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Title of article The Arabian Continental Alkali Basalt Province: Part I
Evolution of Harrat Rahat, Kingdom of Saudi Arabia

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see Bulletin v. 101, p. 71 - 95

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APPENDIX A. MAJOR AND TRACE ELEMENT COMPOSITION AND NORMATIVE MINERALOGY FOR 179 SAMPLES FROM HARRAT RAHAT, KINGDOM OF SAUDI ARABIA

Notes:

(1) Ten major elements (SiO_2 , TiO_2 , Al_2O_3 , FeO , MnO , MgO , CaO , Na_2O , K_2O , and P_2O_5) and eleven trace elements (Ni, Cr, Ba, Rb, Sr, Zr, Y, Nb, Ga, Cu, and Zn) were determined by X-ray fluorescence at Washington State University (for accuracy and precision see Hooper and Johnson [1987]). Four trace elements (Sc, V, La, and Ce) were determined by inductively coupled plasma spectrometry (ICP) at King's College, London University, England (for accuracy and precision see Walsh [1980] and Walsh and others [1981]).

(2) Major element data and normative mineralogy are in weight percent, whereas trace element data are in ppm.

(3) The major element analyses are the non-normalized raw data with total iron presented as FeO .

(4) Iron was recalculated to a $\text{Fe}^{2+}/\text{Fe}^{3+}$ ratio of 9:1 and the major element data was then normalized on a volatile-free basis before the CIPW normative mineralogy was calculated.

(5) The data are presented in four parts based on the major stratigraphic units; these are (1) Shawahit-complete data, (2) Hammah-complete data, (3) Madinah-AOB, and (4) Madinah-OTB-hawaiite-mugearite-benmoreite-trachyte. Each of these four data sets are presented in order of decreasing SiO_2 . The designations of stratigraphic subunits are as shown except for the Lower Shawahit (LS) and the Upper Shawahit (US). Rock type designations are: alkali olivine basalt (AOB), olivine transitional basalt (OTB), hawaiite (HAW), mugearite (MUG), benmoreite (BEN), and trachyte (TRACH). Designation of harrat subdivisions are: Harrat Rashid (R), Harrat Bani Abdullah (BA), Harrat Turrah (T), and Harrat Ar Rukhq (A).

SHAWAHIT-COMplete DATA - Page 1
(51 samples)

Sample	4229	4189	4181	4180	4180	4150	4201	4235	4188	4191	4254	4239	4241	4256	4157
Rock Type	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB
Harrat	T	T	BA	BA	BA	T	BA	T	T	T	A	T	T	T	BA
Subunit	LS	LS	LS	LS	LS	LS	LS	US	LS	US	US	LS	US	US	LS
SiO2	49.69	49.53	49.20	49.03	48.94	48.91	48.88	48.80	48.76	48.75	48.72	48.71	48.71	48.65	48.64
TiO2	1.39	1.44	1.64	1.65	1.35	1.54	1.65	1.61	1.29	1.29	1.77	1.42	1.35	1.43	1.66
Al2O3	16.55	15.63	16.69	15.89	16.22	15.92	16.79	16.27	16.51	15.98	16.83	15.60	15.59	15.85	16.22
FeO	10.24	10.84	9.96	10.14	10.74	11.38	10.85	11.20	10.38	11.32	11.03	10.90	10.38	10.25	11.13
MnO	0.17	0.17	0.17	0.18	0.18	0.18	0.17	0.18	0.17	0.18	0.18	0.18	0.16	0.17	0.18
MgO	7.19	9.20	8.05	10.29	9.14	9.56	7.41	8.36	8.45	9.22	7.15	10.02	9.72	9.06	8.49
CaO	10.85	9.47	10.65	9.50	10.71	9.95	11.37	10.74	10.54	10.60	10.60	9.35	9.58	10.46	10.84
Na2O	3.32	2.97	3.16	3.09	3.02	2.83	2.96	3.14	2.55	2.89	3.36	2.80	2.80	3.22	3.05
K2O	0.55	0.53	0.68	0.79	0.35	0.55	0.32	0.43	0.27	0.37	0.45	0.57	0.48	0.63	0.31
F2O5	0.17	0.18	0.24	0.28	0.16	0.22	0.17	0.21	0.15	0.16	0.25	0.19	0.18	0.21	0.21
Total	100.12	99.95	100.44	100.83	100.81	101.04	100.57	100.94	99.07	100.76	100.34	99.74	98.95	99.93	100.73
NI	106	185	102	224	165	192	107	134	142	239	78	215	210	213	151
CR	228	312	295	396	414	317	239	223	281	367	154	377	391	352	296
EA	113	101	110	132	41	132	54	341	36	77	105	113	96	168	41
RB	7	7	8	8	1	6	2	4	1	5	5	10	6	10	2
SR	316	276	387	406	299	391	288	334	317	288	399	285	568	337	318
ZR	101	93	142	164	95	101	105	112	95	85	133	103	127	108	109
Y	21	19	24	22	20	20	20	22	20	19	26	18	19	20	21
NB	14	14	17	24	11	17	6	15	6	9	15	15	15	18	8
GA	17	20	18	21	15	20	19	20	17	18	21	22	9	18	21
CU	72	116	72	69	99	108	117	134	127	105	95	109	111	115	124
ZN	75	80	78	78	75	84	79	87	78	83	86	82	82	80	84
SC	26	25	29	27	30	26	30	25	26	25	31	26	26	24	28
V	211	210	226	212	236	208	252	211	207	201	247	207	203	194	235
LA	6	8	8	12	2	8	4	7	4	5	8	8	8	9	3
CE	30	28	33	37	26	31	25	31	25	26	34	30	28	31	26
AN	51.35	52.48	53.47	51.61	54.25	54.87	55.77	53.79	60.32	54.71	52.72	54.44	54.65	53.36	53.89
or	3.25	3.13	4.02	4.67	2.07	3.25	1.89	2.54	1.60	2.19	2.66	3.37	2.84	3.72	1.83
ab	27.12	25.13	25.54	25.46	25.02	23.95	25.05	24.94	21.58	24.45	26.47	23.69	23.69	23.54	25.37
an	28.63	27.75	29.35	27.16	29.67	29.11	31.58	29.03	32.81	29.54	29.51	28.32	28.55	26.94	29.65
ne	0.53	0.00	0.65	0.37	0.29	0.00	0.00	0.88	0.00	0.00	1.06	0.00	0.00	2.01	0.24
di	19.76	14.74	17.88	14.74	18.30	15.32	19.48	18.73	15.10	17.97	17.62	13.69	14.48	19.22	18.61
hy	0.00	7.90	0.00	0.00	0.00	5.06	1.03	0.00	11.70	0.58	0.00	6.17	7.31	0.00	0.00
ol	16.26	16.53	17.83	23.15	20.92	18.31	16.39	19.59	11.94	21.51	17.43	19.73	17.54	19.76	19.71
st	1.65	1.74	1.61	1.64	1.73	1.84	1.75	1.80	1.67	1.83	1.78	1.75	1.67	1.65	1.80
il	2.63	2.73	3.11	3.13	2.56	2.93	3.13	3.05	2.44	2.44	3.36	2.70	2.57	2.71	3.15
ap	0.40	0.41	0.56	0.64	0.37	0.50	0.39	0.49	0.36	0.38	0.58	0.44	0.42	0.48	0.49

