Progress Report: Lunar Sample Program

ION MICROPROBE MASS ANALYSIS OF LUNAR SAMPLES

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by

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INTRODUCTION

Mass analyses of selected minerals, glasses and soil particles of lunar, meteoritic and terrestrial rocks have been made with the ion microprobe mass analyzer in partial fulfillment of our proposed lunar sample analysis program. Major, minor and trace element concentrations have been determined in situ in major and accessory mineral phases in polished rock thin sections. The Pb isotope ratios have been measured in U and Th bearing accessory minerals to yield radiometric (Pb 207/206) age dates and heavy volatile elements have been sought on the surfaces of free particles from Apollo 14 soil samples.

Although the primary objective of Contract NAS9-11566 is the analysis of Apollo 14 and 15 lunar material, we have also actively pursued investigations of Apollo 11 and 12, Luna 16, basaltic achrondrites and representative terrestrial basaltic rocks in order to build a reference library of analyses for comparison with the lunar analyses. Most of these analyses are presented in the tables and figures accompanying this report. The reported analyses are in a preliminary state of quantitative correction and await a final calibration. We do not anticipate large errors, however, and the relative concentrations of an element between different minerals should be fairly accurate. A considerable effort has been made to develop a quantitative method for the ion microprobe mass analyzer and typical results of the method applied to silicates are given in Tables I, II, and III. (New partition functions for Fe I improve the IMMA analysis for this element significantly.) The final calibration of the preliminary lunar data reported here should produce results equivalent to those given in these tables. The quantitative procedure has been described by Andersen (1).

The versatility of the instrument for the quantitative analysis of many different elements in widely different concentration ranges is illustrated in Figure 1 where ion microprobe analyses of crust and vein glasses in 10085/17-17 are compared to whole rock analyses performed by other laboratories using a variety of techniques. The crust glasses are generally considered to be nearly total melts of the breccia and therefore it should be possible to compare the chemistries of the two. The whole rock analyses represent the composite work of eight laboratories where an analytic method was selected for each individual element. Methods such as neutron activation, spark source mass spectrometry, atomic absorption, optical emission, flame emission, x-ray fluorescense, isotope dilution, and wet chemcial analysis are represented. The vertical spread is laboratory spread while the horizontal spread represents the variation observed with the ion probe between three different glasses within the same rock thin section. Each ion probe analysis represents much less than a microgram of material. Si was used as an internal standard in these analyses. The correlation over five orders of magnitude of concentration is good enough to confirm the general quantitative method proposed. Some of the discrepancies such as noted for P and Zr might be related to the presence of these elements in highly refractory phases that have not melted completely into the glass.

SAMPLES

The ion microprobe investigations were conducted on polished, rock thin sections and on hand selected and mounted free soil particles. The lunar samples analyzed in this report are identified by their standard NASA designations. Thin Sections 14321,23; 14053,15; and 14310,12 prepared by LRL and assigned to this investigation were not usable for radiometric Pb age dating because they were contaminated with common Pb during the thin section polishing procedure.

The basaltic achondrites were supplied by the Smithsonian Institution and are generally discussed by Moore (2) who lists more detailed references. References to the terrestrial rocks are as follows. Oceanite C-112 and trachyte C-116 (3); nephelinite 425 (4); high-Al basalt 4-412 (5); tholeiitic basalt 51-2 and basanite B-1 (6); St. Paul's Rocks peridotite (7); and Disko basalt (8).

The soil particles were hand selected under a stereomicroscope with stainless steel forceps and mounted on Au coated glass slides. The particles were attached by sitting them in a small droplet of white glue. No metallic overcoatings of any type were used in these investigations and the surfaces of the particles were analyzed directly. Surface charge-up on the insulating particles was eliminated by using a negatively charged primary ion beam (9).

DISCUSSION OF RESULTS

The ion microprobe analyses of the lunar material have shown that U, Th, Pb and REE are concentrated in accessory minerals such as apatite, whitlockite, zircon, baddelyite, zirkelite and tranquillityite. K, Ba, Rb and Sr have been localized in a K rich, U and Th poor glass phase that is commonly associated with the U and Th bearing accessory minerals. Li is observed to be fairly evenly distributed between the various accessory phases. The Pb isotope ratio measurements, the resulting radiometric age dates, and the REE abundance patterns of these phases have been adequately discussed in the renewal proposal ("Quantitative Ion Microprobe Analysis of the Distribution of U, Th, Pb and the KREEP Elements in Returned Lunar Material," C. A. Andersen) that accompanies this progress report.

In accordance with our proposal we have analyzed the surfaces of free particles from Apollo 14 soil in an attempt to find the heavy volatile elements. The mass spectra of these particles have been searched for indications of Hg, Tl, Bi, In, Sn and Pb unsupported by U or Th. To date 75 particles from Samples 14003,2; 14141,35, and 14165,2 have been analyzed with negative results. Of the 75 particles three contained Pb but in each case the Pb was supported by U and Th. Isotope ratios could not be measured accurately because of the low Pb concentrations. In addition, two measurements were made on the surface of the crust glass of Sample 14047,40 and four free soil particles from 12028,68 and 12028,60 were analyzed all with negative results. The absolute detection limit for Pb under the experimental conditions used was approximately 5×10^{-18} gms which corresponds to about 2 x 10^4 atoms in a vertical section approximately ten monolayers thick. The other heavy volatile elements have detection limits within about a factor of five Pb. In with a better detection limit and Hg with the poorer detection limit define the range. No distinctly unusual heavy mass peaks (up to approximately mass 270) were noted in the mass spectra of any of the particles discussed in this report.

In general the trace element contents of the individual olivine, pyroxene and plagioclase grains in the Apollo 14, 12, and 11 fines materials studied reflect the abundance trends reported for the bulk chemical analyses of these materials (10,11). Figure 2 compares the trace element contents of single olivine and plagioclase phenocrysts from an Apollo 12 basalt with similar minerals from an Apollo 11 basalt and anorthositic-like fragment (12). We have not yet had time to add the Apollo 14 and Luna 16 results to this figure but the data given in the accompanying tables show the following trends. The olivine of Apollo 14 has less Ti, Cr and V than that of Apollo 12 or 11. Li, however, is much enriched and approaches the levels found in the anorthostic-like fragment. The olivine in this fragment appears to be enriched in Na, K, B and Li compared to the olivine grains in Apollo 14, 12, or 11 material. The plagioclase of Apollo 14 appears to be enriched in K, Na and Ba and depleted in P, Ti, and Zr compared to Apollo 12 and 11.

