Results of Sample Analysis of Heavy-mineral Deposits in the Point Lookout Sandstone, Southwest Colorado and Northwest New Mexico

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by

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This report has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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Introduction

The Division of Energy and Minerals, Bureau of Indian Affairs, began a energy and mineral resources program of the Ute Mountain Ute Indian Reservation at the request of the Tribe. As part of that program, the U.S. Geological Survey studied the heavy-mineral deposits that occur on the Reservation. This report summarizes the results of chemical analyses of samples collected from the deposits.

Heavy-mineral deposits were discovered in and around the San Juan Basin in the mid 1950's by airborne radiometric surveys flown by the U.S. Atomic Energy Commission. Early interest in these deposits focused on uranium; however zircon, niobium, and gold were included in later studies. Most of these deposits occur in the Upper Cretaceous Point Lookout Sandstone. The Ute Mountain Ute Indian Reservation (fig. 1) in southwestern Colorado and northwestern New Mexico contains the largest grouping of these deposits within the basin.

The heavy-mineral deposits on the Ute Mountain Ute Reservation are dominantly a rutile and zircon concentration in a diagenetic ferric oxide matrix. All deposits are beach placers in a foreshore environment which represents the upper Point Lookout Sandstone.

Acknowledgments

The study was greatly aided by Steve Manydeeds of Energy and Minerals Division of the Bureau of Indian Affairs and Steve Graham of the Bureau of Indian Affairs in Towaoc, Colorado. In particular, we thank the Energy Office of the Ute Mountain Ute Tribe and the Tribal Council for their assistance and permission to publish the results of this study. Gary Skipp assisted greatly in preparation of samples for analysis.

Locations of Deposits

The locations of most deposits were first described in a series of Atomic Energy Commission Preliminary Reconnaissance Reports(Dow and Batty, 1961). These reports served as a basic reference in most of the later publications including the general location of each deposit and the related airborne anomaly (AA) number. This report follows the same airborne anomaly number sequence.

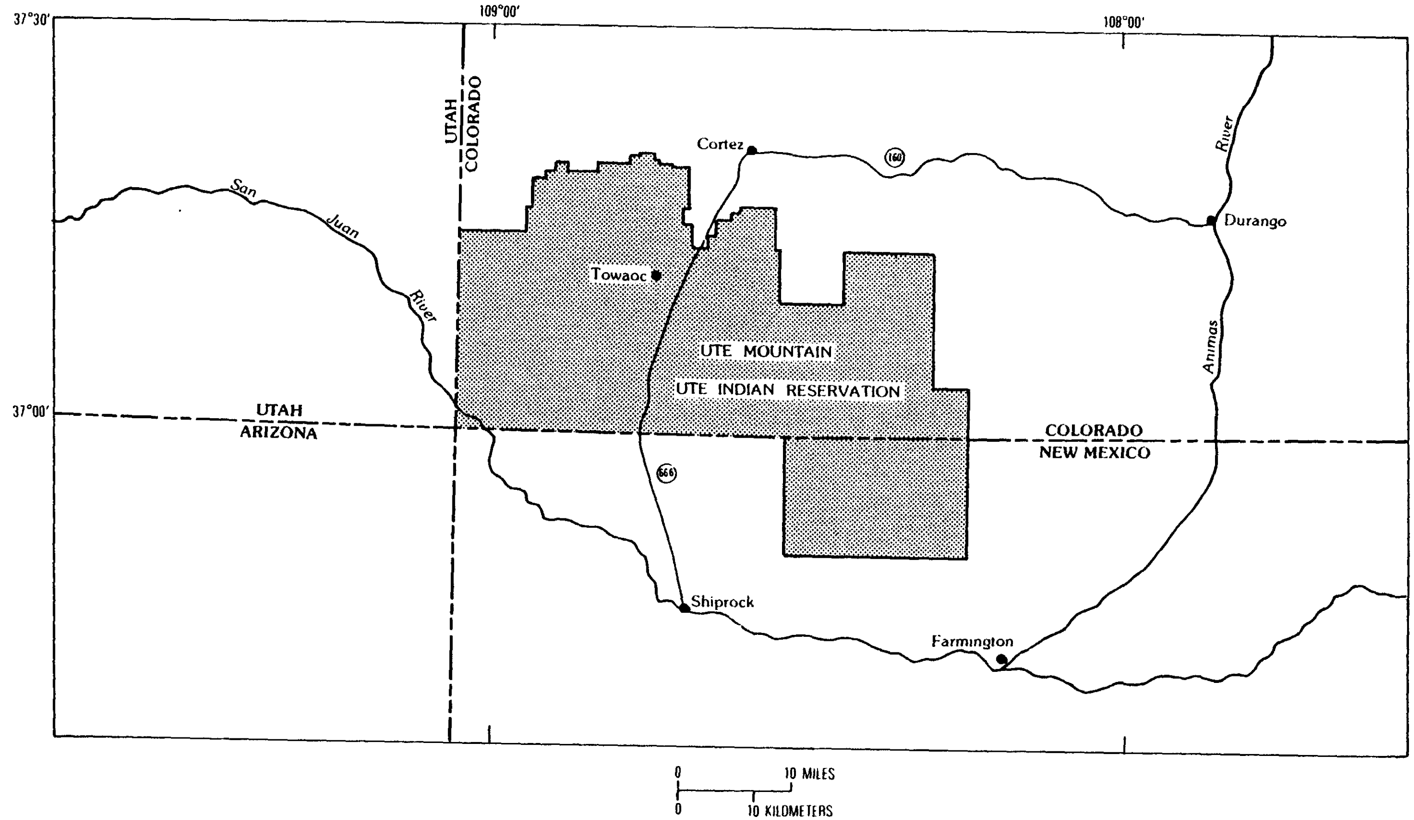

Figure 1. Location of the Ute Mountain Ute Indian Reservation

The deposits were located using maps and descriptions in previous publications(Dow and Batty, 1961; Houston and Murphy, 1977), air photos, and scintillometer traverses. Most, but not all, of the previously identified anomalies were found. All located heavy-mineral deposits are in the central and southeastern part of the Reservation (fig. 2) in the Point Lookout Sandstone. They invariably occur at the top of the Point Lookout, which forms prominent cliffs or outcrops. The deposits, which are better cemented than the surrounding sandstone, form small knolls along the top of the Point Lookout. Figure 2 also shows the conspicuous northwest-southeast alignment of the deposits. This linear form reflects the paleoshoreline and is useful in locating deposits and inferring potential areas of buried deposits.