SHAWAHIT-COMplete DATA - Page 2

Sample	4217	4266	4222	4253	4153	4164	4251	4255	4226	4215	4269	4204	4218	4095	4207
Rock Type	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB
Harrat	T	A	T	A	BA	BA	A	A	T	T	A	T	T	BA	T
Subunit	us	us	us	us	us	LS	us	us	LS	us	us	us	us	us	LS
SiO ₂	48.61	48.45	48.44	48.36	48.21	48.21	48.11	48.10	48.09	48.06	48.06	47.92	47.84	47.81	47.80
TiO ₂	1.26	1.56	1.43	1.58	1.50	1.89	1.42	1.53	1.06	1.40	1.36	1.48	1.40	1.51	1.44
Al ₂ O ₃	15.86	17.29	16.29	16.30	16.65	16.53	15.49	16.65	16.55	15.55	15.89	15.73	15.79	15.27	16.19
FeO	10.45	10.31	10.73	10.99	10.86	10.99	10.86	10.90	10.29	11.00	11.64	10.75	11.22	11.12	10.61
MnO	0.17	0.17	0.17	0.18	0.18	0.17	0.17	0.17	0.17	0.17	0.18	0.17	0.17	0.18	0.18
MgO	9.30	7.27	8.13	8.86	8.92	8.23	9.76	6.87	9.10	9.62	9.11	9.11	9.24	9.88	8.17
CaO	10.89	11.57	10.91	9.79	11.10	11.32	10.16	11.66	11.48	11.07	10.73	11.12	10.55	10.89	11.51
Na ₂ O	2.99	3.06	3.20	3.23	2.93	2.88	3.05	3.23	2.89	2.78	2.87	3.05	2.90	2.96	3.04
K ₂ O	0.39	0.30	0.39	0.60	0.27	0.43	0.65	0.49	0.32	0.29	0.38	0.56	0.42	0.52	0.37
P ₂ O ₅	0.18	0.19	0.17	0.29	0.19	0.19	0.25	0.18	0.15	0.14	0.16	0.21	0.17	0.20	0.19
Total	100.11	100.18	99.86	100.19	100.80	100.84	99.92	99.78	100.10	100.09	100.38	100.11	99.71	100.34	99.49
NI	202	106	135	169	177	114	220	84	218	230	200	222	214	241	136
CR	420	197	263	262	334	247	349	180	391	458	322	353	375	364	246
BA	58	53	88	128	64	39	188	146	65	39	127	98	88	123	70
RB	4	3	4	8	1	4	7	5	4	3	4	8	4	5	4
SR	287	386	322	352	316	379	414	344	266	281	324	382	324	345	345
ZR	111	110	105	130	107	117	124	109	99	91	91	109	97	103	103
Y	20	22	21	25	22	24	20	20	20	19	20	19	19	20	19
MB	10	11	13	21	9	12	16	12	7	7	10	19	13	16	12
GA	18	21	16	24	20	16	15	19	15	16	16	16	21	20	18
CU	109	119	110	108	113	128	94	92	126	104	146	103	123	94	120
ZN	76	77	84	80	80	78	82	81	74	83	83	74	80	84	80
SC	29	32	27	26	29	31	23	26	29	29	28	27	28	24	29
V	229	232	215	202	226	255	194	228	202	233	238	202	213	195	230
LA	6	5	5	12	2	6	10	5	4	3	6	8	7	6	6
CE	28	28	28	38	29	29	37	32	23	24	29	31	28	28	29
AN	54.79	57.34	54.60	52.60	57.55	57.56	54.10	57.67	59.77	56.42	56.22	57.51	55.75	57.02	57.87
or	2.30	1.77	2.30	3.55	1.60	2.54	3.84	2.90	1.89	1.71	2.25	3.31	2.48	3.07	2.19
ab	23.69	24.22	24.06	25.42	23.22	22.79	22.61	21.64	21.03	22.48	22.86	20.37	22.88	20.24	21.44
an	28.70	32.56	28.94	28.21	31.48	30.91	26.66	29.49	31.24	29.10	29.35	27.58	28.83	26.85	29.44
ne	0.87	0.91	1.63	1.04	0.85	0.86	1.73	3.08	1.86	0.57	0.77	2.94	0.90	2.61	2.32
di	19.69	19.33	19.74	15.07	18.24	19.65	18.00	22.41	20.19	20.30	18.68	21.37	18.28	21.10	21.61
ol	20.46	16.43	18.48	21.58	20.50	18.43	22.18	15.31	20.00	21.30	21.78	19.61	21.60	21.48	17.74
mt	1.68	1.67	1.73	1.77	1.75	1.77	1.75	1.75	1.65	1.77	1.87	1.73	1.81	1.80	1.71
il	2.40	2.96	2.72	3.01	2.84	3.58	2.69	2.91	2.01	2.66	2.58	2.81	2.66	2.87	2.73
ap	0.41	0.45	0.38	0.68	0.44	0.44	0.59	0.41	0.34	0.33	0.38	0.49	0.40	0.46	0.44

SHAWAHIT-COMplete DATA - Page 3

Sample	4151	4257	2411	4149	4270	4249	4224	4206	4242	4203	4154	4220	4262	4243	4225
RockType	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	OTB	AOB	OTB	OTB	AOB
Harrat	BA	A	BA	BA	A	A	A	T	T	BA	BA	T	A	T	T
Subunit	US	US	US	US	US	US	US	LS	US	LS	LS	US	US	US	US
SiO2	47.78	47.70	47.65	47.58	47.58	47.57	47.56	47.52	47.37	47.32	47.24	47.11	47.04	47.01	46.90
TiO2	1.58	1.41	1.40	1.90	1.42	1.31	1.52	1.17	1.80	1.52	1.02	1.53	1.96	1.41	1.54
Al2O3	16.75	16.85	15.47	15.62	17.06	16.51	16.31	15.83	15.91	15.85	13.64	15.62	16.51	15.33	15.91
FeO	11.14	9.95	10.36	11.11	10.52	10.88	10.95	10.17	10.71	10.76	11.04	11.10	11.85	10.92	10.51
MnO	0.18	0.17	0.18	0.17	0.18	0.18	0.17	0.17	0.16	0.18	0.18	0.18	0.19	0.17	0.18
MgO	11.53	7.41	9.97	9.72	7.30	8.87	8.34	8.35	8.40	8.00	14.72	9.08	8.12	12.46	9.10
CaO	7.49	12.02	11.71	10.76	12.31	11.69	11.28	12.46	10.84	12.80	9.02	11.17	11.14	9.63	11.35
Na2O	2.93	3.12	2.65	2.86	2.97	2.86	3.14	2.91	2.49	2.66	2.42	3.17	2.96	2.26	2.98
K2O	0.40	0.43	0.34	0.64	0.35	0.20	0.41	0.32	0.67	0.27	0.29	0.59	0.39	0.31	0.61
P2O5	0.24	0.22	0.16	0.25	0.17	0.15	0.22	0.16	0.27	0.18	0.15	0.22	0.29	0.17	0.27
Total	100.02	99.29	99.88	100.61	99.85	100.21	99.91	99.06	98.62	99.53	99.72	99.77	100.45	99.67	99.34
MI	121	131	223	214	136	182	168	226	136	114	449	222	106	317	222
CR	166	210	476	353	184	296	266	442	240	260	643	335	133	469	347
BA	64	151	65	59	57	21	128	32	142	43	46	105	29	37	258
RB	3	4	3	6	1	1	6	2	9	2	3	8	2	3	8
SR	456	411	285	416	355	285	377	292	600	302	238	388	444	455	443
ZR	132	113	90	143	108	82	96	99	137	105	73	107	130	109	143
Y	21	20	19	21	21	22	21	20	21	20	15	20	22	20	22
NB	11	15	10	17	8	9	15	10	25	9	19	24	12	8	16
GA	19	16	17	17	17	17	16	13	20	20	5	18	16	14	15
CU	113	106	109	106	119	114	106	119	114	123	93	102	139	115	92
ZN	79	78	77	82	76	78	78	76	85	82	71	80	81	78	73
SC	30	31	28	28	32	30	28	30	25	31	23	25	28	27	29
V	232	219	216	250	242	215	205	220	224	226	188	201	257	211	215
LA	4	7	3	8	4	2	7	4	11	3	4	8	9	6	11
CE	33	31	24	36	29	24	30	26	37	27	25	32	38	28	36
AM	55.66	60.36	60.15	57.99	62.50	60.90	58.54	61.59	58.95	62.61	55.46	60.06	59.33	61.67	61.65
or	2.36	2.54	2.01	3.78	2.07	1.18	2.42	1.89	3.96	1.60	1.71	3.49	2.30	1.83	3.60
ab	24.79	20.16	19.42	20.21	19.31	20.30	20.68	18.20	21.07	18.23	20.48	17.72	20.98	19.12	17.56
an	31.37	30.70	29.31	27.89	32.19	31.62	29.20	29.19	30.26	30.51	25.50	26.65	30.61	30.77	28.24
ne	0.00	3.38	1.63	2.16	3.15	2.11	3.19	3.48	0.00	2.32	0.00	4.93	2.20	0.00	4.15
di	3.44	22.50	22.55	19.41	22.82	20.78	20.72	25.82	17.78	26.06	14.76	22.32	18.65	12.87	21.45
hy	8.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.75	0.00	1.90	0.00	0.00	5.51	0.00
ol	24.66	15.32	20.38	21.30	15.66	19.76	18.66	16.36	17.15	15.90	31.44	19.59	19.52	24.87	19.22
mt	1.80	1.61	1.67	1.78	1.70	1.75	1.77	1.64	1.73	1.74	1.78	1.78	1.91	1.75	1.70
il	3.00	2.68	2.65	3.61	2.69	2.48	2.88	2.22	3.42	2.88	1.94	2.91	3.71	2.67	2.92
ap	0.55	0.52	0.37	0.58	0.39	0.34	0.51	0.37	0.62	0.41	0.34	0.51	0.68	0.39	0.62

