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Sous-projet SC8a

A geochemical approach to the classification of kimberlitic rocks.

Par

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SUMMARY

Although kimberlites and related ultramafic rocks have long been known to occur in Québec, they have received relatively limited attention from the mining industry until recently when diamonds were discovered in ultramafic rocks in the Torngat Mountains (Twin Mining Corporation), and subsequently in the Otish Mountains. Since then, the search for diamonds has been one of the principal exploration activities of the mining industry in Québec. The objective of project SC-8 has been to use geochemical methods to develop tools for classifying kimberlites and related rock types and discriminating among potentially barren and fertile varieties. Intrusions of kimberlitic and related rocks from eight different areas in Québec have been sampled and analyzed for major and trace elements using X-ray fluorescence spectrometry, inductively coupled plasma - mass spectrometry, and CO_2 using the Leco method. We have classified most kimberlites and related rocks from Québec into group-I kimberlites, group-II kimberlites and lamproites, aillikites, and meimechites on the basis of major elements Mg, Fe and Si. This classification was refined using trace elements and led to the elimination of some samples initially classified as group-II kimberlites; these samples have anomalously low Nb contents and are more appropriately classified as minettes. Samples from the Otish Mountains (Beaver Lake, H2, H3, H4) and Temiscamingue fields are mainly group-I and group-II kimberlites, respectively. However, most samples from the other areas are either aillikites or meimechites. A plot of diamond grade vs. Ti content of group-I and group-II kimberlites in Yakutia, Siberia indicates that kimberlitic rocks rich in diamonds are characterized by low Ti contents similar to those of the kimberlites of the Otish Mountain Field. Kimberlitic rocks from Québec and the rest of Canada are being analyzed to determine whether or not this relationship can be used to discriminate between barren and fertile kimberlites in Québec.

1. INTRODUCTION

1.1 Objectives

Although kimberlites and related ultramafic rocks have long been known to occur in Québec, they have received relatively limited attention from the mining industry until 1999, when significant numbers of diamonds were discovered in ultramafic rocks in the Torngat Mountains (Twin Mining Corporation), and subsequently in the Otish Mountains. Since then, the search for diamonds has been one of the principal exploration activities of the mining industry in Québec. As a result, kimberlitic and related rocks are now the subject of intense interest in the exploration community. Explorationists would like to know how to distinguish kimberlites from other kimberlitic rock types and how to assess their diamond potential. The objective of project SC-8 has been to address these issues by using geochemical methods to develop tools for classifying kimberlites and related rock types and discriminating among potentially barren and fertile varieties.

1.2 Background

There are four main areas of kimberlitic and related rocks in Québec (Moorehead et al., 1999; 2000):

- The Otish Mountains field, located in the northeast portion of the Opatica subprovince
- The Temiscamingue field in the Pontiac and Abitibi subprovinces
- The Desmaraisville field in the north-central part of the Abitibi subprovince
- The Torngat field near the Abloviak Fjord in the Torngat Mountians (Fig. 1).

Most exploration activity is currently focused on the Otish Mountain field, where Ashton Mining of Canada Inc. recently discovered nine diamondiferous kimberlitic pipes (Renard I through IX). A hypabyssal-facies kimberlite pipe at Lac Beaver (Girard, 2001), which is weakly diamondiferous, and four other kimberlite pipes, which are currently being explored by Ditem Exploration Inc., are also located in the Otish Mountains field. Prior to the Otish Mountains play, the Torngat field was the principal focus of exploration as a result of the discovery of diamondiferous dykes of lamprophyric affinity (Digonnet et al., 2000) by Twin Mining Corporation. Unfortunately this exploration has not yet identified any intrusions with encouraging economic potential. The Temiscamingue field straddles the Ontario border and includes five diamondiferous hypabyssal and diatreme-facies kimberlite pipes in Québec, two of which have been found in the last year (Tres-Or Resources). In the Desmaraisville area, there are five weakly diamondiferous hypabyssal-facies kimberlite pipes, and an accompanying dyke swarm (Sharma and Lauziere, 1984).

