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Some post-equilibrium reactions in kimberlite-derived eclogites Paper A-00081

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ABSTRACT

Eclogites from the Chicundo (Angola) and Lace (S. Africa) kimberlites have been subject to post-equilibrium heating and/or decrease in pressure. These effects, and attendant metasomatism, are here interpreted as taking place during entrainment and transport in the host kimberlites. Phases formed during arrested retrograde reactions include corundum, orthopyroxene and K-feldspar which have previously been reported as uncommon, but well-equilibrated, phases in eclogites.

1. Introduction

Eclogite xenoliths found in kimberlite intrusions are coarse-grained, mainly bimineralic rocks consisting primarily of garnet and clinopyroxene but sometimes containing less common phases such as rutile, diamond, coesite, sanidine, orthopyroxene, kyanite and corundum, some indicative of an ultra-high pressure (UHP) origin (Dawson and Carswell, 1990). Some theories hold eclogites to be high pressure accumulations of phases precipitating from basaltic melts, but the present-day consensus is that, although a small number do arise from high-pressure crystallization of mafic or ultramafic melts (e.g. Schmickler et al., 2004), most represent subducted oceanic crust (e.g. Jacob, 2004; Spetsius et al., this issue; Jacob et al., this issue). Other high-Mg eclogites may have arisen by hybridized melts reacting with peridotitic mantle (Aulbach et al., 2007).

Many studies have ascertained the compositions and PT conditions of initial equilibration of the dominant phases in eclogites occurring as xenoliths in both kimberlites or in regional UHP terranes, but the almost-ubiquitous presence around the primary garnet and clinopyroxene of coronae containing low PT phases such as plagioclase, mica and amphibole, indicates that most eclogites have partially readjusted to post-peak metamorphism conditions during regional relaxation or alterations to original P-T conditions during transportation from depth by the host kimberlites. Early studies on alteration products in kimberlite-hosted eclogites were made mainly on samples from the kimberlite intrusions of the Roberts Victor Mine and Bellsbank (S. Africa), and from the Mir and Udachnaya kimberlites (Yakutia). Commonly identified alteration products included secondary pyroxene, plagioclase, amphibole, phlogopite and spinel whereas less common phases are analcime, Ba-feldspar, baryte, calcite, apatite, pectolite, natrolite and glass (Berg, 1968; Lappin, 1978; Dawson, 1980; Windom and Boettcher, 1980; Carswell et al., 1981; McCormick et al., 1994; Pyle and Haggerty, 1994; Misra et al., 2008), in some cases providing evidence for addition of volatiles. Importantly, Switzer and Melson (1969) recognised partial melting of kyanite eclogite in which mullite and corundum formed at the expense of kyanite and, in other partly-melted kyanite eclogites and grospydites, additional identified phases include zoisite and sapphirine (Chinner and Cornell, 1974) and nepheline (Lappin, 1978). Studies on eclogites (including diamondiferous and kyanite-bearing varieties) and grospydites from the Mir and Udachnaya kimberlites of Yakutia (Sobolev et al., 1968; Sobolev, 1977; Ponomarenko, 1977; Spetsius 1980) have identified many similar secondary phases and partial melting, and Spetsius and Taylor (2002) state that *all* the Siberian eclogites have been partly melted; more recently this melting and precipitation of "secondary" diamonds has been attributed to influx of Cl-rich aqueous fluids (Butvina et al., 2008). This result of metasomatising fluids is in contrast to that attributed to metasomatism in Roberts Victor eclogites which is held to be responsible for diamond dissolution. (Ishikawa et al., 2008).