SHAWAHIT-COMPLETE DATA - Page 4

Sample	4205	4238	4250	4252	4223	4240
Rock Type	AOB	OTB	OTB	OTB	AOB	AOB
Harrat	T	T	A	A	T	T
Subunit	US	LS	US	US	US	US
SiO ₂	46.71	46.70	46.67	46.54	45.49	46.47
TiO ₂	1.38	1.53	1.53	1.29	1.19	2.05
Al ₂ O ₃	15.50	14.46	15.18	15.63	15.29	14.95
FeO	10.65	10.55	11.03	11.01	10.94	10.92
MnO	0.17	0.18	0.18	0.18	0.18	0.17
MgO	7.87	11.66	10.39	9.05	9.23	10.30
CaO	13.42	10.72	11.42	10.91	13.00	10.46
Na ₂ O	2.97	2.39	2.79	2.90	2.83	2.89
K ₂ O	0.51	0.90	0.42	0.30	0.32	1.07
P ₂ O ₅	0.19	0.40	0.22	0.15	0.14	0.38
Total	99.37	99.49	99.82	97.96	98.61	99.66
NI	217	266	291	194	274	208
CR	367	504	386	347	434	348
BA	198	227	78	47	107	235
RB	6	16	6	2	4	16
SR	370	564	361	298	301	553
ZR	103	156	98	95	86	166
Y	20	18	20	20	17	20
NB	16	37	20	10	12	44
GA	16	17	16	19	16	17
CU	97	79	105	114	91	66
ZN	79	88	83	86	76	81
SC	28	24	28	24	24	25
V	203	197	209	194	182	227
LA	5	19	7	5	2	18
CE	28	50	30	29	26	49
AN	68.98	61.47	62.52	58.87	73.02	60.98
or	3.01	5.32	2.48	1.77	1.69	6.32
ab	12.35	16.34	16.58	20.08	10.37	15.78
an	27.46	26.07	27.66	28.75	28.07	24.66
ne	6.92	2.10	3.81	2.41	7.35	4.70
di	31.06	19.81	22.44	19.92	28.99	20.11
ol	13.91	24.44	21.81	20.57	17.71	21.69
wt	1.71	1.70	1.78	1.77	1.77	1.75
il	2.62	2.91	2.90	2.45	2.25	3.90
ap	0.43	0.94	0.50	0.35	0.33	0.87

HAMMAH-COMplete DATA - Page 1
(25 samples)

Sample	4272	4264	4261	4271	4233	4211	4164	4258	4155	4234	4273	4209	4228	4161	4214
RockType	BEN	BEN	MUG	HAW	HAW	HAW	AOB	HAW	AOB	AOB	AOB	HAW	AOB	AOB	HAW
Harriet	A	A	A	A	A	T	BA	T	BA	A	A	T	T	BA	T
SiO2	55.58	52.58	52.33	49.60	48.71	48.50	48.39	48.39	48.30	48.13	47.95	47.92	47.78	47.74	47.66
TiO2	1.03	1.89	1.57	2.28	2.22	2.50	2.15	2.22	2.07	2.32	2.23	2.11	2.49	2.11	2.47
Al2O3	17.77	17.33	16.65	16.81	16.32	16.60	15.79	16.34	16.23	15.93	16.03	15.11	16.23	15.52	16.24
FeO	9.20	10.12	11.98	11.45	11.87	10.68	12.76	12.23	10.14	11.99	10.44	10.47	12.13	11.16	11.91
MnO	0.23	0.24	0.27	0.22	0.20	0.17	0.21	0.22	0.17	0.19	0.17	0.17	0.18	0.18	0.20
MgO	1.55	2.99	2.53	4.73	5.70	5.59	8.04	6.34	9.13	7.53	8.16	8.08	7.72	9.08	7.03
CaO	3.99	5.53	5.42	8.00	8.70	8.92	8.76	8.60	9.33	9.48	9.07	9.77	8.49	9.34	8.90
Na2O	6.27	6.04	5.75	4.68	4.42	4.35	3.58	4.17	3.64	3.66	3.57	4.09	3.93	3.70	4.11
K2O	2.68	2.01	1.96	1.26	1.14	1.50	0.79	1.00	1.24	0.81	1.32	1.24	0.83	1.01	1.07
P2O5	0.77	1.15	1.32	0.81	0.71	0.61	0.57	0.72	0.40	0.55	0.56	0.62	0.55	0.49	0.63
Total	99.07	99.89	99.78	99.85	99.99	99.61	101.04	100.22	100.65	100.59	99.49	99.57	100.33	100.33	100.20
NI	7	1	2	34	66	42	172	96	183	117	141	179	127	173	104
CR	0	0	2	57	117	87	265	165	340	262	257	386	182	392	169
BA	461	302	291	189	160	217	95	163	165	107	250	169	124	130	100
RB	31	23	22	12	10	20	5	7	16	7	16	16	9	11	9
SR	2055	800	735	658	656	907	408	482	512	586	1667	1029	755	561	567
ZR	640	383	422	276	256	286	200	294	259	180	279	270	218	255	245
Y	34	34	41	28	29	23	29	35	22	25	22	22	22	23	27
NB	80	51	54	35	32	46	24	29	38	23	40	36	21	33	29
GA	14	15	23	21	14	21	17	19	13	15	17	17	14	23	15
CU	28	20	21	50	52	46	68	63	69	86	64	83	61	82	62
ZN	104	94	108	89	85	92	99	92	80	81	83	80	79	81	83
SC	7	9	8	16	17	20	22	21	27	22	21	22	18	25	22
V	24	50	27	154	166	215	184	162	217	225	197	194	188	217	200
LA	71	52	54	33	27	32	17	27	19	20	29	30	22	22	24
CE	130	106	111	76	68	71	52	68	50	55	66	67	57	56	60
AN	19.92	24.63	23.53	38.59	42.61	45.90	46.36	44.00	52.58	48.23	49.85	47.42	46.63	50.45	47.19
or	15.84	11.88	11.58	7.56	6.74	8.86	4.67	5.91	7.33	4.79	7.80	7.33	4.91	5.97	6.09
ab	49.97	43.57	44.95	33.55	28.73	25.80	28.56	29.16	21.90	26.46	23.96	21.30	27.69	22.35	25.55
an	12.43	14.24	13.83	21.08	21.33	21.89	24.68	22.92	24.29	24.65	23.82	19.21	24.20	22.76	22.82
ne	1.67	4.09	2.01	3.28	4.70	5.97	0.94	3.32	4.82	2.44	3.38	7.21	3.02	4.85	5.00
di	2.02	4.79	3.78	11.10	14.30	15.17	12.36	12.48	15.73	15.42	14.30	20.56	11.76	16.64	14.16
ol	12.03	13.55	15.78	15.36	16.81	14.17	22.50	18.74	20.20	19.35	19.15	16.95	20.94	20.95	18.65
wt	1.48	1.62	1.93	1.84	1.91	1.73	2.06	1.97	1.68	1.94	1.68	1.68	1.96	1.80	1.91
il	1.96	3.60	2.98	4.32	4.21	4.74	4.08	4.22	3.93	4.40	4.23	4.00	4.73	4.01	4.69
ap	1.78	2.66	3.06	1.67	1.63	1.41	1.33	1.66	0.94	1.28	1.29	1.44	1.28	1.12	1.46

