Sm-Nd SYSTEMATICS IN ECLOGITE AND GARNET PERIDOTITE NODULES FROM KIMBERLITES: IMPLICATIONS FOR THE EARLY DIFFERENTIATION OF THE EARTH

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In this study we report Sm-Nd isotopic data for eclogites from the Roberts Victor pipe in South Africa and Yakutia, U.S.S.R. In addition, a garnet lherzolite has been analyzed from the Mir pipe in the Yakutia province. The isotopic systematics have been examined in co-existing garnet and clinopyroxene. These minerals are strongly LREE depleted (low Nd/Sm) and LREE enriched (high Nd/Sm) respectively and thus enable relatively precise determinations of both the initial neodymium isotopic composition and the most recent time of equilibration of these mineral systems. The garnet-clinopyroxene pairs for the Roberts Victor eclogites define mineral isochron ages of 144 ± 10 Ma and 188 ± 33 Ma (figure 1). The younger mineral age of 144 ± 10 Ma is in reasonable agreement with previous estimates of the intrusion age of the host kimberlite given by Rb-Sr mica ages of ~125 Ma, but significantly older than a U-Pb zircon age of 92.2 Ma (Davies et al., 1976) These results are therefore consistent with almost complete isotopic re-equilibration of garnet and clinopyroxene during the kimberlite magmatism. Recent isotopic studies by Richardson et al. (1985) of garnet lherzolites from northern Lesotho also indicate isotopic re-equilibration at the time of kimberlite sampling. Although the Roberts Victor eclogites give similar Sm-Nd mineral isochron ages, the initial $^{143}Nd/^{144}Nd$ ratios vary from $\varepsilon_{Nd} = -14.4 \pm 0.3$ to $\varepsilon_{Nd} = +3.7 \pm 0.1$. This range confirms the observation that the xenoliths are unrelated to the host kimberlite and indicates long-term (> 1000 Ma) heterogeneities in the sources for the eclogites. However, the timing of the events which produced these heterogeneities is not well constrained by the Sm-Nd mineral data due to the almost total isotopic re-equilibration of the garnet-clinopyroxene pairs.

A striking feature of the Sm-Nd isotopic data for a garnet lherzolite (M602) and eclogites from Yakutia (Siberia) is that the garnet-clinopyroxene pairs gives ages of 1540±10 Ma, 2600 ± 150 Ma, 1690 ± 50 Ma, 1320 ± 20 Ma and 674±30 Ma respectively (figures 2a,b), which are all much older than the 150 Ma to 440 Ma age estimated for the kimberlite pipes. In addition, the initial $^{143}Nd/^{144}Nd$ ratios for the garnet lherzolite and one of the eclogites are substantially higher than CHUR with ε_{Nd} values of 24.5±0.2 and 20.1 ± 3.0 respectively. These values are significantly more positive than 'normal' mantle materials (figure 3) and have previously only observed in a garnet lherzolite and an eclogite (McCulloch , 1982 and Jagoutz et al., 1984). In fact, garnet from the garnet lherzolite has a measured value of $\varepsilon_{Nd}(0) = +227$ which is one of the highest values yet reported. The younger eclogites 47639 and 47637 have negative ε_{Nd} values of -2.2±0.2 and -5.5±0.2 respectively.

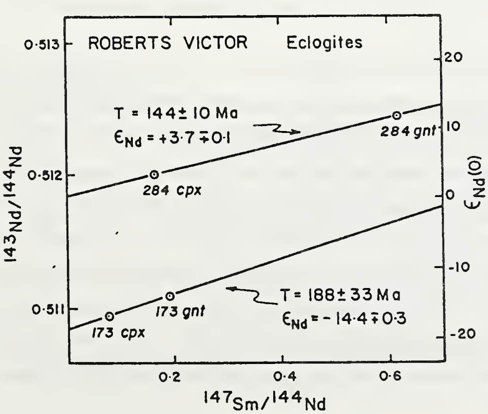

Figure 1. Isochron diagram for co-existing garnet and clinopyroxene from eclogites from Roberts Victor. The mineral ages are only slightly older than the age of the kimberlite host indicating almost complete re-equilibration during kimberlite sampling.