In addition to the major fields noted above, kimberlitic dykes of unknown economic potential were recently discovered near Wemindji, on the east coast of James Bay (Majescor Resources Inc.), and several other areas contain ultramafic-carbonatitic-lamprophyric intrusions, some with possible kimberlitic affinity (Ile Bizard, Ayer’s Cliff). Meimechite-like dykes have been found in the Lac Leclair region (Baragar et al., 2001) and also the Lac Castignon region (Dimroth, 1970).

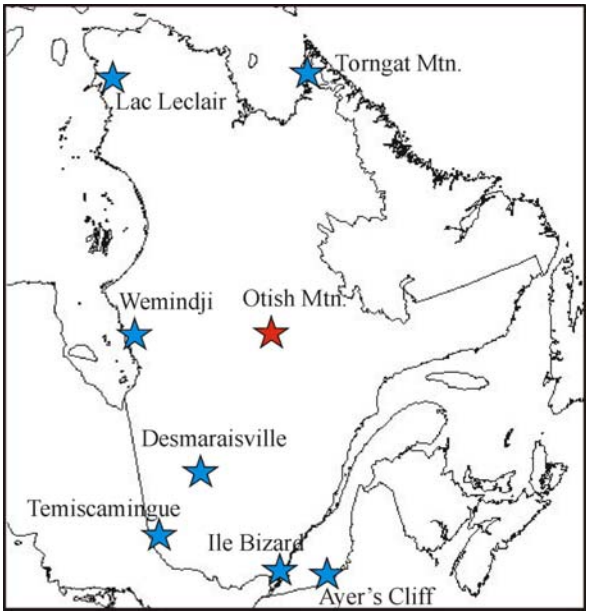


Figure 1. Map of Québec with kimberlitic fields.

The nomenclature and classification of ultramafic magmas hosting diamonds is a subject of continuing debate as is evident from the statement in a recent IUGS report from the Subcommission on the Systematics of Igneous Rocks.

> *"A clear definition of kimberlite should be formulated, particularly for the purposes of distinguishing these rocks from olivine lamproites, and for placing kimberlites in the hierarchical classification system"* (Wooley et al., 1996).

Existing classifications (e.g. Dawson, 1980; Mitchell, 1986; Mitchell, 1995) are based largely on mineralogical and textural features that are not easily applied to diamond exploration. They subdivide diamond-bearing rock-types into group-I and group-II kimberlites, lamproites, and ultramafic lamprophyres. Virtually all significant diamond deposits are hosted by group-I and group-II kimberlites (or lamproites), which can be distinguished by the presence of a calcitic or micaeous matrix with macrocrystic olivine, phlogopite and garnet (Mitchell, 1986). Group-I kimberlites are also commonly referred to as basaltic kimberlite and group-II kimberlites as micaceous kimberlites. Unfortunately, these mineralogically-based classification schemes are difficult to apply and require expertise not generally available to mineral exploration companies, particularly the junior companies responsible for most exploration in Québec. Geochemical methods have been largely ignored in the classification of kimberlitic and related rock types due to the high concentration of xenoliths and alteration effects. However, a preliminary survey of published chemical analyses of diamond-bearing hypabyssal facies intrusive rocks suggests that kimberlitic and related rocks can be distinguished reliably on the basis of their Mg, Si, and Fe contents (Francis, 2003). Thus it may be possible to use inexpensive whole-rock analyses to classify samples of ultramafic rock, and thereby make a preliminary assessment of their diamond potential by establishing whether or not they represent group-I or group-II (lamproite) kimberlite.

