Geochemical and isotopic (Sr, Nd) study of eclogite nodules from the Mbuji Mayi kimberlite, Kasai, Congo.
Nature of the protoliths and evidence for mantle metasomatism

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The 70 Ma old diamond-rich Mbuji Mayi kimberlites (Kasai, Congo) contain, beside the typical megacryst suite, abundant eclogite nodules. Three groups were distinguished petrographically:
- the typical bimineralic eclogites consisting mainly of garnet and omphacitic clinopyroxene; accessory phases are sometimes present : rutile, phlogopite, quartz, pargasite, zoisite, apatite and whitlockite.
- kyanite-bearing eclogites (1 to 25 modal % of kyanite) which are characterized by remarkable kyanite-omphacite intergrowths.
- diamond-bearing eclogite : only one sample has been found out of 152 studied nodules.

The companion abstract (El Fadili and Demaiffe, this volume) gives more complete petrographic description of these nodules as well as mineral chemistry data , P.T estimates and a summary of metasomatic effects registered by the nodules.

Analyzed whole rock major element compositions of bimineralic eclogites are broadly basaltic (43-53 % SiO_2; 8-17 % Al_2O_3; 10-13 % CaO; Mg# = 46-73) with low K_2O (<0.2 %) and TiO_2 (avg. 0.15 %) contents, suggesting a subalcaline affinity. Kyanite-bearing eclogites are peraluminous (17-28 % Al_2O_3) with high CaO content (up to 15 %); their Mg# vary from 42 to 64. The diamond-bearing eclogite is distinguished by its low CaO content (5.8 %); its Mg# is 46.

The primitive mantle-normalized spidergrams show conspicuous positive Ba, Sr and Pb anomalies; they are significantly higher for kyanite-bearing eclogites (avg. Ba/Ba*= 21; Sr/Sr*= 6.5 and Pb/Pb*= 6.3) than for bimineralic samples (avg. Ba/Ba*= 8.6; Sr/Sr*= 4.9 and Pb/Pb*= 2.8). The diamond eclogite exhibits only a slight positive Sr anomaly (Sr/Sr*= 1.2). A Nb enrichment is observed for some rutile-bearing eclogites. Systematic Zr, Hf and Ti depletions (except for diamond eclogite) could result from the HFSE mobility during the eclogite formation.

Analyzed whole rock REE concentrations are low (ΣREE= 11-47 ppm). The diamond-bearing sample has a REE pattern quite similar to those of N-MORB that is a LREE-depleted pattern (La_N = 5 and $(La/Yb)_N$= 0.55), no Eu anomaly. Bimineralic eclogites are more LREE-enriched (La_N= 2-60, $(La/Yb)_N$= 2-30), but have less pronounced positive Eu anomalies (Eu/Eu*= 1.06-1.25) than kyanite-bearing samples (La_N=5-20, $(La/Yb)_N$= 2.1-8, Eu/Eu*= 1.66-2).

Trace element compositions of six leached garnet-clinopyroxene pairs were measured by conventional ICP-MS. Cpx have global REE distribution patterns comparable to those of clinopyroxenes from other mantle-derived eclogites : LREE enriched trends with La_N= 2 to 185 and $(La/Yb)_N$= 6 to 289; Taylor and Neal, 1989; Snyder et al., 1997). The clinopyroxene from kyanite-bearing eclogite has significantly lower LREE content ($(La/Yb)_N$= 20), but more pronounced positive Eu anomaly (Eu/Eu*= 2) than those from bimineralic samples ($(La/Yb)_N$= 23 to 252, Eu/Eu*= 1-1.5). The clinopyroxene from diamond-bearing eclogite is characterized by its much less fractionated pattern ($(La/Yb)_N$ = 2.85) with a lack of Eu anomaly.

Most analyzed garnets show sinusoidal REE patterns with LREE and HREE enrichments ($(La/Nd)_N$ = 1.2 to 2.75 and $(Sm/Yb)_N$ = 0.1 to 0.6) and a relative MREE depletion. Similar patterns have been observed by Shimizu (1975) and Hoal et al., (1994) for garnets of peridotite and kimberlite concentrates. Only the garnet of the diamond-bearing eclogite has "normal" REE pattern, that is a pronounced LREE depletion : $(La/Nd)_N$= 0.4 and $(La/Yb)_N$= 0.05.

