INL CRMO XRF Special Report No. 1

INL/RPT-25-89580

Idaho National Laboratory Cultural Resource Management Office

INL CRMO XRF Calibration Methods for the Analysis of Obsidian Artifacts

JANUARY 2026

Kyle P. Freund,
Jeremias Pink, and
Josh Clements

Idaho National Laboratory
Cultural Resource Management Office

Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy

INL/RPT-25-89580

INL CRMO XRF Special Report No. 1

INL CRMO XRF Calibration Methods for the Analysis of Obsidian Artifacts

Kyle P. Freund,
Jeremias Pink, and
Josh Clements

Idaho National Laboratory

January 2026

Idaho National Laboratory
Cultural Resource Management Office
Idaho Falls, Idaho 83415

http://www.inl.gov

CONTENTS

FIGURES

TABLES

ACKNOWLEDGEMENTS

We would like to acknowledge David Page and the team at the Missouri University Research Reactor for providing the geological standards that are used in this calibration. Steve Shackley also generously loaned us a sample of rock obtained from the RGM-2 boulder at Glass Mountain, CA. We express gratitude to Arin Preston and Sydney Foster for pressing raw powder samples and would like to thank Marissa King, Nicholas Holmer, Shannon Loftus, and Doug Herzog for their support.

ABSTRACT

This report details the analytical methods used by the Idaho National Laboratory Cultural Resource Management Office to characterize obsidian artifacts using X-ray fluorescence spectrometry. More specifically, this report provides details on instrumentation, run times, and calibration protocols, including the geological reference standards that are used to calibrate the raw output from the instrument. The calibration is validated by plotting calibrated results against published reference values, including two geological standards that were not part of the calibration curves.

ACRONYMS

CRMO	Cultural Resource Management Office
ED-XRF	Energy Dispersive X-ray Fluorescence
FP	Fundamental Parameters
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
INL	Idaho National Laboratory
LE	Light Element
MURR	University of Missouri Research Reactor
NAA	Neutron Activation Analysis
PPM	Parts Per Million
RGM	Rhyolite Glass Mountain
SDD	Silicon Drift Detector
USGS	U.S. Geological Survey

Elements

Mg	magnesium
Al	aluminum
Si	silicon
K	potassium
Ca	calcium
Ti	titanium
Mn	manganese
Fe	iron
Zn	zinc
Rb	rubidium
Sr	strontium
Y	yttrium
Zr	zirconium
Nb	niobium
Ba	barium

INL CRMO XRF Special Report No. 1

INL CRMO XRF Calibration Methods for the Analysis of Obsidian Artifacts

OVERVIEW

This report details the analytical methods employed by the Idaho National Laboratory (INL) Cultural Resource Management Office (CRMO) when using energy-dispersive X-ray fluorescence (ED-XRF) spectrometry to analyze archaeological obsidian artifacts to determine their geological origin. More specifically, this report provides details on instrumentation, run times, and calibration protocols, including the geological reference standards that are used to calibrate the raw output from the instrument. The calibration is validated by plotting calibrated results against published reference values, including two geological standards that were not part of the calibration curve. These include JR-1 (rhyolite) from the Geological Survey of Japan and U.S. Geological Survey (USGS) RGM-2 (rhyolite).

ANALYTICAL METHODS

All obsidian samples are analyzed using an Olympus Vanta M-series portable XRF spectrometer equipped with a 4 W X-ray tube, a Rh anode, and 40 mm^2 silicon drift detector (SDD). The instrument operates using a factory "Geochem" mode that relies on a fundamental parameters (FP) calibration, with standards, and a combination of three beam settings to optimize measurements of separate element groups in silica-rich materials. Each sample is analyzed for a total of 180 seconds (60 seconds per beam setting). Twelve elements are regularly quantified by the CRMO for obsidian artifacts. Beam 1 measures manganese (Mn), iron (Fe), zinc (Zn), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), and niobium (Nb). Beam 2 measures potassium (K), calcium (Ca), and titanium (Ti). Beam 3 measures barium (Ba). Table 1 provides a summary of energy, current, and filter parameters used for each beam setting.

Table 1: Energy, current, and filter parameters used for each beam setting for Olympus Vanta instruments employing a three-beam factory "Geochem" calibration.

Beam	Energy (kV)	Current (µA)	Filter Material	Filter Thickness (µm)	Filter Diameter (µm)	Elements Quantified
1	40	58	Aluminum (Al)	2,000	2,718	Mn, Fe, Zn, Rb, Sr, Y, Zr, Nb
2	10	65	None	-	2,718	K, Ca, Ti
3	50	56	Copper (Cu)	350	2,718	Ba

To further improve the accuracy of results, elemental estimates exported from the instrument are adjusted using calibration curves derived from the analysis of 40 obsidian calibration standards available from the University of Missouri Research Reactor (MURR) (Glascock 2020; Glascock and Ferguson 2012) as well as a series of international igneous rock standards (Appendix A). The MURR standards are provided to researchers in the form of solid, polished cubes of obsidian. The igneous rock standards are provided in the form of finely ground powders to homogenize the bulk composition of mineral constituents. All powdered standards were pressed into 20 mm pellets using a hydraulic press to 10 tons following the addition of ~0.5g of polyvinylpyrrolidone binder. Together, the two groups of standards encompass the full range of elemental variability found in geological obsidian sources represented in the INL CRMO geological reference database (Table 2). The composition of each standard has been independently determined through techniques such as Neutron Activation Analysis (NAA) or Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Recommended reference values for the 12 elements of interest for each standard are compiled in Appendix A.

Table 2. Elemental ranges for geological obsidian samples in the INL CRMO reference database (n=2,245). All measurements are in ppm.

Element	Min	Max	Median	Mean	1s
K	23,023	52,719	41,084	40,511	4,358
Ca	1,477	17,749	4,746	5,115	2,094
Ti	15	3,912	1,432	1,362	601
Mn	111	984	265	296	121
Fe	3,427	35,614	14,170	13,831	5,034
Zn	28	265	57	73	51
Rb	73	540	193	199	60
Sr	0	259	42	45	40
Y	17	231	58	64	41
Zr	42	1,193	388	370	200
Nb	7	298	44	54	55
Ba	0	3,527	1,048	941	524

A check standard is regularly analyzed under equivalent conditions at the start and end of each analytical run to monitor instrument performance. This standard is a solid, slabbed sample of obsidian from the USGS RGM-2 boulder (Govindaraju 1994; Wilson 2009).

LIGHT ELEMENT CORRECTION

Under some XRF calibration protocols (i.e., Compton-normalization), development of calibration routines with pressed powder pellets does not significantly skew the accuracy of results for whole rock samples (Shackley 2011: 2). However, combining pressed powders and solid rocks to set up elemental calibration curves does have its challenges for instruments employing FP calibrations (see Gallhofer and Lottermoser 2018). Data output from Olympus Vanta instruments equipped with “Geochem” mode and a FP calibration rely on estimation of the total concentration of light elements (LE) in the sample matrix. The calibration algorithm quantifies LE based on the intensity of the Compton scatter to estimate the concentration of elements on the periodic table below magnesium (Mg) that are difficult to quantify directly due to very low energy fluorescence peaks (Michael Hull, personal communication 2025[a]). In general, LE values are higher for powders and pressed powders compared to whole-rock solid samples due to the presence of air and organic binding material between particles. Because the FP calibration relies on an iterative sum of elemental estimates to 100%, this contributes to a dilution effect that impacts other elements.

For the current calibration routine, we are using both solid samples from the MURR obsidian calibration set as well as pressed powders of geological reference standards. For most elements, the difference between instrument output (raw estimates) and reference values is considerably higher for pressed pellet standards than the solid obsidian standards provided by MURR. As a result, the elemental calibration curves are skewed for certain elements based on the matrix (e.g., Ti; see Figure 4). To account for this effect, a correction was applied to the raw FP output for all elements measured on the pressed powders. This correction assumes that the most dominant element in igneous rocks below Mg is oxygen, though lesser quantities of sodium, carbon, and hydrogen are also present. The expected quantity of oxygen in a sample can be estimated as the sum of the major element oxides (e.g., MgO, Al_2O_3, SiO_2, MnO) minus the major elements (e.g., Mg, Al, Si, Mn) using published reference values. To account for water content and other light elements, major element oxides were not normalized to 100%, but the formula includes the difference between 1 million (100% in ppm) and the sum of the major element oxides. This method assumes that each element is electrically neutral and exists in a stoichiometric (specific, consistent, and stable) oxidation state, but it provides a rough measure of the light elements in each sample that is unbiased by organic binder and air between particles. In this context, LE estimates in the pressed powders in excess of this value are likely unrelated to the actual LE content of the solid component of the sample. To adjust elemental estimates, raw concentrations for each element were multiplied by the ratio of the LE estimate over our summed oxygen estimate to counter the dilution effect of air and binder in the pressed pellet standards. Raw concentrations for the solid MURR standards were not adjusted to minimize introduction of additional sources of error.

CALIBRATION CURVES

The following section provides an overview of the calibration curves and associated geologic standards used to calibrate each of the 12 elements that are part of the INL CRMO obsidian calibration routine. Table 3 summarizes the slopes, Y-intercepts, and R^2 values for each of the calibration curves.

In most cases, calibration curves relying solely on MURR solid rock standards had a sufficient compositional range for the element in question. In the case of K and Ti, pressed powder samples with LE adjusted values were used either on their own (K) or were used to supplement the MURR curves (Ti). Pressed powder standards that overlapped the range of values for the MURR standards were excluded to preserve a normal distribution of values. Standards were also excluded if they were outliers, and curves were forced through zero when the p-values for the Y-

[a] Michael Hull, Ph.D. is Director of Product Management at Evident Scientific (formerly Olympus).

intercepts were not significant with an alpha of 0.05. Zr was an exception and was forced through zero due to concern over its negative Y-intercept value.

Table 3. Slopes, Y-intercepts, and R^2 values for the calibration curves for each of the 12 elements of interest.

Element	Slope	Y-Intercept	R^2
K	1.0729553	511.9387	0.997264
Ca	0.880421	168.4333	0.994035
Ti	1.032241	0	NA
Mn	1.0724246	8.645192	0.990213
Fe	0.94293	0	NA
Zn	0.8036292	5.073962	0.998675
Rb	0.9463132	0	NA
Sr	0.9917888	0	NA
Y	0.8858712	0	NA
Zr	0.9907204	0	NA
Nb	0.8763165	3.294938	0.998946
Ba	0.8058096	0	NA

Potassium (K)

Figure 1 shows the raw K values plotted against the published reference values, and in this context a LE correction was applied. The adjusted calibration curve for K is shown in Figure 2, encompassing the following 26 geologic standards: AGV-1, BCR-1, BIR-1, DNC-1, DR-N, DT-N, DTS-1, G-2, GS-N, JA-2, JA-3, JB-2, JB-3, JG-1a, JG-2, JG-3, JGb-1, JP-1, JR-2, SARM-1, SARM-3, SARM-6, PCC-1, SRM688, UB-N, and W-2 (Appendix A; see Govindaraju 1994).

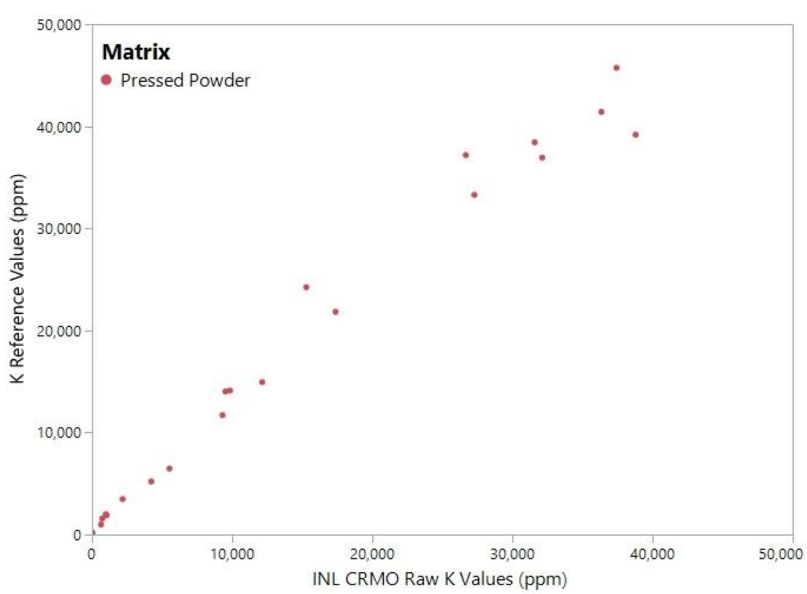


Figure 1. Bi-plot of FP calibrated K values in parts per million (ppm) vs. published reference values.

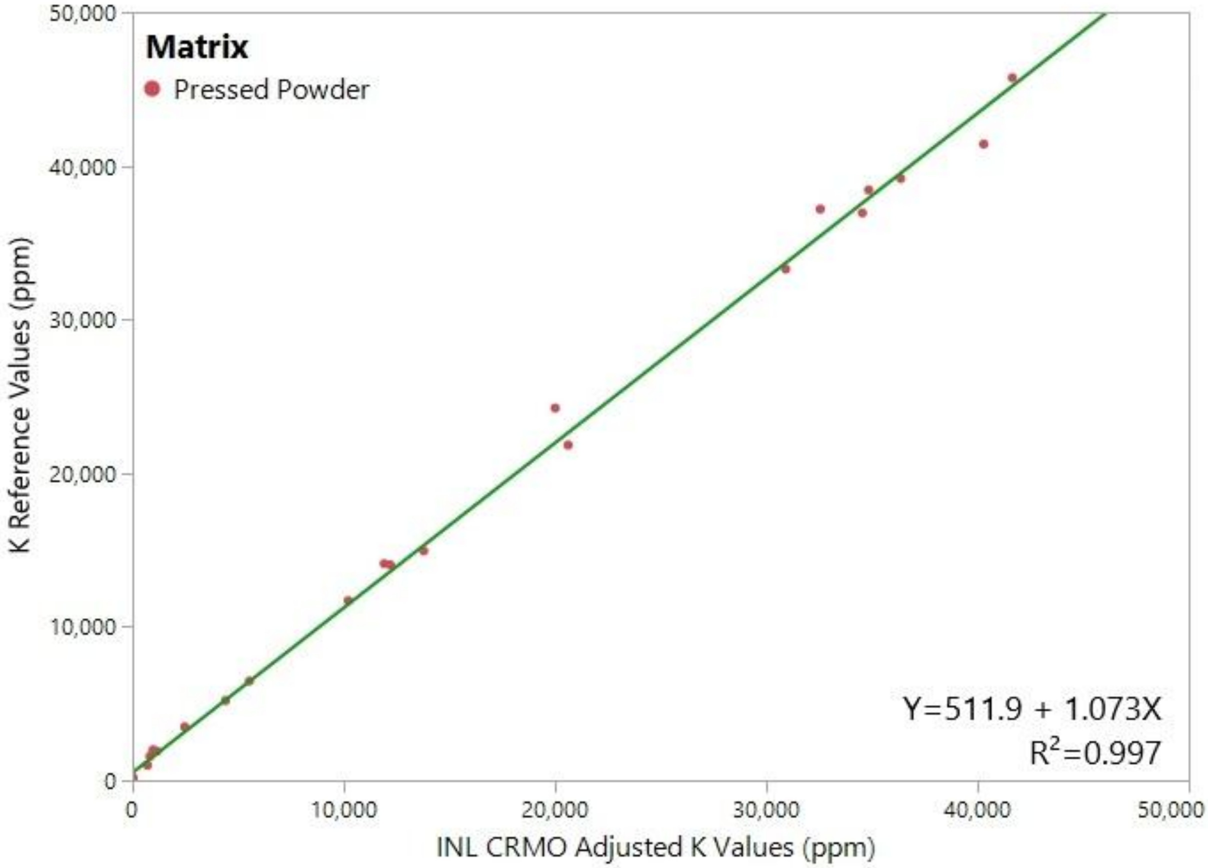


Figure 2. LE adjusted K values (in ppm) vs. published reference values. The calibration curve for K is shown in green.