HAMMAH-COMPLETE DATA - Page 2

Sample	4152	4237	4212	4263	4167	4213	4274	4268	4265	4221
RockType	AOB	AOB	HAW	HAW	AOB	AOB	HAW	HAW	HAW	AOB
Harriet	BA	T	T	A	BA	T	A	A	A	T
SiO2	47.39	47.37	47.13	46.47	46.37	45.95	45.70	45.64	45.62	45.59
TiO2	2.31	2.79	2.78	2.83	2.43	2.28	2.13	2.17	2.60	2.15
Al2O3	15.31	16.63	16.93	16.83	16.20	14.84	15.25	15.43	15.18	14.80
FeO	11.62	12.41	11.80	11.48	11.53	11.65	11.35	11.37	12.29	11.89
MnO	0.18	0.21	0.18	0.18	0.17	0.19	0.18	0.19	0.19	0.18
MgO	9.37	6.62	6.19	6.19	7.69	10.73	8.05	7.53	7.99	8.41
CaO	9.57	9.00	9.05	9.52	11.16	9.52	11.29	10.62	9.37	11.50
Na2O	3.43	3.55	4.13	4.04	3.23	3.34	3.55	4.07	4.54	3.41
K2O	0.92	0.79	1.06	1.20	0.76	0.78	1.24	1.14	1.06	0.89
P2O5	0.33	0.79	0.59	0.59	0.29	0.40	0.57	0.60	0.58	0.43
Total	100.42	100.16	99.84	99.33	99.83	99.67	99.71	98.76	99.42	99.25
NI	177	65	66	54	120	279	152	153	148	239
CR	271	127	116	77	163	615	263	226	213	390
SA	122	125	181	202	105	76	407	738	307	148
RB	10	7	11	14	8	7	16	14	7	10
SR	481	535	737	833	543	531	760	697	758	664
ZR	178	223	246	241	158	185	215	216	237	167
Y	22	30	26	25	22	23	21	22	26	21
NB	24	23	32	49	22	23	51	39	54	30
GA	18	20	24	19	18	17	20	18	21	17
CU	72	66	54	53	101	76	93	64	70	71
ZN	89	90	77	80	80	75	103	86	93	91
SC	21	22	20	17	27	24	25	21	19	24
V	239	211	218	231	263	223	236	207	196	224
LA	14	21	27	26	10	18	30	25	34	19
CE	45	59	65	65	39	48	69	62	71	51
AN	52.88	48.19	49.93	53.47	61.36	56.52	65.52	59.21	52.00	63.93
or	5.44	4.67	6.26	7.09	4.49	4.61	7.33	6.74	6.26	5.26
ab	21.09	29.14	24.60	21.10	17.29	17.84	10.64	14.10	16.53	12.67
an	23.66	27.11	24.53	24.25	27.46	23.20	20.22	20.47	17.91	22.45
ne	4.30	0.48	5.60	7.09	5.44	5.64	12.34	11.02	11.85	8.77
di	17.64	10.22	13.64	15.76	21.30	17.38	26.23	23.22	20.31	26.07
ol	21.41	19.55	16.79	15.58	16.83	24.00	15.86	15.99	18.41	17.18
mt	1.87	2.00	1.90	1.86	1.86	1.87	1.83	1.83	1.99	1.91
il	4.38	5.30	5.28	5.37	4.62	4.32	4.05	4.13	4.94	4.09
ap	0.77	1.83	1.36	1.37	0.68	0.93	1.33	1.39	1.35	0.98

MADINAH-OTB-HAWAIIITE-MUGEARITE-BENMOREITE-TRACHYTE - Page 1
(55 samples)

Sample	4147	4232	2390	2373	4257	2377	2376	2372	4259	2371	4176	2391	4146	4097	4215
Rock Type	TRACH	BEN	TRACH	BEN	BEN	BEN	BEN	BEN	BEN	BEN	MUG	MUG	MUG	MUG	HAW
Harrat	R	T	R	R	T	R	R	R	T	R	BA	R	R	R	T
Subunit	Qm4	Qm1	Qm5	Qm4	Qm1	Qm3	Qm3	Qm4	Qm1	Qm4	Qmb	Qm5	Qm3	Qm4	Qm1
SiO ₂	63.00	59.01	58.87	57.75	57.52	57.51	56.55	55.66	55.15	54.73	54.07	53.26	50.61	50.34	50.09
TiO ₂	0.17	0.66	0.54	0.88	0.77	0.89	0.88	1.15	1.06	1.32	1.71	1.87	2.07	2.19	2.12
Al ₂ O ₃	17.55	17.23	17.62	17.19	17.36	17.66	17.16	16.47	17.11	16.31	17.15	16.81	16.47	16.19	16.94
FeO	4.91	8.32	7.58	9.88	8.51	9.19	9.71	11.27	10.32	11.58	10.07	10.40	12.65	12.11	11.43
MnO	0.18	0.25	0.24	0.30	0.26	0.26	0.26	0.34	0.31	0.34	0.23	0.28	0.27	0.27	0.21
MgO	0.17	0.81	0.64	0.99	0.82	1.13	1.13	1.37	1.32	1.55	2.83	2.67	2.93	3.27	5.67
CaO	1.37	3.15	3.27	3.97	3.71	3.83	4.14	4.83	4.78	5.39	5.50	5.88	6.43	7.28	8.63
Na ₂ O	7.98	6.66	7.53	6.06	6.85	6.37	6.05	5.77	6.50	5.56	5.80	5.75	5.65	5.21	4.20
K ₂ O	5.07	3.79	3.73	3.38	3.41	3.18	3.09	2.66	2.72	2.44	2.55	2.26	1.77	1.93	1.12
P ₂ O ₅	0.04	0.35	0.26	0.48	0.39	0.56	0.55	0.64	0.62	0.77	0.50	1.09	1.45	1.66	0.56
Total	100.44	100.23	100.29	100.88	99.60	100.57	99.51	100.16	99.89	99.99	100.41	100.26	100.49	100.44	100.96
MI	17	7	8	0	6	3	1	1	3	2	15	7	0	0	67
CR	0	0	3	0	0	0	0	2	0	2	4	6	0	0	103
BA	11	776	474	639	518	412	518	635	604	518	451	372	169	288	183
RB	71	34	31	24	31	31	27	22	19	22	19	18	14	15	6
SR	28	268	343	292	316	324	389	359	400	375	416	458	589	541	494
ZR	1496	1048	787	505	730	688	700	476	768	462	488	480	394	358	309
Y	99	58	53	52	48	50	50	56	73	56	43	47	47	51	30
NB	154	83	77	53	73	71	72	50	77	49	48	47	41	47	28
GA	50	30	32	29	26	26	28	33	28	30	25	29	20	22	21
CU	13	23	12	15	14	36	27	17	27	21	29	20	26	21	65
ZM	211	134	133	132	110	140	131	152	145	149	117	136	114	126	89
SC	3	12	7	18	10	9	8	28	16	31	19	20	13	17	23
V	12	12	12	12	11	14	14	15	15	18	108	61	50	59	175
LA	120	73	65	52	64	62	58	53	74	55	47	49	47	49	25
CE	221	150	129	107	124	124	117	112	148	117	99	105	98	111	61
AN	0.00	10.47	6.40	16.47	12.06	16.88	17.82	18.95	17.58	20.96	24.48	23.69	25.78	28.93	42.72
or	29.96	22.40	22.04	19.98	20.15	18.79	18.26	15.72	16.07	14.42	15.07	13.36	10.46	11.41	6.62
ab	52.43	50.66	47.74	49.30	47.78	50.23	48.63	47.85	44.43	46.55	40.82	43.12	38.74	37.07	32.27
an	0.00	5.93	3.26	9.72	6.55	10.20	10.54	11.19	9.48	12.34	13.23	13.38	13.46	15.09	24.06
ne	5.21	3.08	8.66	1.07	5.52	1.99	1.39	0.53	5.73	0.27	4.47	3.00	5.83	3.80	1.77
di	5.78	6.44	9.82	5.98	8.09	4.48	5.57	7.47	8.82	8.10	9.13	7.37	7.65	8.64	12.52
ol	4.26	8.40	5.99	10.58	7.86	10.52	10.73	12.05	10.37	12.28	11.77	12.41	15.18	14.64	16.70
ac	1.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
mt	0.00	1.33	1.22	1.59	1.38	1.48	1.57	1.81	1.67	1.87	1.62	1.68	2.04	1.96	1.84
il	0.32	1.25	1.03	1.67	1.46	1.69	1.66	2.18	2.02	2.51	3.25	3.55	3.92	4.15	4.02
ap	0.09	0.82	0.61	1.10	0.91	1.29	1.27	1.48	1.44	1.79	1.15	2.51	3.35	3.83	1.29

