

Aphanitic kimberlite samples from Jericho, NWT, Canada: A Step Towards A Primary Kimberlite Magma?

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APHANITIC KIMBERLITE SAMPLES FROM JERICHO, NWT, CANADA: A Step Towards A Primary Kimberlite Magma?

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INTRODUCTION

The chemical and physical properties of primary kimberlite melts remain enigmatic due to the lack of quenched “glassy” kimberlite (Mitchell, 1986). In particular, it is difficult to determine the nature of primary, or even primitive, kimberlite melts because of their hybrid nature, which includes substantial amounts of xenolithic material. Unfortunately, the difference between cognate and xenolithic material is not obvious. Olivine macrocrysts which are ubiquitous throughout macrocrystal kimberlite, and occupy approximately 50% by volume, might be cognate or derived from the disaggregation of peridotite nodules (Mitchell, 1986). The rounded nature of many of these macrocrysts (non-genetic name) suggests that they are xenocrysts that were milled during transport and emplacement.

In the absence of glassy kimberlite, aphanitic kimberlite represents the next best approximation to the melt phase. It is scientifically and economically important to determine the nature of primary kimberlite magmas. As kimberlite magmas originate in the mantle, the composition of primary kimberlite magmas will give us an insight into the composition of the mantle. Economically, if primary magmas can be identified at individual kimberlite deposits, it may be possible to determine whether that particular kimberlite magma sampled diamondiferous mantle. For example, did the kimberlite have a low enough fO_2 and/or temperature such that diamonds would not be completely resorbed? Thus, characterizing the primary magma allows speculation on diamond content, which may help in determining the economic potential of the kimberlite.

There are two approaches to obtaining information about primary kimberlite magma from available kimberlite samples. The first approach is to take macrocrystal kimberlite and attempt to remove the xenolithic components. This is troublesome due to 1) the uncertainty in which material is xenolithic, e.g. choosing which olivine crystals are phenocrysts or xenocrysts, and 2) the practical difficulty of extracting these crystals, considering they make up approximately 40-60 vol% of a typical kimberlite sample. The second option is to obtain aphanitic kimberlite samples, from which either crystals have been physically removed or were never present. Once these samples have been investigated, it may be possible to model whether phenocrysts have been lost from these samples. This second option is more realistic and this study focuses on

aphanitic samples.

A suite of six aphanitic kimberlite samples were collected at the Jericho kimberlite in the Northwest Territories of Canada with the objective of characterizing the melt phase. These are the only aphanitic kimberlite samples presently identified at Jericho.

PETROGRAPHY

Chilled Margin Samples

The chilled margin samples (JD51, JD69 and JD82) are very fine-grained, occur at the contact with other rocks, and show no obvious mineral alignment or other features indicative of flow differentiation. The aphanitic samples are from the edges of thin (<5m) dykes of macrocrystal kimberlite which intrude highly sheared mafic dykes. The contact between the aphanitic kimberlite and wall rock is generally sharp.

Flow Differentiated Samples

Samples 4S and 4SA form thin (up to 20 cm) selvages between diatreme facies macrocrystal kimberlite and the host granite. The contact between the aphanitic and macrocrystal kimberlite is fairly sharp, grading over 0.5 cm. The aphanitic texture of these samples is interpreted to be a result of flow differentiation processes occurring near the edge of the diatreme. Mineral alignment in some areas of these samples suggest flow processes may have occurred, and the aphanitic texture was likely a result of the large crystals being sorted away from the edges of the diatreme. These samples have a macrocrystal texture, although finer grained, similar to more coarse-grained kimberlite. This suggests there may be a significant proportion of the olivines may be xenocrysts.

Sample LGS07 represents a thin selvedge of aphanitic kimberlite, which has intruded against previously emplaced kimberlite. This sample still has a macrocrystal, "porphyritic" texture and the crystals are quite rounded suggesting they may have been milled during emplacement. As this sample is similar to macrocrystal kimberlite, it is likely the olivine is largely xenolithic, and therefore this sample is not a good representation of the melt phase. The aphanitic texture of this sample is therefore interpreted to be a result of flow differentiation processes occurring at the edge of the dyke during emplacement.

The chilled margin samples therefore represent good examples of liquids, with negligible amounts of macrocrystic or xenolithic material. These samples appear to be good examples of rapidly cooled kimberlite melt. The flow differentiated samples should be treated with more caution as they appear to have significant numbers of xenocrysts.

