Unravelling the tectonic framework of the Musgrave Province, central Australia

Benjamin P. Wade, B.Sc (Hons)

Geology and Geophysics
School of Earth and Environmental Sciences
The University of Adelaide

This thesis is submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in the Faculty of Science, University of Adelaide

September 2006

Appendix 3

Geochemistry and Isotopes on ca. 1.08 Ga Giles Complex

Table 5.1 - Chemical data for Giles Complex ultramafic rocks

Sample	314/157	314/156	314/155	314/154	314/226C	314/225	314/224	314/223	314/222	314/221	314/218
Easting	52 516328	52 516286	52 516248	52 516226	52 515020	52 514904	52 514829	52 514585	52 514478	52 514372	52 513973
Northing	7110072	7109903	7109724	7109580	7110896	7110762	7110678	7110389	7110325	7110262	7109783
Intrusion	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka
Lithology	Orthopyroxenite	Websterite	Websterite	Websterite	Gabbronorite	Gabbronorite	Gabbronorite	Gabbronorite	Gabbronorite	Gabbronorite	Gabbronorite
SiO_2	53.10	52.90	52.80	52.60	49.90	50.50	50.80	50.70	51.60	50.30	50.90
Al_2O_3	5.95	4.07	5.79	6.55	20.10	19.80	19.30	19.10	18.20	17.50	12.60
Fe_2O_3	10.20	9.85	8.60	9.00	5.65	5.85	5.60	5.76	6.82	6.03	7.82
MnO	0.21	0.21	0.20	0.19	0.11	0.10	0.11	0.11	0.12	0.12	0.16
MgO	20.40	21.80	20.60	21.00	10.70	10.50	10.40	10.50	9.40	9.53	13.90
CaO	9.49	9.84	11.40	10.20	10.90	11.00	11.40	11.10	10.80	14.60	12.80
Na_2O	0.60	0.42	0.45	0.44	1.64	1.88	1.85	1.86	2.17	1.73	1.23
K_2O	0.17	0.17	0.06	0.05	0.27	0.29	0.30	0.27	0.49	0.13	0.14
TiO_2	0.30	0.30	0.23	0.19	0.21	0.22	0.27	0.22	0.39	0.20	0.24
P_2O_5	0.02	0.02	0.01	0.01	0.03	0.03	0.03	0.03	0.05	0.02	0.01
LOI	<0.01	0.02	0.11	0.25	0.07	0.12	0.22	0.39	0.13	0.25	0.12
Total	100.44	99.60	100.25	100.48	99.58	100.29	100.28	100.04	100.17	100.41	99.92
Ba	60.00	90.00	60.00	90.00	100.00	110.00	130.00	110.00	250.00	50.00	60.00
Co	98.00	96.00	84.00	92.00	70.00	58.00	56.00	58.00	62.00	47.00	74.00
Cr	1350.00	2000.00	1700.00	2950.00	800.00	600.00	750.00	750.00	430.00	900.00	750.00
Cu	16.00	14.50	7.00	4.50	23.00	14.00	22.50	22.00	78.00	31.00	38.50
Ga	8.00	6.50	7.00	7.50	16.00	16.00	15.50	16.00	19.00	13.50	12.00
Nb	<0.5	<0.5	<0.5	1.50	<0.5	1.00	2.50	<0.5	1.50	<0.5	<0.5
Ni	550.00	600.00	550.00	550.00	270.00	310.00	260.00	270.00	270.00	170.00	280.00
Pb	1.00	1.00	<0.5	<0.5	3.00	1.50	2.00	1.50	3.00	5.50	2.00
Rb	3.50	4.20	1.10	0.70	4.20	4.30	4.90	4.00	8.50	1.00	0.20
Sc	40.00	42.00	42.00	38.00	14.00	14.00	16.00	16.00	18.00	28.00	32.00
Sr	58.00	33.00	54.00	58.00	230.00	250.00	230.00	250.00	270.00	200.00	165.00
Th	0.39	0.41	0.11	0.17	0.38	0.29	0.28	0.27	0.69	0.13	0.04
U	0.07	0.06	0.03	0.04	0.10	0.08	0.08	0.05	0.10	0.05	0.02
V	170.00	180.00	170.00	150.00	70.00	60.00	80.00	70.00	100.00	120.00	140.00
W	145.00	150.00	120.00	175.00	450.00	270.00	270.00	270.00	270.00	200.00	290.00
Y	10.50	11.00	8.50	6.50	4.80	4.60	5.00	5.00	8.00	6.00	7.50
Zn	60.00	58.00	47.50	50.00	40.00	31.50	34.50	34.00	44.00	31.00	42.00
Zr	30.00	30.00	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00	40.00	<20.00	<20.00

Table 5.1 - Contd

Sample	314/157	314/156	314/155	314/154	314/226C	314/225	314/224	314/223	314/222	314/221	314/218
Easting	52 516328	52 516286	52 516248	52 516226	52 515020	52 514904	52 514829	52 514585	52 514478	52 514372	52 513973
Northing	7110072	7109903	7109724	7109580	7110896	7110762	7110678	7110389	7110325	7110262	7109783
Intrusion	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka
Lithology	Orthopyroxenite	Websterite	Websterite	Websterite	Gabbronorite	Gabbronorite	Gabbronorite	Gabbronorite	Gabbronorite	Gabbronorite	Gabbronorite
La	3.50	3.50	1.50	1.00	4.00	3.50	4.50	2.50	5.50	1.50	2.00
Ce	7.00	6.50	3.50	2.50	8.00	7.00	8.00	5.50	11.00	3.00	4.50
Pr	1.15	1.20	0.60	0.45	0.90	0.80	0.90	0.65	1.35	0.50	0.70
Nd	5.50	5.50	3.30	2.40	3.90	3.30	3.40	3.00	5.50	2.40	3.40
Sm	1.65	1.65	1.10	0.88	0.88	0.78	0.83	0.75	1.35	0.78	1.05
Eu	0.47	0.44	0.35	0.29	0.40	0.41	0.43	0.40	0.61	0.42	0.41
Gd	2.20	2.20	1.60	1.30	1.05	0.95	1.10	1.00	1.65	1.20	1.50
Tb	0.36	0.37	0.27	0.22	0.16	0.15	0.17	0.17	0.27	0.20	0.24
Dy	2.30	2.30	1.75	1.50	1.05	1.00	1.10	1.10	1.70	1.45	1.70
Ho	0.44	0.44	0.34	0.29	0.20	0.19	0.22	0.20	0.32	0.28	0.32
Er	1.40	1.40	1.05	0.90	0.65	0.60	0.70	0.70	1.05	0.90	1.00
Tm	0.20	0.20	0.15	0.15	0.10	0.10	0.10	0.10	0.15	0.10	0.15
Yb	1.40	1.35	1.00	0.90	0.65	0.65	0.70	0.70	1.05	0.90	1.00
Lu	0.19	0.18	0.14	0.12	0.09	0.08	0.10	0.09	0.14	0.12	0.14
Mg#	80	81	83	82	79	78	79	78	73	76	78
(Eu/Eu*)N[a]	0.75	0.71	0.81	0.83	1.27	1.46	1.38	1.41	1.25	1.33	1.00
(La/Yb)N[a]	1.69	1.75	1.01	0.75	4.16	3.64	4.34	2.41	3.54	1.13	1.35
(La/Sm)N[a]	1.34	1.34	0.86	0.72	2.86	2.82	3.41	2.10	2.56	1.21	1.20
(La/Yb)PM[b]	1.60	1.66	0.96	0.71	3.95	3.46	4.13	2.29	3.36	1.07	1.28

Coordinates in GDA94 datum

[a] Normalised to chondrite of Taylor and McLennan (1985)

[b] Normalised to Primitive Mantle of McDonough and Sun (1995)

Mg# : 100xMg/(Mg+total Fe)

Table 5.1 - Contd

Sample	314/217	314/216	314/213	314/211	314/209	314/208	314/207	314/206	314/205	314/204	314/203	314/202
Easting	52 513866	52 513776	52 513493	52 513415	52 513244	52 512767	52 512624	52 512325	52 512325	52 512203	52 512179	52 512052
Northing	7109831	7109803	7109608	7109560	7109436	7109189	7109088	7108922	7108922	7108928	7108910	7108781
Intrusion	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka
Lithology	Gabbronorite	Gabbronorite	Picrite	Gabbronorite	Gabbronorite	Gabbronorite	Gabbronorite	Gabbronorite	Picrite	Gabbronorite	Gabbronorite	Gabbronorite
SiO_2	50.70	51.30	44.30	49.80	51.20	50.20	51.60	43.90	41.00	49.10	48.50	48.10
Al_2O_3	19.00	8.93	6.32	16.30	17.50	16.60	16.20	3.93	5.24	15.30	19.20	16.70
Fe_2O_3	4.99	8.39	11.50	6.10	5.80	9.44	8.38	20.00	20.80	11.20	7.92	10.60
MnO	0.11	0.19	0.18	0.13	0.14	0.17	0.17	0.31	0.30	0.20	0.14	0.17
MgO	9.31	16.30	29.00	11.70	9.47	7.57	8.30	21.50	26.80	8.29	8.33	10.10
CaO	13.90	13.80	7.21	14.80	13.30	12.50	12.30	10.10	5.51	12.80	13.30	12.00
Na_2O	1.84	0.81	0.47	1.07	2.00	2.26	2.28	0.46	0.52	2.12	2.15	1.96
K_2O	0.12	0.07	0.03	0.12	0.18	0.42	0.43	0.06	0.05	0.19	0.15	0.17
TiO_2	0.14	0.25	0.07	0.19	0.16	0.73	0.48	0.55	0.25	0.76	0.22	0.40
P_2O_5	0.01	0.02	0.02	0.02	0.01	0.04	0.06	0.03	0.03	0.03	0.02	0.02
LOI	0.32	0.10	0.89	0.41	0.33	0.12	0.19	<0.01	<0.01	<0.01	0.17	<0.01
Total	100.44	100.16	99.99	100.64	100.09	100.05	100.39	100.84	100.50	99.99	100.10	100.22
Ba	70.00	30.00	<20	60.00	80.00	160.00	210.00	40.00	40.00	90.00	60.00	90.00
Co	60.00	72.00	115.00	62.00	58.00	62.00	60.00	150.00	150.00	64.00	60.00	70.00
Cr	550.00	1750.00	2500.00	1150.00	300.00	330.00	30.00	450.00	1700.00	80.00	140.00	310.00
Cu	14.00	12.50	11.00	10.50	2.00	115.00	24.50	52.00	140.00	250.00	64.00	2.00
Ga	15.00	9.00	3.50	13.00	15.50	19.50	19.50	6.00	3.90	18.50	17.00	16.00
Nb	<0.5	<0.5	<0.5	2.00	3.50	2.50	2.00	<0.5	<0.5	<0.5	1.00	2.00
Ni	190.00	320.00	1050.00	210.00	135.00	100.00	120.00	240.00	1300.00	94.00	145.00	240.00
Pb	1.00	1.50	3.00	8.00	1.00	3.50	3.50	<0.5	1.50	1.00	1.00	2.00
Rb	0.80	0.80	0.50	1.60	1.20	5.00	4.00	1.50	0.60	1.70	1.30	1.10
Sc	22.00	44.00	18.00	28.00	28.00	32.00	36.00	54.00	22.00	40.00	24.00	28.00
Sr	210.00	78.00	50.00	150.00	230.00	200.00	250.00	47.00	70.00	260.00	240.00	190.00
Th	0.07	0.10	0.06	0.22	0.30	1.10	0.59	0.16	0.09	0.22	0.15	0.08
U	0.02	0.04	0.03	0.09	0.10	0.16	0.07	0.04	0.03	0.05	0.04	0.04
V	100.00	190.00	60.00	110.00	130.00	220.00	140.00	260.00	140.00	280.00	90.00	180.00
W	340.00	250.00	210.00	290.00	280.00	270.00	280.00	185.00	210.00	230.00	230.00	250.00
Y	4.10	8.00	2.00	6.00	4.80	14.50	13.50	8.00	3.30	10.00	4.90	7.00
Zn	24.50	37.00	31.00	34.00	26.00	60.00	54.00	64.00	54.00	56.00	31.00	44.00
Zr	<20.00	<20.00	<20.00	<20.00	<20.00	50.00	50.00	<20.00	<20.00	<20.00	<20.00	<20.00

Table 5.1 - Contd

Sample	314/217	314/216	314/213	314/211	314/209	314/208	314/207	314/206	314/205	314/204	314/203	314/202
Easting	52 513866	52 513776	52 513493	52 513415	52 513244	52 512767	52 512624	52 512325	52 512325	52 512203	52 512179	52 512052
Northing	7109831	7109803	7109608	7109560	7109436	7109189	7109088	7108922	7108922	7108928	7108910	7108781
Intrusion	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka
Lithology	Gabbronorite	Gabbronorite	Picrite	Gabbronorite	Gabbronorite	Gabbronorite	Gabbronorite	Gabbronorite	Picrite	Gabbronorite	Gabbronorite	Gabbronorite
La	1.00	1.00	0.50	2.00	1.50	8.50	8.50	2.50	1.50	3.50	2.00	2.50
Ce	2.00	3.00	1.00	5.00	3.00	18.50	18.50	6.00	3.00	8.00	4.50	5.50
Pr	0.30	0.50	0.15	0.75	0.40	2.20	2.20	0.95	0.40	1.00	0.60	0.80
Nd	1.50	2.90	0.66	3.40	2.00	9.50	9.50	4.70	1.95	4.80	2.80	3.80
Sm	0.50	1.05	0.24	1.00	0.64	2.40	2.50	1.45	0.57	1.50	0.85	1.15
Eu	0.31	0.41	0.10	0.41	0.37	0.87	0.84	0.45	0.22	0.64	0.48	0.60
Gd	0.75	1.70	0.40	1.35	0.95	3.00	3.10	2.00	0.70	2.00	1.20	1.60
Tb	0.12	0.28	0.06	0.22	0.16	0.50	0.48	0.32	0.12	0.33	0.20	0.27
Dy	0.90	1.95	0.45	1.50	1.05	3.20	3.10	2.10	0.77	2.20	1.30	1.75
Ho	0.17	0.37	0.09	0.27	0.21	0.60	0.58	0.39	0.15	0.40	0.24	0.34
Er	0.55	1.20	0.30	0.85	0.65	1.90	1.85	1.25	0.45	1.30	0.70	1.10
Tm	0.05	0.15	0.05	0.10	0.10	0.25	0.25	0.15	0.05	0.15	0.10	0.15
Yb	0.50	1.15	0.30	0.85	0.65	1.85	1.75	1.10	0.50	1.20	0.70	1.00
Lu	0.07	0.15	0.04	0.11	0.09	0.25	0.23	0.15	0.07	0.16	0.09	0.14
Mg#	79	79	83	79	76	61	66	68	72	59	68	65
(Eu/Eu*)N[a]	1.55	0.94	0.99	1.08	1.45	0.99	0.92	0.81	1.06	1.13	1.45	1.35
(La/Yb)N[a]	1.35	0.59	1.13	1.59	1.56	3.10	3.28	1.54	2.03	1.97	1.93	1.69
(La/Sm)N[a]	1.26	0.60	1.31	1.26	1.48	2.23	2.14	1.09	1.66	1.47	1.48	1.37
(La/Yb)N[b]	1.28	0.56	1.07	1.51	1.48	2.95	3.12	1.46	1.93	1.87	1.83	1.60

Table 5.1 - Contd

Sample	314/201	314/200	314/199	314/198	314/197	314/196	314/193	314/192	314/191	314/190	300/113
Easting	52 512052	52 512052	52 511677	52 511623	52 511587	52 511517	52 511450	52 511378	52 511270	52 511181	52 516300
Northing	7108781	7108781	7108713	7108677	7108643	7108621	7108583	7108527	7108456	7108390	7116292
Intrusion	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Ewarara
Lithology	Gabbronorite	Gabbronorite	Leucogabbro	Anorthosite	Leucotroctolite	Leucotroctolite	Leucogabbro	Leucotroctolite	Leucotroctolite	Leucogabbro	Ol. Orthopyroxenite
SiO_2	49.60	46.70	49.90	49.60	45.80	46.50	49.40	47.80	47.60	50.50	47.50
Al_2O_3	16.90	11.20	22.70	29.90	21.50	25.20	25.60	20.90	19.00	17.30	7.96
Fe_2O_3	10.90	11.70	4.86	1.33	8.17	5.74	3.38	9.70	11.00	8.21	11.60
MnO	0.18	0.20	0.08	0.01	0.11	0.08	0.05	0.13	0.15	0.15	0.18
MgO	8.20	18.00	5.19	0.38	10.40	6.78	3.08	8.41	9.78	7.82	24.60
CaO	11.00	10.80	14.40	14.40	11.30	13.30	14.00	9.99	9.07	13.10	6.62
Na_2O	2.34	1.33	2.59	3.35	1.88	2.00	2.99	2.83	2.66	2.53	1.06
K_2O	0.23	0.11	0.15	0.16	0.13	0.11	0.15	0.19	0.17	0.17	0.30
TiO_2	0.70	0.38	0.22	0.10	0.16	0.14	0.15	0.15	0.23	0.38	0.40
P_2O_5	0.02	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.05
LOI	<0.01	<0.01	0.23	0.82	1.12	0.19	0.65	0.05	<0.01	0.29	<0.01
Total	100.07	100.44	100.33	100.06	100.59	100.05	99.46	100.16	99.67	100.46	100.27
Ba	120.00	60.00	60.00	60.00	50.00	40.00	60.00	70.00	70.00	70.00	100.00
Co	82.00	88.00	60.00	56.00	80.00	60.00	40.50	86.00	92.00	64.00	98.00
Cr	370.00	1900.00	140.00	20.00	30.00	20.00	70.00	20.00	20.00	50.00	3300.00
Cu	150.00	1.50	24.50	6.50	19.00	17.50	60.00	115.00	82.00	105.00	62.00
Ga	19.50	8.50	20.50	25.50	18.50	19.50	22.50	18.00	18.00	17.50	7.00
Nb	<0.5	<0.5	<0.5	<0.5	1.00	1.00	1.50	1.50	2.50	1.50	2.50
Ni	130.00	600.00	70.00	9.00	270.00	195.00	43.00	175.00	190.00	94.00	1050.00
Pb	1.50	1.00	1.00	<0.5	<0.5	<0.5	1.00	1.00	1.50	1.00	2.50
Rb	1.10	0.70	0.70	0.50	1.10	0.70	0.40	1.60	1.20	1.60	7.50
Sc	28.00	30.00	18.00	5.00	5.00	5.00	10.00	6.00	8.00	34.00	24.00
Sr	270.00	130.00	330.00	400.00	290.00	330.00	370.00	350.00	330.00	280.00	74.00
Th	0.07	0.10	0.08	0.11	0.18	0.11	0.05	0.08	0.12	0.12	1.05
U	0.02	0.02	0.02	0.02	0.05	0.03	0.02	0.05	0.08	0.07	0.17
V	250.00	150.00	80.00	20.00	40.00	40.00	50.00	40.00	70.00	150.00	150.00
W	150.00	145.00	210.00	320.00	135.00	145.00	135.00	115.00	110.00	125.00	120.00
Y	7.50	8.50	3.80	1.10	2.00	1.95	2.40	1.90	2.20	8.00	10.50
Zn	60.00	33.00	21.00	8.50	33.00	23.50	16.50	41.00	56.00	37.00	35.50
Zr	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00	50.00

