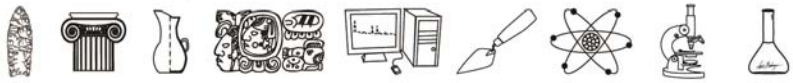
Archaeometry Laboratory
University of Missouri Research Reactor



Report on the Analysis of Obsidian Source Samples by Multiple Analytical Methods

Michael D. Glascock and Jeffrey R. Ferguson
Archaeometry Lab
University of Missouri
Research Reactor Center
1513 Research Park Drive
Columbia, MO 65211

January 2012

Introduction

At the request of Bruce Kaiser, samples from forty different obsidian sources were analyzed by multiple analytical methods in the Archaeometry Laboratory at MURR to create a collection of samples useful for X-ray Fluorescence calibration. The samples were selected to provide a broad range of element concentrations from high-to-low, especially for the elements useful in obsidian sourcing by XRF.

The calibration samples were prepared by sawing square pieces of a single sample from each source (except for sample XRF-19 which used multiple small cobbles). The samples are generally at least 1 cm thick and have at least one surface with an area of 1 cm^2. One surface was polished and numbered with the standard number.

Analytical samples were prepared for neutron activation analysis (NAA), microwave digestion inductively coupled plasma mass spectrometry (MD-ICP-MS) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). The analytical procedures are described below. Following analysis, data for all elements was tabulated and comparisons between the methods were made.

Neutron Activation Analysis (NAA)

Samples were prepared for NAA using procedures described by Glascock et al. (1988). In particular, larger chunks of obsidian were crushed to produce several clean interior fragments on the order of 25-50 mg. A sample was prepared for short-irradiation by placing ~100 mg of fragments in a clean high-density polyvial. A sample for long-irradiation was prepared by placing ~200 mg in a clean high-purity quartz vial. Both samples were weighed to the nearest 0.01 mg. Samples of the NIST SRM-278 Obsidian Rock standard were similarly prepared.

The short-irradiation samples and standards were irradiated in pairs for five seconds each in a neutron flux of $8x10^{13}$ n cm^{-2} s^{-1}, followed by 25-minute decay, and 12-minute counting time. Gamma spectra were collected using two high-purity germanium detectors. The elements measured by short irradiation were: Al, Ba, Cl, Dy, K, Mn, and Na.

The long-irradiation samples and standards were bundled in batches of 50 samples and standards. The bundles were irradiated in a neutron flux of $5x10^{13}$ n m^{-2} s^{-1} for 24 hours. The bundles were

allowed to decay for seven days before the first of two measurements were performed. After unwrapping the bundles, the samples were loaded on an automatic sample changer and counted for 1800 seconds using a high-purity germanium detector. Three weeks later the samples were counted again for 7500 seconds on the same sample changer/detector system. The elements measured by long irradiation were: Ba, La, Lu, Nd, Sm, U, Yb, Ce, Co, Cs, Eu, Fe, Hf, Rb, Sb, Sc, Sr, Ta, Tb, Th, Zn, and Zr.

Microwave Digestion Inductively Coupled Plasma Mass Spectrometry (MD-ICP-MS)

The MD-ICP-MS measurements were performed on a high-resolution VG Axiom ICP-MS after preparation by a microwave digestion procedure similar to that described in Falciani et al. (2000). Chunks of obsidian weighing about 200 mg were cut, washed, dried, and weighed. Samples were digested in a sealed Teflon vessel to which 3 ml of Optima grade nitric acid and 3 ml of Fisher brand Trace Metal grade HF were added. The vessels were sealed and heated to 190°C in the microwave digester for two hours. The samples were inspected after cooling to see if the digestion was successful. If the obsidian chunks did not completely digest, the heating cycle was repeated. After inspecting to prove that the chunks had dissolved, 35 ml of a 4% solution of Aldrich 99.999% boric acid in ultrapure water was added. The vessels were re-sealed and re-heated to 180°C in order to fully dissolve any insoluble fluorides that had formed during the previous cycle(s).

After the vessels had cooled, the contents were transferred into cleaned Nalgene LDPE bottles and gravimetric dilution factors were calculated. Each digestion batch consisted of 9 obsidian samples, one standard, and two vessel blanks. Dilutions of the digestates were prepared for analysis by taking 100 µL of sample liquid, adding internal standards Sc, In, and Tl to it, and diluting with 2% nitric acid to a volume of 10 mL.

The high-resolution ICP-MS was fitted with an HF-resistant sample introduction system and operated at a nominal resolution setting of 6000. Standards were re-analyzed repeatedly during the analytical run to ensure continuous correct instrument response. The following analytes were measured: ^{23}Na, ^{24}Mg, ^{27}Al, ^{29}Si, ^{39}K, ^{44}Ca, ^{47}Ti, ^{55}Mn, ^{57}Fe, ^{59}Co, ^{63}Cu, ^{66}Zn, ^{69}Ga, ^{75}As, ^{85}Rb,

^{88}Sr, ^{89}Y, ^{90}Zr, ^{93}Nb, ^{95}Mo, ^{118}Sn, ^{133}Cs, ^{137}Ba, ^{139}La, ^{140}Ce, ^{146}Nd, ^{147}Sm, ^{153}Eu, ^{157}Gd, ^{159}Tb, ^{163}Dy, ^{172}Yb, ^{175}Lu, ^{178}Hf, ^{181}Ta, ^{232}Th, and ^{238}U.

Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS)

The measurements were performed with a NexION ICP-MS spectrometer coupled to a Photon Machines Analyte-193 laser ablation system using procedures described by Gratuze et al. (2001).

Samples of obsidian for LA-ICP-MS were sawed into small blocks of about 3x3X3 mm (~50 mg) each. Five obsidian blocks and one standard sample of NIST SRM-612 glass were mounted on glass slides using Blu-Tack putty. The samples were positioned on the slides such that the top surfaces were level and at the same height. Slides were placed inside a 5 cm diameter quartz ablation cell and viewed through a high-resolution CCD video camera. Prior to ablation, the individual samples were placed in focus on the computer monitor and four raster lines 40 μ in length were drawn. When using a spot size of 40 μ, the final ablation pattern would look like an oval. The 193nm laser was operated at a fluence of 2.28 J cm^{-2} and repetition rate of 10 Hz. Each of the data acquisition runs was preceded by operating the laser for 20 seconds to collect a background. The sample cell was flushed by 0.95 L min^{-1} of Helium carrier gas. The ablated aerosol was mixed with approximately 1.2 L min^{-1} of Argon before injection into the plasma torch. The analyte suite included the following isotopes: ^{7}Li, ^{23}Na, ^{26}Mg, ^{27}Al, ^{30}Si, ^{39}K, ^{43}Ca, ^{47}Ti, ^{55}Mn, ^{57}Fe, ^{63}Cu, ^{66}Zn, ^{75}As, ^{85}Rb, ^{88}Sr, ^{89}Y, ^{90}Zr, ^{133}Cs, ^{137}Ba, ^{139}La, ^{140}Ce, ^{178}Hf, ^{232}Th, and ^{238}U.

Signals from each of the four runs were integrated and backgrounds were subtracted. Internal standardization was accomplished using the method described by Gratuze et al. (2001). The matrix element silicon served as the individual standard with all oxides summing to a total of 100% after correcting for isotopic abundances. SRM-612 served as the external standard used to calculate response factors. Final concentrations were converted from oxide to ppm of element to produce the final data table.

Results and Conclusions

The data collected by all three methods are presented in Tables I, II, III. They were surprisingly consistent with most differences not exceeding five percent between techniques. An error was noticed for the sample XRF-20 analyzed by LA-ICP-MS. We believe this sample was a duplicate of XRF-21 instead of the intended sample.

Based on our experience with these analytical methods, we recommend that XRF calibrations be based on elements measured either by NAA or MD-ICP-MS. The preferred elements by NAA are: Na, Al, Cl, K, Sc, Mn, Fe, Co, Zn, Rb, Sb, Cs, Na, Ce, Nd, Sm, Eu, Tb, Dy, Yb, Lu, Hf, Ta, Th, and U. The preferred elements by MA-ICP-MS are: Mg, Si, Ca, Ti, Cu, Ga, As, Sr, Y, Zr, Nb, Mo, Sn, Ba, and Gd. Table IV lists the recommended concentrations.

Acknowledgements

We acknowledge the assistance of several people who worked on this project. Mr. Alex Brechbuhler prepared and analyzed the samples for NAA. Ms. Shilo Bender and Mr. James Guthrie prepared and analyzed the samples by MD-ICP-MS. Mr. Timothy Ferguson and Mr. Barry Higgins prepared and analyzed the samples by LA-ICP-MS.

References

Falciani, R., Novaro, E., Marchesini, M., and Gucciardi, M.
2000 Multi-element analysis of soil and sediment by ICP-MS after a microwave assisted digestion method. *Journal of Analytical Atomic Spectrometry,* 15(5): 561-565.

Glascock, M.D., Elam, J. M., and Cobean, R. H.
1988 Differentiation of obsidian sources in Mesoamerica. In *Archaeometry '88: Proceedings of the 26th International Archaeometry Symposium,* edited by Farquhar, R.M., Hancock, R. G. V., and Pavlish, L. A., pp. 245-251. University of Toronto, Toronto.

