OXIDE MINERALS IN CHICKEN PARK KIMBERLITE NORTHERN COLORADO

M.E. McCallum

Department of Earth Resources
Colorado State University, Fort Collins, Colorado 80523, U.S.A.

Hypabyssal phases of the Chicken Park kimberlite complex in the State Line District of northern Colorado are characterized by high concentrations of ilmenite, spinel, and perovskite, and minor amounts of rutile. Total oxide content locally exceeds 20 volume percent. Spinel and ilmenite occur primarily as macrocrysts (> 1 mm) and microcrysts (< 1 mm) (grains of probable xenocrystic and/or very early phenocrystic origin), and as euhedral or corroded anhedral grains in the kimberlite groundmass. Titanomagnetite commonly rims ilmenite, chromian spinel and perovskite, occurs as reduction "exsolution" lamellae along {0001} planes in some macrocrystic-microcrystic ilmenite, and as atolls surrounding many groundmass spinels. Perovskite occurs predominantly as euhedral to subhedral crystals in the groundmass, but also is an important component (intergrown with titano magnetite) of reaction mantles rimming many ilmenite grains. Rutile is found as tiny acicular to rod-like inclusions in the outer parts of serpentinized olivine macrocrysts and as small irregular "intergrowths" with perovskite in ilmenite reaction mantles.

Picroilmenites dominate the opaque mineral macrocryst-microcryst suite, and their generally rounded, corroded and mantled nature is distinctive from most of the typically small (< 0.1 mm), euhedral to subhedral "lath" or rhombohedral platelet groundmass ilmenites. The groundmass ilmenites are characterized by enrichment in manganese and iron (1.0-8.2 wt.% MnO and 35 to 41 wt.% FeO) and low MgO (0.5 to 6.0 wt.%) (Table 1, analyses 17 and 18). Macrocrystic-microcrystic ilmenites (Table 1, analyses 13-16) generally are MnO poor (< 1.0 wt.%) and contain 10-21 wt.% MgO; low MgO (< 12 wt.%) grains tend to be enriched in iron, and some high Fe_2O_3 (17-21 wt.%) varieties are enriched in Cr_2O_3 (1.0-3.6 wt.%). Ilmenite with reduction "exsolution" lamellae of spinel generally have lower MgO and higher FeO contents (Table 1, analyses 11 and 12) but exhibit a rather wide range of compositions. Many ilmenite grains show a core to rim enrichment in MgO and depletion in FeO.

Spinels are abundant in the groundmass as small (most < 0.05 mm) compositionally simple euhedral grains of titanomagnetite, Mg-titanomagnetite (as much as 12.5 wt.% MgO), and local Ti-Mg-chromites (Table 1, analyses 3-5). Zoned groundmass spinel grains tend to be somewhat larger (most 0.03-0.13 mm), and exhibit a generally consistent trend from Cr-Al-rich and Ti-Mn-poor cores (28-60 wt.% Cr_2O_3, 5-20 wt.% Al_2O_3, 0.3-7.0 wt.% TiO_2 and 0.2-0.5 wt.% MnO) to mantles and rims that are progressively enriched in TiO2 and MnO (as much as 12.3 and 1.5 wt.% respectively) and depleted in Cr_2O_3 and Al_2O_3 (as little as 0.23 and 0.61 wt.% respectively) (Table 1, analyses 1 and 2; Fig. 1, B-E). Zoned crystals with highly chromian cores (> 45 wt.% Cr_2O_3) exhibit intermediate zones that are more aluminous than adjacent core and rim (Fig. 1, B). These zones are comparable in composition to cores of the generally smaller, less chromian, zoned spinel crystals (Fig. 1, C-E) which apparently nucleated during the same period of crystallization. Atoll textured or skeletal spinels occur as discrete forms or as "mantles" on chromite or Cr-titanomagnetite cores. These spinels typically are manganoan titanomagnetites (Table 1, analysis 6; Fig. 1, E), and are compositionally similar to most of the smallest (< 0.02 mm) euhedral-anhedral titanomagnetite grains in the groundmass and to many of the reaction mantle spinels rimming earlier formed groundmass and xenocrystic(?) oxide minerals (Table 1, analyses 7 and 8; Fig. 1, H and rims for A-D). Titanomagnetite reduction "exsolution" lamellae in ilmenite macrocrysts and microcrysts are chemically similar to associated reaction mantle spinels (Table 1, analyses 7-10; Fig. 1, H and I) although the lamellae generally are less enriched in MnO (0.1-2.1 vs. 0.5-3.6 wt.%), more enriched in FeO (37-52 vs. 25-37 wt.%), and exhibit a greater range of Fe_2O_3, TiO_2 and MnO values. Rare xenocrysts of aluminous chromite (Fig. 1, A) are compositionally similar to Al-chromite grains in spinel peridotite xenoliths recovered from the district, and are rimmed by manganoan titano magnetite. Some tiny (< 0.002 mm) opaque grains in serpentinized olivine macrocrysts give energy dispersive x-ray patterns that are consistent with magnetite.

