APPENDIX 1: ANALYTICAL TECHNIQUES

MAJOR AND TRACE ELEMENTS

Whole-rock major element analyses were performed on fused discs following standard techniques at the Open University (Potts et al, 1984). Trace element concentrations were determined using ICP-MS at Durham University. Powders were dissolved using a standard HF-HNO_3 technique, and spiked with Rh, In and Bi - to monitor internal drift - before dilution to 3.5% HNO_3 . Solutions were analysed on a Perkin-Elmer-SCIEX Elan 6000 inductively coupled plasma mass spectrometer using a cross-flow nebuliser. Appropriate corrections were made using oxide/metal ratios measured on matrix-matched standard solutions; oxide interferences were minimal for most analyses. Total procedural blanks for all elements were negligible for all analyses. Reproducibility, based on repeated analyses of samples and standards was between 1 and 3%, and analysed standard (BHVO-1, AGV) values deviated less than 2% from published values.

ELECTRON MICROPROBE

Electron microprobe analyses were performed at the Open University using a wavelength dispersive cameca SX 100 microprobe, following techniques outlined in Reed (1995). Phlogopites separated from samples were mounted within resin blocks, and subsequently polished and carbon coated. Analyses used a 20kV accelerating potential and a beam current of 20nA, the beam was defocussed to a 10µm spot. Appropriate primary and secondary standards were used for calibration. Analytical reproducibility was generally better than 2% (2sigma), based on repeat analyses of a kaersutitic amphibole standard. H_2O contents of phlogopites were calculated following Tindle and Webb, (1990).

SR AND ND ISOTOPES

The Sr and Nd isotope analyses reported here were carried out on a Nu Instruments multi-collector ICPMS at the Open University; and by TIMS on a Finnigan MAT 262 mass spectrometer (Nd, samples T4A and T5A only), both in static mode. Following dissolution using standard HF-HNO_3 techniques, Sr and REE fractions were separated using cationic ion-exchange resin columns. Nd was separated from the REE fraction using hydrogen-diethyl-hexyl-phosphate (HDEHP) columns (Richard et al, 1976). The collected Sr and Nd fractions were evaporated and subsequently dissolved in 2 % HNO_3 to give solutions for analysis. Sample solutions were nebulised and desolvated using a Cetac Aridus nebuliser and introduced into the plasma torch. Ions are extracted from the plasma through sampling and skimmer cones, which have aperture diameters of 1.0 mm and 0.6 mm, respectively. The nebuliser and torch setup was cleaned between subsequent analyses by alternately aspirating 2% HNO_3 and IPA (isopropyl alcohol) through the nebuliser for a period of approximately 15 minutes.

The Nu Plasma detector array consists of 12 Faraday cups and 3 ion counters in fixed positions; beams are directed into the collectors by varying the dispersion of the instrument using an electrostatic zoom lens. We measured masses 88, 87, 86, 85, and 84 simultaneously on Faraday cups 2, 4, 6, 8, 10, respectively for Sr analyses. For Nd, masses 150, 148, 147, 146, 145, 144, 143 and 142 were analysed on cups 1, 2, 3, 4, 5, 6, 7, and 8. All analyses were carried out in static multi-collector mode. Peak integration times for 10 seconds for Sr and 8 seconds for Nd, and baselines were collected for twice these integration times at half mass. 10 measurements were made per block of ratios; 20 blocks were collected for Sr, 10 for Nd.

During the period of sample analysis, we analysed the Sr standard NBS 987 and Johnson and Matthey Nd, to assess 1) reproducibility of isotope analyses and 2) the mass fractionation

effects of the Nu Plasma. Repeat analyses of NBS 987 gave a mean value of 0.710232 ± 0.000032 (2 s.d.; n=10) for the standard. We assume that the slight deviation of our value for NBS 987 and the globally accepted value (0.710230) is dependent solely on exponential fractionation caused by mass bias. By iteratively correcting our value to the accepted value of 0.710230, we obtain a value of $^{86}Sr/^{88}Sr$ = 0.119401 ± 0.000012 (2s.d.). The value obtained for $^{86}Sr/^{88}Sr$ is then used to normalise the sample analyses. This approach is analogous to the common practice of normalising TIMS data to the global value for NBS 987, using a normalisation factor derived from the ratio of the measured NBS 987 to the accepted value of 0.710230. However, a critical difference to emphasise is that our normalisation procedure takes exponential fractionation laws into account, whereas the commonly used ratio approach assumes a linear fractionation relationship only. Finally, interference of ^{87}Rb on ^{87}Sr in the sample analyses was corrected for by measuring the interference free ^{85}Rb isotope and using the recommended value of $^{85}Rb/^{87}Rb$ (0.386).

