

Preliminary calculations on a model natural peridotite "pyrolite III" indicate that the spinel-garnet reaction is shifted downwards to about 10 kbar at 900°C. This result is in good agreement with the experimental data of Jenkins and Newton (1979). Calculations on the gabbro-eclogite reaction in an Fe-rich bulk composition indicate that garnet should appear at 8 kbar at 900°C. This is in good agreement with the experiments of Green and Ringwood (1967), bearing in mind the small overpressure (~2 kbar) required to achieve nucleation of garnet.

References

- Boyd F. R., 1970: *Min. Soc. Amer. Spec. Pap.* 3, 63-75.
 Green D. H., and A. E. Ringwood, 1967: *Geochim. Cosmochim. Acta* 31, 767-833.
 Haselton, H. T., and E. F. Westrum, 1980: *Geochim. Cosmochim. Acta* 44, 701-709.
 Herzberg, C. T. 1978: *Geochim. Cosmochim. Acta* 42, 945-957.
 Jenkins, D. M., and R. C. Newton, 1979: *Contrib. Mineral. Petrol.* 68, 407-419.
 Kushiro, I., and H. S. Yoder, Jr., 1966: *Jour. Petrol.* 7, 337-362.
 Nicholls, J., 1977: *Contrib. Mineral. Petrol.* 60, 119-142.

H19

KIMBERLITES OF SOUTHERN AFRICA - ARE THEY RELATED TO SUBDUCTION PROCESSES?

H. HELMSTAEDT¹, J. J. GURNEY²¹Dept of Geological Sciences, Queen's University Kingston, Canada, K7L 3N6²Dept of Geochemistry, University of Cape Town, Rondebosch, South Africa

Although proposed by Sharp (1974) that the Mesozoic kimberlites in Southern Africa originated from activity at the deep end of a subducted oceanic plate, a connection of kimberlites with subduction processes has not been generally accepted. Dawson (1980 p. 220) states that such "hypothesis is contrary to the observed random distribution of kimberlites in Southern Africa ...", and remarks further that "... the confinement of kimberlite magmatism to the cratonic centers of continents well away from any major fold belts, together with the very limited amounts of kimberlite magma, appear to preclude any connection with classical subduction zones."

However, in spite of recent progress in our knowledge of kimberlite formation and emplacement, the "... vexing problem of why kimberlites occur, and why they occur where they do has not been solved" (Meyer, 1979). Other plate-tectonic-related hypotheses of kimberlite distribution, such as transform fault models (Williams and Williams, 1977; Stracke et al., 1979) or hot spot models (Hastings and Sharp, 1979; Crough et al., 1980), do not explain the ultimate source of H₂O and CO₂ necessary for kimberlite formation, and we can only speculate whether these volatiles "come from deeper" or from "recycling via subduction" (Wyllie, 1979). While the hypothesis that the volatiles are juvenile gases from the deep mantle provides no means of predicting the location and timing of kimberlite eruptions, the possibility of a causal relationship to subduction can be tested because kimberlites should be localized above remnants of subducted plates. For such relationships to become obvious, the classical view that all subduction zones are steeply dipping and therefore cannot reach far enough under continents where most kimberlites originated must be abandoned. This is justified by the occurrence of fragments of subducted oceanic lithosphere as eclogite xenoliths in kimberlites from the Colorado plateau (Helmstaedt and Doig, 1975) as well as by the distribution of Tertiary magmatic rocks in the southwestern United States that suggest the former existence of a shallow-dipping subduction zone in this region (Dickinson and Snyder, 1978). The fact that a similar "flat-plate" subduction model was proposed by Lock (1980) for the formation of the Cape Fold belt warrants a new look at Sharp's original hypothesis.

Two independent questions are pursued:

1. Did such low-angle subduction occur under Southern Africa and if so, are the kimberlites related to it?

2. Do xenolith suites of these kimberlites include possible samples of subducted material?

1. Both Sharp and Lock relate the Permian to Middle Triassic Cape folding to subduction under Gondwanaland prior to its breakup, when according to Sharp "... the oceanic plate associated with this orogeny dived to great depth and went hundreds of kilometers inland underneath the former continent". As folding in the Cape Fold belt was broadly contemporaneous with the opening of the Tethys ocean we suggest that spreading of the Tethys caused the increase in plate convergence rates necessary to initiate low-angle subduction along the southern margin of Gondwanaland.

