

Subcontinental lithospheric and asthenospheric metasomatism
in the region of Jagersfontein South Africa

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The Cretaceous Jagersfontein kimberlite is located close to the edge of the Kaapvaal craton, displaced from the Kimberley cluster in the interior of the craton. Historically, the diatreme is of interest because it was at Jagersfontein that the association between diamonds and host rock was first established. Mineralogically, it is one of four localities at which high-pressure alkali titanates of the crichtonite series (lindsleyite-mathiasite) have been recognized along with Nb-Cr-rutile and armalcolite (Haggerty et al., 1983). In addition to the metasomatic oxides, metasomatic silicates, most notably amphiboles and phlogopites, have been identified in peridotite nodules recovered from the diatreme (Johnston, 1983; Harte and Gurney, 1980). The chemistries and textures of these silicates, major targets of this study, can be used to model metasomatic events in asthenospheric and lithospheric peridotites in the upper mantle beneath Jagersfontein. The position of this kimberlite with respect to the Kimberley cluster permits a comparison of metasomatism at the cratonic edge with interior-craton metasomatism. Jagersfontein is, therefore, a potentially important region for modelling the geometry of the subcontinental lithosphere.

Ultramafic xenoliths found at Jagersfontein include garnet lherzolites (ol+opx+gt+>5%cpx), garnet harzburgites (ol+opx+gt+<5%cpx), harzburgites (ol+opx±<5%cpx) and diopsidic-harzburgites (ol+opx+>5%cpx); the latter considered here to be refertilized harzburgites. Petrographic evidence and electron microbeam analyses suggest that the peridotites were subjected to at least two episodes of metasomatism, hereafter referred to as Stage A and Stage B metasomatism.

Phlogopites form two distinct textural and chemical populations (Table 1): large (1.5–2.5mm) grains many of which are intergrown with amphiboles, and fine-grained (<1mm) phlogopites usually found rimming or replacing other silicate minerals. The large phlogopites (Al₂O₃ 12.4–15.1 wt%, MgO 25.3–27.1 wt%, FeO 2.6–3.6 wt%) are considered to have formed during the Stage A metasomatic event along with amphibole. They contain lower Cr₂O₃ (0.3–1.1 wt%) and TiO₂ (0.1–0.9 wt%) (Fig.1) but higher BaO (0.3–3.4 wt%) than their fine-grained counterpart. Stage A metasomatic phlogopites are present in harzburgites and diopsidic-harzburgites but are rare in garnet lherzolites and garnet harzburgites. Fine grained Stage B metasomatic phlogopite is a constituent of most samples. The phlogopites are found in veins or rims, in association with fine-grained Cr-spinels and Cr-diopsides replacing opx, cpx, ol and amphibole. Barium contents are low in these grains (0–0.4 wt%), but TiO₂ (0.5–4.48 wt%) and Cr₂O₃ (0.9–2.2 wt%) are high (Fig.1), compared to stage A metasomatic phlogopites. A correlation is present between phlogopite composition and nodule type. Garnet lherzolite and garnet harzburgite Stage B phlogopites are generally richer in FeO (4.4–6.0 wt%) and lower in MgO (20–23 wt%) than Stage B metasomatic phlogopite (FeO 2.5–4.5 wt%, MgO 25.0–27.0 wt%) in harzburgites and diopsidic harzburgites. Phlogopites in garnet-bearing peridotites are also generally richer in Al₂O₃.

Cr-diopsides are commonly found as small grains with phlogopite replacing cpx, opx, or amphibole. These Cr-diopsides are considered to have formed during the Stage B metasomatic event. They are lower in Al₂O₃ and generally higher in FeO and TiO₂ content than the Cr-diopsides that comprise the original host rock mineralogy. Stage B metasomatic phlogopites are commonly accompanied by fine-grained, Al-rich, Cr-spinel.

Amphiboles are present in garnet lherzolites, garnet harzburgites, harzburgites, and diopsidic-harzburgites and are considered to have formed during the Stage A metasomatic event. They display both equilibrated and non-equilibrated textures. Grains in apparent disequilibrium with their host rock minerals contain inclusions of host rock minerals, usually cpx. Grain boundaries are irregular and diffuse. These amphiboles have varying mineral chemistries and exhibit weak zoning, especially in Cr₂O₃, around the inclusions. Texturally equilibrated amphiboles contain no fragments of other minerals, although they are frequently intergrown with garnet, pyroxene, Cr-spinel, or phlogopite. These amphiboles are chemically homogeneous.