Gratuze, B., Blet-Lemarquand, M., and Barrandon, J.N.
2001 Mass spectrometry and laser sampling: a new tool to characterize archaeological materials. *Journal of Radioanalytical and Nuclear Chemistry,* 247(3): 645-656.

Table I. Results from Neutron Activation Analysis in parts per million (columns with green background are recommended)

ANID	Na	Al	Cl	K	Sc	Mn	Fe	Co	Zn	Rb	Sr	Zr	Sb
XRF 1	31665.0	73280.0	nd	36514.4	4.80	755.2	3690.1	0.119	59.0	172.4	nd	79.2	0.85
XRF 2	32766.0	70893.1	595.6	34026.0	1.71	519.2	4255.4	0.129	27.3	90.6	67.4	53.4	0.23
XRF 3	28565.0	71311.5	118.3	36044.0	2.78	327.5	6179.2	0.372	28.0	94.1	69.1	115.1	0.19
XRF 4	42678.1	56473.7	1175.9	27655.8	10.39	1633.6	27448.0	0.024	160.4	58.7	nd	387.4	0.41
XRF 5	32102.7	60095.6	404.7	17109.8	8.41	592.5	8587.0	0.516	49.9	32.2	235.7	124.0	0.47
XRF 6	30732.1	64997.2	1173.9	40605.0	0.12	297.4	11668.5	0.067	253.0	272.6	nd	340.3	0.41
XRF 7	29235.4	66968.7	450.2	35341.4	1.78	357.4	7772.6	0.123	43.0	179.5	nd	145.5	0.89
XRF 8	34917.4	68441.3	288.9	33466.5	0.29	440.6	7202.8	0.080	134.2	361.5	nd	249.9	1.60
XRF 9	27850.6	68078.0	156.2	33443.8	3.43	249.8	7577.8	0.710	32.3	112.7	118.3	146.0	0.65
XRF 10	27236.6	71655.9	226.7	39778.3	2.13	279.2	9278.2	0.794	33.3	144.9	140.0	218.1	1.02
XRF 11	30106.2	69727.3	363.3	34978.3	2.41	521.5	4673.8	0.150	31.1	98.0	46.8	100.9	0.30
XRF 12	28861.1	71966.7	351.3	36636.8	4.28	264.4	10409.9	1.515	33.8	140.8	93.4	244.7	1.58
XRF 13	28992.0	69881.0	371.7	37577.7	3.74	268.8	9234.3	1.131	31.9	134.7	79.8	194.0	1.46
XRF 14	35345.5	69504.6	633.5	24645.7	1.48	537.0	10824.6	0.390	52.2	81.1	179.9	97.5	0.35
XRF 15	33418.6	56847.5	529.6	35021.6	1.01	457.5	17193.1	0.120	126.4	97.6	nd	543.3	2.02
XRF 16	35220.1	55310.3	966.7	34751.7	0.73	581.5	18850.6	0.034	129.0	157.3	nd	698.2	0.91
XRF 17	55544.3	35985.4	2744.9	33147.3	0.16	1775.0	53658.0	0.052	591.6	436.3	nd	2735.2	0.66
XRF 18	37178.0	70303.7	716.5	41436.2	2.64	1076.7	23364.4	1.423	139.5	203.2	37.2	977.9	0.57
XRF 19	28656.9	72744.5	433.7	35671.2	2.01	402.7	6619.0	0.254	39.1	229.5	nd	140.1	0.55
XRF 20	25557.7	78723.8	nd	2036.2	16.22	1082.4	68537.4	34.310	123.1	11.2	369.9	93.6	0.00
XRF 21	33880.0	76885.8	628.8	38973.0	2.95	632.0	9943.0	0.290	64.0	154.6	212.7	288.0	0.14
XRF 22	36143.2	63380.2	2591.5	36775.9	0.19	460.7	23294.8	0.026	212.4	337.5	nd	985.4	0.19
XRF 23	39921.8	52739.1	1328.2	34972.3	0.47	648.9	25159.8	0.194	175.1	205.1	nd	1034.5	0.92
XRF 24	36141.3	57597.6	1082.3	37605.9	0.15	233.6	19350.3	0.021	242.2	218.6	nd	1078.2	0.13
XRF 25	44977.9	43364.4	1525.5	30206.6	0.13	1215.2	43834.8	0.127	277.8	185.9	nd	1105.4	0.57
XRF 26	32616.7	64424.4	398.5	35190.2	7.20	433.5	11807.6	0.587	64.2	103.5	nd	290.0	2.60
XRF 27	29026.1	67658.3	204.4	40119.4	1.89	410.2	5282.9	0.235	27.7	108.4	75.3	118.2	0.26
XRF 28	30852.2	63704.8	743.0	36373.1	1.40	414.0	7120.6	0.143	57.0	149.7	nd	168.5	0.25
XRF 29	32225.2	61885.3	348.7	32214.2	4.15	307.9	8148.5	0.131	69.8	91.7	38.3	151.7	0.37
XRF 30	37187.3	60772.4	1058.4	32866.6	3.29	1112.8	16266.6	0.149	211.7	198.1	nd	878.7	0.26
XRF 31	29749.9	67896.1	365.5	39783.5	2.73	448.4	3809.8	0.058	33.4	144.5	nd	108.0	0.26
XRF 32	32319.3	62234.5	599.1	35626.7	0.54	255.3	12382.2	0.014	102.8	147.5	nd	427.8	0.41
XRF 33	24662.0	65913.3	568.3	45650.7	3.08	171.7	10633.3	1.257	38.8	277.8	24.1	168.3	1.04
XRF 34	29510.9	62038.8	858.3	39065.4	2.47	364.9	8527.1	0.258	57.2	163.7	nd	211.4	1.23
XRF 35	28195.4	75509.2	688.3	31712.3	2.42	545.8	8666.0	0.661	48.5	114.0	402.6	144.6	0.10
XRF 36	35722.4	67043.1	328.1	34571.7	1.84	538.0	9348.7	0.172	73.5	195.9	nd	298.7	0.42
XRF 37	29633.1	64082.4	111.3	39203.9	1.90	351.2	5465.1	0.125	29.9	131.3	26.2	140.6	0.75
XRF 38	27897.7	71058.0	551.4	36044.6	2.57	669.8	6490.7	0.245	42.0	74.1	171.7	83.5	0.62
XRF 39	32398.2	69105.2	437.3	28261.1	1.64	309.2	7300.3	0.446	30.0	76.4	142.5	114.0	0.17
XRF 40	33736.1	81761.7	303.1	38458.5	0.31	886.1	6098.5	0.167	52.7	215.0	386.3	174.9	0.46

Table I. Results from Neutron Activation Analysis in parts per million (columns with green background are recommended)

