FICTIVE CONDUCTIVE GEOTHERMS BENEATH THE KAAPVAAL CRATON.

Brey, G.

Max-Planck-Institut für Chemie, D-6500 Mainz, F.R.G.

Garnet peridotite xenoliths from kimberlites, lamproites, minette and rarely alkali basalts are the major source of information on the chemistry and physical state of the continental lithosphere and possibly the underlying asthenosphere. Pressures and temperatures of crystallisation may be calculated for these xenoliths with various geothermobarometers. These pressures and temperatures are usually aligned along conductive continental geotherms as calculated from heat flow measurements at the Earth's surface. While the major issue of debate was and is the existence or non-existence of an inflected geotherm (Boyd, 1973; Nickel and Green, 1985; Bertrand et al., 1986; Carswell and Gibb, 1987), opinions also existed which simply questioned the reality and validity of calculated conductive geotherms beneath the Kaapvaal craton (Fraser and Lawless, 1978; Harte and Freer, 1982).

Based on experiments in natural and simple systems from 2-60 kb and 900-1400 °C Brey and Köhler (1990) calibrated new versions of the two-pyroxene thermometer (T_{BKN}) and the Al-in-opx barometer (P_{BKN}). Tests of published geothermobarometers with their experiments in natural systems indicate that the Fe-Mg exchange thermometers of O'Neill and Wood (1979; grt-ol; $T_{O'NEILL}$) and of Krogh (1988; grt-cpx; T_{Krogh}) and a Ca-in-olivine barometer (Köhler and Brey, 1990; P_{KB}) can be used to reliably calculate pressures and temperatures of crystallisation. All these geothermobarometers should yield identical results (within their mutual errors) <u>if</u> the samples were in internal mineral equilibrium.

P,T-conditions calculated with the potentially most accurate combination of the two-pyroxene thermometer with the Al-in-opx barometer are aligned along a conductive geotherm of about 44 mW/m^2 for mostly granular (low-T) nodules from the Kaapvaal craton (examples are shown in Fig. 1 for Bultfontein, Thaba Putsoa and Matsoku) while sheared (high-T) nodules form arrays at higher temperatures and subparallel to conductive geotherms. No kink (inflection) appears in our calculated geotherms (Fig. 1).

Tests for internal mineral equlibrium:

In general, all thermometers and barometers yield consistent results when applied to the *high-T suite* of nodules indicating internal mineral equilibrium.

In contrast, temperatures calculated with $T_{O'Neill}$ are systematically underestimated compared to results from the two-pyroxene thermometer with increasing T_{BKN}; T_{Krogh} gives similar results and P_{KB} systematically overestimates pressures compared to P_{BKN} for granular (low-T) nodules indicating disequlibrium between the various minerals. These inconsistencies may be the result of different blocking temperatures of elements in the different minerals. In the absence of apparent zoning this should be reflected as inconsistencies in mineral chemistry as demonstrated in Figs. 2-4.

Fig. 2 is a diagram of Ca^{opx} vs Ca^{cpx}. Ca in the two pyroxenes should show a negative correlation if the samples under consideration are derived from a range of temperatures. This is the case for the suite of high-T nodules. Orthopyroxenes from low-T nodules have constant Ca at individual localities, but differ between localities indicating a low and constant temperature, whereas Ca in cpx varies widely indicating variable temperatures. The two minerals cannot be equilibrium at least with respect to Ca and in the higher temperature range. Ca in olivine is similarily constant as Ca in opx and Ca in cpx is also not in equilibrium with Ca in olivine.

Al in opx varies concommitantly with Ca in cpx (compare Figs. 2 and 3); it may be argued that these two elements reflect peak metamorphic conditions of the samples, whereas Ca in opx and Ca in olivine had adjusted to lower temperatures. It must then be shown, however, that garnet was in equilibrium with opx and cpx at the peak metamorphic conditions. It can be demonstrated, however, from Ca-Cr relationships of garnets (Fig. 4), that garnet was never in equilibrium with clinopyroxene except if the nodules experienced very high temperatures at one stage of their history (higher than calculated here from the two-pyroxene thermometer), and that the garnet compositions were frozen in at these conditions. Much lower temperatures calculated with $T_{O'Neill}$ argue against this possibility. I must therefore concur with the conclusions of Fraser and Lawless (1978) and of Harte and Freer (1982) that it is not possible to deduce pressures and temperatures of crystallisation for the low-T nodule suite from the Kaapvaal craton and that we do not know the thermal state of its lithospheric mantle. If any estimates are to be made it can only be that the mantle is <u>cooler</u> than a conductive geotherm of 44 mW/m^2.

The Kaapvaal craton nodule suite is unique in that nodules from other localities worldwide (and also from Namibia) generally appear to be in internal mineral equilibrium and realistic geothermal gradients may be determined from the nodule suites. This further demonstrates that the Kaapvaal craton is an inappropriate place to make general models of cratonic parts of the upper mantle.

Bertrand, P., Sotin, C., Mercier, J.-C.C. and Takahashi, E. (1986). Contrib. Mineral. Petrol., 93, 168-178
Boyd, F.R. (1973). Geochim. Cosmochim. Acta, 37, 2533-2546
Brey, G. and Köhler, T. (1990). J. Petrol., 31, 1353-1378
Carswell,D.A. and Gibb, F.G.F. (1987), 97, 473-487
Fraser, D. and Lawless, (1978)
Harte, B. and Freer, R. (1982). Terra Cognita, 2, 273-275
Hervig, R.L., Smith, J.B. and Dawson, J.B. (1986). Trans. Royal Soc. Edinbg.: Earth Sci., 77, 181-201
Köhler, T. and Brey, G. (1990). Geochim. Cosmochim. Acta, 54, 2375-2388
Krogh, E.J. (1988). Contrib. Mineral. Petrol., 99, 44-48
Nickel, K.G. and Green, D.H. (1985), Earth Planet. Sci. Lett., 73, 158-170
O'Neill, H.St.C. and Wood, B.J. (1979). Contrib. Mineral. Petrol., 70, 59-70

Fig. 1: Calculated P,T-conditions (T_{BKN} + P_{BKN}) for garnet peridotites from Matsoku, Bultfontein and Thaba Putsoa (Kaapvaal craton; mineral data from various sources).
Fig. 2: Ca in opx vs Ca in cpx for nodules suites from the Kaapvaal craton (only data from Hervig et al., 1986)
Fig. 3: Ca in opx vs Al in opx for nodules suites from the Kaapvaal craton (only data from Hervig et al., 1986)
Fig. 4: Ca-Cr relationships for garnets from peridotites from Matsoku. Isolines for constant P,T conditions are derived from experiments in natural systems. Garnet compositions should plot along these lines in case of equilibrium between garnet and clinopyroxene. They plot, however, at too low Ca contents.