WHOLE-ROCK GEOCHEMISTRY

Major Element Chemistry

The aphanitic kimberlite samples are characterized by low $\text{Na}_2\text{O}/\text{K}_2\text{O}$ ratios (<6), which is typical for kimberlites (Mitchell, 1986). All aphanitic samples, except 4SA, have "Contamination Indices" (<1.5) suggesting they are not significantly contaminated by crustal rocks (Clement, 1982). Plots of SiO_2 , FeO(t) , H_2O , CaO and CO_2 vs. MgO show linear correlations (Fig. 1) reflecting the proportions of olivine and serpentine to calcite. The most striking geochemical difference between the aphanitic samples is the wide range of CO_2 contents, from 0.3 wt% in sample 4SA to 18.8 wt% in sample JD51. There is a strong linear relationship between CO_2 and CaO , with all samples lying just below a 1:1 $\text{CaO}:\text{CO}_2$ line representing pure calcite. Magnesium numbers for the aphanitic and bulk kimberlite samples are very high. Most samples have Mg#s of 86 - 91, except JD51 and 4SA, which have lower Mg#s of 82 and 73, respectively.

Trace Element Chemistry

Incompatible and compatible elements

A primitive mantle-normalized multi-element diagram (Fig. 2) shows there is significant variation between the aphanitic samples. In general, the aphanitic samples show strong LILE (with the exception of K) and HFSE enrichment, coupled with high LREE. Samples are generally depleted in K, Sr, Zr, Ti and Y. Pb is anomalously high in all aphanitic samples. JD69 and JD82 demonstrate very similar patterns, while JD51, 4S and 4SA are strongly enriched in U and Th and moderately enriched in the other incompatible elements, except Rb, Ba and Sr in which they are depleted. The enrichment in U and Th may be a result of granite contamination. Cr and Ni concentrations are high in the aphanitic samples with Cr concentrations ranging between 1300-7600 ppm (highest in samples 4S and 4SA) and Ni concentrations ranging between 600-1500 ppm.

Rare earth elements

The aphanitic samples all have steep chondrite-normalized patterns (Fig. 3) with extreme light rare earth element (LREE) enrichment (400-900 times chondrite abundances for La); this steep pattern is typical of kimberlites worldwide (Mitchell, 1986). All samples show a similar pattern with a linear trend in the LREE, a kink in the middle REE with slightly elevated Gd and slightly depleted Tb values, and an enrichment towards the heavy rare earth elements (HREE) with the patterns flattening towards Lu. The similar REE patterns and abundances of the aphanitic samples suggest that the REE have not been affected by contamination or alteration.

DISCUSSION

Based on petrographical and geochemical evidence, several properties of the aphanitic samples indicate they are representative of primitive kimberlite melt.

The chilled margin samples JD51, JD69 and JD82 are the best estimates of primitive kimberlite magma with textures representative of a liquid phase, high CO_2 content and Mg#s, high Cr, Ni and incompatible element concentrations. They also appear to be free of contamination by crustal material, although JD51 is possibly weakly contaminated. The aphanitic samples LGS07, 4S and 4SA have a higher proportion of olivine microphenocrysts than JD69 and JD82

and have an almost macrocrystal texture, though finer-grained. The olivine microphenocrysts are quite rounded, possibly representing milling during emplacement. This suggests they may be xenocrysts. Samples 4S and 4SA appear to have been affected by crustal contamination, and/or secondary alteration, and therefore are not as good representatives of primitive magmas.

Aphanitic sample suite vs. macrocrystal Jericho samples

Geochemical and textural evidence suggests that the chilled margin samples represent more primitive kimberlite magmas than Jericho macrocrystal kimberlite. The macrocrystal kimberlite phases are hybrid rocks that include large proportions of xenocrysts, particularly peridotitic olivines. Therefore, they are poor representatives of primitive melts. Also, the aphanitic samples generally have much higher CO₂ contents (10 - 20 wt%) than the macrocrystal kimberlite phases (average is 4 - 5 wt%), suggesting the aphanitic samples have suffered less devolatilization. This makes the aphanitic kimberlite samples better estimates of primitive melts than the macrocrystal samples.