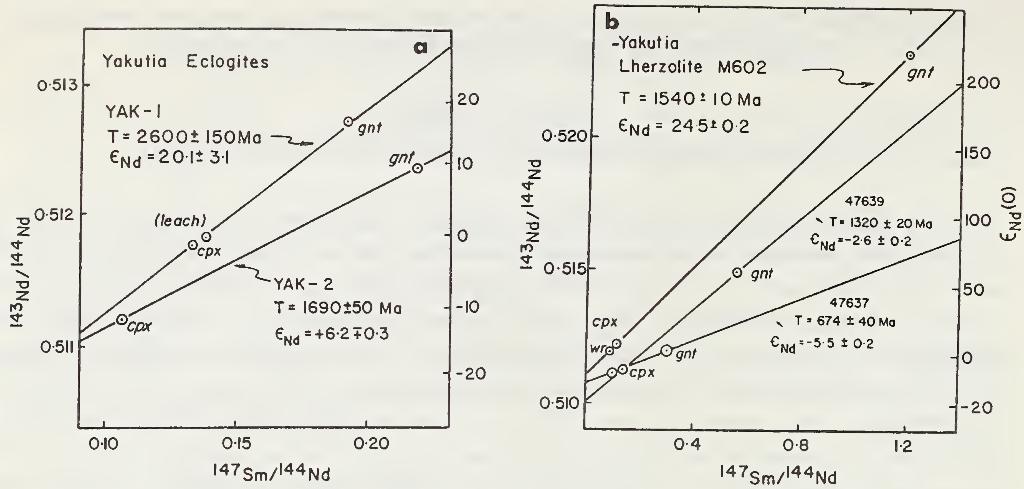

Figure 2. *a*, Sm-Nd internal isochron diagram for the Yakutia 1 and 2 eclogites. The age and initial ratio given by the intersection of co-existing garnet and clinopyroxene represent minimum estimates. Both ages are significantly older than the age of the host kimberlite. *b*, Sm-Nd internal isochron for the garnet lherzolite M602 from the Mir kimberlite pipe and the eclogites 47639 and 47637 from the Yakutia province. The garnet from M602 has an extremely high $^{143}Nd/^{144}Nd$ ratio corresponding to $\varepsilon_{Nd}(0) = +227$.

The major difficulty in interpreting these results is ascertaining the effects of isotopic re-equilibration and evaluating whether the nodules have remained as closed isotopic systems. Isotopic re-equilibration is obviously an important process as evidenced by the young ages from Roberts Victor and the wide range of internal isochron ages from Yakutia (2600 Ma to 680 Ma). If the whole rock systems have Sm/Nd ratios less than chondritic, than later isotopic re-equilibration will produce lower ε_{Nd} values and of course younger ages (c.f. McCulloch and Black, 1984). This effect is apparent in the Yakutia eclogites where the ε_{Nd} values become progressively lower as the internal isochron ages decrease (figure 3). This implies that the highly positive ε_{Nd} values of +24.5 and +20.1 for M602 and Yak-1 are *minimum* values. It is also noted that the converse applies to whole rock systems with Sm/Nd ratios greater than chondritic. Assuming that the nodules acted as essentially closed isotopic systems (on a whole-rock scale), the highly positive ε_{Nd} values from Yakutia therefore require long-lived strongly LREE depleted sources.

A model to account for these highly positive ε_{Nd} values has been proposed by McCulloch (1982) whereby processes similar to those that operated in early Lunar history are envisaged. That is, cumulates precipitating from an early terrestrial magma ocean. To account for the long-lived strongly LREE depleted character observed in the most positive ε_{Nd} nodules, it is necessary to form a chemically stratified (or isolated) garnet-rich layer during the crystallisation of the magma ocean early in the earth's history (i.e. prior to 4000 Ma). Independent petrologic evidence (Ohtani, 1985) suggests that a garnet-rich layer with a thickness of ~200 km thickness may have been present in the lower portion of the earth's primitve upper mantle. An alternative mechanism for producing LREE depletions involves the subduction of oceanic lithosphere with LREE depletions. This process has been proposed by Ringwood (1982) as a means of essentially irreversibly differentiating the earth's mantle and involves the conversion of basaltic components of oceanic crust into eclogite and consequently their sinking deep into the earth's mantle (~650km). To

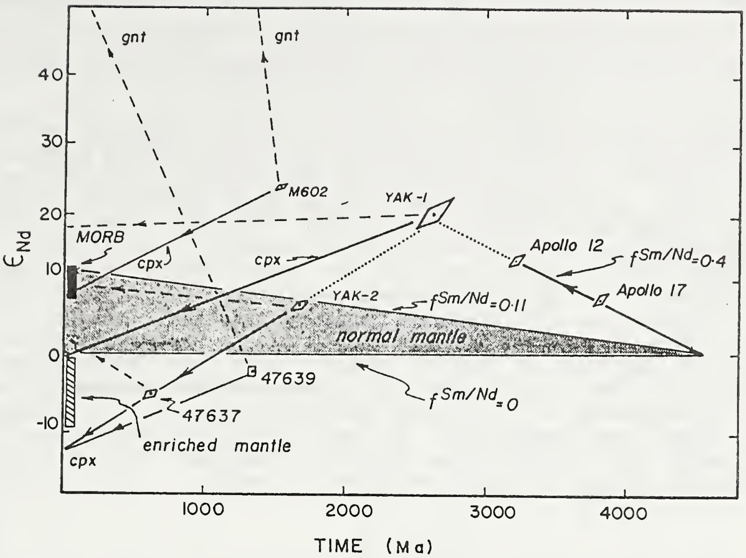

Figure 3. $^{\epsilon}$Nd versus time diagram showing initial ratios and inferred evolutionary history for Yakutia xenoliths. The $^{\epsilon}$Nd values for YAK-1, YAK-2, 47639, 47637 and M602 are given by the intersection of co-existing garnet (broken lines) and clinopyroxene (solid lines). The increase in $^{\epsilon}$Nd values with age is consistent with progressive re-equilibration. The highly positive $^{\epsilon}$Nd values for Yak-1 and M602 indicate that the sources of these xenoliths were probably differentiated in the first 100 to 200 Ma of earth history. Also shown are the $^{\epsilon}$Nd values of the Apollo 12and 17 Lunar basalts. A similar type of evolutionary history could also account for the highly positive $^{\epsilon}$Nd values found in the Yakutia xenoliths.

satisfy the isotopic constraints the early formed oceanic crust would have to be strongly LREE depleted relative to the bulk mantle. At ~2600 Ma (the oldest Sm-Nd mineral age) these materials were then probably partially melted with the resultant LREE enriched melts ascending into the subcontinental lithosphere where they were trapped and solidified within the eclogite stability field and then finally incorporated in later kimberlite magmatism.

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