To understand these abnormal garnet REE patterns, the same minerals were analyzed in situ by Laser Ablation Microprobe (LAM) coupled to an ICP-MS. Most garnet and cpx grains appear compositionnally homogeneous and show normal REE patterns : LREE-enriched convex upwards for clinopyroxene and LREE-depletion for garnet. By contrast, garnet and clinopyroxene grains adjacent to phosphate phases (whitlockite or apatite) show large variations of their LREE contents. In a given grain, the LREE contents increase regularly from "normal" values far (500 µm) from the REE-rich mineral to much higher contents close to the whit/ga or whit/cpx boundary (Fig.1). Other trace elements enriched in the phosphate like Pb, P and Sr show the same behaviour. By contrast, the elements at very low concentrations in the phosphate (such as Co and Sc) are not modified in the garnet and clinopyroxene. These concentration profiles suggest that the LREE, P, Pb and Sr have diffused from the phosphate towards adjacent garnets and clinopyroxenes. The texture of whitlockite or apatite reflects a patent metasomatism which occurred prior to the kimberlite eruption.

Hoal et al. (1994) show that the sinusoidal REE patterns occur for refractory (Fe-poor) garnets and represent a disequilibrium during the metasomatic re-equilibration. By contrast, fertile (Fe-rich) garnets are in equilibrium with the metasomatic fluid and have normal REE patterns. The garnet from diamond eclogite has a low Mg# of 57 (compared to those of other samples: Mg#=66-70) and a normal REE pattern. These features could result from equilibration with the metasomatic fluid or could reflect either a different region source or a higher equilibration pressure than for the other eclogites.

In order to better constrain the composition of the protoliths and to subtract the metasomatic effects, major and trace element whole rock compositions were reconstructed by using the modal proportions and chemical compositions of primary phases (garnet, clinopyroxene, kyanite, quartz and primary rutile).

Compared to the analyzed WR, the recalculated compositions are characterized by decreases in TiO_2 and K_2O, and unexplained enrichment in Na_2O (Sobolev et al., 1994 and Snyder et al., 1997 observe the same behaviour). For the other major elements, the recalculated and analyzed compositions are quite similar.

The positive Ba, Sr and Pb anomalies in the spidergrams persist for recalculated compositions. The Nb enrichment, observed in analyzed WR, disappears in recalculated WR. Recalculated WR (Fig.2) show systematically lower LREE contents than the analyzed whole rocks; the HREE contents and the Eu anomalies remain unchanged.

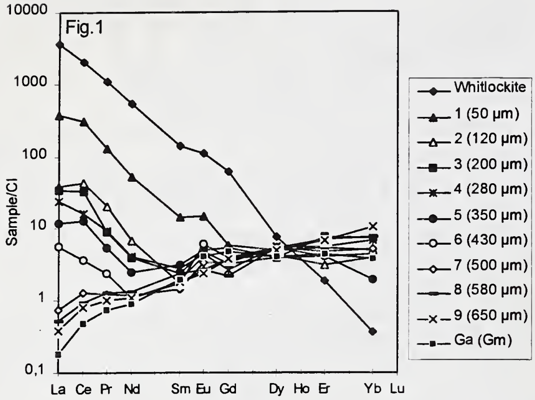
These data show that the metasomatic fluid that interacted with the eclogites introduced Ti, Nb, K, Rb, Sr, Ba, P, LREE, H_2O, F...). These elements were fixed in newly formed rutile (Ti, Nb), phlogopite and pargasite (K, Rb, Ba, Ti, Sr, Pb, H_2O, F), apatite (P, REE), zoisite (REE) or in the thin veins cross-cutting the nodules.

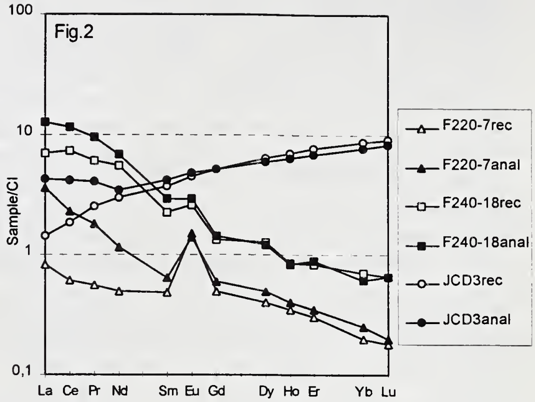
The Rb and Sr contents and the Sr isotopic compositions have been measured in whole rocks and in 6 leached garnet and clinopyroxene separates. Analyzed WR have variable measured Rb/Sr and $^{87}Sr/^{86}Sr$ ratios (0.0056-0.1291 and 0.70350-0.71078 respectively). Clinopyroxenes are quite homogeneous with low Rb/Sr ratios (0.0008-0.0027) and measured $^{87}Sr/^{86}Sr$ in the narrow range 0.70402-070497. Garnets have low Rb and Sr contents (<0.4 ppm and <14 ppm respectively) with Rb/Sr and $^{87}Sr/^{86}Sr$ ratios in the range 0.0123-0.1289 and 0.70458-0.70637. For a given sample, WR, ga and cpx data points do not define linear array, so that age determinations are not possible. The Sr isotopic system has obviously been disturbed.

