The Use of Amphibolite Melting Experiments in Constraining Conditions of Melting in Natural Amphibolite Nodules from the Venetia Kimberlite Pipes

Pretorius, W.[1,2] and Barton, J. M., Jr.[1]

[1]Department of Geology, Rand Afrikaans University, P.O. Box 524, Auckland Park 2006, South Africa

[2]Present address: 5B, 165 E 83rd St., New York City, NY 10028, U.S.A.

At surface, the ~530 Ma Venetia kimberlite pipes intrude predominantly Archean supracrustal and 2.5 to 2.0 Ga granitic rocks and a minor amount of Archean and early Proterozoic tonalitic to trondhjemitic gneisses (*e.g.* Pretorius, 1996; Jaeckel *et al.*, 1997). Integrated petrologic, geochemical and geophysical studies of upper lithospheric nodules from these pipes show that these country rocks, which are characteristic of the Central Zone of the Limpopo Belt, only extend to a depth of at most 10 km. Below that level to a depth of at least 80 km, the upper lithosphere is mafic and ultramafic composed first of various varieties of amphibolite and then also of gabbronorite, pyroxenite, garnet-quartz rocks and eclogite. The break between Central Zone lithologies and amphibolite may be a décollement (Barton and Pretorius, 1998) and reflective seismic data suggest that the rocks below are part of the Zimbabwe Craton (Roering *et al.*, 1992).

Many nodules of amphibolite show evidence for partial melting and melt extraction (Pretorius, 1996), manifested by the formation of zoned poikilitic garnet containing melt inclusions and residual phases and serrate edges on many primary grains of amphibole and plagioclase. There is an increase in modal garnet, quartz, ilmenite and rutile next to primary amphibole and orthopyroxene and there are abundant fluid inclusion trails in residual quartz and garnet, indicating the importance of dehydration in melting processes.

Evidence for melting of three compositions of amphibolite were observed: felsic; intermediate and mafic. Unmelted compositions contain high modal percentages of sub- to euhedral hornblende and have low bulk Mg#'s, low amphibole Mg#'s and enriched chondrite normalized LREE patterns compared to restite compositions. Mafic compositions are characterized by the gradual production of between one and five metastable varieties of amphibole and a pyribole (pyroxene-amphibole hybrid), and finally a pyroxene bearing restite which has a low Ce/Lu ratio (~12) relative to the unmelted composition (~23). Intermediate compositions, however, are conspicuously devoid of pyroxene and are dominated by garnet-quartz restites which have low La/Yb ratios (~0.4) compared to the unmelted composition (~1.7). Hornblende becomes more tschermakitic and plagioclase becomes more anorthitic as melting progresses.

Significant information was gained concerning the conditions of melting of amphibolite beneath the Venetia kimberlite pipes by comparing the intermediate and mafic unmelted and restite compositions to those used and produced in melting experiments (Wolf and Wyllie, 1993; 1994; Patino-Douce and Beard, 1995). Compared with the starting compositions used in the melting experiments, the compositions of unmelted amphibolite are more iron rich and magnesium and calcium poor. Grains of restitic garnet in Venetia amphibolite have prograde zonation profiles, in agreement with experimental observations and consistent with prograde melting. Incompatible components (Na_2O, CaO, K_2O) generally decrease as melting progresses concurrently with increases in MgO, FeO Al_2O_3 and TiO_2. Silica saturation is an important parameter in the control of temperature of melting of amphibolite (Wolf, *pers. comm.*, 1995) and hence we believe that the

most significant deviation in P-T conditions from the experimental results will be due to variations in silica saturation. The major effect of the higher Fe/Mg ratios is to suppress formation of orthopyroxene or increase garnet crystallization.

The higher the activity of albite in intermediate amphibolite, the higher the melting pressure because garnet scavenges Ca (Green, 1969; Fram and Longhi, 1992; Rushmer, 1993; Patino-Douce and Beard, 1995). Garnet and plagioclase in intermediate Venetia amphibolite is Ca and Na rich (gross 26-27%; An 23-32%). For these compositions, plagioclase is only stable at pressures below ~10 kbar, rutile and ilmenite above ~10 kbar and garnet above ~12 kbar (Patino-Douce and Beard, 1995). Thus the Venetia intermediate amphibolite containing garnet-rutile and ilmenite restites probably formed at pressures above ~12 kbar and possibly above ~15 kbar and temperatures above ~850°C. Mineral equilibrium geobarometry on Venetia intermediate amphibolite indicates pressures of ~7 to 10 kbar, showing decompression of at least 2 kbar since melting.

In mafic amphibolite, melting reactions and resulting mineral textures are more complex (Wolf and Wyllie, 1994). During progressive melting of Venetia mafic amphibolite, five metastable amphibolite phases, pyribole (high-Ca cummingtonite), Ca-free cummingtonite, orthopyroxene/clinopyroxene, Fe-Ti oxides, sphene and garnet formed. Abundant growth of garnet and orthopyroxene takes place at temperatures of ~850 to 975°C and <~750°C respectively (Wolf and Wyllie, 1993). Garnet is stable at relatively high pressure (>~11 kbar, Wyllie *et al.*, 1997) but disappears at temperatures between ~975 and 1000°C (Wolf and Wyllie, 1993). Orthopyroxene becomes progressively unstable at pressures >~12 kbar and between ~925 and 950°C and hornblende typically disappears at >~975°C (Wolf and Wyllie, 1993). It is often difficult to distinguish between cummingtonite and orthopyroxene in experimental charges due to their small grain sizes (Wolf, *pers. comm.*, 1995) and hence evidence from the Venetia mafic amphibolite suggests that cummingtonite is also an important melt phase. Venetia mafic amphibolite that contains abundant hornblende and cummingtonite and therefore, probably melted at relatively low temperatures (<~850°C). As temperature increases above ~850°C, amphibolite containing garnet, cummingtonite, hornblende and orthopyroxene is produced. Above ~950°C, garnet and cummingtonite/orthopyroxene become progressively unstable, until the final assemblage of clinopyroxene, plagioclase ± garnet predominates. Thus if relatively high temperatures (~975 to 1000°C) and low hydrous fluid flux were sustained during melting of Venetia mafic amphibolite, clinopyroxene rather than garnet would be the dominant residual phase as observed, in contrast to melting Venetia intermediate amphibolite. Garnet in Venetia mafic amphibolite is interpreted to be a result of subsolidus recrystallization as indicated by its chondrite normalized REE composition.

The lower to middle crust (>~10 km) under the Venetia kimberlite pipes is anomalous compared to other lower to middle crustal estimates by being enriched in FeO, MnO and TiO_2 and lower in Mg/Fe, SiO_2, Al_2O_3, Na_2O and K_2O. This composition is attributed to first its amphibolitic nature and second, the extraction of large volumes of tonalitic to trondhjemitic magma during the Archean. Mass considerations and lithological proportions argue that these voluminous magmas are not present in the Central Zone of the Limpopo Belt (Barton and Pretorius, 1998). Precisely where they are remains a matter of contention although they could have formed major components of either the Northern Marginal Zone of the Limpopo Belt or the Kaapvaal or Zimbabwe Cratons.

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