Table 5.1 - Contd

Sample	314/201	314/200	314/199	314/198	314/197	314/196	314/193	314/192	314/191	314/190	300/113
Easting	52 512052	52 512052	52 511677	52 511623	52 511587	52 511517	52 511450	52 511378	52 511270	52 511181	52 516300
Northing	7108781	7108781	7108713	7108677	7108643	7108621	7108583	7108527	7108456	7108390	7116292
Intrusion	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Kalka	Ewarara
Lithology	Gabbronorite	Gabbronorite	Leucogabbro	Anorthosite	Leucotroctolite	Leucotroctolite	Leucogabbro	Leucotroctolite	Leucotroctolite	Leucogabbro	Ol. Orthopyroxenite
La	3.00	2.00	1.50	1.00	1.50	1.50	1.50	2.00	3.00	3.00	6.50
Ce	5.50	4.50	2.50	2.00	3.00	2.00	2.00	3.00	4.50	5.00	12.00
Pr	0.95	0.80	0.40	0.30	0.45	0.30	0.35	0.45	0.55	0.80	1.85
Nd	4.60	4.10	2.00	1.35	2.00	1.40	1.55	1.85	2.00	3.80	8.00
Sm	1.25	1.25	0.59	0.29	0.42	0.35	0.42	0.41	0.40	1.20	2.00
Eu	0.70	0.47	0.42	0.39	0.37	0.33	0.43	0.46	0.45	0.61	0.56
Gd	1.65	1.75	0.80	0.35	0.50	0.45	0.55	0.50	0.50	1.70	2.40
Tb	0.27	0.29	0.13	0.05	0.07	0.07	0.09	0.07	0.08	0.29	0.39
Dy	1.75	1.85	0.82	0.27	0.45	0.41	0.55	0.46	0.50	1.80	2.50
Ho	0.34	0.35	0.15	0.05	0.08	0.07	0.10	0.08	0.09	0.34	0.47
Er	1.05	1.10	0.45	0.15	0.25	0.25	0.30	0.25	0.30	1.00	1.50
Tm	0.15	0.15	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.15	0.20
Yb	1.05	1.05	0.40	0.15	0.25	0.20	0.25	0.25	0.30	1.00	1.45
Lu	0.14	0.14	0.05	0.02	0.03	0.03	0.03	0.03	0.04	0.13	0.21
Mg#	60	75	68	36	72	70	64	63	64	65	81
(Eu/Eu*)N[a]	1.49	0.97	1.87	3.74	2.47	2.54	2.73	3.10	3.07	1.31	0.78
(La/Yb)N[a]	1.93	1.29	2.53	4.50	4.05	5.07	4.05	5.41	6.76	2.03	3.03
(La/Sm)N[a]	1.51	1.01	1.60	2.17	2.25	2.70	2.25	3.07	4.72	1.57	2.05
(La/Yb)N[b]	1.83	1.22	2.41	4.28	3.85	4.81	3.85	5.14	6.42	1.93	2.88

Table 5.1 - Contd

Sample	300/128	300/127	300/126	300/125	300/124	300/123	300/121	313/312F	313/312E	313/312B
Easting	52 516813	52 516761	52 516708	52 516673	52 516633	52 516601	52 516555	52 532305	52 532308	52 532328
Northing	7115325	7115511	7115668	7115743	7115821	7115893	7115965	7103575	7103547	7103521
Intrusion	Ewarara	Ewarara	Ewarara	Ewarara	Ewarara	Ewarara	Ewarara	Gosse Pile	Gosse Pile	Gosse Pile
Lithology	Ol. Orthopyroxenite	Ol. Orthopyroxenite	Websterite	Orthopyroxenite	Orthopyroxenite	Orthopyroxenite	Websterite	Picrite	Picrite	Orthopyroxenite
SiO_2	47.90	47.40	53.10	53.30	53.10	53.50	51.90	53.60	44.50	52.50
Al_2O_3	3.99	4.28	4.79	5.35	5.18	4.51	6.02	4.36	4.44	9.53
Fe_2O_3	10.60	10.80	8.12	9.34	9.36	9.12	8.01	9.92	15.40	9.18
MnO	0.18	0.18	0.17	0.19	0.18	0.18	0.18	0.19	0.22	0.17
MgO	31.60	31.90	25.10	26.80	27.60	28.20	20.10	27.20	30.90	20.90
CaO	3.58	3.47	8.24	3.99	3.78	3.30	12.70	3.31	2.19	6.13
Na_2O	0.37	0.46	0.38	0.35	0.36	0.23	0.60	0.32	0.57	0.97
K_2O	0.07	0.10	0.05	0.05	0.05	0.03	0.07	0.05	0.16	0.07
TiO_2	0.17	0.19	0.18	0.20	0.21	0.16	0.29	0.21	0.39	0.20
P_2O_5	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01
LOI	<0.01	<0.01	0.16	0.03	0.11	0.16	0.32	1.12	0.55	0.55
Total	98.49	98.80	100.30	99.61	99.94	99.40	100.20	100.29	99.35	100.21
Ba	30.00	40.00	60.00	50.00	50.00	60.00	70.00	40.00	70.00	30.00
Co	110.00	120.00	86.00	96.00	98.00	105.00	76.00	110.00	165.00	94.00
Cr	5350.00	5700.00	7100.00	6200.00	6100.00	6000.00	4550.00	5100.00	5750.00	3250.00
Cu	23.50	21.00	15.00	26.50	19.50	13.50	20.50	21.00	30.50	62.00
Ga	3.70	3.90	5.50	6.00	6.00	5.50	7.00	5.50	6.50	7.50
Nb	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1.00	<0.5	<0.5	2.50
Ni	1400.00	1400.00	700.00	700.00	750.00	850.00	600.00	900.00	1350.00	550.00
Pb	<0.5	<0.5	4.50	<0.5	<0.5	<0.5	<0.5	<0.5	1.00	1.00
Rb	1.50	2.00	1.00	0.80	1.00	0.90	1.60	0.70	1.90	0.80
Sc	20.00	18.00	32.00	28.00	28.00	28.00	44.00	26.00	14.00	26.00
Sr	25.00	32.50	23.00	26.00	30.50	19.50	44.00	30.00	56.00	110.00
Th	0.16	0.23	0.09	0.06	0.06	0.05	0.14	0.04	0.11	0.08
U	0.05	0.05	0.05	0.03	0.03	0.03	0.10	0.03	0.10	0.06
V	90.00	100.00	140.00	120.00	120.00	110.00	170.00	110.00	130.00	120.00
W	92.00	135.00	155.00	165.00	155.00	180.00	130.00	190.00	230.00	210.00
Y	3.90	4.00	5.00	3.40	3.50	3.10	9.00	3.00	6.00	3.80
Zn	40.50	38.00	64.00	44.50	49.00	46.50	37.00	76.00	68.00	54.00
Zr	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00

Table 5.1 - Contd

Sample	300/128	300/127	300/126	300/125	300/124	300/123	300/121	313/312F	313/312E	313/312B
Easting	52 516813	52 516761	52 516708	52 516673	52 516633	52 516601	52 516555	52 532305	52 532308	52 532328
Northing	7115325	7115511	7115668	7115743	7115821	7115893	7115965	7103575	7103547	7103521
Intrusion	Ewarara	Ewarara	Ewarara	Ewarara	Ewarara	Ewarara	Ewarara	Gosse Pile	Gosse Pile	Gosse Pile
Lithology	Ol. Orthopyroxenite	Ol. Orthopyroxenite	Websterite	Orthopyroxenite	Orthopyroxenite	Orthopyroxenite	Websterite	Picrite	Picrite	Orthopyroxenite
La	1.50	2.00	1.50	1.00	1.00	0.50	1.50	0.50	1.50	0.50
Ce	3.00	3.50	1.50	1.00	1.50	1.00	3.00	1.00	3.00	0.50
Pr	0.45	0.50	0.40	0.25	0.25	0.20	0.60	0.15	0.55	0.15
Nd	2.10	2.20	1.85	1.20	1.15	0.93	3.10	0.90	2.70	0.92
Sm	0.56	0.57	0.57	0.34	0.33	0.26	1.05	0.30	0.86	0.33
Eu	0.17	0.18	0.19	0.14	0.14	0.11	0.37	0.13	0.34	0.18
Gd	0.70	0.75	0.90	0.55	0.55	0.45	1.70	0.50	1.20	0.60
Tb	0.12	0.12	0.16	0.10	0.09	0.08	0.29	0.09	0.20	0.11
Dy	0.82	0.83	1.05	0.70	0.67	0.58	2.10	0.61	1.30	0.76
Ho	0.16	0.16	0.21	0.14	0.14	0.12	0.38	0.13	0.25	0.16
Er	0.55	0.50	0.70	0.50	0.45	0.45	1.30	0.45	0.80	0.55
Tm	0.05	0.05	0.10	0.05	0.05	0.05	0.20	0.05	0.10	0.10
Yb	0.55	0.55	0.70	0.55	0.50	0.50	1.30	0.50	0.85	0.60
Lu	0.08	0.08	0.10	0.08	0.08	0.07	0.18	0.07	0.12	0.08
Mg#	86	85	86	85	85	86	83	84	80	82
(Eu/Eu*)N[a]	0.83	0.84	0.81	0.99	1.00	0.98	0.85	1.03	1.02	1.24
(La/Yb)N[a]	1.84	2.46	1.45	1.23	1.35	0.68	0.78	0.68	1.19	0.56
(La/Sm)N[a]	1.69	2.21	1.66	1.85	1.91	1.21	0.90	1.05	1.10	0.95
(La/Yb)N[b]	1.75	2.33	1.38	1.17	1.28	0.64	0.74	0.64	1.13	0.53

Table 5.1 - Contd

Sample	313/312A	313/200	313/199	313/112	313/111	313/110	313/107	313/105	313/101	313/100
Easting	52 532331	52 532063	52 532050	52 531399	52 531415	52 531422	52 531435	52 531425	52 531495	52 531477
Northing	7103488	7103434	7103375	7103238	7103213	7103166	7103094	7102968	7102549	7102480
Intrusion	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile
Lithology	Orthopyroxenite	Orthopyroxenite	Picrite	Orthopyroxenite	Norite	Gabbro	Gabbro	Orthopyroxenite	Orthopyroxenite	Orthopyroxenite
SiO_2	53.40	53.60	41.80	54.80	52.50	52.10	51.10	53.00	54.20	54.50
Al_2O_3	4.51	4.67	4.62	2.53	7.39	8.97	6.08	4.53	2.79	2.77
Fe_2O_3	10.40	9.94	11.70	8.91	10.60	8.24	8.84	11.00	9.10	9.62
MnO	0.21	0.19	0.17	0.18	0.20	0.17	0.20	0.21	0.19	0.19
MgO	27.30	27.40	34.60	30.30	22.80	17.60	17.20	27.10	29.50	29.70
CaO	3.26	3.45	3.43	2.05	5.28	11.90	15.30	2.82	2.15	2.16
Na_2O	0.39	0.28	0.70	0.10	0.81	1.05	0.63	0.24	0.11	0.09
K_2O	0.07	0.02	0.07	0.02	0.09	0.08	0.07	0.03	0.01	0.01
TiO_2	0.25	0.17	0.16	0.12	0.24	0.25	0.40	0.18	0.14	0.14
P_2O_5	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01
LOI	0.43	0.45	1.34	0.29	0.23	0.31	0.42	0.13	0.11	0.15
Total	100.23	100.18	98.60	99.31	100.15	100.68	100.26	99.25	98.31	99.34
Ba	100.00	70.00	30.00	40.00	40.00	40.00	80.00	30.00	40.00	<20
Co	120.00	100.00	140.00	110.00	105.00	84.00	98.00	125.00	105.00	115.00
Cr	5450.00	5300.00	3500.00	6750.00	3050.00	2700.00	3000.00	4300.00	6350.00	5750.00
Cu	24.00	39.50	29.50	8.00	32.00	27.00	36.00	18.50	9.50	8.00
Ga	6.50	6.00	2.80	3.80	7.50	8.00	8.50	5.50	4.10	3.60
Nb	1.00	2.50	<0.5	1.00	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Ni	700.00	800.00	1800.00	850.00	550.00	410.00	420.00	700.00	800.00	800.00
Pb	1.00	2.00	<0.5	<0.5	1.00	<0.5	<0.5	3.00	<0.5	<0.5
Rb	0.90	0.70	0.30	0.80	0.70	0.50	1.20	0.50	0.40	0.40
Sc	24.00	26.00	10.00	20.00	30.00	40.00	54.00	30.00	22.00	24.00
Sr	33.50	29.50	66.00	6.50	88.00	110.00	46.50	21.50	9.50	3.70
Th	0.10	0.32	0.03	0.17	0.04	0.04	0.06	0.05	0.03	0.03
U	0.05	0.14	0.06	0.13	0.03	0.04	0.06	0.06	0.04	0.06
V	120.00	120.00	60.00	70.00	130.00	160.00	230.00	120.00	80.00	90.00
W	290.00	160.00	130.00	200.00	190.00	200.00	280.00	250.00	175.00	220.00
Y	4.30	2.90	3.40	1.80	4.50	7.00	11.50	2.80	2.40	1.65
Zn	62.00	58.00	30.50	56.00	60.00	38.00	43.50	64.00	60.00	58.00
Zr	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00	<20.00

Table 5.1 - Contd

Sample	313/312A	313/200	313/199	313/112	313/111	313/110	313/107	313/105	313/101	313/100
Easting	52 532331	52 532063	52 532050	52 531399	52 531415	52 531422	52 531435	52 531425	52 531495	52 531477
Northing	7103488	7103434	7103375	7103238	7103213	7103166	7103094	7102968	7102549	7102480
Intrusion	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile
Lithology	Orthopyroxenite	Orthopyroxenite	Picrite	Orthopyroxenite	Norite	Gabbro	Gabbro	Orthopyroxenite	Orthopyroxenite	Orthopyroxenite
La	1.00	1.00	0.50	0.50	1.00	0.50	1.50	0.50	0.50	0.50
Ce	1.50	1.00	1.00	0.50	1.50	1.50	3.00	0.50	0.50	0.50
Pr	0.30	0.20	0.20	0.15	0.30	0.35	0.65	0.15	0.15	0.10
Nd	1.50	0.89	1.05	0.71	1.45	1.85	3.70	0.70	0.72	0.41
Sm	0.48	0.24	0.39	0.19	0.47	0.73	1.30	0.23	0.19	0.13
Eu	0.20	0.11	0.19	0.07	0.21	0.33	0.52	0.11	0.08	0.05
Gd	0.80	0.40	0.65	0.30	0.75	1.30	2.30	0.40	0.35	0.20
Tb	0.13	0.07	0.11	0.05	0.13	0.23	0.41	0.08	0.05	0.04
Dy	0.89	0.57	0.76	0.39	0.93	1.60	2.80	0.56	0.40	0.29
Ho	0.18	0.12	0.15	0.08	0.19	0.32	0.53	0.12	0.09	0.07
Er	0.60	0.45	0.50	0.30	0.70	1.05	1.70	0.45	0.30	0.25
Tm	0.10	0.05	0.05	0.05	0.10	0.15	0.25	0.05	0.05	0.05
Yb	0.65	0.45	0.50	0.35	0.75	1.00	1.60	0.55	0.35	0.30
Lu	0.09	0.07	0.07	0.05	0.11	0.14	0.21	0.08	0.05	0.04
Mg#	84	85	85	87	81	81	79	83	87	86
(Eu/Eu*)N[a]	0.99	1.08	1.15	0.90	1.08	1.04	0.92	1.11	0.95	0.95
(La/Yb)N[a]	1.04	1.50	0.68	0.97	0.90	0.34	0.63	0.61	0.97	1.13
(La/Sm)N[a]	1.31	2.62	0.81	1.66	1.34	0.43	0.73	1.37	1.66	2.42
(La/Yb)N[b]	0.99	1.43	0.64	0.92	0.86	0.32	0.60	0.58	0.92	1.07

Table 5.1 - Contd

Sample	313/122	313/099	313/097	313/095	313/412	314/451A	314/474	314/756	300/701	300/69
Easting	52 531410	52 531361	52 531294	52 531286	52 531260	52 513627	52 515638	52 519516	52 513439	52 518711
Northing	7103290	7102222	7102050	7101998	7101950	7107896	7106119	7109856	7113746	7115586
Intrusion	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Kalka	Kalka	Kalka	Ewarara	Ewarara
Lithology	Websterite	Orthopyroxenite	Norite	Orthopyroxenite	Websterite	Country Rock	Country Rock	Country Rock	Country Rock	Country Rock
SiO_2	51.90	53.90	53.10	53.40	51.20	54.90	70.10	49.00	74.20	75.60
Al_2O_3	5.20	3.04	5.15	4.38	13.40	15.20	14.70	16.10	13.40	13.60
Fe_2O_3	7.80	9.45	8.64	10.00	6.07	8.19	2.29	10.30	2.42	1.41
MnO	0.18	0.18	0.20	0.22	0.13	0.16	0.03	0.17	0.11	0.18
MgO	21.20	29.60	22.00	24.80	13.70	7.25	0.36	9.81	0.86	0.13
CaO	12.50	2.17	11.00	7.05	13.10	10.30	1.37	11.10	2.68	1.48
Na_2O	0.47	0.10	0.39	0.29	1.48	2.10	2.98	2.19	3.97	3.89
K_2O	0.04	0.02	0.04	0.03	0.08	1.17	6.55	0.40	1.71	3.21
TiO_2	0.22	0.15	0.17	0.22	0.21	0.42	0.25	0.67	0.34	0.06
P_2O_5	0.01	0.01	0.01	0.01	0.01	0.07	0.07	0.07	0.05	<0.01
LOI	0.27	<0.01	0.13	<0.01	0.29	0.16	0.22	0.19	0.41	0.45
Total	99.79	98.62	100.83	100.40	99.67	99.92	98.92	100.00	100.15	100.01
Ba	50.00	<20	<20	40.00	40.00	330.00	1100.00	170.00	900.00	230.00
Co	72.00	115.00	115.00	140.00	78.00	62.00	58.00	74.00	66.00	48.00
Cr	5400.00	5400.00	1750.00	4050.00	1750.00	290.00	<20	250.00	<20	<20
Cu	13.00	9.00	8.00	14.50	8.50	52.00	4.00	76.00	4.00	3.00
Ga	5.50	3.80	4.90	5.50	9.50	22.50	39.50	16.00	28.00	25.00
Nb	<0.5	<0.5	1.50	1.00	1.50	9.00	4.50	1.50	3.00	1.50
Ni	550.00	750.00	550.00	650.00	330.00	96.00	3.00	300.00	12.00	<2
Pb	<0.5	<0.5	<0.5	<0.5	1.00	17.50	50.00	2.00	17.50	44.50
Rb	0.70	0.40	0.70	0.50	0.60	36.00	230.00	4.10	15.00	62.00
Sc	44.00	24.00	44.00	38.00	32.00	26.00	5.00	30.00	6.00	8.00
Sr	28.00	3.60	30.00	24.00	170.00	160.00	165.00	220.00	330.00	110.00
Th	0.06	0.03	0.09	0.06	0.04	41.50	100.00	0.31	0.53	0.24
U	0.04	0.06	0.11	0.08	0.03	1.40	3.80	0.05	0.06	0.56
V	160.00	90.00	160.00	140.00	130.00	130.00	<20	180.00	30.00	<20
W	125.00	240.00	340.00	450.00	240.00	320.00	600.00	290.00	390.00	260.00
Y	7.00	1.75	4.90	4.50	5.50	49.50	16.00	13.00	8.50	64.00
Zn	32.00	56.00	43.50	60.00	28.00	84.00	48.00	54.00	56.00	18.50
Zr	<20.00	<20.00	<20.00	<20.00	<20.00	170.00	290.00	30.00	150.00	110.00

Table 5.1 - Contd

Sample	313/122	313/099	313/097	313/095	313/412	314/451A	314/474	314/756	300/701	300/69
Easting	52 531410	52 531361	52 531294	52 531286	52 531260	52 513627	52 515638	52 519516	52 513439	52 518711
Northing	7103290	7102222	7102050	7101998	7101950	7107896	7106119	7109856	7113746	7115586
Intrusion	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Gosse Pile	Kalka	Kalka	Kalka	Ewarara	Ewarara
Lithology	Websterite	Orthopyroxenite	Norite	Orthopyroxenite	Websterite	Country Rock	Country Rock	Country Rock	Country Rock	Country Rock
La	1.00	0.50	1.00	1.00	0.50	78.00	110.00	4.00	28.00	39.50
Ce	1.50	0.50	1.50	1.00	1.00	165.00	195.00	8.50	40.00	50.00
Pr	0.35	0.10	0.30	0.25	0.30	17.00	17.50	1.15	4.50	4.70
Nd	1.90	0.37	1.45	1.25	1.65	62.00	60.00	6.00	16.50	14.00
Sm	0.69	0.12	0.54	0.45	0.65	12.50	8.50	1.80	2.30	2.70
Eu	0.25	0.05	0.19	0.18	0.31	1.20	1.85	0.77	1.95	0.79
Gd	1.15	0.20	0.90	0.75	1.00	11.50	6.00	2.60	2.20	4.20
Tb	0.21	0.04	0.17	0.14	0.18	1.85	0.76	0.42	0.29	0.97
Dy	1.55	0.29	1.15	0.95	1.30	11.00	3.80	3.00	1.70	9.00
Ho	0.30	0.06	0.22	0.19	0.24	2.00	0.61	0.57	0.32	2.40
Er	1.00	0.25	0.75	0.70	0.80	6.00	1.85	1.85	1.00	10.50
Tm	0.15	0.05	0.10	0.10	0.10	0.85	0.25	0.25	0.15	1.80
Yb	1.00	0.30	0.70	0.70	0.80	6.00	1.95	1.85	1.05	15.00
Lu	0.13	0.04	0.10	0.10	0.11	0.76	0.32	0.26	0.16	2.20
Mg#	84	86	83	83	82	64	24	65	41	15
$(Eu/Eu^*)_N$[a]	0.86	0.99	0.83	0.95	1.18	0.31	0.79	1.09	2.65	0.72
$(La/Yb)_N$[a]	0.68	1.13	0.97	0.97	0.42	8.78	38.12	1.46	18.02	1.78
$(La/Sm)_N$[a]	0.91	2.62	1.17	1.40	0.48	3.93	8.15	1.40	7.66	9.21
$(La/Yb)_N$[b]	0.64	1.07	0.92	0.92	0.40	8.34	36.21	1.39	17.12	1.69

