

Figure A1.

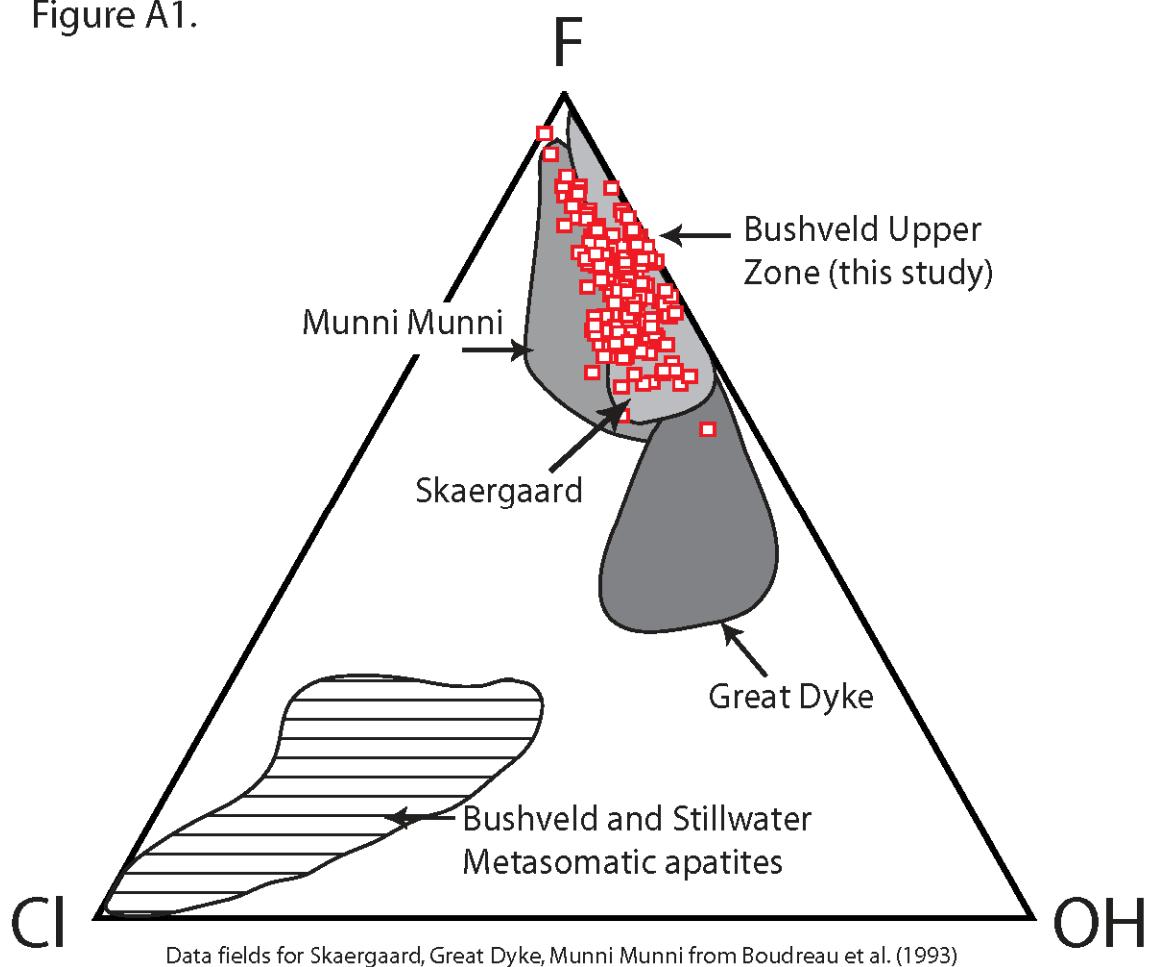


Figure DR1. Proportions of OH, F, and Cl of apatites from the Upper Zone of the Bushveld Complex obtained by electron microprobe (Table A1). Fields for other intrusions from Boudreau et al. (1993).