Pearce Element Ratio (PER) analysis of both the aphanitic and macrocrystal Jericho samples demonstrated that the different Mg, Fe and Si concentrations in these samples (together >50 wt% of the rock) can be explained by olivine, or serpentinized olivine, sorting. This represents microphenocryst sorting in the aphanitic samples and macrocryst sorting in the macrocrystal samples. The aphanitic samples have consistently low olivine or serpentine values and this suggests they are more primitive than the macrocrystal Jericho samples which have had olivine, probably xenocrysts, added to them.

Both the aphanitic and macrocrystal samples from Jericho have similar high Mg#s and high Cr and Ni contents. The low modal content of macrocrysts in the aphanitic samples suggests the high observed Mg#s and Cr and Ni contents are not caused by olivine accumulation, but instead are primary characteristics of the magma.

The aphanitic samples have higher incompatible elements, especially Nb, Zr and Y, than the macrocrystal kimberlite samples. Kopylova *et al.* (1998) identified a trend within the Nb-Zr data from magmas high in Nb and Zr through to magmas low in Nb and Zr. Their “chilled margin” sample (LGS07) had the highest values, followed by the autoliths, then Phase 1, 2 and 3. The aphanitic samples of this study also have high Nb and Zr values, similar to LGS07 (Fig. 8). The flow differentiated samples have anomalously high values, lying off the general trend, and are interpreted as having been affected by secondary processes, probably due to granite contamination. As a temporal trend of kimberlite emplacement has been identified by Cookenboo (1998) from Phase 1 to 3, with Phase 1 being the earliest intrusion and Phase 3 the latest intrusion, this suggests the aphanitic samples were emplaced earlier than Phase 1. This is another good argument that the chilled margin samples represent primitive magmas.

Comparison with other “Primitive” Kimberlites

The Wesselton aphanitic kimberlite (South Africa) is thought to be the best example of an unfractionated “primitive” kimberlite (Mitchell, 1995; Edgar *et al.*, 1988; Edgar and Charbonneau, 1993). This kimberlite has an absence of olivine xenocrysts, low abundances of

xenoliths and xenocrysts (Edgar *et al.*, 1988), high Mg# (83.9), low SiO₂ (25.6 wt%), high Ni (810 ppm) and high Cr (2410 ppm). In comparison, the Jericho primitive kimberlite samples JD69 and JD82 have higher Mg#s (86-88), similar SiO₂ (24-30 wt%), higher Ni (800-1400 ppm) and higher Cr (1300-1900 ppm). The Wesselton kimberlite has approximately 5 wt% CO₂ whereas the Jericho primitive samples have between 10 - 17 wt%. Therefore, the Jericho samples appear to be geochemically more primitive than the Wesselton kimberlite. The Wesselton kimberlite also has a microporphyritic texture similar to the Jericho chill margin sample LGS07 and the flow differentiated samples which suggests the smaller olivines may be xenocrysts.

Without knowing the composition of a primary kimberlite magma, we can only compare these results. If the Wesselton kimberlite is a good example of a primary kimberlite magma, perhaps the differences in the chemistry of the Wesselton and Jericho kimberlites are giving us an insight into the nature of partial melts (and the nature of the mantle) in South Africa and Canada, respectively.

Primary characteristics of the Jericho primitive kimberlite samples

Given that samples JD69 and JD82 represent primitive melts from Jericho, how close are these compositions to the primary kimberlite magma? Due to the hybrid nature of kimberlites and the lack of quenched "glassy" kimberlite, it is difficult to speculate on the nature of a kimberlite primary magma. The Jericho primitive magmas have high Mg#s, high Cr and Ni, and high incompatible elements and these properties directly reflect primary melt properties. Although some CO₂ devolatilization may have occurred during ascent, these samples still have much higher CO₂ contents than most kimberlites, and these values represent a minimum CO₂ content for the primary magma.

The olivine microphenocrysts in samples JD69 and JD82 have been completely serpentinized. The replacement of olivine by serpentine involves a volume increase, the addition of water, and either the addition of Si or the removal of Mg. The concentration of Fe in the olivine can also be affected. This serpentinization results in a change in the Si/Mg ratio and, unless the system is closed, serpentinization results in an increase in this ratio for the whole rock.

