

interpreted to be an altered, partly disaggregated Cr-diopside series xenolith. Olivine is pseudomorphed by calcite and the Cr-diopside is extensively replaced by titaniferous pargasite compositionally equivalent to that in the amphibole/apatite xenoliths. Other xenoliths appear to have been originally normal, apatite-free Al-augite series xenoliths consisting of clinopyroxene, spinel and olivine. Extensive alteration of the olivine to calcite and talc(?) and of the clinopyroxene to kaersutite and to the Fe-rich clinopyroxenes typical of some of the amphibole/apatite suite xenoliths has taken place.

The range of textural and chemical features of the amphibole/apatite xenolith suite is consistent with an origin as part of a fractional crystallisation sequence. The lack of feldspar, the Mg-rich, Al-poor nature of the ilmenite and the $Al^{IV}:Al^{VI}$ ratios in the clinopyroxenes suggest high-pressure formation, probably in excess of 17 kb. The alteration of Cr-diopside series xenoliths to titaniferous pargasite indicates metasomatic penetration of mantle wall rock by a fluid phase associated with the formation of the amphibole/apatite suite xenoliths. The solid-state deformation effects observed in the amphibole/apatite suite, imply a significant time gap between their original precipitation and eventual entrainment in the host magma.

Analogous clinopyroxenes and amphiboles are recorded from ultrabasic rocks from the Fen carbonatite complex in Norway. Potassic volcanics of South West Uganda and the sodi-potassic volcanics of West Eifel, Germany contain similar Fe-rich clinopyroxene, amphibole, dark mica and apatite. Phenocryst assemblages in dykes of kimberlitic and carbonatitic affinity from Quebec closely parallel those in the amphibole/apatite suite xenoliths. Enrichment in Ti, P and Fe is characteristic also of similar mineral phases in autoliths from kimberlite pipes in Lesotho.

However, the southeastern New South Wales assemblages appear unique in their association of magnesian ilmenite and abundant apatite with the other phases. These amphibole/apatite suite xenoliths evidence the presence of mantle liquids rich in alkalis, volatiles and incompatible elements which are interpreted to have crystallised partially or fully in the upper mantle under conditions conducive to fractional crystallisation. The Fe-rich nature of the assemblages and the abundance of apatite suggests prior fractionation of the parent melt has resulted in the increased concentration of volatiles and incompatible elements and in depletion of Mg, Cr and Ni. This may have occurred at deeper levels within the mantle below the level of generation of the host basanite. The resultant high-pressure differentiation sequence was then sampled by accidental entrainment in subsequent magmas probably generated in later, unrelated, episodes of partial melting. As yet there is little evidence of low-pressure equivalents of related kimberlitic magmas in southeastern N.S.W., although stream gravels in the area contain magnesian ilmenite, pyrope-almandine garnet and rare diamonds which suggest the occurrence of kimberlitic rocks and Ferguson *et al.*, (1977) have reported rare kimberlitic diatremes further to the south-west.

References

- FERGUSON, J., ELLIS, D.J., ENGLAND, R.N. (1977) Unique spinel-garnet lherzolite inclusion in kimberlite from Australia. *Geology* 5:278-280.
- WASS, S.Y. (in prep.) Geochemistry of clinopyroxenes of diverse origins in alkali basaltic rocks from the Southern Highlands (NSW) and the Massif Central (France).
- WASS, S.Y., IRVING, A.J. (1976) XENMEG: a catalogue of occurrences of xenoliths and megacrysts in volcanic rocks of eastern Australia. Australian Museum, Sydney, 441 pp.

The chemical composition of kimberlites compared with that of three basaltic magma types

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New data on Li, F, S, V, Cr, Mn, Co, Ni, Cu, Zn, Rb, Sr, Y, Zr, Cd, Ba, Hg, Tl, Pb, Bi and the major elements in 11 South African kimberlites (sampled during the first Kimberlite Conference) will be presented. With the exception of the alkali elements and sulfur their concentrations are rather close to their arithmetic means (\bar{x}). Most values of 26 elements range from $\bar{x}/2$ to $2 \bar{x}$ only. The composition of olivine, serpentine, pyroxenes, phlogopite, perovskite, spinel, magnetite and Fe-Ni-Cu-S ores from selected kimberlites has been investigated by microprobe. In this study perovskite occurs as a major host of the REE in kimberlite. Native copper has been observed in a sample from the De Beers mine.