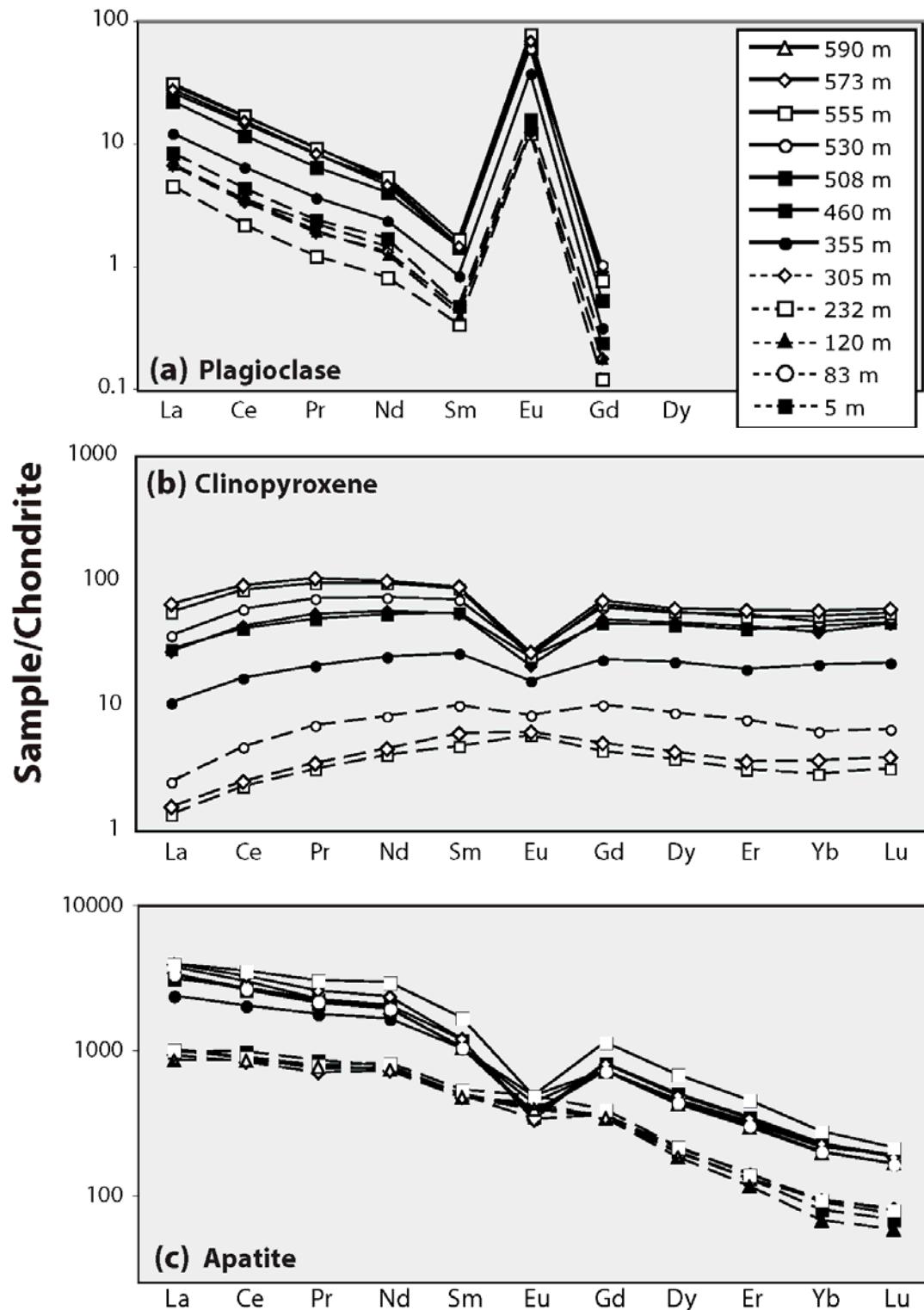


Figure DR2. Chondrite-normalized rare earth element concentrations measured in (a) plagioclase, (b) clinopyroxene, and (c) apatite (Tables DR1- DR3). Note the different scales of the ordinates. Dashed lines indicate analyses from the lower samples, and solid lines correspond to those from the upper samples. The stratigraphic height (m above apatite saturation) for each sample in the upper 625 m section are shown in the legend.

