of enrichment to permit extraction of light REE enriched lavas at moderate degrees of melting.

Fragments of "veined mantle" have been analysed for REE, Nd and Sr isotopes. Co-existing kaersutite and diopside give an "age" of 169 ± 21 MA (1σ) (MSWD = 0.63) with an $(^{143}Nd/^{144}Nd)_I$ = 0.51287. Clinopyroxenes separated from five petrographically distinct peridotites exhibit an extreme range in $^{143}Nd/^{144}Nd$ = 0.512983 - 0.512603 and $^{87}Sr/^{86}Sr$ = 0.70272 - 0.704697, that overlaps the "mantle array". If the linear arrays on trace element and isotope diagrams represent "mixing lines" then we can define the enriched (E) and depleted (D) components in the mantle. First, the kaersutite veined Type I lherzolites from Geronimo and Dish Hill comprise a MORB residue (D) and an enriched component identical to Basin and Range lavas. Clearly kaersutite veins represent frozen conduits of basanitic magma. Second the anhydrous Type I and Type II lherzolites at Geronimo and San Carlos comprise a MORB residue (D) and an enriched component with $\Sigma_{Nd} \approx 0$. Mantle below the southwestern U.S.A. has experienced a multi-stage history comprising a major widespread depletion event (> 1 b.y.) and enrichment events caused by migration and infiltration of LIL element rich fluids. (Σ_{Nd} = 0 to 8.)

E14
MANTLE HETEROGENEITY: ISOTOPIC AND TRACE ELEMENT EVIDENCE FROM NUNIVAK ISLAND ALASKA

M.F. RODEN, D.M. FRANCIS, F.A. FREY
Dept. Earth & Planetary Sci, MIT, Cambridge, MA 02139 USA

A diverse suite of ultramafic and mafic nodules occurs in Quaternary basanites on Nunivak Island (166°W, 60°N), including granuloblastic-equant (GE), coarse-equant (CE), and coarse-tabular (CT) lherzolites, amphibole-pyroxenites, and pyroxene granulites. GE nodules have La/Yb ratios less than chondrites, and clinopyroxenes from these nodules have $^{87}Sr/^{86}Sr$ (0.70203-0.70264) and $^{143}Nd/^{144}Nd$ (0.51321-0.51330) ratios similar to those of oceanic-ridge basalts. We interpret these nodules to be petrogenetically related to oceanic-ridge basalts however, very low bulk rock K contents (9-17 ppm) complicate simple models. The CT and CE peridotites, some of which contain hydrous minerals, all have La/Yb ratios greater than chondrites, and have high concentrations of K (80-1065 ppm), Rb (0.058-2.83 ppm), Ba (3.7-42 ppm), and Sr (11-82 ppm) relative to the GE nodules (0.01-0.11 ppm Rb, 0.56-0.83 ppm Ba, 12-16 ppm Sr). These CE and CT nodules are similar to metasomatized peridotites from other localities. Isotopic data indicate that some of the amphibole-bearing peridotites ($^{87}Sr/^{86}Sr$= 0.70289-0.70313; clinopyroxene $^{143}Nd/^{144}Nd$ = 0.51309) are petrogenetically related to the amphibole-pyroxenites ($^{87}Sr/^{86}Sr$=0.70288-0.70297; 2 whole rocks $^{143}Nd/^{144}Nd$ = 0.51310). These pyroxenites have trace element characteristics consistent with an origin as crystal accumulates. We infer that this example of metasomatism is the result of the infiltration of a H-C-O-rich fluid and/or residual silicate melt which originated in the pyroxenites. Based on consideration of isotopic data, we concur with Menzies and Murthy (1980) that the metasomatism occurred recently, and that it is petrogenetically related to the basaltic volcanism on Nunivak. Metamorphic textures in the pyroxenites preclude a direct relationship with the host basalts.