Table 5.1 - Contd

301/174B	313/404	313/413	313/418a
52 517593	52 529441	52 532839	52 531296
7117764	7103433	7101223	7104423
Ewarara	Gosse Pile	Gosse Pile	Gosse Pile
Country Rock	Country Rock	Country Rock	Country Rock
62.90	72.40	68.60	77.60
14.60	14.00	13.70	12.30
7.64	2.02	3.70	0.84
0.12	0.02	0.06	0.03
1.07	0.81	0.24	0.13
4.60	1.05	1.80	1.67
3.90	2.64	2.55	4.68
2.68	5.60	6.24	1.26
1.25	0.23	0.96	0.06
0.62	0.14	0.16	<0.01
0.46	0.33	0.64	0.24
99.84	99.24	98.65	98.81
1750.00	260.00	1500.00	600.00
52.00	45.50	60.00	62.00
<20	<20	<20	<20
31.00	4.00	4.50	7.50
47.50	19.00	21.00	13.50
13.00	2.50	32.50	2.00
7.00	3.00	<2.00	2.00
15.50	36.50	28.00	9.50
17.50	200.00	110.00	9.00
14.00	<5	10.00	-
450.00	74.00	195.00	115.00
0.05	12.00	8.00	16.00
0.07	1.15	0.25	2.00
50.00	<20	<20	<20
280.00	550.00	750.00	550.00
44.00	9.50	29.00	13.50
115.00	24.00	66.00	7.50
650.00	140.00	290.00	150.00

Table 5.1 - Contd

301/174B	313/404	313/413	313/418a
52 517593	52 529441	52 532839	52 531296
7117764	7103433	7101223	7104423
Ewarara	Gosse Pile	Gosse Pile	Gosse Pile
Country Rock	Country Rock	Country Rock	Country Rock
40.00	33.50	60.00	38.00
78.00	58.00	98.00	72.00
11.50	7.00	12.00	8.50
52.00	25.50	47.00	32.50
11.50	4.50	8.00	5.50
5.00	0.87	4.10	0.60
12.50	2.90	7.00	3.70
1.75	0.38	1.05	0.59
10.00	1.95	6.50	2.80
1.75	0.29	1.15	0.48
5.00	0.90	3.40	1.40
0.65	0.10	0.45	0.20
4.30	0.90	3.10	1.40
0.59	0.12	0.42	0.22
22	44	11	23
1.27	0.74	1.67	0.41
6.29	25.15	13.08	18.34
2.19	4.69	4.72	4.35
5.97	23.89	12.42	17.42

Table 5.2 . Major and Trace element compositions of selected clinopyroxenes

Sample	314/192	314/209	314/221	314/156	300/121	300/125	300/127	313/111	313/200
Intrusion	Kalka	Kalka	Kalka	Kalka	Ewarara	Ewarara	Ewarara	Gosse Pile	Gosse Pile
Mineral	cpx	cpx	cpx	cpx	cpx	cpx	cpx	cpx	cpx
n	5	4	4	5	5	4	4	5	4
SiO_2	51.12	51.49	51.35	52.17	50.57	50.15	50.93	49.34	50.87
TiO_2	0.41	0.24	0.38	0.43	0.29	0.52	0.46	0.44	0.48
Al_2O_3	3.66	5.71	3.66	2.88	4.70	4.68	5.13	4.67	4.33
Cr_2O_3	0.04	0.11	0.34	0.37	0.87	1.04	0.82	0.82	1.11
FeOt	8.59	6.39	6.98	5.37	4.74	3.26	4.06	5.37	4.06
MnO	0.25	0.18	0.16	0.16	0.14	0.12	0.06	0.13	0.16
MgO	15.55	15.26	16.08	16.81	17.46	15.21	16.86	16.47	17.52
CaO	19.63	19.16	19.85	20.86	19.44	22.61	18.52	19.80	20.09
Na_2O	0.69	0.67	0.69	0.52	0.67	0.92	1.75	0.80	0.71
K_2O	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Total	99.95	99.22	99.51	99.58	98.91	98.51	98.60	97.85	99.35
Mg no.	76.35	80.97	80.41	84.80	86.77	89.28	88.08	84.54	88.49
$Wo_{mol\%}$	0.409	0.422	0.416	0.431	0.410	0.488	0.410	0.422	0.422
$En_{mol\%}$	0.451	0.468	0.469	0.483	0.512	0.457	0.520	0.489	0.512
$Fs_{mol\%}$	0.140	0.110	0.114	0.087	0.078	0.055	0.070	0.089	0.067
Sc	81.83	109.63	98.49	106.29	74.46	86.21	99.91	72.59	85.79
V	183.19	420.11	290.68	380.15	210.93	247.68	309.92	243.07	259.06
Cr	137.34	790.99	2519.40	3413.58	5367.74	7130.20	9500.62	4691.80	6602.36
Mn	1506.92	1625.07	1583.84	2785.75	1310.38	692.22	1391.00	933.54	816.60
Co	41.63	68.12	55.25	129.31	55.44	30.80	71.01	36.66	38.35
Ni	82.12	285.37	288.21	1081.74	629.09	369.30	662.08	343.95	485.80
Cu	1.38	bdl	3.73	6.07	3.62	1.45	3.48	3.73	9.24
Ti	2029.11	2056.87	2338.72	2722.92	1611.73	2418.45	2913.20	1892.73	2473.68
Hf	1.25	0.69	0.62	1.34	0.54	0.67	1.96	0.44	0.47
Ta	0.02	bdl	0.02	0.03	0.03	0.06	0.08	0.03	0.02
Y	19.44	17.01	15.34	23.32	11.22	16.68	22.44	13.69	14.12
Zr	38.12	17.21	20.52	44.11	13.57	24.50	75.50	14.21	14.40
Nb	0.15	bdl	0.21	bdl	0.34	0.65	0.65	0.53	0.18
Ga	8.02	6.57	8.01	9.93	7.31	5.54	8.95	5.81	5.31
Rb	0.12	0.34	bdl	1.51	0.93	bdl	1.84	0.10	bdl
Sr	10.31	8.99	8.34	8.70	45.49	11.49	24.50	15.55	11.96
Ba	0.23	0.57	0.37	2.19	bdl	bdl	14.24	0.19	1.12
La	1.01	0.74	0.87	3.74	1.09	2.30	7.95	1.33	0.53
Ce	4.99	3.89	3.85	12.68	2.56	6.31	18.42	4.58	1.90
Pr	1.02	0.77	0.69	1.99	0.41	0.93	2.43	0.71	0.35
Nd	6.60	5.12	4.41	10.20	2.43	4.84	11.41	3.92	2.30
Sm	2.51	2.01	1.70	3.15	0.96	1.59	3.10	1.37	1.09
Eu	0.71	0.58	0.56	0.90	0.38	0.63	1.01	0.60	0.47
Gd	3.24	2.59	2.17	3.82	1.47	2.06	3.39	1.83	1.66
Tb	0.61	0.47	0.40	0.75	0.29	0.46	0.66	0.38	0.38
Dy	3.76	3.28	2.89	4.40	2.04	2.97	4.29	2.45	2.49
Ho	0.78	0.67	0.59	0.93	0.43	0.65	0.91	0.55	0.57
Er	2.10	1.91	1.71	2.65	1.33	1.85	2.52	1.50	1.61
Tm	0.28	0.25	0.23	0.36	0.19	0.28	0.36	0.21	0.22
Yb	1.94	1.77	1.65	2.59	1.35	1.80	2.47	1.47	1.44
Lu	0.27	0.24	0.22	0.36	0.20	0.27	0.35	0.22	0.21
Pb	0.11	0.07	0.10	0.50	0.40	0.25	0.98	0.13	0.11
Th	0.31	0.09	0.24	0.83	0.09	0.03	0.89	0.07	0.02
U	0.05	bdl	0.03	0.01	0.02	0.01	0.12	0.03	0.01
(La/Sm)N	0.25	0.23	0.32	0.75	0.72	0.91	1.62	0.61	0.30
(Eu/Eu*)N	0.77	0.77	0.89	0.79	0.98	1.06	0.95	1.15	1.07

N: chondrite normalised; (bdl) below detection limit; Mg no: 100xMg/(Mg+total Fe)

Table 5.3 . Major and Trace element compositions of selected orthopyroxenes

Sample	314/209	314/221	314/156	300/121	300/125	300/127	300/113	313/111	313/200	313/101
Intrusion	Kalka	Kalka	Kalka	Ewarara	Ewarara	Ewarara	Ewarara	Gosse Pile	Gosse Pile	Gosse Pile
Mineral	opx	opx	opx	opx	opx	opx	opx	opx	opx	opx
n	4	4	4	5	4	3	4	4	4	6
SiO_2	52.36	51.83	54.09	52.92	52.87	53.26	52.20	52.55	52.35	53.71
TiO_2	0.12	0.16	0.11	0.08	0.08	0.04	0.12	0.14	0.12	0.10
Al_2O_3	1.52	2.65	1.86	3.56	3.48	2.62	3.23	3.58	3.11	2.38
Cr_2O_3	0.10	0.12	0.23	0.45	0.47	0.32	0.83	0.46	0.61	0.71
FeOt	15.33	15.49	12.29	9.98	8.82	8.84	11.26	11.20	9.32	8.16
MnO	0.32	0.36	0.33	0.25	0.22	0.25	0.27	0.24	0.21	0.21
MgO	27.08	26.48	28.76	29.43	31.36	32.44	29.62	29.74	30.70	32.41
CaO	0.76	1.06	1.31	2.02	0.61	0.23	0.92	0.62	1.10	0.88
Na_2O	0.04	0.04	0.03	0.10	0.05	0.02	0.08	0.03	0.05	0.03
K_2O	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01
Total	97.63	98.18	99.03	98.81	97.97	98.03	98.53	98.57	97.59	98.61
Mg no.	75.89	75.29	80.66	84.00	86.36	86.73	82.42	82.56	85.44	87.62
$Wo_{mol\%}$	0.015	0.021	0.026	0.040	0.012	0.004	0.018	0.012	0.021	0.017
$En_{mol\%}$	0.748	0.737	0.786	0.807	0.853	0.864	0.809	0.816	0.836	0.861
$Fs_{mol\%}$	0.237	0.242	0.188	0.154	0.135	0.132	0.173	0.172	0.142	0.122
Sc	24.35	31.75	24.71	25.49	15.85	8.77	13.75	28.27	21.79	12.56
V	81.88	71.94	92.99	81.20	50.74	29.31	56.74	99.93	66.48	37.19
Cr	190.28	424.22	990.73	2500.46	1556.41	1295.71	3220.16	2067.03	2357.01	2154.68
Mn	1309.79	1458.29	1437.81	1499.63	643.13	386.46	1033.76	1347.26	897.74	621.66
Co	61.14	60.71	72.97	73.03	35.55	19.05	42.82	73.82	53.61	38.37
Ni	200.65	237.02	549.91	679.71	345.09	168.11	321.36	529.43	513.13	400.97
Cu	bdl	bdl	1.21	0.95	13.90	0.15	0.80	16.14	1.51	0.95
Ti	565.87	487.64	804.72	362.90	301.67	180.28	305.96	621.66	463.66	301.23
Hf	0.04	0.04	0.18	0.08	0.06	0.08	0.12	0.05	0.03	0.05
Ta	0.01	0.00	bdl	bdl	0.01	bdl	0.01	bdl	bdl	bdl
Y	0.72	1.05	1.79	1.09	0.60	0.72	1.64	0.95	0.79	0.54
Zr	1.18	1.11	6.11	1.29	1.46	2.12	5.33	1.44	1.20	0.71
Nb	0.02	bdl	0.26	0.09	0.05	0.03	0.05	0.03	0.05	0.08
Ga	2.23	3.58	4.03	4.77	2.65	1.35	2.82	5.82	3.10	1.93
Rb	0.30	bdl	0.10	0.14	0.39	bdl	bdl	0.21	bdl	0.24
Sr	0.16	0.22	0.22	0.69	0.20	0.53	0.53	0.37	0.14	0.16
Ba	0.14	bdl	bdl	0.39	0.50	bdl	bdl	1.17	0.12	1.03
La	0.04	0.03	0.24	0.09	0.04	0.21	0.40	0.02	0.01	0.04
Ce	0.09	0.10	0.56	0.16	0.08	0.42	0.84	0.07	0.03	0.09
Pr	0.01	0.02	0.08	0.02	0.02	0.06	0.11	0.02	0.01	0.02
Nd	0.07	0.12	0.39	0.18	0.09	0.25	0.50	0.06	0.04	0.09
Sm	0.04	0.05	0.19	bdl	0.07	0.06	0.17	0.12	bdl	bdl
Eu	0.01	0.02	bdl	0.11	0.07	0.04	0.09	0.09	0.05	0.17
Gd	0.05	0.08	0.19	0.11	0.06	0.07	0.16	0.07	0.05	0.07
Tb	0.02	0.02	0.08	0.10	0.04	0.04	0.10	0.06	bdl	0.04
Dy	0.09	0.14	0.30	0.17	0.11	0.12	0.26	0.12	0.09	0.09
Ho	0.03	0.04	0.07	0.05	0.02	0.03	0.06	0.04	0.03	0.02
Er	0.10	0.15	0.24	0.19	0.11	0.09	0.25	0.18	0.12	0.08
Tm	0.02	0.02	0.04	0.03	0.02	0.02	0.04	0.03	0.02	0.02
Yb	0.19	0.24	0.35	0.22	0.13	0.12	0.23	0.22	0.14	0.12
Lu	0.04	0.04	0.07	0.04	0.02	0.02	0.06	0.04	0.03	0.02
Pb	0.05	0.02	0.06	0.07	0.03	0.05	0.16	0.79	0.03	bdl
Th	0.05	0.13	0.37	0.02	0.03	0.13	0.77	0.02	bdl	0.02
U	0.04	0.01	0.01	bdl	0.01	0.02	0.07	0.00	bdl	bdl
(La/Sm)N	0.57	0.37	0.81	-	0.35	2.38	1.44	0.12	-	-
(Eu/Eu*)N	0.91	1.16	-	-	3.19	1.98	1.69	3.08	-	-

Abbreviations as in Table 2

Table 5.4 . Major and Trace element compositions of selected plagioclases

Sample	314/192	314/209	314/221	314/156	300/125	300/113	313/111	313/200
Intrusion	Kalka	Kalka	Kalka	Kalka	Ewarara	Ewarara	Gosse Pile	Gosse Pile
Mineral	plag	plag	plag	plag	plag	plag	plag	plag
n	4	4	4	1	2	4	4	4
SiO_2	51.73	50.73	49.78	51.83	53.87	58.45	53.00	50.85
TiO_2	0.04	0.02	0.01	0.04	0.04	0.04	0.05	0.05
Al_2O_3	28.56	29.97	30.43	29.22	27.55	24.55	28.04	29.33
Cr_2O_3	0.03	0.05	0.00	0.03	0.03	0.02	0.03	0.00
FeOt	0.05	0.07	0.05	0.04	0.03	0.31	0.03	0.01
MnO	0.04	0.00	0.02	0.01	0.01	0.01	0.00	0.01
MgO	0.06	0.00	0.00	0.03	0.01	0.25	0.00	0.00
CaO	12.35	13.86	14.36	12.90	10.99	6.39	11.53	13.16
Na_2O	4.50	3.76	3.38	4.10	5.31	7.90	4.82	4.07
K_2O	0.10	0.13	0.14	0.50	0.16	0.31	0.39	0.14
Total	97.47	98.58	98.17	98.69	98.01	98.22	97.89	97.62
$Or_{mol\%}$	0.004	0.004	0.005	0.018	0.006	0.014	0.014	0.005
$Ab_{mol\%}$	0.247	0.196	0.175	0.220	0.302	0.521	0.270	0.218
$An_{mol\%}$	0.750	0.800	0.821	0.763	0.691	0.466	0.715	0.777
Sc	8.94	23.90	24.76	16.27	12.765	11.84	11.21	12.74
V	1.99	bdl	bdl	7.89	8.79	12.83	0.34	1.09
Cr	7.96	18.87	bdl	48.3	278.705	116.20	4.79	25.22
Mn	32.95	12.36	12.55	90.89	47.04	88.31	8.05	21.49
Co	2.65	bdl	bdl	2.56	3.89	37.97	0.47	1.70
Ni	2.52	bdl	bdl	113.62	219.83	330.95	7.37	53.83
Cu	3.16	bdl	bdl	60.08	98.555	7.93	2.50	15.47
Ti	143.78	79.38	47.95	188.65	85.715	385.20	69.75	71.59
Hf	0.40	bdl	bdl	1.43	4.73	0.68	bdl	bdl
Ta	0.58	0.01	bdl	0.161	0.5455	0.13	bdl	bdl
Y	0.75	0.21	0.11	4.46	13.6945	0.98	0.12	0.22
Zr	0.58	0.52	0.71	74.85	337.585	19.53	bdl	0.17
Nb	1.13	bdl	0.10	bdl	0.2615	0.44	bdl	bdl
Ga	27.50	23.60	17.16	45.78	9.86	18.99	13.45	17.64
Rb	1.86	1.12	0.43	138.88	1.21	3.59	0.61	0.59
Sr	403.97	350.54	290.26	429.65	377.955	601.23	476.21	425.92
Ba	265.39	107.38	69.08	2167.27	71.455	241.43	135.40	458.73
La	2.40	1.63	1.55	8.67	3.96	15.64	1.95	0.88
Ce	3.43	2.52	2.31	9.94	4.145	12.55	2.41	1.16
Pr	0.47	0.24	0.19	0.715	0.3425	0.70	0.20	0.09
Nd	1.24	0.82	0.62	2.04	1.3055	1.81	0.58	0.27
Sm	0.38	0.10	0.05	0.29	0.5	bdl	bdl	bdl
Eu	1.90	0.35	0.26	1.01	bdl	0.41	0.25	0.24
Gd	0.42	0.09	bdl	0.303	bdl	0.21	0.13	0.06
Tb	0.14	0.02	bdl	0.254	bdl	0.22	0.11	0.09
Dy	0.12	bdl	bdl	bdl	bdl	0.22	bdl	bdl
Ho	0.02	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Er	0.10	bdl	bdl	bdl	bdl	bdl	bdl	0.10
Tm	0.08	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Yb	0.04	bdl	bdl	bdl	bdl	bdl	bdl	bdl
Lu	0.06	bdl	bdl	bdl	bdl	bdl	bdl	0.03
Pb	2.99	1.28	1.16	28.34	14.18	19.45	1.54	1.29
Th	0.41	0.02	bdl	111.53	101.11	65.35	bdl	0.00
U	1.66	0.15	bdl	0.146	0.53	0.10	bdl	bdl

Abbreviations as in Table 2

Table 5.5 Sm-Nd isotope data for Giles Complex ultramafic rocks (from this study)