Experimental determinations of primary kimberlite melts

The high concentrations of incompatible elements suggest kimberlites represent low-degree partial melts (Dalton and Presnall, 1998). The high LREE/HREE ratios and low Al concentrations in kimberlite necessitates that garnet is retained in the solid residua during melting (Mitchell, 1986). Therefore, most authors agree that the source rock for kimberlite magmas is a carbonate-bearing garnet lherzolite. Dalton and Presnall (1998) investigated the CaO-MgO-Al₂O₃-SiO₂-CO₂ system at 6 GPa. They started with a slightly modified lherzolite composition from Canil and Scarfe (1990), and performed experiments near the liquidus where they determined the crystal and melt phases. The melt phase was composed of both quench Ca-Mg carbonates and quench silicate phases and they found that the melt compositions showed a systematic variation with temperature from carbonatitic at the solidus (1380°C) through intermediary compositions to kimberlitic 70-100EC above the solidus. For their modelling of a

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lherzolite with 0.15wt% CO₂, they found that this continuous change occurs within the melting range 0-1 volume%.

The geochemical characteristics of Dalton and Presnall's (1998) partial melts of a carbonated garnet lherzolite at 6 GPa are similar to the composition of the Jericho primitive kimberlites. These partial melts are <1 vol% of the source rock and exist at temperatures between approximately 1450-1500°C. Given the Kopylova *et al.* (1998) geotherm for the Jericho peridotites and pyroxenites, which suggests the Jericho primary kimberlite magma originated from pressures of approximately 6.5 GPa (220 km), and at temperatures greater than 1300°C, results of their experiments are relevant. In the absence of contrary evidence, a carbonated garnet lherzolite source is plausible.

With the further collection of examples of primitive kimberlite worldwide, we may start to see differences in the nature of the primary magmas. These differences may give us an insight into mantle composition and heterogeneity, and/or partial melting processes.

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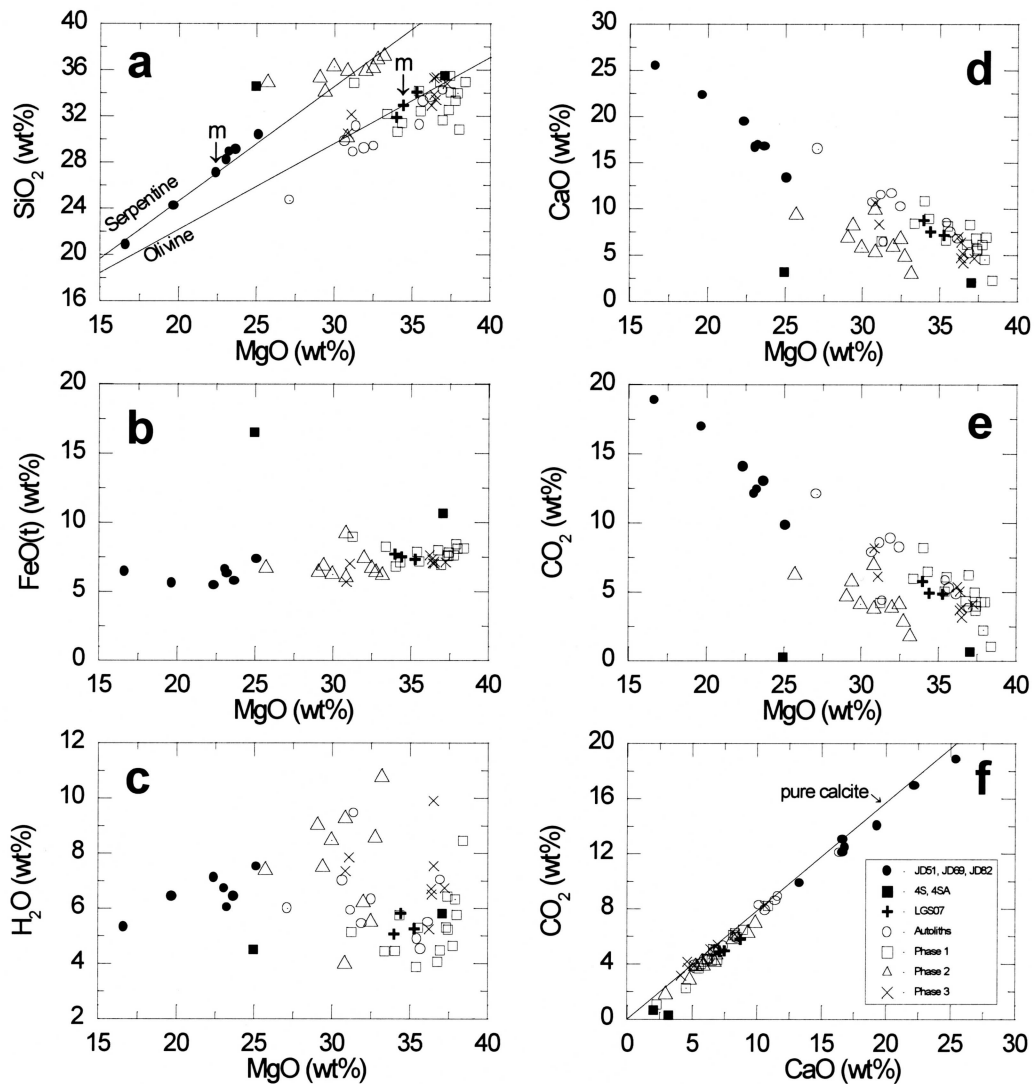


