

of  $\text{SiO}_2$ ,  $\text{TiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{P}_2\text{O}_5$  and incompatible trace elements.

The geochemical evolution have been investigated by molecular ratio diagrams with Zr as the ratio element in order to eliminate deformation of the data by the closure effect.

The kimberlites and lamproites have differing trends, and one rock type cannot have evolved from the other. The geochemical variation of the lamproites modelled with congruent melting of known mantle phases give rich/phl/cpx/ap/ru = 30/45/20/3/2. This solution yields too high (Fe,Mg)O values and too low alkali content. A model is proposed where incongruent melting of phlogopite to a melt of sanidine-ilmenite composition leaves a residue of olivine. This model gives rich/phl/cpx/san/ap/ilm = 38/27/11/16/3/5. The kimberlite variation can be explained by melting of ol/phl/cc/cpx/spi/ap = 65/17/9/5/3/1.

REE distributions of both rock types indicates that the mantle source was heavily enriched in REE and especially the LREE.

## C14

### PETROGRAPHY, GEOCHEMISTRY AND Sr ISOTOPIC COMPOSITION OF THE MBUJI-MAYI AND KUNDULUNGU KIMBERLITES (ZAÏRE).

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At Mbuji-Mayi the diamond-rich kimberlite breccia, of late Cretaceous age, contains nodules of "primary kimberlite". Phenocryst phases are Cr-chlorite (often rimmed or replaced by phlogopite) and two generations of olivine completely pseudomorphosed to phlogopite and calcite. The very fine-grained matrix consists of Cr-chlorite, hydromica and calcite with minor amounts of apatite, magnetite and rutile. The phenocryst assemblage and mineral transformations are rather peculiar. Given the absence of phlogopite phenocrysts, one cannot rule out the possibility that these kimberlites were originally of basaltic type.

Except for a higher carbonate content, they are chemically similar to South-African kimberlites. The  $^{87}\text{Sr}/^{86}\text{Sr}$  initial ratios are low (0.7040-0.7045) which point to a mantle origin without crustal contamination. The isotopic ratio in rare carbonate inclusions is equally low suggesting that they are genetically linked to the kimberlites. REE patterns are the same as those observed in South-African kimberlites:  $(\text{La}/\text{Yb})_{\text{N}} \approx 100$ ;  $\text{La}_{\text{N}} = 100-600$ ; no Eu anomaly. Cr-rich diopside megacryst have lower  $^{87}\text{Sr}/^{86}\text{Sr}$  ratios (ca. 0.7030) implying a xenolithic character. The pronounced HREE depletion seems to indicate that they formed in equilibrium with garnet.

The Kundulungu kimberlites are of the basaltic type (fresh olivine phenocrysts, fine-grained chloritic matrix, absence of phlogopite phenocrysts). They are much lower in carbonates but, in terms of trace element and Sr isotopic geochemistry they are very similar to the Mbuji-Mayi and other kimberlites.

## C15

### Nd AND Sr ISOTOPIC COMPOSITIONS AND REE GEOCHEMISTRY OF ALKALI BASALTS FROM THE MASSIF CENTRAL, FRANCE.

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Cenozoic volcanic rocks of alkali basalt family are widespread in the Massif Central. They are underlain by the Hercynian granitic basement. The compositions of basalts range from hawaiitic to basanitic, but basanites dominate the rock types. Results show that the basalts from the Cantal, the Aubrac and the Mont Dore ( $T < 10$  m.y.) have  $^{143}\text{Nd}/^{144}\text{Nd} = 0.51283$  to  $0.51299$  or  $\epsilon_{\text{Nd}} = +3.7$  to  $+6.7$ , and  $^{87}\text{Sr}/^{86}\text{Sr} = 0.70338$  to  $0.70435$ . Quaternary basalts from the Chaîne des Puys yield  $^{87}\text{Sr}/^{86}\text{Sr} = 0.70366$  to  $0.70458$ . In a Nd-Sr isotopic correlation diagram, these data fall within the correlation band. The positive  $\epsilon_{\text{Nd}}$  values suggest that their magma sources have had a time-integrated LREE depletion, similar to that observed for the MORB sources.

The REE data show typical LREE enrichment of alkali basalts, with  $\text{La}_{\text{N}} = 80-250$  X,  $\text{Lu}_{\text{N}} = 7-13$  X,  $(\text{La}/\text{Yb})_{\text{N}} = 10-20$ , and practically no Eu anomalies. Geochemical arguments do not favor any significant crustal contamination for the derivation of these basalts studied. Theoretical considerations call for a recent mantle metasomatism in which a LREE depleted source region was enriched in LREE and other LIL elements before partial melting events. Since the positive  $\epsilon_{\text{Nd}}$  values and enriched LREE abundances are so common to most alkali basalts and related rocks, it appears that mantle metasomatism is precursory to the generation of alkali basalts and that the influx of metasomatic fluids have localized the melting events.

