ILMENITE AND SILICATE MEGACRYSTS FROM HAMILTON BRANCH: TRACE ELEMENT GEOCHEMISTRY AND FRACTIONAL CRYSTALLIZATION.

W.L. Griffin[(1)]; C.G. Ryan[(1)] and D.J. Schulze[2].

(1) CSIRO Div. of Exploration Geoscience, Box 136, North Ryde, NSW 2113, Australia; (2) Dept. of Geology, Univ. of Toronto, Erindale College, Mississuagua, Ontario L5L1C6, Canada.

Introduction: The Hamilton Branch kimberlite in eastern Kentucky contains a well-developed suite of ilmenite and silicate (cpx+opx+gnt) megacrysts. The ilmenites range in MgO from 15% to 9% and in Cr2O3 from 5% to 0.2%, describing a rough parabola in a Cr-Mg plot (Fig. 1;Schulze, 1984). High-Cr, high-Mg ilmenites occur as inclusions in silicates, and lower-Cr, high-Mg ones in intergrowths with clinopyroxene; small silicate inclusions occur in low-Cr ilmenites with 12-14% MgO. No silicates are known to be associated with the ilmenites containing <12% MgO. This trend has been interpreted as the result of fractional crystallization; a continuous increase in Ca/(Ca+Mg) in clinopyroxene with decreasing Cr in silicates and ilmenite suggests that silicates and ilmenite crystallized together over a T range from ca. 1450-1200 °C. This study presents trace-element data, obtained by proton microprobe, on the ilmenites and associated clinopyroxene, and provides further information on the processes of fractional crystallization that have produced the ilmenite megacrysts.

Data: Schulze (1984) showed that Cr in cpx decreases as Ca/(Ca+Mg) increases, i.e. with declining T. Our data show that Ni in cpx also decreases, and Zr increases, as Cr and Mg decrease; these trends are consistent with the fractional crystallization model. Sr in cpx decreases slightly, from 180-140 ppm, as Ni drops from 350-110 ppm, then drops to 80 ppm at 60 ppm Ni. This trend suggests that clinopyroxene was a major fractionating phase, and is consistent with its abundance in the megacryst assemblage.

Nb in ilmenite ranges from 400-2600 ppm, and is positively correlated with Zr (250-900 ppm) (Fig. 2). Nb shows a strong negative correlation with Mg in ilmenite (Fig. 3), while the Mg content of the ilmenites is positively correlated with Mg in coexisting silicates. Nb and Zr appear to have behaved as incompatible elements during the entire crystallization process, and the Nb content of the ilmenites is therefore taken as an index of fractionation.

Most of the increase in the Nb content of ilmenite takes place after MgO has declined below 12%, i.e. after the point where coexisting silicates have not been recognized. The Cr and Ni contents of ilmenites decrease as Nb rises; Cr drops to its minimum value at a lower Nb content than does Ni (Figs. 4,5). The smooth covariation of Mg and Ni against Nb is interupted by a major spike at ca. 1000 ppm Nb; Ni rises from 200-950 ppm, and MgO from 12.5-15%, at essentially constant Nb and Zr. Another possible spike is represented by 2 points near 2000 ppm Nb.

Al2O3 in ilmenite decreases steadily (from >1% to 0.25%) as Nb increases. Ga contents of ilmenites show a weak and irregular increase from ca. 12 ppm to ca. 20 ppm with increasing Nb. Zn contents also rise, from ca. 100-120 ppm, following the end of silicate crystallization, then fall slowly again. Nb/Ta varies irregularly at first, then rises from 6 to 8 as Nb increases from 1000-2600 ppm.