Calcium (Ca)

The calibration curve for Ca is shown in Figure 3, encompassing the following 34 geologic standards: XRF-1 through XRF-40, excluding XRF-8, XRF-17, XRF-20, XRF-21, XRF-26, and XRF-33 (Appendix A; see Glascock 2020; Glascock and Ferguson 2012).

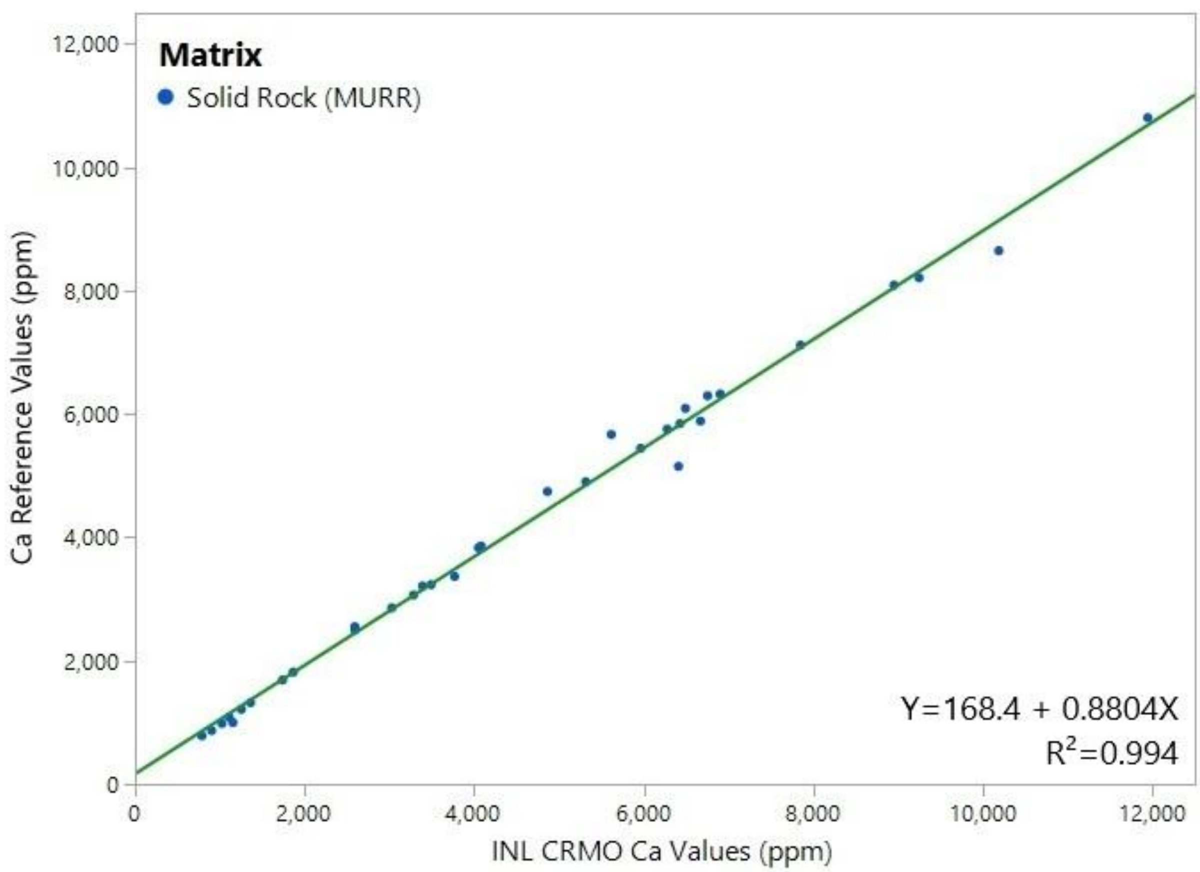


Figure 3. INL CRMO Ca values (in ppm) vs. published reference values. The calibration curve for Ca is shown in green.

Titanium (Ti)

Figure 4 shows the raw Ti values plotted against the published reference values, and in this context a LE correction was applied. The adjusted calibration curve for Ti is shown in Figure 5, encompassing the following 55 geologic standards: XRF-1 through XRF-40, excluding XRF-8 and XRF-33, AGV-1, BIR-1, DNC-1, DR-N, DT-N, G-2, GS-N, JA-2, JA-3, JB-2, JB-3, JG-3, JGb-1, SARM-3, SARM-6, SRM688, and W-2 (Appendix A; see Glascock 2020; Glascock and Ferguson 2012; Govindaraju 1994). Before fitting the curve through zero as shown in Figure 5, the Y-intercept was -33.34 with a slope of 1.039 and an R^2 of 0.995. The p-value for the Y-intercept was 0.3189, which was not statistically significant at an alpha of 0.05, indicating that the intercept value was not significantly different from 0.

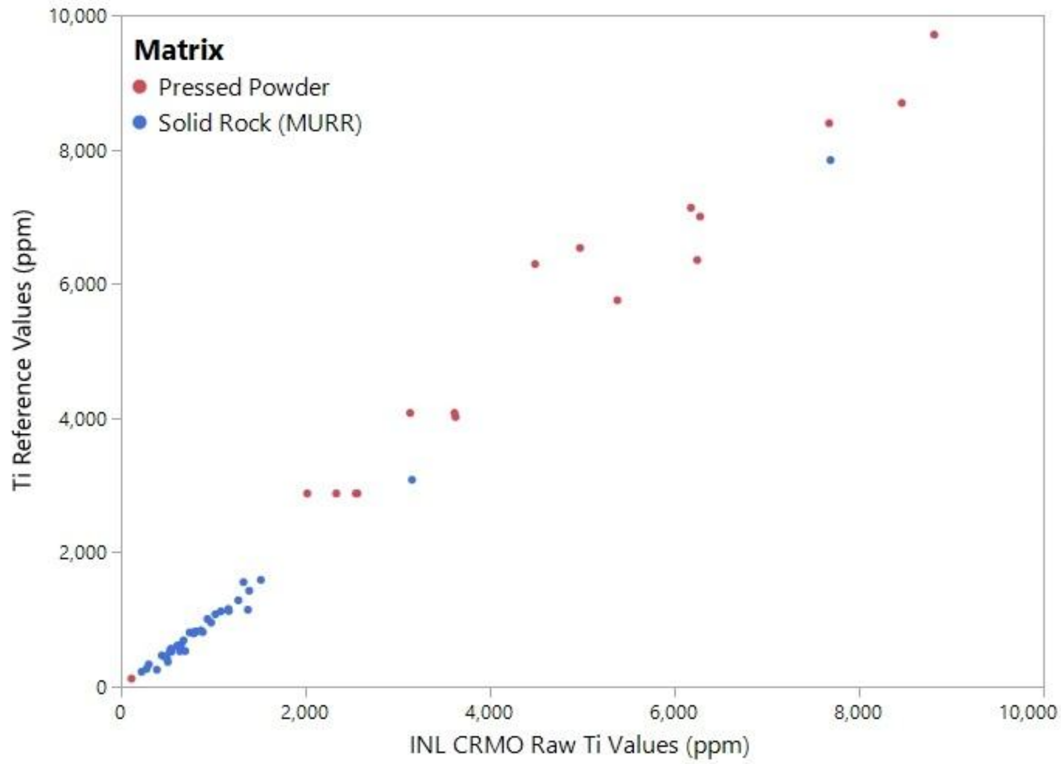


Figure 4. Bi-plot of FP calibrated Ti values (in ppm) vs. published reference values.

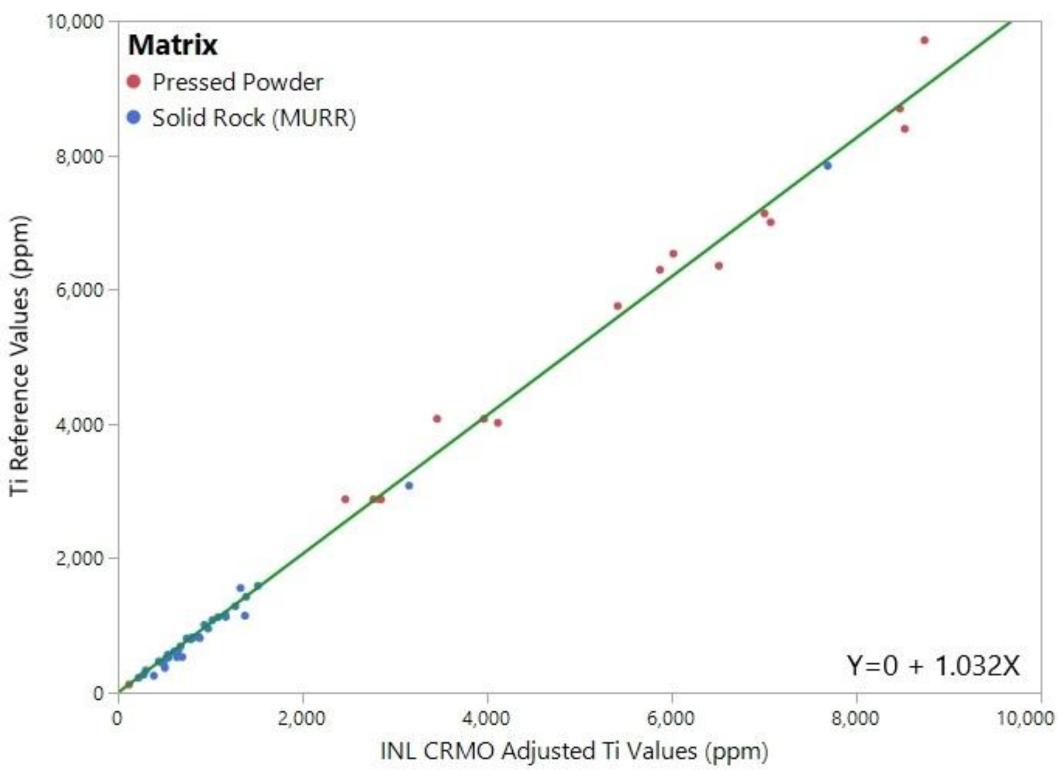


Figure 5. LE adjusted Ti values (in ppm) vs. published reference values. The calibration curve for Ti is shown in green.

Manganese (Mn)

The calibration curve for Mn is shown in Figure 6, encompassing the following 36 geologic standards: XRF-1 through XRF-40, excluding XRF-15, XRF-17, XRF-21, and XRF-25 (Appendix A; see Glascock 2020; Glascock and Ferguson 2012).

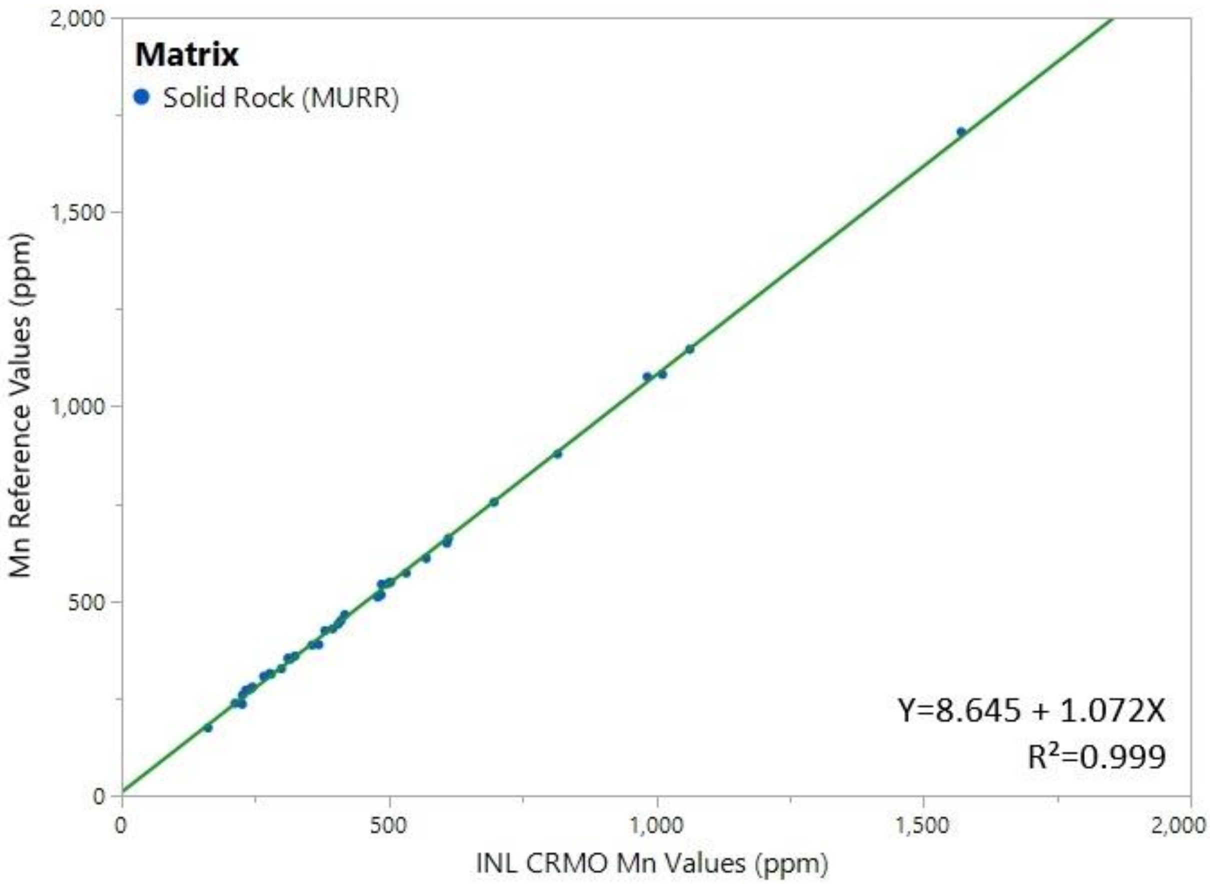


Figure 6. FP calibrated Mn values (in ppm) vs. published reference values. The calibration curve for Mn is shown in green.

