SIBERIAN ECLOGITE XENOLITHS: KEYS TO DIFFERENTIATION OF THE ARCHEAN MANTLE

Gregory A. Snyder, Lawrence A. Taylor, Brian L. Beard, and Vladimir N. Sobolev, Planetary Geosciences Institute, Department of Geological Sciences, University of Tennessee, Knoxville, TN 37996, U.S.A.
D.Graham Pearson, Dept. of Geology, University of Durham, South Road, Durham DH1 3LE, U.K.
Alex N. Halliday, Dept. of Geological Sciences, University of Michigan, Ann Arbor, MI, 48109, U.S.A.
Ghislaine Crozaz, McDonnell Center for Space Sciences, Washington Univ., St. Louis, MO 63130, U.S.A.
Robert N. Clayton and Toshiko K. Mayeda, Enrico Fermi Institute, University of Chicago, Chicago, IL 60637
Peter Deines, Dept. of Geosciences, Pennsylvania State University, University Park, PA 16802, U.S.A.
Nikolai V. Sobolev, Institute of Min. & Petr., Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia

Introduction -- Eclogite xenoliths have received attention in greater proportion than their actual abundance in kimberlite pipes due in large part to their proclivity to host diamonds. Some workers believe that all eclogite xenoliths are derived from the subduction and high-pressure melting of oceanic crust (e.g., Jacob et al., 1994; Ireland et al., 1994), while others have stated that at least some eclogites could also be derived directly from the mantle (McGregor & Manton, 1986; Shervais et al., 1988; McCulloch, 1989; Neal et al., 1990; Jerde et al., 1993; Snyder et al., 1993). We present all the data known for the Udachnaya eclogites and compare them to data on other Siberian eclogites as well as eclogites from southern Africa.

Petrography and Mineral Chemistry -- Eclogite xenoliths extracted from kimberlites in Siberia are generally quite small (3-7 cm, on average, in longest dimension, though some samples are in excess of 20 cm), are coarse-grained, generally equigranular, and consist of a bimineralic assemblage of clinopyroxene and garnet varying in proportions from 70:30 to 30:70 (Sobolev et al., 1994).

Most notable among the Udachnaya eclogites is the virtual absence of both inter- and intra-grain compositional zoning (Sobolev et al., 1994). This is in direct contrast to eclogites from other Siberian localities (e.g., Mir; Beard et al., 1995). Udachnaya garnets vary from pyrope- (or Mg-) rich to relatively grossular-rich. Clinopyroxene compositions of most samples plot within the B and C eclogite fields (at lower MgO and greater Na_2O values) and only a few samples plot within the A field (at higher MgO and lower Na_2O values). Some of these are true Group A eclogites (as per Taylor & Neal, 1989) and contain elevated Cr_2O_3.

Clinopyroxenes from Udachnaya eclogites are generally more LREE-depleted than those from southern Africa or other Siberian localities (Figure 1). Udachnaya clinopyroxenes have similar MREE abundances (i.e., Nd = 2-20x C1 chondrites), but LREE and HREE abundances which vary by over two orders of magnitude. The clinopyroxenes have been divided into three types based on their REE patterns (Jerde et al., 1993; Snyder et al., 1995): 1) most abundant are those with "typical" clinopyroxene patterns [$(La/Nd)_n$ = 0.4-0.7, $(Sm/Yb)_n$ < 15]; 2) HREE-depleted clinopyroxene, $(Sm/Yb)_n$ = 15-50, with almost flat to LREE-enriched patterns, [$(La/Nd)_n$ = 0.5-1.3]; and 3) LREE- and HREE-depleted clinopyroxene; [$(La/Nd)_n$ < 0.25; $(Sm/Yb)_n$ > 20]. Although this latter group exhibits the most LREE-depleted (i.e., depleted in La and Ce) clinopyroxenes found at Udachnaya, Sm/Nd ratios are either chondritic or much lower. Furthermore, samples from this group yield sinusoidal REE patterns. A sample from this group yields by far the most nonradiogenic $^{143}Nd/^{144}Nd$ determined for Udachnaya clinopyroxenes ($\varepsilon_{Nd(0)}$ = -25), and suggests long-

