ECLOGITES FROM THE MIR KIMBERLITE, RUSSIA: EVIDENCE OF AN ARCHEAN OPHIOLITE PROTOLITH

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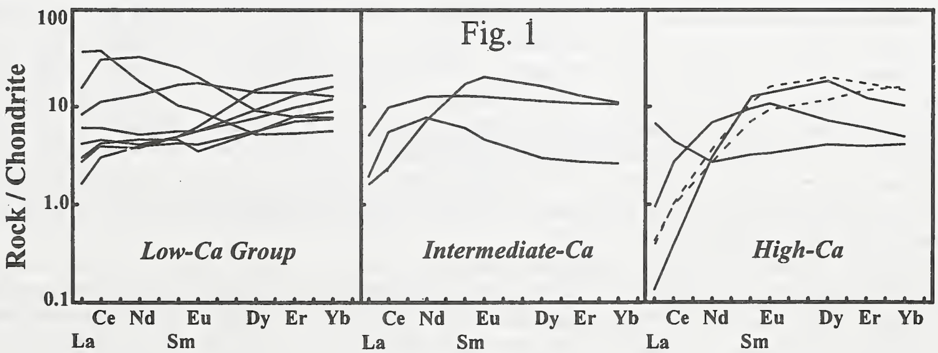
Introduction -- The Mir kimberlite is part of the Malo-Botuoba kimberlite group which is the southernmost diamond-bearing kimberlite group in the Siberian Platform. The Siberian Platform consists of Archean and Proterozoic meta-sedimentary and igneous rocks that are covered by a thick package of Late Proterozoic, Paleozoic, and Mesozoic sedimentary rocks, and early Mesozoic flood basalts (Dawson, 1980). Over eight hundred kimberlite pipes of mid-Paleozoic and Mesozoic age have erupted through the Siberian Platform. These kimberlites have been evaluated extensively for diamond exploitation and some are actively mined for diamonds.

Petrography -- The suite of Mir eclogite xenoliths used for this study consists of 16 samples, all of which are diamond-bearing. The primary mineralogy consists of orange- to red-colored garnet and greenish-colored omphacite. One sample (M-86) contains trace amounts of kyanite, and one sample (M-772) consists of rounded garnets 3 mm in diameter and irregularly shaped rods (probably exsolution) of garnet that occur as inclusions in clinopyroxene. Phlogopite and amphibole are associated with garnet alteration; only rarely do these phases occur in association with clinopyroxene. Calculated primary modal garnet contents range from 17% to 73%, which is similar to modes determined for eclogite xenoliths from the Udachnaya pipe (Sobolev et al., 1994). We have divided the Mir eclogites into three groups based primarily on the Ca content in garnet. The low-Ca group typically has a low modal % of garnet (17 to 48%), whereas the high-Ca group typically has a higher percentage of garnet (35 to 73%). The intermediate-Ca group, which may be transitional between the high- and low-Ca groups, has a moderate garnet content (38 to 50%).