## C16

### Sr, Nd ISOTOPES AND TRACE ELEMENT GEOCHEMISTRY OF MELILITES FROM WESTERN EUROPE

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Melilitite bearing nephelinites (melilitites) are commonly found in provinces where evidence of melting at deep levels in the mantle (kimberlites, carbonatites) exists. They are actually among the most mafic basaltic rocks and their high content in REE and Sr together with a fairly rapid eruption mode would suggest little contribution of high level contamination in their genesis.

Twenty cenozoic melilitites from Europe (Spain, France, W. Germany and Czechoslovakia) have been analysed for Sr, Nd isotopic composition and trace element (REE + transition elements) contents.  $^{87}\text{Sr}/^{86}\text{Sr}$  and  $^{143}\text{Nd}/^{144}\text{Nd}$  ratios plot mostly within and partly below the oceanic trend with no obvious regional variation. The average  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio is 0.703776 (range 0.70322-0.70446), the average  $^{143}\text{Nd}/^{144}\text{Nd}$  ratio of 0.512832 (0.51269-0.51300). Leaching experiments show isotopic inhomogeneities and suggest the present of a high  $^{87}\text{Sr}/^{86}\text{Sr}$  component interpreted as being of crustal origin. The origin of melilitite could be found in an ordinary (oceanic type) upper mantle of which the melting products experienced contamination at high level during upward migration of the magma in the crust. The Sr/Nd ratio of the contaminant is tentatively estimated to fall in the range 3 to 15 which could fit upper crustal rocks such as shales or granites.

REE elements present the usual pattern of alkali-rocks with high concentration level, high Ce/Yb ratios (58 to 130) and no Eu anomaly.

Beside additions evidence for crustal contamination, REE and tran-

sition elements may carry information on the origin of the magmas. If melting of a recently metasomatized mantle could provide a satisfactory interpretation, wall rock alteration formalized with the zone refining equation fit well the present data. An important implication of this process is the rapid equilibration of high partition coefficient elements (HRE for instance) with conduit walls in contrast with low partition coefficient elements (LRE). It is found that a liquid generated in the garnet stability field of the mantle and rising through spinel hercynites or harzburgites would result in magmas having geochemical characteristics similar to melilitites or kimbberlites.

## C17

### Nd ISOTOPES IN KIMBERLITES AND MANTLE EVOLUTION

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Estimation of P, T, conditions of equilibration of garnet peridotite xenoliths in kimberlites indicates that kimberlitic liquids are derived from depths greater than 180 kms. No other rock, with a depth of origin greater than 180 kms, is readily available for analysis. A Nd-isotopic study of kimberlites of different ages from different continents is, therefore, important in understanding the history and evolution of the mantle. The present study is an extension of our earlier study (Basu and Tatsumoto, 1978, 1979, 1980) where we demonstrated that kimberlites are derived from a relatively undifferentiated chondritic mantle.

We have analyzed the Nd-isotopic composition of the following kimberlites and related rocks: Nine kimberlite pipes from South Africa and Lesotho; two from southern India; one from the U.S.S.R.; fifteen kimberlite pipes and related dike rocks from eastern and central U.S. and three pipes from the Shangdong Province of eastern China. The age of emplacement of these pipes ranges from 1300 m.y. to 90 m.y. before present. The initial Nd-isotopic compositions of these kimberlitic rocks expressed as  $\epsilon_{Nd}^t$  with respect to a chondritic bulk earth  $^{147}\text{Nd}/^{144}\text{Nd}$  growth curve show a range between 0 to +4, with the majority of the kimberlites being in the range 0 to +2. This result strengthens our earlier conclusions that kimberlitic liquids are derived from a relatively primeval and unique mantle reservoir with a nearly chondritic Sm/Nd ratio.

## C18

### THE EVOLUTION OF OLIVINE MELILITE AND KIMBERLITE MAGMAS

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Olivine melilitites and olivine nephelinites occur in two pipe clusters in the Namaqualand-Bushmanland area of western South Africa. Disparate ages and differences in initial Sr-isotope ratios indicate that it is not possible to relate these rocks to a common parental magma. Nevertheless, it is possible to model the differences in bulk rock chemistry between the pipes in terms of processes common to magmas generated in the same tectonic environment, although it is recognised that the rocks themselves cannot be comagmatic.

Chemical characteristics of the southern (Garies) pipes lower MgO and higher concentrations of some incompatible elements indicates that they are compositionally more "evolved" than those in the Gamoep pipe cluster to the north. Compositional variation within the southern pipe cluster has been dominated by fractional crystallisation of olivine, melilite, perovskite and titanomagnetite (the low pressure phase assemblage in these rocks).

Compositional variation within the northern pipe cluster reflects the imprint of polybaric fractional crystallisation which has involved both a

high pressure (megacryst) phase assemblage of olivine, clinopyroxene and ilmenite and the same low-pressure phases that dominantly control the compositional variation in the southern pipes.