Kimberlitic dykes have been assumed to be a conveyor belt on which diamonds reach the surface, implying that diamond grade should be independent of kimberlitic composition. However, Vasilenko et al. (2002) have presented data which show that the diamond grade of kimberlite pipes in the Yakutia region of Russia is correlated with the major element chemistry of the kimberlite. Vasilenko et al. present multi-element (ten majors) expressions for predicting diamond grade, and Francis (2003) has shown that there is a simple inverse correlation between Ti and diamond grade. If these correlations are valid, it would indicate that the diamond potential of a kimberlitic magma is related to the magma.

2. ACTIVITIES OF THE FISCAL YEAR

2.1 Sampling

As kimberlitic rocks typically do not outcrop, the samples used in this study are largely comprised of drill core supplied by mining companies. In those cases where outcrops of kimberlitic rocks were available mining companies assisted greatly by providing helicopter support and other logistical resources. The following companies provided samples or assisted in sample collection: Ashton Mining of Canada Inc., DeBeers Canada Exploration Inc, Dianor Resources Inc., Ditem Exploration Inc. and Pure Gold Corporation. Additional samples were provided by J. Moorehead from the extensive collection of the MRNFP, and from other research projects at McGill and UQAM. A total of 37 pipes and other intrusive bodies of rocks from the Temiscamingue, Desmariasville, Otish Mountains, Wemindji, Lac Leclair, Torngat Mountains, Ile Bizard, and Ayer's Cliff regions were sampled.

2.2 Analytical Work

Polished thin sections were prepared of 63 samples representing 35 of the 37 intrusions referred to above. These were used to make detailed petrographic descriptions of the kimberlitic material and to assess xenolith contamination. Based on this petrography, 58 samples were selected for major and trace element bulk rock geochemistry. These samples were crushed and hand-picked under a binocular microscope to remove obvious crustal material before grinding for subsequent chemical analyses. Care was also taken to avoid veinlets of secondary calcite and zones of alteration. The samples were analyzed for major elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K and P) and selected (Ba, Cr, Ni, Zn, V, Ga, Nb, Pb, Rb, Sr, Th, U, Y and Zr) using X-ray florescence spectrometry (XRF). Additional trace elements (V, Cr, Co, Ni, Cu, Zn, Ga, Ge, As, Rb, Sr, Y, Zr, Nb, Mo, Ag, In, Sn, Sb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Tl, Pb, Bi, Th and U) in 45 samples were analyzed using inductively coupled plasma - mass spectrometry (ICP-MS) (Actlabs, Ancaster, ON) after assessing the results of the XRF analyses. The CO_2 content of all 65 samples was analyzed by the McGill Geochemical Laboratory using the Leco method. These data were used in conjunction with published analyses to characterize the affinities of the magmatic rocks in each of Québec's "kimberlite" fields and to test major element classification of these for "kimberlitic rocks", as well as to evaluate their diamond potential.