For Nd, repeat analyses of the Johnson and Matthey standard on the Nu Plasma gave an average value of 0.511804±0.000036 (2s.d.; n=11). We do not use the same procedure as for Sr isotopes to correct for mass fractionation, as there is yet no widely accepted value for Johnson and Matthey Nd. For both standard and sample analyses, interference of ^{144}Sm on ^{144}Nd was first corrected for by measuring the intensity of the ^{147}Sm isotope and using the accepted value for $^{147}Sm/^{144}Sm$ (0.20667). The interference-corrected value that we obtain for $^{144}Nd/^{146}Nd$ is then corrected to the generally accepted value for $^{144}Nd/^{146}Nd$ (0.7219), assuming that that any deviation is a function of exponential mass fractionation. The derived fractionation factor is then used to perform a second fractionation correction on ^{144}Nd, this time taking fractionation effects on $^{147}Sm/^{144}Sm$ into account. The value of $^{144}Nd/^{146}Nd$ obtained from this calculation is then

compared with the accepted $^{144}Nd/^{146}Nd$ values, and used to calculate a final fractionation factor, which is then applied to the measured $^{143}Nd/^{144}Nd$. Nd isotope ratios analysed by TIMS were fractionation corrected to $^{144}Nd/^{146}Nd=0.7219$, repeat analyses of the Johnson and Matthey standard gave an average of 0.511760±0.000004 (2s.d. n=36); isotope ratios were normalised to the value for the Johnson and Matthey standard obtained on the Nu Plasma.

REFERENCES CITED

Potts, P.J., Webb, P.C., and Watson, J.S., 1984, Energy dispersive X-ray flourescence of silicate rocks for major and trace elements: X-ray spectrometry, v. 13, p. 2-15.

Reed, S.J.B., 1995, Electron probe microanalysis, *in* Potts, P.J., Bowles, J.F.W., Reed, S.J.B., Cave, M.R, eds., Microprobe techniques in the Earth Sciences: London, Chapman and Hall, p. 49-89.

Richard, P., Shimizu, N., and Allègre, C.J., 1976, $^{143}Nd/^{144}Nd$, a natural tracer: an application to oceanic basalts: Earth and Planetary Science Letters, v. 31, p. 269-278.

Tindle, A.G. and Webb, P. C., 1990, Estimation of lithium contents in trioctahedral micas using microprobe data; application to micas from granitic rocks: European Journal of Mineralogy, v. 2, p. 595-610.

APPENDIX 2. DYKE ORIENTATIONS

sample	locality	trend
T2A	Pabbai Zong	022°
T3B	Pabbai Zong	159°
T4A	Pabbai Zong	008°
T5A	Pabbai Zong	157°
T6	Pabbai Zong	180°
T11B	Daggyai Tso	000°
JPT14.2	Daggyai Tso	025°