MADINAH-OTB-HAWAIIITE-MUGEARITE-BENMOREITE-TRACHYTE - Page 2

Sample	2384	4185	4186	2416	2394	4170	2409	4145	4114	4148	2393	4162	4216	2420	2395
Rock Type	HAW	HAW	HAW	HAW	HAW	HAW	HAW	HAW	HAW	OTB	HAW	HAW	HAW	HAW	HAW
Harriet	R	BA	BA	R	R	R	R	R	R	R	R	BA	T	R	R
Subunit	Qmb	Qml	Qml	Qmb	Qm5	Qm2	Qml	Qm3	Qm5	Qm4	Qmb	Qm2	Qml	Qmb	Qm5
SiO2	49.50	49.40	49.37	49.28	49.22	49.16	49.14	49.13	49.10	49.03	48.99	48.80	48.71	48.63	48.56
TiO2	2.52	2.14	2.05	2.32	2.53	2.36	2.40	2.40	2.50	1.57	2.22	2.61	2.02	2.34	2.51
Al2O3	16.72	16.12	16.50	16.41	16.48	16.39	16.52	16.24	16.40	15.96	16.20	15.82	16.30	16.47	16.15
FeO	12.04	9.86	11.46	11.88	12.10	12.03	11.63	12.35	12.92	10.64	12.06	10.35	10.75	11.89	12.49
MnO	0.21	0.16	0.19	0.24	0.26	0.20	0.20	0.25	0.26	0.17	0.24	0.16	0.17	0.23	0.26
MgO	4.92	7.81	6.82	4.72	3.86	6.22	5.88	3.50	3.77	9.15	4.46	8.13	6.85	5.18	3.77
CaO	7.90	8.43	7.93	7.95	7.22	8.49	8.14	7.02	7.12	11.01	8.08	8.58	7.96	8.53	7.33
Na2O	4.50	4.26	4.51	4.25	5.04	4.20	4.59	5.48	5.22	2.88	4.76	4.05	5.06	4.39	4.88
K2O	1.34	1.54	1.29	1.47	1.71	1.06	1.23	1.82	1.71	0.40	1.51	1.61	1.45	1.23	1.69
P2O5	0.54	0.48	0.61	1.01	1.68	0.56	0.65	1.69	1.68	0.19	1.02	0.34	0.58	0.88	1.66
Total	100.19	100.20	100.72	100.02	100.11	100.67	100.38	99.88	100.68	101.01	99.54	100.45	99.84	99.76	99.10
NI	27	148	126	33	0	83	87	0	0	167	28	135	127	44	10
CR	20	268	246	41	3	118	110	5	7	357	34	268	194	60	19
BA	214	266	139	232	253	141	159	256	257	38	233	161	200	185	273
PB	10	16	13	11	13	8	10	15	13	4	12	18	16	8	13
SR	493	588	656	540	585	479	537	562	597	305	559	526	746	528	567
ZR	299	299	299	324	357	236	263	362	362	104	334	229	302	280	356
Y	34	22	24	39	46	29	29	44	45	20	38	22	24	35	45
MB	32	39	36	32	44	23	33	45	43	9	34	39	41	27	43
GA	19	18	16	24	25	19	21	23	21	20	23	24	19	23	23
CU	40	67	68	44	26	65	57	29	20	121	36	59	62	53	26
ZN	103	77	79	112	118	95	82	114	117	75	109	78	89	109	119
SC	21	20	20	19	16	23	18	17	17	30	20	21	19	19	16
V	184	189	173	132	82	198	163	84	87	240	122	213	176	152	84
LA	27	25	28	33	42	21	27	46	46	3	33	17	29	26	43
CE	65	58	65	78	98	55	66	99	102	27	80	45	63	67	99
AN	40.13	43.84	41.59	37.24	32.25	42.78	40.77	29.01	31.49	54.71	37.07	46.40	40.75	41.55	33.12
or	7.92	9.10	7.62	8.69	10.11	6.26	7.27	10.76	10.11	2.36	8.92	9.51	8.57	7.27	9.99
ab	32.03	26.03	29.45	32.22	36.34	30.42	30.28	35.10	35.40	24.37	31.20	23.37	25.42	30.39	34.67
an	21.47	20.32	20.97	19.12	17.30	22.74	20.84	14.34	16.27	29.44	18.38	20.23	17.48	21.60	17.17
ne	3.28	5.43	4.72	4.32	3.42	2.77	4.64	6.11	4.75	0.00	4.92	5.90	9.42	3.66	3.59
di	11.85	14.99	11.88	11.47	6.34	13.00	12.65	7.97	6.80	19.50	12.58	16.36	14.99	12.45	7.04
hy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.00	0.00	0.00	0.00	0.00
ol	15.83	17.68	19.07	15.69	16.10	17.88	16.90	15.29	16.78	19.60	15.14	17.76	17.18	16.13	16.16
xt	1.94	1.59	1.84	1.91	1.94	2.00	1.87	1.99	2.09	1.71	1.94	1.67	1.73	1.91	2.02
il	4.78	4.07	3.89	4.40	4.81	4.48	4.55	4.55	4.74	2.59	4.22	4.96	3.83	4.44	4.76
ap	1.24	1.11	1.40	2.33	3.89	1.30	1.51	3.92	3.90	0.44	2.37	0.79	1.33	2.04	3.84

MADINAH-OTB-HAWAIIITE-MUGEARITE-BENMOREITE-TRACHYTE - Page 3

Sample	4236	4175	2378	4200	4171	4182	4194	2450	2379	4155	4199	4156	4160	4052	2446
Rock Type	HAW	HAW	OTB	HAW	OTB	HAW	OTB	HAW	OTB	HAW	HAW	HAW	HAW	HAW	HAW
Harrat	T	R	R	BA	R	BA	T	R	R	BA	BA	BA	BA	R	R
Subunit	Qm1	Qm1	Qm4	Qm2	Qm2	Qmb	Qm1	Qm1	Qm4	Qm2	Qm2	Qmb	Qmb	Qm7	Qmb
SiO2	48.32	48.14	48.12	48.10	48.04	48.03	47.93	47.88	47.86	47.56	47.38	47.31	47.30	47.30	47.03
TiO2	2.68	2.45	1.63	2.39	1.78	2.59	1.77	1.92	1.99	2.49	2.37	2.76	2.81	2.95	2.61
Al2O3	16.93	16.08	16.77	15.81	16.50	16.31	16.38	15.84	15.55	15.74	15.70	16.11	16.20	16.15	16.26
FeO	12.26	12.03	10.29	11.62	11.21	11.78	10.85	11.41	11.21	11.65	11.76	12.19	12.73	12.98	11.92
MnO	0.21	0.21	0.17	0.19	0.18	0.18	0.18	0.19	0.19	0.19	0.19	0.17	0.18	0.22	0.21
MgO	5.59	6.37	8.14	8.23	8.68	6.72	8.96	7.27	6.70	8.40	8.47	7.54	7.10	5.97	6.02
CaO	8.39	8.48	11.62	8.55	10.93	7.57	11.73	8.84	12.24	8.90	8.61	7.92	7.63	8.72	8.92
Na2O	4.21	4.17	2.87	4.02	2.95	5.09	2.61	4.00	2.71	4.05	4.07	4.67	4.91	4.21	4.01
K2O	1.07	1.14	0.44	1.15	0.39	1.30	0.24	1.07	0.52	0.98	1.14	1.13	1.28	0.92	0.98
P2O5	0.66	0.85	0.17	0.53	0.23	0.67	0.23	0.52	0.19	0.55	0.55	0.61	0.66	1.02	0.87
Total	100.32	99.92	100.21	100.59	100.88	100.24	100.87	98.94	99.16	100.51	100.23	100.40	100.80	100.44	98.83
NI	32	85	110	146	150	94	154	149	65	150	157	128	98	58	67
CR	22	154	223	268	257	130	299	270	202	296	319	229	137	117	144
BA	241	192	83	119	32	112	13	109	187	83	109	75	92	97	135
RB	10	9	4	12	3	12	2	11	5	8	10	9	11	6	8
SR	594	497	372	715	390	905	355	485	402	668	691	817	903	584	586
ZR	261	246	103	291	120	369	112	253	124	273	283	328	365	245	229
Y	31	32	19	26	21	23	21	28	23	27	25	22	23	34	30
NB	33	32	10	36	8	30	8	29	14	28	33	27	33	26	28
GA	23	21	18	20	20	25	13	18	18	21	15	22	22	23	24
CU	49	62	96	69	124	62	124	72	126	76	70	64	50	41	62
ZN	69	99	76	84	81	104	72	86	90	82	81	100	103	97	94
SC	20	23	28	22	27	15	32	20	32	22	21	15	16	22	22
V	198	190	249	205	240	180	259	171	288	211	205	190	188	193	183
LA	26	27	5	27	4	31	5	23	5	23	25	25	31	26	24
CE	66	66	26	64	31	76	28	57	29	62	63	67	74	81	63
AN	44.77	42.88	59.25	46.48	57.03	40.04	59.37	46.42	57.00	47.87	48.13	44.20	42.94	43.64	45.96
or	6.32	6.74	2.60	6.80	2.30	7.68	1.42	6.32	3.07	5.79	6.74	6.68	7.56	5.44	5.79
ab	29.78	29.03	21.72	24.98	23.08	26.68	22.09	25.52	21.68	23.83	22.86	24.82	24.43	29.00	27.60
an	24.14	21.79	31.58	21.70	30.63	17.82	32.27	22.11	28.73	21.88	21.20	19.66	18.39	22.45	23.47
ne	3.16	3.39	1.39	4.89	1.02	8.88	0.00	4.51	0.68	5.66	6.27	7.96	9.27	3.59	3.43
di	10.94	12.19	20.41	14.11	18.07	12.63	19.93	15.11	25.33	15.26	14.68	12.87	12.49	11.73	12.46
hy	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ol	17.79	18.37	17.50	20.72	20.19	18.30	19.54	18.81	13.76	20.33	20.94	19.95	19.89	18.33	17.31
nt	1.97	1.94	1.65	1.87	1.81	1.90	1.75	1.84	1.81	1.88	1.90	1.97	2.06	2.09	1.91
il	5.08	4.66	3.10	4.54	3.38	4.92	3.36	3.65	3.79	4.73	4.51	5.23	5.34	5.60	4.95
ap	1.53	1.96	0.39	1.23	0.53	1.56	0.53	1.20	0.44	1.28	1.26	1.40	1.53	2.36	2.02

