

The role of eclogites in the growth of Archean cratons: a case study from west Africa

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Eclogites, bi-mineralic rocks composed of garnet and omphacite, are minor but ubiquitous constituents in mantle xenolith suites brought up by kimberlites in Archean cratons. They have been variously interpreted as cumulates from mantle-derived magmas or as fragments of recycled oceanic crust. Recently, some eclogites have been interpreted as residues from partial melting of oceanic crust to produce felsic magmas of tonalite-trondhjemite-granodiorite (TTG) composition (Ireland et al., 1994; Rudnick, 1995; Rollinson, 1997), which make up large portions of the crust in Archean cratons. If true, this has important implications: 1) subduction was operative in the Archean and 2) one reason the continental crust is more evolved than basalt is because Archean crustal growth was accomplished, at least in part, by direct addition of felsic magmas from the mantle.

Although the major and trace element data suggest a link between xenolithic eclogites and TTGs, no systematic study of these rocks from a single region has yet been performed in order to test this hypothesis.

We report here oxygen isotopic and trace element compositions of eclogite xenoliths from the Mesozoic Koidu kimberlite pipes located on the Man Shield of the West African Craton. The Man Shield is an ideal region to study the growth of Archean cratons for several reasons. First, extensive suites of eclogite xenoliths (Tompkins and Haggerty, 1984) and TTGs (Rollinson, 1978) have been collected from the same area. Second, previous petrological and mineral chemistry studies (Hills and Haggerty, 1989; Fung and Haggerty, 1995) provide an excellent starting point for trace element and isotopic investigations. Third, Koidu is one of few localities where whole rock data for major and trace elements are available for 25 eclogite xenoliths (Hills and Haggerty, 1989).

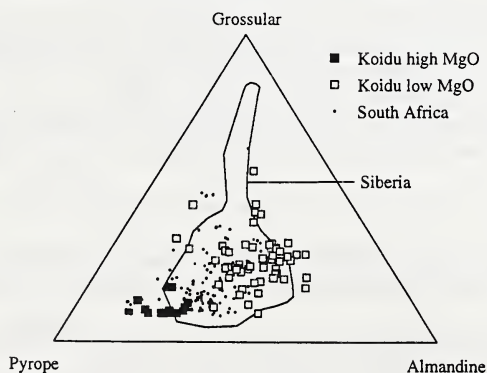


Fig. 1. Garnet compositions from Koidu eclogite xenoliths compared with those from other areas. The field encompasses data from Siberia. Diamondiferous eclogites are restricted to the low MgO group.

The Koidu eclogites fall into two groups, based on their major element chemistry: 1) A high MgO group (>16 wt% MgO) that is essentially bi-mineralic (garnet and omphacite), with only minor rutile, ilmenite, and/or sulfide. 2) A low MgO group (6-13 wt% MgO), which commonly contains accessory phases such as kyanite, quartz (after coesite), graphite, diamond, amphibole, and/or corundum plus rutile, ilmenite, and sulfides in addition to garnet and omphacite. The difference in bulk composition is reflected in the garnet composition (Fig. 1).

Results

Oxygen isotopic data were obtained from 17 clean garnet mineral separates by laser fluorination techniques (Valley et al., 1995). Garnet has been analyzed because it is the freshest phase in the Koidu eclogites. $\delta^{18}\text{O}_{\text{SMOW}}$ values of the west African garnets range between 4.73 and 6.09‰ (Fig. 2). Thus, neither very heavy nor very light values, as reported from South African eclogites (between 2.2 and 8.0‰, MacGregor and Manton, 1986), are observed. The majority of the samples lie within the range of average mantle values (5.5 ± 0.4 ‰, Matthey et al., 1994). Calculated fractionation factors between garnet (gt) and clinopyroxene (cpx) are 0.2 to 0.3‰ (Rosenbaum et al., 1994), depending on equilibration temperature and composition of the sample. Therefore, the isotopic composition of gt is 0.1 to 0.15‰ lighter than the bulk rock, assuming equal amounts of gt and cpx. If we apply this correction to our gt $\delta^{18}\text{O}$ data, four samples exceed the mantle range, being both isotopically lighter and heavier (Fig. 2).

