# CHEMICAL AND ISOTOPIC EVOLUTION OF THE SE AUSTRALIAN SUBCONTINENTAL LITHOSPHERE

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Integrated petrologic, chemical and isotopic data for spinel-bearing lherzolite and harzburgite xenoliths from the Newer basalt field, southeastern Australia provide an internally consistent multistage model for the evolution of the subcontinental lithosphere. Whole rock isotopic compositions show exceedingly large variations including nodules from the same host basalt, with  ${}^{87}Sr/{}^{86}Sr$  ranging from 0.7034 to 0.7084 and  $\epsilon_{Nd}$  values ranging from +10.6 to -7.5. Constant Sr/Nd ratios of 15 for whole rocks and clinopyroxenes is consistent with the added incompatible element enriched component (component B) being a basaltic melt with intraplate chemical characteristics. The isotopic compositions of these peridotites indicate long-term, small-scale heterogenities in the subcontinental lithosphere, and are in marked contrast to the near uniform isotopic compositions of the host alkali basalts ( ${}^{87}Sr/{}^{86}Sr = 0.7038$  to 0.7041 and  $\epsilon_{Nd} = +3.6$  to +2.9). The data are consistent with lithospheric mantle growth involving the underplating of refractory peridotite diapirs. A minimum of three evolutionary stages are identified: an early basalt depletion event, recording the initial development and stabilization of the lithospheric mantle, and subsequent enrichment episodes, documenting later reactivation events.

#### SAMPLES

Trace element and Sr and Nd isotopic compositions of whole rocks and mineral separates for 14 peridotite inclusions are combined with previously reported petrologic and geochemical data for these samples (Frey and Green, 1974; Nickel and Green, 1984). These lherzolite and harzburgite inclusions all contain, in decreasing order of abundances, olivine, orthopyroxene, clinopyroxene and spinel, and some also contain amphibole, phlogopite or apatite. Samples are coarse to medium grained, with porphyroclastic textures. Four samples are strongly foliated. More detailed petrographic descriptions are given in (Frey and Green, 1974; Nickel and Green, 1984).

### Sr AND Nd ISOTOPIC COMPOSITIONS

The whole rock data shows the largest known variation in Sr and Nd isotopic compositions for spinel-bearing lherzolite and harzburgite xenoliths from a given basalt field (Fig. 1). Three samples from Mt. Gambier alone display nearly as large a range in isotopic compositions as found in the field. Combined with earlier isotope data (Chen and Frey, 1981) the Mt. Leura peridotites show an enormous variation in Nd isotope composition from  $\epsilon_{Nd}$  = +10.6 to -7.5. Most significantly, these isotopic heterogeneities occur within a single vent and reveal significant compositional diversity in the present day southeast Australian subcontinental lithosphere over a restricted vertical section, the spinel lherzolite stability field (e.g., some 40 to 70 kms depth).

FIGURE 1.  ${}^{87}$ Sr/ ${}^{86}$ Sr versus  $\varepsilon_{Nd}$ values for whole rock spinel-bearing peridotite xenoliths from southeast Australia. Open symbols identify peridotites with a well defined foliated fabric. The field of Sr and Nd isotopic compositions for the Newer basalts includes tholeiitic and alkalic basalts from McDonough et al (1985).



The large variation in their Sr and Nd isotope compositions is in marked contrast to the limited range in isotope composition of the host alkalic basalts (McDonough et al, 1985), thus precluding significant host basalt contamination. Note that contamination by the host basalts would only reduce the total isotopic variation and therefore, the present spread would represent a minimum for the peridotite source region. Rb-Sr and Sm-Nd isotope compositions for the peridotites show considerable scatter (Fig. 2), although there is a positive trend in the <sup>1+7</sup>Sm/<sup>1+4</sup>Nd versus <sup>1+3</sup>Nd/<sup>1+4</sup>Nd data. Reference isochrons are provided in Fig. 2, although these isochrons are neither geologically nor statisitically significant.



FIGURE 2. (a) <sup>97</sup>Sr/<sup>86</sup>Sr versus <sup>97</sup>Rb/<sup>86</sup>Sr and (b) <sup>1+3</sup>Nd/<sup>1+\*</sup>Nd versus <sup>1+7</sup>Sm/<sup>1+\*</sup>Nd whole rock variation for Australian peridotites. 1100 Ma Rb-Sr reference isochron is shown for three Mt. Gambier peridotites. Sm-Nd reference isochrons for three Mt. Gambier peridotites (1500 Ma), and four Mt. Leura peridotites (610 Ma) are shown, however all ages have no geological significance, see text. Symbols as in Fig. 1.