MADINAH-OTB-HAWAIIITE-MUGEARITE-BENMOREITE-TRACHYTE - Page 4

Sample	4100	4260	4202	1380	2403	2410	4179	4166	2412	2440
Rock Type	OTB	HAW	HAW	OTB	OTB	HAW	HAW	HAW	HAW	HAW
Harrat	R	T	BA	R	R	R	BA	BA	R	R
Subunit	Qm3	Qm1	Qm6	Qm7	Qm6	Qm5	Qm3	Qm2	Qm5	Qm1
SiO2	47.01	46.99	46.56	46.53	46.18	46.15	45.85	45.77	45.56	45.55
TiO2	1.50	2.91	2.84	2.24	2.22	3.56	2.96	2.93	3.51	3.61
Al2O3	15.82	16.40	15.84	15.90	15.91	16.21	15.26	15.40	15.84	15.87
FeO	10.48	11.25	12.36	11.18	11.69	12.94	12.78	12.40	13.34	13.21
MnO	0.17	0.20	0.18	0.18	0.18	0.22	0.18	0.18	0.23	0.22
MgO	10.86	6.91	8.25	8.91	8.73	5.32	8.19	8.92	4.99	5.24
CaO	11.04	9.65	8.50	11.66	11.40	8.90	8.97	9.04	9.06	9.02
Na2O	2.66	3.91	4.22	2.77	2.76	4.09	4.11	4.11	4.21	4.16
K2O	0.25	1.11	1.08	0.39	0.40	1.02	1.04	1.23	1.10	1.07
P2O5	0.16	0.64	0.54	0.23	0.23	0.98	0.56	0.60	1.08	1.01
Total	99.94	99.97	100.36	99.99	99.69	99.39	99.90	100.59	98.90	98.95
NI	268	79	127	153	147	23	122	134	16	21
CR	446	151	239	310	279	24	249	179	17	25
BA	5	180	111	32	19	135	71	134	133	112
RB	1	10	10	3	4	7	9	12	9	7
SR	340	659	755	425	433	612	744	747	604	600
IR	102	256	306	133	133	247	283	286	269	251
Y	18	26	23	21	21	31	23	26	34	33
NB	6	32	28	12	10	28	27	42	28	28
GA	15	22	18	21	19	19	18	16	25	21
CU	112	55	60	106	109	45	61	60	46	55
ZN	73	82	87	83	80	105	94	91	109	108
SC	28	22	19	28	28	21	19	22	19	21
V	233	230	208	269	269	223	235	237	198	222
LA	3	28	23	6	6	26	24	28	27	26
CE	25	68	61	32	31	67	64	66	68	68
AN	61.19	51.59	49.40	62.07	62.12	46.01	50.89	54.40	45.90	46.39
or	1.48	6.56	6.38	2.30	2.36	6.03	6.15	7.27	6.50	6.32
ab	19.34	22.45	21.60	18.21	18.20	26.83	19.42	16.71	24.84	24.81
an	30.49	23.92	21.09	29.80	29.84	22.86	20.12	19.94	21.08	21.47
ne	1.72	5.76	7.64	2.83	2.75	4.21	8.32	9.79	5.84	5.63
di	18.86	16.20	14.38	21.65	20.60	12.37	16.97	17.12	14.04	13.88
ol	23.28	16.38	20.78	18.73	19.40	16.12	20.09	20.93	15.46	15.67
wt	1.68	1.81	1.99	1.80	1.88	2.09	2.06	2.00	2.15	2.13
il	2.85	5.52	5.39	4.25	4.21	6.77	5.62	5.57	6.66	6.85
ap	0.36	1.49	1.25	0.53	0.54	2.27	1.31	1.40	2.49	2.34

MADINAH-AOB - Page 2

Sample	4168	4172	4193	4197	4227	4163	4174	4112	2425	4231	4163	4099	2382	2436	4192
RockType	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB
Harrat	R	R	T	T	T	BA	R	R	R	T	BA	R	R	R	T
Subunit	Qm1	Qm2	Qm3	Qm1	Qm1	Qm2	Qm2	Qm3	Qm5	Qm1	Qm3	Qm3	Qmb	Qm5	Qm1
SiO2	47.44	47.41	47.38	47.31	47.19	47.14	47.08	47.08	47.06	47.06	47.01	46.96	46.93	46.91	46.89
TiO2	2.56	2.07	2.48	2.75	2.42	2.76	2.73	3.04	3.19	2.97	2.36	2.02	3.57	2.63	2.41
Al2O3	16.02	16.76	16.07	16.41	16.21	16.32	16.40	16.49	16.42	16.47	15.60	16.87	16.38	16.26	15.41
FeO	11.80	11.49	11.47	11.47	12.86	12.46	12.57	12.54	12.95	13.24	11.20	11.49	12.78	12.37	11.20
MnO	0.19	0.18	0.19	0.16	0.22	0.19	0.20	0.19	0.20	0.21	0.17	0.18	0.19	0.22	0.19
MgO	7.39	8.03	8.08	7.27	6.84	7.24	6.85	7.12	6.27	6.07	8.75	8.17	6.76	6.20	6.65
CaO	9.53	10.36	9.44	9.24	9.51	9.77	9.35	9.62	9.10	8.39	9.56	10.25	9.01	9.05	10.74
Na2O	3.65	3.16	3.76	3.72	3.54	3.59	3.82	3.55	3.79	3.96	3.92	3.22	3.74	4.09	3.38
K2O	0.92	0.55	0.91	1.02	0.70	0.59	0.70	0.72	0.82	0.90	0.64	0.58	0.83	0.88	0.87
P2O5	0.55	0.27	0.54	0.55	0.64	0.33	0.44	0.37	0.54	0.69	0.50	0.28	0.44	0.94	0.47
Total	100.04	100.28	100.32	99.90	100.33	100.39	100.14	100.72	100.33	100.17	99.91	100.02	100.64	99.55	100.40
NI	112	115	124	114	72	83	76	80	62	54	183	113	76	51	188
CR	203	182	256	193	156	160	101	125	79	82	393	119	122	56	442
BA	143	45	97	132	130	25	55	56	114	122	62	9	84	93	95
RB	8	4	10	7	6	3	5	6	4	6	8	3	7	6	11
SR	511	477	611	657	482	471	509	559	623	552	687	506	588	566	531
ZR	206	143	239	251	204	167	191	181	220	239	282	157	203	224	204
Y	24	20	27	27	31	23	24	24	28	33	22	22	24	32	26
MB	25	16	28	25	21	16	20	19	25	26	23	13	24	22	28
GA	20	22	20	20	20	22	18	17	16	18	15	21	18	20	19
CU	78	92	76	61	74	84	60	59	59	53	82	75	51	51	95
ZN	68	62	79	80	92	90	85	78	88	85	94	92	84	96	73
SC	25	25	25	21	24	25	24	24	22	20	21	24	23	22	26
V	228	242	226	216	206	260	243	276	239	197	204	233	281	195	236
LA	17	9	23	23	20	11	16	14	21	24	20	11	18	23	18
CE	49	36	58	60	57	41	46	45	52	64	57	37	48	63	53
AN	50.17	56.61	50.95	50.49	49.17	52.25	50.40	52.55	48.84	45.43	51.33	58.01	49.54	46.36	57.11
or	5.44	3.25	5.38	6.03	4.14	3.49	4.14	4.26	4.65	5.32	4.96	3.43	4.91	5.20	5.14
ab	24.44	22.94	23.38	24.58	27.16	24.38	25.13	24.32	26.58	29.44	21.33	21.62	25.94	27.09	18.26
an	24.61	29.92	24.29	25.07	26.28	26.68	25.54	26.94	25.37	24.51	22.49	29.87	25.46	23.41	24.31
ne	3.49	2.06	4.57	3.74	1.52	3.25	3.90	3.10	2.97	2.20	6.42	3.05	3.09	4.07	5.60
di	15.69	16.13	15.55	14.10	12.76	16.15	14.82	15.13	13.46	9.35	17.67	15.67	13.47	12.69	21.10
ol	18.48	19.69	19.48	18.18	20.02	18.57	18.52	18.48	17.66	19.65	19.72	20.17	18.05	18.05	18.65
wt	1.90	1.86	1.84	1.84	2.07	2.02	2.03	2.02	2.09	2.13	1.80	1.86	2.06	2.00	1.80
il	4.86	3.94	4.71	5.22	4.60	5.24	5.18	5.78	6.05	5.64	4.49	3.83	6.79	5.00	4.57
ap	1.26	0.63	1.26	1.27	1.94	0.77	1.02	0.85	1.24	2.07	1.16	0.66	1.02	2.18	1.09