Iron (Fe)

The calibration curve for Fe is shown in Figure 7, encompassing the following 38 geologic standards: XRF-1 through XRF-40, excluding XRF-17 and XRF-33 (Appendix A; see Glascock 2020; Glascock and Ferguson 2012). Before fitting the curve through zero, the Y-intercept was -63.86 with a slope of 0.9454 and an R^2 of 0.999. The p-value for the Y-intercept was 0.3642, which was not statistically significant at an alpha of 0.05, indicating that the intercept value was not significantly different from 0.

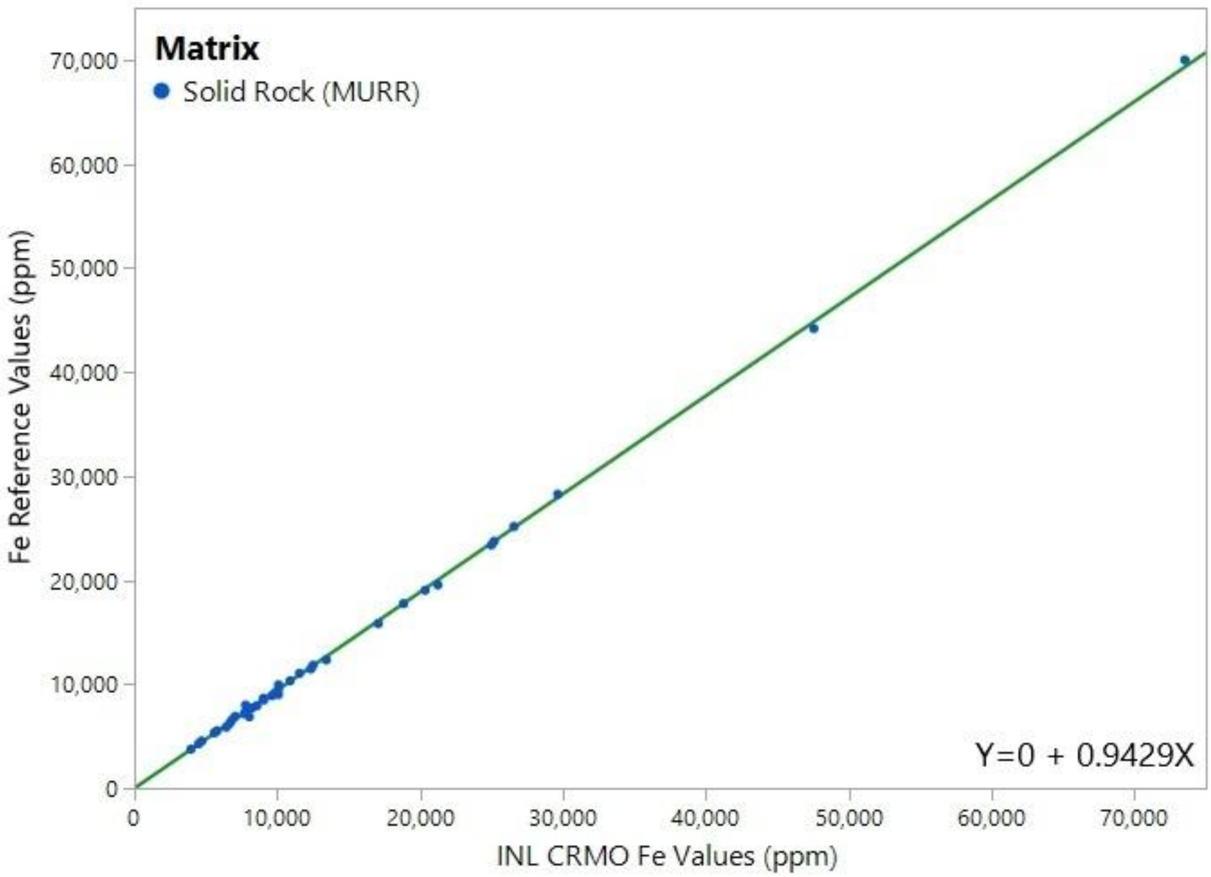


Figure 7. INL CRMO Fe values (in ppm) vs. published reference values. The calibration curve for Fe is shown in green.

Zinc (Zn)

The calibration curve for Zn is shown in Figure 8, encompassing the following 34 geologic standards: XRF-1 through XRF-40, excluding XRF-17, XRF-20, XRF-21, XRF-26, XRF-33, and XRF-40 (Appendix A; see Glascock 2020; Glascock and Ferguson 2012).

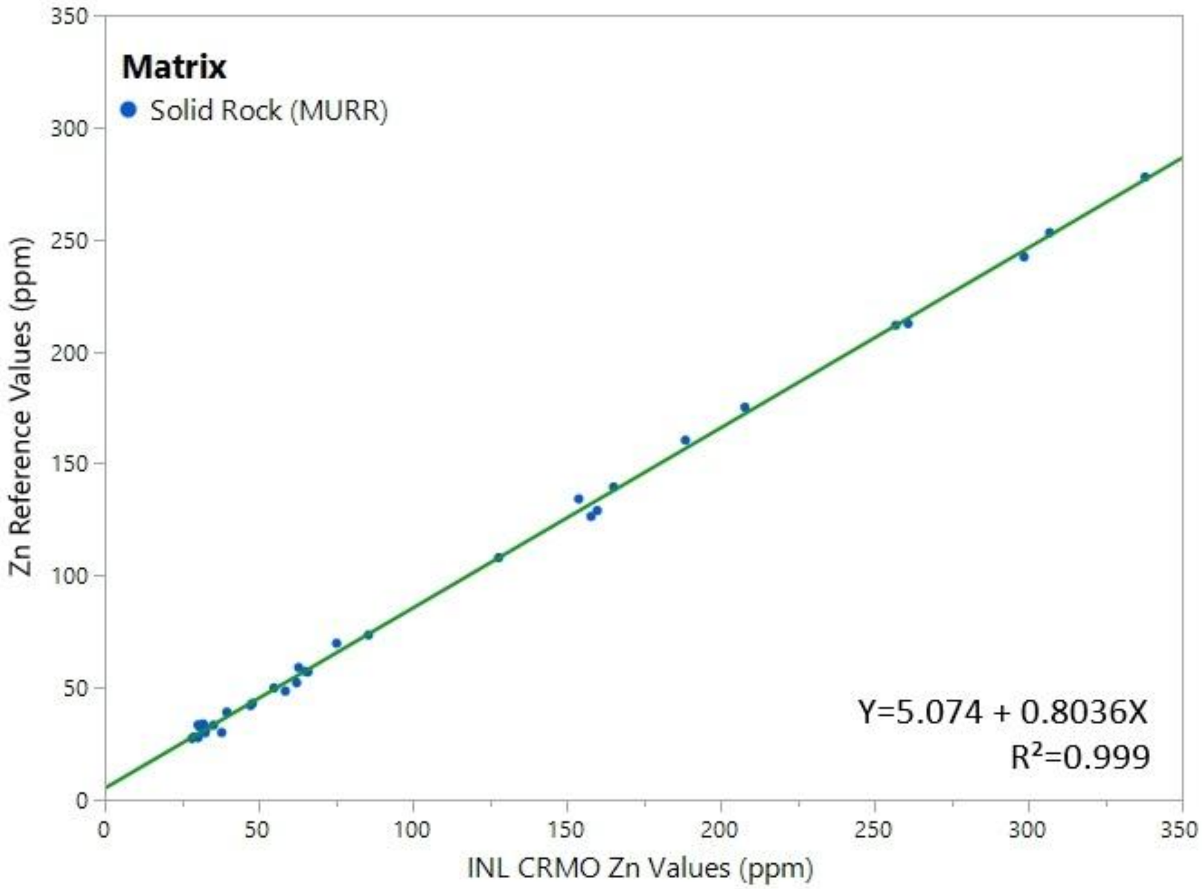


Figure 8. FP calibrated Zn values (in ppm) vs. published reference values. The calibration curve for Zn is shown in green.

Rubidium (Rb)

The calibration curve for Rb is shown in Figure 9, encompassing the following 34 geologic standards: XRF-1 through XRF-40, excluding XRF-17, XRF-20, XRF-21, XRF-26, XRF-33, and XRF-40 (Appendix A; see Glascock 2020; Glascock and Ferguson 2012). Before fitting the curve through zero, the Y-intercept was 0.9263 with a slope of 0.9417 and an R^2 of 0.999. The p-value for the Y-intercept was 0.1950, which was not statistically significant at an alpha of 0.05, indicating that the intercept value was not significantly different from 0.

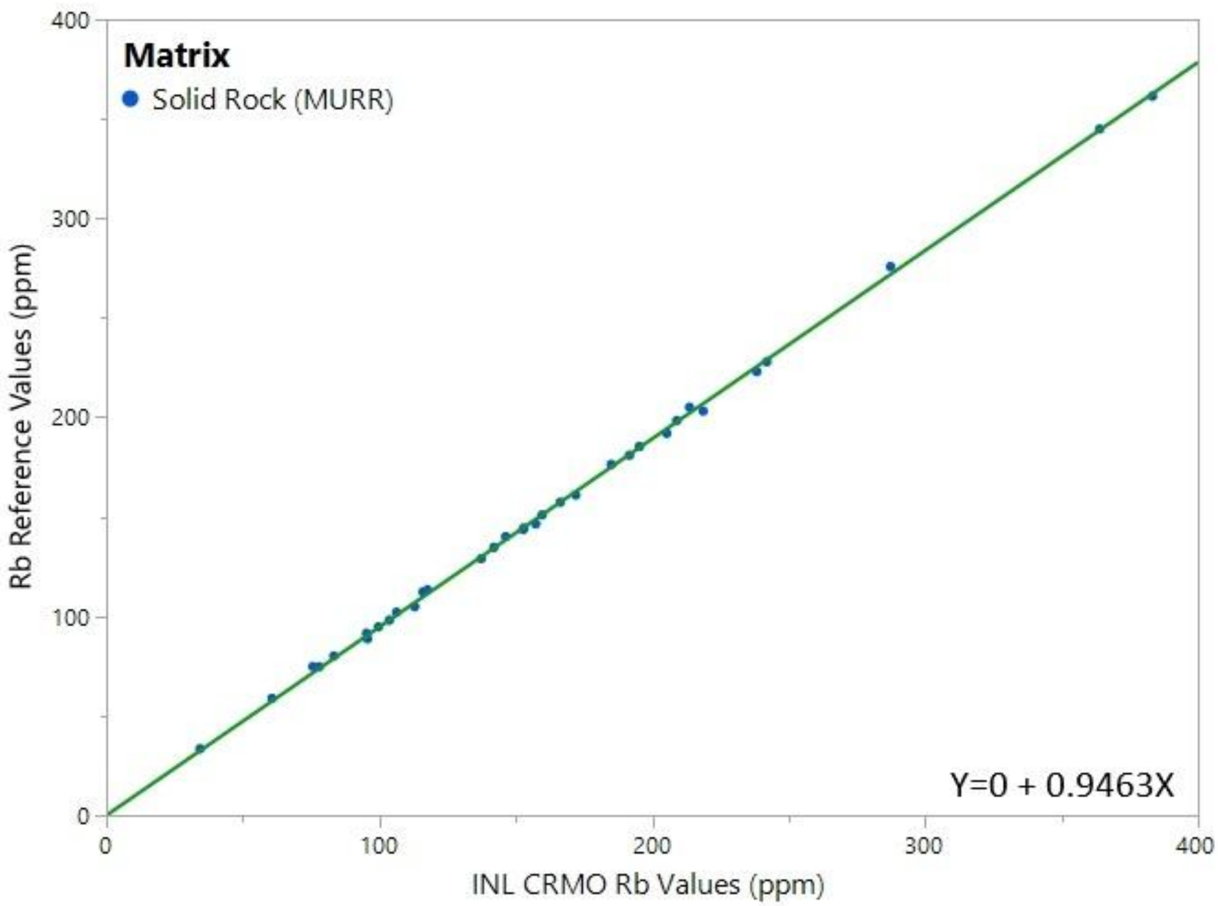


Figure 9. FP calibrated Rb values (in ppm) vs. published reference values. The calibration curve for Rb is shown in green.

Strontium (Sr)

The calibration curve for Sr is shown in Figure 10, encompassing the following 25 geologic standards: XRF-1 through XRF-40, excluding XRF-4, XRF-6, XRF-16, XRF-17, XRF-20, XRF-21, XRF-22, XRF-23, XRF-24, XRF-26, XRF-30, XRF-32, XRF-33, XRF-35, and XRF-40 (Appendix A; see Glascock 2020; Glascock and Ferguson 2012). Before fitting the curve through zero, the Y-intercept was -0.7643 with a slope of 0.9991 and an R^2 of 0.998. The p-value for the Y-intercept was 0.3178, which was not statistically significant at an alpha of 0.05, indicating that the intercept value was not significantly different from 0.