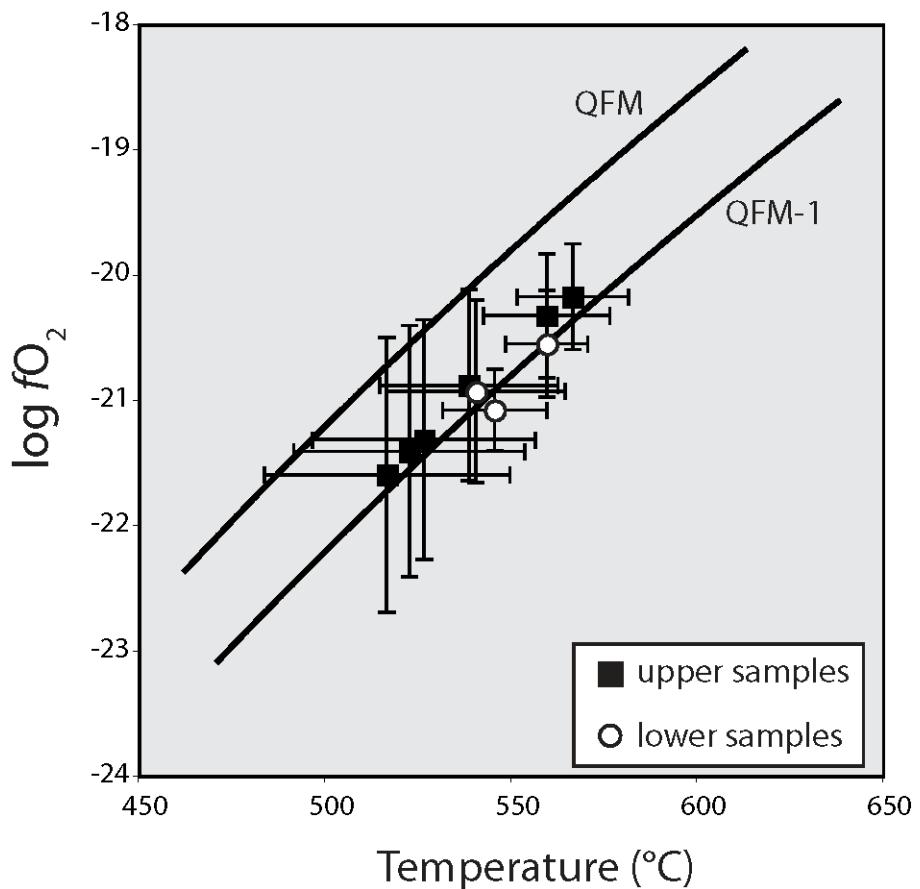


Figure DR3. Oxygen fugacity and temperature calculated using the program QUILF (Anderson et al., 1993), given the measured mineral compositions and assemblage in each sample. While closure temperatures are $\sim 550^{\circ}\text{C}$, empirical observations show that crystalline assemblages consistently cool along paths nearly parallel to solid oxygen buffers such as FMQ (e.g., Haggerty, 1976), suggesting that the low temperature $f\text{O}_2$ s are representative of those at magmatic conditions. Note that there is no measurable difference in $f\text{O}_2$ between the lower samples (circles) and upper samples (squares).

Appendix DR1

DLaAp = 8 (Watson and Green, 1981)	Mode Apatite = 5%
DLaCpx= 0.05 (Wood and Blundy, 1997)	Mode Clinopyroxene = 10%
DLaPlag = 0.2 (Bindeman et al., 1998)	Mode Plagioclase = 55%
DLaOther = 0	Mode Other = 30%

Apatite in the lower section (where olivine and magnetite are dominant) accounts for nearly 100% of the REE budget in the whole rock, suggesting that Ds for all other minerals are small.

Analytical Procedure

For electron microprobe analyses on apatites, an acceleration potential of 15 keV, beam current of 10 nA, count times of 30s on peak and 15s on each background, and a defocused beam of 5 microns diameter were used for all elements with the exception of Na and F, which were analyzed with a beam current of 4 nA. The Durango apatite standard was regularly reanalyzed as an unknown to monitor accuracy. Plagioclase, clinopyroxene and olivine analyses were collected with an acceleration potential of 15 keV, beam current of 20 nA, and count times of 30s on peak and 15s on each background for all elements. Standards for each phase were regularly reanalyzed as unknowns.