Euhedral to subhedral, groundmass perovskite crystals range from about 0.05-0.13 mm in diameter and generally are zoned, the larger grains exhibiting more pronounced chemical variations. Cores typically contain in excess of 2.5 wt.% REE (Ce, Nd and La the major contributors), but rim totals generally are less than 0.5 wt.% (Table 1, analyses 19 and 20). Na_2O content, which may exceed 0.50 wt.% in cores, also decreases towards rims (commonly by about one half). FeO systematically increases from core to rim (about 0.9-1.2 vs. 1.1-1.7 wt.%) and Nb_2O_5 also is slightly more enriched in rims (0.36-0.44 vs. 0.44-0.52 wt.%). Perovskite in reaction mantles of ilmenite grains is chemically similar to rims of groundmass euhedra, although FeO contents tend to be somewhat higher (locally exceed 2 wt.%).

The small size of the rutile grains (generally less than 0.002 mm wide although acicular crystals may exceed 0.02 mm in length) present difficulties in obtaining accurate chemical analyses. However, partial analyses indicate that the rutiles are chromian, and low totals may in part indicate the presence of Nb which has been reported from kimberlite rutiles elsewhere (e.g. Mitchell, 1979).

The Chicken Park kimberlite oxide mineral assemblage reflects crystallization from a Ti-rich liquid that became progressively more enriched in Fe and Mn as Al-Mg-Cr spinels and picroilmenite formed. Most picroilmenite crystallized early in the mantle although more magnesian rims on some grains probably were added during magma ascent. Reduction "exsolution" of titanomagnetite lamellae in picroilmenite also occurred early as indicated by extensive resorption of these grains and involvement of the lamellae in reaction mantles of perovskite and titanomagnetite. Variable chemistry of the lamellae apparently reflects changes in f_{O_2} and T during the reduction exsolution process, and this information will be useful in providing data on the redox state of the upper mantle under northern Colorado.

The earliest groundmass spinels were Al-deficient aluminous-magnesian chromites that were subsequently partially resorbed and rimmed by titaniferous-aluminous-magnesian chromite which also nucleated as discrete crystals. Ilmenite was no longer crystallizing at this point and the residual melt became progressively enriched in Ti along with Fe^{3+} and Mn which favored the formation of chromian titanomagnetite and eventually manganoan titanomagnetite (Fig. 1). These phases occur as progressive growth rims on zoned spinels, as small discrete crystals and as reaction mantles on ilmenite grains. Perovskite crystallization was initiated by increased Ca levels in the melt. Accompanying increases in CO_2 content favored the transport of Mn and Nb-REE, the former concentrated in late stage, euhedral, Mn-rich ilmenites and titanomagnetites, the latter in perovskites, particularly the euhedral to subhedral groundmass grains. Some late stage Mn- ilmenites also have significant enrichment in Nb. The final oxide phase to crystallize was manganoan titanomagnetite that occurs as atolls, skeletal and tiny groundmass crystals, and as rims and/or reaction mantles on spinel, ilmenite and perovskite crystals. Irregular grains of rutile "intergrown" with perovskite in reaction mantles appear to be replacing the perovskite and if so, would also be very late stage. Variations in compositions of zoned crystal sequences and reaction mantles reflect changes in cation activities along with redox conditions and temperature.

REFERENCE

MITCHELL, R.H., 1979, Mineralogy of the Tunraq kimberlite, Somerset Island, N.W.T., Canada. In: F.R. Boyd and H.O.A. Meyer (eds.), Kimberlite, Diatremes and Diamonds, Vol. 1, pp. 161-171. American Geophysical Union, Washington.

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Table 1. Representative Chemical Compositions of Oxide Minerals from Chicken Park Kimberlite.

