ISOTOPIC AND GEOCHEMICAL STUDIES OF KIMBERLITE AND INCLUDED XENOLITHS

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KIMBERLITE

Initial Sr, Nd and Pb isotopic compositions of southern African Jurassic-Cretaceous kimberlites define two distinctive varieties that must be derived from different types of upper mantle sources (Smith, 1983). Group I kimberlites, commonly referred to as "basaltic", generally lack appreciable mica and with some exceptions have consistent Nd isotopic compositions slightly higher than the bulk earth value. $^{87}Sr/^{86}Sr$ ratios are somewhat more variable ranging from about .7035 to .7050 in reasonably fresh hypabyssal samples. Pb isotopic compositions are more variable, spanning nearly the full range of oceanic island basalts (OIB). Group II kimberlites have high groundmass mica contents and tend to lack ilmenite, zircon and perovskite, minerals characteristic of Group I kimberlites, as well as having somewhat older emplacement ages (Smith et al., in press). In addition, inclusions of the Cr-poor subcalcic megacryst assemblage and high P-T sheared lherzolite xenoliths with isotopic characteristics suggestive of asthenospheric origins are apparently absent in Group II intrusives. The Group II kimberlites have radiogenic Sr ($^{87}Sr/^{86}Sr$ = .7075 to greater than .710) and non-radiogenic Nd ($^{143}Nd/^{144}Nd$ = .5120 to .5123, relative to .51264 in standard BCR-1), plotting in the enriched mantle quadrant of the Sr-Nd correlation diagram. Compared to Group I, Group II source rocks have had high time-averaged Rb/Sr and LREE enrichment, with minimum model source ages from Sm-Nd systematics being of the order of 600 million years. Pb isotopic compositions are considerably less radiogenic and less variable than Group I, OIB or most mid-ocean ridge basalts (MORB).

Major and trace element analyses of the samples analyzed for isotopic compositions confirm that Group I and Group II kimberlites are chemically distinctive, the K/Ti ratio alone serving as an efficient discriminator. Stepwise discriminant function analysis using isotopic character as the independent grouping variable identifies the combination of chemical features that best separate the two groups and successfully classifies a large number of kimberlites for which published data are available, as well as highlighting second order distinctions. Among other features, Group II kimberlites have significantly greater enrichment in SiO_2 and the most incompatible trace elements K, Rb, Ba, Pb and LREE compared to Group I. The latter have significantly higher abundances of Ti and Nb. Group I kimberlites can be subdivided into two gradational varieties that are not, from limited available data, correlative with isotopic character. Compared to IA, kimberlites of the IB subgrouping tend to have higher Fe/Mg and higher abundances of the high field strength incompatible elements (Zr, Y, Ti, P). In the data set analyzed, the IB kimberlites tend to be those situated at or outside the margins of the Kaapvaal Craton although a number of exceptions are known.

Since chemical differences between Groups I and II are correlated with isotopic character, it is likely that at least some of the chemical distinctions (particularly incompatible element abundances) reflect distinctions in source compositions. The isotopic evidence, in conjunction with apparent distribution of high P-T xenolith suites, suggests that Group I kimberlites are derived from asthenospheric plume sources similar to those from which OIB are produced (Kramers, 1977). In contrast, Group II kimberlites may originate within enriched portions of the subcontinental lithosphere that has been stabilized against convective disruption for a long period of time (Smith et al., in press). The geochemical evidence, though not inconsistent with this, is neither particularly supportive, however. Group I and Group II kimberlites have similar OIB-like incompatible element abundance patterns implying similar trace element incompatibility sequences in the sources. Both groups could be plume related although basalts with isotopic character similar to Group II kimberlites have not yet been documented from the ocean basins. le Roex (in press) has compared isotopic and geochemical signatures of southern African kimberlites with South Atlantic ridge and plume basalts, and argues persuasively that the chemical signatures of the two kimberlite groups are extensions of the diverging chemical trends characteristic of DUPAL (Group II) and non-DUPAL (Group I) types of basalt sources.