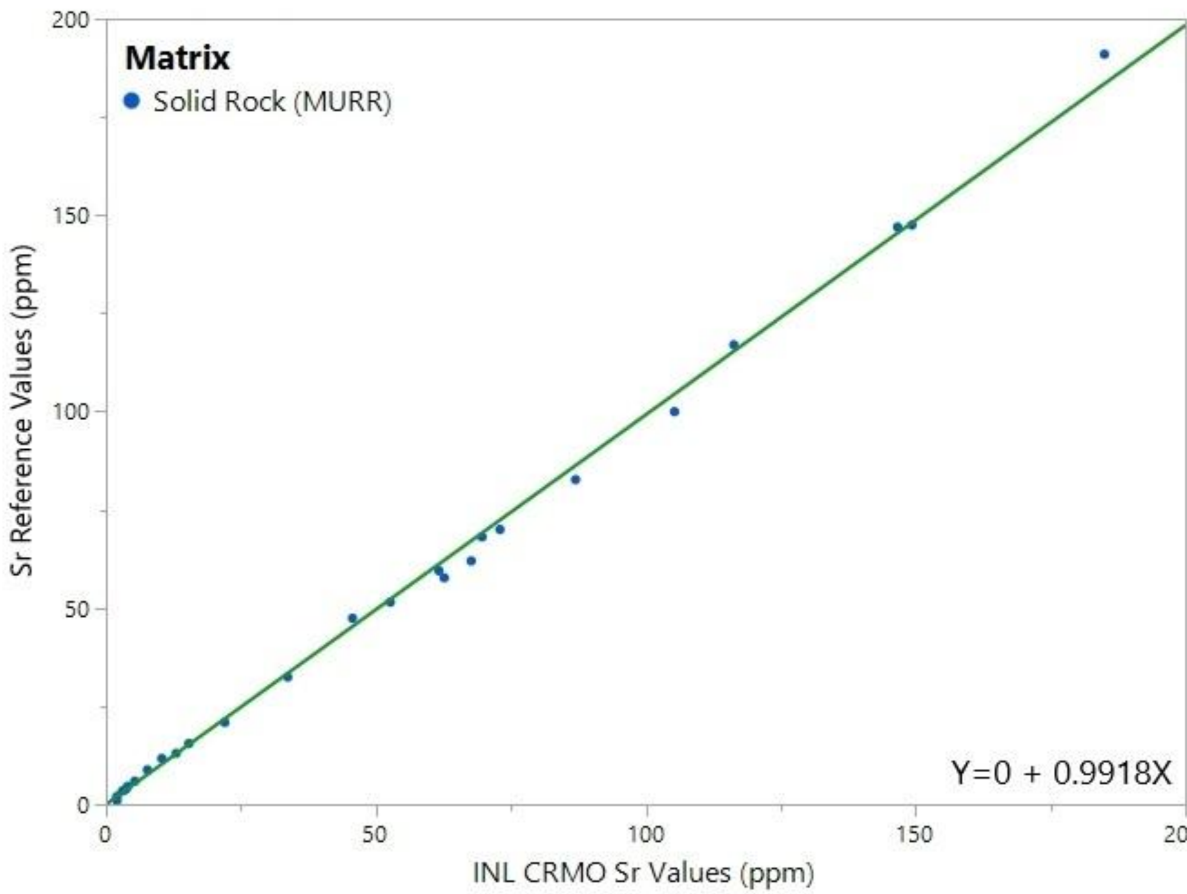


Figure 10. INL CRMO Sr values (in ppm) vs. published reference values. The calibration curve for Sr is shown in green.

Yttrium (Y)

The calibration curve for Y is shown in Figure 11, encompassing the following 34 geologic standards: XRF-1 through XRF-40, excluding XRF-3, XRF-4, XRF-6, XRF-17, XRF-18, and XRF-33 (Appendix A; see Glascock 2020; Glascock and Ferguson 2012). Before fitting the curve through zero, the Y-intercept was -0.2001 with a slope of 0.8882 and an R^2 of 0.999. The p-value for the Y-intercept was 0.4417, which was not statistically significant at an alpha of 0.05, indicating that the intercept value was not significantly different from 0.

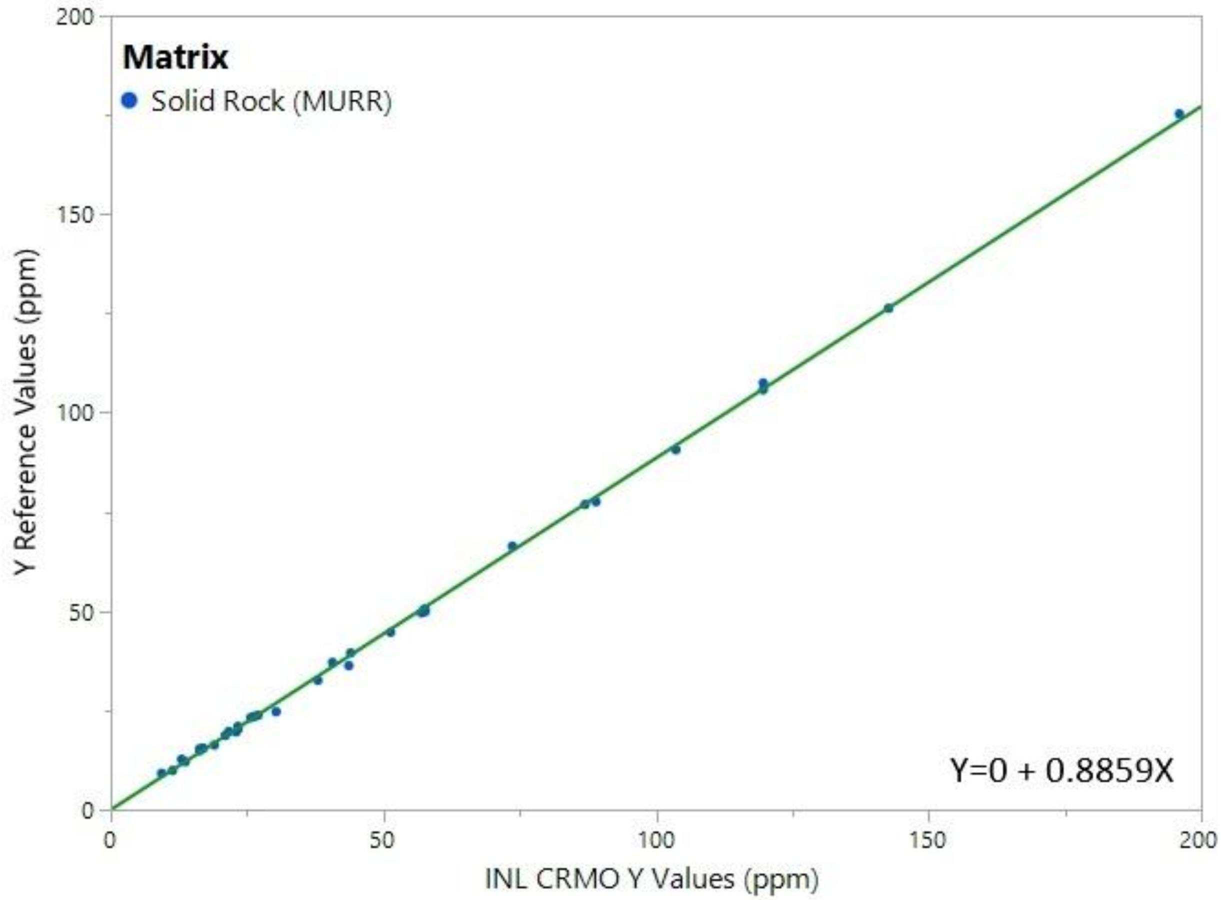


Figure 11. FP calibrated Y values (in ppm) vs. published reference values. The calibration curve for Y is shown in green.

Zirconium (Zr)

The calibration curve for Zr is shown in Figure 12, encompassing the following 37 geologic standards: XRF-1 through XRF-40, excluding XRF-17, XRF-18, and XRF-33 (Appendix A; see Glascock 2020; Glascock and Ferguson 2012). Before fitting the curve through zero, the Y-intercept was -3.437 with a slope of 0.9954 and an R^2 of 0.999. The p-value for the Y-intercept was 0.0261, which was statistically significant at an alpha of 0.05.

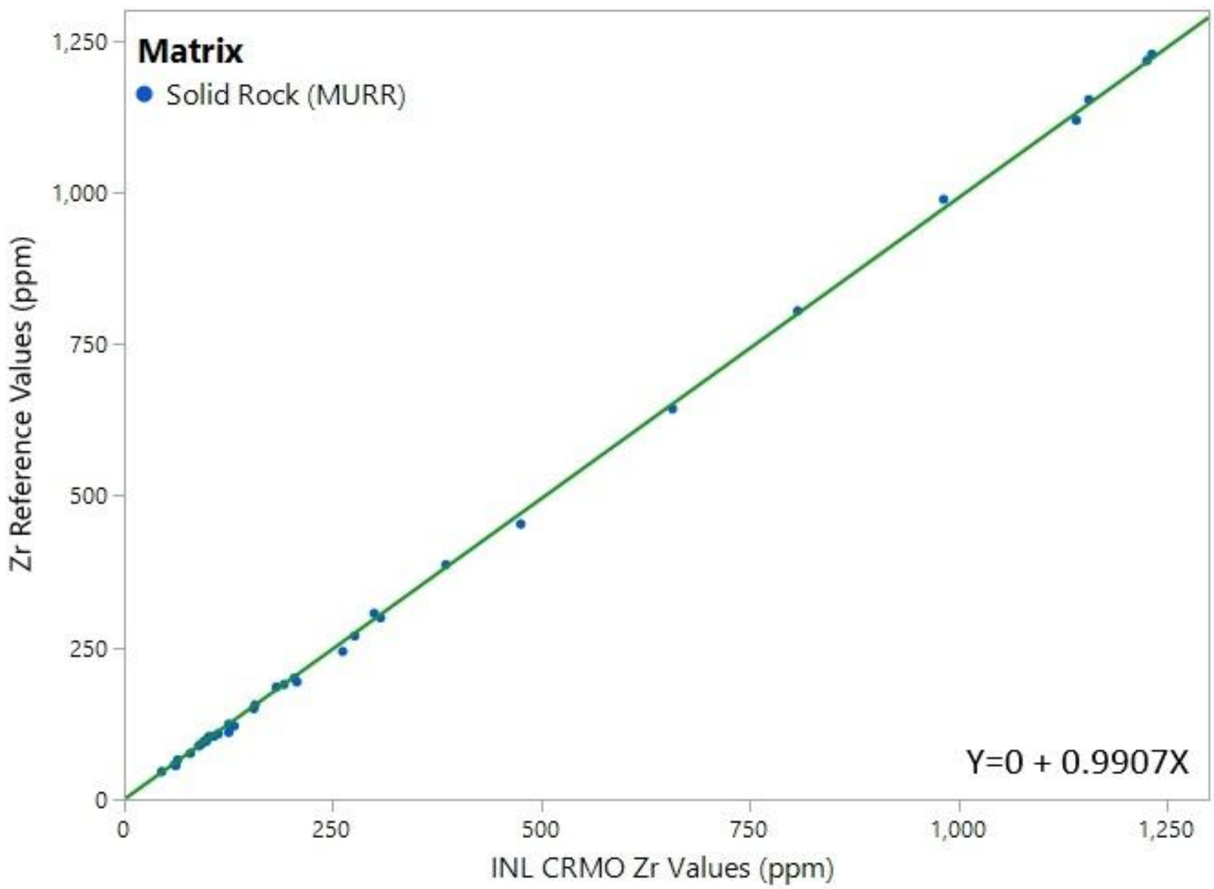


Figure 12. FP calibrated Zr values (in ppm) vs. published reference values. The calibration curve for Zr is shown in green.

Niobium (Nb)

The calibration curve for Nb is shown in Figure 13, encompassing the following 34 geologic standards: XRF-1 through XRF-40, excluding XRF-5, XRF-6, XRF-17, XRF-20, XRF-22, and XRF-24 (Appendix A; see Glascock 2020; Glascock and Ferguson 2012).

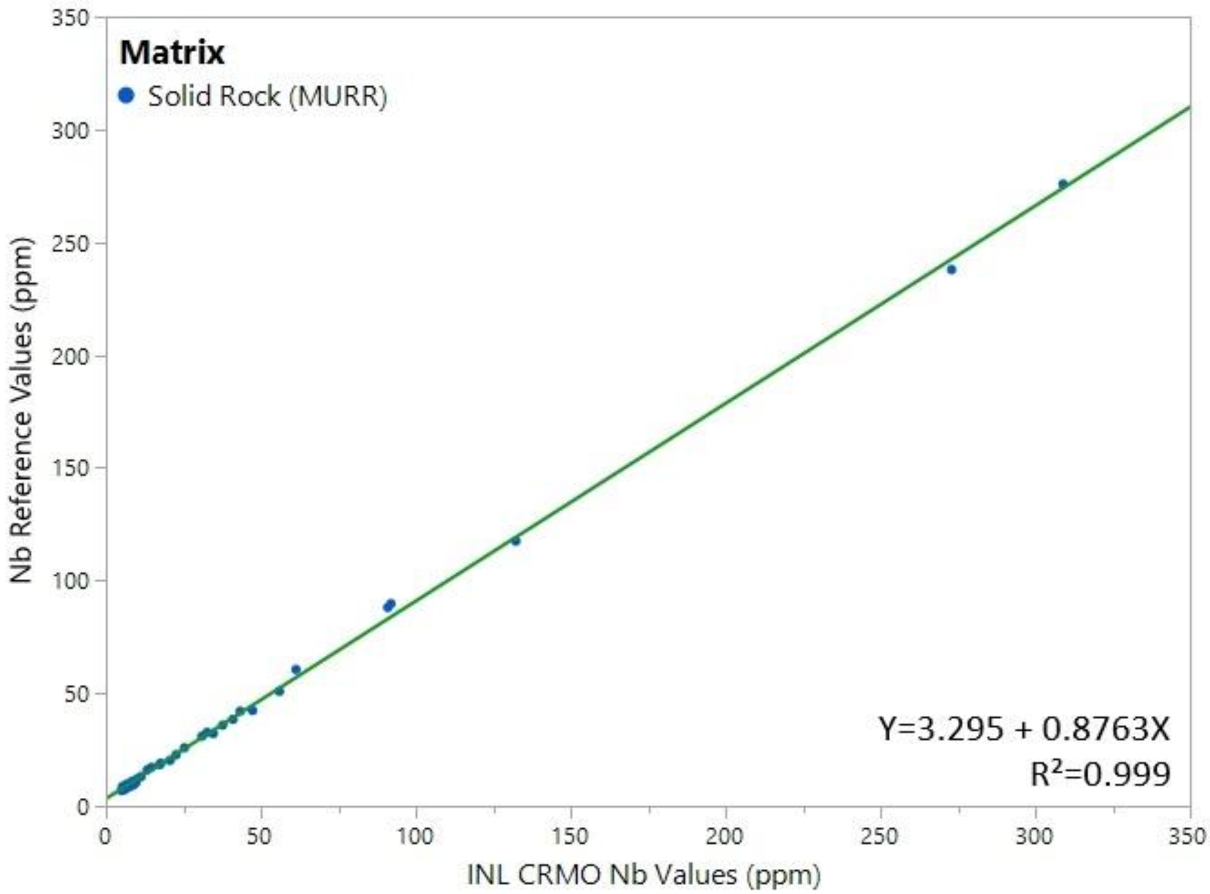


Figure 13. FP calibrated Nb values (in ppm) vs. published reference values. The calibration curve for Nb is shown in green.

Barium (Ba)

The calibration curve for Ba is shown in Figure 14, encompassing the following 34 geologic standards: XRF-1 through XRF-40, excluding XRF-3, XRF-4, XRF-8, XRF-16, XRF-32 and XRF-33 (Appendix A; see Glascock 2020; Glascock and Ferguson 2012). Before fitting the curve through zero, the Y-intercept was -9.538 with a slope of 0.8125 and an R^2 of 0.998. The p-value for the Y-intercept was 0.1543, which was not statistically significant at an alpha of 0.05, indicating that the intercept value was not significantly different from 0.

