Apatite from the Kimberley Kimberlites (South Africa): Petrography and Mineral Chemistry

Ashton Soltys[1], Andrea Giuliani[1,2], David Phillips[1]

[1] KiDs (Kimberlites and Diamonds), School of Earth Sciences, The Univeristy of Melbourne, Parkville, 3010 Victoria, Australia

soltysa@student.unimelb.edu.au

[2] ARC Centre of Excellence for Core to Crust Fluid Systems and GEMOC, Department of Earth and Planetary Sciences, Macquarie University, North Ryde, 2019 NSW, Australia

Introduction

Apatite ($Ca_5(PO_4)_3(F,Cl,OH)$) is a common accessory phase in a variety of igneous, metamorphic, and sedimentary rocks on Earth, as well as a diverse range of extra-terrestrial bodies (e.g., the Moon, Mars, and meteorites). Apatite is a robust mineral that is commonly used in thermochronology and geochronology studies, for tracing magmatic evolution (e.g., Chakhmouradian et al., 2017), and as a discrimination tool for exploration purposes (e.g., Mao et al., 2016).

Apatite is a near ubiquitous, late-stage, groundmass phase in archetypal kimberlites worldwide (e.g., Mitchell, 1986). In addition, it is a magmatic phase that does not contain xenocrystic components, unlike many other apparently magmatic phases in kimberlites (e.g., spinel, olivine, ilmenite, mica). Despite this, major element data for apatite in kimberlitic apatite is sparse (e.g., Chakhmouradian et al., 2002; Mitchell, 1986), in contrast with the numerous analyses published for other kimberlitic minerals, such as olivine, spinel, and mica (e.g., Mitchell, 1986; Roeder and Schulze, 2008, and references therein). In this contribution, we report the petrography and major-minor element chemistry of apatite from the Kimberley kimberlites (South Africa). The studied samples are derived from the Kimberley Mine, De Beers, Wesselton (units W2 and W3 – Shee, 1985), Wesselton water tunnel sills, and Benfontein. The samples range in texture from "evolved" aphanitic kimberlites (i.e., without olivine macrocrysts - Benfontein) to highly macrocrystic kimberlites (i.e., ~30 vol.% olivine macrocrysts - Wesselton (W3) and Kimberley Mine).

Apatite Petrography

Apatite from the Kimberley kimberlites occurs in two textural settings: (1) discrete subhedral-euhedral hexagonal prisms, which range from ~1-100 μm in size, with most grains ~20-50 μm in length and characterised by hopper-like crystal forms; and (2) aggregates of elongate (up to 400 μm in length) acicular apatite with radial growth forms that are confined to carbonate-rich or carbonate-serpentine segregations These textural descriptions are consistent with previous petrographic reports of apatite in kimberlites (e.g., Mitchell, 1986; Malarkey et al., 2010), and both textural types commonly occur within the same thin section.

Most apatite grains appear unzoned in back-scattered electron (BSE) images, except for apatite from the Kimberley Mine which have a thin (<5 μm) overgrowth of Na-rich apatite (~3.5 wt.% Na_2O based on semi-quantitative SEM-EDS measurement). Acicular apatite in radial aggregates associated with carbonate-rich segregations of the Wesselton water tunnel sills show zonation under cathodo-luminescence (CL); however, no compositional variation was detected by EMP analysis, consistent with the lack of change in BSE response, and findings from previous studies of various other rock types (e.g., carbonatites, porphyries, skarns – Mao et al., 2016)

Apatite Composition

Average compositions of apatite from the Kimberley kimberlites are reported in Table 1. Measured grains can effectively be considered as solid solutions between fluorapatite (2.2 ± 0.4 wt.% F) and hydroxyapatite (0.70 ± 0.20 wt.% H_2O), with a negligible chlorapatite component (Cl was below the

detection limits of EMP measurements in most instances). Apatite from serpentine-rich segregations in the De Beers kimberlite have the highest H_2O contents (1.0 ± 0.1 wt.%). The studied apatite grains contain relatively homogeneous CaO (55.0 ± 1.0 wt.%) and P_2O_5 (38.9 ± 0.7 wt.%) contents. Minor impurities include variable SiO_2 (0.77 ± 0.48 wt.%) and SrO (2.1 ± 1.4 wt.%) contents, as well as subordinate concentrations of Na_2O (≤0.4 wt.%), FeO (≤0.5 wt.%), and LREE oxides (≤0.3 wt.% Ce_2O_3) in some samples. These compositions are broadly consistent with the limited published data available (e.g., Mitchell, 1986).