The olivine of Luna 16 shows an enrichment of Ca and Ti over other lunar rocks. Li is enriched over Apollo 12 and 11 but is depleted relative to Apollo 14 and the anorthositic fragment. The B, Na and K levels in the Luna 16 olivine are greater than those of Apollo 14, 12, and 11 and approach or exceed the levels found in the anorthositic fragment. V and Cr are lower in the Luna 16 olivine than in any of the other lunar rocks. The Luna 16 plagioclase is generally depleted in Li, Sr, Y and Zr. Ti is depleted to the levels observed in Apollo 14 material and the anorthositic fragment.

Figure 3 illustrates the element distribution across a zoned pyroxene grain from Apollo 12. The grain has a core of pigeonite surrounded by a sub-calcic augite that is rimmed with a pyroxene of an intermediate composition. It is observed that practically all the trace elements analyzed have preferentially entered the augite phase. Sr is the only exception noted. The pyroxene data of Apollo 14 and Luna 16 show similar concentration levels. Li and V are generally enriched in the pyroxenes measured from these two sample areas, however, and B is greatly enriched in some Luna 16 pyroxenes. Zr and Ba are depleted compared to Apollo 12 and 11 pyroxenes. (The Cr concentration at the 1000 ppm level in Figure 3 has been mislabled Co).

The glasses that have been analyzed generally reflect the chemical trends noted in the bulk rock analyses. Apollo 14 and 12 glasses appear to be enriched and Luna 16 glasses depleted in KREEP component. B is more concentrated in Apollo 14 and Luna 16 glasses. Li and Na are generally depleted in Luna 16 and V is depleted in both Luna 16 and Apollo 14 glasses.

Approximately 100 grains and fragments of Luna 16 material in polished thin Sections G308 and A317 were analyzed for U, Th, and Pb in hopes of finding some of the accessory mineral phases known to concentrate these elements in order to age date the material. We were not able to locate such a phase.

10-18-71
CAA:dd

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COMPARISON OF ION MICROPROBE AND WET CHEMICAL ANALYSES OF MINERAL STANDARDS

	PLAGIOCLASE AC-362		CLINOPYROXENE AC-362-Cl		ORTHOPYROXENE AC-362-Or	
	Ion	Wet	Ion	Wet	Ion	Wet
Na	3.17	3.14	0.22	0.27	-	-
Mg	-	-	6.32	6.69	9.12	9.03
Al	11.87	12.0	1.10	0.97	0.59	0.66
Si	18.82	18.77	20.55	19.30	19.69	19.57
K	0.16	0.08	0.01	0.02	-	-
Ca	4.29	4.29	8.54	8.54	0.32	0.35
Fe	0.13	0.11	3.06	3.69*	9.87	10.0

* Fe^{+2}

Table I

COMPARATIVE AMPHIBOLE ANALYSES

	HORNBLENDE ML1A1		CUMMINGTONITE ML1A1	
	IMMA	EMX	IMMA	EMX
Si	16.51	16.49	20.80	20.80
Al	7.47	7.17	.75	.54
Ti	.088	.080	.029	.017
Fe	4.43	5.28	6.41	7.35
Mn	.13	.13	.34	.24
Mg	5.73	5.66	10.82	10.00
Ca	4.19	4.18	.14	.24
Na	1.49	1.06	.047	.13
K	.11	.07	.006	.009

EMX analyses by J. H. Stout, UCLA.

Table II

COMPARATIVE MINERAL ANALYSES OF CAMPERDOWN PERIDOTITE

	ORTHOPYROXENE		OLIVINE	
MAJOR ELEMENTS IN ATOMIC PERCENT				
	IMMA	EMX	IMMA	EMX
Si	19.22	19.22	14.21	14.21
Al	1.42	1.22	n.d.	n.d.
Mg	17.37	17.58	26.64	25.80
Fe	1.29	1.72	1.85	2.89
Ca	0.40	0.31	0.018	0.025
TRACE ELEMENTS IN ATOMIC PPM				
	IMMA	MS-7	IMMA	MS-7
Ti	150	160	77	64
V	45	24	23	4
Cr	1120	1180	195	160
Mn	350	320	340	320
Co	16	19	32	78
Ni	n.d.	240	520	750

EMX and MS-7 analyses by Smithsonian Inst., Dept. Min. Sci.
n.d.—not determined.