	Zoned spinels				Unzoned spinels			Atoll spinel	Reaction mantle spinels		"Exsolution" lamellae spinels in ilmenite macrocrysts	
	1		2		3	4	5	6	7	8	9	10
wt.%	core	rim	core	rim								
TiO_2	0.29	8.26	4.48	8.69	6.24	7.41	9.20	7.90	11.43	21.45	29.11	23.72
Al_2O_3	8.81	1.88	16.95	2.24	8.36	10.88	6.41	3.41	4.46	1.16	1.06	1.07
Cr_2O_3	56.45	3.27	34.34	4.91	13.04	8.32	0.40	0.84	4.55	0.50	0.98	3.02
FeO	14.77	26.03	16.96	25.38	23.28	20.89	25.70	28.58	30.79	46.04	49.81	49.34
Fe_2O_3	6.55	50.75	12.52	48.87	38.66	39.93	47.97	51.90	40.34	26.39	12.14	19.02
MnO	0.47	0.61	0.44	0.68	0.73	0.67	0.68	0.90	0.95	2.02	0.85	0.38
MgO	11.87	7.81	13.88	8.68	9.54	11.99	9.22	6.09	6.83	1.96	4.73	2.12
	99.21	98.61	99.57	99.45	99.85	100.09	99.58	99.62	99.35	99.52	98.68	98.67

	Ilmenite macrocrysts with spinel "exsolution" lamellae		Ilmenite macrocrysts		Mantled ilmenite microcrysts		Euhedral ilmenites		Zoned perovskites			
	11	12	13	14	15	16	17	18	19		20	
wt.%									core	rim	core	rim
TiO_2	55.28	53.55	59.89	52.23	56.43	57.45	54.14	52.81	55.65	56.00	55.39	54.86
Al_2O_3	0.62	0.07	0.09	0.38	0.07	0.00	0.01	0.00	0.27	0.24	0.00	0.00
Cr_2O_3	0.11	0.31	0.09	0.29	0.22	0.14	0.20	0.22	0.00	0.03	0.00	0.03
FeO	26.88	29.73	15.48	26.64	21.94	21.62	36.64	38.75	1.06	1.34	1.40	1.74
Fe_2O_3	4.68	5.74	3.22	8.70	4.91	2.99	0.51	0.17	*	*	*	*
MnO	0.39	0.95	0.66	0.20	0.63	0.97	3.19	7.74	0.05	0.00	0.04	0.09
MgO	12.61	9.81	21.13	11.28	15.81	16.29	4.92	0.25	0.13	0.08	0.14	0.08
CaO	0.00	0.03	0.07	0.04	0.00	0.06	0.09	0.37	39.38	40.87	38.42	40.57
Na_2O	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.40	0.23	0.39	0.17
Nb_2O_3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.42	0.45	0.41	0.52
REE	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	2.59	0.23	2.57	0.51
	100.57	100.19	100.63	99.76	100.01	99.52	99.70	100.31	99.95	99.47	98.76	98.57

n.a. - not analyzed. * all Fe as FeO. Electron microprobe analyses obtained at the University of Cape Town, South Africa, and the U.S. Geological Survey, Denver, Colorado.

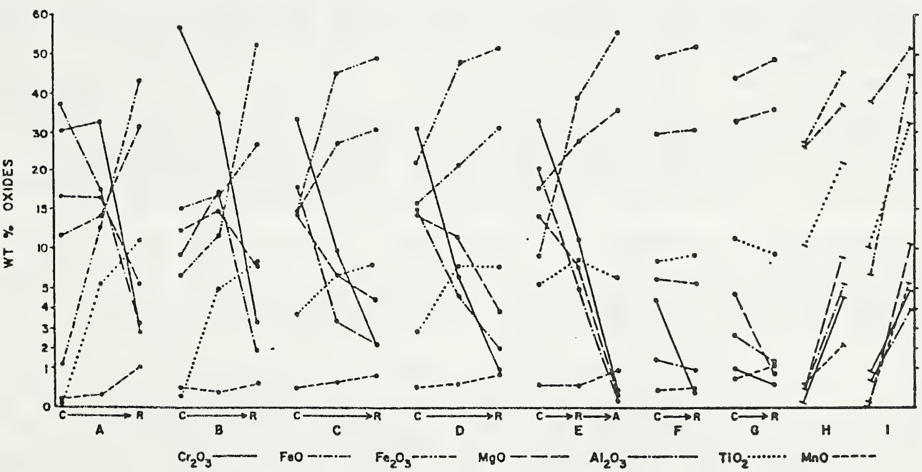

Fig. 1. Major element variations in spinels. A: Red-brown aluminous chromite macrocryst (derived from spinel peridotite xenolith) with titanomagnetite rim (R). B-D: Zoned spinels with chromian cores (C) and titanomagnetite rims (R). E: Zoned chromian spinel with titanomagnetite atoll (A). F and G: Small (> 0.04 mm), euhedral, groundmass titanomagnetites. H: General compositional range of titanomagnetite reaction rims on ilmenite. I: General compositional range of titanomagnetite "exsolution" lamellae in ilmenite.