For LA-ICPMS analyses standards BCR, BIR, and BHVO were regularly reanalyzed for continuous calibration to account for machine drift, and NIST610 and 612 were analyzed as unknowns to monitor accuracy. A spot size of 25 um, a 10 Hz beam current, and a power of 2.02 GW/cm² were used for all apatite analyses. For each analysis, the location of the spot was determined with a petrographic microscope attached to the laser apparatus with both plane- and cross-polar light capabilities in order to avoid inclusions or secondary alteration. For all elements, the calibration regression had an $r^2 > 0.99$. Plagioclase and clinopyroxene analyses were performed at both LDEO and the Oregon State University Keck Observatory under similar conditions

Supplementary References Cited

- Andersen, D.J., Lindsley, D.H., and Davidson, P.M., 1993, QUILF - a Pascal Program to Assess Equilibria among Fe-Mg-Mn-Ti Oxides, Pyroxenes, Olivine, and Quartz: Computers & Geosciences, v. 19, p. 1333-1350.
- Boudreau, A.E., Love, C., and Hoatson, D.M., 1993, Variation in the Composition of Apatite in the Munni Munni Complex and Associated Intrusions of the West Pilbara Block, Western-Australia: Geochimica Et Cosmochimica Acta, v. 57, p. 4467-4477.
- Haggerty, S.E., 1976, Opaque mineral oxides in terrestrial igneous rocks, *in* Oxide Minerals, Rumble III, D., ed., Reviews in Mineralogy 3, p. Hg101-300.

Table DR1. *In Situ* Major and Trace Elements in Apatite

Uncertainties reported are 1-sigma standard deviations of the mean of the analyses for each sample

Table DR2. *In Situ* Major and Trace Elements in Plagioclase

Uncertainties reported are 1-sigma standard deviations of the mean of the analyses for each sample