		Lithology	Est. Age (Ma)	MgO (%)	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd^{a}$ (±2σ)	$\varepsilon_{Nd}(1.08\ Ga)^{b}$	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr^{c}$	$\varepsilon_{Sr}(1.08\ Ga)^{b}$
Kalka Intrusion														
314/190	WR	Leucogabbro	1080	7.82	0.9	2.8	0.2004	0.512559±0.000012	-2.1±0.3	1.4	228.8	0.0177	0.705514±0.000012	24.7
314/192	WR	Leucotroctolite	1080	8.41	0.4	1.4	0.1597	0.512195±0.000014	-3.6±0.3	2.5	187.0	0.0387	0.705412±0.000011	18.7
	Plag				0.1	1.0	0.0785	0.511725±0.000016	-1.5±0.3	.5	196.6	0.0074	0.705187±0.000012	22.4
	Ol.				0.6	1.5	0.2193	0.512764±0.000012	-0.7±0.6	.7	15.1	0.1341	0.707100±0.000015	21.7
	Cpx				1.0	2.9	0.2206	0.512739±0.000013	-1.3±0.3	1.2	13.7	0.2534	0.707181±0.000035	-3.3
314/199	WR	Leucogabbro	1080	5.19	0.6	1.9	0.1811	0.512401±0.000012	-2.5±0.3	.8	287.2	0.0081	0.705574±0.000013	27.7
314/203	WR	Gabbronorite	1080	8.33	0.7	2.4	0.1750	0.512350±0.000012	-2.6±0.3	1.4	214.8	0.0189	0.706839±0.000009	43.3
314/208	WR	Gabbronorite	1080	7.57	2.3	9.0	0.1524	0.512136±0.000009	-3.7±0.2	5.8	191.4	0.0877	0.708307±0.000012	49.1
314/209	WR	Gabbronorite	1080	9.47	0.5	1.6	0.1996	0.512396±0.000071	-5.2±1.4	1.2	165.2	0.021	0.708154±0.000010	61.5
	Plag				0.1	1.0	0.0810	0.511618±0.000035	-3.9±0.7	1.5	200.0	0.0217	0.708055±0.000013	60.0
	Opx				0.3	0.9	0.2252	0.512570±0.000064	-5.3±1.3	.2	8.3	0.0697	0.709954±0.000020	76.4
	Cpx				1.6	4.4	0.2249	0.512695±0.000024	-2.8±0.5	.2	12.5	0.0463	0.708880±0.000019	66.3
314/213	WR	Picrite	1080	29.00	0.2	0.5	0.2190	0.512596±0.000016	-3.9±0.3	0..3	46.9	0.0185	0.707956±0.000013	59.3
314/217	WR	Gabbronorite	1080	9.31	0.4	1.2	0.2005	0.512432±0.000009	-4.6±0.2	.9	140.0	0.0186	0.707685±0.000012	55.4
314/221	WR	Gabbronorite	1080	9.53	0.6	1.9	0.1975	0.512480±0.000014	-3.2±0.3	1.0	176.0	0.0164	0.708310±0.000012	64.8
	Plag				0.1	1.0	0.0849	0.511924±0.000194	1.5±3.8	.5	173.3	0.0083	0.708057±0.000013	62.9
	Opx				0.9	2.5	0.2183	0.512631±0.000026	-3.1±0.5	1.2	16.6	0.2092	0.710015±0.000013	46.6
	Cpx				1.5	4.1	0.2233	0.512687±0.000018	-2.7±0.4	.3	20.6	0.0421	0.708568±0.000014	62.8
314/223	WR	Gabbronorite	1080	10.50	0.7	2.7	0.1507	0.512147±0.000011	-3.2±0.3	5.5	173.0	0.092	0.708997±0.000012	57.9
314/226c	WR	Gabbronorite	1080	10.70	0.8	3.5	0.1384	0.512011±0.000010	-4.2±0.2	5.5	122.0	0.1305	0.709676±0.000016	59.1
314/155	WR	Websterite	1080	20.60	1.0	2.9	0.1986	0.512432±0.000009	-4.3±0.2	1.1	46.0	0.0692	0.709843±0.000035	75.0
314/156	WR	Websterite	1080	21.80	1.4	4.8	0.1719	0.512267±0.000009	-3.8±0.2	4.4	28.6	0.4454	0.715103±0.000013	67.1
	Plag				-	-	-	-	-	51.4	174.9	0.8508	0.714103±0.000015	-36.2
	Opx				0.5	2.0	0.1667	0.512293±0.000031	-2.6±0.6	1.6	7.9	0.5865	0.716225±0.000015	52.0
	Cpx				2.6	9.2	0.1724	0.512302±0.000031	-3.2±0.6	6.2	34.6	0.5188	0.714091±0.000044	36.6
314/157	WR	Orthopyroxenite	1080	20.40	1.3	4.7	0.1698	0.512239±0.000009	-4.1±0.2	3.7	51.0	0.2100	0.711231±0.000011	63.8
314/451a		Granulite	1550?		12.2	64.4	0.1148	0.511804±0.000008	-5.0	37.8	152.6	0.718	0.726270±0.000012	165.9
314/474		Granulite	1550?		8.3	58.7	0.0858	0.511537±0.000009	-6.2	275.7	159.2	5.0528	0.794005±0.000013	176.5
314/756		Granulite	1550?		1.5	4.9	0.1819	0.512348±0.000011	-3.6	4.1	208.4	0.0569	0.706682±0.000014	32.7

Table 5.5 contd.

		Lithology	Est. Age (Ma)	MgO (%)	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$[a] (±2σ)	ε_{Nd}(1.08 Ga)[b]	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$[c]	ε_{Sr}(1.08 Ga)[b]
Ewarara Intrusion														
300/121	WR	Websterite	1080	20.10	0.8	2.5	0.1986	0.512488±0.000011	-3.2±0.3	1.5	40.1	0.1082	0.707166±0.000016	28.3
	Opx				0.2	0.5	0.2202	0.512647±0.000011	-3.1±0.3	.2	7.3	0.0793	0.708005±0.000012	46.6
	Cpx				-	-	-	-	-	.9	39.0	0.0668	0.707463±0.000020	41.7
300/123	WR	Pyroxenite	1080	28.20	0.2	0.8	0.1796	0.512380±0.000022	-2.7±0.5	.6	15.4	0.1127	0.707719±0.000056	35.2
300/124	WR	Pyroxenite	1080	27.60	0.3	1.0	0.1839	0.512405±0.000018	-2.8±0.4	1.0	27.2	0.1064	0.707005±0.000021	26.5
300/125	WR	Pyroxenite	1080	26.80	0.3	0.9	0.1841	0.512508±0.000111	-0.8±2.2	.7	20.2	0.1003	0.707882±0.000011	40.3
	Plag				0.1	0.9	0.0974	0.511929±0.000067	-0.1±1.3	1.0	207.7	0.0139	0.705653±0.000012	27.5
	Opx									.5	7.6	0.1904	0.709588±0.000015	44.7
	Cpx				1.2	4.3	0.1722	0.512494±0.000150	-0.2±2.5	1.1	32.7	0.0973	0.706589±0.000013	22.5
300/126	WR	Pyroxenite	1080	25.10	0.5	1.5	0.1853	0.512413±0.000010	-2.8±0.2	1.1	20.4	0.1560	0.709337±0.000017	48.7
300/127	WR	Ol. Orthopyroxenite	1080	31.90	0.5	1.9	0.1547	0.512199±0.000012	-2.8±0.3	2.1	28.4	0.2140	0.708809±0.000015	27.8
	Plag				0.7	4.9	0.0891	0.511795±0.000020	-1.6±0.4	3.7	1005.0	0.0107	0.706454±0.000016	39.6
	Opx				0.5	1.9	0.1545	0.512167±0.000029	-3.4±0.6	1.2	9.1	0.3817	0.711626±0.000016	31.7
	Cpx				2.4	9.4	0.1539	0.512233±0.000014	-2.0±0.3	1.5	30.0	0.1447	0.708166±0.000015	34.5
300/128	WR	Ol. Orthopyroxenite	1080	31.60	0.5	1.7	0.1605	0.512253±0.000020	-2.5±0.5	1.7	23.0	0.2139	0.708986±0.000014	31.0
300/113	WR	Ol. Orthopyroxenite	1080	24.60	1.5	6.4	0.1456	0.512132±0.000009	-2.8±0.2	7.9	65.6	0.3486	0.711424±0.000049	36.1
	Plag				0.5	3.8	0.0802	0.511652±0.000033	-3.1±0.7	5.1	545.4	0.0271	0.707086±0.000012	45.0
	Opx				0.8	3.3	0.1472	0.512151±0.000016	-2.7±0.3	2.7	13.9	0.5627	0.719669±0.000014	106.2
300/701		Granulite	1550?		2.1	14.4	0.0901	0.511560±0.000008	-6.3	16.9	288.7	0.1694	0.710957±0.000011	68.8
301/174b		Granulite	1550?		10.5	48.9	0.1300	0.511947±0.000009	-4.3	20.4	398.1	0.1483	0.709846±0.000011	57.6
300/69		Granulite	1550?		2.4	12.6	0.1171	0.511865±0.000009	-4.1	71.6	98.8	2.1105	0.774788±0.000012	549.7
Gosse Intrusion														
313/412	WR	Websterite	1080	13.70	0.5	1.3	0.2239	0.512637±0.000017	-3.8±0.4	.3	94.0	0.0092	0.706884±0.000014	46.1
313/100	WR	Orthopyroxenite	1080	29.70	0.1	0.3	0.1972	0.512490±0.000037	-3.0±0.7	.4	3.5	0.3308	0.712907±0.000028	61.0
313/101	WR	Orthopyroxenite	1080	29.50	0.1	0.5	0.1824	0.512347±0.000026	-3.7±0.5	.4	8.0	0.1362	0.711608±0.000012	85.3
	Opx				0.1	0.3	0.1820	0.512995±0.000024	-3.6±0.5	.3	4.5	0.193	0.711417±0.000014	70.1
313/110	WR	Gabbro	1080	17.60	0.6	1.5	0.2347	0.512777±0.000009	-2.6±0.2	.5	102.3	0.0141	0.705771±0.000018	29.2
313/111	WR	Norite	1080	22.80	0.4	1.1	0.1920	0.512438±0.000009	-3.3±0.2	.7	78.1	0.0259	0.705847±0.000013	27.7
	Plag				0.1	0.9	0.0927	0.511805±0.000067	-5.3±1.3	2.0	157.8	0.0367	0.705830±0.000020	25.1
	Opx				0.3	1.0	0.2030	0.512527±0.000027	-3.1±0.5	.8	4.6	0.5034	0.713264±0.000013	28.2
	Cpx				1.9	5.5	0.2095	0.512441±0.000105	-5.6±2.0	1.4	23.2	0.1746	0.707746±0.000014	22.0
313/199	WR	Picrite	1080	34.60	0.3	0.8	0.2287	0.512812±0.000012	-1.1±0.3	.3	57.2	0.0152	0.705483±0.000013	24.9

Table 5.5 contd.

		Lithology	Est. Age (Ma)	MgO (%)	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd^a$ (±2σ)	ε_{Nd}(1.08 Ga)[b]	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr^c$	ε_{Sr}(1.08 Ga)[b]
Gosse Intrusion contd..														
313/200	WR	Orthopyroxenite	1080	27.40	0.2	0.6	0.1968	0.512582±0.000032	-1.1±0.6	.4	24.8	0.0467	0.707186±0.000016	42.1
	Plag				0.1	0.5	0.1080	0.511976±0.000048	-0.7±0.9	.8	237.8	0.0097	0.705743±0.000012	29.7
	Opx				0.1	0.3	0.2273	0.512838±0.000057	-0.3±1.1	.3	8.9	0.0976	0.710550±0.000013	78.8
	Cpx				0.9	2.1	0.2534	0.513029±0.000070	-0.2±1.4	.5	61.5	0.0235	0.706505±0.000013	37.5
313/312A	WR	Orthopyroxenite	1080	27.30	0.2	0.7	0.2072	0.512626±0.000015	-1.7±0.3	.7	23.2	0.0873	0.707360±0.000010	35.7
313/312B	WR	Orthopyroxenite	1080	20.90	0.3	0.8	0.2360	0.512843±0.000022	-1.5±0.5	.5	85.2	0.017	0.705613±0.000013	26.3
313/404		Granulite	>1550?		4.1	22.8	0.1091	0.511254±0.000016	-14.9	260.9	79.4	9.8702	1.098310±0.0000153	3443.8
313/418A		Granulite	>1550?		5.2	28.1	0.1126	0.511438±0.000012	-11.8	10.3	119.5	0.2496	0.716296±0.000015	127.1
313/413		Granulite	1550?		8.1	43.2	0.1132	0.511803±0.000015	-4.8	154.5	195.7	2.2939	0.751163±0.000028	173.6

[a] Isotope error measurements are $2\sigma_m$ 143Nd/144NdCHUR(0)=0.512638, 147Sm/144NdCHUR=0.1967

[b] εNd and εSr are calculated at 1080 Ma and errors are 2σ

[c] Isotope error measurements are $2\sigma_m$ $^{87}Sr/^{86}SrCHUR(0)=0.70482$, $^{87}Rb/^{86}SrCHUR=0.0854$

Table 5.6 - Mixing component compositions

	Potential parental magmas[a]				Possible Contaminants			Average Intrusion Compositions		
Sample	N-MORB	Depleted Tholeiitic Basalts	Avg. Alcurra[a] Dyke	Primitive Picritic Basalt	Avg. Juvenile Crust n=7	Avg. Evolved Crust n=2	Avg. Crust n=9	Avg. Kalka	Avg. Ewarara	Avg. Gosse Pile
Column	1	2	3	4	5	6	7			
SiO_2	50.45	49.51	49.20	46.86	65.04	75.00	67.26	49.37	50.96	51.95
Al_2O_3	15.26	14.11	15.69	13.85	14.47	13.15	14.18	15.77	5.26	5.46
Fe_2O_3	10.43	10.65	10.70	8.83	5.14	1.43	4.31	8.52	9.62	9.71
MnO	0.18	0.19	0.17	0.17	0.12	0.03	0.10	0.15	0.18	0.19
MgO	7.58	7.93	8.32	16.36	2.82	0.47	2.30	12.23	26.99	25.21
CaO	11.30	11.65	10.45	11.66	4.76	1.36	4.01	11.71	5.71	6.07
Na_2O	2.60	1.55	2.50	1.18	3.08	3.66	3.21	1.72	0.48	0.50
K_2O	0.11	0.09	0.45	0.09	3.14	3.43	3.20	0.18	0.09	0.05
TiO_2	1.62	0.76	1.07	0.61	0.56	0.14	0.47	0.29	0.22	0.21
P_2O_5	0.11	0.06	0.13	0.08	0.17	0.14	0.17	0.02	0.02	0.01
Rb	1.26	2.77	6.75	-	67.80	104.50	75.96	-	-	-
Sr	115.20	147.00	300.00	52.00	232.86	94.50	202.11	-	-	-
Th	0.12	0.18	0.20	0.23	21.50	14.00	19.85	-	-	-
Y	28.00	18.13	17.50	-	32.00	11.50	27.44	-	-	-
La	2.50	1.99	7.18	1.70	51.36	35.75	47.89	-	-	-
Nd	7.30	4.76	9.27	3.40	36.79	29.00	35.06	-	-	-
Sm	2.63	1.62	2.48	1.10	6.76	5.00	6.37	-	-	-
Eu	1.02	0.66	0.92	-	2.24	0.74	1.90	-	-	-
Yb	3.05	1.93	1.65	1.20	4.75	1.15	3.95	-	-	-
Th/La	0.05	0.09	0.03	0.14	0.42	0.39	0.41	-	-	-
La/Sm	0.95	1.23	2.90	1.55	7.60	7.15	7.52	-	-	-
La/Yb	0.82	1.03	4.35	1.42	10.81	31.09	12.12	-	-	-
Mg#	59	57	61	90	35	34	34	74	85	84
εNd@1.08 Ga	+7.5	+4.7	+0.7	+0.0	-4.9	-13.4	-9.1	-3.6	-2.6	-2.4
εSr@1.08 Ga	-22.9	-19.7	+44.0	0.0	+175.0	+127.1	+151.0	+51.9	+34.2	+42.0

[a] See relevant text section for references

Table 5.7 - Mixing models

	Simple Mixing Models[a]				AFC Mixing Models (r=0.8)[a]				Intrusions								
	Column 1 +30% avg. crust	Column 2 +30% avg. crust	Column 3 +30% avg. crust	Column 4 +15% avg. crust	Column 1 +20% avg. crust	Column 2 +20% avg. crust	Column 3 +20% avg. crust	Column 4 +8% avg. crust	Kalka Average			Ewarara Average			Gosse Average		
									Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Th/La	0.13	0.16	0.11	0.16	0.10	0.14	0.09	0.15	0.02	0.20	**0.08**	0.06	0.16	**0.09**	0.04	0.34	**0.10**
La/Sm	3.01	3.20	4.37	2.49	2.32	2.55	3.88	2.05	0.95	7.50	**2.92**	1.43	3.51	**2.67**	0.68	4.17	**2.12**
La/Yb	8.18	8.33	10.65	5.01	5.72	5.89	8.55	3.33	0.87	10.00	**3.82**	1.00	4.48	**2.37**	0.5	2.22	**1.26**

[a] Relevant parental magma by column number as per Table 6

Appendix 4

Location, geochemistry and isotopic composition tables of Officer Basin sedimentary rocks

Table 6.1 *Summary of lithologies and depositional environment*

Stage	Tectonic Setting*	Group	Formations	Depositional environment†
4	Ordovician N-S extension	Munda	Blue Hills Sst	Shallow marine
			Indulkana Sh	Highstand systems tract
			Mt Chandler Sst	Shallow marine
3	Extensional	Marla	Trainor Hill Sst	Deltaic to shallow marine
			Apamurra Fm	Shallow marine
			Arcoeillinna Sst	Fluvial to shallow marine
			Observatory Hill Fm	Fluvial to shallow marine
			Relief Sst	Fluvial to shallow marine
2	N-S contraction	Ungoolya	Mena Mdst Mbr	Shallow marine
			Munyarai Fm	Shallow marine
			Tanana Fm	Shallow marine
			Karlaya Fm	Sub-tidal to shelfal
			Dey Dey Mdst	Marine
		Lake Maurice	Murnaroo Fm	Fluvial to shallow marine
			Meramangye Fm	Fluvial to shallow marine
			Tarlina Sst	Fluvial
1	NE-SW crustal extension	Callanna	Alinya Fm	Tidal to sabhka/aeolian
			Pindyin Sst	Tidal setting

*† See section "Geological Setting" for references

Table 6.2 *Sample types (from this study) and localities*

Sample #	Unit	Sample Type	Locality	Absolute Age Constraints*	Estimated Age (Ma)
2012-608	Munda Group - Blue Hills Sst	Sst	Lairu 1		440
2012-609	Munda Group - Indulkana Sh	Sst	Lairu 1	460±15	460
2012-611	Munda Group - Mount Chandler Sst	Sst	Lairu 1		470
2012-612	Munda Group - Mount Chandler Sst	Sst	Lairu 1		470
2012-613	Marla Group - Trainor Hill Sst	Sst	Lairu 1		510
2012-614	Marla Group - Trainor Hill Sst	Sst	Lairu 1		510
2012-615	Marla Group - Trainor Hill Sst	Sst	Lairu 1		510
2012-620	Marla Group - Apamurra Fm	Mdst	Karlaya 1		520
2012-831	Marla Group - Arcoeillinna Sst	Mdst	Karlaya 1		520
2012-902	Marla Group - Observatory Hill Fm	Mdst	Observatory Hill 1		520
2012-616	Marla Group - Observatory Hill Fm	Sh	Marla 3		520
2012-904	Marla Group - Relief Sst	Sst	Observatory Hill 1		530
2012-827	Marla Group - Relief Sst	Sst	Meramangye 1		530
2012-833	Ungoolya Group - Mena Mdst Mbr	Mdst	Karlaya 1		560
2012-260	Ungoolya Group - Tanana Fm	Mdst	Karlaya 1		570
2012-261	Ungoolya Group - Tanana Fm	Mdst	Karlaya 1		570
2012-262	Ungoolya Group - Tanana Fm	Sst	Karlaya 1		570
2012-266	Ungoolya Group - Dey Dey Mdst	Mdst	Karlaya 1		588
2012-910	Ungoolya Group - Dey Dey Mdst	Mdst	Murnaroo 1	588±35	588
2012-990	Lake Maurice Group - Murnaroo Fm	Sh	Munta 1		595
2012-991	Lake Maurice Group - Murnaroo Fm	Sst	Munta 1		595
2012-992	Lake Maurice Group - Murnaroo Fm	Mdst	Munta 1		595
2012-014	Lake Maurice Group - Murnaroo Fm	Sst	Lake Maurice East 1		595
2012-015	Lake Maurice Group - Murnaroo Fm	Mdst	Lake Maurice East 1		595
2012-018	Lake Maurice Group - Murnaroo Fm	Sst	Lake Maurice East 1		595
2012-997	Lake Maurice Group - Meramangye Fm	Sltst	Giles 1		595
2012-001	Lake Maurice Group - Tarlina Sst	Sst	Giles 1		600
2012-337	Chambers Bluff Tillite	Rhythmite	Nicholson 2		720
2012-341	Chambers Bluff Tillite	Rhythmite	Nicholson 2		720
2012-005	Callanna Group - Alinya Fm	Dol. Slst	Giles 1	802±10	800
2012-008	Callanna Group - Pindyin Sst	Sst	Giles 1		800
2012-358	Callanna Group - Cadlareena Volcanics	Redbed	Manya 5	827±6	827
2012-360	Callanna Group - Coominaree Dolm	Dol. Slst	Manya 5		830