ANID	Cs	Ba	La	Ce	Nd	Sm	Eu	Tb	Dy	Yb	Lu	Hf	Ta
XRF 1	4.83	75.6	6.76	16.42	8.46	3.43	0.202	0.809	5.64	4.23	0.82	3.41	2.33
XRF 2	3.68	935.4	13.79	27.26	10.18	2.38	0.352	0.289	1.84	1.18	0.18	2.71	0.79
XRF 3	3.43	1265.0	25.31	48.35	16.59	3.63	0.576	0.550	3.20	2.69	0.45	3.64	0.66
XRF 4	2.36	1064.7	40.16	85.68	44.37	9.87	2.006	1.744	10.48	8.02	1.21	10.04	0.86
XRF 5	1.22	300.7	11.89	27.02	16.75	4.01	0.828	0.668	4.15	3.10	0.47	3.71	0.11
XRF 6	4.28	nd	64.08	130.39	47.51	13.90	0.298	3.889	29.92	21.98	2.96	15.46	17.37
XRF 7	5.36	31.1	23.01	49.34	20.52	4.74	0.139	0.652	3.63	2.78	0.57	4.65	1.76
XRF 8	9.35	55.6	10.27	30.56	13.40	6.53	0.026	1.540	11.19	8.54	1.22	10.00	23.17
XRF 9	5.49	1585.0	24.99	47.79	18.50	3.74	0.510	0.541	3.22	2.32	0.40	4.08	0.77
XRF 10	5.22	1106.4	35.60	60.24	19.75	3.33	0.436	0.381	2.17	1.62	0.37	5.27	1.22
XRF 11	4.27	270.3	12.47	24.75	9.42	2.91	0.323	0.491	3.39	2.63	0.51	3.17	1.00
XRF 12	8.93	743.0	24.06	48.96	18.55	4.39	0.515	0.627	4.01	3.00	0.56	6.12	0.83
XRF 13	7.47	745.5	24.51	49.02	20.40	4.31	0.433	0.649	4.52	3.07	0.57	5.46	0.86
XRF 14	3.82	810.7	21.26	42.09	17.05	3.33	0.488	0.430	2.56	1.59	0.27	3.30	0.64
XRF 15	4.57	nd	60.22	122.10	54.52	11.99	0.825	2.063	14.49	8.72	1.27	15.22	2.39
XRF 16	3.80	nd	67.05	138.33	59.80	12.48	0.153	1.903	11.32	7.15	1.07	18.51	3.74
XRF 17	7.09	nd	446.98	866.70	314.56	63.97	4.463	10.684	65.20	40.70	5.73	76.21	33.96
XRF 18	3.06	304.9	153.11	281.85	96.58	15.96	1.720	2.259	14.93	9.17	1.33	27.17	15.39
XRF 19	7.22	87.8	27.91	58.73	24.40	5.69	0.208	0.932	6.22	4.43	0.71	4.49	2.69
XRF 20	0.19	121.9	6.04	14.58	10.36	3.67	1.388	0.647	3.63	1.43	0.19	2.20	0.22
XRF 21	3.01	1022.2	54.87	105.82	40.56	7.43	1.277	0.933	5.69	3.83	0.61	7.93	2.43
XRF 22	5.19	nd	132.34	254.60	97.86	19.37	0.517	2.975	19.76	11.05	1.64	27.29	6.24
XRF 23	7.39	nd	89.99	179.88	67.83	14.86	0.536	2.489	16.07	10.57	1.57	27.38	6.14
XRF 24	3.19	nd	55.26	141.31	85.72	21.81	0.491	4.594	31.17	16.98	2.34	32.28	3.75
XRF 25	4.03	106.3	110.63	226.60	96.36	21.88	3.294	3.649	20.89	12.76	1.80	27.87	7.55
XRF 26	6.43	1300.1	33.73	71.74	32.57	7.55	0.756	1.312	8.61	5.93	0.91	8.79	1.21
XRF 27	2.71	637.6	23.98	41.49	15.11	2.84	0.413	0.365	2.08	2.02	0.34	3.57	1.03
XRF 28	4.91	40.6	45.37	88.97	33.12	6.88	0.185	1.085	6.74	4.26	0.81	6.41	3.33
XRF 29	3.56	1234.7	17.68	41.34	21.62	6.45	0.757	1.281	8.47	5.62	0.84	5.24	0.83
XRF 30	4.07	44.5	39.09	95.43	39.55	10.38	1.629	2.334	15.93	12.58	1.91	27.69	5.02
XRF 31	4.37	62.5	17.13	37.68	14.61	3.66	0.170	0.497	2.76	2.12	0.30	3.16	4.09
XRF 32	3.50	51.3	55.48	112.76	48.36	10.26	0.239	1.531	9.34	5.30	0.79	12.51	2.25
XRF 33	15.66	252.2	52.84	107.99	33.08	8.42	0.467	1.191	7.29	4.93	0.70	7.07	1.92
XRF 34	5.58	68.2	55.02	111.87	43.41	8.14	0.223	1.201	7.66	5.56	0.85	7.52	3.02
XRF 35	2.74	859.2	54.79	98.77	33.05	5.24	1.034	0.508	2.09	1.55	0.30	4.00	1.28
XRF 36	9.25	80.8	31.23	69.22	30.73	7.71	0.372	1.268	8.42	5.69	0.88	8.43	2.31
XRF 37	4.54	497.7	26.35	47.87	17.06	3.53	0.362	0.543	3.37	2.53	0.51	3.51	1.07
XRF 38	2.99	2244.6	15.40	29.61	18.18	3.03	0.660	0.512	3.15	2.29	0.36	2.66	0.86
XRF 39	2.68	874.6	20.24	38.11	16.40	2.65	0.412	0.372	2.15	1.53	0.25	3.09	0.75
XRF 40	17.34	1178.8	19.57	35.57	12.78	2.56	0.502	0.227	1.09	1.21	0.19	4.01	1.45

Table I. Results from Neutron Activation Analysis in parts per million (columns with green background are recommended)

ANID	Th	U
XRF 1	11.97	6.50
XRF 2	7.64	4.63
XRF 3	8.50	3.35
XRF 4	6.17	2.42
XRF 5	1.48	1.11
XRF 6	18.96	16.07
XRF 7	18.84	6.96
XRF 8	42.65	25.12
XRF 9	9.21	4.54
XRF 10	15.29	5.50
XRF 11	7.58	4.17
XRF 12	15.13	6.04
XRF 13	13.01	5.21
XRF 14	6.71	2.79
XRF 15	7.71	2.58
XRF 16	15.84	6.85
XRF 17	82.93	35.28
XRF 18	35.76	16.61
XRF 19	28.62	7.67
XRF 20	0.75	nd
XRF 21	17.87	5.42
XRF 22	40.65	10.94
XRF 23	26.11	12.76
XRF 24	29.81	8.12
XRF 25	21.53	10.16
XRF 26	7.73	3.34
XRF 27	9.58	3.64
XRF 28	16.22	6.61
XRF 29	6.88	2.88
XRF 30	18.66	8.94
XRF 31	16.42	10.28
XRF 32	14.39	5.14
XRF 33	35.83	11.56
XRF 34	17.35	7.27
XRF 35	14.87	3.23
XRF 36	23.66	8.40
XRF 37	16.44	6.72
XRF 38	3.82	2.37
XRF 39	6.85	3.17
XRF 40	11.48	9.01

Table II. Results from Microwave Digestion-ICP-MS in parts per million (columns with green background are recommended)

ANID	Na	Mg	Al	Si	K	Ca	Ti	Mn	Fe	Co	Cu	Zn	Ga
XRF 1	32783.6	235.5	70045.7	354139.2	36276.2	4903.2	252.3	721.6	3620.4	0.00	nd	50.78	20.57
XRF 2	30906.5	535.3	65437.9	352905.9	33648.5	3367.7	575.9	485.8	3921.3	0.14	0.61	25.10	14.29
XRF 3	27751.0	411.5	59239.2	351248.5	33927.7	5151.9	626.6	304.2	5737.9	0.37	1.12	23.74	12.77
XRF 4	42562.5	nd	52642.3	327461.1	28773.1	998.9	1156.3	1623.3	27888.9	0.00	0.83	153.30	23.15
XRF 5	33065.8	1275.9	64078.5	345470.6	18871.9	8648.2	1145.4	573.7	8935.6	0.48	3.04	44.77	11.10
XRF 6	32112.4	nd	64924.3	343718.5	39876.1	3212.8	518.2	289.8	11934.0	0.00	1.23	252.77	37.54
XRF 7	28199.0	342.7	62597.0	346655.8	38347.4	3832.7	368.5	343.4	7325.4	0.14	1.58	40.56	17.39
XRF 8	34374.4	nd	72084.9	330715.0	36864.9	2544.0	155.6	420.7	7163.0	0.00	2.60	128.40	32.83
XRF 9	27885.3	1186.5	63285.1	352570.0	34997.0	6324.2	820.6	231.5	7118.7	0.64	1.73	27.55	13.13
XRF 10	26826.8	980.1	67939.3	341438.6	43931.8	6092.4	1122.1	259.9	8801.8	0.73	1.88	30.49	14.79
XRF 11	28875.3	nd	69544.5	350272.7	39918.0	5443.4	265.8	493.3	4522.7	0.16	1.73	28.96	14.78
XRF 12	29370.7	1322.3	67283.0	333161.4	37674.5	6297.0	1428.6	253.3	9918.2	1.51	8.30	28.08	14.43
XRF 13	29661.6	1148.5	68796.0	347919.6	38128.6	5844.3	1286.4	257.1	8979.7	1.30	7.67	29.54	14.38
XRF 14	34582.6	725.5	73106.0	342932.0	25994.4	7116.7	464.5	502.6	10145.9	0.45	1.95	53.09	16.11
XRF 15	34140.8	nd	59110.0	344492.9	36744.2	1321.7	954.1	439.4	17647.5	0.00	3.05	128.68	19.99
XRF 16	38226.7	nd	63037.7	357186.9	37091.2	1213.8	837.0	577.3	19033.5	0.00	2.66	133.82	24.23
XRF 17	57677.3	nd	38402.3	311571.0	32791.9	1483.9	1556.9	1883.7	55079.2	0.09	5.41	631.57	34.40
XRF 18	37765.3	1923.7	72341.8	317747.6	42349.1	5669.3	3081.3	1058.7	24020.2	1.47	6.72	136.30	27.00
XRF 19	29234.4	nd	69112.7	359091.1	40335.7	3859.2	419.2	375.9	6556.9	0.19	1.19	34.47	16.74
XRF 20	25422.2	32136.4	78725.7	266038.6	3777.1	49864.4	7842.1	1015.6	68276.9	33.81	42.95	108.48	19.71
XRF 21	33818.2	1439.3	76214.6	313689.2	36309.2	6877.3	1589.5	606.2	9796.7	0.30	0.63	56.58	18.44
XRF 22	35814.4	nd	58148.1	329890.7	37653.7	1816.8	1007.5	445.9	23663.1	0.00	4.49	220.26	29.50
XRF 23	40547.0	nd	56159.4	343675.2	33450.5	870.0	813.7	625.2	25523.9	0.10	4.11	169.79	27.63
XRF 24	36373.2	nd	58037.0	348231.8	34914.8	1088.6	793.3	220.8	18974.7	0.00	4.41	243.27	35.15
XRF 25	47320.1	nd	43774.2	337385.9	33281.2	984.4	688.9	1275.2	46044.3	0.16	2.21	278.17	29.93
XRF 26	29716.9	558.0	61152.4	301657.7	30933.1	4248.9	1078.8	412.3	10075.8	0.53	3.73	56.82	16.49
XRF 27	29022.4	596.9	71350.7	363429.1	38676.3	5755.7	530.3	381.5	5315.9	0.25	1.44	26.82	13.92
XRF 28	31896.6	298.3	67028.0	351424.6	37781.2	2500.3	527.8	396.0	7541.5	0.19	0.90	54.78	19.65
XRF 29	33690.5	nd	69221.6	354533.5	31279.4	4745.1	332.9	293.2	7928.7	0.14	2.44	64.24	18.01
XRF 30	38608.6	425.5	60871.6	359241.9	37362.8	784.6	1127.8	1130.4	15443.0	0.00	0.00	210.55	28.61
XRF 31	28493.7	426.9	62972.8	344287.4	35497.8	3066.6	447.0	416.8	3584.4	0.00	0.00	26.81	15.63
XRF 32	31946.4	nd	59533.6	339584.2	36198.2	1689.9	612.6	245.2	11838.3	0.00	1.97	104.12	21.10
XRF 33	25766.2	648.2	67090.8	354966.1	45245.2	4778.1	1174.9	159.8	10205.0	1.12	2.03	33.14	18.95
XRF 34	29189.9	272.8	62539.7	342434.7	39925.6	2554.3	818.5	336.2	8276.9	0.24	1.01	50.80	18.89
XRF 35	28202.8	1432.2	72975.4	354744.0	33025.6	10803.9	807.1	531.1	8183.0	0.70	1.02	49.22	17.26
XRF 36	34693.3	234.8	69012.9	345378.9	34907.6	2858.8	454.9	514.2	9072.3	0.21	0.68	67.57	18.96
XRF 37	29565.6	371.6	67983.7	359549.0	37111.5	3234.9	525.1	327.3	5173.7	0.12	1.14	28.52	12.73
XRF 38	27089.3	403.3	71460.5	352519.7	36593.1	8209.1	221.7	633.6	6325.9	0.18	4.99	40.20	13.97
XRF 39	30716.0	691.2	63633.9	339234.7	26758.2	5886.7	564.1	290.7	6921.7	0.41	3.99	28.18	14.26
XRF 40	30721.1	522.2	70714.3	337140.6	34773.0	8090.3	548.5	853.8	5693.0	0.15	0.79	56.23	20.03