APPENDIX 3. ^{40}Ar-^{39}Ar DATA

sample	mineral	$^{40}Ar/^{39}Ar$	± 1 σ	$^{38}Ar/^{39}Ar$	± 1 σ	$^{37}Ar/^{39}Ar$	± 1 σ	$^{36}Ar/^{39}Ar$	± 1 σ	^{39}Ar ($cm^3 x10^{-10}$)	± 1 σ	$^{40}Ar^*/^{39}Ar$	± 1 σ	Age (Ma)	± 1 σ
T2A/98	phl	13.5367	0.0232	0.0351	0.0003	0.0324	0.0018	0.0333	0.0008	0.0489	0.0000	3.6925	0.2499	21.63	1.45
T2A/98	phl	15.9166	0.0262	0.0420	0.0004	0.0435	0.0023	0.0375	0.0011	0.0365	0.0001	4.8254	0.3342	28.21	1.94
T2A/98	phl	16.7508	0.0302	0.0412	0.0008	0.0601	0.0032	0.0393	0.0014	0.0293	0.0001	5.1443	0.4163	30.06	2.41
T2A/98	phl	15.9483	0.0372	0.0405	0.0006	0.0600	0.0022	0.0371	0.0010	0.0396	0.0001	4.9818	0.3081	29.12	1.79
T2A/98	phl	20.4344	0.1282	0.0441	0.0015	0.0787	0.0238	0.0468	0.0049	0.0215	0.0001	6.5945	1.4533	38.44	8.38
T2A/98	phl	14.3659	0.0190	0.0383	0.0004	0.0428	0.0033	0.0323	0.0007	0.1567	0.0002	4.8122	0.1991	28.13	1.16
T2A/98	phl	14.0879	0.0080	0.0407	0.0001	0.0442	0.0003	0.0318	0.0002	0.1625	0.0001	4.7044	0.0516	27.51	0.30
T2A/98	phl	12.2807	0.0088	0.0387	0.0001	0.0432	0.0005	0.0280	0.0002	0.1577	0.0001	3.9959	0.0532	23.39	0.31
T2A/98	phl	13.7764	0.0150	0.0388	0.0004	0.0449	0.0008	0.0313	0.0002	0.0745	0.0001	4.5126	0.0723	26.40	0.42
T2A/98	phl	14.8857	0.0094	0.0415	0.0002	0.0444	0.0005	0.0353	0.0002	0.1379	0.0001	4.4635	0.0539	26.11	0.31
T2A/98	phl	13.7365	0.0305	0.0411	0.0003	0.0518	0.0019	0.0312	0.0005	0.0954	0.0002	4.5239	0.1431	26.46	0.83
T2A/98	phl	18.2325	0.0637	0.0424	0.0004	0.0571	0.0020	0.0454	0.0006	0.0918	0.0003	4.8224	0.1595	28.19	0.93
T2A/98	phl	14.0378	0.0153	0.0397	0.0002	0.0505	0.0016	0.0312	0.0003	0.1040	0.0001	4.8066	0.1029	28.10	0.60
T2A/98	phl	12.9844	0.0245	0.0432	0.0004	0.0507	0.0028	0.0293	0.0003	0.0612	0.0001	4.3360	0.0971	25.37	0.56
T2A/98	phl	14.2582	0.0170	0.0425	0.0001	0.0509	0.0015	0.0316	0.0004	0.1035	0.0001	4.9082	0.1319	28.69	0.77
T2A/98	phl	15.0702	0.0503	0.0461	0.0009	0.0507	0.0131	0.0253	0.0041	0.0121	0.0000	7.6044	1.2057	44.26	6.93
T3B/98	bi in xenolith*	6.2075	0.0107	0.0288	0.0011	0.0000	0.0000	0.0001	0.0004	0.0403	0.0001	6.1708	0.1328	36.00	0.77
T3B/98	bi in xenolith*	9.9306	0.0514	0.0379	0.0005	0.0005	0.0002	0.0132	0.0001	0.1889	0.0009	6.0286	0.0540	35.18	0.31