Fig. 1 Bivariate plots of selected major elements for the aphanitic and major phases of the Jericho kimberlite, demonstrating the control by the proportions of olivine or serpentine to calcite. **a)** SiO_2 vs. MgO shows control by olivine or serpentine. The slope of the control lines is determined by the molar ratio of Si/Mg for end-member serpentine ($\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$) and forsterite (Mg_2SiO_4), and is drawn through the median datapoint (m); **b)** Total iron, $\text{FeO}(\text{t})$ vs. MgO . **c)** H_2O vs. MgO ; **d, e)** CaO and CO_2 vs. MgO ; **f)** CO_2 vs. CaO . The straight line represents pure calcite, with a CaO/CO_2 molar ratio = 1. Data for sample LGS07, autoliths, and Phases 1-3 are from Kopylova *et al.* (1998).

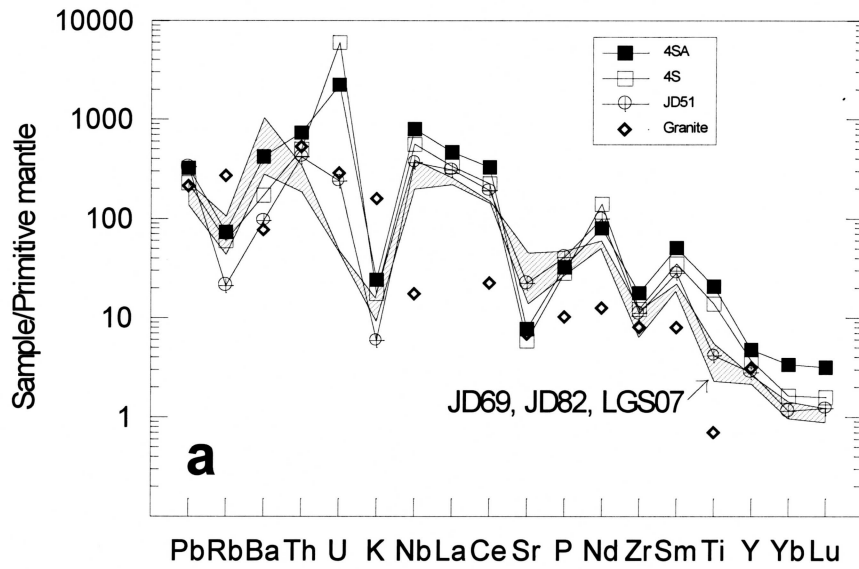


Fig. 2 Primitive mantle normalized multi-element diagrams. **a)** all aphanitic kimberlite samples, **b)** aphanitic samples (JD69, JD82 and LGS07 within cross-hatched region) with Contwoyto batholith (B. Davies, pers. comm.) **c)** Aphanitic samples with bulk Phase 1 chemistry (stippled).