Table II. Results from Microwave Digestion-ICP-MS in parts per million (columns with green background are recommended)

ANID	As	Rb	Sr	Y	Zr	Nb	Mo	Sn	Cs	Ba	La	Ce	Nd
XRF 1	3.49	172.2	13.4	36.3	45.8	32.2	1.70	2.64	4.77	37.1	6.2	14.1	8.9
XRF 2	1.24	84.9	59.5	9.9	55.6	9.3	2.33	1.02	3.59	907.2	11.2	23.4	9.8
XRF 3	0.74	81.8	54.7	16.7	95.9	6.9	2.68	1.18	3.23	1140.5	17.8	34.9	13.7
XRF 4	2.50	54.4	0.8	65.4	386.6	16.1	2.33	2.74	2.49	1085.2	40.0	87.9	45.6
XRF 5	6.18	30.7	168.0	24.7	120.9	2.2	3.90	1.05	1.25	319.2	11.7	27.0	17.6
XRF 6	3.44	272.2	0.2	201.7	306.3	281.5	3.85	24.50	4.73	2.6	65.4	131.7	52.4
XRF 7	4.16	175.2	5.9	23.5	104.1	20.3	2.55	3.30	5.28	23.4	20.2	44.3	19.9
XRF 8	10.54	361.2	0.6	76.9	155.7	237.9	1.57	17.74	9.40	3.2	9.3	26.6	15.7
XRF 9	1.46	107.7	82.7	19.7	123.9	8.4	2.82	1.69	5.33	1581.7	23.4	45.4	18.2
XRF 10	7.12	137.8	108.1	12.7	189.3	12.1	3.49	2.49	5.07	1065.1	32.5	55.7	18.6
XRF 11	1.67	93.7	43.0	19.6	65.0	10.1	2.93	1.83	4.02	272.4	11.6	24.1	10.7
XRF 12	10.18	133.9	70.0	23.2	199.7	8.7	3.02	2.69	8.90	720.2	22.6	45.8	20.2
XRF 13	8.06	131.2	68.1	23.8	184.8	9.7	3.02	2.76	7.56	759.8	23.8	48.9	21.2
XRF 14	2.56	77.6	139.1	14.9	96.3	8.2	1.61	2.02	3.95	855.2	21.3	42.5	17.6
XRF 15	12.98	95.5	1.7	77.6	643.2	42.1	5.03	3.77	4.77	43.0	59.2	122.6	59.1
XRF 16	4.93	153.8	0.8	66.4	804.6	60.6	9.40	5.59	3.88	3.7	66.5	137.9	62.4
XRF 17	5.26	450.8	6.1	395.1	3489.3	605.6	14.17	26.70	7.65	26.1	474.0	928.1	349.9
XRF 18	2.79	207.5	51.5	83.3	1156.7	275.8	7.51	9.11	3.36	261.4	155.2	289.4	97.4
XRF 19	4.97	223.2	10.5	37.1	103.2	25.9	3.21	3.82	7.40	55.0	27.6	56.6	23.3
XRF 20	0.48	10.2	291.3	16.3	75.9	3.7	0.41	1.24	0.24	137.1	5.7	13.9	12.2
XRF 21	1.08	143.4	167.2	32.6	243.7	35.9	3.47	2.26	2.91	1107.3	52.5	101.9	39.7
XRF 22	1.34	330.8	0.9	107.5	1118.6	118.6	5.33	8.31	5.29	4.2	131.7	254.7	102.2
XRF 23	6.25	195.0	1.5	90.7	1152.6	89.8	8.49	10.80	7.34	6.5	87.9	175.1	69.9
XRF 24	2.89	217.4	0.4	175.3	1227.3	58.0	6.38	11.77	3.44	1.3	56.0	143.6	80.1
XRF 25	5.02	178.9	8.8	126.3	1216.7	117.5	7.49	10.48	4.17	55.9	106.3	225.8	102.7
XRF 26	20.90	97.9	21.6	50.3	299.0	19.0	3.56	2.92	6.26	1388.3	33.2	68.6	33.6
XRF 27	2.16	100.1	57.7	15.5	87.9	10.9	4.59	1.22	2.84	618.7	22.5	40.1	14.7
XRF 28	2.00	144.9	3.4	39.5	149.5	50.9	5.67	3.62	4.91	27.0	44.7	86.1	32.8
XRF 29	2.31	86.7	32.4	49.9	122.8	10.9	2.13	3.08	3.50	1298.3	17.1	39.8	22.5
XRF 30	3.08	191.2	2.1	105.8	988.2	88.1	6.91	6.64	4.14	10.7	38.0	90.9	39.5
XRF 31	2.23	137.8	3.8	18.7	57.1	42.4	3.53	1.74	4.29	11.0	15.6	33.9	11.5
XRF 32	3.52	142.6	0.3	50.6	453.5	32.7	3.97	4.71	3.63	5.9	54.2	110.5	48.2
XRF 33	12.77	275.2	33.9	43.9	206.0	17.2	3.86	9.77	15.12	278.4	50.9	102.5	39.5
XRF 34	11.53	154.2	4.6	44.7	193.5	38.5	8.45	4.90	5.31	62.1	50.7	104.8	40.6
XRF 35	1.18	106.6	282.8	15.4	108.1	18.4	2.32	1.38	2.81	876.2	51.5	94.0	32.9
XRF 36	2.11	186.8	15.5	49.6	269.2	31.0	3.16	4.79	9.12	58.2	29.2	64.4	31.1
XRF 37	3.38	123.6	20.9	21.0	91.1	13.1	4.34	2.29	4.44	519.1	25.1	45.6	17.4
XRF 38	4.17	71.3	137.3	20.3	58.1	10.7	3.07	1.57	2.87	2287.3	14.2	28.6	12.7
XRF 39	0.98	72.4	100.8	12.1	88.3	7.3	2.07	1.52	2.64	875.8	19.4	36.3	14.3
XRF 40	4.41	205.7	273.9	9.2	110.5	22.8	2.86	0.84	16.73	1124.0	17.8	33.3	12.4

Table II. Results from Microwave Digestion-ICP-MS in parts per million (columns with green background are recommended)

