OLIVINE BAROMETRY IN THE SPINEL AND GARNET STABILITY FIELDS: PRECISION, ACCURACY AND A BASIN AND RANGE (USA) GEOTHERM

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Experimental calibration of the solubility of Ca in olivine coexisting with ortho- and clinopyroxene revealed a pressure effect (Finnerty and Boyd, 1978) that is useful for barometry in the garnet (ibid.) and spinel (Finnerty and Rigden, 1981) stability fields. The pressure effect and the original calibration were quantitatively confirmed by run reversals (Adams and Bishop, 1982). The contribution of ±10°C imprecision in temperature estimation, attainable with thermometers based on the pyroxene miscibility gap (Finnerty and Boyd, 1984), to imprecision in the pressure estimate is ±1.3 kbar. Calcium in olivine can be analyzed by electron microprobe with precision better than ±5% relative, contributing an additional ±1.8 kbar to the imprecision of the pressure estimate (±3.1 kbar total).

The accuracy of thermobarometers, obtained by combining the olivine barometer with a variety of thermometers, was tested by comparing P-T estimates for graphite- and diamond-bearing garnet lherzolite xenoliths from the northern Lesotho suite with stability fields of the two carbon polymorphs. Although the olivine barometer passes this accuracy test in combination with a variety of thermometers for the northern Lesotho suite (e.g. Fig. 1, Wells, 1977, thermometer vs. Finnerty and Rigden, 1981, barometer), it gives acceptable results only in combination with the Wells (1977) thermometer for spinel lherzolite xenoliths from alkali basalt at San Carlos, Arizona, USA. With the other thermometers tested, pressure estimates for some xenoliths are too low for spinel stability, or higher than the upper stability of the analyzed Cr-rich spinel (O'Neill, 1981). Even with the Wells thermometer, pressure estimates several kbar too high for spinel stability were obtained for some xenoliths from eastern China. The minerals in each xenolith are chemically homogeneous, indicating that disequilibrium is not the problem. The accuracy of the olivine barometer will most likely by improved by calibration experiments on compositions that more closely resemble those of the xenoliths.

Inflected geotherms observed for northern Lesotho and other kimberlite localities are not artifacts of the thermometer used (Finnerty and Boyd, 1984). The inflections cannot be artifacts of the barometer either because the inflections persist when the olivine barometer is used (Fig. 1). Although inflected geotherms probably do not characterize average upper mantle, they must be real and are most likely peculiar to sub-cratonic regions in which kimberlite liquid is being formed.

The spinel lherzolite xenolith suite from San Carlos basalt (erupted 5.3 ma ago, Holloway and Cross, 1978) yields a geotherm ranging from 940°C, 12 kbar (40 km) to 1070°C, 26 kbar (85 km), with a slope of ~8°C/kbar (3°C/km, Fig. 2). This gradient is similar to the slope of the Ca isopleths for the olivine barometer, but extends over a range much greater than can be attributed to imprecision in P-T estimation, and thus the gradient is significant. The San Carlos locality is near the border between the Colorado Plateau and the Basin and Range province, a region of extension, high heat flow and thin lithosphere. The lower depth limit of the San Carlos geotherm coincides with the 45 km crustal thickness estimated for the Colorado Plateau using Rayleigh wave dispersion and seismic refraction (Keller et al., 1979), and thus it appears that peridotite wall rock was sampled by the ascending magma from depths of 85 km up to the crust-mantle boundary at 40-45 km.

A steep thermal gradient (~23°C/km) is required between the surface and the shallow depth limit of the San Carlos geotherm. Characteristic geotherms calculated for depths to 30 km, constrained by observed high heat flows and assumed conductive heat transport, from steady state thermomechanical models for the Basin and Range province (Lachenbruch and Sass, 1978) intersect the San Carlos geotherm at the lower pressure limit (Fig. 2, heavy solid lines). The combined geotherm is similar to that which would be expected for a conductive thermal boundary layer overlying a region characterized by heat transport by convection or diapiric uprise (e.g. Schubert, 1979; Oxburgh and Parmentier, 1978). The unusually low shear wave velocity (~4.5 km.sec, Keller et al., 1979) for this region is suggestive of the existence of a small proportion of melt in the uppermost mantle beneath the Basin and Range province, although there is no evidence for a melt phase in the ultramafic xenoliths.

The San Carlos geotherm, geophysical observations and heat flow models are consistent with a model in which a diapir or convective upwelling emplaces hot mantle material against lithospheric crust. Melting induced in the ascending mantle rock by decreasing pressure produces basaltic magma, which transports ultramafic xenoliths to the surface. The thermal gradient in the uppermost mantle is small because heat is transported by mass movement, but is very steep in the overlying conductive crust. Thermal expansion, perhaps coupled with a temperature-induced transition from brittle to ductile rheological behaviour and silicic magmatism in the crust (e.g. Eaton, 1982), causes crustal extension and thinning.