Table III

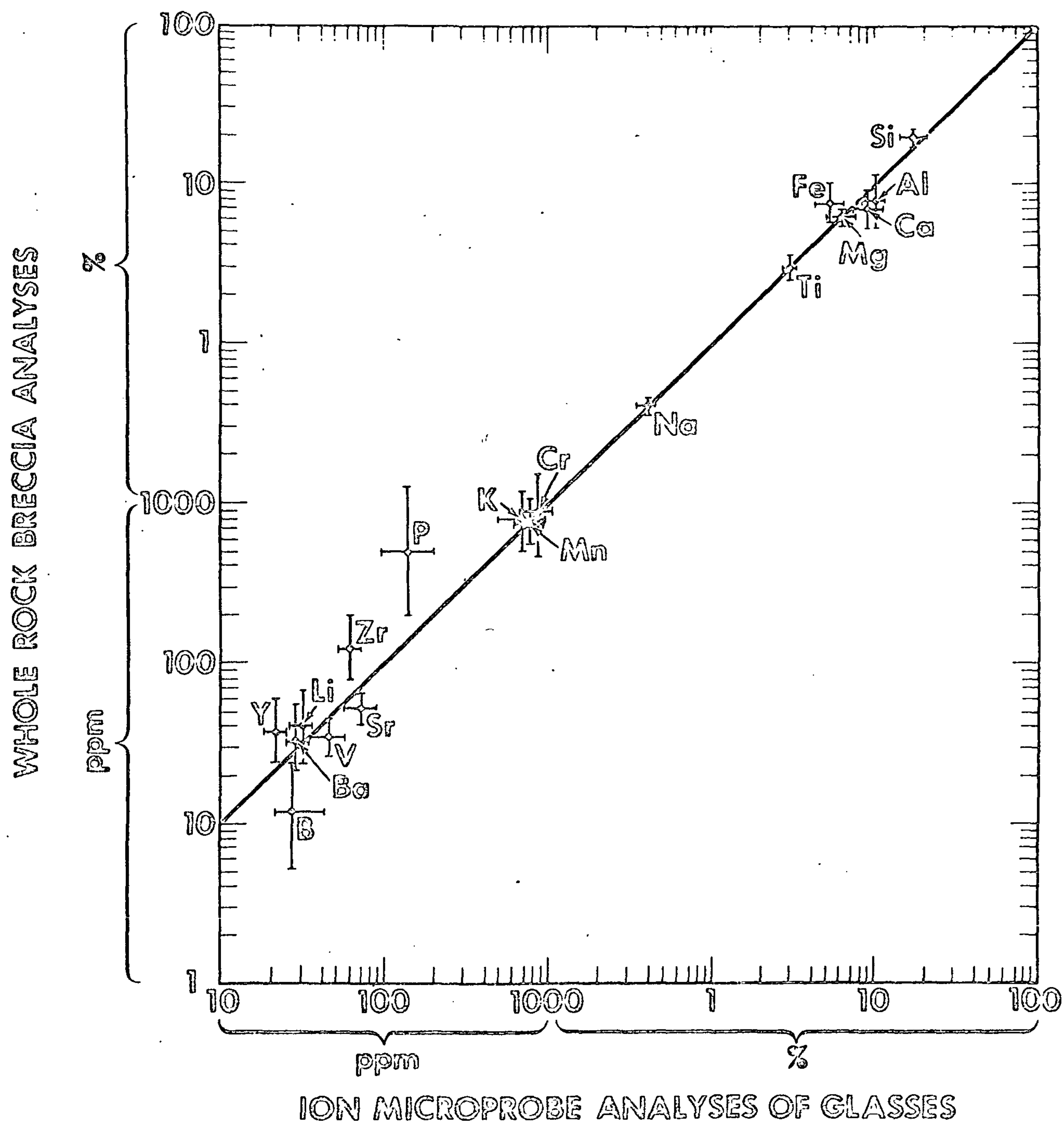
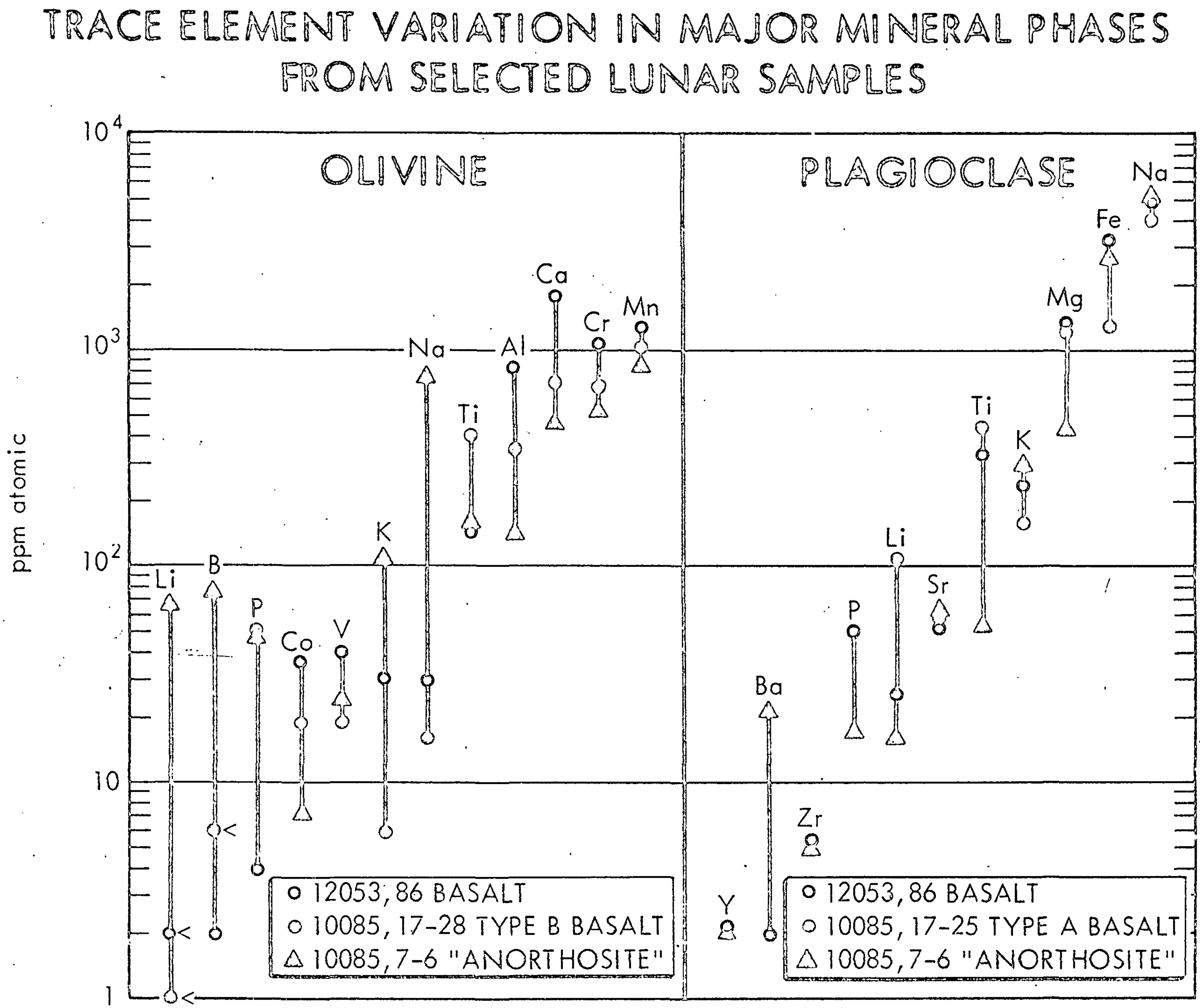