3. RESULTS

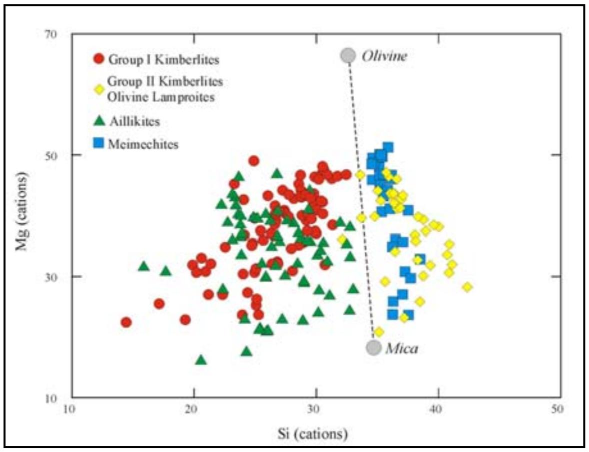
3.1 Major Elements

Potassium-bearing ultramafic magmas evolving by the fractionation of olivine and phlogopite phenocrysts will become enriched or improvished in Si according to whether their initial Si content is greater or less than the fractionating minerals, respectively. The effect of this is to separate group-I kimberlites and aillikites from group-II kimberlites and meimechites, as seen on plots of Mg vs. Si comparing the compositions of mineralogically classified samples of these rocks taken from the literature (Fig. 2a). These four rock types can be further classified on the basis of their Fe contents. Aillikite and meimechite magmas are relatively enriched in Fe, at any given Mg content, while group-I and group-II kimberlite magmas are relatively poor in Fe (Fig. 2b). Consequently these four rock types form separate fields on a plot of Fe vs. Si, as shown in Figure 3a for the sample set compiled from the literature. We have used this diagram to classify the samples of Québec kimberlitic rocks analyzed in this study. The compositions of all Québec samples analyzed in this study are shown in Figure 3b, whereas in Figures 4-8 we show the compositions of these samples in terms of field area. The Otish samples (Beaver Lake, H2, H3, H4) mainly plot in the group-I kimberlite field (Fig. 4), with a few plotting in the group-II kimberlite field, whereas the Desmaraisville samples plot in the aillikite field with a few outliers in the group-II kimberlite and meimechite fields. The Torngat samples also plot mainly in the aillikite field (Fig. 5), but range from the group-I kimberlite field into the meimechite field. The Wemindji samples are from two different field areas: one group plots at very low Si and Fe (group-I kimberlites) and the other plots at high Si, but low Fe (group-II kimberlites) (Fig. 5). The Ile Bizzard samples define a trend from group-I kimberlite field into the aillikite field, while Temiscamingue samples range in composition from group-II kimberlites to aillikites (Fig. 6). The Lac Leclair samples plot in the aillikite and meimechite fields, whereas the Ayer's Cliff samples define two clusters, one in the group-II kimberlite field and the other in the aillikite field (Fig. 7).

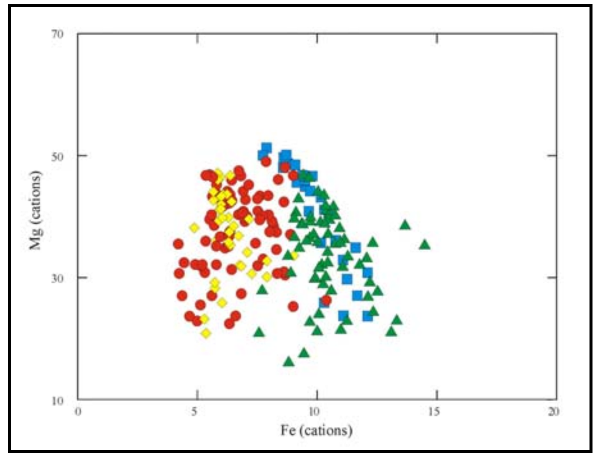
3.2 Trace Elements

The trace elements for the Québec group-I kimberlites, group-II kimberlites, aillikites and meimechites are very similar when compared to chondritic values (Fig. 8). As seen in Figure 9, only a few samples show positive Pb anomalies, indicating that our hand picking has successfully removed the effects of crustal contamination (le Roex *et al.*, 2003). In a plot of La/Y against La the Québec group-I kimberlites plotted at higher La/Y ratios than the other samples (Fig. 10). The group-I kimberlites also have distinctly higher LREE/HREE ratios than all the other rock types in the Québec data set.

A number of the samples with high Al from the Wemindji area which fall in the group-II kimberlite field in a plot of Fe vs. Si have conspicuous negative Nb anomalies in primitive mantle normalized spider

