lithosphere (Allegré 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 (v1 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 Archean Kaapvaal cration. 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 Kapvaal craton, but are not obvious in kimberlites within the craton.

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H20 DIFFUSION DATA AND THEIR BEARING ON THE INTERPRETATION OF MANTLE NODULES AND THE EVOLUTION OF THE MANTLE LITHOSPHERE.

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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 $D\!\approx\!x^2/t$ (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-



monly diffuse more slowly than divalent cations (Freer 1980).

For coarse ultramafic mineral assemblages the diffusion data suggests that major aspects of mineral chemistry will be unable to equilibrate in time periods of several hundred million years unless temperatures exceed about 900°C. Some divalent cation diffusion, such as Fe-Mg in olivine and probably in garnet will however be effective at lower temperatures. The rough guiding temperature of 900°C receives some support from the restricted transformations shown by coarse-grained anhydrous rocks in granulite facies crustal metamorphism (e.g. McLelland and Whitney 1980). Estimated geotherms for continental shields and platforms, and ocean basins (e.g. Clark and Ringwood 1964) indicate that temperatures around 900°C do not occur until significant depths beneath the Moho: the uppermost mantle lithosphere may thus contain largely frozen mineral compositions which are unlikely to yield consistent T-P data appropriate to their ambient T-P conditions. This conclusion provides a possible explanation for the commonly observed lack of ultramafic nodules which yield T-P estimates characteristic of the uppermost mantle lithosphere in stable tectonic regions.

The textures of the coarse ultramafic nodules often show little evidence of their petrogenetic history. Some preferred mineral orientation may occur, and there is the occasional occurrence of exsolution lamellae suggesting reasonably slow cooling at high temperatures. The temperatures estimated for the coarse rocks by various geothermometers (e.g. Carswell and Gibb 1980a) are dominantly in the range 1100 to 800°C. The overlap of this temperature range with the approximate minimum temperatures estimated above for diffusional equilibration suggests the strong possibility that many of the temperatures estimated by geothermometry are 'blocking' temperatures for diffusion in moderate to slow cooling. Carswell and Gibb (1980a, fig. 2) compare the estimated temperatures yielded by equilibria involving: two pyroxene Ca-Mg exchange, garnet-pyroxene Fe-Mg exchange, and garnet-olivine Fe-Mg exchange. In terms of the diffusion data of figure 1 the last of these equilibria may be expected to equilibrate at the lowest temperatures, and it is this geothermometer which yields the majority of temperature estimates below 900°C (Carswell and Gibb 1980a, fig. 2). This correlation must be treated circumspectly because of dependence of the extent of cation exchange on other factors (distribution coefficients, diffusion coefficient ratios and cooling rates) beside self-diffusion coefficients (Lasaga et al. 1977). However, we consider it most likely that the mineral compositions in many coarse nodules were frozen long before eruption, rather than being quenched in the rocks at the time of eruption. Thus many of these nodules may have been erupted from relatively shallow depths, and even from immediately beneath the Moho, in the upper mantle. These inferences provide an explanation for the relatively narrow ranges of temperature estimates obtained from coarse nodules.

It follows from the above arguments that the rocks occupying the uppermost mantle over a major part of the lithosphere must be the cooled relics of events dating back to a time when the mantle section converned was subjected to a major tectonothermal disturbance. This may have been connected either with the hot and dynamic environments associated with lithospheric plate boundaries or with a major intraplate thermal perturbation associated with igneous activity and/or lithosphere attenuation. Temperatures in excess of 800°C (the lowest geothermometry estimates for nodules) must have existed near the crust-mantle boundary at the time of the tectonthermal event concerned. Such temperatures are clearly a ceptable where the event has involved extensive basic - ultrabasic magmatism. In orogenesis, temperatures of 800°C and higher may occur at the base of the crust both with crustal thickening by magma addition (Wells 1980) and with tectonic crustal thickening (even without abnormal mantle heat flows -England 1978). The common occurrence of temperature estimates of 700 to 900°C for granulite facies rocks often believed to form the lower crust accords with the above considerations, as does the continuity of temperature estimates for alpine-type and mantlederived garnet peridotites (Carswell and Gibb 1980b).

Following from the above, it appears that the approximate compatability of T-P estimates of coarse nodules from kimberlites with the Clark and Ringwood (1964) shield geotherm (Boyd 1973; Carswell and Gibb 1980a) is partly a result of the coincidence of that portion of the geotherm concerned with the cooling temperatures imposed by diffusion. The low dT/dP slope given by the coarse nodule estimates may result from the differences in 'blocking' temperatures of T-dependent and P-dependent mineral equilibria, and the dependence of the P estimates on T estimates (Fraser and Lawless 1978).

The temperature estimates of 1200 to 1400°C given by the high temperature deformed peridotite nodules from kimberlites must have a generally different significance to the temperature estimates from coarse nodules. At the high temperatures indicated these deformed rocks would equilibrate rapidly (fig. 1) especially in the case of neoblasts with grain sizes around 0.1mm. Relatively rapid quenching of these rocks is therefore indicated, and this accords with an origin closely associated with eruption (Mercier 1979).

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