E15
METASOMATISM AND CHEMICAL HETEROGENEITY IN THE SUB-CONTINENTAL MANTLE: Sr and Nd ISOTOPIC ANALYSIS OF APATITE RICH XENOLITHS AND ALKALINE MAGMAS FROM EASTERN AUSTRALIA

M.A. MENZIES & S.Y. WASS
Dept. of Earth Sciences, Open University, Milton Keynes, MK7 6AA, England

Cenozoic volcanic rocks from E. Australia are relatively uncontaminated (viz. high Mg values, high Ni, Cr, Co and Sc) and offer a unique opportunity to study mantle isotopic heterogeneities. Most of the magmas in the S. Highlands province are geochemically distinct and reached the surface as isolated flows of limited volume. Consequently the considerable range in $^{87}Sr/^{86}Sr$ = 0.70289 - 0.70444 and $^{143}Nd/^{144}Nd$ = 0.512965 - 0.512611 (13 rocks) can best be reconciled by melt extraction from a geochemically and mineralogically inhomogeneous mantle. Trace element and isotopic analyses of Al-augite series xenoliths reveal the following: (1) Apatite-rich pyroxenites have a narrow $^{143}Nd/^{144}Nd$ = 0.51257 - 0.51266 and $^{87}Sr/^{86}Sr$ = 0.70368 - 0.70397, similar to that of the host dike rocks (i.e. $^{143}Nd/^{144}Nd$ = 0.512611 - 0.512663 and $^{87}Sr/^{86}Sr$ = 0.70405 - 0.70414). (2) Whole rock pyroxenites have slightly higher $^{87}Sr/^{86}Sr$ ratios than constituent minerals perhaps due to the presence of mica. (3) Minerals separated from the xenoliths (viz. apatite, amph. and cpx.) exhibit an extremely narrow range in $^{87}Sr/^{86}Sr$ = 0.703543 - 0.703665 and a wide range in $^{143}Nd/^{144}Nd$ = 0.51252 - 0.51276, with the exception of spinel which has a higher $^{87}Sr/^{86}Sr$ = 0.704139. The minerals and whole rocks plot to the left of the mantle array. (4) Co-existing spinel, apatite and clinopyroxene exhibit a narrow range in Sm/Nd that does not permit accurate dating of pyroxenite formation (≈500 m.y.). The pyroxenites are believed to represent the products of infiltration and crystallisation of a kimberlitic liquid into the mantle. The mantle heterogeneities produced by such metasomatism may be widespread in the Southern Highlands and may explain the diverse nature of the volcanic rocks.

E16
Nd ISOTOPIC DISEQUILIBRIUM IN GARNET PERIDOTITES FROM THE BULTFONTEIN KIMBERLITE AND IMPLICATIONS FOR MANTLE METASOMATIC COMPONENT ADDITION

S.H. RICHARDSON, A.J. ERLANK, N. SHIMIZU
Center for Geoalchemy, Dept. of Earth & Planetary Sciences, MIT, Cambridge, MA 02139 USA

The Sm-Nd and Rb-Sr isotopic systematics of garnet, diopside and phlogopite from coarse granular peridotite xenoliths in the southern African Bultfontein kimberlite pipe indicate addition of a mantle metasomatic component. $^{147}Sm/^{144}Nd$ and $^{143}Nd/^{144}Nd$ ratios of garnet, diopside and phlogopite (major REE carrier phases), corrected back to the time of kimberlite emplacement (90 m.y.), are negatively correlated precluding conventional Nd isochron relationships and requiring exotic component addition without reequilibration. On a Nd-Sr correlation diagram these phases lie on an extension of the mantle array defined by mantle derived volcanics, at lower Nd and higher Sr isotopic ratios, as previously demonstrated for a suite of Bultfontein diopsides (Menzies & Murthy, 1980). Pipe emplacement initial $^{143}Nd/^{144}Nd$ ratios decrease in the sequence phlogopite-diopside-garnet such that garnet lies furthest into the "enriched" quadrant. Identification of one or more of these phases as representative of the metasomatic component is complicated by the complex histories of the host peridotites, which appear to have included previous melt extraction. If phlogopite (diopside) is metasomatic, then its source evolved with a higher Sm/Nd ratio than the host garnet harzburgite. This seems counterintuitive given the conventional high Sm/Nd ratios of garnet and is the subject of further investigation.