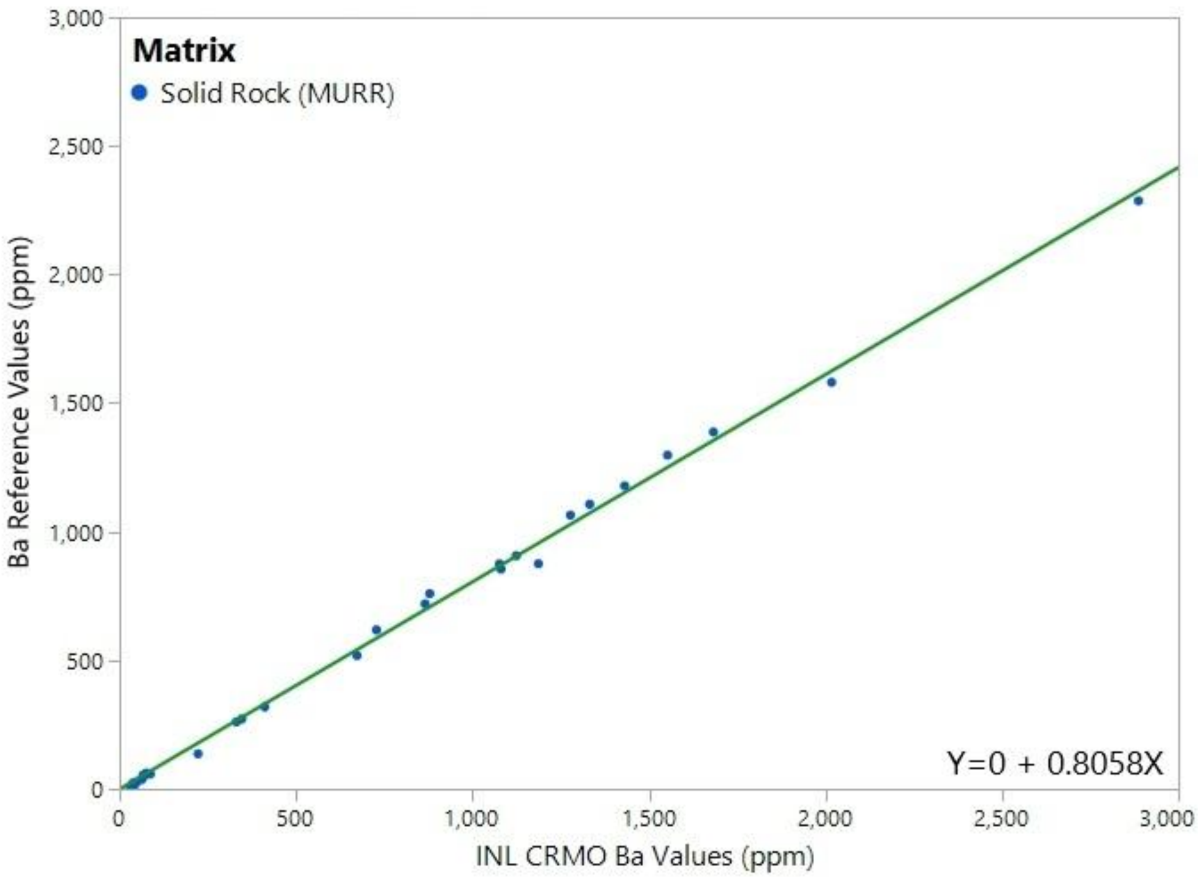
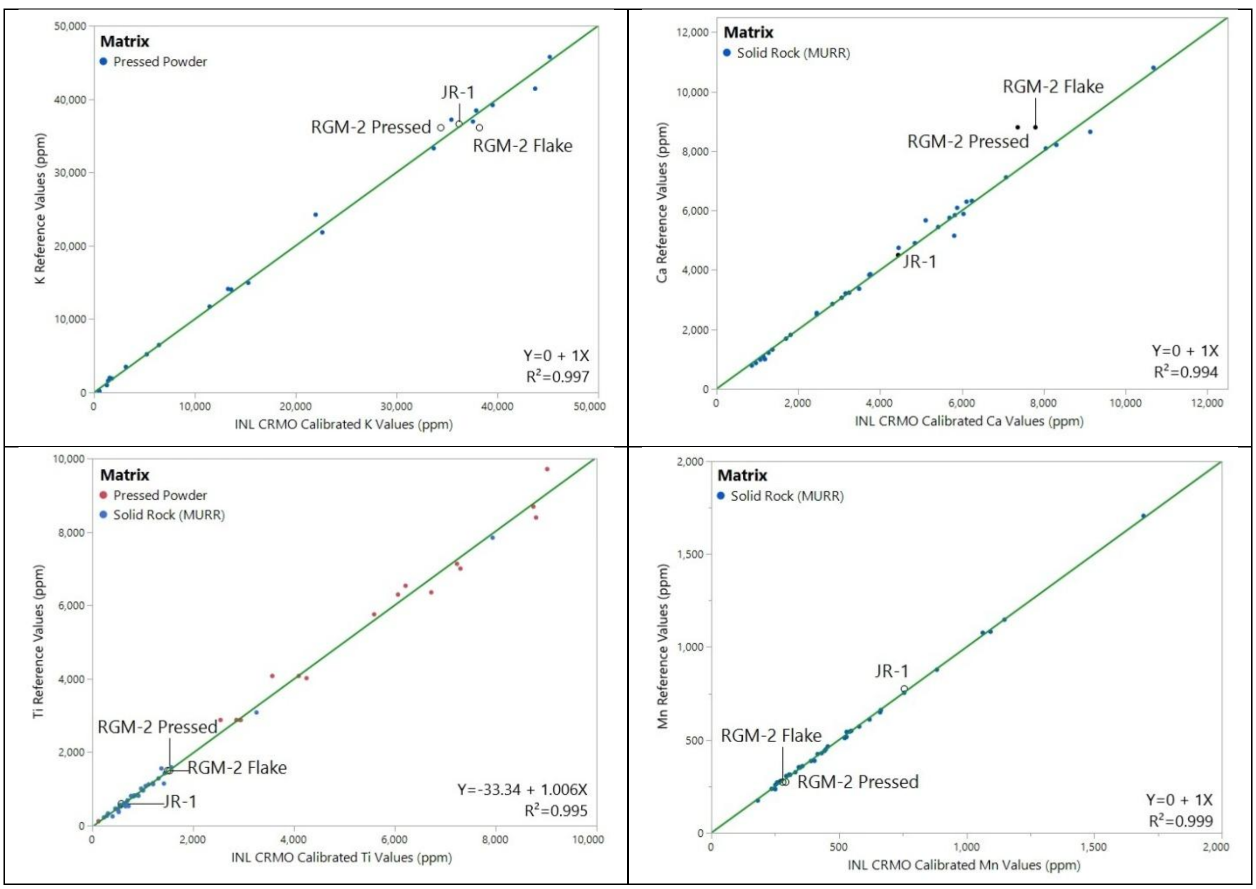


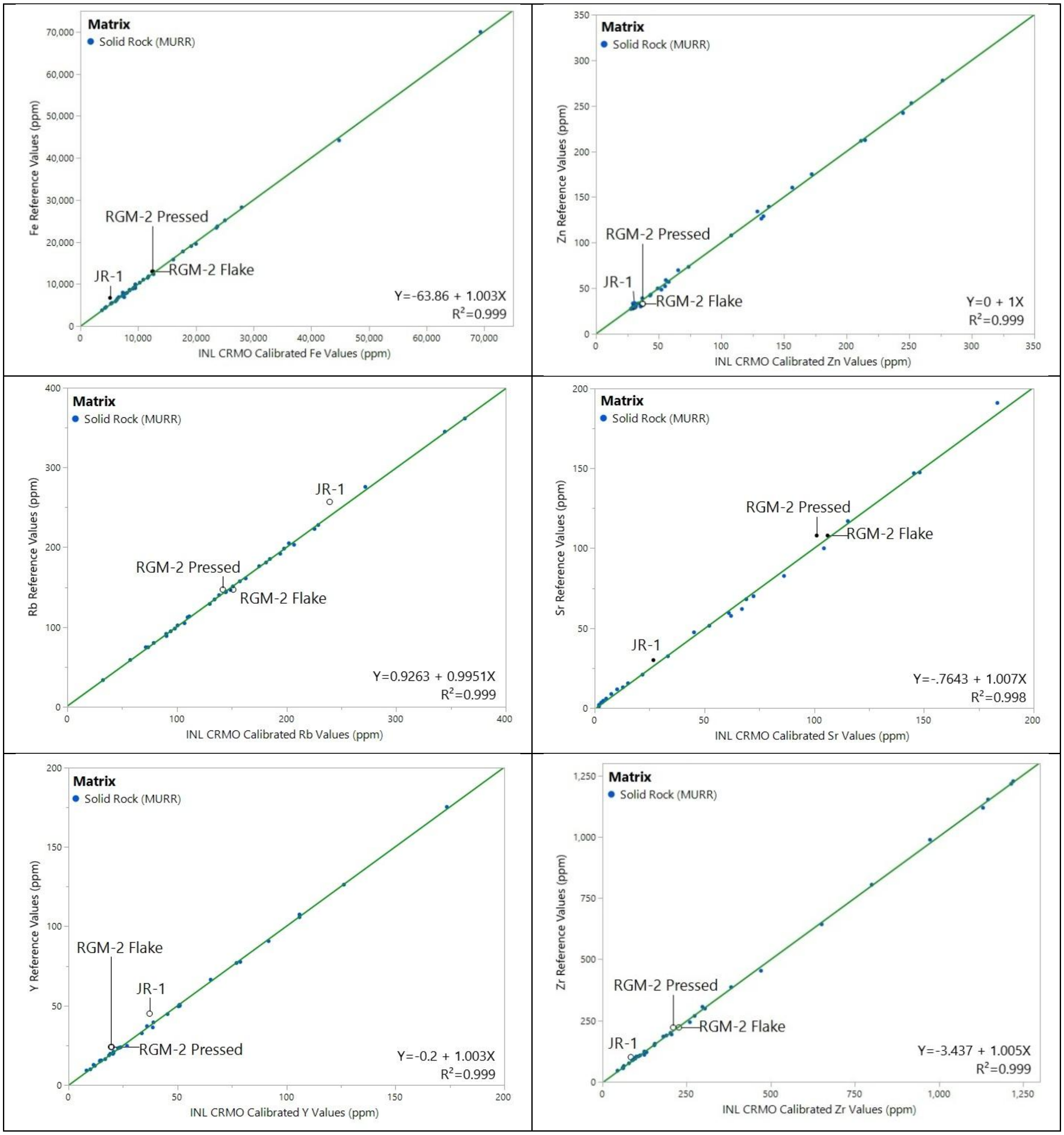
Figure 14. FP calibrated Ba values (in ppm) vs. published reference values. The calibration curve for Ba is shown in green.

VALIDATION

To validate the calibration, the calibrated values for the reference standards were plotted against the published reference values (Figure 15). In this context, one would expect a line of best fit with a slope as close to 1 as possible with a Y-intercept of 0. In general, these lines displayed very good accord, with slopes ranging from 0.9951 (Rb) to 1.007 (Sr). The R^2 values for all elements were 0.994 or higher.

After LE adjustment, calibrated values for two geological reference standards were also plotted on Figure 15, including JR-1 (rhyolite) from the Geological Survey of Japan and USGS RGM-2 (rhyolite). The RGM-2 sample included both the pressed powder sample and the solid flake from the RGM-2 boulder. Table 4 provides a comparison of the calibrated results to published values and standard deviations by element for each of these check standards. Most of the calibrated values (76%) fall within two standard deviations of the reference values, and 88% fall within three. Of the four that are above three standard deviations from the reference value, most have especially small standard deviations. Generally, there is strong agreement between calibrated values and published reference values, particularly for elements that are critical for obsidian sourcing such as Fe, Rb, Sr, Y, Zr, and Nb, providing justification for the implementation of this calibration for analyses of obsidian artifacts in Idaho.




Matrix
Solid Rock (MURR)
Fe Reference Values (ppm)
INL CRMO Calibrated Fe Values (ppm)
RGM-2 Pressed
RGM-2 Flake
JR-1
Y=-63.86 + 1.003X
R²=0.999
Matrix
Solid Rock (MURR)
Zn Reference Values (ppm)
INL CRMO Calibrated Zn Values (ppm)
RGM-2 Pressed
JR-1
RGM-2 Flake
Y=0 + 1X
R²=0.999
Matrix
Solid Rock (MURR)
Rb Reference Values (ppm)
INL CRMO Calibrated Rb Values (ppm)
JR-1
RGM-2 Pressed
RGM-2 Flake
Y=0.9263 + 0.9951X
R²=0.999
Matrix
Solid Rock (MURR)
Sr Reference Values (ppm)
INL CRMO Calibrated Sr Values (ppm)
RGM-2 Pressed
RGM-2 Flake
JR-1
Y=-.7643 + 1.007X
R²=0.998
Matrix
Solid Rock (MURR)
Y Reference Values (ppm)
INL CRMO Calibrated Y Values (ppm)
RGM-2 Flake
JR-1
RGM-2 Pressed
Y=-0.2 + 1.003X
R²=0.999
Matrix
Solid Rock (MURR)
Zr Reference Values (ppm)
INL CRMO Calibrated Zr Values (ppm)
RGM-2 Pressed
RGM-2 Flake
JR-1
Y=-3.437 + 1.005X
R²=0.999

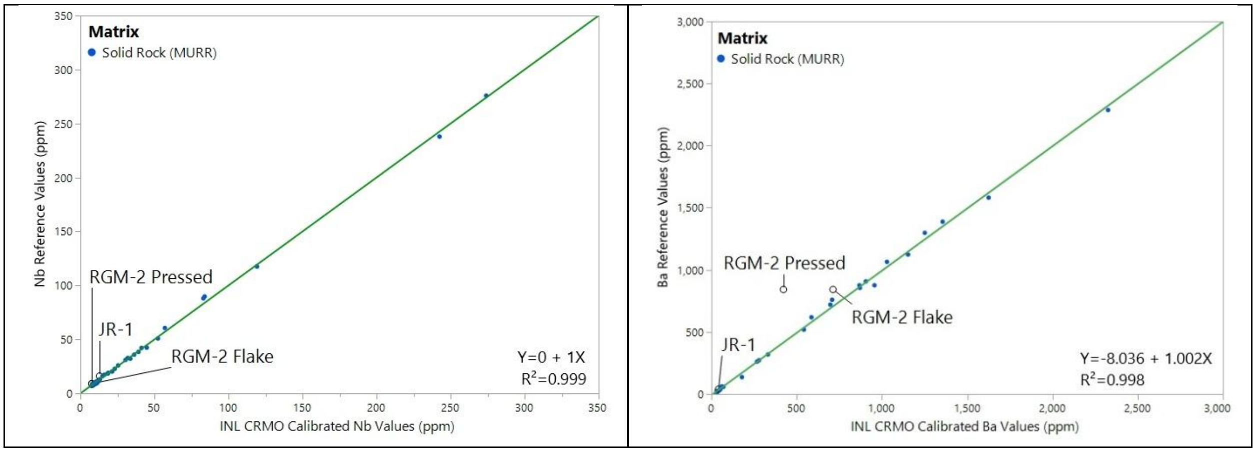


Figure 15. Calibration validation showing calibrated elemental values (in ppm) vs. published reference values with associated regression lines. The reference standards used to validate the accuracy of the calibration are labeled.