Figure 2 shows only those deposits that cropout. Several airborne anomalies may be incorporated into one mapped deposit based on field mapping, depositional patterns, and inference across limited areas of cover. Because of the linear form of this type of deposit, some of the deposits may continue across covered areas. Generally, the deposits range from 3 to 5 feet in thickness and 75 to 200 feet in width. The length of a deposit ranges from 100 to 2000 feet.

Sampling and Analysis

Samples of the heavy-mineral deposits were collected and analyzed to identify the elements are present, particularly those that may have economic value. A complete reserve determination for heavy-mineral placer deposits requires very large samples, many samples per deposit, and drilling in covered areas to determine size of deposit. Such a sampling program was beyond the scope of this study.

All samples were collected from outcrops. The intent was to sample an area that would represent the deposit. In reality, many deposits have very limited outcrops. Generally, only the upper part of a deposit is exposed above a cover of colluvium or eolian sand. The relation of the outcrop to the rest of the deposit is unknown. The high degree of induration made representative sampling difficult. Commonly, only areas of increased fracturing and weathering, or less induration, were available for sampling. Because of these reasons, many of the samples are from or near the top of a deposit. Thus, no single sample should be assumed to represent a deposit. The samples as a group do characterize the heavy-mineral deposits.

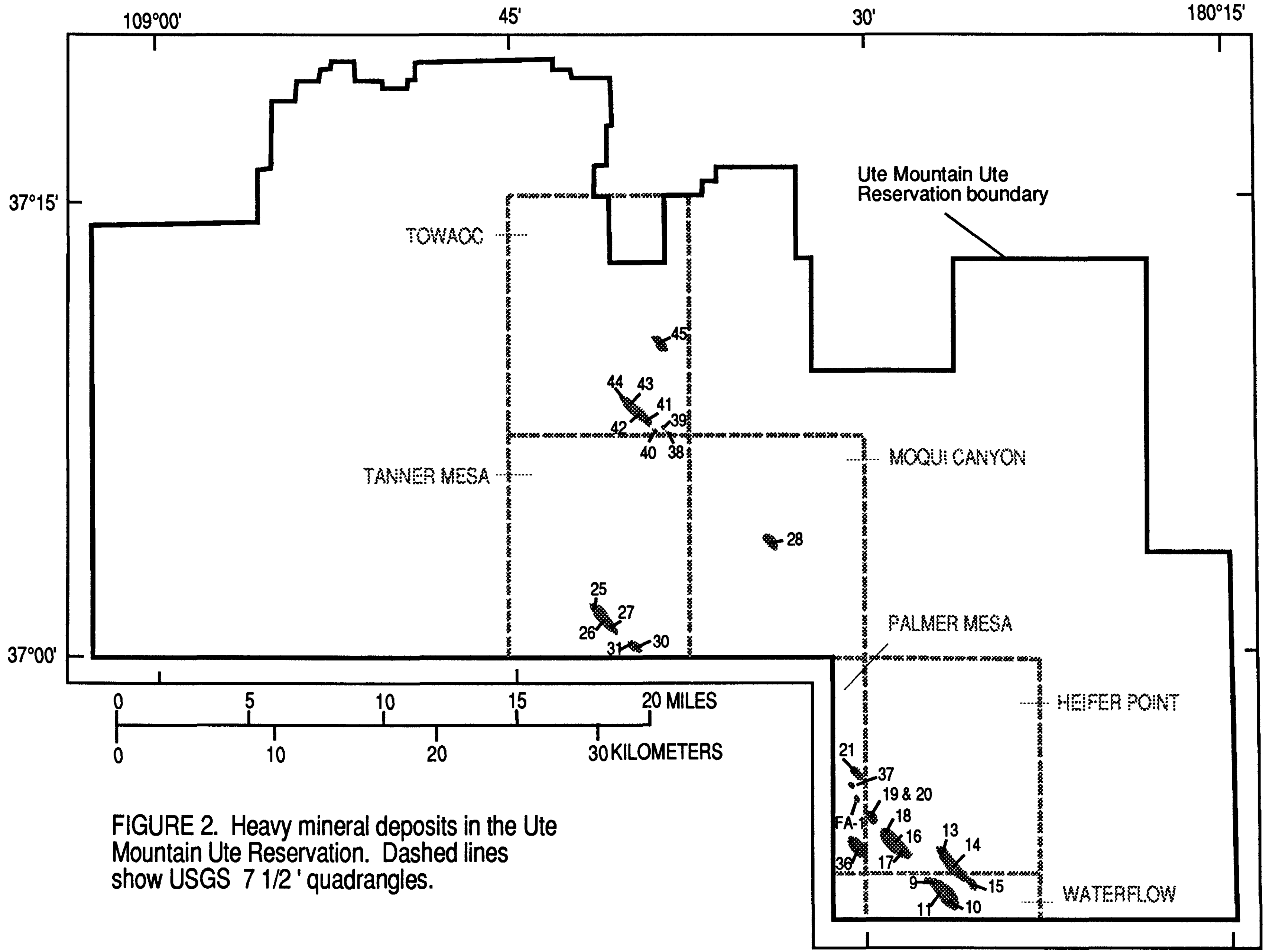

FIGURE 2. Heavy mineral deposits in the Ute Mountain Ute Reservation. Dashed lines show USGS 7 1/2 ' quadrangles.

One or two 0.5-to 1.5-kg samples were taken from each deposit with the exceptions of airborne anomalies AA-10 and AA-17. These two areas were sampled more thoroughly because of better outcrop. Sampling for these two anomalies began in barren rock below and ended at the top of the deposit.

Each field sample was cut with rock saw for thin sections and whole rock specimens. A split of the remaining sample was pulverized (with ceramic shatterbox laboratory mill to -200 mesh) for instrumental neutron activation analysis (INAA) and X-ray fluorescence analysis (XRF). Pulverized samples were split using a mechanical splitter: one split was for INAA, and one split was pressed into pellets for XRF analysis.