WHOLE ROCK BRECCIA ANALYSES
ppm
%
ION MICROPROBE ANALYSES OF GLASSES
ppm
%
1
10
100
1000
1
10
100
Si
Fe
Al
Ca
Mg
Ti
Na
Cr
K
Mn
P
Zr
Li
Y
Sr
V
Ba
B

Figure 1



TRACE ELEMENT VARIATION IN MAJOR MINERAL PHASES FROM SELECTED LUNAR SAMPLES
OLIVINE
PLAGIOCLASE
ppm atomic
10^4
10^3
10^2
10
1
Li
B
P
Co
V
K
Na
Ti
Al
Ca
Cr
Mn
Y
Ba
Zr
P
Li
Sr
Ti
K
Mg
Fe
Na
12053,86 BASALT
10085, 17-28 TYPE B BASALT
10085,7-6 "ANORTHOSITE"
12053,86 BASALT
10085, 17-25 TYPE A BASALT
10085,7-6 "ANORTHOSITE"

Figure 2

ELEMENT DISTRIBUTION IN ZONED CLINOPYROXENE, SAMPLE 12032, 46-6

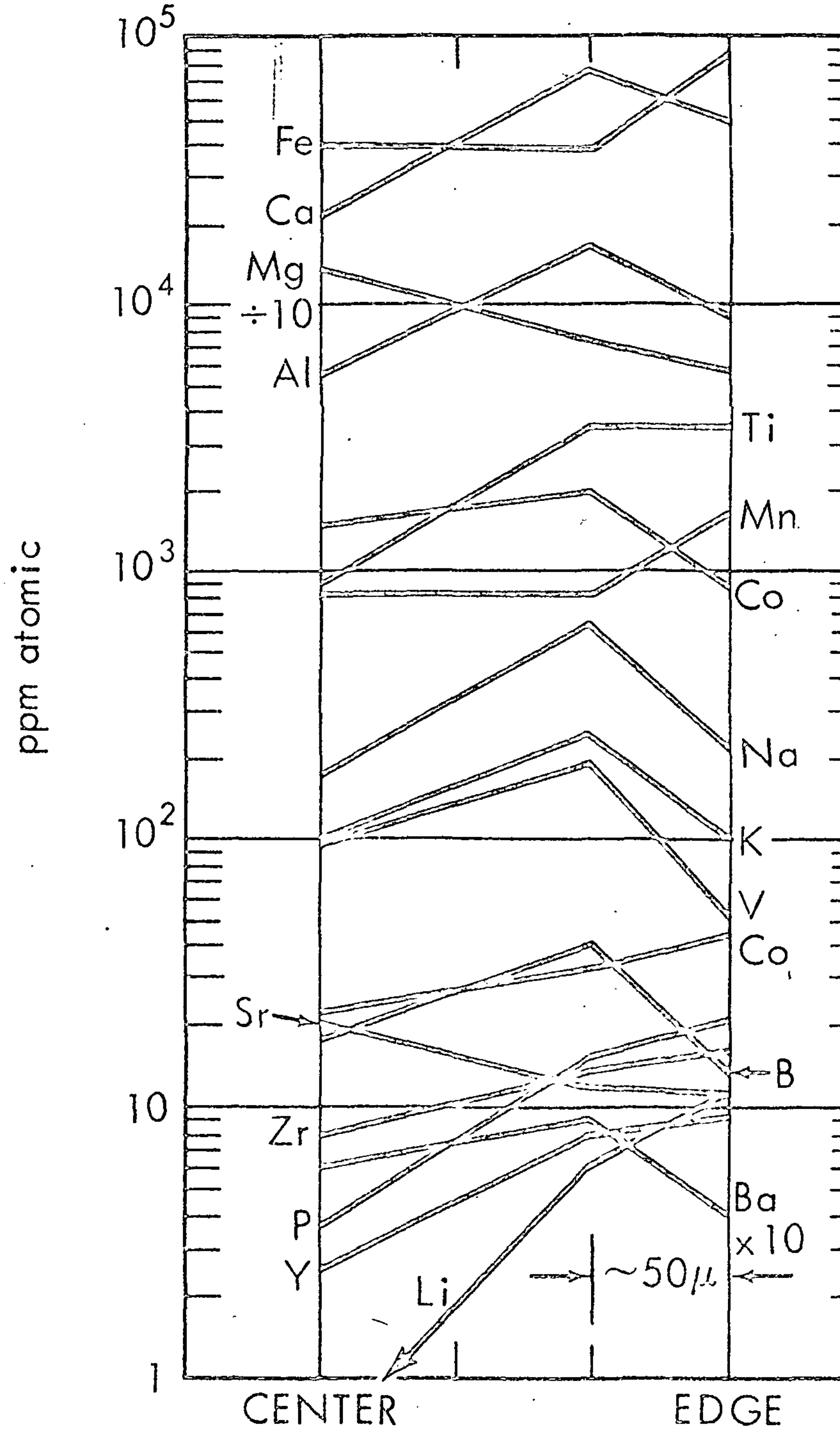


Figure 3

APOLLO 14 MINERAL ANALYSES (Preliminary Data Reduction)

	14321,23	14259,26-103A		14053,15					14163,86-A4
	Oliv.	CPX	Plag.	Oliv.	CPX	Plag.	Cristob.	Ilmen.	Spinel
Li	31	31	64	39	37	30	10	12	68
B	1.9	14	39	<0.5	4.4	10	14	3.7	<1.0
Na	45	750	8842	84	518	6158	467	489	31
P	5.2	20	20	5.3	10	6.6	7.2	4.7	0.3
K	27	339	862	21	56	331	680	632	45
Ti	79	2606	113	116	2915	64	450	2020	3045
V	21	99	5.3	16	26	3.6	0.8	67	488
Cr	578	1785	4.5	278	644	2.4	0.7	1449	2.1%
Mn	735	974	47	1268	1434	44	9.6	2758	168
Co	28	25	-	34	31	-	-	1.0	-
Rb	-	<6.4	2.8	-	-	<1.4	-	-	-
Sr	< 2	< 29	117	<1.5	< 8	33	-	-	-
Y	< 2	<3.9	<1.0	<0.5	8.3	<0.5	-	7.5	-
Zr	< 2	<5.5	<1.0	<0.5	< 4	<0.5	-	222	-
Ba	-	<0.5	73	-	0.2	5.7	8.4	-	-
La	-	-	<0.5	-	-	<0.5	-	-	-
Ce	-	-	<0.5	-	-	-	-	-	-

NOTE: P value may be in error.