MADINAH-AOB - Page 3

SAMPLE	2423	4210	2427	4198	4169	2422	4167	2424	4195	4230	4196	4173	4177	2400	2402
RockType	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB
Harrat	R	T	R	BA	R	R	R	R	T	T	T	R	BA	R	R
Subunit	Qm1	Qm1	Qm1	Qm2	Qm3	Qm3	Qm3	Qm5	Qm1	Qm1	Qm5	Qm3	Qm3	Qmb	Qmb
SiO2	46.82	46.80	46.78	46.78	46.59	46.55	46.53	46.49	46.39	46.24	46.23	46.21	46.20	45.87	45.86
TiO2	2.69	2.78	2.47	2.25	2.98	2.73	2.96	3.20	2.73	2.56	2.54	2.93	2.74	3.55	3.43
Al2O3	16.16	15.97	16.46	15.27	16.53	16.21	16.41	16.31	15.68	16.34	14.94	16.33	16.27	16.11	15.89
FeO	12.48	11.91	12.28	11.48	12.52	12.56	12.49	13.13	11.49	12.23	10.82	12.64	12.57	12.31	12.32
MnO	0.20	0.19	0.19	0.18	0.20	0.20	0.20	0.20	0.19	0.19	0.18	0.20	0.20	0.19	0.19
MgO	6.95	8.00	6.86	8.96	6.64	6.80	6.67	6.24	8.72	6.95	9.58	6.67	6.71	6.89	7.22
CaO	9.82	9.31	10.31	9.64	9.63	9.85	9.72	9.00	9.83	10.65	10.03	9.48	10.15	9.52	9.65
Na2O	3.67	3.64	3.36	3.55	3.67	3.48	3.57	3.88	3.68	3.50	3.47	3.71	3.63	3.44	3.50
K2O	0.72	0.70	0.56	0.80	0.86	0.68	0.85	0.88	1.07	0.55	1.06	0.85	0.67	0.77	0.78
P2O5	0.53	0.37	0.54	0.51	0.79	0.63	0.80	0.56	0.54	0.34	0.51	0.78	0.70	0.39	0.39
Total	100.04	99.67	99.82	99.42	100.42	99.69	100.21	99.89	100.32	99.55	99.36	99.81	99.84	99.03	99.42
NI	74	140	75	156	60	67	59	58	131	89	171	59	67	82	100
CR	108	166	118	402	98	122	65	74	285	147	448	59	96	118	154
BA	64	73	105	103	94	188	117	118	148	58	144	124	46	63	79
RB	5	6	5	9	6	5	6	8	12	5	14	6	5	7	6
SR	490	514	584	628	567	480	573	570	626	478	683	598	583	597	659
ZR	184	179	167	248	204	177	202	216	223	160	211	201	176	199	197
Y	28	24	25	25	30	27	29	27	26	23	24	28	27	23	22
NB	17	19	18	29	22	21	22	23	34	16	36	22	17	21	22
GA	18	18	17	16	22	19	22	22	17	19	16	20	19	19	22
CU	70	71	75	69	57	66	58	50	75	72	76	60	66	54	50
ZN	92	81	88	83	91	90	93	86	77	77	71	93	91	86	85
SC	24	24	24	23	24	23	24	21	24	23	24	23	23	22	22
Y	232	250	249	210	249	228	246	235	241	231	235	237	238	289	277
LA	14	16	14	19	19	15	20	19	24	11	24	17	17	17	16
CE	46	46	43	54	55	46	55	51	60	42	58	54	50	47	46
AN	51.84	51.32	53.96	51.96	51.73	52.05	51.74	49.44	55.87	57.14	56.08	51.42	53.47	52.96	54.27
or	4.26	4.14	3.31	4.73	5.08	4.02	5.02	5.20	6.32	3.25	6.26	5.02	3.96	4.55	4.61
ab	23.68	23.87	24.04	21.60	24.35	24.51	24.48	25.04	18.25	20.44	17.27	23.99	22.73	23.31	21.36
an	25.50	25.17	28.18	23.37	26.09	26.60	26.24	24.49	23.11	27.25	22.06	25.40	26.12	26.24	25.35
ne	3.99	3.75	2.38	4.57	3.63	2.68	3.10	4.22	6.98	4.97	6.55	4.01	4.33	3.14	4.47
di	16.26	15.20	16.04	17.26	13.62	15.00	13.79	13.65	18.07	19.23	19.78	13.63	16.25	15.15	17.23
ol	18.14	19.61	18.08	20.71	18.37	18.36	18.20	17.94	19.43	16.92	19.80	18.48	17.74	17.16	17.15
st	2.02	1.91	1.97	1.86	2.02	2.03	2.02	2.12	1.86	1.97	1.74	2.04	2.03	1.99	1.99
il	5.10	5.27	4.70	4.28	5.66	5.19	5.63	6.08	5.19	4.85	4.83	5.57	5.21	6.73	6.52
ep	1.24	0.87	1.25	1.17	1.84	1.45	1.86	1.30	1.24	0.79	1.18	1.81	1.61	0.90	0.89

MADINAH-AOB - Page 4

Sample	4158	2386	2449
Rock Type	AOB	AOB	AOB
Harrat	BA	R	R
Subunit	Qm6	Qm7	Qm2
SiO2	45.83	45.82	45.68
TiO2	2.72	2.65	2.61
Al2O3	15.45	15.33	15.87
FeO	11.75	11.44	12.21
MnO	0.18	0.18	0.20
MgO	9.04	9.29	6.81
CaO	9.27	10.79	11.16
Na2O	3.92	3.04	3.13
K2O	0.93	0.57	0.55
P2O5	0.46	0.29	0.59
Total	99.54	99.40	98.81
NI	155	190	70
CR	289	407	136
BA	82	53	94
RB	7	5	4
SR	642	457	442
ZR	266	161	170
Y	23	21	27
NB	43	13	18
GA	6	16	18
CU	60	83	64
ZN	85	82	91
SC	21	26	26
V	232	259	227
LA	20	11	14
CE	55	35	45
AN	54.30	60.05	57.62
or	5.50	3.37	3.26
ab	18.36	17.63	20.32
an	21.82	26.50	27.63
ne	8.02	4.38	3.34
di	17.28	20.46	19.68
ol	20.58	19.64	16.44
mt	1.90	1.84	1.97
il	5.16	5.04	4.95
ap	1.06	0.67	1.37