See text section on "Stratigraphic Correlations"

Table 6.3 *Detrital modes from sandstones and mudstone of the Eastern Officer Basin*

	Qm	Qp	K	P	L	Total	Qm/F	K/P
2012-343 - Relief Sst	80.8	1.0	3.0	15.2	0	100.0	4.4	0.2
2012-344 - Tanana Fmtn	90.9	3.0	3.0	3.0	0	100.0	15.0	1.0
2012-345 - Tarlina Sst	95.2	0.0	1.2	3.6	0	100.0	20.0	0.3
2012-350 - Pindyin Sst	98.8	1.2	0.0	0.0	0	100.0		
2012-351 - Trainor Hill Sst	93.0	3.5	1.2	2.3	0	100.0	26.7	0.5
2012-354 - Arcoeillinna Sst	89.7	2.6	1.3	6.4	0	100.0	11.7	0.2

(Qm = monocrystalline quartz; Qp = polycrystalline quartz; K = K-feldspar; P = plagioclase; F = K+P;
L = Ls, sedimentary lithic fragments)

Table 6.4 *Major and trace element data for Officer Basin samples (from this study)*

	Officer Basin										
Stratigraphic Unit and Lithology	Pindyin Sst (Sst)	Alinya Fm (Dol.Slst.)	Tarlina Sst (Sst)	Meramangye Fm (Slst)	Murnaroo Fm (Sst)	Murnaroo Fm (Mdst)	Murnaroo Fm (Sst)	Murnaroo Fm (Sh)	Murnaroo Fm (Sst)	Murnaroo Fm (Mdst)	Dey Dey Mdst (Mdst)
Sample no.	2012-008	2012-005	2012-001	2012-997	2012-014	2012-015	2012-018	2012-990	2012-991	2012-992	2012-266
SiO_2	98.70	19.46	80.13	66.56	95.96	66.00	89.78	57.25	78.92	67.50	62.68
TiO_2	0.04	0.20	0.47	1.02	0.03	0.78	0.14	1.51	1.30	3.08	0.84
Al_2O_3	0.58	3.49	7.27	11.82	1.58	9.38	3.53	16.34	6.94	10.57	13.78
Fe_2O_3 (T)	0.07	0.96	2.51	5.87	0.28	4.82	1.30	9.17	5.28	8.78	7.76
MnO	0.00	0.39	0.06	0.12	0.00	0.11	0.00	0.09	0.02	0.03	0.10
MgO	0.02	16.17	1.14	2.64	0.06	4.04	0.26	3.56	0.84	1.60	3.48
CaO	0.02	22.36	1.18	1.87	0.03	3.10	0.03	0.78	0.36	0.46	1.18
Na_2O	0.00	0.20	1.56	2.05	0.11	1.31	0.25	1.03	1.33	1.73	1.77
K_2O	0.16	1.39	2.36	2.82	1.18	3.32	1.87	4.94	2.87	3.58	3.68
P_2O_5	0.01	0.07	0.07	0.18	0.02	0.12	0.03	0.15	0.10	0.20	0.12
SO_3	0.02	0.21	0.08	0.04	0.00	0.05	0.01	0.01	0.01	0.01	0.00
LOI	0.24	35.04	2.45	4.42	0.29	6.34	0.92	4.62	1.73	2.17	4.16
Total (%)	99.86	99.94	99.28	99.41	99.54	99.37	98.11	99.45	99.7	99.70	99.56
CIA	73	8	50	55	51	45	59	66	54	58	60
Cr (ppm)	7.00	22.00	34.00	67.00	10.00	61.00	10.0	90.00	43.00	61.0	83.0
Ni	1.00	10.00	17.00	29.00	4.00	28.00	3.0	45.00	20.00	35.0	39.0
Sc	0.80	4.10	6.70	12.20	0.40	11.80	2.1	21.10	7.20	15.6	15.8
V	4.00	40.00	58.00	107.00	10.00	117.00	16.0	161.00	160.00	278.0	111.0
Pb	1.50	3.90	9.90	15.60	6.00	19.60	5.1	19.80	18.00	22.4	11.2
Zn	0.00	29.00	16.00	42.00	2.00	45.00	6.0	134.00	29.00	53.0	85.0
Rb	8.10	57.50	88.10	121.00	39.20	103.40	53.4	207.80	104.20	133.7	172.2
Sr	37.30	74.60	74.20	80.40	18.10	59.70	45.1	85.70	104.20	90.2	64.1
Ba	652.00	287.00	496.00	441.00	181.00	312.00	1947.0	356.00	404.00	363.0	435.0
Ga	2.00	5.70	9.20	12.70	2.80	12.70	4.4	23.10	8.30	16.1	18.1
Nb	0.80	2.30	5.10	16.20	1.30	9.20	2.6	21.50	9.60	26.0	15.9
Zr	70.00	61.20	163.90	264.50	21.90	227.30	116.8	324.20	157.90	423.5	194.3
Y	3.00	20.80	13.90	36.50	3.60	24.20	6.7	43.20	16.10	32.8	32.0
Co	189.00	16.00	34.00	21.00	110.00	29.00	119.0	28.00	40.00	33.0	26.0
Th	2.90	7.50	4.20	16.10	1.70	9.90	3.2	24.50	6.90	14.2	21.1
U	-0.20	1.30	1.50	3.60	0.70	2.30	0.7	8.70	0.60	2.6	1.8
La	14.00	15.00	13.00	33.00	3.00	23.00	7.0	51.00	18.00	36.0	39.0
Ce	27.00	41.00	30.00	69.00	4.00	47.00	18.0	104.00	41.00	79.0	81.0
Nd	10.00	14.00	11.00	28.00	4.00	20.00	8.0	41.00	18.00	30.0	31.0

Abbreviations: Sst=sandstone, Dol.Slst=dolomitic siltstone, Slst=siltstone, Mdst=mudstone, Sh=shale

Table 6.4 contd.

Stratigraphic Unit and Lithology	Dey Dey Mdst (Mdst)	Tanana Fm (Mdst)	Tanana Fm (Mdst)	Tanana Fm (Mdst)	Mena Mdst Mbr (Mdst)	Relief Sst (Sst)	Relief Sst (Sst)	Observatory Hill Fm (Sh)	Observatory Hill Fm (Sh)	Arcoeillinna Sst (Mdst)
Sample no.	2012-910	2012-260	2012-261	2012-262	2012-833	2012-827	2012-904	2012-616	2012-902	2012-831
SiO_2	59.62	62.82	62.33	60.38	57.39	96.11	82.65	54.77	64.50	55.10
TiO_2	0.85	0.66	0.70	0.75	0.66	0.04	0.10	0.62	0.75	0.91
Al_2O_3	15.23	10.70	12.65	13.08	12.76	1.65	5.86	16.55	12.92	17.13
Fe_2O_3 (T)	8.45	5.40	5.98	6.78	5.52	0.24	0.31	8.20	5.31	9.68
MnO	0.11	0.08	0.09	0.10	0.12	0.00	0.01	0.05	0.07	0.11
MgO	3.34	3.65	4.08	4.32	4.06	0.07	1.04	6.71	2.75	5.35
CaO	0.88	4.32	2.45	2.41	5.93	0.05	1.74	1.01	2.76	0.43
Na_2O	1.50	2.70	2.39	1.62	1.51	0.10	0.36	0.93	2.86	1.74
K_2O	5.09	2.79	3.15	3.68	3.53	1.24	4.52	4.81	3.13	4.63
P_2O_5	0.13	0.23	0.19	0.14	0.14	0.02	0.04	0.13	0.20	0.16
SO_3	0.01	0.03	0.04	0.05	0.15	0.02	0.31	0.01	0.08	0.01
LOI	4.10	6.22	5.23	5.98	8.34	0.33	2.56	5.50	4.06	4.43
Total (%)	99.31	99.60	99.27	99.28	100.11	99.87	99.5	99.28	99.38	99.68
CIA	61	41	52	54	43	51	40	66	50	66
Cr (ppm)	89.00	65.0	90.0	80.0	84.00	6.00	15.00	114.0	98.0	130.00
Ni	50.00	23.0	36.0	33.0	35.00	2.00	3.00	53.0	32.0	57.00
Sc	17.90	12.1	13.0	14.2	14.10	1.20	1.80	15.9	12.3	21.60
V	128.00	77.0	90.0	100.0	95.00	5.00	7.00	138.0	90.0	106.00
Pb	30.10	16.5	16.9	8.0	8.60	5.30	18.50	16.9	26.0	32.20
Zn	86.00	54.0	71.0	85.0	68.00	5.00	8.00	118.0	74.0	115.00
Rb	193.80	105.4	134.1	159.2	142.50	33.40	122.20	189.4	144.2	206.30
Sr	79.90	165.9	194.1	215.3	105.40	25.10	92.10	72.9	121.4	65.80
Ba	473.00	645.0	824.0	626.0	437.00	234.00	941.00	447.0	701.0	487.00
Ga	22.00	13.0	15.3	18.8	15.90	2.80	6.30	24.0	17.8	28.30
Nb	15.20	14.6	16.8	15.6	13.20	0.50	2.50	13.2	16.6	18.60
Zr	171.80	306.1	202.4	186.5	170.30	51.70	114.30	116.9	346.5	193.40
Y	32.30	36.5	33.6	31.6	30.00	5.90	6.30	21.7	37.4	34.30
Co	30.00	23.0	25.0	20.0	22.00	80.00	58.00	24.0	24.0	34.00
Th	22.00	17.7	18.9	18.2	16.30	1.60	3.40	17.9	22.7	23.80
U	3.10	3.8	2.8	2.3	3.70	0.30	-0.50	5.2	5.4	6.80
La	46.00	44.0	41.0	35.0	36.00	8.00	8.00	45.0	50.0	64.00
Ce	92.00	91.0	91.0	73.0	74.00	17.00	14.00	96.0	98.0	123.00
Nd	35.00	42.0	36.0	31.0	31.00	7.00	6.00	38.0	42.0	41.00

Table 6.4 contd.

Stratigraphic Unit and Lithology	Apamurra Fm (Mdst)	Trainor Hill Sst (Sst)	Trainor Hill Sst (Sst)	Trainor Hill Sst (Sst)	Mt Chandler Sst (Sst)	Mt Chandler Sst (Sst)	Indulkana Shale (Sst)	Blue Hills Sst (Sst)
Sample no.	2012-620	2012-613	2012-614	2012-615	2012-611	2012-612	2012-609	2012-608
SiO_2	56.73	88.71	85.03	79.83	97.80	99.29	91.24	99.89
TiO_2	0.79	0.16	0.25	0.37	0.06	0.03	0.14	0.02
Al_2O_3	14.01	4.10	5.19	5.13	1.02	0.24	2.97	0.15
Fe_2O_3 (T)	6.33	1.87	3.13	6.14	0.47	0.22	1.63	0.11
MnO	0.14	0.16	0.08	0.07	0.00	0.00	0.01	0.00
MgO	5.13	0.25	0.30	0.51	0.04	0.01	0.28	0.01
CaO	3.22	0.07	0.12	0.17	0.02	0.01	0.05	0.02
Na_2O	0.98	0.13	0.14	0.17	0.02	-0.01	0.15	-0.01
K_2O	5.02	2.80	3.84	3.60	0.07	0.02	0.58	0.01
P_2O_5	0.17	0.05	0.08	0.10	0.01	0.01	0.03	0.01
SO_3	0.03	0.00	0.00	0.02	0.00	0.00	0.01	0.00
LOI	7.40	1.37	1.71	3.27	0.74	0.32	1.61	0.14
Total (%)	99.94	99.68	99.88	99.40	100.26	100.15	98.72	100.35
CIA	52	55	53	53	88	91	75	83
Cr (ppm)	103.0	17.0	19.0	23.0	9.0	6.0	33.0	6.0
Ni	37.0	3.0	5.0	6.0	3.0	1.0	6.0	1.0
Sc	15.6	2.5	3.5	4.1	1.1	0.0	4.8	0.6
V	94.0	18.0	21.0	35.0	6.0	3.0	24.0	3.0
Pb	21.6	12.0	22.0	20.6	1.9	1.4	8.9	1.3
Zn	86.0	10.0	7.0	14.0	18.0	3.0	37.0	2.0
Rb	178.1	68.5	121.7	113.0	3.1	1.0	24.9	1.1
Sr	55.6	59.0	47.7	49.5	15.3	7.8	49.2	3.5
Ba	474.0	555.0	544.0	510.0	21.0	11.0	146.0	13.0
Ga	20.0	4.5	6.4	6.2	2.2	1.6	5.9	2.0
Nb	16.9	3.4	4.6	6.2	0.7	0.8	2.6	1.0
Zr	217.8	128.3	180.9	288.1	147.2	59.3	98.9	43.2
Y	25.0	12.2	20.6	23.9	4.5	2.5	13.3	4.4
Co	32.0	57.0	57.0	45.0	74.0	100.0	36.0	60.0
Th	21.5	7.8	12.0	24.6	2.8	1.7	5.4	1.7
U	4.7	0.8	2.0	3.1	0.4	0.7	1.9	0.6
La	43.0	21.0	22.0	31.0	4.0	4.0	14.0	3.0
Ce	75.0	49.0	47.0	73.0	12.0	6.0	26.0	6.0
Nd	34.0	15.0	20.0	29.0	4.0	2.0	12.0	2.0

Table 6.5 *Sm-Nd isotope data for Officer Basin samples (from this study)*

Rock	Est. Age (Ma)	Sample no.	Nd (ppm)	Sm (ppm)	Sm/ Nd	Nd/ Nd	2σ	ε (0)	ε (t)	Sample type
Indulkana Shale	460	2012-609	11.5	2.4	0.1238	0.511694	15	-18.4	-14.2	sandstone
Mt Chandler Sandstone	470	2012-612	2.8	0.5	0.1159	0.511669	11	-18.9	-14.1	sandstone
Trainor Hill Sandstone	510	2012-614	22.9	4.5	0.1193	0.511705	10	-18.2	-13.2	sandstone
Apamurra Formation	520	2012-620	38.5	7.0	0.1103	0.511738	10	-17.6	-11.8	mudstone
Arcoeillinna sandstone	520	2012-831	41.4	7.6	0.1116	0.511746	9	-17.4	-11.8	mudstone
Observatory Hill Fmtn	520	2012-902	41.7	7.7	0.1121	0.511660	10	-19.1	-13.5	mudstone
Observatory Hill Fmtn	520	2012-616	35.9	6.0	0.1012	0.511670	11	-18.9	-12.6	shale
Relief sandstone	530	2012-827	7.8	1.5	0.1138	0.511840	9	-15.6	-10.0	sandstone
Relief sandstone	530	2012-904	6.7	1.4	0.1232	0.511804	8	-16.3	-11.3	sandstone
Mena Mudstone	560	2012-833	31.8	6.1	0.1152	0.511804	9	-16.3	-10.5	mudstone
Tanana Formation	570	2012-261	38.4	7.2	0.1133	0.511717	10	-18.0	-11.9	mudstone
Dey Dey Mudstone	588	2012-266	33.7	6.4	0.1141	0.511759	9	-17.2	-11.0	mudstone
Dey Dey Mudstone	588	2012-910	36.1	6.9	0.1148	0.511777	9	-16.8	-10.7	mudstone
Murnaroo Formation	595	2012-990	40.2	8.0	0.1202	0.511896	9	-14.5	-8.7	shale
Murnaroo Formation	595	2012-015	20.3	4.1	0.1216	0.511992	7	-12.6	-6.9	mudstone
Meramangye Fmtn	595	2012-997	30.0	6.3	0.1274	0.511883	8	-14.7	-9.5	siltstone
Tarlina Sandstone	600	2012-001	12.1	2.5	0.1226	0.511810	12	-16.2	-10.5	sandstone
Chambers Bluff Tillite	720	2012-341	18.2	3.6	0.1206	0.511902	8	-14.4	-7.6	rhythmite
Chambers Bluff Tillite	720	2012-337	26.7	5.5	0.1238	0.511897	10	-14.5	-8.0	rhythmite
Alinya Formation	800	2012-005	14.0	1.3	0.1008	0.511591	11	-20.4	-10.6	dolomitic siltstone
Alinya Formation	800	2012-004	34.0	6.6	0.1171	0.511722	10	-17.9	-9.8	mudstone
Pindyin Sandstone	800	2012-008	9.2	1.2	0.0772	0.511385	10	-24.4	-12.3	sandstone
Pindyin Sandstone	800	2012-009	11.1	2.0	0.1080	0.511430	10	-23.6	-14.5	sandstone
Cadlareena Volcanics	827	2012-358	17.0	3.2	0.1153	0.511720	8	-17.9	-9.3	redbed
Coominaree Dolomite	830	2012-360	4.3	1.1	0.1276	0.511806	9	-16.2	-8.9	dolomitic siltstone

* Isotope error measurements are 2 S.E. 143Nd/144NdCHUR(0)=0.512638, 147Sm/144NdCHUR=0.1967

Appendix 5

Geochemistry, isotopic composition, CL zircon pictures, and age data of granitic gneiss samples from Mallabie 1

Table 1. - Chemical data for Mallabie 1 granitic gneiss

Sample	658669	658670	658671	658672	658673	Average	Average	Average
Drillhole	Mallabie 1	Mallabie 1	Mallabie 1	Mallabie 1	Mallabie 1	A-type	I-type	S-type
Depth (m)	1404.50-1404.82	1405.43-1405.74	1493.52-1493.83	1494.43-1494.74	1495.35-1495.65			
Lithology	Intensely foliated granitic gneiss	Intensely foliated granitic gneiss	Foliated granitic gneiss	Foliated granitic gneiss	Foliated granitic gneiss			
SiO2	63.50	64.33	58.90	59.10	61.70	73.81	67.98	69.08
Al2O3	14.60	14.95	15.80	16.10	15.20	12.40	14.49	14.30
Fe2O3	6.33	5.03	6.90	6.24	5.49	2.82	2.54	3.96
MnO	0.16	0.14	0.19	0.19	0.18	0.06	0.08	0.06
MgO	1.80	1.62	1.57	1.59	1.36	0.20	1.75	1.82
CaO	3.35	3.04	5.01	4.07	3.18	0.75	3.78	2.49
Na2O	4.16	3.64	4.38	4.68	4.47	4.07	2.95	2.20
K2O	2.20	4.04	3.11	3.05	3.40	4.65	3.05	3.69
TiO2	0.96	0.92	1.31	1.32	1.04	0.26	0.45	0.55
P2O5	0.24	0.27	0.49	0.51	0.41	0.04	0.11	0.13
LOI	1.69	1.50	1.91	1.63	1.65	-	-	-
Total %	98.99	99.45	99.57	98.48	98.08	-	-	-
Ga	38.5	56.0	76.0	76.0	76.0	21.0	16.0	17.0
Cr	4.0	4.5	9.0	5.0	5.0	3.0	27.0	46.0
Ni	8.0	5.0	4.0	3.0	3.0	2.0	9.0	17.0
Sc	18.0	16.5	18.0	18.0	16.0	14.0	15.0	14.0
V	100.0	62.8	64.0	64.0	52.0	10.0	74.0	72.0
Y	38.5	51.5	41.0	49.0	40.0	76.0	27.0	32.0
Rb	66.0	72.1	48.0	50.0	64.0	199.0	132.0	180.0
Ba	850.0	1745.0	2700.0	2850.0	2700.0	605.0	520.0	480.0
Th	7.5	7.9	5.5	6.5	7.0	105.0	16.0	19.0
U	2.7	3.0	1.6	1.6	1.8	23.0	3.0	3.0
Nb	14.0	23.4	24.0	30.0	22.0	22.0	9.0	11.0
Pb	23.5	26.0	25.5	31.5	24.5	-	-	-
Sr	390.0	355.0	490.0	550.0	470.0	105.0	253.0	139.0
Zr	280.0	330.0	750.0	750.0	600.0	342.0	143.0	170.0
La	32.0	44.1	50.0	58.0	56.0	55.0	29.0	31.0
Ce	64.0	92.3	105.0	125.0	110.0	134.0	63.0	69.0
Pr	9.0	12.5	14.0	17.0	14.5	-	-	-
Nd	39.5	49.6	60.0	70.0	60.0	56.0	23.0	25.0
Sm	8.5	10.4	12.0	14.0	11.0	-	-	-
Eu	2.8	3.2	4.8	5.5	4.6	-	-	-
Gd	8.0	9.5	10.0	12.5	9.5	-	-	-
Tb	1.2	1.5	1.4	1.7	1.3	105.0	-	-
Dy	7.0	8.8	7.5	9.0	7.0	-	-	-
Ho	1.4	1.8	1.5	1.8	1.4	-	-	-
Er	4.1	5.4	4.2	4.8	3.9	-	-	-
Tm	0.6	0.8	0.6	0.7	0.5	-	-	-
Yb	3.6	4.6	3.2	3.9	3.1	342.0	-	-
Lu	0.6	0.7	0.5	0.6	0.5	22.0	23.0	25.0
ASI	0.95	0.94	0.80	0.88	0.90	0.95	0.96	1.18
(La/Yb)N	6.01	6.58	10.56	10.05	12.21	-	-	-
(La/Sm)N	2.37	2.67	2.62	2.61	3.20	-	-	-
(Gd/Yb)N	1.80	1.68	2.53	2.60	2.48	-	-	-
(Eu/Eu*)N	1.04	0.99	1.34	1.27	1.38	-	-	-

