COMPOSITIONAL CLASSIFICATION OF "KIMBERLITIC" AND "NON-KIMBERLITIC" ILMENITE, WITH IMPLICATIONS FOR VISUAL SELECTION AND DISCRIMINATION

Mike Baumgartner[1], Eva Ankar[2], Herman Grutter[3]

[1] Mineral Services, South Africa; [2] UCT Kimberlite Research Group, South Africa; [3] Mineral Services, Canada

INTRODUCTION

The distinction of ilmenites derived from kimberlitic versus non-kimberlitic rocks is important in the context of diamond exploration in regions in which these minerals are present in relatively low abundance, but where they are the dominant type of kimberlitic indicator mineral recovered. Ilmenite is also the indicator mineral whose compositional variety could be used to resolve provenance issues related to mineral dispersions with contributions from one or more kimberlite sources. This study provides a new scheme for separating kimberlitic from non-kimberlitic ilmenite on the basis of major element compositions.

The visual distinction of kimberlitic versus non-kimberlitic ilmenite during the extraction of these grains from exploration sample concentrates is imperfect. Distinguishing ilmenite derived from kimberlites versus similar ultramafic rocks such as ultramafic lamprophyres is practically impossible, even for highly trained mineral sorters. The latter problem is a direct result of their compositional similarity in the range 4 to 6 wt% MgO. In addition, ilmenite populations derived from kimberlites or lamprophyres share similar mantle-derived petrogenetic origins, but have different significance in the context of diamond exploration. Since ilmenite is a key indicator mineral in the search for kimberlites, its correct identification is critical and this cannot be done on the basis of visual characteristics alone. This study highlights the need to determine the compositions of ilmenites picked from exploration sample concentrates, particularly during early phases of sampling being conducted in new exploration areas.

METHODS

The compositions of ilmenite derived from potentially diamondiferous sources (kimberlites and lamproites) and other non-kimberlitic sources (e.g. ultramafic lamprophyres, basalt and gabbro) have been compiled from published data and characterised. Compositional fields for ilmenites derived from kimberlites (sensu stricto), and other non-kimberlitic rock types have been defined on selected bi-variate graphs and form the basis of a robust new classification scheme. Ilmenite TiO_2-MgO diagrams were found to be particularly useful to discriminate kimberlitic from non-kimberlitic ilmenite compositions, and we have inserted lines of equal hematite content in scatter plots of TiO_2 vs. MgO. The Fe_2O_3-content lines were calculated from stoichiometric relations in the simplified system TiO_2-MgO-FeO-Fe_2O_3 and do not account for actual variations in ilmenite Fe_2O_3 contents that result from the presence of Cr_2O_3 or Al_2O_3. These apparent Fe_2O_3-content lines may nevertheless aid in estimating the relative oxidation state of ilmenite populations and are also useful in assessing the integrity of analytical data.

KIMBERLITIC ILMENITES

Mineral compositions for ilmenites derived from southern African kimberlite concentrates were compiled from the University of Cape Towns' Kimberlite Research Group (KRG) database. The available analyses largely represent ilmenite core compositions and were separated into on-craton and off-craton localities. Figures 1 and 2 are bi-variate plots of major element MgO versus TiO_2 showing the compositional ranges of ilmenites in off-craton and on-craton Group I kimberlites respectively.

A parabolic arc encompassing ~ 90% of the data has been drawn by eye, and the area to the MgO-rich side of the arc is defined as the "Kimberlitic" ilmenite field. The arc is well-defined by kimberlitic ilmenite compositions from on-craton and off-craton localities at MgO contents between 4 and 15 wt% (Fig. 1 and 2). The apparent Fe_2O_3 contents in kimberlitic ilmenites from on-craton and off-craton sources is broadly similar, and fall in the range 10 to 30% hematite (Fig.1 and 2).

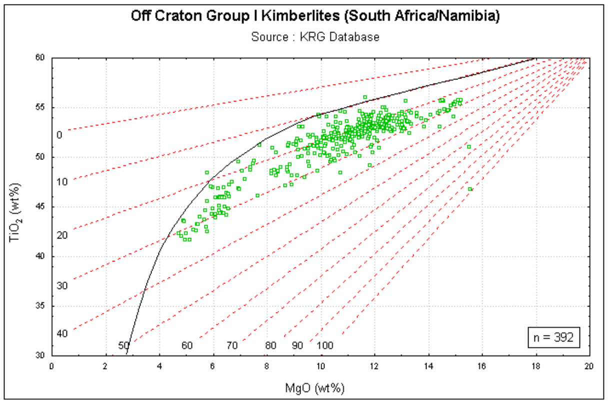

Figure 1: Plot of MgO versus TiO_2 for off-craton group I kimberlites from South Africa and Namibia. Percentage Fe_2O_3 lines (dashed red) were calculated using simple ilmenite stoichiometry. The black line represents the boundary of the kimberlitic ilmenite field.