Additional data on 60 elements in bulk kimberlites have been compiled from the literature. The averages computed for 44 elements are based on more than 40 values each. The element averages for geographic subgroups scatter about the total average in a range which is specific for certain elements. These ranges generally increase with the rate in which a certain element is accumulated in kimberlites relative to ultramafic rocks. Good correlations between the following elements have been observed in kimberlites: Cr-Ni-Co, K-Rb. But expected correlations between Pb-Tl-K and Na-K are apparently not existent. The detailed chemical information has been published by MURAMATSU (1977).

Analytical data for the same group of elements in olivine nephelinites, alkali olivine basalts, tholeiitic basalts and ultramafic rocks have been compiled and evaluated by WEDEPOHL (1975 and unpublished; major source: Handbook of Geochemistry).

The number of values on element concentrations in basaltic rock types used for averages is comparable to that in kimberlites. Less chemical information is available on ultramafic rocks and nephelinites. It has to be kept in mind that some ultramafics, used for this compilation, are residual material from partial melting.

Magmas of kimberlites, nephelinites and basalts are thought to be melting products of mantle rocks. Therefore, they are to be compared chemically with ultramafics from the upper mantle. Ratios of element concentrations in the 4 magmatic rock types to those in ultramafic rocks, indicating accumulations or depletions from mantle materials, are plotted in Fig. 1. There exists a surprisingly similar behavior of large groups of elements in the 4 magma series shown in this diagram. The specific difference between the 4 series is the degree of element accumulations relative to ultramafics.

Elements like Cr, Ni, Mg, Co are incorporated in the residual ultramafic material, increasingly from kimberlites to tholeiites. Mn, Fe, Sc must have distribution coefficients

between the total of mantle minerals and the four melts which are close to one. Al and Ga have a tendency towards the residual minerals garnet and orthopyroxene and are low in kimberlites exclusively. The so-called incompatible elements Th, U, light REE, Nb, Ta etc. are almost consistently increasing from tholeiites to kimberlites. The heavy alkalies, alkaline earths, Pb, Tl and Li follow this tendency but in a less pronounced way. From these regularities it can be concluded that the rocks have been formed from magmas which represent increasing fractions of partially melted mantle rocks. In this case, tholeiitic basalt has been formed from the relative largest and kimberlite from the smallest fraction of partial melt; the other rock types are intermediate.

Melting experiments of olivine melilitite under high CO₂ and H₂O pressure (30 kb) have demonstrated the persistence of garnet and orthopyroxene as near-liquidus phases at increasing CO₂-H₂O proportions (BREY and GREEN, 1977). They indicate an increasing contribution of olivine and clinopyroxene from mantle rocks to partial melts under these specific vapor pressures. The specific accumulation of Ni and Co and depletion of Al, Ga and heavy REE in kimberlites relative to basalts can be explained by the increased melting of olivine and loss of garnet and orthopyroxene to the residual mantle respectively. Sodium could have been lost from kimberlitic magmas to country rocks by means of CO₂ vapor transport (fenitization).

The degree of element accumulation in magmas relative to mantle rocks seems to depend on the deviations of their ionic size from that of the host ions in mantle minerals.

A constant increase of the heavy sulfur isotope and of the Fe³⁺/Fe²⁺ ratio can be observed in the 4 rock groups from tholeiitic basalts ($\delta^{34}\text{S} - 0.3\%$; Fe₂O₃/FeO = 0.32) to kimberlites ($\delta^{34}\text{S} + 4.6\%$; Fe₂O₃/FeO = 1.3). It must be due to an increase of the oxygen fugacity in this sequence. For $\delta^{34}\text{S}$ values of basalts see SCHNEIDER (1970).

References

- BREY, G., GREEN, D.H.: Systematic study of liquidus phase relations in olivine melilitite + H₂O + CO₂ at high pressures and petrogenesis of an olivine melilitite magma. *Contrib.Mineral.Petrol.* 61, 141 (1977).
- MURAMATSU, Y.: Geochemische Untersuchungen an Kimberliten, einem Granatperidotit und einem Eklogit-Einschluß aus Kimberley, Südafrika. PhD-Thesis Göttingen (1977).
- SCHNEIDER, A.: The sulfur isotope composition of basaltic rocks. *Contrib.Mineral.Petrol.* 25, 95 (1970).
- WEDEPOHL, K.H.: The contribution of chemical data to assumptions about the origin of magmas from the mantle. *Fortschr.Mineral.* 52, 141 (1975).