A compilation on a map of the reconstructed Gondwana continent shows that the distribution of kimberlites is considerably less random than suggested by distribution maps using the present configuration of continents. A broad zone of kimberlites cuts numerous different geological provinces and lies parallel to the belt of Late Paleozoic igneous rocks stretching from South America past South Africa, through Antarctica to Australia (Samfrau geosyncline of DuToit, 1937). In South America and Southern Africa the southwestern boundary of this kimberlite belt lies between 1500-2000 km cratonwards from the assumed Late Paleozoic to Triassic continental margin. Although the timing of the kimberlite eruptions (between 79 and 133 m.y., Davis, 1977) approximately coincides with the break up of Gondwanaland, the southwestern margin of the belt shows no relationship to the orientation of the South Atlantic rift. Similarly, a correlation with transform faults, as proposed by Williams and Williams (1977) for West African kimberlites, is not obvious. In a subduction model the time lag between subduction and kimberlite emplacement may be explained as a consequence of the emplacement mechanism. If kimberlites traverse the lithosphere along stress corrosion fractures (Anderson, 1979), emplacement was not possible until Gondwanaland became an extensional regime. Scatter in timing of kimberlite eruptions can be explained by differences in lag times following cessation of subduction that are a function of variations in thermal gradients within the sub-continental mantle as well as local structural conditions.

A subduction model for the Mesozoic kimberlites in Southern Africa must also account for the Karroo magmatism, as there is a common regional association of kimberlites with Karroo dykes and sills. Isotopic data appear to suggest that tholeiitic flood basalts are derived from continental

lithosphere (Allegre et al., 1981; 1982), whereas kimberlites and alkali basalts come from a deeper source which at present cannot be identified as typically sub-oceanic or sub-continental. It is therefore possible that Karroo magmatism was triggered by subduction (Cox, 1978) below the continental lithosphere, and that the later kimberlites shared the same fracture systems as access routes to the surface.

2. Although Late Paleozoic to Triassic low-angle subduction may have supplied volatiles for the formation of the Cretaceous kimberlites, actual samples of this young subduction zone have not been identified among the various xenoliths of Southern African kimberlites. However, chemical arguments and relics of prograde metamorphic reactions suggest that certain eclogites are subducted metabasites, and the different ages of such eclogites from Robert Victor (2.5 b.y.; Kramers, 1979) and the Karroo kimberlites (1 b.y., Robey, 1981) imply sampling of remnants of at least two earlier subduction episodes. Milashev (1973) interpreted the regional zonation of kimberlites and their xenoliths from the diamond subfacies to the pyrope subfacies as evidence for ascending convection currents under the diamond-bearing province. We consider it more likely that the zonation apparent in South African xenoliths reflects processes related to the Precambrian subduction under, and the accretion of continental fragments to the Archaean Kaapvaal craton. This interpretation is consistent with the observations by Griffin et al. (1979) that nodules of garnet granulites and "crustal" eclogites are common in kimberlites around the edge of the Kaapvaal craton, but are not obvious in kimberlites within the craton.