Table 2. - U-Pb LA-ICPMS age data for Mallabie 1 granitic gneiss

LA-ICPMS Spot name	206Pb/ 238U	±206Pb/ 238U	207Pb/ 235U	±207Pb/ 235U	207Pb/ 206Pb	±207Pb/ 206Pb	Apparent Ages (Ma) 206/ 238	±206/ 238	207/ 235	±207/ 235	207/ 206	±207/ 206	Conc. (%)
Sample 658673													
1	0.25273	0.0026	3.26943	0.0370	0.09382	0.00107	1453	14	1474	9	1505	21	96
2	0.25475	0.0028	3.29005	0.0380	0.09399	0.00101	1460	14	1479	9	1508	20	97
3	0.25504	0.0027	3.25472	0.0372	0.09256	0.00104	1464	14	1470	9	1479	21	99
4	0.24869	0.0027	3.21970	0.0376	0.09390	0.00107	1432	14	1462	9	1506	21	95
5	0.26209	0.0030	3.38001	0.0392	0.09398	0.00101	1499	15	1503	9	1508	20	99
6	0.25571	0.0030	3.30605	0.0405	0.09377	0.00103	1468	15	1483	10	1504	21	98
7	0.25540	0.0029	3.32290	0.0402	0.09392	0.00102	1464	15	1481	9	1507	20	97
8	0.26185	0.0029	3.39283	0.0392	0.09407	0.00101	1491	15	1499	9	1510	20	99
9	0.25845	0.0029	3.33891	0.0392	0.09371	0.00103	1482	15	1490	9	1502	21	99
10	0.25720	0.0028	3.31063	0.0378	0.09437	0.00108	1466	15	1486	9	1516	21	97
11	0.26201	0.0029	3.34648	0.0390	0.09355	0.00099	1501	15	1500	9	1499	20	100
12	0.25325	0.0028	3.27768	0.0390	0.09388	0.00106	1455	14	1476	9	1506	21	97
13	0.25975	0.0032	3.35340	0.0454	0.09364	0.00115	1489	16	1494	11	1501	23	99
14	0.25058	0.0029	3.24645	0.0408	0.09398	0.00109	1441	15	1468	10	1508	22	95
15	0.26064	0.0033	3.34396	0.0486	0.09425	0.001	1486	14	1497	9	1513	20	98
16	0.26395	0.0032	3.39963	0.0454	0.09394	0.00097	1508	15	1508	9	1507	19	100
17	0.25417	0.0028	3.27103	0.0362	0.09335	0.00097	1460	14	1474	9	1495	19	98
18	0.25639	0.0028	3.31403	0.0391	0.09401	0.00117	1469	16	1485	11	1508	23	97
19	0.26026	0.0029	3.37520	0.0385	0.09330	0.00109	1498	16	1496	10	1494	22	100
20	0.26007	0.0032	3.36336	0.0472	0.09381	0.00121	1490	16	1496	11	1504	24	99
21	0.26689	0.0029	3.45095	0.0397	0.09363	0.00105	1525	15	1515	9	1501	21	102
22	0.26234	0.0028	3.38429	0.0382	0.09347	0.001	1502	15	1500	9	1498	20	100
23	0.26448	0.0028	3.42874	0.0424	0.09387	0.00117	1513	14	1510	10	1506	23	100
24	0.25453	0.0027	3.30674	0.0378	0.09421	0.00106	1461	14	1482	9	1512	21	96
25	0.26464	0.0028	3.43651	0.0390	0.09417	0.00105	1512	14	1512	9	1512	21	100
26	0.25545	0.0028	3.34287	0.0399	0.09492	0.00112	1465	14	1490	9	1527	22	96
27	0.26312	0.0029	3.40499	0.0398	0.09387	0.00104	1506	15	1506	9	1505	21	100
28	0.25838	0.0029	3.35003	0.0408	0.09404	0.00108	1482	15	1493	10	1509	22	98
29	0.27020	0.0031	3.49164	0.0406	0.09373	0.001	1542	15	1525	9	1503	20	103
30	0.26401	0.0029	3.40318	0.0396	0.09350	0.00103	1510	15	1505	9	1498	21	101
31	0.26729	0.0029	3.41839	0.0419	0.09275	0.00111	1527	15	1509	10	1483	23	103
32	0.25822	0.0029	3.39341	0.0399	0.09531	0.00105	1481	15	1503	9	1534	21	96
33	0.27073	0.0031	3.47168	0.0435	0.09300	0.0011	1545	16	1521	10	1488	22	104

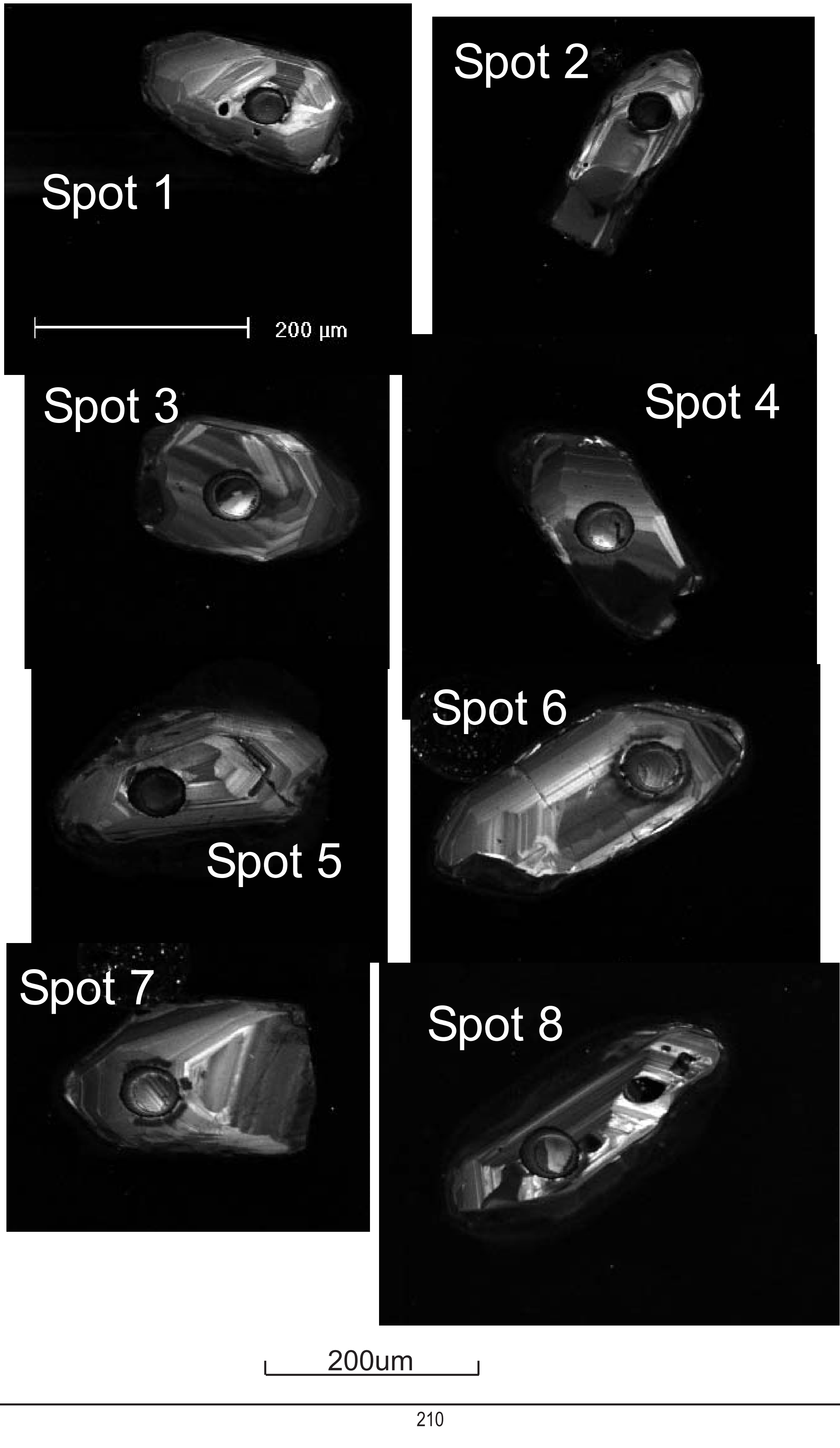
LA-ICPMS	206Pb/238U	±206Pb/238U	207Pb/235U	±207Pb/235U	207Pb/206Pb	±207Pb/206Pb	208Pb/232Th	±208Pb/232Th	Apparent Ages (Ma) 206/238	±206/238	207/235	±207/235	207/206	±207/206	208/232	±208/232
GJ-1																
	0.09797	0.0010	0.81261	0.0088	0.06016	0.0006	0.03252	0.0006	603	6	604	5	609	22	647	11
	0.09752	0.0010	0.80944	0.0086	0.06020	0.0007	0.02937	0.0006	600	6	602	5	611	23	585	12
	0.09744	0.0010	0.80963	0.0087	0.06027	0.0006	0.03031	0.0006	599	6	602	5	613	23	604	12
	0.09710	0.0010	0.80330	0.0089	0.06000	0.0006	0.03201	0.0006	597	6	599	5	604	23	637	11
	0.09858	0.0010	0.82031	0.0090	0.06035	0.0007	0.02983	0.0006	606	6	608	5	616	23	594	12
	0.09730	0.0010	0.80977	0.0090	0.06036	0.0006	0.03055	0.0006	599	6	602	5	617	23	608	12
	0.09802	0.0010	0.81548	0.0091	0.06035	0.0007	0.03097	0.0006	603	6	606	5	616	23	617	12
	0.09739	0.0011	0.80090	0.0090	0.05965	0.0006	0.03085	0.0006	599	6	597	5	591	23	614	11
	0.09784	0.0011	0.80967	0.0092	0.06002	0.0006	0.03021	0.0006	602	6	602	5	604	23	602	11
	0.09744	0.0011	0.80605	0.0091	0.06000	0.0006	0.03152	0.0006	599	6	600	5	604	23	627	11
	0.09792	0.0010	0.81977	0.0091	0.06072	0.0007	0.03025	0.0006	602	6	608	5	629	23	602	12
	0.09659	0.0011	0.80273	0.0092	0.06028	0.0006	0.03030	0.0006	594	6	598	5	614	23	603	11
	0.09748	0.0011	0.80513	0.0093	0.05991	0.0006	0.03122	0.0006	600	6	600	5	600	23	622	11
	0.09800	0.0011	0.81474	0.0094	0.06030	0.0006	0.03115	0.0005	603	6	605	5	615	23	620	11
	0.09965	0.0011	0.82204	0.0093	0.05984	0.0007	0.03134	0.0007	612	6	609	5	598	23	624	13
	0.09793	0.0011	0.81167	0.0092	0.06012	0.0006	0.02989	0.0006	602	6	603	5	608	23	595	12
	0.09712	0.0010	0.80830	0.0091	0.06038	0.0007	0.03075	0.0006	598	6	602	5	617	23	612	12
	0.09728	0.0011	0.80654	0.0091	0.06014	0.0007	0.03091	0.0006	598	6	601	5	609	23	615	12
	0.09727	0.0010	0.80728	0.0088	0.06020	0.0006	0.03041	0.0006	598	6	601	5	611	22	605	11
	0.09774	0.0011	0.80988	0.0090	0.06010	0.0006	0.03179	0.0006	601	6	602	5	607	23	633	11
	0.09885	0.0011	0.82001	0.0092	0.06017	0.0006	0.03203	0.0006	608	6	608	5	610	22	637	11
	0.09604	0.0010	0.79206	0.0088	0.05982	0.0006	0.02949	0.0005	591	6	592	5	597	23	587	11
	0.09718	0.0011	0.80542	0.0090	0.06012	0.0006	0.02926	0.0005	598	6	600	5	608	23	583	10
	0.09656	0.0011	0.80143	0.0090	0.06020	0.0006	0.02929	0.0005	594	6	598	5	611	22	584	10
	0.09795	0.0011	0.81277	0.0092	0.06019	0.0006	0.03118	0.0006	602	6	604	5	610	23	621	11
	0.09783	0.0011	0.81136	0.0092	0.06016	0.0006	0.03152	0.0006	602	6	603	5	609	23	627	11
	0.09650	0.0011	0.79854	0.0092	0.06002	0.0006	0.03036	0.0005	594	6	596	5	604	23	605	11
	0.09780	0.0011	0.80985	0.0093	0.06006	0.0006	0.03005	0.0006	602	6	602	5	606	23	599	11
	0.09871	0.0011	0.81371	0.0094	0.05979	0.0006	0.03065	0.0006	607	6	605	5	596	23	610	11
	0.09785	0.0011	0.81052	0.0093	0.06008	0.0006	0.03050	0.0006	602	6	603	5	606	23	607	12
	0.09741	0.0011	0.81131	0.0093	0.06041	0.0006	0.03058	0.0006	599	6	603	5	618	23	609	11
	0.09757	0.0011	0.80610	0.0093	0.05992	0.0006	0.03188	0.0006	600	6	600	5	601	23	634	12
	0.09866	0.0011	0.82631	0.0096	0.06074	0.0007	0.03205	0.0006	607	6	612	5	630	23	638	12
	0.09794	0.0011	0.80980	0.0094	0.05997	0.0006	0.03086	0.0006	602	6	602	5	603	23	614	12

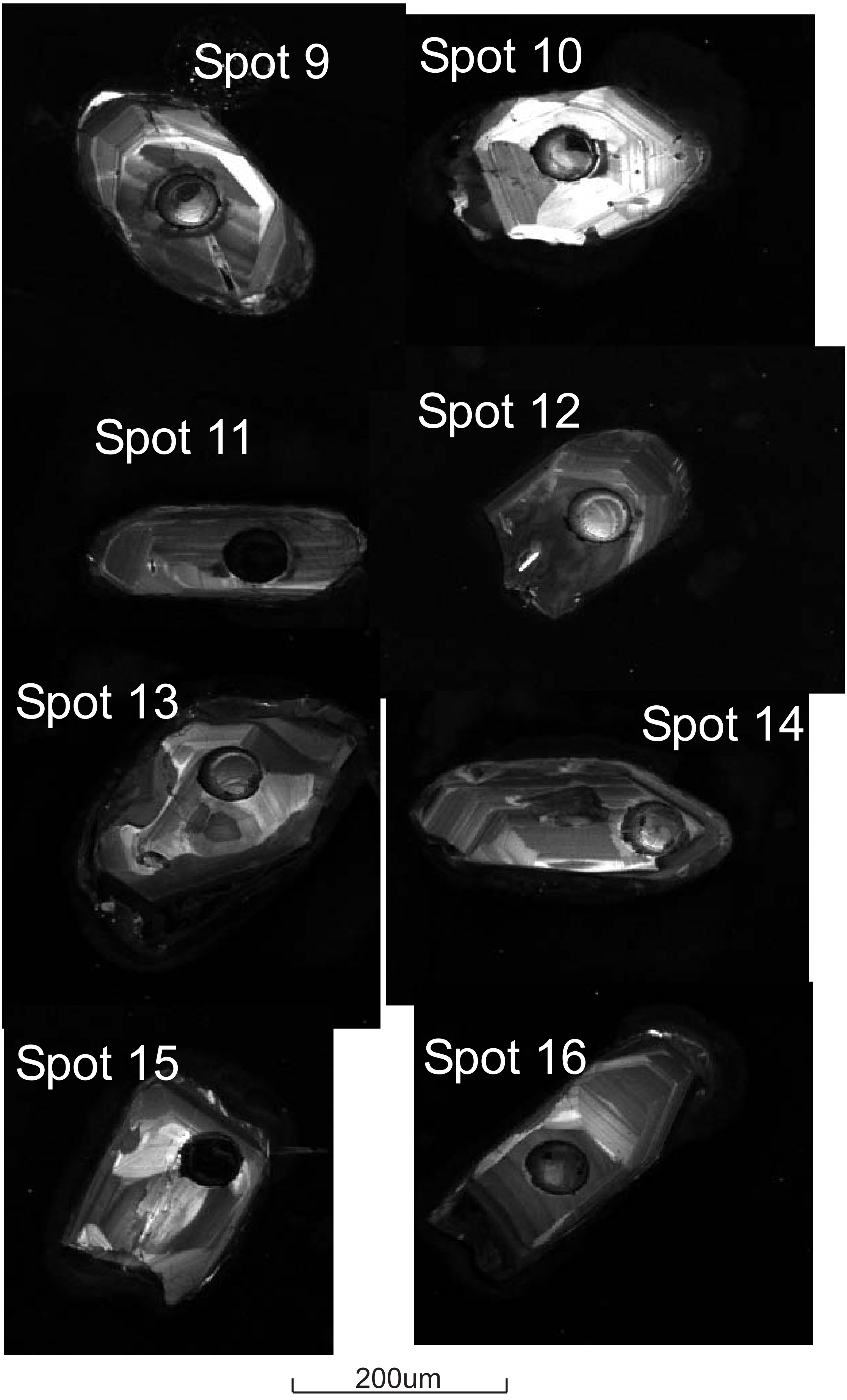
LA-ICPMS									Apparent Ages (Ma)							
	206Pb/ 238U	±206Pb/ 238U	207Pb/ 235U	±207Pb/ 235U	207Pb/ 206Pb	±207Pb/ 206Pb	208Pb/ 232Th	±208Pb/ 232Th	206/ 238	±206/ 238	207/ 235	±207/ 235	207/ 206	±207/ 206	208/ 232	±208/ 232
GJ-1 contd.																
	0.09852	0.0011	0.82018	0.0096	0.06038	0.0006	0.02991	0.0006	606	6	608	5	617	23	596	12
	0.09681	0.0011	0.79905	0.0093	0.05986	0.0006	0.03069	0.0006	596	6	596	5	599	23	611	11
	0.09763	0.0011	0.81102	0.0095	0.06025	0.0006	0.03166	0.0006	601	6	603	5	613	23	630	11