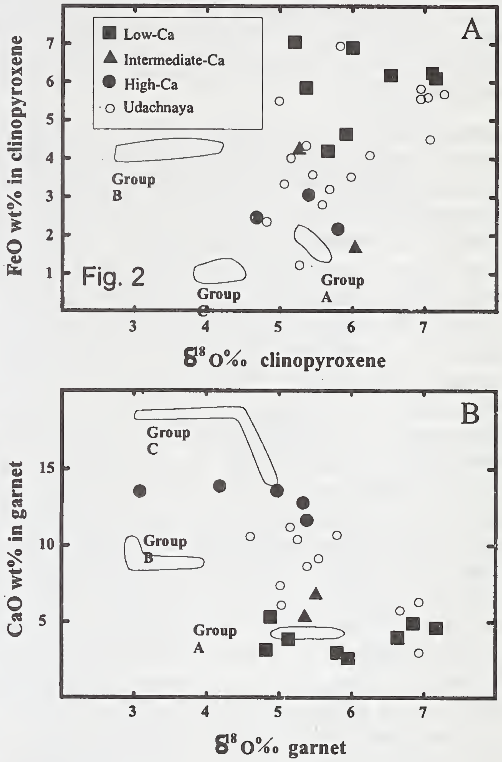
Mineral Chemistry -- On the basis of compositional variations in garnet and clinopyroxene, this suite of eclogites can be divided into three groups: high-Ca, low-Ca, and intermediate-Ca. Compared to the Udachnaya eclogite xenoliths, Mir eclogites define a slightly more restricted range in Fe and Mg contents, but a similar range in Ca contents (Jerde et al., 1993; Sobolev et al., 1994). These three groups may appear arbitrary, but these divisions also correspond to differences in clinopyroxene composition, as well as in trace-element and oxygen isotopic compositions of garnet and clinopyroxene. One group has low Ca contents (2.65 to 5.39 wt% CaO) and variable Mg/(Mg+Fe) ratios (0.65 to 0.38). A second group has intermediate Ca contents (5.31 to 9.09 wt% CaO) and a range of Mg/(Mg+Fe) ratios similar to the low Ca garnets (0.67 to 0.40). The third compositional group of garnets has high Ca contents (11.70 to 13.64 wt% CaO) and a restricted range of Mg/(Mg+Fe) ratios (0.57 to 0.48). Chromium contents in the three different groups are low and overlap one another.

Garnets from the low-Ca group have low light-REE (LREE) contents and typically have $[Dy/Yb]_n < 1$. The high-Ca group garnet have higher LREE contents and typically have $[Dy/Yb]_n > 1$. Garnets from the intermediate-Ca group have REE contents between the high- and low-Ca groups (Figure 1). Clinopyroxenes from the low-Ca group have



convex-upward REE patterns with relatively high REE contents (10 times chondrite), whereas those from the high-Ca group have similar convex-upward shapes, but lower REE contents, approximately chondritic. Reconstructed bulk-rock REE patterns for the low-Ca group eclogites are relatively flat at approximately 10 times chondrites. In contrast, the high-Ca group samples typically have LREE-depleted patterns and lower REE contents.

The oxygen isotopic composition of minerals from the low- and high-Ca groups are different. Garnets from the low-Ca group have $\delta^{18}O$ values that range from 7.18 to 4.90‰, and garnets from the high-Ca group have $\delta^{18}O$ values that range from 5.40 to 3.09‰ (Figure 2). The oxygen isotopic composition of many of these samples are either lower (the high-Ca group) or higher (the low-Ca group) than typical ultramafic, mantle-derived rocks. ***These isotopic compositions are consistent with high-temperature hydrothermal seawater alteration of oceanic crust (low $\delta^{18}O$ values, high-Ca group) or low-temperature seawater alteration of oceanic crust (high $\delta^{18}O$ values, low-Ca group).***