O'Reilly and Griffen (1985) obtained a geotherm for garnet websterite xenoliths from basalts in southeastern Australia. The geotherm is steeper than that for San Carlos (Fig. 2, heavy dashed line), and thus does not require an abrupt change in slope in order to project to a reasonable surface temperature. The authors interpret the Australian geotherm in terms of convective heat transport, related to lithospheric thinning and diking of the crust by magmas, and infer that the seismic Moho coincides with the phase transition from spinel lherzolite to garnet lherzolite. Apparently, very different processes have operated in the Basin and Range province than in southeastern Australia. Thermobarometry of spinel lherzolite xenoliths from southeastern Australia and from other localities within the Basin and Ranges province and the Colorado Plateau will be needed to confirm the differences between the two regions.

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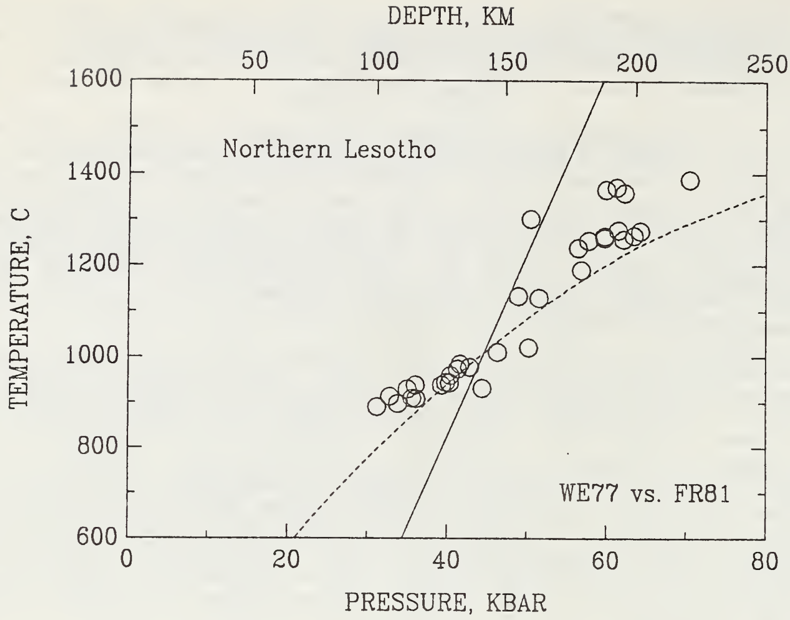

Fig. 1. Geotherm for garnet lherzolite xenoliths from northern Lesotho, southern Africa. Solid line represent the graphite to diamond transition. The dashed line is a calculated conductive geotherm for a cratoic setting.

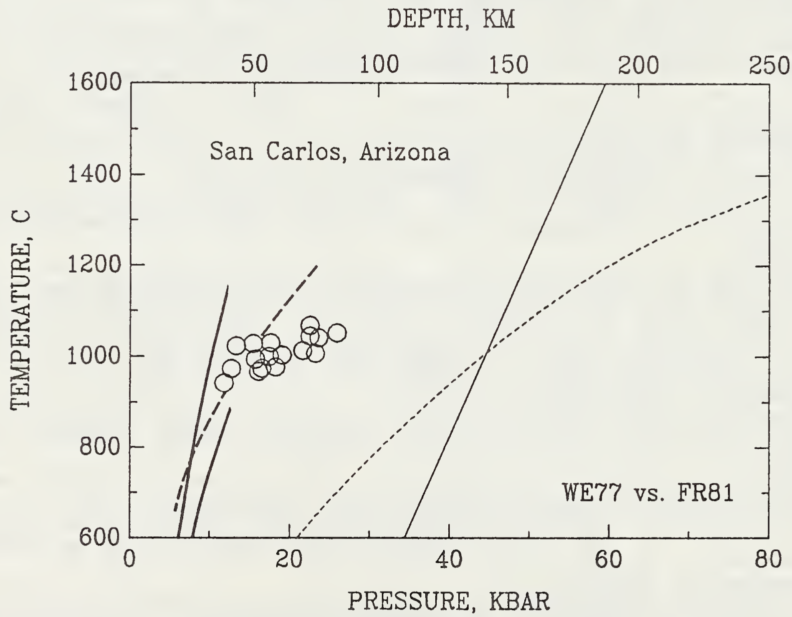

Fig. 2. Geotherm for spinel lherzolite xenoliths from San Carlos, Arizona. Heavy solid lines outline model conductive geotherms for average Basin and Range heat flows. Heavy dashed line represents garnet websterite geotherm for southeastern Australia.