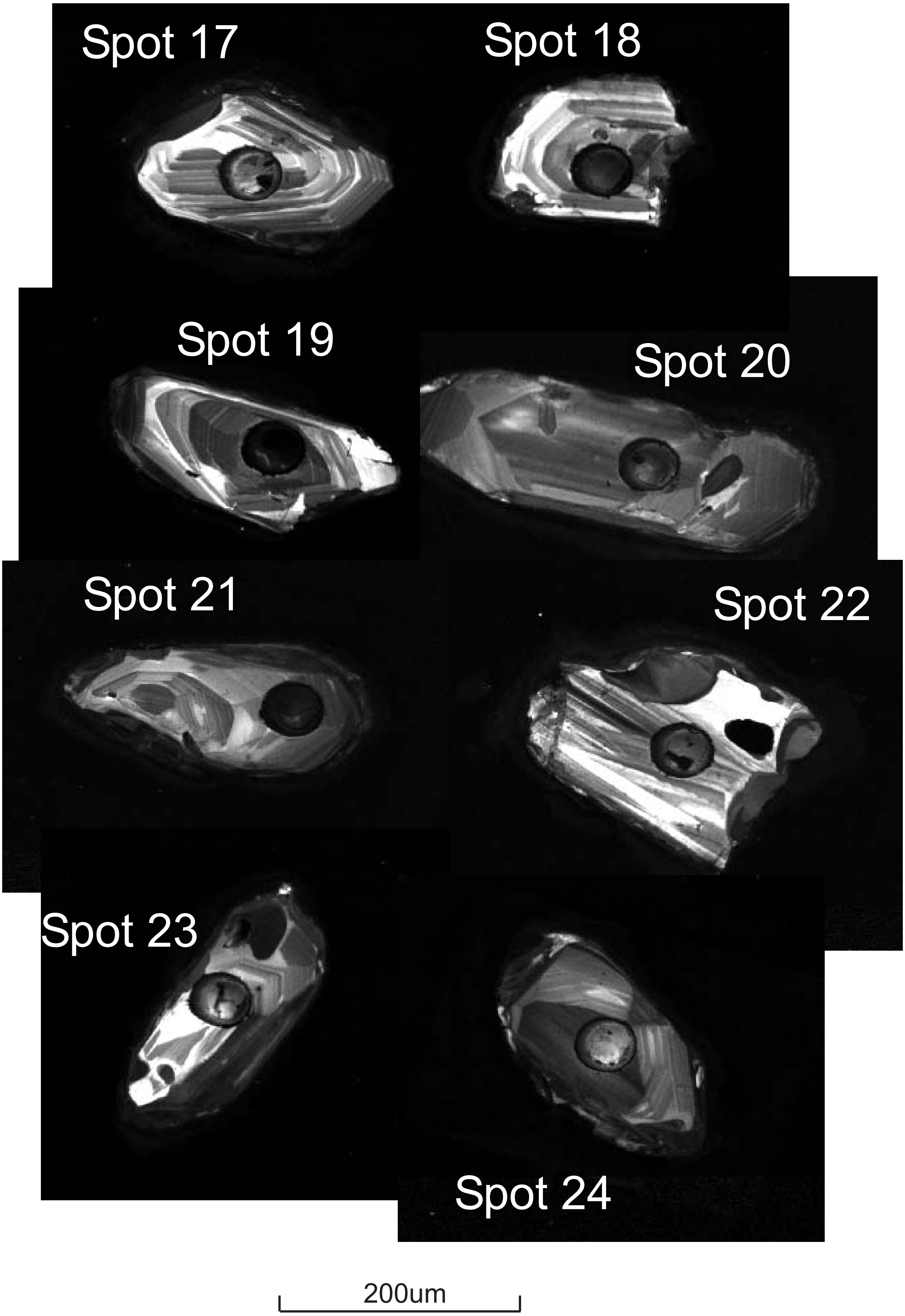
Table 3. - Nd isotopic data for Mallabie 1 granitic gneiss

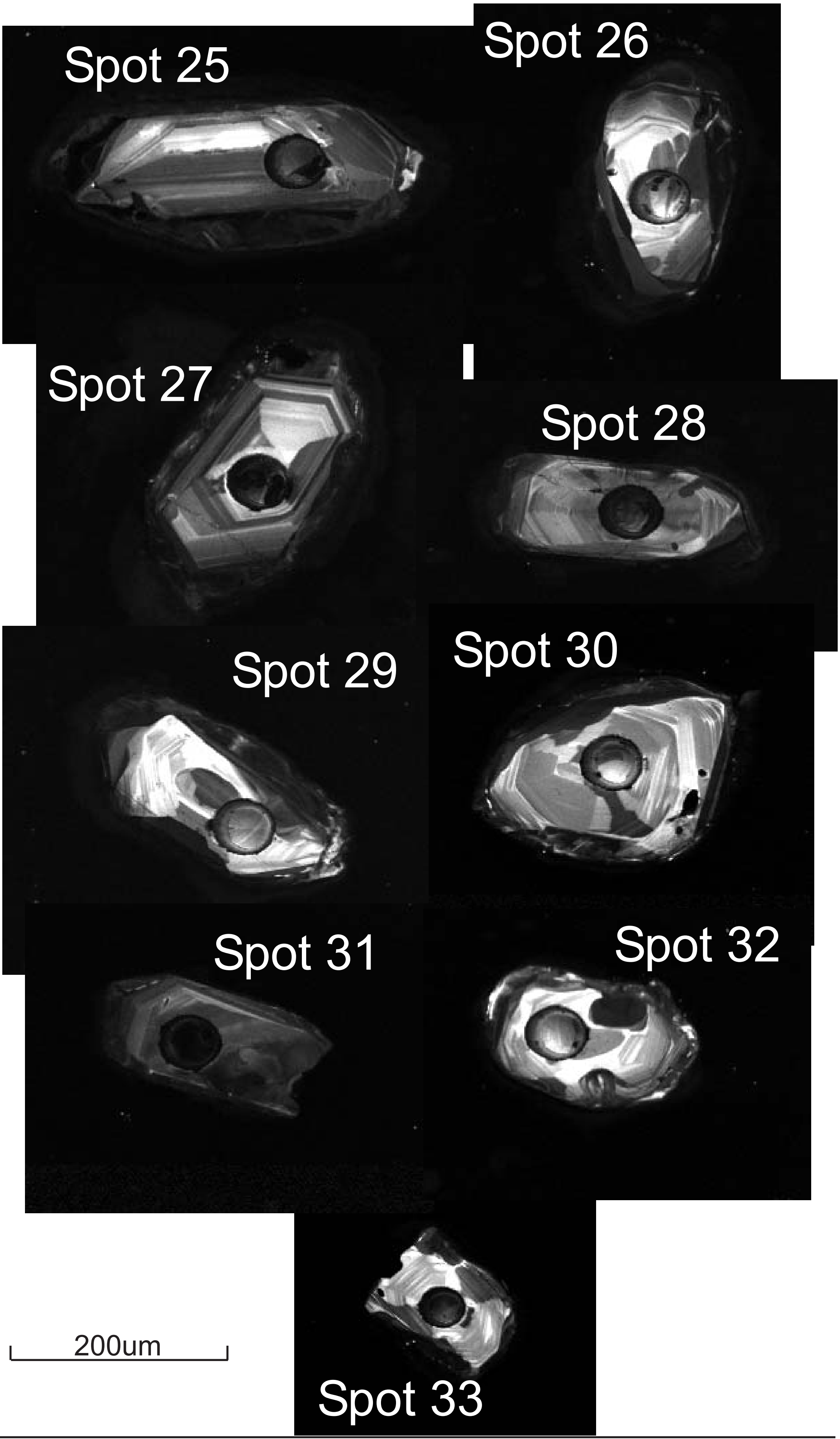
Sample	Lithology	Drillhole Depth (m)	Nd (ppm)	Sm (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	$\varepsilon_{Nd}(0)$	$\varepsilon_{Nd}(1500)$	T_{DM}
658669	Intensely foliated granitic gneiss	1404.50-1404.82	45.8	9.7	0.1284	0.512051	-11.5	1.7±0.2	1940
658671	Foliated granitic gneiss	1493.52-1493.83	70.8	13.5	0.1151	0.511894	-14.5	1.2±0.2	1921
658672	Foliated granitic gneiss	1494.43-1494.74	82.1	15.7	0.1153	0.512003	-12.4	3.3±0.2	1758

Measured $^{143}Nd/^{144}Nd$ ratios were normalized to $^{146}Nd/^{144}Nd$ = 0.721903. Nd blank carried out during the course of the analyses was 63 pg. The $^{143}Nd/^{144}Nd$ ratio of the in-house standard (Johnson Matthey) at the Adelaide University laboratory during the course of the analysis was 0.511601 ± 0.000007 (1 sd, no. of analyses = 2). Running average for La Jolla over the study is 0.511837 ± 0.000004 (1 st.dev., no. of analyses = 6). Present-day depleted mantle values used were 143Nd/144Nd = 0.513151 and 147Sm/144Nd = 0.2145 (Goldstein et al., 1984).


Spot 1
200 µm
Spot 2
Spot 3
Spot 4
Spot 5
Spot 6
Spot 7
Spot 8
200um


Spot 9
Spot 10
Spot 11
Spot 12
Spot 13
Spot 14
Spot 15
Spot 16
200um


Spot 17
Spot 18
Spot 19
Spot 20
Spot 21
Spot 22
Spot 23
Spot 24
200um


Spot 25
Spot 26
Spot 27
Spot 28
Spot 29
Spot 30
Spot 31
Spot 32
200um
Spot 33

Appendix 6

MonAnal v1.0 for Excel: A spreadsheet package for calculating chemical ages, errors and chemical variations of monazite from electron microprobe analyses

This chapter is submitted as: Wade, B.P, Clark, C., Hand, M. (2006) MonAnal v1.0 for Excel: A spreadsheet package for calculating chemical ages, errors and chemical variations of monazite from electron microprobe analyses. Computers and Geosciences, *in review*. See appendix for full article.

Abstract

MonAnal v1.0 is an MS Excel spreadsheet designed to carry out individual spot age determination and classification of monazite solid solution end member chemistry from electron microprobe (EPMA) data files. Age calculation included in MonAnal v1.0 gives U-Th-Pb spot ages with 1σ errors based on probe peak and background counting statistics. Mole fractions, cation normalisation to oxygen and exchange vector diagrams have all been implemented in various worksheets to assist in determination of end-member solid solutions between Huttonite ($ThSiO_4$), Brabanite ($CaTh(PO_4)_2$) and pure monazite (LREE PO_4). Worksheets of cation substitutions and cation frequency distributions further assist in interpretation of monazite chemistry by examining the possibility of probing of sub-surface inclusions. Also included in a worksheet is a cut down version of the YAG-Monazite thermometer designed by Pyle et al., (2001), and a worksheet for plotting REE and Primitive Mantle normalised spidergrams.

Keywords: Monazite; Spreadsheet; Chemical; EPMA; Age determination

1. Introduction

Monazite is a LREE enriched phosphate [(Ce,La,Th)PO4] that plays an important part in studies of igneous and metamorphic rocks. Perhaps its most important use is its ability to date specific events in a microstructural sense through in-situ EPMA dating (e.g. Parrish, 1990; Montel et al., 1996, Suzuki et al., 1996; Finger et al., 2003). Parrish (1990) demonstrated that monazite contains minor common Pb (<10ppm) and the vast majority of Pb measured in a monazite can be attributed to the radiogenic breakdown of Th and U, making monazite a perfect candidate for non-isotopic geochronologic techniques. The high closure temperature (~900°C at a cooling rate of 10°C/My in a 10µm grain (Cherniak et al., 2004)) of monazite enables the recording of multiple episodes of monazite growth and regrowth thus recording multiple tectonic events.

The ease with which data can be collected has led to studies focussing on how to correctly interpret the data rather than how to collect it (Suzuki and Adachi, 1993; Montel et al., 1996; Cocherie and Albarede, 2001; Williams et al., 1999; Williams et al., 2006). With no widely available data reduction programs in circulation, MonAnal v1.0 (**Mon**azite **Anal**ysis v1.0) was designed with this in mind and is an MS Excel spreadsheet designed to carry out age determination of monazite data obtained from the electron microprobe. MonAnal v 1.0 also includes a number of geochemical classifications to aid in unravelling multistage monazite growth with potential non-uniform age populations. It is designed so that the user can input the data directly from the microprobe's output file and view the geochemical discrimination plots. MS Excel represents a widely accessible base onto which a program can be designed, incorporating a multitude of visual and computational options for the general user. An additional benefit is that Excel spreadsheets can be simultaneously used with a number of other geochemical and geochronological computational programs and add-ins, such as Isoplot (Ludwig, 2003). This MS EXCEL 2000 spreadsheet can be shared/used with any PC and requires that the Solver.xla add-in has been installed. This aim of this paper is not to instruct users on how to statistically treat and interpret data generated from EPMA analysis of monazite, simply to give the reader a starting point for spot age calculation and chemistry. For a comprehensive review on data collection, statistical treatment and interpretation, the reader is referred to Williams et al. (2006).

2. Review of Chemical Monazite Dating

The theoretical basis for monazite geochronology is outlined in detail in the papers by Montel (1996) and Rhede et al. (1996) and the technique was first implemented by Parrish (1990), Suzuki and Adachi (1991) and Suzuki et al (1994). Th, U and Pb are measured by the electron microprobe and the values are substituted in to the chemical age equation for monazite (after Montel, 1996):

$$Pb = (Th/232)[e^{\lambda^{232}\tau}-1]\,208 + (U/238.04)\,0.9928 \times [e^{\lambda^{238}\tau}-1]\,206 + (U/238.04)\,0.0072 \times [e^{\lambda^{236}\tau}-1]\,207 \quad ...(1)$$

where Pb, Th and U are in ppm and λ^{232}, λ^{238} and λ^{235} are the radioactive decay constants of Th^{232}, U^{238} and U^{235} respectively. Individual ages are calculated by entering age estimates in to the equation with the known concentrations of Th, U and calculating the expected value of Pb, the age is then calculated iteratively by varying the calculated Pb until it matches the measured Pb (Williams and Jercinovic, 2002).

The accuracy of this method has two major caveats, firstly that all measured Pb is a product of the radiogenic breakdown of Th and U and secondly that there is no alteration of Th, U and Pb ratios by subsequent lead loss or thermal resetting. Of the two decay systems, Th/Pb and U/Pb, relevant to monazite the U/Pb system is best documented and previous work (Parrish, 1990) has demonstrated that this system behaves in a concordant manner. The theoretical basis for the Th/Pb system for monazite has been established (Steiger and Wasserberg, 1966; Allegre, 1967) and recent work on the system by Barth et al. (1994) in allanite has demonstrated that the system may in fact be more stable than in the U/Pb system. These factors suggest that it realistic to assume that in most cases partial lead loss in monazite will not hinder the ability to acquire reliable chemical ages from electron microprobe analysis (Montel, 1996).

Understanding the specific chemical reactions involved in the formation of monazite becomes important when it is used as a thermochronometer, and can potentially aid age interpretation of data.

3. Discussion

Relatively little is known about monazite forming reactions despite their importance in the interpretation of P-T-t data. Monazite is the main host of the Sm-Nd isotopic system in the continental crust, and typically carries between 40 and 80% of the LREE content of their host rock (Bea 1996; Schitter 1997). Previous studies concentrating on monazite chemistry have focussed on a number of factors, the controls on monazite growth (Ayers et al., 1999), the behaviour of monazite in hydrothermal environments (Poitrasson et al., 2000; Crowley and Ghent, 1999), compositional zoning in monazites (Zhu and O'Nions, 1999a, 1999b), and the effect of melting events on monazites (Watt, 1995). The behaviour of monazite involved in reactions with other REE-accessory minerals has been addressed (Broska and Siman; 1998; Pan, 1997; Ferry, 2000;), but only to a limited extent. Recently, the potential of monazite as a coupled geochronometer/thermobarometer has been investigated and applied to pelitic rocks (e.g. Gratz and Heinrich, 1997; Andrehs and Heinrich, 1998; Pyle et al., 2001).

It is envisioned that MonAnal v1.0 will be used as a tool for deciphering separate age events which may or may not be related to the bulk chemistry of the rock in which the monazite grew. Different chemical end-members of monazite can yield separate age populations that may be related to the variable bulk chemistry of the lithology monazite is growing. End-member classification is useful in determining whether the monazites being dated are more or less susceptible to Pb loss, or incorporate more common Pb into their crystal structure. This is important when interrogating the reliability of age populations. As the electron beam on electron microprobes penetrates a monazite to depth, excitation of underlying inclusions may then have an affect on the resultants obtained. The presence of micro-inclusions can be qualitatively assessed using MonAnal v1.0 through observations of the included cation frequency distribution plots, and resultant affected points can be discarded at the users discretion.

4. Description of the Program

MonAnal v1.0 is an MS spreadsheet with a set of functions programmed using Visual Basic to perform a range of computations in age and compositional classification of monazite. This package of worksheets represented in MonAnal v1.0 enables the simple manipulation of EPMA monazite data into:

1) U-Th-Pb spot ages;
2) 1σ errors for individual ages based on probe counting statistics; and be
3) Assessed for the degree of substitution between the various solid solution end-members involving monazite.

The MonAnal v.1.0 package contains nine worksheets;

- Insert Probe Data
- Age and Error
- Cation Frequency Distribution
- YAG Monazite Thermometer
- Monazite Spidergram Plots
- Exchange Vectors
- Cation Substitutions
- Mole Fractions
- Cation Normalisation

The package utilizes these linked worksheets and macros to perform the calculations and construct the plots. Details of the separate worksheets are outlined below.

Included in the worksheet, as an example, is data from MAD, the University of Adelaide's in-house monazite standard, that has a known age of ~514

Ma determined by SHRIMP (Kinny, 1997, Hand et al., 1999).

4.1 Insert Probe Data

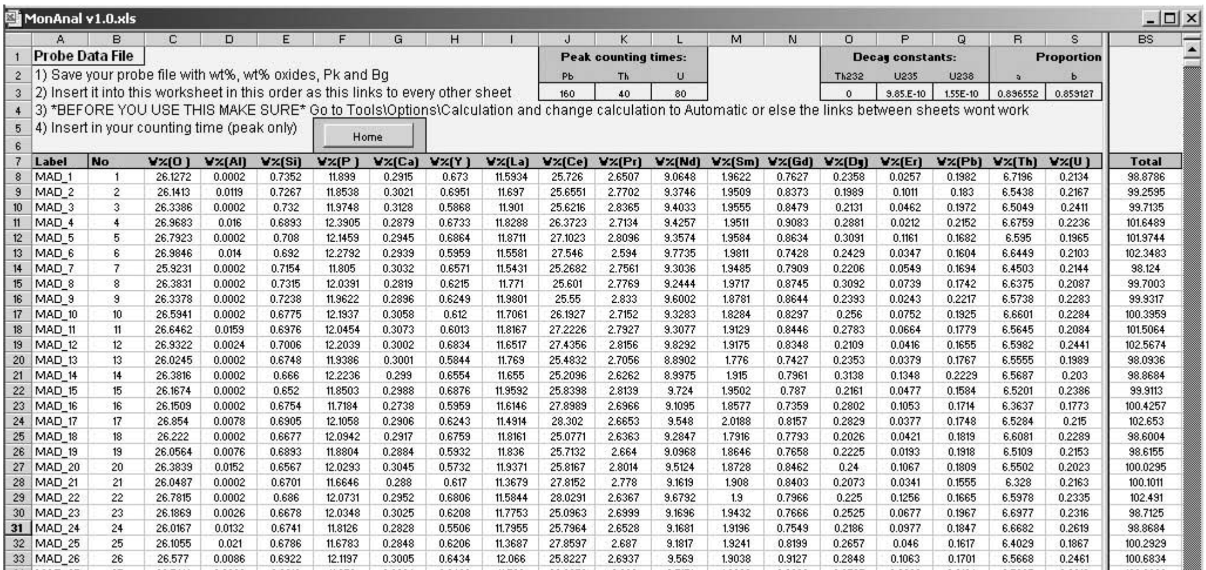
Data is entered into this worksheet by simply cutting and pasting values from the microprobe output text files acquired during a monazite analysis session. When deleting data from this sheet it is important that this is done by highlighting cells via cell selection with the mouse and not via row selection by clicking on the row number. Four different data groups are required for full use of MonAnal v1.0:

1) Weight % element;
2) Weight % oxide;
3) Peak counts per element; and
4) Background counts per element.