APOLLO 14 GLASSES (Preliminary Data Reduction)

	14259,26-103A					14047,40		14259,33-1D		14321,23	14163,86-A3			
	Gr. 42	Gr. 4	Gr. 54	Gr. 39	Gr. 81	Crust gl.	Crust gl.	Sph. 2	Sph. 10	gl.	Sph. 19	Sph. 6	Sph. 8	Sph. 7
Li	94	77	103	81	10	104	128	38	71	62	30	69	22	58
B	141	244	66	130	71	76	89	102	107	74	62	59	94	16
Na	8194	7177	5677	5384	1351	12544	9679	6215	5910	4850	8462	2975	2952	617
P	366	427	135	324	36	206	218	349	274	264	278	36	81	12
K	9280	7623	5080	3125	346	7334	4453	4392	3832	1969	2950	1742	1279	879
Ti	3143	2538	3325	4688	746	3883	2954	5358	3792	2562	2459	3148	1330	4170
V	30	25	23	22	30	36	22	32	36	21	16	44	51	41
Cr	198	198	223	277	228	404	242	378	320	341	183	517	897	306
Mn	235	269	196	368	209	460	305	511	408	335	240	532	740	485
Co	38	36	19	23	26	44	45	40	38	21	22	32	43	34
Rb	12	12	6.9	<5.4	<2.9	<16.1	<9.3	9.4	10.4	4.9	5.3	5.4	4.4	4.0
Sr	34	50	29	51	31	55	36	62	59	40	91	58	17	56
Y	30	49	38	69	< 45	44	42	68	59	41	36	75	9.4	55
Zr	58	73	76	127	<5.9	77	107	67	78	57	25	126	15	85
Nb	2.6	4.1	4.3	7.4	-	6.0	5.8	4.4	3.9	3.2	2.7	5.7	1.0	4.4
Ba	186	640	174	157	121	164	210	139	127	171	109	153	18	173
La	5.8	7.5	7.2	6.3	<0.6	6.5	8.9	8.2	5.1	4.3	3.0	6.3	1.0	5.5
Ce	11.7	14.6	14.9	10.4	<8.8	14.9	14.4	17.3	10.7	8.1	6.0	13.0	2.3	11.4

NOTES: Glasses listed in order of decreasing K content for each sample.
All P values may be consistently low by up to a factor of five.

LUNA 16 OLIVINES

(Preliminary Data Reduction)

	308-201	308-225	317-462	317-26
Li	11	16	19	11
B	42	30	34	<1
Na	620	64	150	380
Al	8700	4300	3400	2300
P	14	9	14	15
K	230	20	30	120
Ca	3700	1400	1500	1400
Ti	850	180	290	310
V	13	14	12	14
Cr	280	270	270	300
Mn	1500	1000	1300	1100
Co	30	22	21	20
Sr	<3	<2	<6	<4
Y	<1	<3	<2	<2
Zr	<1	<2	<1	<1

NOTES: P values may be consistently low by up to a factor of 5.

Values for Al probably too high because of polishing with Al_2O_3.

LUNA 16 CLINOPYROXENES

(Preliminary Data Reduction)

	308-86	308-168	317-505	317-422
Li	14	13	31	19
B	43	4	130	<20
Na	490	280	560	1100
Al	1.1%	9700	1.6%	3.2%
P	12	20	40	17
K	130	75	30	13
Ti	3200	850	3300	8800
V	39	38	28	86
Cr	650	1000	530	1000
Mn	1200	1300	1200	850
Ni	<100	< 1	< 1	<20
Co	34	25	36	150
Rb	< 3	< 2	< 3	< 4
Sr	< 5	< 3	<10	16
Y	< 4	< 3	9	13
Zr	< 3	< 1	5	9
Nb	< 1	--	<.4	<.2
Ba	< 1	<.5	1	<.3

NOTE: P values may be consistently low by up to a factor of 5.

LUNA 16 PLAGIOCLASES

(Preliminary Data Reduction)

	308-12 An 90	317-469 An 96	317-504+ An 96
Li	25	2	4
B	50	24	--
Mg	1900	1100	610
P	21	16	6
K	210	80	37
Ti	82	28	36
V	6	2	2
Cr	11	3	5
Fe	2100	2100	1600
Mn	64	54	32
Co	-	<26	<13
Rb	3	< 3	2
Sr	36	22	30
Y	.5	1	< 1
Zr	.3	--	--
Ba	.2	1	3

NOTES: 317-504+ is an unnumbered grain between grains 504 and 508.

P values may be low by up to a factor of 5.

LUNA 16 GLASSES (Preliminary Data Reduction)

	317-16	317-425	308-116	317-276	308-215	308-(9)	308-100	308-27	317-337	317-30	317-272+	317-347	Breccia 308-31
Li	51	13	25	30	21	16	14	9	13	17	9	.5	22
B	51	170	96	74	117	41	11	120	100	68	110	29	100
Na	2200	4200	3800	1300	2500	2800	1700	1900	2700	1000	690	1000	4000
P	34	88	73	51	63	45	9	31	120	17	18	12	59
K	1400	940	800	730	720	670	660	540	360	290	110	80	160
Ti	3700	4600	9300	8200	1200	730	660	1300	1800	7100	600	390	1.2%
V	26	26	27	30	28	14	18	29	38	31	29	22	23
Cr	320	320	510	450	360	190	170	330	330	440	180	120	340
Mn	360	410	790	720	340	200	200	310	550	590	190	150	710
Ni	<10	<37.0	<33.0	<6	<19	<55	<14	<20	<18	<30	-	-	<1
Co	20	44	51	34	25	36	22	23	32	36	28	18	26
Rb	34	5	3	3	<3	<5	<2	<3	3	<2	3	<2	3
Sr	43	50	74	51	31	47	37	31	27	60	36	39	110
Y	60	8	14	10	<7	<8	<6	<5	4	12	6	<2	10
Zr	110	12	24	23	<9	<12	<7	<5	4	20	7	<4	19
Nb	50	<1	-	2	<1	<1	-	<.2	-	<1	-	-	1
Ba	150	12	22	36	17	17	13	13	6	27	10	<1	37
La	6	8	1	<1	<.4	<1	<1	<1	.5	1	1	-	1
Ce	12	15	2	<2	<1	<2	<1	<1	1	1	1	-	2

NOTES: Glasses listed in order of decreasing K content.
308-(9) is an unnumbered fragment near grain 9.
317-272+ is an unnumbered fragment between grains 272 and 273.
308-31 is a breccia fragment
All P values may be consistently low by up to a factor of 5.