Bondar-Clegg & Company, Vancouver, Canada, performed the INAA work. The U.S. Geological Survey, Branch of Central Mineral Resources Rock Analysis Laboratory supplied analytical equipment for the XRF analysis. INAA was chosen to analyze for the majority of elements, XRF was selected to support INAA results and analyze some elements not covered by INAA. Results of INAA and XRF analysis are in appendix 1. INAA and XRF values are not directly comparable for some elements because: 1) particle sparsity caused a difference in composition of the sample splits and 2) detection limits and precision of the amounts of some elements are affected by the relative abundance of other elements (such as iron, titanium, and zirconium). Data shown in appendix 1 are reported as received and are not rounded to significant numbers.

Description of Analytical Methods

Instrumental Neutron Activation Analysis (INAA)

The INAA technique is well summarized in an article by Baedecker and McKowen (1987):

> "Instrumental activation analysis with thermal neutrons (INAA) is a versatile technique for elemental analysis because it has a high sensitivity for many elements, *** provides precise data for many major, minor, and trace elements in a single sample aliquant without chemical treatment. *** The method is based on the irradiation of samples and standards in a reactor neutron flux and the measurement of the induced radioactivity using high resolution gamma-ray spectrometry. The technique has a sensitivity ranging from 0.1 to 10 parts per million for a

wide range of elements including many of the first row transition elements, rare earths, alkali, and alkaline earths."

The lower detection limits for INAA are listed in appendix 2. These limits are under ideal conditions. Sample composition, preparation, and relative elemental concentrations all affect the detection limits. High concentrations of an element such as iron also have an affect on the detection limits and accuracy. It should be noted that gold in this analysis has a sensitivity of 2 ppb.

The Bondar-Clegg staff believes that samples with relatively high levels of Fe (>5percent) have higher detection limits and slightly lower the accuracy for some elements. In general, they expect the values for the elements in high-Fe samples to have a precision of plus or minus 20 percent.

Because the purpose of the analysis is to indicate the higher (i.e., potentially economic) elemental abundances, errors in the detection level are of minor importance. Errors of as much as 20 percent will still show concentration trends. Further confirmation of the abundance of an element can be made by comparing the INAA results with the X-ray fluorescence analyses.

Energy Dispersive X-ray Fluorescence (XRF)

XRF analysis uses a radioactive source to irradiate a sample. In this study, both ^{109}Cd and ^{55}Fe sources were used. A summary of this method by Johnson and King (1987) follows:

"X-ray fluorescence analysis entails the excitation of X-rays within a sample and their subsequent detection and measurement. ***During sample irradiation, inner shell electrons of the elements in the sample absorb specific X-ray photons and are ejected from the atom. Rearrangement of the remaining electrons to fill these vacancies causes the emission of so-called fluorescent X-rays, whose energies are characteristic of the elements from which they originate. ***X-rays emitted by the sample are absorbed in the detector, which acts as a diode in converting these incident X-rays to electronic pulses whose amplitudes are proportional to the energies of the corresponding X-rays. Pulses then are processed and sorted according to amplitude: ***The intensity, or number of counts in a peak, is a direct result of the number of fluorescing atoms of that element in the sample; thus, the area under a peak is proportional to the concentration of that element in the sample."

The minimum detection limits for XRF are listed in appendix 3. These limits were determined under ideal conditions. Sample composition, preparation, and relative elemental concentrations all affect the detection limits. Like INAA, high concentrations of an element such as iron also affect the detection limits and accuracy.

References

Baedecker, P.A. and McKowen, D.M., 1987, Instrumental neutron activation analysis of geochemical samples, in Baedecker, P.A., ed., Methods for Geochemical Analysis: U.S. Geological Survey Bulletin 1770, p. H1-H14.

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Johnson, R.G., and King, B.-S.L., 1987, Energy-dispersive X-ray fluorescence spectrometry, in Baedecker, P.A., ed., Methods for Geochemical Analysis: U.S. Geological Survey Bulletin 1770, p. F1-F5.

APPENDIX 1: Chemical data from neutron activation and X-ray fluorescence analysis of selected whole rock samples[1]

[NA, neutron activation; XRF, X-ray fluorescence; PCT, percent; PPM, parts per million; PPB, parts per billion ; <, below detection limit; ---, no data; Cd, Ir, Sm, and Te not detected; see text for discussion of techniques, comparability, and significant figures]

Elements	Sample numbers						
	AA-8	AA-9	AA-10-1	AA-10-2	AA-10-3	AA-10-4	AA-10-5
Ag (PPM, NA)	14	<10	<2	<2	<2	<2	<2
As (PPM, XRF)	<13	41	21	4	12	18	7
As (PPM, NA)	10	<4.9	3.2	3.4	7.7	4.4	0.7
Au (PPB,NA)	11	20	20	130	160	36	140
Ba (PPM, XRF)	343	487	715	351	768	239	431
Ba (PPM, NA)	540	690	720	340	740	290	410
Br (PPM, NA)	3.7	5.1	<2	<2	<2	6.5	<2
CaO (PCT, XRF)	---	---	0.61	0.68	0.62	1.16	0.42
Ce (PPM, XRF)	1066	1756	73	56	61	261	60
Ce (PPM, NA)	1680	2740	60	43	42	280	47
Co (PPM, NA)	81	50	8	<5	7	55	<5
Cr (PPM, NA)	890	1500	91	77	66	400	96
Cs (PPM, NA)	<1.5	<1.6	2.8	1.2	1.8	3.3	1
Cu (PPM, XRF)	116	283	34	31	59	71	60
Eu (PPM, NA)	<4	8	<1	<1	<1	<1	<1
FeO (PCT, XRF)	[1]>30	[1]>30	1.6	1.3	1.1	2.1	0.8
Fe (PCT, NA)	36.4	23	1.4	1.2	1	1.9	0.7
Ga (PPM, XRF)	37	144	6	7	16	24	17
Hf (PPM, NA)	513	727	6	5	2	90	3
K_2O (PCT, XRF)	---	---	4.2	1.7	4.96	0.7	1.94
La (PPM, XRF)	583	1126	38	29	31	156	34
La (PPM, NA)	814	1710	32	25	25	150	28
Lu (PPM, NA)	7.6	14	0.4	0.2	0.2	2	0.3
Mn (PPM, XRF)	12172	10177	73	165	138	190	116
Mo (PPM, XRF)	27	<4	5	8	7	22	5
Mo (PPM, NA)	<4	<5	<1	<1	1	4	<1
Na (PCT, NA)	0.11	<0.37	2.2	0.6	1.9	0.16	0.8
Nb (PPM, XRF)	147	385	11	6	6	71	5
Ni (PPM, XRF)	178	148	<120	<120	<120	<120	3
Ni (PPM, NA)	96	<45	<20	<20	<20	37	<20
Pb (PPM, XRF)	230	136	8	8	18	33	15
Rb (PPM, NA)	<25	<27	70	35	76	24	49
Sb (PPM, NA)	2.5	1.5	1	0.7	1.1	3.1	0.4
Sc (PPM, NA)	42.4	92.7	9.3	3.7	3.8	24.6	3.6
Se (PPM, XRF)	15	61	<15	<15	8	6	11
Se (PPM, NA)	<13	<14	<5	<5	<5	<5	<5
Sm (PPM, NA)	121	161	5	3.8	3.2	18	3.6
Sr (PPM, XRF)	210	300	437	82	130	89	100
Sr (PPM, NA)	56	50	89	36	94	21	54
Ta (PPM, NA)	14	32	0.7	<0.5	<0.5	6.3	<0.5
Tb (PPM, NA)	16	18	0.6	0.6	<0.5	2.1	0.6
Th (PPM, XRF)	291	408	<12	<12	<12	47	<12
Th (PPM, NA)	602	608	11	6.6	7.2	94.3	6.3
TiO_2 (PCT, XRF)	---	---	1.03	0.39	0.51	6.76	0.34
U (PPM, XRF)	<13	<13	16	19	26	<13	19
U (PPM, NA)	100	85.3	3	1.6	2.1	14	1.6
V (PPM, XRF)	---	---	116	<5	56	671	2
W (PPM, NA)	7	<12	2	<1	1	3	<1
Yb (PPM, NA)	34	82	3	<2	<2	12	<2
Y (PPM, XRF)	300	511	19	10	10	72	20
Zn (PPM, XRF)	416	602	75	47	68	122	54
Zn (PPM, NA)	<260	500	<100	<100	<100	120	<100
Zr (PPM, XRF)	15740	23205	242	177	85	2803	90
Zr (PPM, NA)	26900	30000	430	<200	<200	3900	<200