ECLOGITE XENOLITHS FROM THE ORAPA KIMBERLITE

Eclogite xenoliths, many with accessory diamond, are the dominant nodule type in the Orapa kimberlite (Shee and Gurney, 1979) and likely represent the major source of diamond in the pipe. Sr and Nd isotopic compositions of clinopyroxene and garnet from a compositionally diverse suite of eclogite xenoliths are characterized by extreme variability, with $^{87}Sr/^{86}Sr$ ratios in clinopyroxene ranging from .7025 to .709 and corresponding variation in emplacement age corrected $^{143}Nd/^{144}Nd$ of .5128 to .5122, and in this regard are similar to Roberts Victor eclogites studied by Kramers (1979). In contrast to the Roberts Victor samples, Pb isotopic compositions are consistent and similar to modern MORB and do not provide age constraints. Isotopic character is to some degree correlated with major element chemistry for the compositional groupings thus far examined. Type 2 websterite group samples with Ca-poor magnesian garnet have clinopyrxenes with radiogenic $^{87}Sr/^{86}Sr$ (.705 to .709) and the least radiogenic $^{143}Nd/^{144}Nd$ (.5122 to .5125). Type 1 eclogites with higher Ca and Fe in garnets have less radiogenic $^{87}Sr/^{86}Sr$ (.7024 to .7066) and bulk earth or higher $^{143}Nd/^{144}Nd$ ratios. In the context of the subdivision of the type 1 eclogites by Shee and Gurney (1979), the Ca-rich subgroup has the least radiogenic Sr and most radiogenic Nd compared to main and Ca+Fe rich subgroups. Diamond eclogites are all type 1 samples, and have variable isotopic character consistent with variable subgrouping according to major element compositions of the garnets. Type 1 and type 2 clinopyroxenes differ considerably in their trace element contents, with type 1 pyroxenes having significantly lower Sr, Nd, Sm and Pb but higher Rb (in keeping with generally higher jadeite). Rb/Sr and Sm/Nd ratios tend to be anticorrelated with Sr and Nd isotopic compositions in type 1 pyroxenes, suggestive of mixing processes in parent liquids and not supportive of old ages for the eclogites themselves. Coexisting clinopyroxene and garnet were in Nd isotopic equilibrium at the time of kimberlite emplacement in all but one of the samples, thus precluding internal Sm-Nd age determinations from mineral pairs. A garnet-clinopyroxene apparent age of about 180 million years in one sample is marginally older than pipe emplacement.

Despite the lack of age constraints, the variable isotopic character of the samples analyzed so far indicate that the xenoliths do not likely comprise a related group of samples, and as concluded for the Roberts Victor assemblage, likely represent cumulates of melts derived from a variety of sources. Parents of type 2 eclogites must have had time-averaged enriched Rb/Sr and LREE character, suggestive of derivation from enriched lithospheric mantle sources. Type 1 eclogites could be derived from more primitive to depleted mantle, and in some cases could have had MORB as a parent.

MEGACRYSTS

Minerals of the Cr-poor subcalcic megacryst assemblage are abundant in Group I kimberlites in southern Africa and other localities worldwide. Although the origins of the assemblage have not been satisfactorily resolved, the constituent minerals are generally regarded to have crystallized at high pressures from a fractionating kimberlite-like liquid. Pb, Sr and Nd isotopic compositions of clinopyroxene megacrysts of this suite are distinctive, with $^{87}Sr/^{86}Sr$ = .7028 to .7032 throughout southern Africa except Orapa, where Sr in both Cr-poor and Cr-rich megacrysts is somewhat more primitive ($^{87}Sr/^{86}Sr$ = .7025). Nd isotopic compositions are marginally higher than bulk earth, and $^{206}Pb/^{204}Pb$ ratios are notably radiogenic except in one sample from Jwaneng. Isotopically, the Cr-poor megacrysts are generally dissimilar to megacrysts of other associations and to kimberlite in which they are entrained. Hence a cognate origin is possible only if kimberlite has been contaminated subsequent to megacryst crystallization. Isotopic compositions of Cr-poor clinopyroxenes are similar to the St. Helena type of oceanic basalt (e.g. White, 1985). The assemblage may thus have an important bearing on the origins of some oceanic basalts, and in kimberlites older than the age of the ocean basins may be useful in constraining the isotopic evolution of some OIB reservoirs.

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