow can also be differentiated from this group by Y and Zr values.

For the elements that appear to be most diagnostic for differentiating the intracaldera flows—Mn, Fe, Zr, and Sc—the Buried Obsidian Flow values are intermediate between those of the Big Obsidian Flow and the Newberry Volcano geochemical group. Even though this may be a potential source of confusion, particularly if additional samples from these tested sources serve to muddy the previously clear distinction between the Big Obsidian Flow and the other intracaldera flows, the distinction between the Newberry Volcano geochemical group and a Big Obsidian Flow/Buried Obsidian Flow geochemical group appears maintainable. Furthermore, the present data suggest that the Buried Obsidian Flow may be distinguishable from the Big Obsidian Flow based on Mn values, but the present sample size is insufficient to verify that this apparent distinction is statistically valid. The elements Y and Hf exhibit consistently higher values in the Buried Obsidian Flow than in the Big Obsidian Flow, but the differences are not of a degree that can be considered diagnostic.

Apart from the geochemistry, potential difficulties in distinguishing the Buried and Big Obsidian Flows from one another may not be seriously problematic for archaeological applications for two important reasons. First, the obsidians may be at least partially visually distinguishable. Whereas exposures of the Buried Obsidian Flow are quite limited, obsidian from both sampled exposures appears moderately and uniformly porphyritic, contrasting with the generally more evenly glassy Big Obsidian Flow obsidian. Second, and more important, consideration of chronological context may be useful in separating these obsidians in archaeological applications. Access to the Buried Obsidian Flow was severely limited by about 6500 B.P., when it was buried by Mazama and East Lake Tephras. By contrast, Big Obsidian Flow glass was available for quarrying only within the last 1300 years B.P.

Table 11.3.
INAA trace element profiles of seven Newberry caldera obsidian flows.
All values in parts per million (ppm), except iron (Fe) expressed as weight percent of FeO.

Element[a]		Big Obs. Flow (n=4)	Buried Obs. Flow (n=3)	Game Hut Obs. Flow (n=3)	Central Pumice Cone Flow (n=4)	Interlake Obs. Flow (n=5)	East Lake-A (n=2)	East Lake-B (n=2)
FeO	X	2.03	1.98	1.79	1.58	1.61	1.85	1.85
	s.d.	.03	.02	.01	.39	.34	.05	.01
	CV%	1	1	1	25	21	3	1
	r.s.d.	.10	.10	.09	.08	.08	.09	.09
Sc	X	5.90	5.51	5.00	4.95	4.95	5.09	5.11
	s.d.	.08	.06	.01	.08	.10	.12	.01
	CV%	1	1	<1	2	2	2	<1
	r.s.d.	.18	.17	.15	.15	.15	.15	.15
Zn	X	44.25	70.33	57.5	43.5	40.0	45.5	62.5
	s.d.	21.25	4.04	3.54	21.44	16.0	29.0	3.54
	CV%	48	6	6	49	40	64	6
	r.s.d.	6.64	10.55	8.63	6.53	6.00	6.83	9.38
Rb	X	110.75	119.0	123.67	122.25	123.20	120.5	125.5
	s.d.	3.78	4.00	4.73	1.26	4.55	2.10	2.12
	CV%	3	3	4	1	4	2	2
	r.s.d.	11.08	11.90	12.37	12.23	12.32	12.05	12.55
Cs	X	4.53	4.97	5.15	5.22	5.07	5.20	5.09
	s.d.	.13	.13	.32	.15	.17	.01	.03
	CV%	3	3	6	3	3	<1	1
	r.s.d.	.23	.25	.26	.26	.25	.26	.25
Ba	X	793.8	766.7	802.33	731.5	783.00	722.5	791.0
	s.d.	45.4	30.7	28.99	82.0	24.47	92.6	14.1
	CV%	6	4	4	11	3	13	2
	r.s.d.	79.38	76.67	80.23	73.15	78.30	72.25	79.10
La	X	31.30	30.97	30.90	30.33	30.52	30.35	30.15
	s.d.	1.04	.51	.53	.31	.48	.21	.07
	CV%	3	2	2	1	2	1	<1
	r.s.d.	.94	.93	.93	.91	.92	.91	.90
Ce	X	63.2	69.3	64.83	63.23	60.84	63.50	62.85
	s.d.	3.3	2.0	1.12	2.51	5.12	1.70	.35
	CV%	5	3	2	4	8	3	1
	r.s.d.	4.42	4.85	4.54	4.43	4.26	4.45	4.40
Nd	X	32.0	28.97	27.10	36.90	29.04	32.20	26.30
	s.d.	7.20	1.50	.36	14.32	6.11	8.30	.14
	CV%	23	5	2	39	21	26	1
	r.s.d.	3.84	3.48	3.25	4.43	3.48	3.86	3.16
Sm	X	6.37	7.03	6.05	5.96	5.95	5.97	5.95
	s.d.	.13	.14	.12	.16	.18	.04	.00
	CV%	2	2	2	3	3	1	<1
	r.s.d.	.32	.35	.30	.30	.30	.30	.30
Yb	X	4.85	5.68	4.63	4.48	4.57	4.30	4.55
	s.d.	.12	.17	.05	.22	.12	.28	.06
	CV%	3	3	1	5	3	7	1
	r.s.d.	.24	.28	.23	.22	.23	.22	.23
Hf	X	9.02	9.56	7.75	7.97	7.81	8.05	7.89
	s.d.	.33	.12	.01	.22	.32	.07	.04
	CV%	4	1	<1	3	4	1	1
	r.s.d.	.45	.48	.39	.40	.39	.40	.39
Th	X	11.35	11.53	12.37	12.15	12.16	12.40	12.30
	s.d.	.19	.35	.12	.51	.70	.28	0
	CV%	2	3	1	4	6	2	<1
	r.s.d.	.57	.58	.62	.61	.61	.62	.62

NOTE:
[a] The samples were ground in a tungsten-carbide mill, and measured values for W (Tungsten) and possibly for Co (Cobalt) and Ta (Tantalum) are not considered reliable and are not reported here.