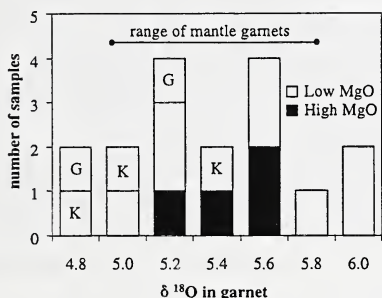


Fig. 2. $\delta^{18}\text{O}_{\text{SMOW}}$ for Koidu garnets. The range of mantle garnets is shifted towards lighter isotopic composition by 0.1‰ relative to the whole rock mantle range due to the fractionation between garnet and whole rock. See text for details.

G = graphite-bearing low MgO eclogites
K = kyanite-bearing low MgO eclogites

The high MgO garnets have a restricted range of $\delta^{18}\text{O}$ values (5.21 to 5.54‰) and lie within average mantle values. The low MgO garnets have a broader range of isotopic and major element compositions. $\delta^{18}\text{O}$ does not show a correlation with other elements (e.g., FeO, CaO) of garnet or whole rock, as reported for Siberian eclogite xenoliths (Jacob et al., 1994).

Whole rock trace element data were obtained by ICP-MS. All samples show variable degrees of enrichment in light rare earth elements (LREE, Fig. 3) and other highly incompatible elements due to kimberlite-related alteration. The degree of LREE enrichment correlates with the degree of alteration visible in thin section. Note that the freshest sample (KEC 81-5) exhibits depletion of middle REE relative to heavy REE.

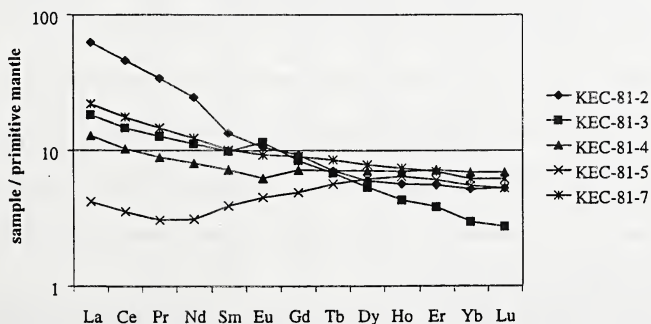


Fig. 3. Mantle-normalized whole rock REE data for Koidu eclogite xenoliths. Sample KEC 81-2 belongs to the high MgO group, all other samples belong to the low MgO group.

Implications for the origin of eclogite xenoliths and Archean crustal growth

The most compelling evidence for a crustal origin of eclogite xenoliths are stable isotope compositions that deviate from established peridotitic values, i.e., $\delta^{18}\text{O}$ values that lie beyond $5.5 \pm 0.4\text{‰}$ (e.g., MacGregor and Manton, 1986; Jacob et al., 1994). Eclogites with high and low $\delta^{18}\text{O}$ values are believed to have obtained their isotopic compositions through low- and high-temperature seawater alteration prior to subduction.

The observed oxygen isotopes of the Koidu high MgO eclogites show mantle-like $\delta^{18}\text{O}$, indicating either a mantle origin, hydrothermal alteration at intermediate temperatures, or a lack of hydrothermal alteration. The restricted range of compositions (Fig. 1) and high MgO, Ni and Cr contents (Hills and Haggerty, 1989) support an intra-mantle origin for these samples.

In contrast, the broader range of $\delta^{18}\text{O}$ of the low MgO eclogites suggests a crustal origin. In addition, the low MgO contents and the occurrence of kyanite in some eclogites put important constraints on possible petrogenetic models. Kyanite-bearing eclogites cannot coexist with peridotites at pressures in the diamond stability field, but would react with olivine to form pyroxenes and garnet. Thus, if the low MgO eclogites represent cumulates of fractionated high-pressure mantle melts, it requires that these melts must have been kept isolated from the surrounding peridotite. However, these features can also be explained by metamorphism of mantle-derived melts that crystallized at low pressure, i.e., by subduction of oceanic crust.

The Koidu low MgO eclogite major element compositions are similar to Archean greenstone belts and complementary to granitoids of the West African Craton (Rollinson, 1997), implying that the eclogites are residues from Archean granitoid crust formation. The high heavy REE content of the Koidu eclogites and the depletion of middle REE relative to heavy REE of sample KEC 81-5 support the model that melting of the mafic protolith occurred in the garnet stability field. In situ Laser ablation ICP-MS analyses of garnet and cpx are currently underway in order to define the pre-entrapment trace element composition of the eclogites.

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