[1] XRF Fe data values > 30 PCT could not be calculated with available standards

APPENDIX 1: Chemical data from neutron activation and X-ray fluorescence analysis of selected whole rock samples[1]--Continued

[NA, neutron activation; XRF, X-ray fluorescence; PCT, percent; PPM, parts per million; PPB, parts per billion ; <, below detection limit; ---, no data; Cd, Ir, Sm, and Te not detected; see text for discussion of techniques, comparability, and significant figures]

	Sample numbers						
Elements	AA-10-6	AA-10-7	AA-10-8	AA-10-9	AA-10-10	AA-10-11	AA-10-12
Ag (PPM, NA)	<6	<7	<2	<9	<11	<2	<10
As (PPM, XRF)	<13	<13	15	<13	<13	13	21
As (PPM, NA)	2.8	<2.0	<1.1	9	<3.0	5.5	<2.9
Au (PPB,NA)	<5	<7	26	<9	<10	20	14
Ba (PPM, XRF)	340	254	195	159	201	381	347
Ba (PPM, NA)	410	290	200	<190	320	410	470
Br (PPM, NA)	<2	<2	<2	<2	<2	<2	2.1
CaO (PCT, XRF)	0.51	---	2.04	---	---	0.37	0.86
Ce (PPM, XRF)	517	574	545	777	669	275	1431
Ce (PPM, NA)	586	723	595	1170	1010	280	1840
Co (PPM, NA)	36	53	9	86	130	29	<11
Cr (PPM, NA)	520	700	400	1600	1300	350	1200
Cs (PPM, NA)	<0.5	<1.2	<0.5	<1.5	<1.8	1.6	<1.6
Cu (PPM, XRF)	8	60	32	139	67	73	118
Eu (PPM, NA)	<4	<5	<2	6	<6	4	<7
FeO (PCT, XRF)	4.5	24.6	6.4	[1]>30	[1]>30	11	14.9
Fe (PCT, NA)	3.8	14	5.2	42	38.1	7	7.2
Ga (PPM, XRF)	<26	<26	<26	73	<26	<26	86
Hf (PPM, NA)	86	189	87	489	362	71	555
K_2O (PCT, XRF)	1.24	---	0.69	---	---	1.28	1.32
La (PPM, XRF)	298	341	336	439	380	156	871
La (PPM, NA)	3100	417	355	715	572	160	1120
Lu (PPM, NA)	2.4	4.1	2.7	10	6.7	1.4	13
Mn (PPM, XRF)	219	4143	414	12744	13160	629	945
Mo (PPM, XRF)	11	8	15	40	35	<4	64
Mo (PPM, NA)	<1	<3	<1	<4	<4	<1	<5
Na (PCT, NA)	0.51	0.21	0.29	<0.09	<0.13	0.53	0.25
Nb (PPM, XRF)	88	108	120	192	171	47	278
Ni (PPM, XRF)	<120	<120	<120	269	232	<120	<120
Ni (PPM, NA)	<29	<33	<20	<43	<50	32	<46
Pb (PPM, XRF)	26	63	18	243	162	32	154
Rb (PPM, NA)	46	<20	11	<25	<29	33	<29
Sb (PPM, NA)	1.2	1.2	0.7	2.3	2	2	2.1
Sc (PPM, NA)	35.4	43.5	33.9	55.2	50.8	18	59.1
Se (PPM, XRF)	2	9	9	19	3	8	51
Se (PPM, NA)	<5	<10	<5	<11	<12	<5	<17
Sm (PPM, NA)	36.8	42.7	31.5	76.2	59.5	16	128
Sr (PPM, XRF)	82	266	175	194	131	75	175
Sr (PPM, NA)	32	31	13	65	53	37	70
Ta (PPM, NA)	7.7	8.8	11	16	14	3.9	18
Tb (PPM, NA)	4.2	4.7	3.8	9.2	7	1.6	13
Th (PPM, XRF)	39	55	55	149	110	38	402
Th (PPM, NA)	88.5	161	94.6	353	268	62.4	567
TiO_2 (PCT, XRF)	6.56	---	7.96	---	---	3.86	>10
U (PPM, XRF)	<13	<13	<13	<13	<13	8	<13
U (PPM, NA)	15	28.7	18	62.4	51	10	81.7
V (PPM, XRF)	978	---	723	---	---	659	2129
W (PPM, NA)	6	7	5	5	6	<2	9
Yb (PPM, NA)	16	25	17	50	39	8	63
Y (PPM, XRF)	112	141	107	291	225	46	398
Zn (PPM, XRF)	178	339	74	379	534	231	690
Zn (PPM, NA)	180	330	<100	320	360	140	450
Zr (PPM, XRF)	2640	5376	2440	16203	12554	2433	20105
Zr (PPM, NA)	4200	8200	3600	20500	16000	3100	27400