Sm and Nd contents and $^{143}Nd/^{144}Nd$ ratios have been obtained on the same samples. The Nd isotopic compositions are roughly correlated with $^{147}Sm/^{144}Nd$ ratios; the complete data set yields a rough age indication of 2649 +- 260 Ma with an initial ε_{Nd} of +2.4 (Fig.3). For 3 samples, internal Sm-Nd isochrons give, within error limits, similar age estimates of 2586 +/-308 Ma, 2655 +/-360 Ma, and 2745+/-232. These computed ages are quite comparable to the U-Pb upper intercept age of 2528 +-452 Ma obtained for 45 analyses of baddeleyite and zircon megacrysts (Schärer et al., 1997). This confirms that the eclogitic metamorphism is of late Archean age. On the contrary, for the 3 analyzed eclogites in which metasomatic minerals (phlogopite, zoisite, apatite and whitlockite) are quite abundant, the ga-cpx pairs give meaningless or even negative ages. This behaviour is interpreted as another evidence for the interaction, at various degrees, between a LREE-rich metasomatic fluid and eclogites within the mantle.

The positive Ba, Sr, Pb and Eu anomalies correlate with the high Al_2O_3 and CaO contents, which suggests that the protoliths of kyanite eclogites were plagioclase-rich rocks (cumulate gabbros, anorthosites). The protoliths of bimineralic eclogites were less- or not enriched in plagioclase and probably correspond to basalts.

These eclogites were variously affected by (several ?) metasomatic events marked by the presence of newly formed minerals and veins, and in some cases by the sinusoidal REE pattern of garnets.





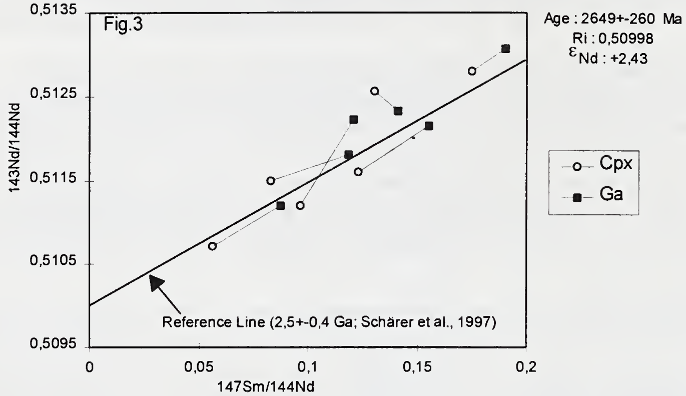


Fig.1. REE variations in a single garnet (Ga) grain at the contact with whitlockite.
Fig.2. Recalculated (rec) and analyzed (anal) whole rock REE patterns for Mbuji Mayi eclogites Bimineralic eclogite: F240-18; Kyanite-bearing eclogite: F220-7 and Diamond-bearing eclogite: JCD3
Fig.3. $^{147}Sm/^{144}Nd$ vs. $^{143}Nd/^{144}Nd$ isochron diagram for garnet-clinopyroxene pairs.

References

Hoal, K.E.O., Hoal, B.G., Erlank, A.J., and Shimizu, N., 1994, Metasomatism of the mantle lithosphere recorded by rare earth elements in garnets: Earth. Planet. Sci. Lett., 126, p. 303-313.

Jerde, E.A., Taylor, L.A., Crozaz, G.C., Sobolev, N.V., and Sobolev, V.N., 1993, Diamondiferous eclogites from Yakutia, Siberia : Evidence for a diversity of protoliths: Contrib. Mineral. Petrol., 114, p. 13-22.

Schärer, U., Corfu, F., and Demaiffe, D., 1997, U-Pb and Lu-Hf isotopes in baddeleyite and zircon megacrysts from the Mbuji Mayi kimberlite: constraints on the subcontinental mantle: Chem. Geol., 143, p. 1-16.

Shimizu, N., 1975, Rare earth elements in garnets and clinopyroxenes from garnet lherzolite nodules in kimberlites: Earth. Planet. Sci. Lett., 25, p. 26-32.

Snyder, G.A., Taylor, L.A., Crozaz, G.C., Halliday, A.N., Beard, B.L., Sobolev, N.V., and Sobolev, V.N., 1997, The origins of Yakutian eclogite xenoliths: J. Petrol., 38, 85-113.

Sobolev, V.N., Taylor, L.A., Snyder, G.A., and Sobolev, N.V., 1994, Diamondiferous eclogites from the Udachnaya kimberlite pipe, Yakutia: Int. Geol. Rev., 36, p. 42-64.

Taylor, L.A., and Neal, C.R. J., 1989, Eclogites with oceanic crustal and mantle signatures from the Bellsbank kimberlite, South Africa, Part I: Mineralogy, petrography and whole rock chemistry: J. Geol., 97, p. 551-567.