ANID	Sm	Eu	Gd	Tb	Dy	Yb	Lu	Hf	Ta	Th	U
XRF 1	3.41	0.18	3.69	0.83	5.43	4.51	0.71	3.20	2.86	12.50	5.91
XRF 2	2.09	0.31	1.40	0.28	1.73	1.11	0.15	2.46	1.72	7.32	3.99
XRF 3	2.71	0.48	2.38	0.36	2.65	2.33	0.37	3.65	1.05	6.68	3.32
XRF 4	10.24	2.09	10.14	1.69	12.67	8.33	1.30	10.44	1.31	6.47	2.35
XRF 5	4.14	0.89	3.78	0.61	4.17	3.20	0.50	3.89	0.86	1.63	1.10
XRF 6	13.87	0.28	16.68	3.81	30.25	22.71	3.04	16.16	19.57	19.67	9.47
XRF 7	4.66	0.11	3.44	0.56	4.21	2.69	0.40	4.47	2.94	18.97	6.62
XRF 8	5.81	0.00	6.90	1.39	11.33	8.24	1.25	9.87	25.14	44.38	15.26
XRF 9	3.67	0.50	3.00	0.44	3.50	2.18	0.37	4.44	2.11	9.17	4.59
XRF 10	2.97	0.36	1.98	0.34	2.30	1.61	0.27	5.41	2.12	15.36	5.78
XRF 11	2.74	0.32	2.61	0.46	3.21	2.36	0.40	2.97	1.37	7.41	3.72
XRF 12	4.17	0.52	3.20	0.53	4.18	2.75	0.46	6.03	1.22	15.83	6.07
XRF 13	4.11	0.49	3.44	0.54	4.13	3.22	0.51	5.84	1.32	13.63	4.92
XRF 14	3.44	0.59	2.54	0.40	2.24	1.66	0.25	3.36	2.16	6.69	2.70
XRF 15	12.12	0.75	11.34	2.12	12.90	8.41	1.19	15.50	3.71	8.08	3.41
XRF 16	11.98	0.15	10.38	1.96	11.68	6.27	0.98	19.34	5.52	15.75	5.93
XRF 17	65.45	4.35	63.45	11.12	67.91	40.30	5.80	82.52	43.62	86.63	20.69
XRF 18	16.66	1.84	12.46	2.34	13.83	8.99	1.24	27.92	20.17	37.07	9.49
XRF 19	5.13	0.18	4.73	0.86	6.00	4.27	0.61	4.80	4.43	29.10	6.58
XRF 20	3.90	1.48	3.73	0.57	3.87	1.23	0.22	2.45	0.65	0.85	0.29
XRF 21	6.49	1.26	5.91	0.91	5.37	3.87	0.48	7.41	3.28	17.81	4.62
XRF 22	19.23	0.51	16.62	3.06	18.13	10.97	1.45	28.41	8.19	41.24	7.90
XRF 23	14.16	0.49	13.27	2.39	14.87	10.15	1.40	28.26	7.50	25.74	9.28
XRF 24	21.75	0.47	24.84	4.39	29.32	16.63	2.38	32.81	4.69	29.41	6.68
XRF 25	21.13	3.19	21.56	3.51	22.17	12.34	1.67	28.60	9.53	21.72	6.77
XRF 26	7.32	0.89	7.08	1.23	7.87	5.54	0.86	8.60	2.02	7.81	3.32
XRF 27	2.53	0.44	2.15	0.37	2.24	1.85	0.28	3.58	1.64	9.47	3.58
XRF 28	6.80	0.18	6.45	1.06	6.54	4.26	0.62	6.33	4.30	15.99	4.95
XRF 29	5.79	0.79	7.19	1.21	7.75	5.16	0.80	5.36	1.42	6.88	2.80
XRF 30	9.27	1.62	11.26	2.13	15.11	11.96	1.81	28.46	6.63	18.69	6.74
XRF 31	2.53	0.16	2.91	0.49	3.28	1.99	0.22	3.35	4.97	15.71	7.82
XRF 32	10.10	0.24	9.31	1.39	9.04	5.08	0.76	12.42	3.38	14.47	4.48
XRF 33	7.15	0.52	6.16	1.06	6.79	4.42	0.61	6.95	2.72	35.71	9.48
XRF 34	7.37	0.19	6.34	1.18	6.93	4.95	0.72	7.53	4.53	17.07	5.45
XRF 35	4.87	1.14	3.54	0.54	2.82	1.65	0.18	3.84	2.33	14.97	3.19
XRF 36	6.48	0.33	6.93	1.26	7.77	5.51	0.80	8.91	3.35	23.64	8.55
XRF 37	3.09	0.39	2.87	0.51	3.23	2.67	0.36	3.51	1.87	16.22	5.92
XRF 38	3.33	0.69	2.82	0.49	3.33	2.28	0.34	2.73	2.66	3.94	2.27
XRF 39	2.69	0.39	1.93	0.32	2.02	1.49	0.25	3.08	1.21	6.85	2.74
XRF 40	1.78	0.47	1.53	0.21	1.53	1.10	0.19	3.46	2.02	11.96	8.53

Table III. Results from Laser Ablation ICP-MS in parts per million (data is for reference only, not recommended)

ANID	Li	Na	Mg	Al	Si	K	CA	Ti	Mn	Fe	Cu	Zn	As
XRF 1	66.2	31655.9	160.6	74894.6	354058.5	38707.2	3818.0	312.9	629.8	2856.4	2.81	58.9	4.63
XRF 2	33.9	30547.7	435.1	79977.7	350752.1	33462.9	3054.0	746.3	459.3	6281.7	1.54	33.4	1.16
XRF 3	32.3	26816.7	572.8	84385.4	346716.3	36123.8	5163.9	756.0	294.2	5400.3	2.51	26.9	0.85
XRF 4	34.4	41808.9	57.7	66652.0	341741.0	31558.9	1187.5	1569.8	1456.5	28167.5	2.45	186.8	2.69
XRF 5	20.1	29738.0	1172.2	86129.2	346832.8	19049.7	9490.6	1565.3	556.4	8869.2	3.89	50.0	6.95
XRF 6	113.4	33082.3	6.9	74038.5	346137.2	40533.4	2801.3	577.6	276.4	13126.3	3.21	276.4	4.55
XRF 7	38.2	30217.2	150.6	75390.9	351358.7	38407.7	3202.9	425.2	308.1	8640.7	4.86	46.6	5.48
XRF 8	470.4	37044.6	12.4	79777.6	344830.8	37090.1	2305.8	187.5	371.0	7335.7	1.53	135.7	12.45
XRF 9	39.8	28809.0	894.9	71232.3	353279.9	36107.8	5431.0	1022.9	260.2	10031.3	2.82	38.4	2.75
XRF 10	35.5	25372.1	1147.5	86566.0	335990.8	41649.3	6301.6	1376.3	269.2	12637.1	1.90	35.4	8.22
XRF 11	43.8	31113.4	228.7	81126.7	346331.4	41944.5	4236.0	316.0	437.9	3654.0	3.06	31.4	2.62
XRF 12	46.2	27280.0	1240.5	93754.5	330327.2	40857.5	5948.4	1757.2	233.9	10539.8	7.41	30.6	10.56
XRF 13	46.7	33142.6	1013.3	83476.7	335411.1	43245.5	5130.5	1518.4	257.5	10375.7	9.45	39.3	9.50
XRF 14	37.8	34479.5	692.6	94717.5	332671.2	28902.6	6487.8	601.6	475.0	10377.5	3.64	62.6	3.33
XRF 15	46.9	32846.5	39.5	73642.8	343370.2	41020.6	1389.2	1193.9	401.8	18421.8	4.88	144.8	17.07
XRF 16	37.3	36701.6	21.3	72063.8	340312.5	41480.5	1321.1	946.6	548.5	21117.2	3.71	162.5	6.44
XRF 17	112.1	54288.8	16.1	47171.8	326944.0	37649.7	1385.7	1686.5	1511.2	54077.3	6.67	681.3	8.30
XRF 18	38.0	35535.6	1467.3	84385.3	320459.5	47050.0	4610.8	3113.0	882.7	22379.1	5.49	156.2	3.86
XRF 19	53.2	26515.0	164.6	74840.0	351978.9	45151.1	3128.4	501.1	331.2	6054.8	1.97	40.4	4.91
XRF 20 ??	31.7	30614.9	1637.3	92175.8	329012.5	40576.9	6620.4	1901.6	543.5	9720.6	1.79	62.8	1.45
XRF 21	32.2	34250.4	1202.2	93028.9	324496.9	44052.3	6129.3	1988.1	558.0	9948.9	1.59	70.1	1.79
XRF 22	65.6	36719.7	27.7	72851.8	335707.6	44185.6	1742.6	1254.7	411.9	23245.1	6.91	249.0	2.38
XRF 23	68.7	42065.2	53.6	67160.4	340197.2	38513.7	1043.7	1012.5	576.4	24861.2	6.39	211.1	8.39
XRF 24	55.7	36779.6	11.8	72545.5	340493.4	41621.7	1402.5	1003.9	220.9	19510.3	4.93	265.1	4.04
XRF 25	54.5	44732.4	60.6	61587.0	330637.6	38358.1	1148.4	876.0	1114.9	43192.8	3.96	316.6	7.87
XRF 26	41.4	34223.9	533.2	74596.2	343896.2	41861.2	3383.8	1281.4	382.4	11587.1	4.71	68.5	24.50
XRF 27	40.6	29975.8	352.5	70487.9	352539.7	46386.2	4358.1	680.7	361.1	4948.2	2.76	31.0	2.98
XRF 28	44.0	30707.2	248.9	78858.4	346068.3	43869.6	2382.6	670.4	396.7	7072.5	1.92	61.6	2.12
XRF 29	38.7	28773.9	150.7	85895.4	343286.9	33360.3	4476.0	447.5	258.5	10437.5	2.96	66.5	2.52
XRF 30	67.9	39172.0	280.9	70987.3	339930.0	44250.5	1090.3	1479.1	1040.5	16977.2	1.79	254.4	3.94
XRF 31	63.1	29125.1	355.3	78366.2	348007.4	46084.0	2917.5	617.2	424.2	4004.3	1.70	30.6	2.78
XRF 32	42.7	33352.2	12.2	69467.0	348744.6	44697.8	1662.2	789.6	239.9	12986.4	2.99	130.5	4.47
XRF 33	76.3	23070.2	809.7	79434.8	341695.3	50109.8	4402.1	1500.8	174.5	11060.1	2.03	40.1	15.16
XRF 34	54.8	27514.5	347.2	81897.9	341451.4	47713.5	2425.8	1051.3	341.1	9063.0	20.57	60.8	13.80
XRF 35	44.6	24973.0	1609.6	91827.4	333385.1	38718.9	9858.0	1109.8	509.1	8572.1	2.03	55.5	1.85
XRF 36	80.0	32769.5	219.9	90115.4	343729.3	25566.5	2717.5	490.5	455.8	8839.5	2.67	77.2	2.54
XRF 37	34.0	27439.1	259.5	74574.4	362067.8	27901.1	2721.2	543.5	289.3	5189.9	5.01	45.5	3.81
XRF 38	39.3	24526.2	336.7	89128.5	346981.3	27233.6	7545.1	234.4	581.0	6100.5	6.68	44.9	4.42
XRF 39	37.8	28286.0	530.5	84851.4	353440.9	19780.0	5366.1	597.1	276.2	7390.5	4.26	32.3	1.17
XRF 40	42.2	30744.7	404.1	90235.5	342169.4	27019.7	7529.1	570.9	766.6	5911.2	2.94	60.3	5.00