Table DR3. *In Situ* Major and Trace Elements in Clinopyroxene

Sample #	B06-028	B06-029	B06-030	B07-027	B06-037	B06-055	B07-036	B07-037	B07-038	B07-039	B07-040	
Height above 4000 m (m)	5	83	120	232	305	355	460	508	530	555	573	
(a) Major Elements by EPMA (oxide wt%)												
SiO ₂	no pyroxene	51.32	0.17	no pyroxene	50.88	0.30	50.82	0.16	n/a	49.57	0.42	
TiO ₂		0.51	0.05		0.47	0.06	0.43	0.06		0.39	0.13	
Al ₂ O ₃		1.54	0.09		1.49	0.15	1.49	0.11		1.13	0.26	
Cr ₂ O ₃		0.01	0.00		0.01	0.01	0.00	0.00		0.01	0.01	
FeO		14.74	0.41		14.09	0.53	14.11	0.62		19.13	0.58	
MgO		11.47	0.12		11.82	0.15	11.95	0.15		8.28	0.27	
MnO		0.36	0.04		0.34	0.02	0.34	0.03		0.42	0.02	
CaO		20.79	0.43		20.71	0.77	20.64	0.55		20.47	0.44	
Na ₂ O		0.23	0.03		0.22	0.02	0.24	0.05		0.21	0.02	
Total		100.96	0.41		100.02	0.44	100.02	0.32		99.60	0.44	
En		33.08			34.15		34.43			24.55		
Mg#		58.11			59.92		60.15			43.55		
(b) Trace Elements by LAICPMS (ppm)												
Sc	n/a	Mean, n = 7	±1 Std Dev	n/a	Mean, n=5	±1 Std Dev	Mean, n=7	±1 Std Dev	Mean, n = 1	±1 Std Dev	Mean, n = 6	±1 Std Dev
Ti		151.95	11.62		174.27	9.91	171.94	7.86	169.04	220.62	4.39	235.04
V		3430.75	361.26		2529.75	273.88	2,506.76	387.26	2207.35	2976.53	629.06	2545.19
Cr		28.47	1.08		15.07	1.62	14.26	0.54	29.09	7.45	0.45	3.09
Mn		4.62	0.60		b.d.	b.d.	5.66	0.58	5.47	4.66	0.50	4.92
Cu		3254.67	117.39		3053.05	166.32	3,228.89	144.14	3423.35	3883.62	40.35	3681.55
Zn		0.75	0.20		0.42	0.06	0.50	0.37	1.82	0.50	0.11	0.54
Rb		103.71	5.13		96.80	13.99	99.04	6.24	160.70	213.82	4.70	180.53
Sr		0.03	0.02		b.d.	b.d.	b.d.	b.d.	b.d.	b.d.	0.17	0.10
Y		12.91	1.00		12.81	0.45	12.80	0.63	12.82	16.49	2.14	16.88
Zr		11.58	1.17		4.47	1.08	5.45	2.06	26.75	57.55	5.26	62.40
Ba		12.90	0.64		24.62	3.32	27.86	1.62	69.79	56.32	10.92	53.33
La		0.25	0.09		0.13	7.40	0.18	0.29	0.20	0.17	0.05	0.48
Ce		0.57	0.05		0.32	0.03	0.37	0.05	2.47	6.68	0.16	6.36
Pr		2.84	0.25		1.37	0.11	1.49	0.27	10.13	25.15	0.92	26.33
Nd		0.64	0.08		0.29	0.03	0.32	0.07	1.92	4.54	0.22	4.97
Sm		3.73	0.52		1.82	0.23	2.05	0.53	11.13	24.40	1.53	25.84
Eu		1.48	0.26		0.70	0.10	0.88	0.30	3.86	8.17	0.72	7.97
Gd		0.47	0.04		0.32	0.03	0.34	0.07	0.88	1.36	0.04	1.17
Dy		2.00	0.31		0.85	0.19	0.99	0.42	4.61	8.97	0.84	9.62
Er		2.14	0.25		0.91	0.16	1.04	0.44	5.49	10.80		11.25
Yb		1.22	0.20		0.49	0.10	0.57	0.24	3.10	6.43	1.12	6.83
Lu		0.99	0.19		0.45	0.11	0.58	0.23	3.39	6.92		6.21
Hf		0.16	0.03		0.08	0.01	0.09	0.04	0.54	1.13	0.56	1.10
Pb		0.17	0.02		0.89	0.05	0.97	0.11	2.40	1.85		0.56
Th		0.07	0.02		0.07	0.01	0.08	0.01	0.30	0.65	0.10	0.57
U		b.d.	b.d.		b.d.	b.d.	b.d.	b.d.	0.00	0.02	0.11	0.03
		b.d.	b.d.		b.d.	b.d.	b.d.	b.d.	0.11	0.11	0.02	0.07
		b.d.	b.d.		b.d.	b.d.	b.d.	b.d.	0.02	0.03	0.03	0.08

Uncertainties reported are 1-sigma standard deviations of the mean of the analyses for each sample

Table DR 4. Mineral proportions

Sample #	B06-028	B06-029	B06-030	B07-027	B06-037	B06-055	B07-036	B07-037	B07-038	B07-039	B07-040*
Height above 4000 m	5	83	120	232	305	355	460	508	530	555	573
Modes %**											
Plagioclase	46	53	52	61	55	45	46	55	55	53	57
Olivine	28	19	24	14	22	22	25	21	20	18	14
Clinopyroxene	1	10	1	7	6	5	9	5	7	12	16
Fe-Ti oxide	13	10	12	11	9	12	10	6	9	8	7
Apatite	13	8	11	7	8	14	7	6	6	5	5
Quartz	0	0	0	0	0	0	1	1	0	0	3
Orthoclase	0	0	0	0	0	0	2	7	4	4	5

N.B. These rocks are cumulates and therefore the modes of individual samples do not reflect the proportions of phases crystallizing from the liquid at any one time. This is especially the case at the top of the Bushveld Complex where numerous layers of variable thickness are present within the stratigraphy. See text for additional discussion of this issue.

*The stratigraphic height of sample B07-040 has been adjusted from VanTongeren et al. (2010)

**Modes were determined by point counting of 750 - 1000 points per thin section. Previously published modes for a portion of these samples (VanTongeren et al., 2010) were determined by least squares from the composition of the whole rock and mineral compositions and were therefore subject to bias resulting from the presence of secondary alteration minerals present in the whole rock analysis. The modes presented here are preferred.