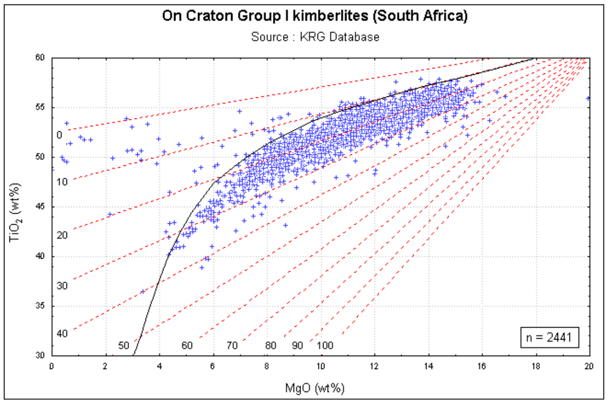

Figure 2: Plot of MgO versus TiO_2 for on-craton group I kimberlites from South Africa. Percentage Fe_2O_3 lines (dashed red) were calculated using simple ilmenite stoichiometry. The black line represents the boundary of the kimberlitic ilmenite field based on these rocks.

In order to assess the broader applicability of the kimberlitic ilmenite boundary defined by Southern African sources, we show in Fig. 3 the compositions of ilmenite in mineral concentrates from North American kimberlites. All but one of the 1071 available analyses fall to the MgO-rich side of the defined arc. The North American kimberlitic ilmenite compositions extend to lower MgO content than those from Southern Africa, and hence aid in defining the kimberlitic ilmenite field boundary at very low MgO contents (Fig. 3). Most kimberlitic ilmenites from North America have apparent Fe_2O_3 contents between 20 to 40%, and they cannot therefore attain the high levels of TiO_2 seen in kimberlitic ilmenites from Southern Africa. The position of the kimberlitic ilmenite field boundary at MgO contents > 4.0 wt% therefore depends on the quantities of Fe_2O_3, Al_2O_3 and Cr_2O_3 present in ilmenite populations. We have chosen the arc defined by the Southern African sources as the kimberlitic field boundary since it would correctly classify kimberlitic ilmenites from a variety of kimberlite sources

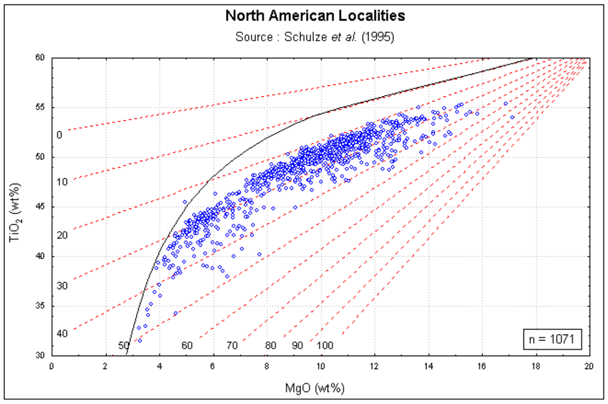

Figure 3: Plot of MgO versus TiO_2 for ilmenite from North American kimberlites (data of Schulze et al, 1995).Percentage Fe_2O_3 lines are shown as the dashed red lines. The black line represents the boundary of the kimberlitic ilmenite field defined by kimberlite localities in South Africa and Namibia.

NON-KIMBERLITIC ILMENITES

A variety of non-kimberlitic ilmenite sources were used to define the compositional range of these ilmenites. These included abundant ilmenite compositions from gabbros and picrites that form part of the Mount Ayliff Intrusion (Insizwa Complex) studied by Cawthorn et al. (1988), ilmenites from Karoo Basalts (Clement, 1980), and groundmass ilmenites in gabbroic phases of the Okenyenya Igneous Complex in Namibia (Le Roex, pers. comm.).

The major element MgO versus TiO_2 compositions for these non-kimberlitic ilmenites are presented in Figure 4. The non-kimberlitic ilmenites have lower MgO contents at equivalent TiO_2 contents than ilmenites derived from kimberlites (Fig. 4), and are noted to contain Cr_2O_3 contents below 1.0 wt% (not illustrated). The maximum MgO contents of non-kimberlitic ilmenites was used to define, by eye, a compositional field boundary for these ilmenite types. This is illustrated in Fig. 4 along with the position of the kimberlitic field boundary. The non-kimberlitic ilmenites have apparent Fe_2O_3 contents falling in the range 0 to 10 % hematite, significantly lower than observed for many kimberlitic ilmenites (Fig. 4).