Subtraction of the high-pressure phases from an average Gamoep (northern magma composition) will produce a composition similar in "compatible" major element contents to that of an average Garies (southern) magma. This suggests that the Garies pipes could have been derived by high-pressure crystal fractionation of a more primitive magma which was similar in major element chemistry to an average Gamoep composition. However, the enrichment of incompatible trace elements such as Zr and Nb in the Garies rocks relative to those in the Gamoep pipes is far higher than would be predicted by a simple crystal fractionation model. This suggests that the primary magmas for the two pipe clusters were produced by different degrees of partial melting so that there were compositional differences between their respective source areas.

Although it is possible to model the compositional derivation of the Garies rocks from a Gamoep-type magma it would appear that the parental magma for the Gamoep pipes was itself relatively evolved, since olivine phenocrysts in the Gamoep rocks are always more Fe-rich than would be expected in an unmodified mantle-derived liquid. A consideration of the compositional data suggests that an average Gamoep type magma could be derived from a "primary" magma very similar to an average South African kimberlite by crystal fractionation of the kimberlite megacryst assemblage comprising olivine, orthopyroxene, clinopyroxene, garnet and ilmenite. Sr isotope evidence is also supportive of a genetic relationship between South African kimberlites and the olivine melilitites of Namaqualand-Bushmanland since both have clearly been derived from isotopically "oxygenated" mantle source areas.

Alvaine volcanic pipes of post-Gondwanaland age show a systematic variation in composition with their geographic position on the southern African subcontinent. Dianioniferous kimberlites, which appear to be the least evolved chemically, are confined to the central, ancient, cratonic areas. More evolved alkaline rocks (olivine melilitites and olivine nephelinites) are concentrated closer to the continental margin in the east and west of South Africa. While the most evolved alkaline rocks (the trachybasalts of the Alford Banks) occur on the southern continental shelf, it is postulated that this chemical zonation may be related to a steepening of the geotherm from the centre of the subcontinent towards its edges.

## C19

### THE GEOCHEMISTRY OF SOME KIMBERLITES FROM THE TYPE AREA IN KIMBERLEY SOUTH AFRICA, IN RELATION TO MODELS OF KIMBERLITE PETROGENESIS

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When compared to the available information about more widespread and thoroughly studied rocks such as basalts, considerable uncertainty remains about the chemical composition of kimberlite magmas. This is because the frequently violent emplacement of kimberlite leads to contamination during emplacement, and further renders kimberlite susceptible to post-emplacement alteration by groundwater which can percolate through the relatively permeable tuffs and brecciated kimberlite, for which many analyses appear in the literature. Quietly intruded magmatic kimberlites which are free of crustal inclusions and impermeable groundwater after emplacement are rare. However, some such specimens are included together with altered rocks in a collection of seventy kimberlites for which full major and some trace element analyses are presented in the present work. (See Berg and Allsopp, 1972 and Barret and Berg, 1975 for brief descriptions and isotope data for some of these rocks).

Systematic appraisal of the geochemical data was combined with the petrographic assessment of freshness as described in Barret and Berg (1975). This approach was designed to characterise the geochemistry of kimberlite magma as closely as possible and to identify rocks in which the original kimberlite chemistry has been altered to such an extent that their analyses no longer represent the original kimberlite magma's composition sufficiently closely to be satisfactory for testing models for kimberlite formation. Alteration and contamination lead to increases, for example, in the concentrations of  $\text{Na}_2\text{O}$  and  $\text{Al}_2\text{O}_3$ . There are no significant differences in the concentrations of some elements like MgO between fresh magmatic and altered kimberlites, but many altered kimberlites have significantly higher concentrations of  $\text{SiO}_2$  than fresh kimberlites. Those altered kimberlites which do have similar concentrations of  $\text{SiO}_2$  to fresh kimberlites, nevertheless have relatively high  $\text{SiO}_2/\text{MgO}$  ratios, as have the altered kimberlites which contain higher concentrations of  $\text{SiO}_2$ . Care must be taken to distinguish between increases in the concentration of  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2/\text{MgO}$  ratios which are due to an increase in the amounts of primary phlogopite in a sample rather than to contamination and alteration reactions.

It was found that composition such as the averages for Lesotho kimberlites given by Dawson (1962) and Gurney and Ebrahim (1973), which have been used by other investigators to represent the chemistry of kimberlite magmas, fall in the range of the altered kimberlites studied here. An outcome of the alteration of kimberlite is to increase the amount of orthopyroxene in the norm of average compositions, which may lead to incorrect differentiation models and influence the results of high pressure phase equilibrium studies based on the chemistry of average kimberlite. Consequently it is suggested that some current models for the formation of kimberlite and related rocks may require considerable refinement.

Some implications are considered, such as the indicated partition coefficients for Cr and Ni, when the assumption is made that kimberlite is a partial melt of low degree in the mantle, and that the fresh kimberlites here described adequately represent the composition of such kimberlite magma at its source.

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