[1] XRF Fe data values > 30 PCT could not be calculated with available standards

APPENDIX 1: Chemical data from neutron activation and X-ray fluorescence analysis of selected whole rock samples[1]--Continued

[NA, neutron activation; XRF, X-ray fluorescence; PCT, percent; PPM, parts per million; PPB, parts per billion ; <, below detection limit; ---, no data; Cd, Ir, Sm, and Te not detected; see text for discussion of techniques, comparability, and significant figures]

Elements	Sample numbers						
	AA-10-13	AA-11	AA-13	AA-14	AA-16	AA-17-1	AA-17-2
Ag (PPM, NA)	<5	7	<5	10	12	<2	<8
As (PPM, XRF)	<13	<13	<13	<13	14	16	<13
As (PPM, NA)	2.5	3.7	<2.7	2.7	5.1	1.7	6.5
Au (PPB,NA)	89	40	59	<5	29	11	19
Ba (PPM, XRF)	530	202	313	177	382	377	222
Ba (PPM, NA)	790	290	350	210	450	510	410
Br (PPM, NA)	2.5	<2	<2	<2	2.9	2.6	<2
CaO (PCT, XRF)	---	4.98	---	---	---	---	---
Ce (PPM, XRF)	785	94	925	655	1166	68	649
Ce (PPM, NA)	1100	90	1140	947	2080	61	870
Co (PPM, NA)	40	35	<5	30	92	21	90
Cr (PPM, NA)	840	100	1000	330	1300	150	1000
Cs (PPM, NA)	<0.5	0.7	<0.5	<0.5	<1.6	0.9	<1.2
Cu (PPM, XRF)	180	88	89	13	279	52	29
Eu (PPM, NA)	<3	1	4	3	5	<1	<4
FeO (PCT, XRF)	[1]>30	[1]>30	28.5	[1]>30	[1]>30	21.4	[1]>30
Fe (PCT, NA)	31.9	21	13	22.4	25.5	13	36
Ga (PPM, XRF)	76	29	78	19	93	13	60
Hf (PPM, NA)	298	7	342	173	712	3	279
K_2O (PCT, XRF)	---	0.33	---	---	---	---	---
La (PPM, XRF)	469	56	554	379	719	34	389
La (PPM, NA)	652	54	673	452	1080	40	559
Lu (PPM, NA)	6.5	0.6	5.9	3.8	12	0.5	6.1
Mn (PPM, XRF)	9133	10416	993	6835	7658	1246	9434
Mo (PPM, XRF)	<4	<4	36	16	46	<4	24
Mo (PPM, NA)	<1	<1	<2	<1	<4	<1	<3
Na (PCT, NA)	0.09	0.08	<0.18	0.10	<0.04	1.20	0.14
Nb (PPM, XRF)	156	3	178	103	299	3	146
Ni (PPM, XRF)	369	224	<120	<120	289	<120	261
Ni (PPM, NA)	<22	30	<21	28	87	<20	67
Pb (PPM, XRF)	131	36	74	56	166	14	173
Rb (PPM, NA)	<13	11	14	<15	<28	49	28
Sb (PPM, NA)	0.7	0.5	1.8	1	3.9	0.5	1.8
Sc (PPM, NA)	42.7	12	53.9	40	71.6	16	49.1
Se (PPM, XRF)	35	13	28	12	47	6	4
Se (PPM, NA)	<5	<5	<5	<5	<18	<5	<11
Sm (PPM, NA)	60.8	580	68.7	47.7	105	4.3	49.2
Sr (PPM, XRF)	297	282	226	189	273	98	105
Sr (PPM, NA)	36	16	30	18	54	50	46
Ta (PPM, NA)	12	0.8	14	11	24	<0.5	13
Tb (PPM, NA)	7.7	1.3	7.9	6.6	16	0.6	6.2
Th (PPM, XRF)	100	<12	184	64	263	<12	86
Th (PPM, NA)	223	9.5	284.7	162	494	7.1	210
TiO_2 (PCT, XRF)	---	0.34	---	---	---	---	---
U (PPM, XRF)	<13	<13	<13	<13	<13	18	<13
U (PPM, NA)	41.8	10	41.9	32.2	87	<3.3	38
V (PPM, XRF)	---	210	---	---	---	---	---
W (PPM, NA)	5	<1	11	5	14	<1	6
Yb (PPM, NA)	38	3	36	23	66	3	36
Y (PPM, XRF)	242	17	249	150	417	15	193
Zn (PPM, XRF)	269	78	207	151	568	91	297
Zn (PPM, NA)	180	<100	<100	180	360	<100	320
Zr (PPM, XRF)	10888	253	12102	5087	20213	89	10037
Zr (PPM, NA)	13000	430	1400	8400	31200	390	12000

[1] XRF Fe data values > 30 PCT could not be calculated with available standards

APPENDIX 1: Chemical data from neutron activation and X-ray fluorescence analysis of selected whole rock samples[1]--Continued

[NA, neutron activation; XRF, X-ray fluorescence; PCT, percent; PPM, parts per million; PPB, parts per billion ; <, below detection limit; ---, no data; Cd, Ir, Sm, and Te not detected; see text for discussion of techniques, comparability, and significant figures]