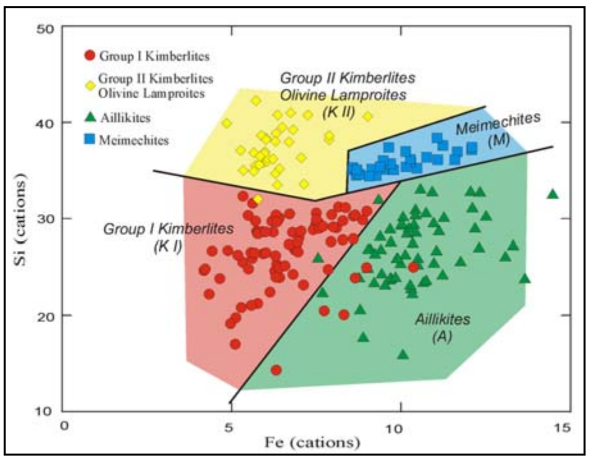


a) Si vs. Mg

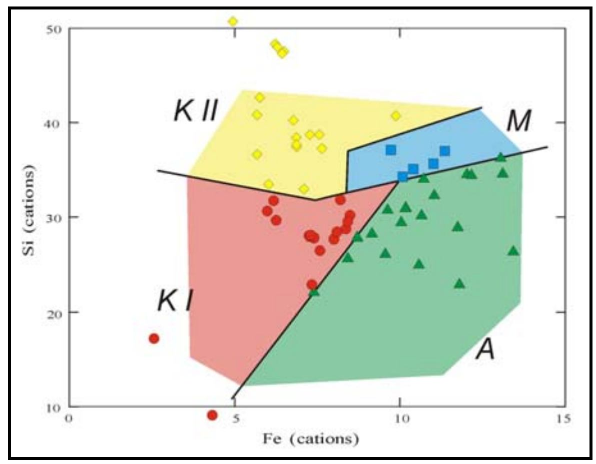


b) Fe vs. Mg

Figure 2. Major elements comparison for published data



a) Published data



b) Québec samples

Figure 3. Fe vs. Si with kimberlitic fields.

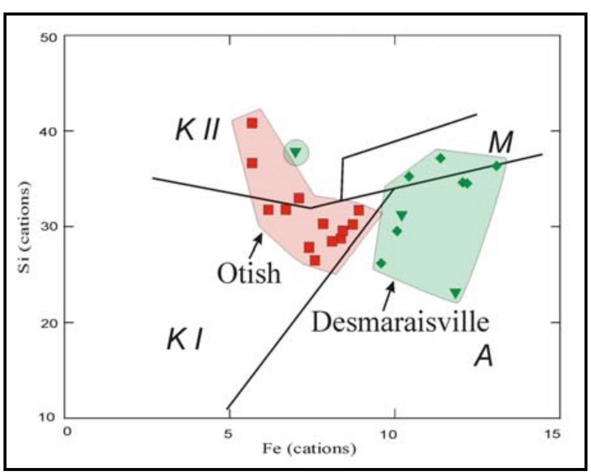


Figure 4. Fe vs. Si for Otish Mountains and Desmaraisville samples.

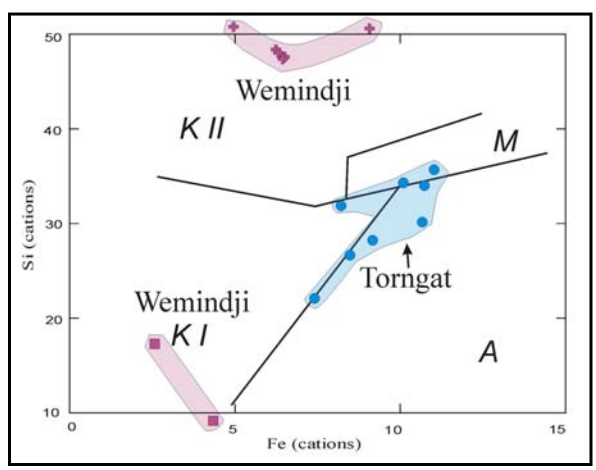


Figure 5. Fe vs. Si for Torngat Mountains and Wemindji samples.