Another aspect of eclogite geology has been that of erecting criteria for differentiating between primary bi-mineralic assemblages. An early classification was based on the textures of samples from the Roberts Victor Mine, defining Group I as characterised by rounded garnet surrounded by pyroxene, and Group II in which equant garnet, often with planar faces, and clinopyroxene have an interlocking fabric; Group I rocks were interpreted as forming during accumulation from an igneous parent, and Group II as the associated crystallised mafic melts (MacGregor and Carter, 1970). These textural differences were suggested as being accompanied by chemical differences, with more Cr_2O_3, CaO, FeO and MnO in the clinopyroxene and more MgO, NiO, Li_2O and Na_2O in the garnets in Group I eclogites. The presence of the small amounts of Na_2O in garnet in eclogite established by MacGregor

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and Carter (1970) has been confirmed for garnets in other eclogites and mantle peridotites (e.g. Bishop et al., 1976, 1978) and, because it was found in garnet inclusions in diamond, Sobolev and Lavrent'yev (1971) attributed this to unusually high pressure; a critical value of >0.09 wt.% Na_2O was proposed for garnets in the high-pressure assemblages. Subsequently, Reid et al. (1976) found values ranging from 0.08 to 0.15 wt.% Na_2O in garnet from South African diamondiferous eclogites.

McCandless and Gurney (1989) reviewed the linked texture/composition classification of MacGregor and Carter (1970) and proposed an alternative classification, independent of texture, based on both the sodium content of garnet and the potassium content of clinopyroxene; in Group I, garnet Na_2O is ≥0.09 wt.%, less in Group II; and K_2O in Group I pyroxene is ≥0.08 wt.%, less in Group II.

The main objective of the present study is to document the secondary phases formed during three types of arrested re-equilibration in eclogites from new locations in Angola and South Africa but, because the samples are from both textural groups of eclogite, a secondary aspect has been to ascertain whether mineral compositions correlate (or not) with the textures or with the GroupI/Group II chemical criteria.

2. Analytical methods

Mineral compositions were analysed by WDS techniques on a Camebax Microbeam electron microprobe at the University of Edinburgh. Standards used were: for Ca and Si — wollastonite; Ti — rutile; Al — corundum; Fe, Mn — metals; Mg — periclase; Na — jadeite; K — orthoclase, Ba — barite. Na and K were analysed early in the routine to avoid volatility/migration effects. Counting times were 30 s for peaks and 15 s for backgrounds. Minerals were analysed with a spot beam of ~1 μm at 20 kV and a probe current of 20 nA, and data were reduced using the PAP routine.

3. Sample descriptions and mineral chemistry

3.1. Sample 1

Kyanite-corundum eclogite BD2745 is from kimberlite pipe137-K1, one of a small cluster of pipes centred on 10°S 19°E in the Chicundo area of Angola. The specimen was donated by L. Doig and earlier probe analyses were made on some minerals in this rock by Boyd and Danchin (1980). Texturally the rock is a group II eclogite. The garnet and pyroxene grains are up to 4 mm in size and comprise ~95% of the rock by volume. As is common in peraluminous eclogites, the omphacite is extensively altered with bright green relict cores set in a fine-grained white-grey matrix consisting of secondary clinopyroxene intergrown with plagioclase. Kyanite is in elongate though rounded grains up to 1.5 mm long; it does not have the bladed morphology of kyanite interpreted as having exsolved from clinopyroxene in some kyanite eclogites from Kuruman, South Africa (Schmickler et al., 2004). Equant rutile grains are up to 1 mm in size. The rock is cut by thin (0.5 to 1 mm) sub-parallel veins containing glass, plagioclase, phlogopite, a barian silicate and rare apatite (Fig. 1).

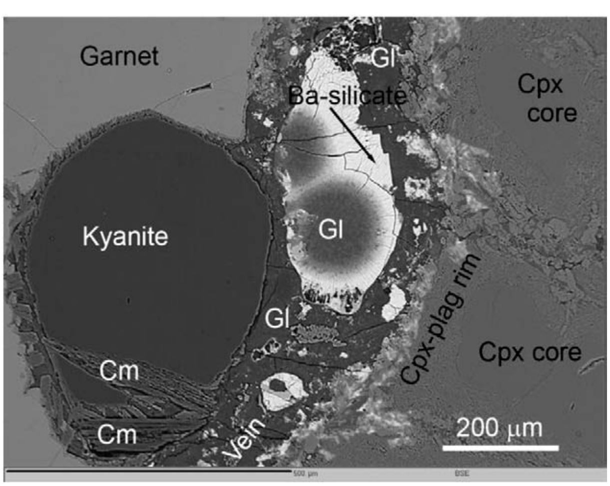

Fig. 1. Back-scattered electron image of Chicundo eclogite showing garnet, kyanite, clinopyroxene rimmed by clinopyroxene + plagioclase, and a glassy (GL — glass) vein containing a Ba silicate (bright in B.S.E.). Kyanite is partly replaced by skeletal corundum (Cm).