Discussion: The smooth covariance of Ni, Zr etc. against Nb is typical of ilmenite megacryst suites from kimberlites and some lamproites, worldwide (Moore et al., 1991; Griffin and Ryan, unpubl.). These smooth variations are generally consistent with the fractional crystallization of a single batch of magma. At Hamilton Branch, most of the rise in the Nb and Zr contents of ilmenite takes place after mafic silicates apparently stopped crystallizing; this corresponds to the late stages of crystallization, at T<1200°C. Simple calcilations, treating Nb and Zr as perfectly incompatible elements, show that >60% of the liquid crystallized between the beginning of ilmenite precipitation and the end of cpx crystallization. Half of the remainder crystallized to produce the lowest-Mg, highest-Nb ilmenites. Since Nb and Zr were obviously not completely incompatible, these are minimum estimates of the degree of crystallization, and any pre-ilmenite crystallization of mafic silicates would raise these estimates. The rise in Nb/Ta of the ilmenites at high Nb is further evidence of extreme fractional crystallization.

The major spike in the Ni-Nb and Mg-Nb curves (Figs. 2-4) is interpreted as the result of mixing between the main batch of magma and a similar, less-fractionated magma. This would have the most severe effects on the strongly depleted, compatible elements, but less on Nb and Zr. Similar magma-mixing episodes earlier in the sequence may have contributed to the scatter in the high-Mg limb of the Mg-Cr plot (Fig. 1); these would be difficult to recognize without the enrichment of Nb and Zr as benchmarks.

Schulze (1984) argued that other phases (olivine, phlogopite and/or carbonate) must have crystallized together with ilmenite in the late stages of fractionation, to prevent the magma from being enriched in Mg. However, the relatively gradual drop in Ni, and the fact that the Ni content of ilmenite does not drop below 100 ppm, suggest that olivine was not a coprecipitating phase. However, the fact that Ni appears to remain constant as Nb increases from 1000 to >2000 ppm argues for the crystallization of a Ni-bearing phase, perhaps sulfide. Cr is incompatible at this stage, rising from 0.2 to 0.4% (Fig. 1). The slow drop in Al during the fractionation may reflect the precipitation of phlogopite, but the rise in Ga during the late fractionation would appear to contradict this. The ilmenites from the Twin Knobs lamproite (Griffin et al, 1991) are quite similar to those from Hamilton Branch, but show a rise in Ni and Cr equivalent to the rise in Nb late in the fractionation, consistent with the absence of any mafic silicates in the cumulate assemblage.

The high Nb and Zr contents of the ilmenites, compared to the Nb and Zr contents of known magmatic rocks, suggest that ilmenite/magma K_D values for these elements are >>1. The apparently continuous rise in Nb and Zr during fractionation, despite the high Nb and Zr contents of ilmenite, therefore implies that ilmenite was never more than a minor phase in the cumulate assemblage. If olivine and phlogopite are ruled out as late cumulate phases, then carbonate may be required to buffer the Mg content of the liquid, as suggested by Schulze (1984).

The low-Mg, moderate-Cr ilmenites that define the low-Mg arm of the "parabola" in Fig. 1 may not be related to the main ilmenite assemblage. Both analyzed grains lie off the main Nb-Ni curve, and one has lower Zr than the main trend. While they appear on Fig. 1 to represent the latest stages of fractionation, they do not have the highest Nb contents. There is therefore no clear evidence that they represent a continuation of the main fractionation trend. However, their high Nb and Zr contents show that they are late-stage ilmenites, and they may be from a related but separate batch of cumulates, sampled by the ascending kimberlite.

Griffin, W.L., O'Reilly, S.Y., Ryan, C.G. and Waldman, M.A., 1991 (this vol).

Moore, R.O., Griffin, W.L., Gurney, J.J., Ryan, C.G., Cousens, D.R., Sie, S.H. and Suter, G.F., 1991. Contrib. Mineral. Petrol., in press.

Schulze, D.J., 1984. in Kornprobst, J. (ed.) Kimberlites II: the Mantle and Crust-Mantle Relationships. Elsevier, Amsterdam. pp. 97-108.