Table III. Results from Laser Ablation ICP-MS in parts per million (data is for reference only, not recommended)

ANID	Rb	Sr	Y	Zn	Nb	Cs	Ba	La	Ce	Hf	Th	U
XRF 1	181.9	8.5	26.2	34.6	40.8	5.38	24.9	4.3	11.8	2.44	10.16	6.48
XRF 2	83.3	43.8	7.8	43.7	12.9	3.58	663.6	7.9	18.5	1.69	6.10	3.72
XRF 3	92.1	44.3	17.9	83.1	8.5	3.30	936.4	20.4	40.0	3.37	7.55	3.54
XRF 4	59.0	0.7	60.1	343.2	20.7	2.58	797.9	34.0	79.6	9.15	6.16	2.54
XRF 5	32.9	147.7	26.5	131.9	2.6	1.27	296.2	12.6	26.0	3.84	1.72	1.04
XRF 6	269.4	0.2	160.4	243.1	327.5	4.60	1.4	48.2	104.5	12.60	16.84	9.57
XRF 7	172.8	4.0	18.4	76.5	23.4	5.03	15.2	14.8	36.9	3.43	15.08	6.27
XRF 8	382.3	0.4	58.0	119.2	280.6	9.69	1.9	7.1	21.3	7.04	35.56	15.97
XRF 9	121.7	52.3	14.9	94.8	9.1	5.44	1051.1	17.7	38.8	2.97	7.39	4.87
XRF 10	143.9	83.3	12.1	172.5	15.2	5.12	875.9	29.9	51.5	5.06	14.91	5.53
XRF 11	100.0	27.6	15.3	49.6	12.7	4.01	178.9	8.5	18.0	2.43	6.07	3.93
XRF 12	139.2	54.7	23.6	194.2	11.2	8.18	567.8	20.5	40.4	5.61	15.96	5.78
XRF 13	143.2	48.1	20.9	158.6	11.6	7.81	515.2	19.4	38.2	4.65	11.94	4.97
XRF 14	78.8	108.8	13.9	88.7	9.2	3.65	610.8	17.8	34.5	2.87	6.66	2.75
XRF 15	99.5	1.3	72.6	612.2	51.8	4.68	28.0	50.6	102.2	14.57	7.81	3.34
XRF 16	171.5	0.6	60.8	735.8	74.9	4.15	1.7	58.7	123.4	18.53	15.95	6.86
XRF 17	454.7	4.7	381.0	3057.6	693.5	7.83	18.4	420.0	758.6	79.28	86.90	22.51
XRF 18	217.9	35.9	70.3	966.7	315.2	3.30	181.8	135.6	248.5	25.20	36.22	10.25
XRF 19	235.8	7.3	30.8	87.8	32.0	7.46	38.3	23.1	50.3	4.07	26.79	7.02
XRF 20 ??	152.2	118.6	29.1	215.3	43.9	2.95	858.0	47.8	91.3	6.87	17.40	4.80
XRF 21	155.7	115.1	29.8	209.1	43.7	2.93	759.2	43.2	87.9	6.97	15.94	4.86
XRF 22	348.0	0.8	96.7	1039.1	136.8	5.26	2.1	108.2	212.0	25.85	40.28	8.28
XRF 23	203.8	1.1	81.5	1023.3	104.1	7.29	4.4	70.3	145.8	24.78	24.54	10.50
XRF 24	224.5	0.3	167.0	1173.6	67.5	3.02	0.8	49.6	120.0	31.56	31.41	6.67
XRF 25	185.2	7.5	133.6	1301.1	150.8	4.09	43.2	106.4	202.8	30.20	25.17	7.42
XRF 26	106.4	15.4	39.4	242.2	21.1	6.51	914.3	26.4	56.6	7.40	6.81	3.72
XRF 27	116.2	33.6	10.3	64.1	12.5	3.03	367.2	16.6	31.7	2.60	7.92	4.35
XRF 28	152.9	2.3	34.3	134.1	61.0	4.91	17.8	39.4	78.3	5.79	16.03	5.00
XRF 29	85.4	25.7	46.9	120.6	12.5	3.30	1002.3	16.9	36.0	4.97	7.84	2.87
XRF 30	213.5	1.5	94.3	899.4	107.3	4.43	6.8	34.7	83.9	26.63	19.49	7.66
XRF 31	159.6	2.1	15.8	52.9	52.9	4.56	5.4	12.8	29.1	2.46	14.80	8.64
XRF 32	152.3	0.3	41.5	391.0	37.4	3.50	4.1	41.6	87.4	9.74	12.98	5.05
XRF 33	283.1	25.4	35.4	178.6	20.2	15.90	196.9	42.0	90.0	5.89	32.85	9.76
XRF 34	167.0	3.8	40.5	181.6	47.9	5.33	45.1	41.2	87.1	6.10	14.76	5.09
XRF 35	115.7	215.5	14.6	103.1	22.7	2.69	672.5	47.6	83.8	3.09	14.96	3.28
XRF 36	196.6	11.7	44.3	233.1	38.2	9.00	42.7	25.0	56.7	7.49	22.37	8.38
XRF 37	132.9	14.5	14.7	61.5	15.3	4.38	344.7	17.8	35.8	2.37	12.41	6.36
XRF 38	73.2	101.8	17.6	47.3	13.0	3.16	1659.8	13.0	24.9	1.96	3.39	2.26
XRF 39	71.5	71.1	11.1	73.8	9.3	2.61	646.5	16.7	31.4	2.54	6.36	2.75
XRF 40	205.4	188.6	7.8	82.5	27.5	17.41	851.5	14.9	27.6	3.06	9.86	9.06

Table III. Results from Laser Ablation ICP-MS in parts per million (data is for reference only, not recommended)

ANID	
XRF 1	
XRF 2	
XRF 3	
XRF 4	
XRF 5	
XRF 6	
XRF 7	
XRF 8	
XRF 9	
XRF 10	
XRF 11	
XRF 12	
XRF 13	
XRF 14	
XRF 15	
XRF 16	
XRF 17	
XRF 18	
XRF 19	
XRF 20 ??	looks like duplicate of XRF 21
XRF 21	
XRF 22	
XRF 23	
XRF 24	
XRF 25	
XRF 26	
XRF 27	
XRF 28	
XRF 29	
XRF 30	
XRF 31	
XRF 32	
XRF 33	
XRF 34	
XRF 35	
XRF 36	
XRF 37	
XRF 38	
XRF 39	
XRF 40	

Table IV. Recommended concentration data in parts per million for XRF and other types of calibration