References

Allegre, C.J., Dupré, B., Lambret, B., and Richard,

- P., 1981: *Earth Planet. Sci. Lett.*, **52**, 85-92.
 Allegre, C.J., Dupré, B., Richard, P. and Rousseau, D., 1982: *Earth Planet. Sci. Lett.*, **57**, 25-34.
 Anderson, O.L., 1979, *Proc. 2. Int. Kimberlite Conf.*, vol. 1, AGU, Washington, p. 344-353.
 Cox, K.G., 1978: *Nature*, **274**, 47-49.
 Crough, S.T., Morgan, W.J. and Hargraves, R.B., 1980: *Earth Planet. Sci. Lett.*, **50**, 260-274.
 Davis, G.L., 1977: *2. Int. Kimberlite Conf.*, Santa Fe, Extended Abstracts.
 Dawson, J.B., 1980: *Kimberlites and their xenoliths*, Springer-Verlag.
 Dickinson, W.R. and Snyder, W.S., 1978: *Geol. Soc. America, Mem.* **151**, 355-366.
 DuToit, A.L., 1937: *Our wandering Continents*, Oliver and Boyd, Edinburgh.
 Griffin, W.L., Carswell, D.A. and Nixon, P.H., 1979: *The Mantle Sample. Proc. 2. Int. Kimberlite Conf.*, Vol. 2, 59-86, AGU, Washington.
 Hastings, D.A. and Sharp, W.E., 1979: *Nature*, **277**, 152.
 Helmstaedt, H. and Doig, R., 1975: *Phys. Chemistry Earth*, **9**, 95-111.
 Kramers, J.O., 1979: *Earth Planet. Sci. Lett.*, **42**, 58-70.
 Lock, B.E., 1980: *Geology*, **8**, 35-39.
 Meyer, H.O.A., 1979: *Proc. 2. Int. Kimberlite Conf.*, vol. 1, AGU, Washington, preface.
 Milashev, V.A., 1973: *1. Int. Kimberlite Conf.*, Cape Town, Extended Abstracts, 229-230.
 Robey, J.v.A., 1981: *Ph.D. thesis, Dept. Geochemistry, Univ. of Cape Town*.
 Sharp, W.E., 1974: *Earth Planet. Sci. Lett.*, **21**, 351-354.
 Stracke, K.J., Ferguson, J. and Black, L.P., 1979: *Proc. 2. Int. Kimberlite Conf.*, Vol. 1, 71-91, AGU, Washington.
 Williams, H.R. and Williams, R.A., 1977: *Nature*, **270**, 507.
 Wyllie, P.J., 1979: *Proc. 2. Int. Kimberlite Conf.*, Vol. 1, AGU, Washington, p. 319-329.

H20

DIFFUSION DATA AND THEIR BEARING ON THE INTERPRETATION OF MANTLE NODULES AND THE EVOLUTION OF THE MANTLE LITHOSPHERE.

Ben HARTE and Robert FREER,

Grant Institute of Geology, Edinburgh EH9 3JW, Scotland.

A common assumption in the interpretation of the ultramafic nodules erupted with kimberlitic and basic igneous magmas is that their mineralogy reflects the ambient pressure-temperature conditions of either their location in the mantle immediately prior to eruption or conditions obtaining during their entrainment. Considerations of nodule petrology and diffusion data suggest that this assumption needs modification for the upper part of the mantle lithosphere.

The erupted ultramafic nodules indicate that a major part of the mantle lithosphere consists of moderately coarse-grained (around 2mm or more) assemblages of anhydrous minerals (olivine, orthopyroxene, clinopyroxene, garnet, spinel). The amounts of biotite or amphibole present in the rocks prior to interaction with the transporting kimberlitic or other melt usually appears to be very small; and there is generally little evidence of the presence of a pervasive volatile phase. The achievement and maintenance of chemical equilibrium within and between the crystals in such rocks will be dependent on diffusion and, in the absence of deformation, presently available volume diffusion coefficient data for anhydrous conditions should be applicable. An extract of such data is given in figure 1 for the minerals and diffusing cations indicated in the figure; solid lines refer to the temperature range of the experiments involved and the dashed lines are extrapolations to lower temperatures. The numbers against each line indicate the

source of the data as given in the reference list at the end of the paper.

The approximate magnitude of the diffusion coefficient necessary to achieve and maintain equilibrium compositions in crystals may be calculated using the relation $D = x^2/t$ (Kingery et al. 1976, p. 226); where D is the diffusion coefficient, t is time, and x is distance. In figure 1 the horizontal lines show the D values appropriate to certain distances (in mm) and times (in Ma) according to the above equation, and the minimum temperatures necessary for these D values may therefore be determined from figure 1. Thus for pyroxene crystals figure 1 indicates that equilibration of Ca-Mg across a distance of 1mm (representing margin to core distance) in times ranging from 10 to 100 Ma will require temperatures approximately in the range 1050 to 950°C. It should be noted that the pyroxene D values (in figure 1) leading to these temperature estimates do not appear to be unreasonably small when the large number of 'null' experiments on pyroxene diffusion are considered (Freer et al., in press). Relative to this pyroxene data, figure 1 shows olivine Fe-Mg diffusion to be extremely fast. Of the two sets of Fe-Mg garnet data shown the low temperature extrapolated values of line 4 (Fig. 1) are in reasonable agreement with estimates based on natural rocks (Lasaga et al. 1977). Ca diffusion in garnets appears to be somewhat faster (Duckworth and Freer 1981). Little data is available for trivalent cations in silicates, but in spinels Al and Cr com-