Table 4. Reference standards used for validation of the calibration curves, including calibrated values (predicted) and published reference values (expected) and standard deviations by element (Bower et al. 1985; Govindaraju 1994; Sims et al. 1988; Wilson 2009). Calibrated values that are more than two standard deviations from expected values are highlighted in red.

Standard	Element	Predicted (ppm)	Expected (ppm)		Difference	Z-Score
			x̄	1 s		
RGM-2: Rhyolite Glass Mountain Pressed Powder USGS	K	34,468	36,100	1,600	-1,632	-1.02
	Ca	7,364	8,800	300	-1,436	-4.787
	Ti	1,539	1,500	140	39	0.2786
	Mn	292	273	8	19	2.375
	Fe	12,419	13,000	300	-581	-1.937
	Zn	37	33	2	4	2
	Rb	142	147	5	-5	-1
	Sr	101	108	5	-7	-1.4
	Y	20	24	2	-5	-2
	Zr	210	222	20	-12	-0.6
	Nb	8	9	-	-1	-
	Ba	422	842	46	-420	-9.130
RGM-2: Rhyolite Glass Mountain Solid Flake USGS	K	38,222	36,100	1,600	2,122	1.326
	Ca	7,797	8,800	300	-1,003	-3.343
	Ti	1,494	1,500	140	-6	-0.0429
	Mn	280	273	8	7	0.875
	Fe	12,601	13,000	300	-399	-1.33
	Zn	37	33	2	4	2
	Rb	151	147	5	4	0.8
	Sr	106	108	5	-2	-0.4
	Y	19	24	2	-5	-2.5
	Zr	227	222	20	5	0.25
	Nb	8	9	-	-1	-
	Ba	713	842	46	-129	-2.804

Standard	Element	Predicted (ppm)	Expected (ppm) x̄	1 s	Difference	Z-Score
JR-1: Rhyolite Pressed Power Geological Survey of Japan	K	36,196	36,607	830	-411	-0.4952
	Ca	4,439	4,503	214	-64	-0.2991
	Ti	577	599	60	-22	-0.3667
	Mn	756	775	15	-19	-1.267
	Fe	5,124	6,714	699	-1,590	-2.275
	Zn	31	30	5	1	0.2
	Rb	239	257	5	-18	-3.6
	Sr	27	30	5	-3	-0.6
	Y	37	45	5	-8	-1.6
	Zr	84	101	10	-17	-1.7
	Nb	13	16	4	-3	-0.75
	Ba	42	40	50	2	0.04

REFERENCES CITED

Bower, N.W., E.S. Gladney, R.C. Hagan, P.E. Trujillo, and R.G. Warren
1985 Elemental concentrations in Japanese silicate rock standards JA-1, JR- 1 and JB-2. *Geostandards Newsletter* 9(2): 199–203.

Gallhofer, Daniela, and Bernd G. Lottermoser
2018 The influence of spectral interferences on critical element determination with portable X-ray fluorescence (pXRF). *Minerals* 8: 320.

Glascock, Michael D.
2020 A systematic approach to geochemical sourcing of obsidian artifacts. *Scientific Culture* 6(2): 35–47.

Glascock, Michael D., and Jeffrey R. Ferguson
2012 Report on the Analysis of Obsidian Source Samples by Multiple Analytical Methods: Technical Report prepared for Bruce Kaiser of Bruker Corporation. Submitted to Archaeometry Laboratory, University of Missouri Research Reactor, Columbia, MO.

Govindaraju, K.
1994 1994 compilation of working values and sample description for 383 geostandards. *Geostandards Newsletter* 18: 1–158.

Shackley, M. Steven
2011 X-ray fluorescence spectrometry in twenty-first century archaeology. In *X-ray Fluorescence Spectrometry (XRF) in Geoarchaeology*, edited by M. Steven Shackley, pp. 1–6. Springer, New York, NY.

Sims, K.W., E.S. Gladney, C. Lundstrom, and N.W. Bower
1988 Elemental concentrations in Japanese silicate rock standards : A comparison with the literature. *Geostandards Newsletter* 12(2): 379–389.

Wilson, Stephen
2009 Certificate of Analysis: Rhyolite, Glass Mountain RGM-2. Submitted to United States Geological Survey, Reston, VA.

APPENDIX A

Published Elemental Values for Geological Reference Standards

Appendix A. Published elemental values for geological reference standards (in ppm). NR: Not reported; GSJ: Geological Survey of Japan; USGS: U.S. Geological Survey; NIST: National Institute of Standards and Technology; ANRT: Association Nationale de la Recherche et de la Technologie; SARM: South African Reference Materials; MURR: Missouri University Research Reactor.

Sample ID	Agency	Description	Matrix	Al	Si	K	Ca	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Reference
JA-2	GSJ	Andesite	Pressed Powder	81,089	262,585	14,942	46,313	4,016	852	42,943	63	68	252	18	119	10	317	Govindaraju 1994
JA-3	GSJ	Andesite	Pressed Powder	82,412	291,003	11,704	44,883	4,076	821	46,090	68	36	294	21	119	3	318	Govindaraju 1994
AGV-1	USGS	Andesite	Pressed Powder	90,775	275,018	24,239	35,306	6,294	697	47,349	88	67	662	20	227	15	1,226	Govindaraju 1994
JB-2	GSJ	Basalt	Pressed Powder	77,648	248,657	3,486	70,684	7,133	1,549	100,294	110	6	178	25	51	1	208	Govindaraju 1994
JB-3	GSJ	Basalt	Pressed Powder	89,399	238,561	6,475	70,469	8,691	1,239	83,089	106	13	395	27	98	2	251	Govindaraju 1994
SRM-688	NIST	Basalt	Pressed Powder	91,834	225,988	1,577	86,979	7,001	1,293	72,318	58	2	169	19	59	6	200	Govindaraju 1994
BCR-1	USGS	Basalt	Pressed Powder	72,197	252,910	14,029	49,672	13,427	1,394	93,790	130	47	330	38	190	14	681	Govindaraju 1994
DNC-1	USGS	Diabase	Pressed Powder	96,862	219,865	1,901	80,547	2,877	1,154	69,450	66	5	145	18	41	3	114	Govindaraju 1994
W-2	USGS	Diabase	Pressed Powder	81,248	245,105	5,205	77,688	6,354	1,262	75,116	77	20	194	24	94	8	182	Govindaraju 1994
DR-N	ANRT	Diorite	Pressed Powder	92,733	247,021	14,112	50,386	6,533	1,704	67,842	145	73	400	26	125	7	385	Govindaraju 1994
DT-N	ANRT	Disthene	Pressed Powder	313,346	170,367	996	286	8,392	62	4,616	28	6	30	7	370	34	130	Govindaraju 1994
SARM-6, NIM-D	SARM	Dunite	Pressed Powder	1,588	182,099	83	2,001	120	1,704	118,618	90	NR	3	NR	20	NR	10	Govindaraju 1994
DTS-1	USGS	Dunite	Pressed Powder	1,006	188,876	8	1,215	30	929	60,708	46	0	0	0	4	2	2	Govindaraju 1994
JGb-1	GSJ	Gabbro	Pressed Powder	93,474	203,039	1,992	85,621	9,710	1,317	106,029	111	4	321	11	34	3	63	Govindaraju 1994
GS-N	ANRT	Granite	Pressed Powder	77,648	307,549	38,434	17,868	4,076	434	26,228	48	185	570	16	235	21	1,400	Govindaraju 1994
JG-2	GSJ	Granite	Pressed Powder	65,686	359,664	39,181	5,718	240	116	6,434	13	297	16	88	101	15	67	Govindaraju 1994
SARM-1, NIM-G	SARM	Granite	Pressed Powder	63,939	353,822	41,422	5,575	539	163	14,128	50	320	10	143	300	53	120	Govindaraju 1994
G-2	USGS	Granite	Pressed Powder	81,459	323,160	37,188	14,008	2,877	232	18,604	86	170	478	11	309	12	1,882	Govindaraju 1994
JG-1a	GSJ	Granodiorite	Pressed Powder	75,266	337,416	33,287	15,223	1,499	465	14,338	39	180	185	32	121	12	458	Govindaraju 1994
JG-3	GSJ	Granodiorite	Pressed Powder	82,147	313,625	21,832	26,873	2,877	558	26,088	45	66	372	17	143	6	453	Govindaraju 1994
BIR-1	USGS	Icelandic Basalt	Pressed Powder	81,248	223,277	224	94,626	5,754	1,324	78,752	71	0	108	16	16	1	7	Govindaraju 1994
SARM-3, NIM-L	SARM	Lujavrite	Pressed Powder	72,197	244,918	45,739	23,013	2,877	5,964	69,660	400	190	4,600	22	11,000	960	450	Govindaraju 1994

Sample ID	Agency	Description	Matrix	Al	Si	K	Ca	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Reference
JP-1	GSJ	Peridotite	Pressed Powder	3,282	198,131	27	4,002	NR	929	58,330	30	NR	NR	NR	6	1	17	Govindaraju 1994
PCC-1	USGS	Peridotite	Pressed Powder	3,573	194,953	58	3,716	60	929	57,701	42	0	0	0	10	1	1	Govindaraju 1994
JR-1	GSJ	Rhyolite	Pressed Powder	68,227	352,466	36,607	4,503	599	775	6,714	30	257	30	45	101	16	40	Bower et al. 1985; Govindaraju 1994; Sims et al. 1988
JR-2	GSJ	Rhyolite	Pressed Powder	67,856	353,588	36,939	3,216	539	852	6,015	27	297	8	51	97	19	39	Govindaraju 1994
RGM-2	USGS	Rhyolite	Pressed Powder	73,100	343,072	43,500	12,300	1,500	273	13,000	33	147	108	24	222	9	842	Govindaraju 1994; Wilson 2009
UB-N	ANRT	Serpentine	Pressed Powder	15,350	184,296	166	8,576	659	929	58,330	85	4	9	3	4	0	27	Govindaraju 1994
XRF 01	MURR	Rhyolite	Solid Rock	73,280	354,139	36,514	4,903	252	755	3,690	59	172	13	36	46	32	37	Glascock and Ferguson 2012; Glascock 2020
XRF 02	MURR	Rhyolite	Solid Rock	70,893	352,906	34,026	3,368	576	519	4,255	27	91	60	10	56	9	907	Glascock and Ferguson 2012; Glascock 2020
XRF 03	MURR	Rhyolite	Solid Rock	71,312	351,249	36,044	5,152	627	328	6,179	28	94	55	17	96	7	1,141	Glascock and Ferguson 2012; Glascock 2020
XRF 04	MURR	Rhyolite	Solid Rock	56,474	327,461	27,656	999	1,156	1,634	27,448	160	59	1	65	387	16	1,085	Glascock and Ferguson 2012; Glascock 2020
XRF 05	MURR	Rhyolite	Solid Rock	60,096	345,471	17,110	8,648	1,145	593	8,587	50	32	168	25	121	2	319	Glascock and Ferguson 2012; Glascock 2020
XRF 06	MURR	Rhyolite	Solid Rock	64,997	343,719	40,605	3,213	518	297	11,669	253	273	0	202	306	282	3	Glascock and Ferguson 2012; Glascock 2020
XRF 07	MURR	Rhyolite	Solid Rock	66,969	346,656	35,341	3,833	369	357	7,773	43	180	6	24	104	20	23	Glascock and Ferguson 2012; Glascock 2020
XRF 08	MURR	Rhyolite	Solid Rock	68,441	330,715	33,467	2,544	156	441	7,203	134	362	1	77	156	238	3	Glascock and Ferguson 2012; Glascock 2020
XRF 09	MURR	Rhyolite	Solid Rock	68,078	352,570	33,444	6,324	821	250	7,578	32	113	83	20	124	8	1,582	Glascock and Ferguson 2012; Glascock 2020
XRF 10	MURR	Rhyolite	Solid Rock	71,656	341,439	39,778	6,092	1,122	279	9,278	33	145	108	13	189	12	1,065	Glascock and Ferguson 2012; Glascock 2020
XRF 11	MURR	Rhyolite	Solid Rock	69,727	350,273	34,978	5,443	266	522	4,674	31	98	43	20	65	10	272	Glascock and Ferguson 2012; Glascock 2020
XRF 12	MURR	Rhyolite	Solid Rock	71,967	333,161	36,637	6,297	1,429	264	10,410	34	141	70	23	200	9	720	Glascock and Ferguson 2012; Glascock 2020
XRF 13	MURR	Rhyolite	Solid Rock	69,881	347,920	37,578	5,844	1,286	269	9,234	32	135	68	24	185	10	760	Glascock and Ferguson 2012; Glascock 2020
XRF 14	MURR	Rhyolite	Solid Rock	69,505	342,932	24,646	7,117	465	537	10,825	52	81	139	15	96	8	855	Glascock and Ferguson 2012; Glascock 2020
XRF 15	MURR	Rhyolite	Solid Rock	56,848	344,493	35,022	1,322	954	458	17,193	126	98	2	78	643	42	43	Glascock and Ferguson 2012; Glascock 2020
XRF 16	MURR	Rhyolite	Solid Rock	55,310	357,187	34,752	1,214	837	582	18,851	129	157	1	66	805	61	4	Glascock and Ferguson 2012; Glascock 2020
XRF 17	MURR	Trachyte	Solid Rock	35,985	311,571	33,147	1,484	1,557	1,775	53,658	592	436	6	395	3,489	606	26	Glascock and Ferguson 2012; Glascock 2020