E17

ZONED MINERALS IN PERIDOTITE NODULES: CLUES TO MANTLE DYNAMICS

D. SMITH[1], C. WILSON[1], S. N. EHRENBERG[2]
[1]Dept Geology, Univ. Texas, Austin, Texas 78712 USA
[2]Shell Development Co., P. O. Box 481, Houston, Texas 77001 USA

Compositional zoning within peridotite phases has been measured by electron probe microanalysis in order both to constrain rates of pressure and temperature change and metasomatism in mantle peridotite and to infer relative cation mobilities in the mantle. Rocks studied include garnet-inclusion pairs from ultramafic diatremes on the Colorado Plateau, composite peridotite nodules from Kilbourne Hole, and garnet lherzolite nodules from The Thumb, a minette diatreme on the Colorado Plateau.

Results from garnet lherzolite nodules from The Thumb document metasomatism and constrain its timing. Calculated temperatures for sheared and coarse nodules are mostly in the range 1050-1400°C. Garnets in two sheared nodules have rims enriched in Fe, Ti, and Na and depleted in Mg relative to grain cores. Olivine and diopside inclusions in garnet are enriched in Mg and Cr and depleted in Na, Ti, and Fe relative to matrix phases. Matrix pyroxenes homogenized distinctly faster than garnet. Ti mobility in garnet was less than those of Fe and Mg by about a factor of 4. Our data support the earlier hypothesis that these sheared nodules formed by deformation and metasomatism of coarse peridotite. Garnets in two coarse peridotites, however, are also zoned, so deformation and metasomatism are not necessarily related. Several nodules with zoned garnets have relatively flat normalized REE patterns, and there is no evidence that the Fe-Ti metasomatism was accompanied by LREE enrichment. Comparison of observed and calculated diffusion gradients suggests metasomatism occurred within a short period (perhaps tens of years) before minette eruption.

E18

KIMBERLITE: «THE MANTLE SAMPLE» FORMED BY ULTRAMETASOMATISM

D.K. BAILEY
Department of Geology, University of Reading, England, RG6 2AB.

Even with optimum general mantle compositions and regardless of the mechanism of melt generation, a kimberlite melt fraction would be minute. Melt segregation to give localised eruption, exploiting pre-existing zones of weakness, poses insuperable problems for mechanisms of pervasive melt generation that are favoured for other types of magmatism. Neither diapiric, nor "hotplate" melting could suffice because any initial melt would be intergranular and extremely diffuse.

Experiments indicate that the kimberlite solidus inflects to a positive dP/dT between 100 and 200 km deep. Diatremic kimberlite activity is consistent with flashover eruption from the near-solidus and can originate only near the inflection, or at shallower levels. Ascent of kimberlite melt from greater depths would mean upward departure from the solidus and hence vapour undersaturation. This is the unavoidable path of deep diapirs, which would never provide the activity in its observed form. Xenolith PT trajectories, of all ages and from all cratons, are in grazing incidence with the inflection zone, indicating its critical nature, and adding to the case against rising diapirs.

Stockwork metasomatism represents a plausible alternative. It concentrates the incompatibles in linked channelways prior to melting, and eliminates the need for segregation after melting of liquid traces from a large mantle volume. The channelway extensions to the surface form the guides to kimberlite eruption once the stage of ultrametasomatism/melting is achieved.

(Late abstract)

CONTRASTING TYPES OF MANTLE METASOMATISM

J.B. DAWSON
(Department of Geology, University, Sheffield SI 3JD, U.K.)

Within the past decade, metasomatism of upper mantle peridotites has been increasingly invoked to account for major element, trace element and isotopic inhomegeneities in the upper mantle and to create source areas for volcanic rocks whose geochemical properties would be otherwise difficult to explain.

Two major types of metasamotism can be recognised:-

(1) Patent metasomatism in which textural replacement of primary phases by later generally-hydrous phases is evident. This has been recognised in kimberlite and basaltic xenolith suites and includes replacement of garnet, clinopyroxenes and orthopyroxene by amphibole and/or phlogopite. In some specimens this metasomatism is clearly related to recognisable veins or zones comprising phases rich in K, Na, Rb, Ti, Nb etc., whilst in other specimens the metasomatism is pervasive on the hand-specimen scale. A more subtle type of patent metasomatism has been recently recognised in peridotite xenoliths from S. Africa