Mineral phases in a phlogopite lherzolite (84-413) are in gross Sr isotopic disequilibrium. The  ${}^{87}\text{Rb}/{}^{86}\text{Sr}$  of the phlogopite is much higher than that of the clinopyroxene (and whole rock), whereas the clinopyroxene has a higher  ${}^{87}\text{Sr}/{}^{86}\text{Sr}$  (0.70710) than the  ${}^{87}\text{Sr}/{}^{86}\text{Sr}$  of phlogopite (0.70498); the whole rock has an intermediate  ${}^{87}\text{Sr}/{}^{86}\text{Sr}$  value (0.70553). The low  ${}^{87}\text{Sr}/{}^{86}\text{Sr}$  of the phlogopite indicates a recent addition of a low  ${}^{87}\text{Sr}/{}^{86}\text{Sr}$  to this rock; it is possible that this addition is associated with the Pliocene-Recent basaltic magmatism in the region.

# THE NATURE AND TIMING OF THE LREE-ENRICHED ADDED COMPONENT

Frey and Green (1974) suggested the major and compatible minor element characteristics of these peridotites (their component A) resulted from the extraction of a basaltic melt, whereas the incompatible element composition is dominated by a later added component (their component B) that is genetically unrelated to component A and was derived by a small degree (<5%) of melting in equilibrium with garnet. The Sr and Nd concentrations in these peridotites show an excellent correlation (Fig. 3), and allows us to place constraints on the nature and origin of this component. The average whole rock Sr/Nd ratio of 15 is similar to that found in the clinopyroxenes (14.5), and in marked contrast to that in phlogopite (1800). The averaged Sr/Nd ratio of these peridotites is similar to the primitive earth Sr/Nd ratio (17.1), primitive MORBs (10-15) and primitive intraplate basalts (15-20) and less than the ratio commonly measured for primitive island arc basalts (30-35). The added component B documented by Frey and Green (1974) and recorded by the Nd isotope system is suggested to be a LREE-enriched melt with intraplate basaltic characteristics, although a melt component derived by low degrees (<2%) of melting of the MORB source would have most of the necessary chemical characteristics. The isotopic composition of these peridotites are distinct from their host basalts, suggesting that the introduced melt component is generally unrelated to this intraplate magmatic event.

FIGURE 3. Sr (ppm) versus Nd (ppm) concentrations for whole rock and their clinopyroxene mineral separates for peridotite xenoliths from southeast Australia. A single phlogopite mineral separate clearly shows a markedly different Sr/Nd ratio.



Given that these peridotites are mixtures of at least 2 components, then traditional isochron diagrams cannot yield any significant age information. Assuming a two stage model, whereby the peridotites experienced one depletion event and one enrichment event, an age estimate for the LREE-enrichment event may be calculated using a  $\rm T_{DM}$  model.  $\rm T_{DM}$  model ages for these peridotites vary from 600 to 1370 Ma. These models yield only a gross age estimate for the timing of the enrichment event, as they assume only a single stage enrichment event. The pholgopite in peridotite 84-413 has a lower <sup>87</sup>Sr/<sup>86</sup>Sr than the whole rock and coexisting clinopyroxene, indicating a recent addition tha post-dates the earlier partial melt extraction and incompatible element enrichment event recorded in the clinopyroxene. It would take 60 Ma for the phlogopite to evolve to its present <sup>87</sup>Sr/<sup>86</sup>Sr value if it was introduced from a depleted mantle source (i.e.,  ${}^{97}$ Sr/ ${}^{86}$ Sr = 0.7025). If the component was derived from a less depleted mantle, that is a higher "7Sr/"6Sr source, then the age of the phlogopite would be less than 60 Ma. Therefore, phlogopite generation occurred sometime during the Cenozoic, consistent with the observation that intraplate magmatism occurred throughout this period. An important result which comes from documenting a minimum of 3 evolutionary stages for the phlogopite-bearing peridotite is that it records an earlier mantle enrichment event which pre-dates the present alkaline volcanism.

## EVOLUTION OF THE SUBCONTINENTAL LITHOSPHERE

Subcontinental lithospheric mantle accreted during interplate and intraplate magmatism would most likely be depleted peridotite, having a petrologic and chemical composition similar to component A as characterized by Frey and Green (1974). Such Mg-rich, refractory residuum is less dense than the ambient mantle and thus, intrinsically buoyant. The residual peridotite bodies produced during interplate or intraplate magmatism become permanently trapped beneath the continents and are incorporated into the lithosphere as a gravitationally stable, depleted lithospheric mantle. However, undepleted or less-depleted peridotite accreted directly from the asthenosphere during conductive cooling of the lithosphere would be denser and gravitationally unstable upon cooling. The early partial melting event identified in these peridotites documents the initial development and stablization of the subcontinental lithosphere. Deciding whether the tectonic setting of the initial lithospheric growth stage was in an interplate or intraplate environment is not straightforward. Lithospheric growth may have occurred initially in either an oceanic or intracratonic setting, although Frey and Green (1974) have appealled to a mid-ocean ridge setting. Later incompatible element enrichment events, recorded in these peridotites, document reactivation episodes which have occurred in this lithosphere.

#### References

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