T3B/98	bi in xenolith*	29.3064	0.2964	0.0864	0.0062	0.0000	0.0000	0.0912	0.0026	0.0075	0.0001	2.3563	0.7157	13.83	4.19
T3B/98	bi in xenolith*	18.8520	0.0608	0.0822	0.0026	0.0188	0.0025	0.0595	0.0014	0.0177	0.0001	1.2672	0.4168	7.45	2.45
T3B/98	bi in xenolith*	11.6333	0.0410	0.0774	0.0002	0.0065	0.0007	0.0314	0.0010	0.0460	0.0001	2.3466	0.2986	13.77	1.75
T3B/98	bi in xenolith*	7.5601	0.0376	0.0351	0.0002	0.0020	0.0002	0.0073	0.0004	0.1218	0.0006	5.4138	0.1341	31.62	0.78
T3B/98	bi in xenolith*	10.5192	0.0216	0.0492	0.0011	0.0160	0.0032	0.0273	0.0004	0.0453	0.0001	2.4580	0.1191	14.43	0.70
T3B/98	bi in xenolith*	3.8282	0.0025	0.0543	0.0003	0.0217	0.0007	0.0050	0.0001	0.2052	0.0001	2.3522	0.0260	13.81	0.15
T3B/98	bi in xenolith*	5.6291	0.0082	0.0617	0.0003	0.0157	0.0003	0.0109	0.0002	0.2136	0.0002	2.3981	0.0468	14.08	0.27
T3B/98	bi in xenolith*	9.9886	0.0361	0.0468	0.0010	0.0037	0.0026	0.0274	0.0007	0.0261	0.0001	1.8941	0.2044	11.13	1.20
T3B/98	bi in xenolith*	13.8969	0.0191	0.0609	0.0002	0.0191	0.0018	0.0401	0.0003	0.0658	0.0001	2.0475	0.1008	12.02	0.59
T5A/98	phl	0.8650	0.0016	0.0137	0.0001	0.0073	0.0002	0.0000	0.0001	1.7019	0.0029	0.8561	0.0375	16.93	0.74
T5A/98	phl	1.0694	0.0022	0.0140	0.0001	0.0150	0.0001	0.0011	0.0001	2.4058	0.0015	0.7474	0.0270	14.79	0.54
T5A/98	phl	0.7809	0.0018	0.0137	0.0000	0.0072	0.0001	0.0003	0.0001	2.9041	0.0005	0.7004	0.0222	13.86	0.44
T5A/98	phl	1.1314	0.0009	0.0137	0.0001	0.0015	0.0002	0.0015	0.0001	1.7887	0.0011	0.7017	0.0356	13.88	0.71
T5A/98	phl	1.2330	0.0028	0.0140	0.0000	0.0090	0.0001	0.0019	0.0000	8.5638	0.0181	0.6764	0.0077	13.39	0.16
T5A/98	phl	1.0175	0.0025	0.0130	0.0002	0.0013	0.0007	0.0013	0.0005	0.4341	0.0004	0.6423	0.1481	12.71	2.92
T5A/98	phl	0.8505	0.0009	0.0136	0.0000	0.0058	0.0001	0.0007	0.0001	2.7673	0.0010	0.6379	0.0230	12.63	0.46
T5A/98	phl	0.9022	0.0009	0.0131	0.0001	0.0341	0.0002	0.0006	0.0002	1.3023	0.0009	0.7273	0.0491	14.39	0.97
T5A/98	phl	0.9248	0.0009	0.0139	0.0000	0.0105	0.0002	0.0012	0.0001	1.9553	0.0006	0.5801	0.0329	11.49	0.65
T5A/98	phl	0.8751	0.0028	0.0133	0.0001	0.0006	0.0002	0.0006	0.0002	1.3404	0.0027	0.6875	0.0478	13.60	0.94