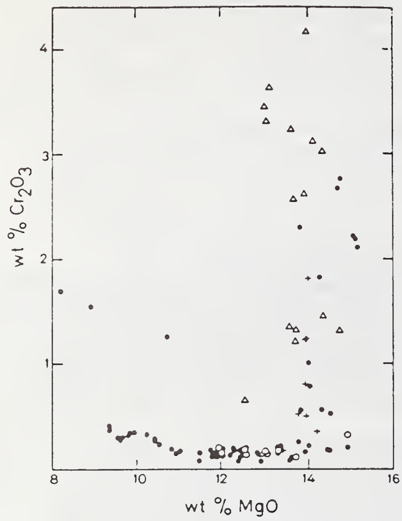
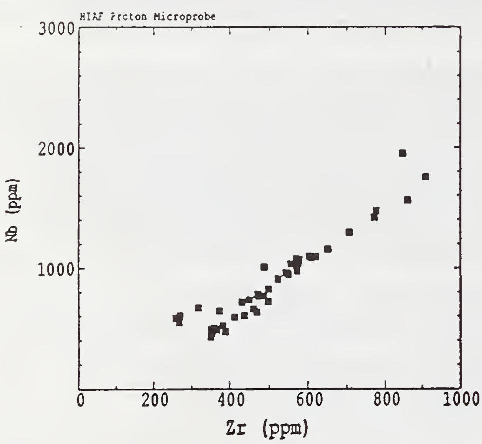
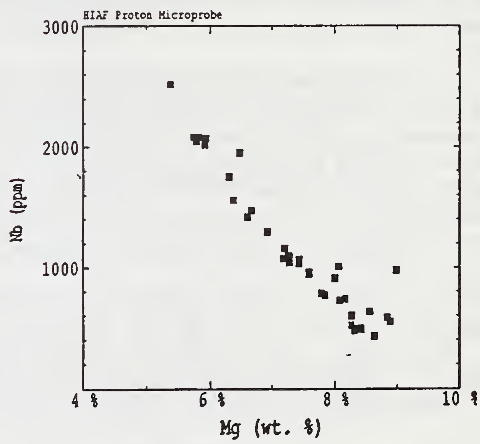
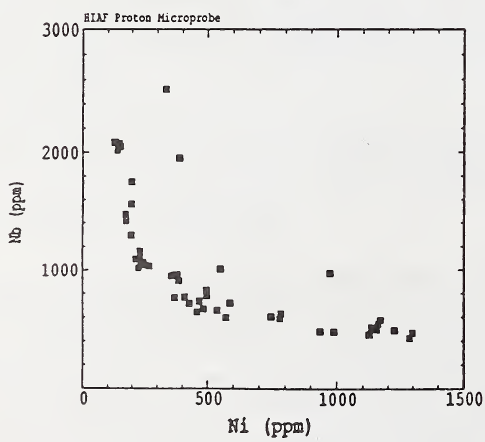


Fig. 1. Mg-Cr in Hamilton Branch ilmenites. Triangles: tiny ilmenites in silicate megacrysts; crosses, cpx-ilm intergrowths; open circles, ilmenites with silicate inclusions; dots, monomineralic ilmenites.







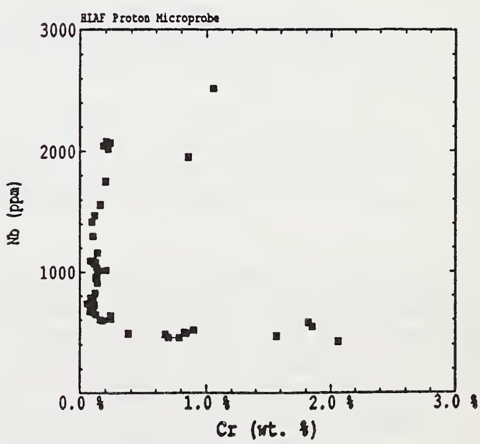


Fig. 2. Nb-Zr relations in ilmenites

Fig. 3. Nb-MgO relations in ilmenites

Fig. 4. Nb-Cr relations in ilmenites

Fig. 5. Nb-Ni relations in ilmenites