	Sample numbers						
Elements	AA-17-3	AA-17-4	AA-17-5	AA-19	AA-20	AA-21	AA-25-NW
Ag (PPM, NA)	<6	<7	<5	<2	<6	<5	<6
As (PPM, XRF)	<13	14	23	<13	<13	26	<13
As (PPM, NA)	<1.8	4.2	10	4.3	2.4	<2.3	<1.9
Au (PPB,NA)	12	14	13	90	38	78	7
Ba (PPM, XRF)	136	605	373	461	199	225	196
Ba (PPM, NA)	<120	890	370	650	290	270	<130
Br (PPM, NA)	<2	2.9	4.9	<2	<2	<2	2.6
CaO (PCT, XRF)	---	---	0.52	---	---	30.29	1.4
Ce (PPM, XRF)	440	589	466	504	731	1122	888
Ce (PPM, NA)	570	678	523	726	1210	1380	1070
Co (PPM, NA)	50	170	12	66	77	9	13
Cr (PPM, NA)	750	740	460	490	750	530	530
Cs (PPM, NA)	1.6	<1.2	<0.5	<0.5	<1.1	<0.5	<1.0
Cu (PPM, XRF)	66	72	14	31	135	130	9
Eu (PPM, NA)	<3	<5	<3	3	5	5	<4
FeO (PCT, XRF)	[1]>30	27	5.6	[1]>30	[1]>30	5.2	13.1
Fe (PCT, NA)	35.9	12	4.3	34.3	37.5	3.9	8.1
Ga (PPM, XRF)	<26	<26	<26	<26	48	38	<26
Hf (PPM, NA)	180	194	125	186	408	304	182
K_2O (PCT, XRF)	---	---	1.57	---	---	0.57	0.85
La (PPM, XRF)	239	367	268	284	428	679	538
La (PPM, NA)	342	411	298	373	580	772	627
Lu (PPM, NA)	3.7	3.7	3	3.9	7.3	5.9	5.2
Mn (PPM, XRF)	6117	16426	572	7318	8620	1941	613
Mo (PPM, XRF)	<4	<4	14	12	18	23	20
Mo (PPM, NA)	<2	<3	<1	<1	<2	<3	<3
Na (PCT, NA)	0.21	0.47	0.67	0.19	0.17	<0.20	0.28
Nb (PPM, XRF)	90	102	72	106	139	136	148
Ni (PPM, XRF)	130	<120	<120	<120	120	<120	<120
Ni (PPM, NA)	<28	100	<22	49	48	<23	<29
Pb (PPM, XRF)	100	53	17	86	136	46	23
Rb (PPM, NA)	<17	<22	35	13	<19	<14	<18
Sb (PPM, NA)	1	1.6	1.6	1.5	1.6	0.5	0.8
Sc (PPM, NA)	29.9	30.3	30	34	47.2	30.6	42.4
Se (PPM, XRF)	<15	15	<15	<15	<15	17	<15
Se (PPM, NA)	<5	<11	<5	<5	<11	<5	<5
Sm (PPM, NA)	34.3	44.7	32.5	37.3	69.1	89.5	55.7
Sr (PPM, XRF)	61	233	110	169	166	384	197
Sr (PPM, NA)	34	48	35	35	62	32	24
Ta (PPM, NA)	8	8.9	6.1	8.9	12	12	13
Tb (PPM, NA)	3.4	5.9	4.4	5.2	10	9.4	6.6
Th (PPM, XRF)	38	93	61	54	135	231	151
Th (PPM, NA)	149	174	112	150	318	325	223
TiO_2 (PCT, XRF)	---	---	5.71	---	---	6.81	7.64
U (PPM, XRF)	<13	<13	<13	<13	<13	<13	<13
U (PPM, NA)	24.8	30.1	20	31.4	59.4	43.4	31.1
V (PPM, XRF)	---	---	743	---	---	845	645
W (PPM, NA)	<3	6	9	5	9	<6	9
Yb (PPM, NA)	21	20	18	22	42	37	32
Y (PPM, XRF)	107	180	106	139	250	261	169
Zn (PPM, XRF)	202	388	161	285	433	171	263
Zn (PPM, NA)	<100	<230	160	160	250	<100	210
Zr (PPM, XRF)	6227	6740	3675	5832	11583	10334	5343
Zr (PPM, NA)	8400	8400	5200	8500	18000	12000	8000

[1] XRF Fe data values > 30 PCT could not be calculated with available standards

APPENDIX 1: Chemical data from neutron activation and X-ray fluorescence analysis of selected whole rock samples[1]--Continued

[NA, neutron activation; XRF, X-ray fluorescence; PCT, percent; PPM, parts per million; PPB, parts per billion ; <, below detection limit; ---, no data; Cd, Ir, Sm, and Te not detected; see text for discussion of techniques, comparability, and significant figures]