APPENDIX 3. ^{40}Ar-^{39}Ar DATA

sample	mineral	$^{40}Ar/^{39}Ar$	± 1 σ	$^{38}Ar/^{39}Ar$	± 1 σ	$^{37}Ar/^{39}Ar$	± 1 σ	$^{36}Ar/^{39}Ar$	± 1 σ	^{39}Ar ($cm^3 x10^{-10}$)	± 1 σ	$^{40}Ar^*/^{39}Ar$	± 1 σ	Age (Ma)	± 1 σ
JPT 7	phl	1.1347	0.0020	0.0130	0.0001	0.0438	0.0249	0.0006	0.0001	0.8234	0.0005	0.9622	0.0184	20.54	0.40
JPT 7	phl	1.4238	0.0029	0.0133	0.0001	0.0441	0.0177	0.0009	0.0000	1.1552	0.0018	1.1457	0.0133	24.43	0.31
JPT 7	phl	2.2396	0.0019	0.0136	0.0001	-0.0239	-0.0324	0.0028	0.0001	0.5713	0.0003	1.4154	0.0264	30.13	0.58
JPT 7	phl	1.6687	0.0034	0.0134	0.0000	0.0086	0.0088	0.0013	0.0000	2.0938	0.0034	1.2855	0.0125	27.39	0.30
JPT 7	phl	2.1709	0.0021	0.0145	0.0001	0.0104	0.0347	0.0021	0.0001	0.5343	0.0003	1.5633	0.0298	33.25	0.65
JPT 7	phl	1.3804	0.0037	0.0128	0.0003	-0.0116	-0.0807	0.0009	0.0002	0.2298	0.0001	1.1095	0.0657	23.66	1.40
JPT 7	phl	2.3245	0.0018	0.0133	0.0001	0.0160	0.0267	0.0022	0.0001	0.6943	0.0004	1.6788	0.0273	35.69	0.60
JPT 7	phl	2.5661	0.0064	0.0155	0.0004	0.1875	0.1049	0.0000	-0.0003	0.1954	0.0002	2.5802	0.0817	54.56	1.72
T11B/98	glass matrix	1.0189	0.0039	0.0154	0.0002	0.0736	0.0010	0.0001	0.0005	0.1419	0.0001	0.9955	0.1336	19.67	2.63
T11B/98	glass matrix	0.8536	0.0029	0.0142	0.0002	0.0730	0.0008	0.0000	0.0004	0.1815	0.0001	0.8515	0.1044	16.84	2.06
T11B/98	glass matrix	1.7361	0.0081	0.0156	0.0003	0.0915	0.0006	0.0013	0.0003	0.1226	0.0004	1.3667	0.0963	26.94	1.89
T11B/98	glass matrix	0.8194	0.0083	0.0147	0.0004	0.0692	0.0020	0.0000	0.0000	0.0708	0.0001	0.8194	0.2677	16.20	5.27
T11B/98	glass matrix	0.8661	0.0055	0.0152	0.0002	0.0571	0.0005	0.0000	0.0000	0.0667	0.0000	0.8661	0.1710	17.12	3.37
T11B/98	glass matrix	1.2771	0.0042	0.0138	0.0002	0.0675	0.0011	0.0000	0.0000	0.1375	0.0001	1.2771	0.1379	25.19	2.70
JPT 14.2	hbl	1.7797	0.0079	0.0140	0.0001	1.1423	0.8745	0.0022	0.0000	1.5565	0.0049	1.1263	0.0129	24.02	0.29
JPT 14.2	hbl	1.1885	0.0034	0.0135	0.0001	1.7676	2.0197	0.0001	0.0001	0.6747	0.0003	1.1670	0.0238	24.88	0.52
JPT 14.2	hbl	1.0386	0.0044	0.0138	0.0001	1.9698	1.2628	0.0000	0.0000	1.0833	0.0035	1.0370	0.0146	22.13	0.33
JPT 14.2	hbl	0.9053	0.0052	0.0134	0.0002	2.2100	3.1450	0.0000	0.0001	0.4340	0.0001	0.9053	0.0351	19.33	0.75
JPT 14.2	hbl	1.1467	0.0061	0.0135	0.0001	2.4758	1.7440	0.0000	0.0001	0.7840	0.0019	1.1363	0.0202	24.23	0.44
JPT 14.2	hbl	1.4217	0.0043	0.0136	0.0000	1.5092	0.4253	0.0007	0.0000	3.2142	0.0071	1.2033	0.0071	25.65	0.19
JPT 14.2	hbl	1.3794	0.0032	0.0140	0.0001	1.9206	0.9794	0.0005	0.0000	1.4014	0.0021	1.2405	0.0118	26.44	0.28
JPT 14.2	hbl	1.3230	0.0021	0.0136	0.0001	1.2194	1.1968	0.0005	0.0000	1.1442	0.0005	1.1819	0.0141	25.20	0.32
JPT 14.2	hbl	1.3995	0.0028	0.0140	0.0001	3.2484	1.6530	0.0005	0.0001	0.8298	0.0003	1.2410	0.0184	26.45	0.41

Samples were irradiated at the McMaster Reactor, Canada, in three separate irradiations. J values for the irradiations, calculated from repeat analyses of biotite standard GA1550 are 0.00327± 0.00001 (T3B); 0.01101± 0.00006 (T2A, T5A, T11B/98) and 0.01220 ± 0.00006 (JPT 7, JPT 14.2).