APOLLO 12 OLIVINE ANALYSES BY ION MICROPROBE MASS SPECTROMETRY

(ppm atomic)

	12032, 46-6		12045, 6		
	#32	#36	A_1 #6	C_1 #31	A_2 #16
Li	4	< .5	6	7	9
B	5	32	13	68	85
Na	43	216	117	305	877
Mg	20.0%	20.65%	18.95%	16.92%	19.90%
Al	815	811	384	540	855
Si	14.25%	14.25%	14.27%	14.26%	14.24%
P	20	2.7	37	12	21
K	20	8.8	33	127	610
Ca	915	1530	~1200	1230	880
Ti	118	171	250	131	207
V	37	48	27	27	31
Cr	1030	2160	829	717	921
Mn	1230	1040	1180	1453	1029
Fe	8.14%	7.33%	9.25%	11.21%	8.19%
Co	60	44	56	52	54
Sr	<3	<1	<3	<3	<4
Y	1	< .5	< .5	1	2
Zr	<2	<1.6	0.1	4	5

DISTRIBUTION OF TRACE ELEMENTS IN MAJOR SILICATE

PHASES OF LUNAR BASALT 12053,86

(Preliminary Data Reduction)

	Plagioclase	Olivine	Clinopyroxene Center	Clinopyroxene Edge	Fe-Pyroxmangite
Li	26	-	-	-	5
B	-	2	-	3	-
Na	4875	30	81	290	568
Mg	1347	M	M	M	M
Al	M	828	1.15%	2.70%	2.25%
P	48	4	-	8	3
K	240	30	30	31	93
Ca	M	1760	M	M	M
Ti	324	146	1450	3910	3330
V	9	40	162	193	10
Cr	8	1036	2664	2725	274
Mn	71	1244	1033	784	1877
Fe	3140	M	M	M	M
Co	-	36	23	49	31
Rb	2	-	-	-	-
Sr	52	-	11	13	18
Y	2	-	5	9	15
Zr	7	-	13	21	17
Ba	2	-	-	1	-

MISCELLANEOUS APOLLO 12 ANALYSES

(Preliminary Data Reduction)

	12013,14 Plagioclase (An_{90})	12010,33 Olivine #2	12010,33 Ilmenite
Li	67	7	-
B	16	6	-
Na	6430	632	34
Mg	944	M	116
Al	M	-	2240
P	60	27	13
K	1550	380	63
Ca	M	1380	120
Sc	-	-	60
Ti	100	193	M
V	10	40	80
Cr	25	1050	1330
Fe	3810	M	M
Mn	77	1215	2450
Co	-	54	20
Rb	5	-	-
Sr	48	<3	-
Y	5	2	6
Zr	13	5	97
Nb	-	-	16
Ba	39	-	-
La	4	-	-
Ce	3	-	-

TRACE ELEMENT ANALYSES OF SELECTED LUNAR GLASSES
(ppm atomic)

	APOLLO 12				APOLLO 11
	57,46-10F #34 CLEAR FRAGMENT	32,46-B #18 TURBID FRAGMENT	57,46-10F #22 BROWN SPHERULE	57,46-10F #39 BLACK FRAGMENT	85,17-17 #5 GREEN CRUST GLASS
Li	115	215	94	24	33
B	73	32	13	22	30
Na	11060	8460	4130	2580	335
P	368	495	17	56	212
K	8840	8470	3330	1120	815
Ti	7330	5900	6890	13000	19000
V	82	51	49	80	59
Cr	877	770	97	1720	1170
Mn	512	763	690	1240	1040
Ni	1070	1020	1275	324	1000
Co	45	55	33	35	30
Rb	13	11	5	4	5
Sr	73	82	85	50	42
Y	93	139	87	15	27
Zr	540	703	288	53	85
Ba	161	267	226	16	67
La	24	36	20	4	< 2
Ce	42	97	54	4	7

TRACE ELEMENT ANALYSES OF LUNAR GLASSES

IN APOLLO 12 SAMPLES

(Preliminary Data Reduction)

	10,33 #1	32,46-6 #28	32,46-B #16	32,46-B #14	57,46-10F #44	57,46-10F #51	01,64-3 #52	01,64-3 #16	01,64-3 #13
Li	20	68	148	153	60	26	22	24	24
B	< 1	30	37	25	20	8	19	13	80
Na	918	4200	5660	4570	5000	3270	700	290	1260
P	50	46	625	527	474	110	20	43	170
K	443	4930	5760	5270	4730	1258	87	110	550
Ti	914	8240	5400	4240	4870	3620	1.4%	6980	6110
V	67	58	61	53	32	56	75	61	54
Cr	1420	688	841	665	483	650	1120	756	1630
Mn	974	659	765	686	473	472	1210	693	644
Co	30	35	84	70	23	23	35	39	37
Rb	2	5	9	11	6	3	2	2	2
Sr	26	56	78	68	49	50	45	41	27
Y	15	14	88	102	100	31	21	52	27
Zr	50	35	606	550	591	176	72	320	204
Ba	6	9	82	172	192	64	13	73	39
La	<.5	2	14	29	24	9	2	15	10
Ce	<.5	4	33	79	66	21	6	33	41

PLAGIOCLASE AND OLIVINE IN APOLLO 11 BASALTS AND GRAIN MOUNT

(Preliminary Data Reduction)