Jagersfontein amphibole chemistries span a wide range of compositions. They are classified, according to Leake (1978), as pargasitic hornblende, edenitic hornblende, Mg-kataphorite, and richterite. Although there are four different classes of amphiboles, there are no distinct groups of amphibole types; the amphiboles define a complete spectrum of compositions that span the four amphibole classification fields. Amphiboles vary gradationally in SiO_2 , Al_2O_3 , Cr_2O_3 , MgO, FeO, and CaO. Silica varies inversely with Al_2O_3 (0.5–12.5 wt%) and a similar relationship exists between FeO (1.2–3.5 wt%) and MgO (19.0–24 wt%) (Fig.2). Aluminum and Cr_2O_3 (0.5–2.5 wt%) contents, however, vary in direct proportion (Fig.3). CaO contents, which range from 5.8–11.0 wt%, vary inversely with $\text{Na}_2\text{O} + \text{K}_2\text{O}$ (3.3–6.6 wt% + 1.0–5.0 wt%). Amphiboles like phlogopites show a correlation between nodule type and composition (Table 2). Garnet Iherzolite and garnet harzburgite amphiboles are pargasitic hornblendes and edenitic hornblendes, whereas harzburgite and diopsidic-harzburgite contain Mg-kataphorites and richterites. The edenitic and pargasitic hornblendes are lower in silica (6.30–6.75 cations/23 oxygens) than Mg-kataphorites and K-richterites (6.90–7.85 cations/23 oxygens). Amphiboles in garnet-bearing rocks are mostly richer in FeO (2.0–3.5 wt%) and poorer in MgO (19.0–20.5 wt%) than the Mg-kataphorites and richterites (FeO 1.4–3.0 wt%, MgO 21.0–24.0 wt%). Harzburgite and diopsidic-harzburgite amphiboles contain less Cr_2O_3 (0.5–1.8 wt%) and Al_2O_3 (0.8–6.0 wt%) than garnet Iherzolite and garnet harzburgite amphiboles (Cr_2O_3 2.0–2.5 wt%, Al_2O_3 9.0–12.5 wt%). The CaO content of garnet Iherzolite and garnet harzburgite amphiboles ranges from 8.0 to 11.0 wt% whereas the CaO content of the harzburgite and diopsidic-harzburgite is usually less than 7.5 wt%. The $\text{CaO}/(\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ ratio of edenitic and pargasitic amphiboles is always higher than that of harzburgite and diopsidic-harzburgite. In general, amphiboles in previously depleted peridotites are richer in SiO_2 , MgO, Na_2O , and K_2O . Amphiboles in the more fertile peridotites are enriched in Al_2O_3 , FeO, and CaO.

Metasomatic mineralogy at Jagersfontein is dominated by amphiboles and phlogopites. Both minerals show continuous trends in mineral chemistries that correlate with peridotite type. Amphibole and phlogopite compositions in part reflect the compositions of their host rock mineralogy. Variations in TiO_2 , BaO, and K_2O suggest variations in the composition of the metasomatizing fluids. The existence of amphibole in garnet Iherzolite nodules suggests that at Jagersfontein, asthenospheric material is probably present above 120 km, the lowest reported stability limit for pargasite (Horiya et al., 1974). This is seemingly incompatible with the occurrence of diamonds which are believed to have formed in the lithosphere at depths greater than 150 km (Boyd and Gurney, 1986). Possible explanations for the presence of K-richterite bearing harzburgites, pargasite-edenite bearing garnet Iherzolites, and diamonds include: (1) multiple paths of kimberlite intrusion, each bearing a distinct xenolith suite; (2) an irregular asthenospheric-lithospheric boundary; (3) remanent lenses or pockets of asthenospheric rocks within the lithosphere; or (4) diamond nucleation and growth over a limited P-T.

CONCLUSIONS Peridotites in the subcratonic lithosphere and asthenosphere beneath Jagersfontein have been modified by two metasomatic episodes. Stage A metasomatism produced amphiboles and phlogopites characterized by relatively low TiO_2 and Cr_2O_3 contents. Stage B metasomatism produced TiO_2 - and Cr_2O_3 -rich, fine-grained phlogopites, TiO_2 -poor Cr-diopsides, and Al_2O_3 -rich Cr-spinels. Amphibole and phlogopite chemistries span a broad range of compositions reflecting the compositions of the host rock minerals and the compositions of the metasomatizing fluids. The metasomatic mineralogy at Jagersfontein is similar to the metasomatic mineralogy at Bullfontein in the Kimberley district and possibly in other parts of the Kaapvaal craton.

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TABLE 1 PHLOGOPITE

| WT. % | STAGE A | | STAGE B | |
|--------------------------------|---------|-------|---------|-------|
| | 276 | 576 | 311 | 236 |
| SiO ₂ | 40.85 | 39.97 | 40.38 | 39.65 |
| TiO ₂ | 0.15 | 0.19 | 3.37 | 4.48 |
| Al ₂ O ₃ | 13.75 | 15.14 | 14.78 | 14.56 |
| Cr ₂ O ₃ | 0.51 | 0.92 | 1.87 | 2.12 |
| FeO | 2.85 | 3.06 | 4.26 | 5.76 |
| MnO | 0.03 | 0.03 | 0.04 | 0.07 |
| MgO | 27.11 | 25.40 | 21.63 | 20.08 |
| NiO | 0.19 | 0.16 | 0.19 | 0.14 |
| CaO | 0.00 | 0.00 | 0.02 | 0.03 |
| BaO | 1.41 | 1.93 | 0.12 | 0.11 |
| Na ₂ O | 1.01 | 1.02 | 0.31 | 0.21 |
| K ₂ O | 8.29 | 7.61 | 9.07 | 8.93 |
| Total | 96.15 | 95.43 | 96.04 | 96.14 |

TABLE 2 AMPHIBOLE

| GT LZ | GT HZ | HZ | DI HZ |
|-------|-------|-------|-------|
| 259 | 576 | 586 | 592 |
| 46.23 | 47.67 | 54.20 | 55.76 |
| 0.34 | 0.06 | 0.26 | 0.30 |
| 11.11 | 10.56 | 3.70 | 0.93 |
| 2.13 | 2.03 | 1.78 | 0.72 |
| 2.55 | 3.21 | 2.32 | 1.88 |
| 0.04 | 0.10 | 0.09 | 0.03 |
| 20.17 | 19.85 | 21.57 | 23.19 |
| 0.12 | 0.09 | 0.11 | 0.07 |
| 10.28 | 8.78 | 6.97 | 6.81 |
| 0.13 | 0.04 | 0.00 | 0.03 |
| 3.93 | 4.72 | 5.61 | 4.10 |
| 1.03 | 0.79 | 1.54 | 3.84 |
| 98.06 | 97.90 | 98.15 | 97.66 |