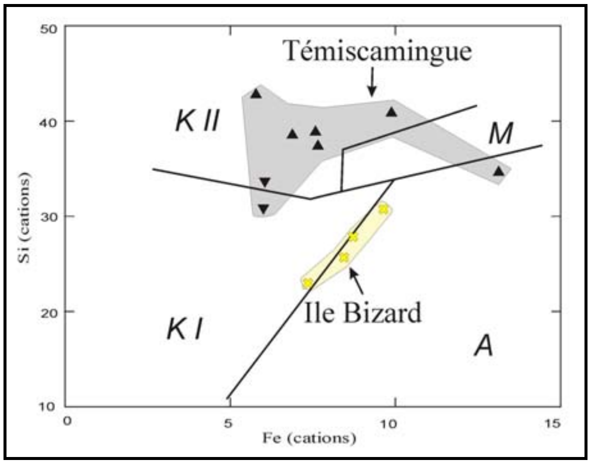


Figure 6. Fe vs. Si for Temiscamingue and Ile Bizard samples.

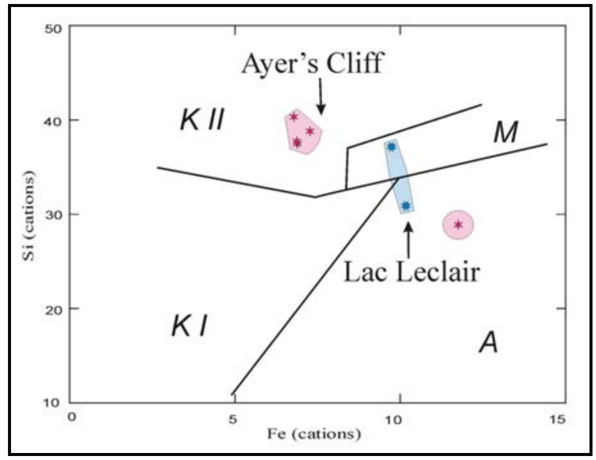


Figure 7. Fe vs. Si for Ayer's Cliff and Lac Leclair samples.

diagrams (Fig. 9) and are more similar to minettes than group-II kimberlites. We have therefore reclassified them as such. The Québec minettes are also characterized by low concentrations of REE compared to other kimberlitic rocks (Fig. 10).

3.3 Diamond Grade

All though conventional wisdom holds that kimberlites are unrelated to the diamonds they bring to the surface, Vasilenko et al. (2002) have shown that there is a link between diamond grade and kimberlite compositions in Yakutian diamond pipes and Francis (2003) has pointed out the simple inverse correlation between Ti and diamond grade (Fig. 11) in their data. Otish and Temiscamingue samples are group-I and group-II kimberlites and plot in the fertile, low-Ti area. The other areas of Québec that host kimberlitic rocks plotted as aillikites and meimechites, with high-Ti concentrations that are generally associated with uneconomic diamond grades.

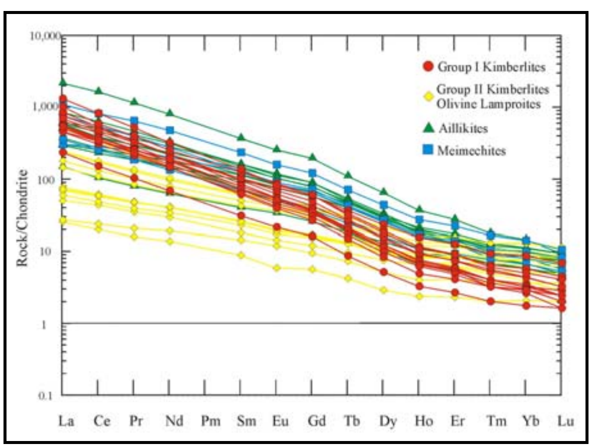


Figure 8. Chondritic noramalized REE diagram for Québec samples.