	PLAGIOCLASE				OLIVINE	
	Lunar 5 Grain Mount		10017,25 (Type A)		10017,28 (Type B)	
	A	G	A	C	Center	Edge
Li	5	61	22	108	-	-
B	8	-	26	-	-	6
Na	4880	6970	3875	4030	16	12
Mg	872	358	1179	1242	M	M
Al	M	M	M	M	354	1575
P	34	174	21	-	52	-
K	408	570	143	158	6	2
Ca	M	M	M	M	685	814
Ti	169	146	218	442	411	351
V	-	-	-	-	19	12
Cr	-	-	5	-	685	598
Mn	51	48	56	53	1010	1180
Fe	1540	1660	1875	1690	M	M
Co	-	-	-	-	19	25
Rb	5	3	-	-	-	-
Sr	76	109	59	58	-	-
Ba	16	1349	1	-	-	-

ANALYSES OF CLINOPYROXENES IN APOLLO 11 FINES

(Preliminary Data Reduction)

	10017-26 (Type B)			10017,25 (Type A)*	10017,17	Lunar 5 Grain Mount				
	Edge	Middle	Center		(Breccia)	11 Center	11 Edge	15	13	Fe-Pyroxmangite
Li	22	19	18	13	-	23	44	18	7	<1
B	25	6	21	16	11	14	9	18	<2	<2
Na	43	421	278	513	342	579	1035	387	530	133
Al	2.95%	2.04%	3.22%	2.85%	1.13%	4.35%	2.52%	3.00%	0.6%	.09%
P	30	25	50	42	33	89	113	-	26	27
K	84	22	41	77	32	104	176	133	22	53
Ti	7760	7530	6155	6260	3750	6890	4500	4190	2060	2500
V	109	105	88	73	32	34	26	44	20	11
Cr	2050	2020	1790	1800	763	1457	948	1240	575	294
Mn	652	760	953	1300	1230	569	896	665	647	2220
Sr	4	4	4	13	3	5	21	6	5	3
Y	9	14	8	10	5	14	39	4	9	16
Zr	7	9	6	14	5	22	79	9	30	14
Ba	1	-	0.5	-	-	-	35	<1	<1	<1

*NOTE: Grain strongly zoned.

ANALYSES OF GRAINS IN APOLLO 11 ANORTHOSITIC FRAGMENTS

(Preliminary Data Reduction)

	PLAGIOCLASE			OLIVINE	
	KAY-17	10085,7-6 (1)	10085,7-6 (2)	10085.7-6 (2)	10085,7-6 (1)
Li	3	16	21	66	70
B	25	3	120	76	124
Na	6510	4974	3038	745	1680
Mg	917	424	1638	M	M
Al	M	M	M	140	246
P	42	17	11	47	60
K	315	289	426	115	207
Ca	M	M	M	464	595
Ti	42	52	36	154	175
V	6	-	-	24	17
Cr	42	-	4	516	467
Mn	62	61	43	842	797
Fe	2960	2710	1140	M	M
Sr	38	61	57	1	2
Y	4	2	-	-	-
Ba	1	16	11	-	-

NOTE: Olivine (1) is adjacent to plagioclase (1) in thin section.

ANALYSES OF GLASS IN APOLLO 11 FINES AND CACHARI METEORITE

(Preliminary Data Reduction)

	Crust Glass in 10085,17-17 (Breccia)			Lunar 5 Grain Mount	Cachari
	Spot 3	Spot 4	Spot 5	#19	Vein Glass
Li	22	22	24	26	10
B	14	10	23	20	19
Na	2520	2085	2430	4015	2600
P	130	99	190	109	38
K	490	281	585	1380	225
Ti	1.74%	1.55%	1.60%	2.09%	.14%
V	35	36	45	54	29
Cr	780	750	900	945	813
Mn	751	780	805	549	1885
Co	22	25	24	16	-
Rb	-	3	3	-	-
Sr	31	36	31	38	16
Y	20	20	20	22	2
Zr	65	65	67	82	8
Ba	15	13	17	25	2
Ce	3	4	5	4	-

ANALYSES OF MINERALS IN ANGRA DOS REIS AND CACHARI METEORITES

(Preliminary Data Reduction)

	ANGRA DOS REIS		CACHARI		
	Large Clinopyroxene	Small Clinopyroxene	Orthopyroxene	Clinopyroxene	Plagioclase
Li	3	3	13	11	9
B	5	3	7	15	42
Na	160	146	364	385	5040
Mg	M	M	M	M	2075
Al	4.35%	4.35%	2730	3310	M
P	44	41	30	30	36
K	7	12	113	79	490
Ca	M	M	9950	M	M
Ti	3590	3610	276	611	76
V	78	72	14	42	-
Cr	605	545	265	675	-
Mn	294	289	4150	3460	281
Fe	M	M	M	M	7285
Ni	-	-	-	405	-
Co	58	49	9	7	-
Rb	-	-	-	-	.5
Sr	38	33	2	2	70
Y	12	11	2	2	1
Zr	39	36	3	2	2
Nb	2	1	-	-	-
Ba	1	1	1	2	17
La	4	3	-	-	-
Ce	10	8	-	-	-

ANALYSES OF MINERALS IN THE JUVINAS METEORITE

(Preliminary Data Reduction)

	Clinopyroxene	Plagioclase	Ilmenite
Li	13	13	2
B	3	5	2
Na	178	4080	35
Mg	M	1170	1.15%
Al	4130	M	196
Si	M	M	27
P	23	10	9
K	9	252	13
Sc	-	-	44
Ti	864	17	M
V	33	-	139
Cr	1640	9	397
Mn	3620	108	6150
Fe	M	3330	M
Ni	74	-	1
Co	23	-	<4
Sr	3	49	-
Y	5	1	2
Zr	9	2	10
Nb	1	-	28
Ba	<1	11	-

ANALYSES OF ZONED OLIVINE IN OCEANITE C-112 FROM HAWAII

(Preliminary Data Reduction)