Sample ID	Agency	Description	Matrix	Al	Si	K	Ca	Ti	Mn	Fe	Zn	Rb	Sr	Y	Zr	Nb	Ba	Reference
XRF 18	MURR	Trachydacite	Solid Rock	70,304	317,748	41,436	5,669	3,081	1,077	23,364	140	203	52	83	1,157	276	261	Glascock and Ferguson 2012; Glascock 2020
XRF 19	MURR	Rhyolite	Solid Rock	72,745	359,091	35,671	3,859	419	403	6,619	39	230	11	37	103	26	55	Glascock and Ferguson 2012; Glascock 2020
XRF 20	MURR	Andesite	Solid Rock	78,724	266,039	2,036	49,864	7,842	1,082	68,537	123	11	291	16	76	4	137	Glascock and Ferguson 2012; Glascock 2020
XRF 21	MURR	Trachydacite	Solid Rock	76,886	313,689	38,973	6,877	1,590	632	9,943	64	155	167	33	244	36	1,107	Glascock and Ferguson 2012; Glascock 2020
XRF 22	MURR	Rhyolite	Solid Rock	63,380	329,891	36,776	1,817	1,008	461	23,295	212	338	1	108	1,119	119	4	Glascock and Ferguson 2012; Glascock 2020
XRF 23	MURR	Rhyolite	Solid Rock	52,739	343,675	34,972	870	814	649	25,160	175	205	2	91	1,153	90	7	Glascock and Ferguson 2012; Glascock 2020
XRF 24	MURR	Rhyolite	Solid Rock	57,598	348,232	37,606	1,089	793	234	19,350	242	219	0	175	1,227	58	1	Glascock and Ferguson 2012; Glascock 2020
XRF 25	MURR	Rhyolite	Solid Rock	43,364	337,386	30,207	984	689	1,215	43,835	278	186	9	126	1,217	118	56	Glascock and Ferguson 2012; Glascock 2020
XRF 26	MURR	Trachydacite	Solid Rock	64,424	301,658	35,190	4,249	1,079	434	11,808	64	104	22	50	299	19	1,388	Glascock and Ferguson 2012; Glascock 2020
XRF 27	MURR	Rhyolite	Solid Rock	67,658	363,429	40,119	5,756	530	410	5,283	28	108	58	16	88	11	619	Glascock and Ferguson 2012; Glascock 2020
XRF 28	MURR	Rhyolite	Solid Rock	63,705	351,425	36,373	2,500	528	414	7,121	57	150	3	40	150	51	27	Glascock and Ferguson 2012; Glascock 2020
XRF 29	MURR	Rhyolite	Solid Rock	61,885	354,534	32,214	4,745	333	308	8,149	70	92	32	50	123	11	1,298	Glascock and Ferguson 2012; Glascock 2020
XRF 30	MURR	Rhyolite	Solid Rock	60,772	359,242	32,867	785	1,128	1,113	16,267	212	198	2	106	988	88	11	Glascock and Ferguson 2012; Glascock 2020
XRF 31	MURR	Rhyolite	Solid Rock	67,896	344,287	39,784	3,067	447	448	3,810	33	145	4	19	57	42	11	Glascock and Ferguson 2012; Glascock 2020
XRF 32	MURR	Rhyolite	Solid Rock	62,235	339,584	35,627	1,690	613	255	12,382	103	148	0	51	454	33	6	Glascock and Ferguson 2012; Glascock 2020
XRF 33	MURR	Rhyolite	Solid Rock	65,913	354,966	45,651	4,778	1,175	172	10,633	39	278	34	44	206	17	278	Glascock and Ferguson 2012; Glascock 2020
XRF 34	MURR	Rhyolite	Solid Rock	62,039	342,435	39,065	2,554	819	365	8,527	57	164	5	45	194	39	62	Glascock and Ferguson 2012; Glascock 2020
XRF 35	MURR	Rhyolite	Solid Rock	75,509	354,744	31,712	10,804	807	546	8,666	49	114	283	15	108	18	876	Glascock and Ferguson 2012; Glascock 2020
XRF 36	MURR	Rhyolite	Solid Rock	67,043	345,379	34,572	2,859	455	538	9,349	74	196	16	50	269	31	58	Glascock and Ferguson 2012; Glascock 2020
XRF 37	MURR	Rhyolite	Solid Rock	64,082	359,549	39,204	3,235	525	351	5,465	30	131	21	21	91	13	519	Glascock and Ferguson 2012; Glascock 2020
XRF 38	MURR	Rhyolite	Solid Rock	71,058	352,520	36,045	8,209	222	670	6,491	42	74	137	20	58	11	2,287	Glascock and Ferguson 2012; Glascock 2020
XRF 39	MURR	Rhyolite	Solid Rock	69,105	339,235	28,261	5,887	564	309	7,300	30	76	101	12	88	7	876	Glascock and Ferguson 2012; Glascock 2020
XRF 40	MURR	Rhyolite	Solid Rock	81,762	337,141	38,459	8,090	549	886	6,099	53	215	274	9	111	23	1,124	Glascock and Ferguson 2012; Glascock 2020

APPENDIX B

INL CRMO Elemental Values for Geological Reference Standards

Appendix B. INL CRMO elemental values for geological reference standards (in ppm). LE: Light Element; Adj: LE Adjusted Values; Cal: Calibrated.

Sample ID	Matrix	LE	K Raw	K Adj	K Cal	Ca Raw	Ca Adj	Ca Cal	Ti Raw	Ti Adj	Ti Cal	Mn Raw	Mn Adj	Mn Cal	Fe Raw	Fe Adj	Fe Cal
JA-2	Pressed Powder	542,750	12,144	13,784	15,302	40,805	46,317	40,947	3,627	4,117	4,250	689	782	847	39,085	44,364	41,832
JA-3	Pressed Powder	519,486	9,306	10,210	11,467	43,957	48,229	42,630	3,615	3,966	4,094	667	732	793	40,533	44,472	41,934
AGV-1	Pressed Powder	626,344	15,291	20,007	21,978	25,571	33,457	29,624	4,489	5,873	6,063	505	661	717	33,033	43,220	40,753
JB-2	Pressed Powder	507,492	2,180	2,472	3,164	64,457	73,083	64,513	6,179	7,006	7,232	1,434	1,626	1,752	89,461	101,434	95,645
JB-3	Pressed Powder	450,304	5,523	5,529	6,444	71,568	71,641	63,243	8,465	8,474	8,747	1,215	1,216	1,313	75,718	75,795	71,470
SRM-688	Pressed Powder	517,317	731	823	1,396	82,253	92,659	81,748	6,278	7,072	7,300	1,004	1,131	1,222	63,213	71,211	67,147
BCR-1	Pressed Powder	585,746	9,522	12,205	13,608	35,305	45,254	40,011	10,262	13,154	13,578	953	1,222	1,319	67,401	86,395	81,464
DNC-1	Pressed Powder	504,045	1,044	1,162	1,759	76,639	85,299	75,268	2,547	2,835	2,926	949	1,056	1,141	61,944	68,944	65,009
W-2	Pressed Powder	473,150	4,223	4,402	5,235	74,799	77,974	68,818	6,247	6,512	6,722	1,061	1,106	1,195	68,393	71,296	67,227
DR-N	Pressed Powder	570,007	9,846	11,909	13,289	41,972	50,765	44,863	4,976	6,018	6,212	1,272	1,538	1,659	55,515	67,145	63,313
DT-N	Pressed Powder	556,749	637	707	1,271	303	337	465	7,677	8,526	8,801	0	0	9	3,762	4,178	3,940
SARM-6, NIM-D	Pressed Powder	453,857	0	0	512	2,210	2,324	2,214	114	120	124	1,416	1,489	1,605	107,609	113,147	106,690
DTS-1	Pressed Powder	476,020	0	0	512	960	1,021	1,067	0	0	0	843	896	970	55,278	58,778	55,423
JGb-1	Pressed Powder	438,940	981	973	1,555	86,982	86,234	76,091	8,816	8,740	9,022	1,273	1,262	1,362	97,802	96,961	91,427
GS-N	Pressed Powder	534,621	31,591	34,846	37,900	15,734	17,355	15,448	3,135	3,458	3,570	331	365	400	22,626	24,958	23,533
JG-2	Pressed Powder	465,125	38,793	36,362	39,527	5,460	5,118	4,674	244	229	236	113	106	122	7,050	6,608	6,231
SARM-1, NIM-G	Pressed Powder	545,070	36,352	40,290	43,741	5,684	6,300	5,715	528	585	604	104	115	132	13,482	14,942	14,090
G-2	Pressed Powder	592,626	26,678	32,553	35,440	10,747	13,114	11,714	2,019	2,464	2,543	163	199	222	13,581	16,572	15,626
JG-1a	Pressed Powder	558,353	27,284	30,918	33,685	14,571	16,512	14,706	1,230	1,394	1,439	400	453	495	13,036	14,772	13,929
JG-3	Pressed Powder	575,359	17,383	20,620	22,636	23,745	28,166	24,967	2,334	2,769	2,858	454	539	586	22,539	26,736	25,210
BIR-1	Pressed Powder	445,749	0	0	512	96,328	96,937	85,514	5,381	5,415	5,590	1,128	1,135	1,226	72,089	72,545	68,405
SARM-3, NIM-L	Pressed Powder	526,784	37,434	41,647	45,198	20,672	22,999	20,417	2,563	2,851	2,943	4,676	5,202	5,588	60,258	67,040	63,214
JP-1	Pressed Powder	466,025	0	0	512	4,343	4,346	3,995	0	0	0	869	870	941	56,672	56,709	53,473
PCC-1	Pressed Powder	468,813	0	0	512	3,682	3,622	3,358	0	0	0	829	816	883	55,721	54,819	51,691
JR-1	Pressed Powder	552,842	30,044	33,257	36,196	4,382	4,851	4,439	505	559	577	630	697	757	5,550	6,144	5,793
JR-2	Pressed Powder	538,756	32,128	34,547	37,579	3,396	3,652	3,383	277	298	307	762	819	887	5,053	5,433	5,123
RGM-2	Pressed Powder	612,416	25,385	31,647	34,468	6,556	8,173	7,348	1,196	1,491	1,539	212	264	292	10,565	13,171	12,392
RGM-2	Solid Rock	497,840	35,146	-	38,222	8,665	-	7,797	1,447	-	1,494	253	-	280	13,364	-	12,601
UB-N	Pressed Powder	575,044	0	0	512	6,088	6,746	6,108	520	576	595	784	869	940	50,293	55,732	52,551
XRF 01	Solid Rock	480,574	34,908	-	37,966	5,316	-	4,849	389	-	402	697	-	756	3,959	-	3,733
XRF 02	Solid Rock	473,593	32,719	-	35,618	3,768	-	3,486	636	-	656	486	-	529	4,493	-	4,237

Sample ID	Matrix	LE	K Raw	K Adj	K Cal	Ca Raw	Ca Adj	Ca Cal	Ti Raw	Ti Adj	Ti Cal	Mn Raw	Mn Adj	Mn Cal	Fe Raw	Fe Adj	Fe Cal
XRF 03	Solid Rock	469,101	34,663	-	37,703	6,409	-	5,811	653	-	674	299	-	329	6,653	-	6,273
XRF 04	Solid Rock	514,362	28,170	-	30,737	1,153	-	1,183	1,165	-	1,203	1,571	-	1,693	29,632	-	27,941
XRF 05	Solid Rock	477,554	18,030	-	19,857	10,187	-	9,138	1,376	-	1,420	570	-	620	9,627	-	9,078
XRF 06	Solid Rock	475,680	37,593	-	40,848	3,390	-	3,153	544	-	562	263	-	290	12,508	-	11,794
XRF 07	Solid Rock	469,624	38,330	-	41,638	4,051	-	3,735	508	-	524	311	-	343	8,244	-	7,774
XRF 08	Solid Rock	477,177	33,886	-	36,870	3,721	-	3,445	602	-	621	405	-	443	7,695	-	7,256
XRF 09	Solid Rock	464,861	33,990	-	36,982	6,900	-	6,243	817	-	843	226	-	251	8,048	-	7,588
XRF 10	Solid Rock	469,259	42,108	-	45,692	6,491	-	5,883	1,083	-	1,118	245	-	271	9,842	-	9,281
XRF 11	Solid Rock	466,931	36,843	-	40,043	5,963	-	5,419	278	-	287	479	-	523	4,715	-	4,446
XRF 12	Solid Rock	484,735	38,243	-	41,545	6,752	-	6,113	1,390	-	1,435	232	-	258	10,898	-	10,276
XRF 13	Solid Rock	463,615	37,709	-	40,972	6,425	-	5,825	1,272	-	1,313	241	-	267	10,079	-	9,504
XRF 14	Solid Rock	466,296	26,701	-	29,161	7,849	-	7,079	442	-	457	498	-	543	11,561	-	10,901
XRF 15	Solid Rock	496,229	35,996	-	39,134	1,362	-	1,368	977	-	1,009	418	-	457	18,836	-	17,761
XRF 16	Solid Rock	469,463	35,632	-	38,743	1,430	-	1,427	868	-	896	532	-	580	20,352	-	19,191
XRF 17	Solid Rock	492,435	32,750	-	35,652	1,381	-	1,384	1,328	-	1,371	1,686	-	1,816	57,342	-	54,069
XRF 18	Solid Rock	472,295	42,033	-	45,611	5,617	-	5,113	3,155	-	3,257	984	-	1,064	24,986	-	23,560
XRF 19	Solid Rock	487,606	38,628	-	41,958	4,080	-	3,760	499	-	515	356	-	391	7,052	-	6,650
XRF 20	Solid Rock	422,871	3,846	-	4,638	59,905	-	52,910	7,691	-	7,939	1,012	-	1,094	73,526	-	69,330
XRF 21	Solid Rock	434,611	36,463	-	39,635	7,033	-	6,360	1,516	-	1,565	560	-	609	10,092	-	9,516
XRF 22	Solid Rock	472,562	37,989	-	41,273	1,865	-	1,810	938	-	968	418	-	457	25,178	-	23,741
XRF 23	Solid Rock	468,069	34,582	-	37,617	903	-	963	887	-	916	609	-	661	26,567	-	25,051
XRF 24	Solid Rock	469,742	36,624	-	39,808	1,109	-	1,145	788	-	813	212	-	236	21,244	-	20,031
XRF 25	Solid Rock	474,402	34,052	-	37,048	1,023	-	1,069	677	-	699	1,200	-	1,296	47,552	-	44,838
XRF 26	Solid Rock	469,823	36,516	-	39,692	4,495	-	4,126	1,023	-	1,056	395	-	432	12,352	-	11,647
XRF 27	Solid Rock	493,823	37,458	-	40,703	6,276	-	5,694	697	-	719	369	-	404	5,595	-	5,276
XRF 28	Solid Rock	482,854	37,779	-	41,047	2,591	-	2,450	638	-	659	380	-	417	7,796	-	7,351
XRF 29	Solid Rock	469,832	31,201	-	33,989	4,864	-	4,451	302	-	311	280	-	309	8,577	-	8,087
XRF 30	Solid Rock	486,338	36,562	-	39,741	788	-	862	1,168	-	1,206	1,063	-	1,149	17,069	-	16,095
XRF 31	Solid Rock	437,567	37,536	-	40,786	3,282	-	3,058	470	-	485	411	-	449	4,003	-	3,775
XRF 32	Solid Rock	446,736	38,615	-	41,944	1,739	-	1,699	610	-	630	226	-	251	13,432	-	12,666
XRF 33	Solid Rock	482,865	37,646	-	40,905	3,504	-	3,253	313	-	323	162	-	182	7,157	-	6,749
XRF 34	Solid Rock	467,160	40,737	-	44,221	2,591	-	2,450	800	-	826	325	-	357	9,054	-	8,537
XRF 35	Solid Rock	432,837	32,976	-	35,894	11,944	-	10,684	744	-	768	503	-	548	9,035	-	8,519
XRF 36	Solid Rock	477,474	35,432	-	38,529	3,028	-	2,834	469	-	484	486	-	530	10,078	-	9,503