technique	NAA	ICP-MS	NAA	ICP-MS	NAA	NAA	ICP-MS	ICP-MS	NAA	NAA	NAA	NAA	ICP-MS
ANID	Na	Mg	Al	Si	Cl	K	Ca	Ti	Sc	Mn	Fe	Co	Cu
XRF 1	31665.0	235.5	73280.0	354139.2	nd	36514.4	4903.2	252.3	4.80	755.2	3690.1	0.119	0.00
XRF 2	32766.0	535.3	70893.1	352905.9	595.6	34026.0	3367.7	575.9	1.71	519.2	4255.4	0.129	0.61
XRF 3	28565.0	411.5	71311.5	351248.5	118.3	36044.0	5151.9	626.6	2.78	327.5	6179.2	0.372	1.12
XRF 4	42678.1	nd	56473.7	327461.1	1175.9	27655.8	998.9	1156.3	10.39	1633.6	27448.0	0.024	0.83
XRF 5	32102.7	1275.9	60095.6	345470.6	404.7	17109.8	8648.2	1145.4	8.41	592.5	8587.0	0.516	3.04
XRF 6	30732.1	nd	64997.2	343718.5	1173.9	40605.0	3212.8	518.2	0.12	297.4	11668.5	0.067	1.23
XRF 7	29235.4	342.7	66968.7	346655.8	450.2	35341.4	3832.7	368.5	1.78	357.4	7772.6	0.123	1.58
XRF 8	34917.4	nd	68441.3	330715.0	288.9	33466.5	2544.0	155.6	0.29	440.6	7202.8	0.080	2.60
XRF 9	27850.6	1186.5	68078.0	352570.0	156.2	33443.8	6324.2	820.6	3.43	249.8	7577.8	0.710	1.73
XRF 10	27236.6	980.1	71655.9	341438.6	226.7	39778.3	6092.4	1122.1	2.13	279.2	9278.2	0.794	1.88
XRF 11	30106.2	nd	69727.3	350272.7	363.3	34978.3	5443.4	265.8	2.41	521.5	4673.8	0.150	1.73
XRF 12	28861.1	1322.3	71966.7	333161.4	351.3	36636.8	6297.0	1428.6	4.28	264.4	10409.9	1.515	8.30
XRF 13	28992.0	1148.5	69881.0	347919.6	371.7	37577.7	5844.3	1286.4	3.74	268.8	9234.3	1.131	7.67
XRF 14	35345.5	725.5	69504.6	342932.0	633.5	24645.7	7116.7	464.5	1.48	537.0	10824.6	0.390	1.95
XRF 15	33418.6	nd	56847.5	344492.9	529.6	35021.6	1321.7	954.1	1.01	457.5	17193.1	0.120	3.05
XRF 16	35220.1	nd	55310.3	357186.9	966.7	34751.7	1213.8	837.0	0.73	581.5	18850.6	0.034	2.66
XRF 17	55544.3	nd	35985.4	311571.0	2744.9	33147.3	1483.9	1556.9	0.16	1775.0	53658.0	0.052	5.41
XRF 18	37178.0	1923.7	70303.7	317747.6	716.5	41436.2	5669.3	3081.3	2.64	1076.7	23364.4	1.423	6.72
XRF 19	28656.9	nd	72744.5	359091.1	433.7	35671.2	3859.2	419.2	2.01	402.7	6619.0	0.254	1.19
XRF 20	25557.7	32136.4	78723.8	266038.6	nd	2036.2	49864.4	7842.1	16.22	1082.4	68537.4	34.310	42.95
XRF 21	33880.0	1439.3	76885.8	313689.2	628.8	38973.0	6877.3	1589.5	2.95	632.0	9943.0	0.290	0.63
XRF 22	36143.2	nd	63380.2	329890.7	2591.5	36775.9	1816.8	1007.5	0.19	460.7	23294.8	0.026	4.49
XRF 23	39921.8	nd	52739.1	343675.2	1328.2	34972.3	870.0	813.7	0.47	648.9	25159.8	0.194	4.11
XRF 24	36141.3	nd	57597.6	348231.8	1082.3	37605.9	1088.6	793.3	0.15	233.6	19350.3	0.021	4.41
XRF 25	44977.9	nd	43364.4	337385.9	1525.5	30206.6	984.4	688.9	0.13	1215.2	43834.8	0.127	2.21
XRF 26	32616.7	558.0	64424.4	301657.7	398.5	35190.2	4248.9	1078.8	7.20	433.5	11807.6	0.587	3.73
XRF 27	29026.1	596.9	67658.3	363429.1	204.4	40119.4	5755.7	530.3	1.89	410.2	5282.9	0.235	1.44
XRF 28	30852.2	298.3	63704.8	351424.6	743.0	36373.1	2500.3	527.8	1.40	414.0	7120.6	0.143	0.90
XRF 29	32225.2	nd	61885.3	354533.5	348.7	32214.2	4745.1	332.9	4.15	307.9	8148.5	0.131	2.44
XRF 30	37187.3	425.5	60772.4	359241.9	1058.4	32866.6	784.6	1127.8	3.29	1112.8	16266.6	0.149	0.00
XRF 31	29749.9	426.9	67896.1	344287.4	365.5	39783.5	3066.6	447.0	2.73	448.4	3809.8	0.058	0.00
XRF 32	32319.3	nd	62234.5	339584.2	599.1	35626.7	1689.9	612.6	0.54	255.3	12382.2	0.014	1.97
XRF 33	24662.0	648.2	65913.3	354966.1	568.3	45650.7	4778.1	1174.9	3.08	171.7	10633.3	1.257	2.03
XRF 34	29510.9	272.8	62038.8	342434.7	858.3	39065.4	2554.3	818.5	2.47	364.9	8527.1	0.258	1.01
XRF 35	28195.4	1432.2	75509.2	354744.0	688.3	31712.3	10803.9	807.1	2.42	545.8	8666.0	0.661	1.02
XRF 36	35722.4	234.8	67043.1	345378.9	328.1	34571.7	2858.8	454.9	1.84	538.0	9348.7	0.172	0.68
XRF 37	29633.1	371.6	64082.4	359549.0	111.3	39203.9	3234.9	525.1	1.90	351.2	5465.1	0.125	1.14
XRF 38	27897.7	403.3	71058.0	352519.7	551.4	36044.6	8209.1	221.7	2.57	669.8	6490.7	0.245	4.99
XRF 39	32398.2	691.2	69105.2	339234.7	437.3	28261.1	5886.7	564.1	1.64	309.2	7300.3	0.446	3.99
XRF 40	33736.1	522.2	81761.7	337140.6	303.1	38458.5	8090.3	548.5	0.31	886.1	6098.5	0.167	0.79

Table IV. Recommended concentration data in parts per million for XRF and other types of calibration

technique	NAA	ICP-MS	ICP-MS	NAA	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	NAA	NAA	ICP-MS
ANID	Zn	Ga	As	Rb	Sr	Y	Zr	Nb	Mo	Sn	Sb	Cs	Ba
XRF 1	59.0	20.57	3.49	172.4	13.4	36.3	45.8	32.2	1.70	2.64	0.85	4.83	37.1
XRF 2	27.3	14.29	1.24	90.6	59.5	9.9	55.6	9.3	2.33	1.02	0.23	3.68	907.2
XRF 3	28.0	12.77	0.74	94.1	54.7	16.7	95.9	6.9	2.68	1.18	0.19	3.43	1140.5
XRF 4	160.4	23.15	2.50	58.7	0.8	65.4	386.6	16.1	2.33	2.74	0.41	2.36	1085.2
XRF 5	49.9	11.10	6.18	32.2	168.0	24.7	120.9	2.2	3.90	1.05	0.47	1.22	319.2
XRF 6	253.0	37.54	3.44	272.6	0.2	201.7	306.3	281.5	3.85	24.50	0.41	4.28	2.6
XRF 7	43.0	17.39	4.16	179.5	5.9	23.5	104.1	20.3	2.55	3.30	0.89	5.36	23.4
XRF 8	134.2	32.83	10.54	361.5	0.6	76.9	155.7	237.9	1.57	17.74	1.60	9.35	3.2
XRF 9	32.3	13.13	1.46	112.7	82.7	19.7	123.9	8.4	2.82	1.69	0.65	5.49	1581.7
XRF 10	33.3	14.79	7.12	144.9	108.1	12.7	189.3	12.1	3.49	2.49	1.02	5.22	1065.1
XRF 11	31.1	14.78	1.67	98.0	43.0	19.6	65.0	10.1	2.93	1.83	0.30	4.27	272.4
XRF 12	33.8	14.43	10.18	140.8	70.0	23.2	199.7	8.7	3.02	2.69	1.58	8.93	720.2
XRF 13	31.9	14.38	8.06	134.7	68.1	23.8	184.8	9.7	3.02	2.76	1.46	7.47	759.8
XRF 14	52.2	16.11	2.56	81.1	139.1	14.9	96.3	8.2	1.61	2.02	0.35	3.82	855.2
XRF 15	126.4	19.99	12.98	97.6	1.7	77.6	643.2	42.1	5.03	3.77	2.02	4.57	43.0
XRF 16	129.0	24.23	4.93	157.3	0.8	66.4	804.6	60.6	9.40	5.59	0.91	3.80	3.7
XRF 17	591.6	34.40	5.26	436.3	6.1	395.1	3489.3	605.6	14.17	26.70	0.66	7.09	26.1
XRF 18	139.5	27.00	2.79	203.2	51.5	83.3	1156.7	275.8	7.51	9.11	0.57	3.06	261.4
XRF 19	39.1	16.74	4.97	229.5	10.5	37.1	103.2	25.9	3.21	3.82	0.55	7.22	55.0
XRF 20	123.1	19.71	0.48	11.2	291.3	16.3	75.9	3.7	0.41	1.24	0.00	0.19	137.1
XRF 21	64.0	18.44	1.08	154.6	167.2	32.6	243.7	35.9	3.47	2.26	0.14	3.01	1107.3
XRF 22	212.4	29.50	1.34	337.5	0.9	107.5	1118.6	118.6	5.33	8.31	0.19	5.19	4.2
XRF 23	175.1	27.63	6.25	205.1	1.5	90.7	1152.6	89.8	8.49	10.80	0.92	7.39	6.5
XRF 24	242.2	35.15	2.89	218.6	0.4	175.3	1227.3	58.0	6.38	11.77	0.13	3.19	1.3
XRF 25	277.8	29.93	5.02	185.9	8.8	126.3	1216.7	117.5	7.49	10.48	0.57	4.03	55.9
XRF 26	64.2	16.49	20.90	103.5	21.6	50.3	299.0	19.0	3.56	2.92	2.60	6.43	1388.3
XRF 27	27.7	13.92	2.16	108.4	57.7	15.5	87.9	10.9	4.59	1.22	0.26	2.71	618.7
XRF 28	57.0	19.65	2.00	149.7	3.4	39.5	149.5	50.9	5.67	3.62	0.25	4.91	27.0
XRF 29	69.8	18.01	2.31	91.7	32.4	49.9	122.8	10.9	2.13	3.08	0.37	3.56	1298.3
XRF 30	211.7	28.61	3.08	198.1	2.1	105.8	988.2	88.1	6.91	6.64	0.26	4.07	10.7
XRF 31	33.4	15.63	2.23	144.5	3.8	18.7	57.1	42.4	3.53	1.74	0.26	4.37	11.0
XRF 32	102.8	21.10	3.52	147.5	0.3	50.6	453.5	32.7	3.97	4.71	0.41	3.50	5.9
XRF 33	38.8	18.95	12.77	277.8	33.9	43.9	206.0	17.2	3.86	9.77	1.04	15.66	278.4
XRF 34	57.2	18.89	11.53	163.7	4.6	44.7	193.5	38.5	8.45	4.90	1.23	5.58	62.1
XRF 35	48.5	17.26	1.18	114.0	282.8	15.4	108.1	18.4	2.32	1.38	0.10	2.74	876.2
XRF 36	73.5	18.96	2.11	195.9	15.5	49.6	269.2	31.0	3.16	4.79	0.42	9.25	58.2
XRF 37	29.9	12.73	3.38	131.3	20.9	21.0	91.1	13.1	4.34	2.29	0.75	4.54	519.1
XRF 38	42.0	13.97	4.17	74.1	137.3	20.3	58.1	10.7	3.07	1.57	0.62	2.99	2287.3
XRF 39	30.0	14.26	0.98	76.4	100.8	12.1	88.3	7.3	2.07	1.52	0.17	2.68	875.8
XRF 40	52.7	20.03	4.41	215.0	273.9	9.2	110.5	22.8	2.86	0.84	0.46	17.34	1124.0