	(1), n=7		(2), n=14		(3), n=13		(4), n=24		(5), n=8		(6), n=19	
	Mean	1σ	Mean	1σ	Mean	1σ	Mean	1σ	Mean	1σ	Mean	1σ
SiO_2	0.70	0.18	0.30	0.17	0.60	0.12	0.47	0.10	1.51	0.40	1.36	0.15
TiO_2	0.02	0.01	0.03	0.06	0.02	0.01	0.02	0.03	0.00	0.00	0.01	0.02
Fe_2O_3	0.26	0.07	0.13	0.05	0.21	0.06	0.28	0.07	0.06	0.05	0.16	0.08
MgO	0.12	0.13	0.02	0.02	0.04	0.03	0.03	0.04	0.04	0.02	0.07	0.02
CaO	53.58	0.56	55.75	0.62	56.05	0.38	53.98	0.75	55.16	0.15	55.47	0.41
Na_2O	0.24	0.07	0.13	0.11	0.05	0.02	0.19	0.10	0.11	0.05	0.08	0.02
P_2O_5	38.03	0.45	39.50	0.45	39.50	0.37	38.52	0.56	38.74	0.65	38.91	0.43
SrO	3.46	0.27	1.68	0.67	1.18	0.12	3.73	0.80	1.40	0.11	0.61	0.07
La_2O_3	0.04	0.04	0.02	0.03	0.08	0.05	0.04	0.04	0.05	0.05	0.16	0.05
Ce_2O_3	0.00	0.00	0.02	0.03	0.03	0.03	0.00	0.01	0.03	0.04	0.22	0.06
SO_3	0.06	0.03	0.07	0.03	0.03	0.02	0.05	0.03	0.04	0.04	0.04	0.03
F	2.65	0.34	1.56	0.23	2.55	0.22	2.33	0.22	2.16	0.23	2.01	0.18
Cl	0.00	0.00	0.02	0.04	0.01	0.01	0.01	0.01	0.02	0.02	0.03	0.01
H_2O(c)	0.45	0.16	1.00	0.11	0.54	0.10	0.61	0.10	0.72	0.11	0.78	0.08
O=F	1.11	0.14	0.66	0.09	1.08	0.09	0.98	0.09	0.91	0.10	0.85	0.08
O=Cl	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Total	98.58	0.48	99.61	0.71	99.86	0.53	99.32	0.63	99.17	0.48	99.10	0.57

Table 1: Average compositions of apatite from the Kimberley Kimberlites: (1) Kimberley Mine; (2) De Beers; (3) Wesselton (W2); (4) Wesselton (W3); (5) Wesselton water tunnel sills; (6) Benfontein.

Apatite from more "evolved" aphanitic carbonate-rich dykes and sills (i.e., Benfontein and Wesselton Water Tunnel Sills) are generally enriched in SiO_2 (and LREE in the case of Benfontein), and generally poorer in Na_2O and SrO, compared with apatite in macrocrystic kimberlites (i.e., Kimberley Mine and Wesselton) (Fig. 1; Table. 1). In addition, bi-variate major-minor element plots can be used to discriminate between different kimberlite samples and, probably, intrusions (e.g., Fig. 1). Apatite compositions exhibit more variation between intrusions than either spinel or olivine from the Kimberley kimberlites (our unpublished results). This may be attributed to the fact that apatite is a relatively late-stage phase in kimberlites (compared with olivine or spinel) and therefore may be more sensitive to the effects of magmatic differentiation.

Although the current apatite grains show variation between intrusions across the Kimberley kimberlites, when compared with other rock types, kimberlitic apatite grains exhibit relatively narrow compositional ranges. For instance, kimberlitic apatite grains contain lower SrO and SiO_2 than those in South African orangeites (e.g., Mitchell, 1995, and references therein), and significantly less BaO and TiO_2 compared to apatite in Western Australian lamproites (Edgar, 1989). In addition, the low Cl concentrations of kimberlitic apatite overlap those of apatite in carbonatites (Piccoli and Candella, 2002, and references therein); however, kimberlitic apatite does not show the same excess of F in the anion site, potentially suggesting lower CO_3^{2-} concentrations in kimberlitic apatite. In addition, kimberlitic apatite grains generally contain less MnO, Na_2O, and S than carbonatitic apatite. These differences in apatite composition appear to reflect variations in bulk-rock composition between these magma types (i.e., carbonatites contain more MnO, Na_2O, CO_2 and S than kimberlites).
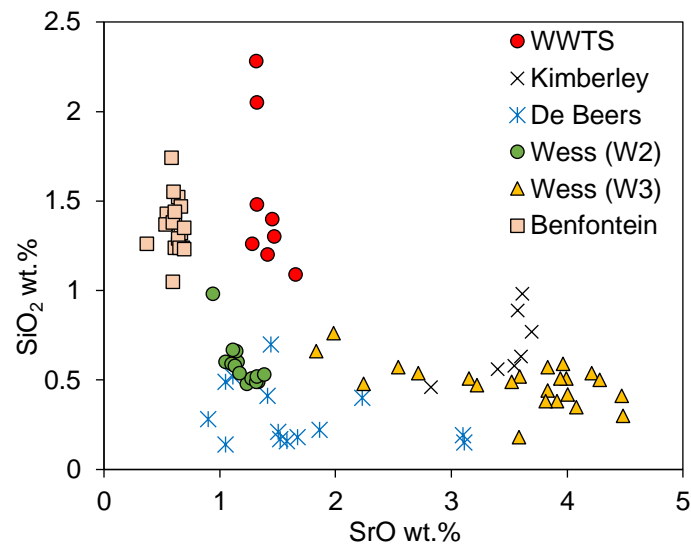
Figure 1: SiO$_2$ vs. SrO varations for apatite grains from the Kimberley Kimberlites.

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