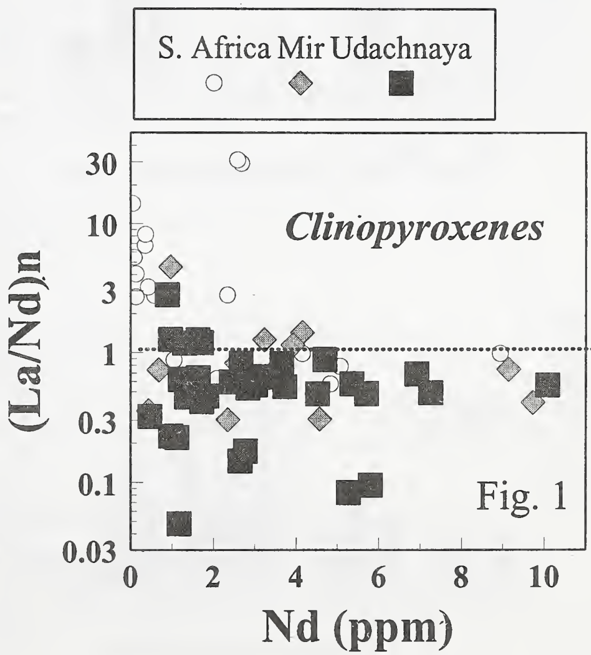


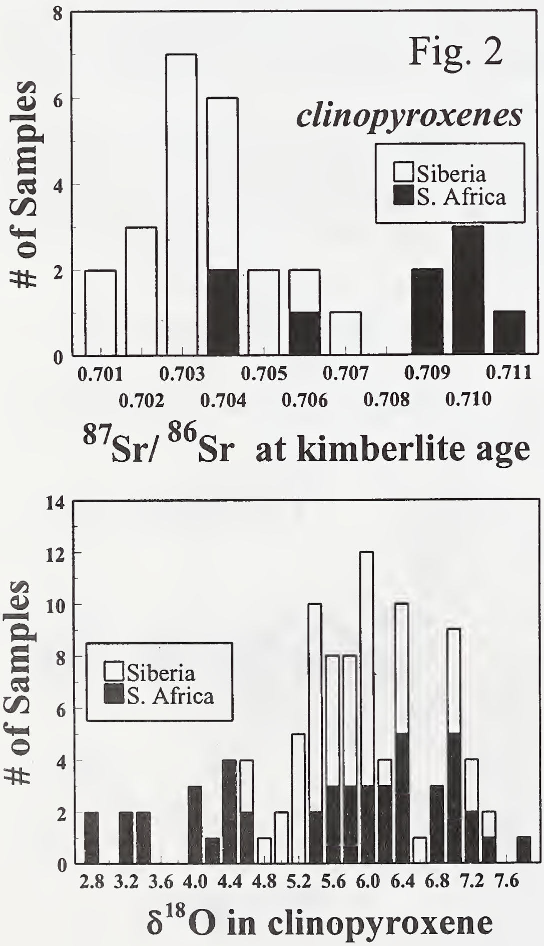
Fig. 1

lived LREE-enrichment of the sample. Based on their REE patterns, garnets can also be subdivided into three groups which are generally sympathetic to the three clinopyroxene groups.

Nd, Sr, and Os Isotopic Data -- All eleven clinopyroxene separates measured by our group (and one by Pearson et al., 1995a) from the Udachnaya pipe give $^{87}Sr/^{86}Sr \leq 0.70425$, whereas Mir samples are routinely above this value (Snyder et al., 1995). However, four of six Udachnaya clinopyroxenes measured by Jacob et al. (1994) give $^{87}Sr/^{86}Sr$ above 0.70425. Mir eclogite clinopyroxenes yield the lowest $^{87}Rb/^{86}Sr$ (0.000122 and 0.000167) by an order of magnitude.

Measured $^{143}Nd/^{144}Nd$ in clinopyroxene separates vary from 0.51134 to 0.51867 and correlate with the $^{147}Sm/^{144}Nd$ (0.0941 - 0.257). The garnets yield $^{147}Sm/^{144}Nd$ ratios of 0.353 to 0.944 and $^{143}Nd/^{144}Nd$ from 0.51205 to 0.52059. A single garnet separate analyzed by Pearson et al. (1994) yielded the highest $^{147}Sm/^{144}Nd$ measured for Udachnaya eclogites. The Udachnaya eclogites yield ages that approximate the time of emplacement of the host kimberlite -- 380-390 Ma. A single Obnazhennaya eclogite gave a Sm-Nd age of 1699$\pm$35 (McCulloch, 1989).

A suite of seven eclogites have also been analyzed for Re and Os abundances and Os isotopic compositions (Pearson et al., 1995b). Re and Os abundances vary from 0.087 to 1.6 ppb and 0.028 to 0.346 ppb, respectively. $^{187}Os/^{188}Os$ ratios vary from 0.8296 to 9.808. These values are extremely radiogenic with 10 to 55% of the total Os being from ^{187}Re decay alone. Five of the seven samples yield model ages between 2.8 and 3.5 Ga and plot along a line which yields an age of 2.90$\pm$0.38 Ga (MSWD = 15.8) and an initial Os isotopic composition, $\gamma_{Os}(i)$, of 82$\pm$41 (Pearson et al., 1995b).