	Sample numbers						
Elements	AA-25-SE	AA-26-NW	AA-26-SE	AA-27	AA-28	AA-30	AA-36-NW
Ag (PPM, NA)	<5	<2	<7	<2	<5	<2	<6
As (PPM, XRF)	<13	10	65	30	<13	24	<13
As (PPM, NA)	6.4	3.8	<3.6	4.4	12	2.7	29
Au (PPB,NA)	8	<2	25	39	59	41	85
Ba (PPM, XRF)	232	552	189	198	378	739	502
Ba (PPM, NA)	220	720	<140	130	480	1100	870
Br (PPM, NA)	<2	2	<2	<2	<2	<2	7.1
CaO (PCT, XRF)	6.95	---	---	---	---	---	---
Ce (PPM, XRF)	615	327	2443	900	629	1451	530
Ce (PPM, NA)	684	370	3890	1260	856	2350	949
Co (PPM, NA)	26	71	23	10	82	<5	88
Cr (PPM, NA)	330	340	2230	480	920	900	1200
Cs (PPM, NA)	0.9	0.7	<1.1	<0.5	1.3	<0.5	<0.5
Cu (PPM, XRF)	<60	<60	471	117	<60	159	78
Eu (PPM, NA)	<3	<2	10	3	4	2	<3
FeO (PCT, XRF)	12.7	26.9	[1]>30	15.4	[1]>30	[1]>30	[1]>30
Fe (PCT, NA)	8.3	14	12	8	29.8	17	34.7
Ga (PPM, XRF)	<26	<26	412	65	<26	111	<26
Hf (PPM, NA)	84	66	1470	360	310	770	342
K_2O (PCT, XRF)	0.5	---	---	---	---	---	---
La (PPM, XRF)	388	171	1527	534	366	905	315
La (PPM, NA)	430	200	2530	588	490	1250	559
Lu (PPM, NA)	2.4	2.5	29.2	6.1	5.7	12	7
Mn (PPM, XRF)	341	7465	3117	918	11045	1731	4095
Mo (PPM, XRF)	<4	14	<4	<4	33	<4	<4
Mo (PPM, NA)	<1	<1	<5	<1	<2	<1	<2
Na (PCT, NA)	0.11	0.38	<0.29	0.13	0.37	0.16	<0.08
Nb (PPM, XRF)	103	48	672	162	126	300	112
Ni (PPM, XRF)	<120	<120	<120	<120	173	<120	<120
Ni (PPM, NA)	<22	51	<33	<20	57	<20	<25
Pb (PPM, XRF)	<19	<19	239	21	133	85	85
Rb (PPM, NA)	<13	25	<19	25	14	<11	<15
Sb (PPM, NA)	0.8	0.6	1	0.8	2.1	1.2	3.1
Sc (PPM, NA)	40.2	28.2	119	39.6	48.9	62.2	50.5
Se (PPM, XRF)	<15	<15	61	20	<15	37	<15
Se (PPM, NA)	<5	<5	<11	<5	<5	<5	<5
Sm (PPM, NA)	35	22.7	265	65	55.5	128	63.5
Sr (PPM, XRF)	150	148	366	148	187	342	317
Sr (PPM, NA)	12	27	105	19	50	45	34
Ta (PPM, NA)	20	4.5	42	14	10	26	13
Tb (PPM, NA)	3.6	2.8	31	8.5	7	17	8.3
Th (PPM, XRF)	87	27	1112	194	106	358	103
Th (PPM, NA)	142	67.4	1080	286	223	559	284
TiO_2 (PCT, XRF)	4.7	---	---	8	---	---	---
U (PPM, XRF)	<13	<13	<13	<13	<13	<13	<13
U (PPM, NA)	18	15	180	42.1	38.2	82.5	48.1
V (PPM, XRF)	553	---	---	737	---	---	---
W (PPM, NA)	221	<2	<9	7	<5	10	62
Yb (PPM, NA)	17	16	150	33	35	65	39
Y (PPM, XRF)	90	85	1205	255	194	475	199
Zn (PPM, XRF)	73	236	521	109	385	152	562
Zn (PPM, NA)	150	240	270	<100	330	<100	570
Zr (PPM, XRF)	2549	2055	60981	11568	10128	24558	9897
Zr (PPM, NA)	3700	2900	59800	16000	13000	36300	15000

[1] XRF Fe data values > 30 PCT could not be calculated with available standards

APPENDIX 1: Chemical data from neutron activation and X-ray fluorescence analysis of selected whole rock samples[1]--Continued

[NA, neutron activation; XRF, X-ray fluorescence; PCT, percent; PPM, parts per million; PPB, parts per billion ; <, below detection limit; ---, no data; Cd, Ir, Sm, and Te not detected; see text for discussion of techniques, comparability, and significant figures]

Elements	Sample numbers						
	AA-36-SE	AA-37	AA-38	AA-39	AA-40	AA-41	AA-43
Ag (PPM, NA)	<4	<6	<8	<7	<8	<6	<7
As (PPM, XRF)	<13	17	21	16	<13	<13	<13
As (PPM, NA)	6.1	<1.3	3.6	4.5	<3.2	<2.7	<1.8
Au (PPB,NA)	<4	59	41	80	21	49	110
Ba (PPM, XRF)	327	261	264	315	336	183	386
Ba (PPM, NA)	500	360	270	430	380	370	550
Br (PPM, NA)	10	<2	3	3.1	2.4	<2	<2
CaO (PCT, XRF)	---	0.73	0.78	1.28	---	---	---
Ce (PPM, XRF)	461	943	1062	1264	1371	741	617
Ce (PPM, NA)	645	1150	1340	1620	1870	1060	791
Co (PPM, NA)	66	20	17	17	44	67	43
Cr (PPM, NA)	780	640	1000	1200	1500	1100	810
Cs (PPM, NA)	1	<1.0	1.6	<1.1	<1.2	1.2	<1.1
Cu (PPM, XRF)	141	98	23	52	63	137	60
Eu (PPM, NA)	3	6	<5	4	5	<3	<4
FeO (PCT, XRF)	[1]>30	10.5	9.8	9.8	[1]>30	[1]>30	[1]>30
Fe (PCT, NA)	33.4	6.5	6.4	6.1	17	37.2	29.2
Ga (PPM, XRF)	40	67	65	85	76	32	49
Hf (PPM, NA)	206	324	397	511	388	363	189
K_2O (PCT, XRF)	---	0.47	1.22	0.89	---	---	---
La (PPM, XRF)	266	511	642	784	855	423	372
La (PPM, NA)	381	577	764	946	1140	633	463
Lu (PPM, NA)	4.5	6.9	8.7	10	10	6.8	4.8
Mn (PPM, XRF)	6344	2775	677	984	2117	9662	8070
Mo (PPM, XRF)	8	12	55	56	37	26	<4
Mo (PPM, NA)	<1	<3	<3	<3	<4	<4	<2
Na (PCT, NA)	0.11	<0.08	0.23	<.21	<0.23	<0.16	<0.08
Nb (PPM, XRF)	101	162	218	331	324	166	135
Ni (PPM, XRF)	212	<120	<120	<120	<120	<120	273
Ni (PPM, NA)	<20	<29	<36	<30	<34	<27	<30
Pb (PPM, XRF)	81	59	68	113	89	140	104
Rb (PPM, NA)	<12	<18	<21	<18	<20	<16	<18
Sb (PPM, NA)	1.3	0.7	2	2.2	2.6	1.7	1.5
Sc (PPM, NA)	34.4	43.7	68.1	87.2	93.9	54	46.9
Se (PPM, XRF)	37	28	<15	24	<15	8	28
Se (PPM, NA)	<5	<10	<12	<5	<10	<5	<5
Sm (PPM, NA)	36.4	63.9	80.5	97.1	107	63.1	46.3
Sr (PPM, XRF)	257	145	175	201	211	146	113
Sr (PPM, NA)	33	30	40	46	34	38	30
Ta (PPM, NA)	7.9	13	16	23	26	14	11
Tb (PPM, NA)	5	8.2	10	12	13	8.8	5.3
Th (PPM, XRF)	67	178	189	233	176	100	70
Th (PPM, NA)	163	255	274	324	295	243	149
TiO_2 (PCT, XRF)	---	9.33	>10	>10	---	---	---
U (PPM, XRF)	<13	13	<13	<13	<13	<13	<13
U (PPM, NA)	28.9	41.5	52	59.4	51.6	42.8	29.1
V (PPM, XRF)	---	595	2384	1903	---	---	---
W (PPM, NA)	3	7	12	13	14	<7	6
Yb (PPM, NA)	25	44	48	65	62	40	28
Y (PPM, XRF)	146	300	359	469	348	260	177
Zn (PPM, XRF)	347	312	102	116	584	462	341
Zn (PPM, NA)	240	270	300	190	500	330	370
Zr (PPM, XRF)	6821	11138	13768	17114	10863	12037	6491
Zr (PPM, NA)	8600	14000	17000	20800	15000	16000	8400