	Center	Middle	Edge
B	34	8	1
Na	2680	656	397
Al	466	528	347
P	22	14	13
K	1100	216	160
Ca	1450	1210	531
Ti	96	64	57
V	18	21	14
Cr	519	572	373
Mn	451	510	589
Fe	2.56%	2.91%	3.84%
Co	41	45	46
Ni	67	81	67
Sr	2	3	2
Zr	1	1	2
Sn	37	13	12

Spinel Inclusion	
Na	897
Mg	8.32%
Al	11.8%
Si	178
K	354
Sc	6
Ti	4895
V	440
Cr	16.3%
Mn	482
Fe	4.12%
Co	44
Ni	30

ANALYSES OF MINERALS IN TRACHYTE (C-116) FROM HAWAII

(Preliminary Data Reduction)

	CLINOPYROXENE	OLIVINE		PLAGIOCLASE	
		Center	Edge	Center	Edge
Li	66	54	59	23	-
Be	40	-	-	-	-
B	11	17	3	3	5
Na	1.52%	1160	688	M	M
Mg	M	M	M	45	47
Al	3760	72	38	M	M
P	65	78	81	13	< 1
K	473	335	190	.47%	3.0%
Ca	M	1140	895	1.75%	.14%
Ti	1370	63	83	-	-
V	17	2	2	-	-
Cr	48	44	35	-	-
Mn	6250	2.15%	2.26%	47	55
Fe	M	M	M	929	1408
Co	102	7	8	-	-
Cu	74	34	41	-	-
Zn	840	1650	1970	-	-
Rb	-	-	-	1	25
Sr	16	4	5	757	67
Y	91	2	4	< 1	-
Zr	2316	4	4	5	-
Nb	8	-	-	-	-
Sn	109	22	26	-	-
Ba	1	-	-	210	105
La	46	-	-	-	-
Ce	200	2	2	4	-
Pb	152	58	47	9	6

ANALYSIS OF MINERALS IN NEPHELINITE
FROM HAWAII (#425)

(Preliminary Data Reduction)

	Clinopyroxene		Nepheline	
	1	2	1	2
Li	6	5	6	4
B	<.5	<.5	<.5	<.5
Na	3610	4240	M	M
Mg	M	M	649	590
Al	3.75%	4.41%	M	M
P	52	123	11	11
K	17	29	M	M
Ti	6640	9370	117	196
V	226	268	-	-
Cr	52	60	-	-
Mn	540	590	106	84
Fe	M	M	3020	2850
Rb	-	-	28	23
Sr	99	151	290	424
Y	8	11	2	-
Zr	120	129	1	-
Nb	3	4	-	-
Ba	<.5	1	19	28
La	11	22	-	-
Ce	33	46	-	-

ANALYSES OF MINERALS IN HIGH-ALUMINA BASALT (4-412)
FROM THE MID-ATLANTIC RIDGE

(Preliminary Data Reduction)

	Clinopyroxene	Plagioclase	Ilmenite
Li	9	4	13
B	11	2	2
Na	2355	74	M
Mg	M	M	1420
Al	2.55%	460	M
P	15	38	4
K	297	40	244
Ca	M	1460	M
Ti	3540	54	44
V	244	10	12
Cr	535	233	3
Mn	826	935	51
Fe	M	M	1900
Ni	57	200	-
Co	31	51	-
Rb	-	-	<.5
Sr	6	-	72
Y	9	-	-
Zr	13	-	-
Ba	3	-	1

ANALYSES OF MINERALS IN THOLEIITIC BASALT (51-2)

FROM THE MOJAVE DESERT

(Preliminary Data Reduction)

	OLIVINE		PLAGIOCLASE	
	Center	Edge	Center	Edge
Li	13	6	0.5	2
B	49	28	6	10
Na	308	147	2.2%	1.6%
Mg	M	M	409	582
Al	384	256	M	M
P	-	9	6	6
K	48	22	1520	759
Ca	1610	1390	M	M
Ti	385	194	314	270
V	15	9	-	-
Cr	309	223	-	-
Mn	1220	1210	39	45
Fe	M	M	1360	1550
Ni	318	314	-	-
Co	70	87	-	-
Zn	386	732	-	-
Rb	-	-	3	5
Sr	2	1	402	279
Ba	-	-	31	8

ANALYSES OF MINERALS IN BASANITE (B-1)
FROM THE MOJAVE DESERT

(Preliminary Data Reduction)

	CLINOPYROXENE		OLIVINE		PLAGIOCLASE
	Center	Edge	Center	Edge	Center
Li	< 1	24	5	10	-
B	62	83	33	43	21
Na	2180	2785	225	749	M
Mg	M	M	M	M	476
Al	2.75%	4.05%	369	-	M
P	14	51	15	27	-
K	249	112	53	89	1090
Ca	M	M	962	340	M
Ti	5900	5890	72	900	288
V	171	130	12	80	4
Cr	443	325	205	310	3
Mn	436	241	723	1140	41
Fe	M	M	M	M	1530
Ni	< 100	-	253	240	-
Co	29	16	35	52	-
Zn	498	458	367	733	-
Rb	-	4	-	-	1
Sr	36	21	2	4	343
Y	9	6	< 1	< 1	-
Zr	63	37	< 1	1	-
Sn	-	17	33	19	-
Ba	6	2	-	-	13
La	-	1	-	-	< 1
Ce	3	4	-	-	-

ANALYSES OF MINERALS IN BASALT FROM DISKO ISLAND

AND MYLONITIZED SPINEL PERIODOTITE FROM ST. PAUL'S ROCKS

(Preliminary Data Reduction)

	DISKO BASALT		ST. PAUL'S ROCKS PERIDOTITE	
	Olivine	Plagioclase	Olivine	Spinel
Li	4	16	-	-
B	3	3	-	-
Na	165	M	116	159
Mg	M	863	M	10.08%
Al	405	M	1970	25.29%
Si	M	M	M	72
P	26	26	17	1
K	18	506	77	41
Ti	57	141	31	46
V	31	-	26	403
Cr	452	-	228	3.28%
Mn	565	64	485	381
Fe	M	4090	M	3.43%
Ni	70	-	72	59
Co	51	-	40	-
Rb	-	2	-	-
Sr	2	94	-	-
Y	-	1	-	-
Zr	<10	<5	-	<4