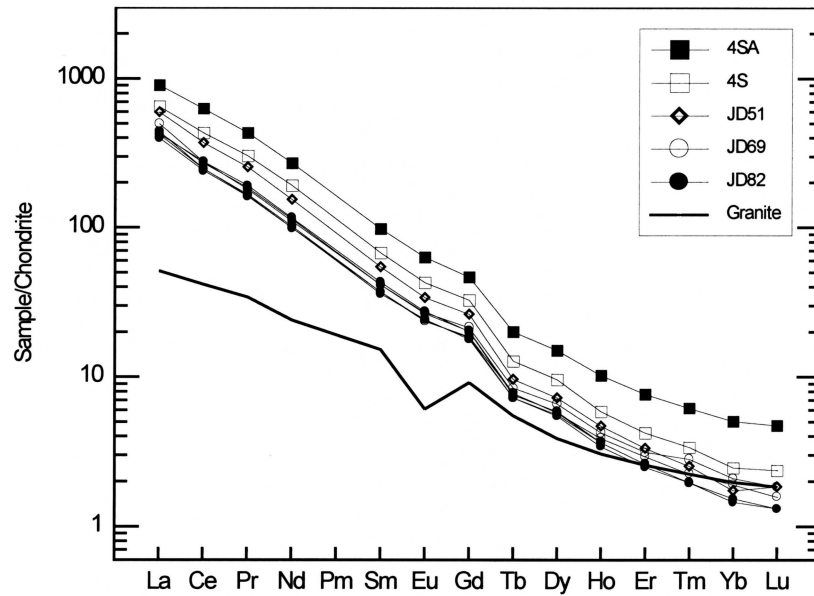
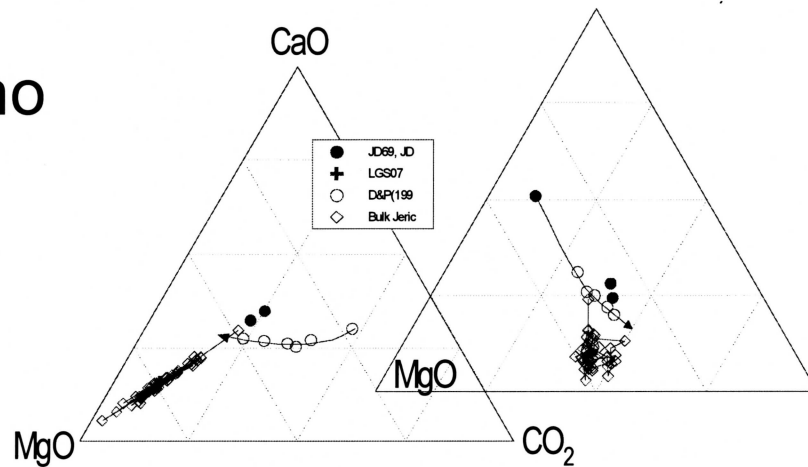


Fig. 3 Chondrite normalized REE diagram for aphanitic kimberlite samples analysed in this study. The host granite (Contwoyto batholith) is also represented (from B. Davies, pers. comm.).

a) Jericho



b) Worldwide

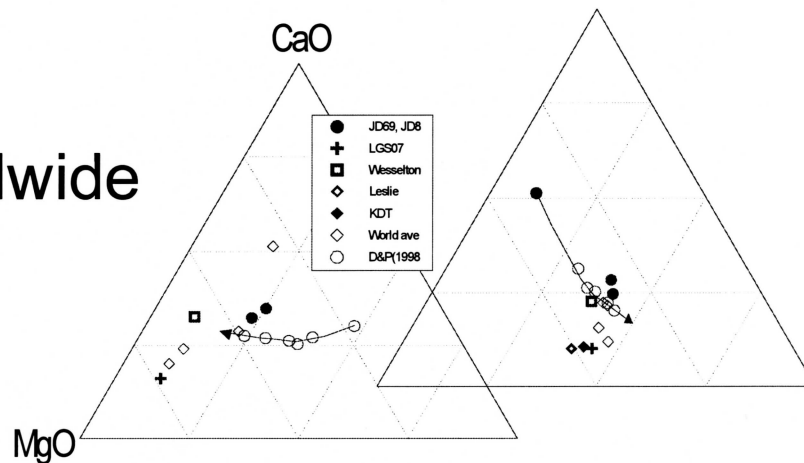


Fig. 4 CaO-MgO-SiO₂ (left) and CaO-MgO-CO₂ (right) ternary plots for a) Jericho aphanitic and bulk macrocrystal kimberlite, and b) Jericho primitive kimberlites, worldwide primitive kimberlites and average worldwide kimberlites. The black arrow is from low to high temperature (higher degrees of partial melts) from Dalton and Presnall's (1990) melting experiments on a carbonated garnet lherzolite.