* biotites from a crustal xenolith entrained in the dyke were analysed to avoid problems of alteration within the sample

APPENDIX 4. MAJOR, TRACE ELEMENT AND ISOTOPE DATA

sample	T2A/98	T3b/98	T4A/98	T5A/98	T11B/98	JPT14.2
series	Pabbai Z.	Pabbai Z.	Pabbai Z.	Pabbai Z.	Daggyai T.	Daggyai T.
lithology	glim dyke	glim dyke	glim dyke	glim dyke	dacite dyke	dacite dyke
(wt%)						
SiO_2	51.27	56.05	51.66	56.97	62.60	61.54
TiO_2	0.96	1.05	1.00	0.683	0.73	0.77
Al_2O_3	10.98	14.37	13.70	11.19	16.50	17.33
Fe_2O_3*	6.42	6.74	6.03	4.19	3.96	4.05
MnO	0.11	0.10	0.08	0.09	0.06	0.06
MgO	11.38	5.23	6.86	4.34	2.23	2.16
CaO	5.35	3.73	5.75	7.08	4.65	4.96
Na_2O	1.14	2.14	2.14	2.02	4.35	4.41
K_2O	7.69	5.96	6.52	5.03	2.82	2.70
P_2O_5	1.29	0.80	0.97	0.641	0.25	0.26
LOI	2.50	3.25	4.10	7.38	2.27	0.99
Total	99.09	99.41	98.97	99.61	100.41	99.23
Mg#	80.51	64.39	72.61	70.71	56.76	55.42
(ppm)						
Rb	642.61	325.63	401.00	283.93	99.76	67.34
Ba	4220.68	2695.74	2736.72	1593.45	740.06	733.93
Th	117.98	68.32	146.91	79.29	9.37	9.20
U	13.64	10.35	21.27	13.85	1.96	2.03
Nb	18.56	20.36	23.78	14.40	6.22	5.93
Ta	0.99	1.25	1.28	0.76	0.39	0.39
La	145.85	95.95	133.70	56.43	28.53	26.82
Ce	314.84	198.94	284.13	123.50	56.16	53.20
Pb	10.26	52.69	59.81	47.01	25.82	24.89
Pr	40.72	25.13	40.47	16.12	6.78	6.49
Sr	920.95	1114.95	698.87	767.48	996.22	856.27
Nd	167.12	101.55	164.95	66.96	26.31	25.01
Sm	30.13	18.19	27.24	11.90	4.28	4.18
Zr	323.33	367.91	484.50	253.46	139.34	130.45
Hf	8.38	9.62	12.62	6.88	3.64	3.49
Eu	5.33	3.49	4.58	2.17	1.11	1.08
Gd	19.92	12.67	15.53	7.89	3.11	3.08
Tb	2.05	1.52	1.50	0.91	0.36	0.36
Dy	8.20	7.07	5.93	4.24	1.70	1.73
Y	36.34	35.82	26.98	22.31	8.82	9.17
Ho	1.17	1.19	0.87	0.72	0.29	0.30
Er	2.70	2.96	2.06	1.84	0.73	0.76
Tm	0.35	0.42	0.27	0.27	0.10	0.11
Yb	2.15	2.55	1.64	1.62	0.61	0.65
Lu	0.31	0.38	0.24	0.24	0.09	0.10
87Sr/86Sr	0.739716	0.712352	0.712004	0.716194	0.706927	0.706957
$87Sr/86Sr_{(i)}$†	0.739947	0.712187	0.711674	0.710639	0.706856	0.706895
143Nd/144Nd	0.511737	0.511878	0.51198	0.511914	0.512085	0.512320
$143/144Nd_{(i)}$†	0.511727	0.511868	0.511971	0.511905	0.512074	0.512244
epsilon(t)Nd	-17.42	-14.67	-12.66	-13.97	-10.58	-7.19

*total Fe

†initial isotope ratios calculated using ^{40}Ar-^{39}Ar emplacement ages, $^{87}Rb/^{86}Sr$=2.981x (Rb/Sr), $^{147}Sm/^{144}Nd$=0.062x(Sm/Nd)