APPENDIX B: Rare earth element data for Harrat Rahat lavas

Sample No.	4147	4210	4232	4261	4149	4204	4270	4226
Rock type	Trach.	AOB	Ben.	Mug.	OTB	OTB	OTB	OTB
Basalt	Madinah	Madinah	Madinah	Hammah	Shawahit	Shawahit	Shawahit	Shawahit
Subunit	Qm 4	Qm 1	Qm 1	-	Upper	Upper	Upper	Lower
La ppm	102.50	15.96	66.90	52.60	10.96	10.68	7.53	6.72
Ce ppm	243.00	38.76	158.10	124.60	27.32	24.69	19.00	16.48
Pr ppm	23.80	4.51	16.60	13.10	3.22	2.30	2.18	1.84
Nd ppm	92.60	21.06	66.20	57.60	15.12	13.11	11.20	9.53
Sm ppm	18.30	4.84	12.78	11.10	3.83	3.30	3.07	2.55
Eu ppm	2.50	1.81	3.79	3.71	1.42	1.21	1.16	.96
Gd ppm	16.70	4.83	11.39	9.98	4.03	3.49	3.43	2.91
Dy ppm	16.75	4.38	10.13	7.74	3.55	3.30	3.55	3.22
Ho ppm	3.45	.88	2.06	1.56	.71	.74	.76	.71
Er ppm	10.56	2.41	6.11	4.18	2.20	1.96	2.23	2.11
Yb ppm	10.80	1.97	6.19	3.49	1.71	1.70	1.98	1.88
Lu ppm	1.68	.31	1.02	.55	.26	.27	.31	.29
La (C.N.)	310.6	48.3	202.7	159.3	33.2	32.3	22.8	20.3
Ce (C.N.)	280.9	44.8	182.7	144.0	31.5	28.5	21.9	19.0
Pr (C.N.)	195.0	36.9	136.0	107.3	26.3	18.8	17.8	15.0
Nd (C.N.)	146.9	33.4	105.0	91.4	24.0	20.8	17.7	15.1
Sm (C.N.)	90.1	23.8	62.9	54.6	18.8	16.2	15.1	12.5
Eu (C.N.)	32.4	23.5	49.2	48.1	18.4	15.7	15.0	12.4
Gd (C.N.)	60.7	17.5	41.4	36.2	14.6	12.6	12.4	10.5
Dy (C.N.)	48.9	12.8	29.6	22.6	10.3	9.6	10.3	9.4
Ho (C.N.)	45.3	11.5	27.1	20.5	9.3	9.7	10.0	9.3
Er (C.N.)	46.9	10.7	27.1	18.5	9.7	8.7	9.9	9.3
Yb (C.N.)	49.0	8.9	28.1	15.8	7.7	7.7	9.0	8.5
Lu (C.N.)	49.4	9.1	30.0	16.1	7.6	7.9	9.1	8.5

Note: Data are shown in measured ppm as well as chondrite normalized ppm (C.N.) against the values of Nakamura (1974). Data were determined by INAA; precision should be 5-10% unless working close to detection limits (N.Walsh, written communication).

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(48 samples)

Sample	2426	2407	2448	4178	4165	2443	4088	4085	2397	4113	2429	4089	2413	2408	4056
Rock Type	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB	AOB
Harriet	R	R	R	BA	BA	R	R	R	R	R	R	R	R	R	R
Subunit	Qm2	Qm7	Qm2	Qm1	Qm1	Qm1	Qm3	Qm7	Qm2	Qm3	Qm1	Qm7	Qm5	Qm1	Qm2
SiO2	49.40	48.84	48.55	48.41	48.23	48.20	48.12	47.88	47.85	47.79	47.78	47.77	47.58	47.53	47.51
TiO2	1.98	2.35	1.92	2.29	2.43	2.49	2.32	2.77	2.60	2.61	2.11	2.09	2.64	1.97	2.77
Al2O3	16.45	16.51	16.04	16.38	16.68	16.13	16.49	16.40	16.27	17.14	16.23	16.73	15.83	16.74	16.80
FeO	10.98	11.38	11.48	12.70	10.42	12.03	11.82	12.77	12.99	11.91	11.73	11.23	11.64	11.16	12.08
MnO	0.19	0.21	0.19	0.21	0.17	0.20	0.20	0.21	0.20	0.20	0.19	0.18	0.19	0.18	0.19
MgO	7.30	6.88	7.64	6.23	7.06	7.16	6.97	6.77	6.54	6.48	7.51	8.96	7.97	7.67	6.47
CaO	8.79	8.66	9.08	8.80	10.44	9.07	8.84	9.09	8.88	9.29	9.08	10.82	9.37	10.50	9.42
Na2O	3.91	3.90	3.79	3.93	3.77	3.88	4.00	3.96	3.80	3.68	3.77	3.16	3.55	3.18	3.84
K2O	0.96	1.06	0.83	0.94	1.10	0.82	0.93	0.84	0.78	0.81	0.87	0.43	0.74	0.48	0.92
P2O5	0.48	0.71	0.46	0.52	0.41	0.43	0.54	0.82	0.58	0.53	0.47	0.29	0.45	0.24	0.58
Total	100.44	100.49	99.97	100.41	100.70	100.41	100.23	101.51	100.49	100.43	99.75	101.66	99.96	99.85	100.58
NI	130	115	146	72	90	104	116	74	89	47	130	150	140	103	63
CR	315	161	344	112	145	199	152	120	145	29	243	250	233	164	117
BA	106	183	94	140	176	74	101	98	223	61	77	4	101	35	87
RB	10	9	8	8	12	7	5	8	5	7	9	4	6	4	8
SR	435	530	443	472	642	457	513	580	478	567	449	449	466	368	526
ZR	239	245	232	232	208	180	217	223	205	204	212	150	182	129	191
Y	26	29	27	30	21	27	27	30	30	26	26	22	24	22	26
NB	27	30	26	21	29	20	23	20	24	20	26	10	21	11	25
GA	16	20	21	23	19	18	18	21	19	19	20	19	20	18	18
CU	83	63	81	63	93	65	61	63	28	54	85	107	68	85	62
ZN	90	93	87	95	90	88	86	97	88	88	88	82	88	84	89
SC	21	18	22	23	25	23	20	24	21	23	22	29	23	27	23
V	173	164	187	198	234	210	183	218	303	230	258	261	230	243	258
LA	21	25	20	22	16	17	19	24	18	17	19	12	16	8	17
CE	50	59	52	56	48	48	55	76	46	51	49	50	46	31	51
AN	45.02	44.77	46.84	45.83	53.91	46.98	47.08	46.66	46.62	50.39	48.95	59.10	49.19	56.09	50.39
cr	5.67	6.26	4.91	5.56	6.50	4.85	5.50	4.96	4.61	4.79	5.14	2.54	4.37	2.84	5.44
ab	29.92	30.11	27.58	28.69	21.67	27.28	27.31	28.00	28.67	27.43	25.86	20.90	25.90	23.47	25.49
an	24.50	24.41	24.31	24.28	25.34	24.18	24.29	24.49	25.04	27.86	24.80	30.20	25.08	29.99	25.69
ne	1.72	1.56	2.43	2.47	5.54	3.01	3.54	2.98	1.89	2.01	3.27	3.16	2.24	1.86	3.79
di	13.10	11.42	14.59	13.24	19.48	14.81	13.19	12.59	12.63	12.18	14.10	17.68	15.14	16.81	14.06
ol	19.02	18.91	19.75	18.71	15.06	18.77	18.98	19.40	19.44	18.20	19.63	21.87	19.45	18.90	17.50
mt	1.77	1.83	1.86	2.04	1.68	1.94	1.90	2.06	2.09	1.91	1.88	1.81	1.87	1.80	1.94
il	3.75	4.46	3.64	4.36	4.61	4.72	4.40	5.25	4.94	4.95	4.02	3.96	5.01	3.74	5.25
ap	1.12	1.65	1.06	1.21	0.94	1.00	1.26	1.90	1.33	1.23	1.10	0.67	1.03	0.56	1.35