Table IV. Recommended concentration data in parts per million for XRF and other types of calibration

technique	NAA	NAA	NAA	NAA	NAA	ICP-MS	NAA	NAA	NAA	NAA	NAA	NAA	NAA
ANID	La	Ce	Nd	Sm	Eu	Gd	Tb	Dy	Yb	Lu	Hf	Ta	Th
XRF 1	6.76	16.42	8.46	3.43	0.202	3.69	0.809	5.64	4.23	0.82	3.41	2.33	11.97
XRF 2	13.79	27.26	10.18	2.38	0.352	1.40	0.289	1.84	1.18	0.18	2.71	0.79	7.64
XRF 3	25.31	48.35	16.59	3.63	0.576	2.38	0.550	3.20	2.69	0.45	3.64	0.66	8.50
XRF 4	40.16	85.68	44.37	9.87	2.006	10.14	1.744	10.48	8.02	1.21	10.04	0.86	6.17
XRF 5	11.89	27.02	16.75	4.01	0.828	3.78	0.668	4.15	3.10	0.47	3.71	0.11	1.48
XRF 6	64.08	130.39	47.51	13.90	0.298	16.68	3.889	29.92	21.98	2.96	15.46	17.37	18.96
XRF 7	23.01	49.34	20.52	4.74	0.139	3.44	0.652	3.63	2.78	0.57	4.65	1.76	18.84
XRF 8	10.27	30.56	13.40	6.53	0.026	6.90	1.540	11.19	8.54	1.22	10.00	23.17	42.65
XRF 9	24.99	47.79	18.50	3.74	0.510	3.00	0.541	3.22	2.32	0.40	4.08	0.77	9.21
XRF 10	35.60	60.24	19.75	3.33	0.436	1.98	0.381	2.17	1.62	0.37	5.27	1.22	15.29
XRF 11	12.47	24.75	9.42	2.91	0.323	2.61	0.491	3.39	2.63	0.51	3.17	1.00	7.58
XRF 12	24.06	48.96	18.55	4.39	0.515	3.20	0.627	4.01	3.00	0.56	6.12	0.83	15.13
XRF 13	24.51	49.02	20.40	4.31	0.433	3.44	0.649	4.52	3.07	0.57	5.46	0.86	13.01
XRF 14	21.26	42.09	17.05	3.33	0.488	2.54	0.430	2.56	1.59	0.27	3.30	0.64	6.71
XRF 15	60.22	122.10	54.52	11.99	0.825	11.34	2.063	14.49	8.72	1.27	15.22	2.39	7.71
XRF 16	67.05	138.33	59.80	12.48	0.153	10.38	1.903	11.32	7.15	1.07	18.51	3.74	15.84
XRF 17	446.98	866.70	314.56	63.97	4.463	63.45	10.684	65.20	40.70	5.73	76.21	33.96	82.93
XRF 18	153.11	281.85	96.58	15.96	1.720	12.46	2.259	14.93	9.17	1.33	27.17	15.39	35.76
XRF 19	27.91	58.73	24.40	5.69	0.208	4.73	0.932	6.22	4.43	0.71	4.49	2.69	28.62
XRF 20	6.04	14.58	10.36	3.67	1.388	3.73	0.647	3.63	1.43	0.19	2.20	0.22	0.75
XRF 21	54.87	105.82	40.56	7.43	1.277	5.91	0.933	5.69	3.83	0.61	7.93	2.43	17.87
XRF 22	132.34	254.60	97.86	19.37	0.517	16.62	2.975	19.76	11.05	1.64	27.29	6.24	40.65
XRF 23	89.99	179.88	67.83	14.86	0.536	13.27	2.489	16.07	10.57	1.57	27.38	6.14	26.11
XRF 24	55.26	141.31	85.72	21.81	0.491	24.84	4.594	31.17	16.98	2.34	32.28	3.75	29.81
XRF 25	110.63	226.60	96.36	21.88	3.294	21.56	3.649	20.89	12.76	1.80	27.87	7.55	21.53
XRF 26	33.73	71.74	32.57	7.55	0.756	7.08	1.312	8.61	5.93	0.91	8.79	1.21	7.73
XRF 27	23.98	41.49	15.11	2.84	0.413	2.15	0.365	2.08	2.02	0.34	3.57	1.03	9.58
XRF 28	45.37	88.97	33.12	6.88	0.185	6.45	1.085	6.74	4.26	0.81	6.41	3.33	16.22
XRF 29	17.68	41.34	21.62	6.45	0.757	7.19	1.281	8.47	5.62	0.84	5.24	0.83	6.88
XRF 30	39.09	95.43	39.55	10.38	1.629	11.26	2.334	15.93	12.58	1.91	27.69	5.02	18.66
XRF 31	17.13	37.68	14.61	3.66	0.170	2.91	0.497	2.76	2.12	0.30	3.16	4.09	16.42
XRF 32	55.48	112.76	48.36	10.26	0.239	9.31	1.531	9.34	5.30	0.79	12.51	2.25	14.39
XRF 33	52.84	107.99	33.08	8.42	0.467	6.16	1.191	7.29	4.93	0.70	7.07	1.92	35.83
XRF 34	55.02	111.87	43.41	8.14	0.223	6.34	1.201	7.66	5.56	0.85	7.52	3.02	17.35
XRF 35	54.79	98.77	33.05	5.24	1.034	3.54	0.508	2.09	1.55	0.30	4.00	1.28	14.87
XRF 36	31.23	69.22	30.73	7.71	0.372	6.93	1.268	8.42	5.69	0.88	8.43	2.31	23.66
XRF 37	26.35	47.87	17.06	3.53	0.362	2.87	0.543	3.37	2.53	0.51	3.51	1.07	16.44
XRF 38	15.40	29.61	18.18	3.03	0.660	2.82	0.512	3.15	2.29	0.36	2.66	0.86	3.82
XRF 39	20.24	38.11	16.40	2.65	0.412	1.93	0.372	2.15	1.53	0.25	3.09	0.75	6.85
XRF 40	19.57	35.57	12.78	2.56	0.502	1.53	0.227	1.09	1.21	0.19	4.01	1.45	11.48

Table IV. Recommended concentration data in parts per million for XRF and other types of calibration

technique ANID	NAA U
XRF 1	6.50
XRF 2	4.63
XRF 3	3.35
XRF 4	2.42
XRF 5	1.11
XRF 6	16.07
XRF 7	6.96
XRF 8	25.12
XRF 9	4.54
XRF 10	5.50
XRF 11	4.17
XRF 12	6.04
XRF 13	5.21
XRF 14	2.79
XRF 15	2.58
XRF 16	6.85
XRF 17	35.28
XRF 18	16.61
XRF 19	7.67
XRF 20	nd
XRF 21	5.42
XRF 22	10.94
XRF 23	12.76
XRF 24	8.12
XRF 25	10.16
XRF 26	3.34
XRF 27	3.64
XRF 28	6.61
XRF 29	2.88
XRF 30	8.94
XRF 31	10.28
XRF 32	5.14
XRF 33	11.56
XRF 34	7.27
XRF 35	3.23
XRF 36	8.40
XRF 37	6.72
XRF 38	2.37
XRF 39	3.17
XRF 40	9.01