ILMENITES FROM OTHER RELATED ROCK TYPES

Having established the compositional ranges for kimberlitic and non-kimberlitic ilmenites in terms of TiO_2 and MgO, the next logical step was to evaluate where ilmenites from related rock types fell into the classification scheme. Related rock types include ultramafic lamprophyres (e.g. alnoites, melilitites etc) and alkali basalts. Related rock types are known to host phenocrystic and groundmass ilmenites, as well as megacrystic ilmenite and xenocrystic ilmenite derived from mafic lower crustal or upper mantle lithologies.

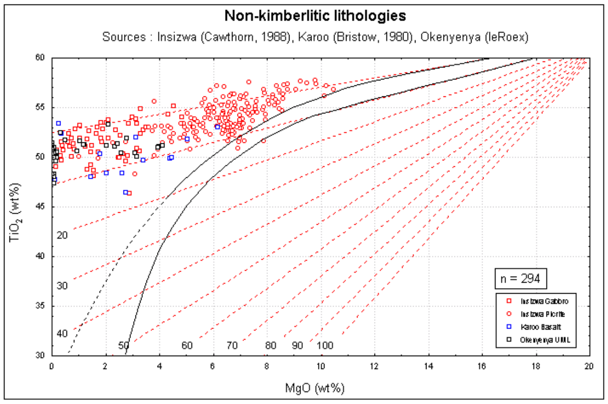

Figure 4: Plot of MgO versus TiO_2 for non-kimberlitic rocks. Percentage Fe_2O_3 lines are shown as the dashed red lines. The black line at lower MgO represents the chosen boundary of the non-kimberlitic ilmenite field. The black line at higher MgO represents the boundary kimberlitic ilmenite compositions defined localities in South Africa and Namibia.

Figure 5 below shows the MgO and TiO_2 compositional range of ilmenites present in the Malaita alnoites, as well as ilmenite megacrysts found in the Okenyenya ultramafic lamprophyre breccia. The linear trend of slightly decreasing TiO_2 contents with decreasing MgO content for the ilmenites derived from Malaita is diagnostic of a magmatic fractionation trend, and these ilmenite compositions transect the field boundaries of kimberlitic and non-kimberlitic ilmenites. The Okenyenya ilmenite megacrysts appear to define a non-kimberlitic field boundary at low MgO content and relatively high apparent Fe_2O_3 content, but additional data from known sources are required to better define this field boundary.

Figure 6 is a plot of MgO versus TiO_2 for ilmenites from the Selco alkaline intrusions, which are described in detail by Janse et al (1986), and classified petrogenetically as alnoites. These ilmenite data also transect the kimberlitic and non-kimberlitic field boundaries, and a high proportion occur in between these field boundaries at apparent Fe_2O_3 contents similar to those seen in Southern African kimberlites (cf. Figs. 1 and 2).

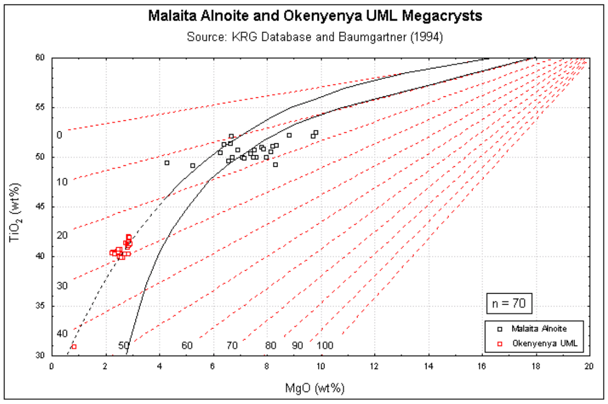

Figure 5: Plot of MgO versus TiO_2 for ilmenites from related rock types. Percentage Fe_2O_3 lines are shown as the dashed red lines. The black lines represent the boundaries of the non-kimberlitic and kimberlitic ilmenite fields respectively.

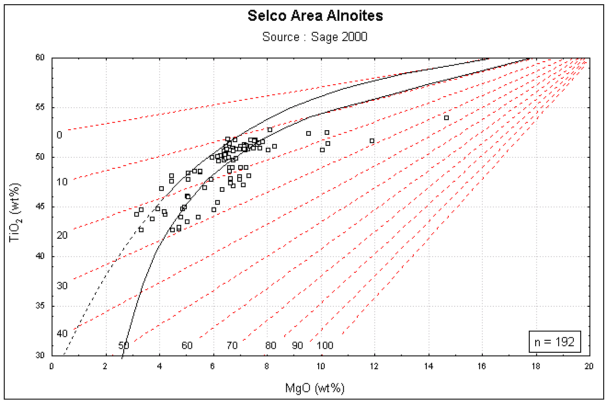

Figure 6: Plot of MgO versus TiO_2 for the Selco Alnoite ilmenites (data from Sage, 2000). Percentage Fe_2O_3 lines are shown as the dashed red lines. The black lines represent the boundaries of the non-kimberlitic and kimberlitic ilmenite fields respectively.