This sheet also requires the user to input peak counting times for U, Th and Pb into the corresponding yellow cells at the top of the spreadsheet (Fig. 1). Relevant decay constants used in the age and error calculations are also displayed here. Included in this sheet is the correction for apparent Pb due to the contribution from the Ce Lα escape peak (see Pyle et al., 2005). This varies between individual machines and different operational set-ups (see Williams et al., (2006) for a comprehensive discussion of operational variables during monazite analysis) and has been calibrated for the Cameca SX-51 at Adelaide Microscopy and has a calibrated value of 100 ppm Pb (ie. a removal of 0.01 wt% Pb). At this point the user must make sure the Solver add-in is installed for this spreadsheet to work. Automatic calculations must also be enabled and is accessed via the Tools/Options/Calculations tab. Once this has been done, check column BS for the total of each spot analyzed and discard points at your discretion. This should be done not only on consideration of total values but should incorporate monitoring of alumina and silica content from each spot. At the present time the workbook has only been set up to handle 200 iterations due to time consideration in age calculations.

4.2 Age and Error

This sheet is linked to worksheet 1 and should automatically load up the relevant data required for the age and error calculations. The spreadsheet utilizes the Solver.xla add-in to iteratively solve for t in the age equation of Montel et al. (1996) displayed in equation 1. To do this simply hit the **Go Baby Go!** Button and your ages and their respective 1ó errors will appear in the highlighted blue columns (Fig. 2). It is currently set up for calculating 200 age iterations. The 1σ errors in this spreadsheet are calculated via the corresponding peak and background counts of Th, U and Pb for each point analyzed, and represents a more realistic error as it takes into account variations in the probe during analysis. This method does not take into account the problems with background estimation discussed in Williams et al. (2006) but the analytical procedure at the University of Adelaide for the measurement of Pb (the major source of error in monazite calculations) is differs to that of Williams et al. (2006). The Pb Mβ peak is analysed in the University of Adelaide



	Label	No	V%(O)	V%(Al)	V%(Si)	V%(P)	V%(Ca)	V%(Y)	V%(La)	V%(Ce)	V%(Pr)	V%(Nd)	V%(Sm)	V%(Gd)	V%(Dy)	V%(Er)	V%(Pb)	V%(Th)	V%(U)	Total
8	MAD_1	1	26.1272	0.0002	0.7352	11.899	0.2915	0.673	11.5934	25.726	2.6507	9.0648	1.9622	0.7627	0.2358	0.0257	0.1982	6.7196	0.2134	98.8786
9	MAD_2	2	26.1413	0.0119	0.7267	11.8538	0.3021	0.6951	11.697	25.6551	2.7702	9.3746	1.9509	0.8373	0.1989	0.1011	0.183	6.5438	0.2167	99.2595
10	MAD_3	3	26.3386	0.0002	0.732	11.9748	0.3128	0.5868	11.901	25.6216	2.8365	9.4033	1.9555	0.8479	0.2131	0.0462	0.1972	6.5049	0.2411	99.7135
11	MAD_4	4	26.9683	0.016	0.6893	12.3905	0.2879	0.6733	11.8288	26.3723	2.7134	9.4257	1.9511	0.9083	0.2881	0.0212	0.2152	6.6759	0.2236	101.6489
12	MAD_5	5	26.7923	0.0002	0.708	12.1459	0.2945	0.6864	11.8711	27.1023	2.8096	9.3574	1.9584	0.8634	0.3091	0.1161	0.1682	6.595	0.1965	101.9744
13	MAD_6	6	26.9846	0.014	0.692	12.2792	0.2939	0.5959	11.5581	27.546	2.594	9.7735	1.9811	0.7428	0.2429	0.0347	0.1604	6.6449	0.2103	102.3483
14	MAD_7	7	25.9231	0.0002	0.7154	11.805	0.3032	0.6571	11.5431	25.2682	2.7561	9.3036	1.9485	0.7909	0.2206	0.0549	0.1694	6.4503	0.2144	98.124
15	MAD_8	8	26.3831	0.0002	0.7315	12.0391	0.2819	0.6215	11.771	25.601	2.7769	9.2444	1.9717	0.8745	0.3092	0.0739	0.1742	6.6375	0.2087	99.7003
16	MAD_9	9	26.3378	0.0002	0.7238	11.9622	0.2896	0.6249	11.9801	25.55	2.833	9.6002	1.8781	0.8644	0.2393	0.0243	0.2217	6.5738	0.2283	99.9317
17	MAD_10	10	26.5941	0.0002	0.6775	12.1937	0.3058	0.612	11.7061	26.1927	2.7152	9.3283	1.8284	0.8297	0.256	0.0752	0.1925	6.6601	0.2284	100.3959
18	MAD_11	11	26.6462	0.0159	0.6976	12.0454	0.3073	0.6013	11.8167	27.2226	2.7927	9.3077	1.9129	0.8446	0.2783	0.0664	0.1779	6.5645	0.2084	101.5064
19	MAD_12	12	26.9322	0.0024	0.7006	12.2039	0.3002	0.6834	11.6517	27.4356	2.8156	9.8292	1.9175	0.8348	0.2109	0.0416	0.1655	6.5982	0.2441	102.5674
20	MAD_13	13	26.0245	0.0002	0.6748	11.9386	0.3001	0.5844	11.769	25.4832	2.7056	8.8902	1.776	0.7427	0.2353	0.0379	0.1767	6.5555	0.1989	98.0936
21	MAD_14	14	26.3816	0.0002	0.666	12.2236	0.299	0.6554	11.655	25.2096	2.6262	8.9975	1.915	0.7961	0.3138	0.1348	0.2229	6.5687	0.203	98.8684
22	MAD_15	15	26.1674	0.0002	0.652	11.8503	0.2988	0.6876	11.9592	25.8398	2.8139	9.724	1.9502	0.787	0.2161	0.0477	0.1584	6.5201	0.2386	99.9113
23	MAD_16	16	26.1509	0.0002	0.6754	11.7184	0.2738	0.5959	11.6146	27.8989	2.6966	9.1095	1.8577	0.7359	0.2802	0.1053	0.1714	6.3637	0.1773	100.4257
24	MAD_17	17	26.854	0.0078	0.6905	12.1058	0.2906	0.6243	11.4914	28.302	2.6653	9.548	2.0188	0.8157	0.2829	0.0377	0.1748	6.5284	0.215	102.653
25	MAD_18	18	26.222	0.0002	0.6677	12.0942	0.2917	0.6759	11.8161	25.0771	2.6363	9.2847	1.7916	0.7793	0.2026	0.0421	0.1819	6.6081	0.2289	98.6004
26	MAD_19	19	26.0564	0.0076	0.6893	11.8804	0.2884	0.5932	11.836	25.7132	2.664	9.0968	1.8646	0.7658	0.2225	0.0193	0.1918	6.5109	0.2153	98.6155
27	MAD_20	20	26.3839	0.0152	0.6567	12.0293	0.3045	0.5732	11.9371	25.8167	2.8014	9.5124	1.8728	0.8462	0.24	0.1067	0.1809	6.5502	0.2023	100.0295
28	MAD_21	21	26.0487	0.0002	0.6701	11.6646	0.288	0.617	11.3679	27.8152	2.778	9.1619	1.908	0.8403	0.2073	0.0341	0.1555	6.328	0.2163	100.1011
29	MAD_22	22	26.7815	0.0002	0.686	12.0731	0.2952	0.6806	11.5844	28.0291	2.6367	9.6792	1.9	0.7966	0.225	0.1256	0.1665	6.5978	0.2335	102.491
30	MAD_23	23	26.1869	0.0026	0.6678	12.0348	0.3025	0.6208	11.7753	25.0963	2.6999	9.1696	1.9432	0.7666	0.2525	0.0677	0.1967	6.6977	0.2316	98.7125
31	MAD_24	24	26.0167	0.0132	0.6741	11.8126	0.2828	0.5506	11.7955	25.7964	2.6528	9.1681	1.9196	0.7549	0.2186	0.0977	0.1847	6.6682	0.2619	98.8684
32	MAD_25	25	26.1055	0.021	0.6786	11.6783	0.2848	0.6206	11.3687	27.8597	2.687	9.1817	1.9241	0.8199	0.2657	0.046	0.1617	6.4029	0.1867	100.2929
33	MAD_26	26	26.577	0.0086	0.6922	12.1197	0.3005	0.6434	12.066	25.8227	2.6937	9.569	1.9038	0.9127	0.2848	0.1063	0.1701	6.5668	0.2461	100.6834
34	MAD_27	27	26.5414	0.0083	0.6916	11.876	0.2984	0.6432	11.563	28.2053	2.696	9.5171	1.9268	0.8002	0.2705	0.0238	0.2124	6.5225	0.2318	102.0283
35			26.2795	0.0002	0.6823	12.0884	0.2981	0.6493	11.5676	25.1253	2.7568	9.4301	1.9362	0.7929	0.2456	0.0301	0.193	6.6591	0.2147	98.9492
36			26.1443	0.0211	0.6789	11.8927	0.2989	0.5814	11.9153	25.7662	2.5684	9.1914	1.9148	0.8385	0.2486	0.064	0.175	6.64	0.2119	99.1514
37			26.4128	0.0002	0.6577	12.0685	0.3075	0.6343	12.0465	25.7064	2.7635	9.6693	1.8219	0.828	0.1932	0.1074	0.2014	6.434	0.2146	100.0672

Figure 1. Screenshot of *Insert Probe Data* worksheet displaying layout for data entry. Peak counting times inserted at top of spreadsheet.

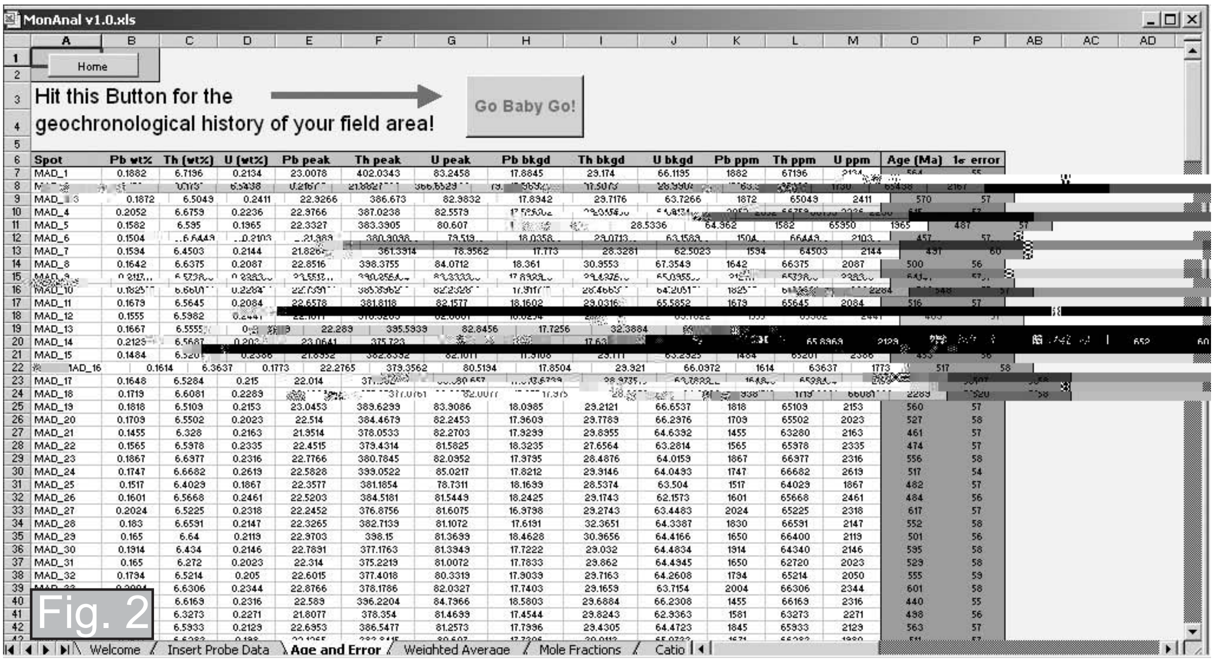


Figure 2. Screenshot of *Age and Error* worksheet displaying resultant age and error calculations for example analyses of MAD.

set-up and this peak is further removed from the interfering Th peaks discussed in the Williams et al. (2006) paper. The user must be aware of the major sources of error in their own set-up and treat them accordingly.

These ages are now ready to be loaded straight into Isoplot for age population and weighted mean calculations.

4.3 Mole Fractions

This worksheet contains the wt% oxides as linked from worksheet 1 (Insert Probe Data). Calculated from this are the mole fractions of the relative compositional end-members of the user's monazite analyzed (X_{LREE}, X_{HREE}, $X_{Huttonite}$, $X_{Brabanite}$, X_{YPO4}). These calculations follow the paper by Pyle et al. (2001), and may help in discriminating the compositional variations in your monazites, which may be linked to age domains.

To the right of this under the yellow headings is a further table delineating the relative mole fractions that the LREE and the HREE contribute.

4.4 Cation Normalization

As the title of this spreadsheet suggests it normalizes your data to however many oxygens you see fit. To use this worksheet simply put the number of oxygens in the yellow cell then scroll far right to the table with the purple headings to view the normalized cations. If choosing anything other than 8, 16 or 24 oxygens, plots on the following Exchange Vectors, Cation Substitutions, and Cation Frequency Distribution worksheets will not work.

4.5 Exchange Vectors

This worksheet displays the exchange vector reactions of monazite with Brabanite and Huttonite as per Pyle et al., (2001) (Fig. 3). The solid solution of pure monazite (LREE PO_4) with Brabanite ($CaTh(PO_4)_2$) and Huttonite ($ThSiO_4$) can explain almost all variations in monazite composition as per Zhu and O'Nions, (1999). These involve the following substitutions:

$Th^{4+} + Ca^{2+} \rightarrow 2LREE^{3+}$
$U^{4+} + Ca^{2+} \rightarrow 2LREE^{3+}$
$Th^{4+} + Si^{4+} \rightarrow LREE^{3+}\ P^{5+}$
$U^{4+} + Si^{4+} \rightarrow LREE^{3+}\ P^{5+}$

On this diagram pure $REEPO_4$ phosphate plots at (8,0), with the Huttonite exchange vector [$(Th,U)SiREE_{-1}P_{-1}$] in red, and the Brabanite exchange vector [$Ca(Th,U)REE_{-2}$] in green (Fig. 3). Our analyses of MAD plot on or very near to the Huttonite exchange vector, probably indicating that it is a solid solution with this.

Also displayed on this worksheet is a ternary plot which plots the compositions of the monazite with respect to three endmembers (pure monazite, Huttonite, and Brabanite) (Fig. 3). This diagram is adapted from Bowie and Horne (1953), and includes the cheralitic composition of monazite (Ce-Ca-Th variant).

4.6 Cation Substitutions

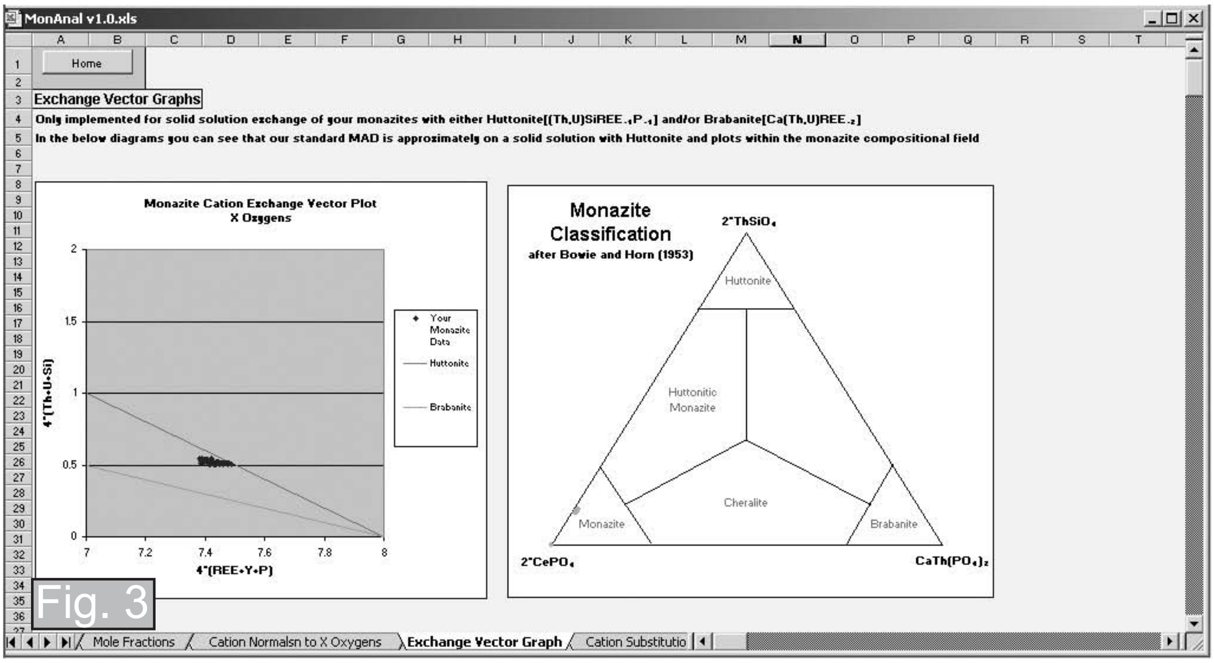


Figure 3. Screenshot of *Exchange Vector Graph* worksheet displaying cation plot normalised to 16 oxygens. MAD analyses plot close to or on the Huttonite exchange vector and within the Monazite field.

Three graphs on are displayed in this worksheet [Th+U vs Ca + Si], [Si vs Ca], and [Th vs Si] (e.g. Townsend et al., 2000). Their uses are outlinedbriefly below.

4.6.1 [Th+U vs Ca + Si]

If coupled substitution is the primary mechanism controlling compositional change (see worksheet Exchange Vectors), then the atomic abundance of Th + U should be equal to Ca + Si. A typical displacement is for points to fall to the right of this 1:1 line, which indicates excess of Ca or Si or both. This is seen in our analyses of MAD, which could be explained by micro inclusions of apatite and quartz within its crystal structure.

4.6.2 [Si vs Ca] and [Th vs Si]

Higher Si with respect to Ca on the graph of Si vs Ca, and high Th and Si on the graph of Th vs Si probably indicates a dominant Huttonite component in the sample. That is depletions in Ca and high Si/Th values close to a 1:1 ratio suggests that Huttonite substitution is the main exchange process, and assumes greater importance at the expense of Brabanite and vice versa. Conversely, low Si coupled with high Ca probably indicates a dominant Brabanite component at the expense of Huttonite.

4.7 Cation Frequency Distribution

Instructions on the construction of the histograms are included in the program itself, and as a result only brief comments on interpretation of these graphs is explained.

The frequency histogram of Si + P should be approximately normal and gaussian, with high values (approximately >1.02) possibly indicating probing of sub-surface quartz micro-inclusions (Pyle et al. 2001). On a histogram of Ca+Si-(Th+U+Pb) the MAD data shows slightly elevated values (between 0 and 0.1). This is common and probably a result of silica excess resulting from probing of sub-surface quartz inclusions. However it has been previously suggested that slight Si excess in monazites may suggest some substitution of Si for P in $(REE,Y)PO_4$, which would result in a charge deficit (Pyle et al., 2001).

4.8 YAG Monazite Thermometer

Use of this worksheet is explained in detail on the worksheet itself. Full details on the use of this thermometer can be obtained from Pyle et al. (2001). The thermometer utilizes the mass transfer between Yttrium aluminous garnet (YAG) and monazite, involving consumption of YAG, apatite, and quartz to produce calcium rich garnet, anorthite, YPO_4 component of garnet and fluid. Selection of monazite in equilibrium with YAG is critical in use of this thermometer, and instructions and outlines on finding these phases is outlined in Pyle et al. (2001). Examples of calculations directly taken from Pyle et al, (2001) are in the spreadsheet.

4.9 Monazite Spidergram Plots

This final worksheet displays Chondrite REE (Taylor and McLennan, 1985) and Primitive Mantle (Sun and McDonough, 1989) normalized plots for your spot points or monazite analyses. Groupings of selected analyses/monazites can be constructed by the user in the usual way with excel tables, through manipulation of the normalized values located in hidden columns X to AY, and changes can be made to reservoir normalizing values in columns BD to BQ. If any, broad groupings will be detectable in these plots, which may correspond to different age populations and allude to different sources of fluid controlling monazite growth.

Acknowledgements

Thanks also go to Dave Steele at Uni of Tas for the template on error calculation.