Discussion -- Compared to eclogites from other Siberian localities, as well as eclogite xenoliths world-wide, ***Udachnaya eclogite xenoliths are unique***. Although previous workers have tended to point out the *un*exceptional nature of Udachnaya eclogites (Jacob et al., 1994; Ireland et al, 1994), we believe that the differences are difficult, if not totally misleading, to overlook. First, Udachnaya eclogites exhibit inter- and intra-grain homogeneity not found in other eclogites, including those from the Mir and Obnazhennaya pipes of Siberia (e.g., Beard et al., 1994). Secondly, Udachnaya clinopyroxenes are generally more LREE-depleted than others from South Africa and from Mir and Obnazhennaya. In fact, several Udachanaya clinopyroxenes are at least an order of magnitude more LREE-depleted than those from South Africa (Figure 1). Third, the Sr isotopic composition of Udachnaya clinopyroxenesare less radiogenic than those from South Africa (Figure 2). With the exception of two samples, Udachnaya clinopyroxenes have $^{87}Sr/^{86}Sr \leq 0.705$, whereas South African clinopyroxenes are generally ≥ 0.706. Fourth, garnet-clinopyroxene pairs from Udachnaya eclogites yield positive slopes on conventional $^{147}Sm/^{144}Nd$ vs. $^{143}Nd/^{144}Nd$ diagrams indicating the age of the kimberlite (Snyder et al., 1993), whereas garnet-clinopyroxene pairs from South African eclogites often given negative slopes indicating negative "ages" and, thus, disequilibrium (Neal et al., 1990). Fifth, garnets and clinopyroxenes from the Siberian eclogites exhibit less oxygen isotopic variability than eclogite xenoliths from South Africa (Figure 2). Therefore, it is the interpretation of the singular nature of the

Udachnaya eclogites which is of paramount importance.

In contrast to Ireland et al. (1994), we are convinced that the isotopic and trace-element signatures of these eclogites yield important evidence about early Earth evolution. The alarm sounded by Ireland et al. (1994) from the study of diamond inclusions seems unwarranted in light of the recent findings of Taylor et al. (1995; this volume). We believe that at least two diverse sources for Siberian eclogites, one mantle and one crustal, is still allowed by the present data set. Based particularly on the consistency of trends in major- and trace-element mineral chemistry with oxygen isotopic compositions that vary above and below mantle values, Fraracci (1994) and Beard et al. (1995) have convincingly argued that the Mir eclogites are dominantly of a subducted ophiolite origin. However, the Udachnaya eclogites have oxygen isotopic values which lie only within and above the mantle range; no convincingly low $\delta^{18}O$ values have been found (Snyder et al., 1995). Also, no consistent mineral-chemical trends have been found with oxygen isotopic values for the Udachnaya eclogites, contrary to the results of Jacob et al. (1994) for a much smaller sampling.

This lack of correlation between mineral-chemical compositions and oxygen isotopes, along with the unzoned nature of the minerals, can be explained in two ways. The Udachnaya kimberlite lies near the center of the Siberian craton and thus could have tapped a source which came from deeper in the mantle keel than that for the more peripheral Mir kimberlite. Thus, the Udachnaya eclogite xenoliths could have remained at much higher temperatures within the mantle for much longer times, leaving the minerals open for extensive isotopic, trace- and major-element diffusion. This could have allowed more complete exchange and equilibration with the surrounding mantle, if indeed their original protolith was oceanic crust. Therefore, any oceanic crustal signature could be masked by later overprinting. Conversely, these eclogites could be indicating that the Udachnaya eclogites, although exhibiting some crustal affinities (either directly from subducted oceanic crust or through assimilation during transport and emplacement), contain a significant mantle component not found in the Mir kimberlites. Again, this mantle component could have been derived from the original source or could have been introduced through diffusion or melt interaction over time.

One of the confounding aspects of such a study is the realization that ***there are no definitive mantle signatures in igneous rocks. It is only the absence of crustal signatures that allows the interpretation of a mantle origin for some igneous rocks.*** It is partly for this reason that a single, unique origin for the Udachnaya eclogites cannot be determined at this time; however, several other conclusions can be drawn: (1) Most of the primary minerals in the Siberian eclogites show little evidence of the effect of later metasomatism or kimberlitic addition; (2) Although some eclogites could be residues of melting to form Archean granitoids, many others seem to preclude such a history; (3) Re-Os, Sm-Nd, and Rb-Sr isotopic studies are consistent with a very old (at least 2.9 Ga) protolith that had its ultimate origin in depleted mantle; (4) Some, though not all, eclogites are best explained as processed portions of subducted oceanic crust; (5) Still other eclogites (the so-called Group A eclogites) are consistent with a mantle derivation alone. It appears that we must still conclude, as did the late Ted Ringwood (1975), that eclogites do indicate a "multiplicity of origins".

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