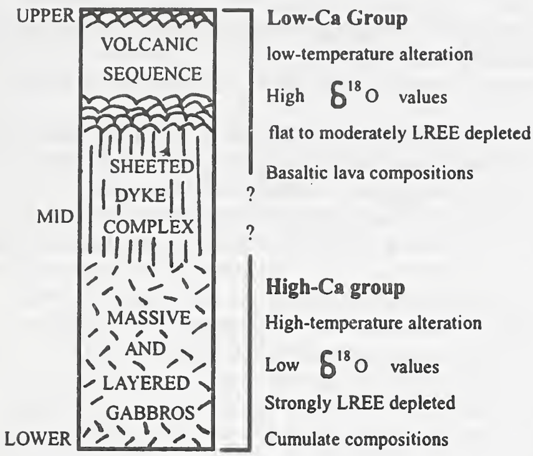


Discussion -- The lack of correlation between the oxygen isotopic compositions of garnet or clinopyroxene and the modal percent of secondary phases may be taken as evidence that the measured isotopic composition of garnet and pyroxene are not artifacts of alteration processes, and are ***probably representative of their primary oxygen isotopic compositions.*** Compared to the oxygen isotopic composition of the mantle sources of mid-ocean-ridge basalts (MORB; 5.35 to 6.05‰; Ito et al., 1987) and the range measured for ultramafic mantle xenoliths (5.5±0.7‰; Mattey et al., 1994), the range for the Mir eclogite xenoliths is larger, extending to values that are slightly greater, to significantly lower than ultramafic mantle assemblages.

The origin of eclogite xenoliths with $\delta^{18}O$ values that have a greater spread than a presumed homogeneous mantle isotopic composition has been explained by suggesting that the protolith of the eclogite was subducted oceanic crust (e.g., MacGregor and Manton, 1986; Shervais et al., 1988; Neal et al., 1990; Jacob et al., 1994). Eclogites with high $\delta^{18}O$ values are believed to have inherited their isotopic compositions through low-temperature seawater alteration prior to subduction (Muehlenbachs and Clayton, 1972a), and eclogites with low $\delta^{18}O$ values are believed to have obtained their isotopic compositions by high-temperature seawater alteration (Muehlenbachs and Clayton, 1972b). In support of such a conclusion, we note that some workers have reported that the chemical composition of some eclogite minerals or bulk-rocks vary systematically with respect to their oxygen isotopic composition, and that these compositional variations are similar to the compositional changes that would be produced during hydrothermal seawater alteration of oceanic crust (MacGregor and Manton, 1986; Jacob et al., 1994). For example, based on 8 samples from the Udachnaya kimberlite, Jacob et al. (1994) showed that the Fe contents increased and Ca contents decreased with increasing degrees of low-temperature alteration, as measured by increasing $\delta^{18}O$ values. Work on additional eclogites from the Udachnaya pipe has shown that some of the systematic trends between the composition of minerals and their oxygen isotopic composition identified by Jacob et al. (1994) are not present, but that those samples with the highest $\delta^{18}O$ values are compositionally distinct relative to samples with lower, mantle-like, $\delta^{18}O$ values (Snyder et al., 1995).

We interpret the differences in oxygen isotopic and mineral compositions in the Mir eclogite groups to be a result of variations in the mineralogy and bulk-rock composition of the presumed oceanic crustal protolith. Based on studies of ophiolite sequences (e.g., Stern et al., 1976; Gregory and Taylor, 1981; Cocker et al., 1982), high-temperature seawater alteration, which produces low $\delta^{18}O$ values, is thought to occur predominantly in mid- to lower sections of oceanic

Fig. 3: Idealized cross-section of oceanic crust showing the proposed protoliths of the Mir eclogites



crust, where massive and layered gabbroic rocks are the predominant lithologies (Figure 3). The upper section of the crust, where lavas and sheeted dikes are the predominant rock types, is thought to be primarily altered by seawater at low temperatures. The high-Ca group Mir samples are aluminous because of their high modal percent of garnet, relative to the low-Ca group samples. Such cumulate rocks probably would be LREE-depleted, and can be Ca-rich because of plagioclase or clinopyroxene accumulation. The differences in Al and Ca contents between the high- and low-Ca group samples can be interpreted as the result of an increased plagioclase component in the protolith of the high-Ca group samples. Arguably, this difference may imply that the high-Ca group samples are representative of the plutonic section of oceanic crust, and the low-Ca group samples are representative of the extrusive section of oceanic crust. This upper section of oceanic crust would consist mainly of extrusive basalts that would have been altered by seawater at low temperatures. These basaltic lavas would probably have relatively flat REE patterns. Such observations are consistent with the high-Ca group samples having experienced high-temperature seawater alteration, and the low-Ca group samples having experienced low-temperature alteration, based on their $\delta^{18}O$ values.

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