ILMENITES FROM EXPLORATION PROGRAMS

The final step in the new classification scheme for kimberlitic and non-kimberlitic ilmenites is to compare the compositions of ilmenites found in exploration datasets to the new classification scheme. Figure 7 below shows the MgO versus TiO_2 contents for a population of ilmenites visually identified as potentially kimberlitic by the Mineral Sorters at Mineral Services diamond laboratory. As is illustrated on this plot, the vast majority of the ilmenites are classified as non-kimberlitic. Importantly however, four of the 142 grains are in fact classified as kimberlitic as these would warrant additional follow-up work since they are highly likely to have been derived from a kimberlite.

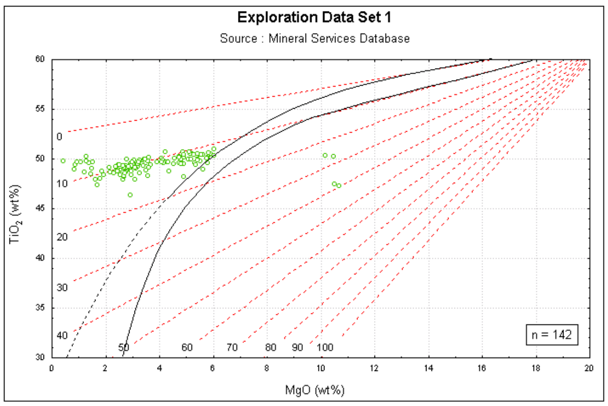

Figure 7: Plot of MgO versus TiO_2 for an exploration dataset. Percentage Fe_2O_3 lines are shown as the dashed red lines. The black lines represent the boundaries of the non-kimberlitic and kimberlitic ilmenite fields respectively.

The MgO and TiO_2 compositions of the ilmenites in the KIDD exploration database for the Slave craton in Canada are shown on Figure 8 below. This plot further highlights the apparent difficulties in visually distinguishing kimberlitic from non-kimberlitic ilmenites. While the majority of the ilmenites shown in this plot are clearly kimberlitic, there dataset also contains a large population of non-kimberlitic grains.

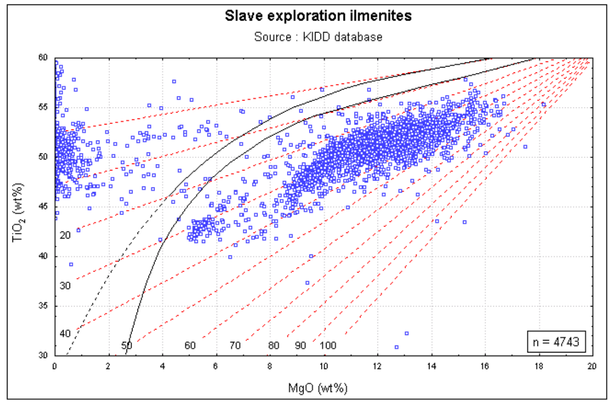

Figure 8: Plot of MgO versus TiO_2 for ilmenites from the Canadian Slave exploration KIDD dataset. Percentage Fe_2O_3 lines are shown as the dashed red lines. The black lines represent the boundaries of the non-kimberlitic and kimberlitic ilmenite fields respectively.

CONCLUSIONS

The results of this study define a new classification scheme, to be used to compositionally discriminate ilmenites derived from kimberlitic sources from those occurring in other sources. The key major elements used in this distinction are MgO and TiO_2. In addition to these two key elements, the Cr_2O_3 content of the ilmenites also needs to be considered since non-kimberlitic ilmenites typically contain low chrome contents.

The fact that both non-kimberlitic and kimberlitic ilmenites are recovered in exploration programs in several regions world-wide illustrates the need to be able to discriminate these effectively. The correct identification of the ilmenite source lithology, especially in areas where ilmenite is the key pathfinder mineral, will results in direct cost saving to the exploration program since false anomalies will be easily identified using this new scheme. In addition to this, the ilmenite classification scheme will also aid in finding kimberlitic rocks in areas that contain high background abundances of non-kimberlitic ilmenite.

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Contact: M C Baumgartner, PO Box 38668 Pinelands, Cape Town, South Africa, 7340, E-mail: mike.baumgartner@minserv.co.za