[1] XRF Fe data values > 30 PCT could not be calculated with available standards

APPENDIX 1: Chemical data from neutron activation and X-ray fluorescence analysis of selected whole rock samples[1]--Continued

[NA, neutron activation; XRF, X-ray fluorescence; PCT, percent; PPM, parts per million; PPB, parts per billion ; <, below detection limit; ---, no data; Cd, Ir, Sm, and Te not detected; see text for discussion of techniques, comparability, and significant figures]

	Sample numbers	
Elements	AA-44	FA-1
Ag (PPM, NA)	<8	<2
As (PPM, XRF)	<13	3
As (PPM, NA)	<3.6	<1.4
Au (PPB,NA)	60	15
Ba (PPM, XRF)	278	302
Ba (PPM, NA)	390	400
Br (PPM, NA)	<2	<2
CaO (PCT, XRF)	---	---
Ce (PPM, XRF)	823	95
Ce (PPM, NA)	990	82
Co (PPM, NA)	55	53
Cr (PPM, NA)	940	170
Cs (PPM, NA)	<1.3	0.9
Cu (PPM, XRF)	175	98
Eu (PPM, NA)	<5	<1
FeO (PCT, XRF)	[1]>30	[1]>30
Fe (PCT, NA)	32	20.5
Ga (PPM, XRF)	25	7
Hf (PPM, NA)	314	4
K_2O (PCT, XRF)	---	---
La (PPM, XRF)	486	63
La (PPM, NA)	623	71
Lu (PPM, NA)	6.4	0.5
Mn (PPM, XRF)	9482	3826
Mo (PPM, XRF)	15	8
Mo (PPM, NA)	<3	<1
Na (PCT, NA)	<0.07	0.34
Nb (PPM, XRF)	193	6
Ni (PPM, XRF)	349	243
Ni (PPM, NA)	<35	40
Pb (PPM, XRF)	195	33
Rb (PPM, NA)	<21	28
Sb (PPM, NA)	2.3	0.4
Sc (PPM, NA)	51	15
Se (PPM, XRF)	32	11
Se (PPM, NA)	<12	<5
Sm (PPM, NA)	67.8	6.7
Sr (PPM, XRF)	170	61
Sr (PPM, NA)	39	33
Ta (PPM, NA)	16	0.5
Tb (PPM, NA)	9	1.3
Th (PPM, XRF)	103	<12
Th (PPM, NA)	275	8.6
TiO_2 (PCT, XRF)	---	---
U (PPM, XRF)	<13	<13
U (PPM, NA)	46.6	31.4
V (PPM, XRF)	---	---
W (PPM, NA)	5	<3
Yb (PPM, NA)	33	3
Y (PPM, XRF)	263	22
Zn (PPM, XRF)	427	227
Zn (PPM, NA)	320	190
Zr (PPM, XRF)	12993	104
Zr (PPM, NA)	14000	<200

[1] XRF Fe data values > 30 PCT could not be calculated with available standards

Appendix 2

Instrumental Neutron Activation Analysis (INAA)
Elements and Lower Detection Limits

	Element		Lower Detection Limit
1	Au	Gold	2. ppb
2	Sb	Antimony	0. 1ppm
3	As	Arsenic	0. 5ppm
4	Ba	Barium	50. ppm
5	Br	Bromine	0.5 ppm
6	Cd	Cadmium	5. ppm
7	Ce	Cerium	0.5 ppm
8	Cs	Cesium	0.5 ppm
9	Cr	Chromium	20. ppm
10	Co	Cobalt	5. ppm
11	Eu	Europium	1. ppm
12	Hf	Hafnium	1. ppm
13	Ir	Iridium	50. ppb
14	Fe	Iron	0.2 %
15	La	Lanthanum	2. ppm
16	Lu	Lutetium	0.2 ppm
17	Mo	Molybdenum	1. ppm
18	Ni	Nickel	20. ppm
19	Rb	Rubidium	5. ppm
20	Sm	Samarium	0.05 ppm
21	Sc	Scandium	0.2 ppm
22	Se	Selenium	5. ppm
23	Ag	Silver	2. ppm
24	Na	Sodium	0.02 %
25	Ta	Tantalum	0.5 ppm
26	Te	Tellurium	10. ppm
27	Tb	Terbium	0.5 ppm
28	Th	Thorium	0.2 ppm
29	Sn	Tin	100. ppm
30	W	Tungsten	1. ppm
31	U	Uranium	0.2 ppm
32	Yb	Ytterbium	2. ppm
33	Zn	Zinc	100. ppm
34	Zr	Zircon	200. ppm

Appendix 3

X-ray fluorescence rock analysis
Ideal minimum detection limits at 95% confidence level*

Source	in ppm										
^{109}Cd	Mn	Fe	Ni	Cu	Zn	Ga	As	Se	Rb	Sr	Y
30mCi	200	150	120	60	30	26	13	15	6	5.5	5
	Zr	Nb	Mo	Pb	Th	U**	Ta	W	A	Bi	
	3.5	3	3.5	19	12	13	60	60	4	25	
^{55}Fe	K	Ca	Ti	V	Cr						
	70	55	11	5***	5***						
100mCi initial activity											

* written comm, Ross Yoman, 1984
**Due to severe compositional interferences, uranium is NEVER detectable at this level in rocks; 100 ppm might be a good practical analytic limit for U; its presence can be reliably detected above 50 ppm.
***Low level vanadium and chromium analyses are sensitive to elevated Ba concentrations; low level vanadium is very sensitive to Ti, and Cr to V abundance. With 0.5% Ti present, 50 ppm is the estimated minimum for V; this is also a likely value for minimum detectable Cr.