Sample ID	Matrix	LE	K Raw	K Adj	K Cal	Ca Raw	Ca Adj	Ca Cal	Ti Raw	Ti Adj	Ti Cal	Mn Raw	Mn Adj	Mn Cal	Fe Raw	Fe Adj	Fe Cal
XRF 37	Solid Rock	469,588	37,836	-	41,109	3,491	-	3,242	531	-	548	316	-	348	5,785	-	5,455
XRF 38	Solid Rock	464,618	35,580	-	38,688	9,247	-	8,309	223	-	230	611	-	664	6,815	-	6,426
XRF 39	Solid Rock	472,339	27,766	-	30,304	6,668	-	6,039	540	-	557	277	-	306	7,778	-	7,334
XRF 40	Solid Rock	472,030	35,822	-	38,948	8,951	-	8,049	546	-	564	816	-	884	6,421	-	6,055

Sample ID	Matrix	Zn Raw	Zn Adj	Zn Cal	Rb Raw	Rb Adj	Rb Cal	Sr Raw	Sr Adj	Sr Cal	Y Raw	Y Adj	Y Cal	Zr Raw	Zr Adj	Zr Cal
JA-2	Pressed Powder	64	73	63	64	73	69	221	251	249	15	17	15	99	112	111
JA-3	Pressed Powder	64	70	62	32	35	33	255	280	277	17	19	17	99	109	108
AGV-1	Pressed Powder	70	92	79	46	60	57	461	603	598	14	18	16	156	204	202
JB-2	Pressed Powder	109	124	104	7	8	8	159	180	179	24	27	24	43	49	48
JB-3	Pressed Powder	99	99	85	14	14	13	385	385	382	25	25	22	85	85	84
SRM-688	Pressed Powder	67	75	66	3	3	3	148	167	165	18	20	18	47	53	52
BCR-1	Pressed Powder	98	126	106	35	45	42	239	306	304	26	33	30	132	169	168
DNC-1	Pressed Powder	59	66	58	4	4	4	124	138	137	16	18	16	31	35	34
W-2	Pressed Powder	74	77	67	18	19	18	174	181	180	20	21	18	83	87	86
DR-N	Pressed Powder	134	162	135	60	73	69	331	400	397	23	28	25	96	116	115
DT-N	Pressed Powder	24	27	26	4	4	4	28	31	31	4	4	4	320	355	352
SARM-6, NIM-D	Pressed Powder	90	95	81	1	1	1	2	2	2	2	2	2	5	5	5
DTS-1	Pressed Powder	44	47	43	0	0	0	0	0	0	0	0	0	2	2	2
JGb-1	Pressed Powder	117	116	98	6	6	6	304	301	299	8	8	7	28	28	28
GS-N	Pressed Powder	36	40	37	161	178	168	503	555	550	12	13	12	192	212	210
JG-2	Pressed Powder	14	13	16	295	277	262	15	14	14	79	74	66	80	75	74
SARM-1, NIM-G	Pressed Powder	58	64	57	325	360	341	10	11	11	133	147	131	244	270	268
G-2	Pressed Powder	74	90	78	125	153	144	352	430	426	4	5	4	228	278	276
JG-1a	Pressed Powder	38	43	40	170	193	182	170	193	191	27	31	27	95	108	107
JG-3	Pressed Powder	45	53	48	58	69	65	327	388	385	13	15	14	114	135	134
BIR-1	Pressed Powder	65	65	58	0	0	0	98	99	98	15	15	13	13	13	13
SARM-3, NIM-L	Pressed Powder	445	495	403	168	187	177	3,905	4,345	4,309	25	28	25	9,548	10,623	10,524
JP-1	Pressed Powder	46	46	42	0	0	0	0	0	0	0	0	0	5	5	5
PCC-1	Pressed Powder	44	43	40	1	1	1	0	0	0	0	0	0	2	2	2
JR-1	Pressed Powder	29	32	31	229	253	240	24	27	26	38	42	37	77	85	84
JR-2	Pressed Powder	27	29	28	284	305	289	7	8	7	44	47	42	76	82	81

Sample ID	Matrix	Zn Raw	Zn Adj	Zn Cal	Rb Raw	Rb Adj	Rb Cal	Sr Raw	Sr Adj	Sr Cal	Y Raw	Y Adj	Y Cal	Zr Raw	Zr Adj	Zr Cal
RGM-2	Pressed Powder	32	40	37	120	150	142	82	102	101	18	22	20	170	212	210
RGM-2	Solid Rock	40	-	37	160	-	151	107	-	106	22	-	19	229	-	227
UB-N	Pressed Powder	80	89	76	4	4	4	6	7	7	3	3	3	4	4	4
XRF 01	Solid Rock	63	-	56	185	-	175	13	-	13	44	-	39	45	-	45
XRF 02	Solid Rock	28	-	28	95	-	90	62	-	61	11	-	10	62	-	61
XRF 03	Solid Rock	29	-	28	100	-	94	68	-	67	26	-	23	99	-	98
XRF 04	Solid Rock	189	-	157	61	-	57	0	-	0	80	-	71	386	-	382
XRF 05	Solid Rock	57	-	51	34	-	32	185	-	183	30	-	27	132	-	131
XRF 06	Solid Rock	307	-	252	287	-	272	0	-	0	235	-	208	300	-	297
XRF 07	Solid Rock	48	-	44	192	-	181	5	-	5	26	-	23	107	-	106
XRF 08	Solid Rock	154	-	129	383	-	363	2	-	2	87	-	77	157	-	156
XRF 09	Solid Rock	31	-	30	118	-	111	87	-	86	22	-	19	125	-	124
XRF 10	Solid Rock	35	-	33	153	-	144	116	-	115	13	-	12	192	-	190
XRF 11	Solid Rock	32	-	31	104	-	98	46	-	45	23	-	20	64	-	63
XRF 12	Solid Rock	32	-	31	146	-	138	73	-	72	26	-	23	204	-	202
XRF 13	Solid Rock	33	-	32	142	-	134	70	-	69	27	-	24	182	-	181
XRF 14	Solid Rock	62	-	55	83	-	79	149	-	148	16	-	14	96	-	95
XRF 15	Solid Rock	158	-	132	106	-	101	2	-	2	89	-	79	657	-	651
XRF 16	Solid Rock	160	-	134	166	-	157	0	-	0	74	-	65	807	-	800
XRF 17	Solid Rock	705	-	572	462	-	437	0	-	0	435	-	385	3,164	-	3,134
XRF 18	Solid Rock	165	-	138	219	-	207	53	-	52	90	-	79	1,122	-	1,111
XRF 19	Solid Rock	40	-	37	242	-	229	10	-	10	41	-	36	101	-	100
XRF 20	Solid Rock	125	-	106	12	-	11	311	-	308	19	-	17	79	-	79
XRF 21	Solid Rock	67	-	59	159	-	150	182	-	180	38	-	34	262	-	260
XRF 22	Solid Rock	261	-	215	364	-	344	0	-	0	120	-	106	1,141	-	1,131
XRF 23	Solid Rock	208	-	172	214	-	202	0	-	0	104	-	92	1,156	-	1,146
XRF 24	Solid Rock	299	-	245	238	-	226	0	-	0	196	-	174	1,232	-	1,221
XRF 25	Solid Rock	338	-	277	195	-	185	8	-	8	143	-	126	1,226	-	1,215
XRF 26	Solid Rock	64	-	57	109	-	103	23	-	22	57	-	51	307	-	304
XRF 27	Solid Rock	30	-	29	113	-	107	63	-	62	17	-	15	89	-	89
XRF 28	Solid Rock	66	-	58	160	-	151	3	-	3	44	-	39	155	-	154
XRF 29	Solid Rock	75	-	66	96	-	91	34	-	33	58	-	51	126	-	125
XRF 30	Solid Rock	257	-	212	205	-	194	0	-	0	120	-	106	982	-	973
XRF 31	Solid Rock	30	-	29	153	-	145	4	-	4	21	-	19	60	-	60

Sample ID	Matrix	Zn Raw	Zn Adj	Zn Cal	Rb Raw	Rb Adj	Rb Cal	Sr Raw	Sr Adj	Sr Cal	Y Raw	Y Adj	Y Cal	Zr Raw	Zr Adj	Zr Cal
XRF 32	Solid Rock	128	-	108	157	-	149	0	-	0	58	-	51	475	-	471
XRF 33	Solid Rock	40	-	37	190	-	180	5	-	5	30	-	27	95	-	94
XRF 34	Solid Rock	65	-	58	172	-	163	4	-	4	51	-	45	207	-	205
XRF 35	Solid Rock	59	-	52	116	-	110	306	-	303	16	-	14	113	-	112
XRF 36	Solid Rock	86	-	74	209	-	198	15	-	15	57	-	50	276	-	274
XRF 37	Solid Rock	33	-	31	137	-	130	22	-	22	23	-	21	93	-	92
XRF 38	Solid Rock	47	-	43	76	-	72	147	-	145	23	-	21	61	-	61
XRF 39	Solid Rock	38	-	36	78	-	74	105	-	104	14	-	12	90	-	89
XRF 40	Solid Rock	71	-	62	226	-	214	290	-	288	9	-	8	125	-	124

Sample ID	Matrix	Nb Raw	Nb Adj	Nb Cal	Ba Raw	Ba Adj	Ba Cal
JA-2	Pressed Powder	5	6	8	296	336	271
JA-3	Pressed Powder	0	0	3	258	283	228
AGV-1	Pressed Powder	6	8	10	810	1,060	854
JB-2	Pressed Powder	0	0	3	169	192	154
JB-3	Pressed Powder	0	0	3	234	234	189
SRM-688	Pressed Powder	0	0	3	165	186	150
BCR-1	Pressed Powder	5	6	9	544	697	562
DNC-1	Pressed Powder	0	0	3	108	120	97
W-2	Pressed Powder	0	0	3	170	177	143
DR-N	Pressed Powder	2	2	5	309	374	301
DT-N	Pressed Powder	33	37	35	102	113	91
SARM-6, NIM-D	Pressed Powder	0	0	3	0	0	0
DTS-1	Pressed Powder	0	0	3	39	41	33
JGb-1	Pressed Powder	0	0	3	91	90	73
GS-N	Pressed Powder	15	17	18	1,028	1,134	914
JG-2	Pressed Powder	8	7	10	71	67	54
SARM-1, NIM-G	Pressed Powder	46	51	48	55	61	49
G-2	Pressed Powder	5	6	9	1,297	1,583	1,275
JG-1a	Pressed Powder	6	7	9	249	282	227
JG-3	Pressed Powder	2	2	5	360	427	344
BIR-1	Pressed Powder	0	0	3	34	34	28

Sample ID	Matrix	Nb Raw	Nb Adj	Nb Cal	Ba Raw	Ba Adj	Ba Cal
SARM-3, NIM-L	Pressed Powder	946	1,052	926	366	407	328
JP-1	Pressed Powder	0	0	3	46	46	37
PCC-1	Pressed Powder	0	0	3	39	38	31
JR-1	Pressed Powder	10	11	13	47	52	42
JR-2	Pressed Powder	12	13	15	39	42	34
RGM-2	Pressed Powder	4	5	8	420	524	422
RGM-2	Solid Rock	5	-	8	885	-	713
UB-N	Pressed Powder	0	0	3	51	57	46
XRF 01	Solid Rock	35	-	34	62	-	50
XRF 02	Solid Rock	9	-	11	1,124	-	906
XRF 03	Solid Rock	5	-	8	1,624	-	1,308
XRF 04	Solid Rock	13	-	15	1,202	-	969
XRF 05	Solid Rock	0	-	0	411	-	331
XRF 06	Solid Rock	323	-	287	34	-	27
XRF 07	Solid Rock	21	-	21	38	-	31
XRF 08	Solid Rock	273	-	243	0	-	0
XRF 09	Solid Rock	7	-	10	2,017	-	1,626
XRF 10	Solid Rock	10	-	12	1,277	-	1,029
XRF 11	Solid Rock	9	-	11	346	-	279
XRF 12	Solid Rock	5	-	8	866	-	698
XRF 13	Solid Rock	7	-	9	879	-	708
XRF 14	Solid Rock	6	-	9	1,081	-	871
XRF 15	Solid Rock	43	-	41	65	-	52
XRF 16	Solid Rock	61	-	57	0	-	0
XRF 17	Solid Rock	654	-	576	45	-	36
XRF 18	Solid Rock	309	-	274	331	-	267
XRF 19	Solid Rock	25	-	25	67	-	54
XRF 20	Solid Rock	0	-	0	222	-	179
XRF 21	Solid Rock	38	-	36	1,332	-	1,073
XRF 22	Solid Rock	122	-	110	31	-	25
XRF 23	Solid Rock	92	-	84	38	-	31
XRF 24	Solid Rock	52	-	49	33	-	27
XRF 25	Solid Rock	132	-	119	72	-	58

Sample ID	Matrix	Nb Raw	Nb Adj	Nb Cal	Ba Raw	Ba Adj	Ba Cal
XRF 26	Solid Rock	18	-	19	1,683	-	1,356
XRF 27	Solid Rock	9	-	11	728	-	587
XRF 28	Solid Rock	56	-	52	48	-	39
XRF 29	Solid Rock	8	-	11	1,553	-	1,251
XRF 30	Solid Rock	91	-	83	40	-	32
XRF 31	Solid Rock	47	-	45	40	-	32
XRF 32	Solid Rock	33	-	32	0	-	0
XRF 33	Solid Rock	15	-	16	50	-	41
XRF 34	Solid Rock	41	-	39	76	-	62
XRF 35	Solid Rock	17	-	18	1,187	-	956
XRF 36	Solid Rock	31	-	30	87	-	70
XRF 37	Solid Rock	11	-	13	673	-	542
XRF 38	Solid Rock	10	-	12	2,887	-	2,326
XRF 39	Solid Rock	6	-	9	1,076	-	867
XRF 40	Solid Rock	23	-	23	1,431	-	1,153