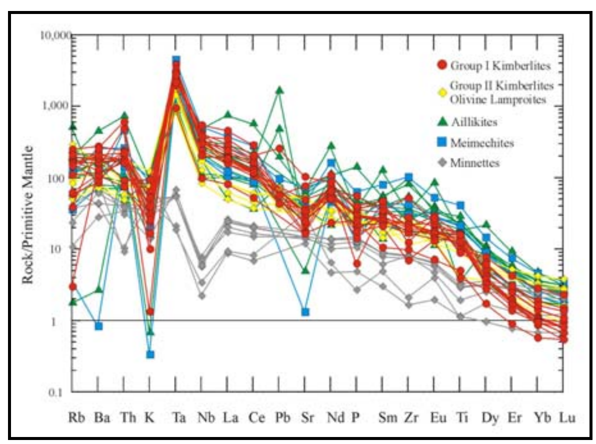


Figure 9. Primitive mantle noramalized spider diagram for Québec samples.

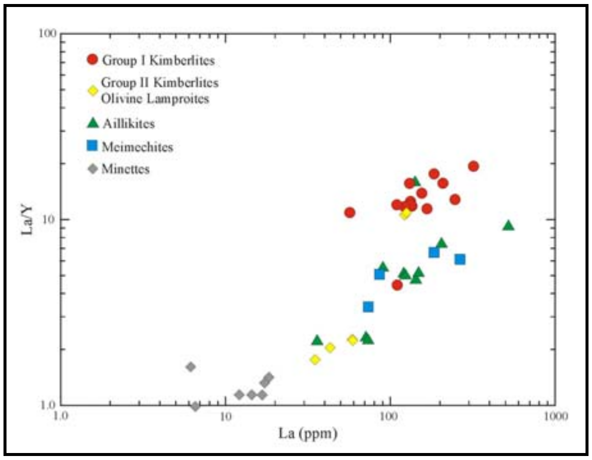


Figure 10. La vs. La/Y for Québec samples.

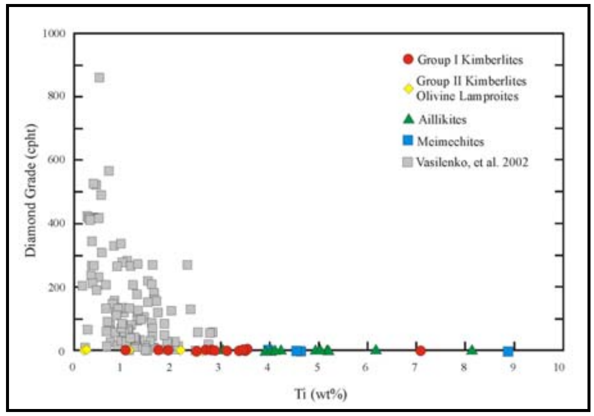


Figure 11. Ti vs. Diamond grade for published and Québec samples

4. FUTURE WORK

Additional samples from the Otish Mountains kimberlite field are in the process of being acquired from Ashton Resources Inc. and Dios Exploration Inc. All new samples will be analyzed for major and selected trace elements with XRF, then by ICP-MS (trace elements) and Leco (CO_2), as in the first set. Electron microprobe work will be done on any thin sections created along with petrographic analyses. Work on kimberlitic rocks by D. Francis will continue after the completion of this project, with the procurement of kimberlitic samples from other localities in order to understand the origin of the Ti vs. diamond grade relationship.

5. CONCLUSIONS

Intrusions of kimberlitic and related rocks from eight areas in Québec have been sampled and analyzed for major and trace elements using X-ray fluorescence spectrometry, inductively coupled plasma - mass spectrometry, and CO_2 with the Leco method. We have classified the Québec samples into group-I kimberlites, group-II kimberlites and lamproites, aillikites and meimechites, using the major elements Mg, Fe and Si. This classification was refined using trace elements which led to some samples initially classified as group-II kimberlites being reclassified as minettes on the basis of their negative Nb anomalies. Samples from the Otish Mountains and Temiscamingue fields are mainly group-I and group-II kimberlites, respectively, and have low Ti contents similar to diamondiferous kimberlites of Siberia. Most samples from the other areas in Québec are either aillikites or meimechites and have high Ti contents, which are less favourable for diamonds. Kimberlitic rocks from Québec and the rest of Canada are being analyzed to investigate the origin of this relationship.

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