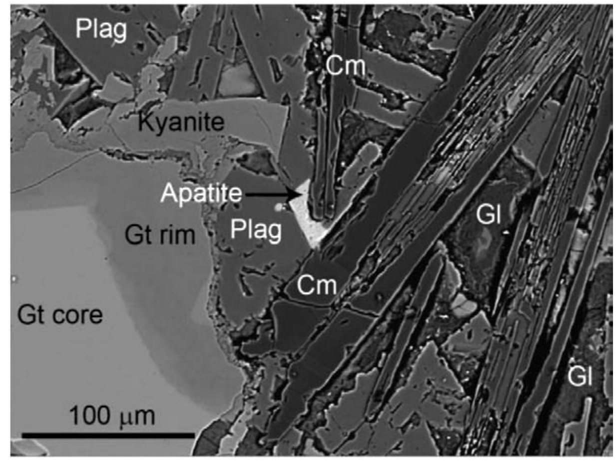

Fig. 2. B.S.E. image of Chicundo eclogite, showing zoned garnet and part of a vein containing plagioclase, skeletal corundum (Cm), apatite and glass (Gl).

Adjacent to the veins, some kyanite grains are marginally melted giving rise to acicular corundum, the texture of which suggests it was a quench product. Some quench corundum grains are intergrown with plagioclase.

The garnet has proved to be zoned, with a sharp boundary between the garnet core and the rim (Fig. 2). Cores (Table 1) are calcic pyrope–almandine (Ca_{29} Mg_{40} Fe_{31}) whereas the rims are pyrope–grossular–almandine (Ca_{25} Mg_{55} Fe_{20}) i.e. group 3 and 6, respectively, of the Dawson and Stephens (1975) garnet classification scheme. Further differences are in TiO_2 (core 0.06, rim 0.32 wt.%) and Na_2O (core 0.10, rim 0.05 wt.%). Although the rock contains kyanite and corundum (and hence a peraluminous eclogite), the garnet (Ca 25–29 mol%) does not have the >50% Ca mole for the rock to be termed a grospydite. The core of the clinopyroxene is omphacite and contains ~5 mol% Ca-Eskola molecule, a characteristic of peraluminous eclogites in general. The omphacite contains no K_2O that could be detected by the electron microprobe (unlike the clinopyroxene analysed by the same technique in other eclogites to be discussed below). This, and the low Na_2O content of the garnet rim are in the ranges established by McCandless and Gurney (1989) for their chemical criteria for Group II eclogites. The clinopyroxene in the coronas around the primary omphacite is sodic fassaite containing a higher amount of the diopside molecule but a lower jadeite content than the primary omphacite; in addition, like the rim on the garnet, it contains higher MgO and TiO_2. Plagioclase intergrown with the corona pyroxene is a sodic variety (Ab77.2) that contains detectable BaO (0.02 wt.%). In the primary kyanite and the secondary corundum, the only significant oxide, in addition to Al_2O_3 and SiO_2, is iron, and the Fe_2O_3 content of the corundum which also contains appreciable TiO_2, is x2 that in the kyanite. The rutile is slightly zoned with lower Fe and Al in rims compared with crystal cores. With the exception of the rutile, the phases rimming and/or replacing the main primary phases are consistently higher in Mg and Ti.

The compositions of phases in the veins cutting the rock are given in Table 2. Glass which, due to partial devitrification, is of variable composition, is overall low in SiO_2 but high in Al_2O_3 and MgO. The