DENSITY ESTIMATES OF MAGMAS AT HIGH PRESSURE, P.C. Hess, Dept. of Geological Sciences, Brown University, Providence, RI 02912

Several authors (1,2) have speculated that the density contrast between mantle peridotite, \( \rho^c \), and basic anhydrous magma, \( \rho^m \), should approach zero at some critical depth on terrestrial planets. If this were true, then the time scales for magma segregation would approach infinity, and magma could not segregate from the mantle under its own buoyancy. This mechanism could have created a global melt layer at depths of about 250 km that was the source for the Archean komatiites (2). Similar density caps might limit the depth from which the parental magmas for lunar mare basalts are derived.

Magma densities at high pressures have not been determined experimentally but have been estimated using a 3rd order Birch-Murnaghan equation of state with 1 atm isothermal bulk moduli as well as their pressure derivatives (1). Calculation of \( \rho^m \) to pressures of 40 kb'or greater obviously involve considerable uncertainty. The purpose of this abstract is to test the validity of the conclusion that \( \Delta \rho = \rho^c - \rho^m \) approaches zero between 40 to 80 kb for terrestrial basic to ultrabasic magma (1).

One simple test of the model that \( \Delta \rho \to 0 \) as \( (P_{kb}) \to 80 \) is to observe whether the \( dT/dP \) slope of congruent melting curves approach zero as pressure is increased. The \( dT/dP \) slopes of fusion curves for forsterite (3), fayalite (4), diopside (5), enstatite (6) and jadeite (7) are decidedly positive to pressures up to 50 kb, signifying that \( V^m > V^c \) or \( \rho^c > \rho^m \). Redetermination of the pressure correction for frictional losses and the temperature correction for the effect of pressure on the emf of the thermocouple(s) suggest that the slopes of the melting curves determined by (3), (4), and (6) are too low and that the true positive slopes are even larger. Extrapolation of these curves to higher pressures using Simon's equation indicate that \( \rho^c > \rho^m \) for pressures up to 100 kb. Since the major normative melt components are included above (except for \( CaAl_2Si_2O_6 \)) and since densities of magmas (at 1 atm) can be calculated from the partial molar volumes of the oxide components (8), it is cautiously concluded that \( \Delta \rho \) does not approach zero at pressures up to 50 kb and possibly to 100 kb.

A more quantitative estimate of the maximum densities of magmas at high pressures is to measure the densities of the glasses of temperature-quenched liquids. Below 15 kb, the density of glass is about 10% greater than the corresponding basalt melt but this reduces to an approximately 1% difference at higher pressures (14). If this is generally true, then liquid densities can be obtained within a few percent by measuring the densities of the quenched glasses. In any case, the density of the quenched glass must be larger than the melt and sets an upper limit to magma densities.

This appears to be a simple solution but unfortunately, tabulations of densities of glasses quenched from high pressures virtually are nonexistent. However, a number of empirical relations such as the Gladstone-Dale (G-S) law \( (n-1)/\rho = \text{constant} \) where \( n \) = index of refraction and relations deduced from classical dielectric theory such as Drude's (Dr) law \( (n^2-1)/\rho = \text{constant} \) correlate the index of refraction of the glass to its density. The constants, the specific refractivity for Gladstone-Dale and Drude constant, are functions of the bulk composition of the phase and not of \( P \) and \( T \) (9). These laws are limited to substances with a mean-atomic weight close to 21 (mean-atomic weight = molecular weight divided by the number of atoms in the chemical formula) and probably to densities below \( \rho = 4 \) (9).

Table 1 gives the densities of \( CaMgSi_2O_6 \), \( Ab_{150} \) and \( An_{68} \) glass quenched
from the temperature above the liquidus. Densities are calculated from both the G-S and Dr equations from \((10,11)\). Scarfe et al. \((12)\) found that the density of diopside glass quenched from 25 kb and 1725°C to be \(\rho = 3.00\) which compares favorably with \(\rho = 2.97\) calculated for 30 kb and 1710°C. Similar comparisons using NaAlSi3O8 glass at 25 kb and \(T \sim 1400°C\) yields \(\rho = 2.54\) (measured) and \(\rho = 2.51\) (calculated). It is concluded that the \(\rho\) obtained in Table 1 are probably accurate to ±2%. Thus the \(\rho\) of the glasses of two of the most important normative components of basalt indicate that the densities of the corresponding melts should be less than 3.0 gm/cm³ at pressures of <50 kb.

The same procedure is used to calculate the densities of olivine tholeiite melts quenched to glasses \((13)\) from the liquidus (Fig. 1). These calculated \(\rho\)'s are compared to experimentally measured \(\rho\)'s of glass and melt of a different but similar olivine tholeiite obtained at 1400°C \((14)\). The \(\rho\) of the two glasses are virtually the same, with the 1400°C sample slightly lower as expected from its higher quench temperature. Note that the \(\rho\) of the melt is only a few % lower than the glass at 20 kb. It is concluded that \(\rho\) of basaltic melts are about 10% less than mantle peridotite at 50 kb. Linear extrapolation indicates that \(\Delta \rho = \rho\) only at \(P > 80\) kb.

It is important to note that the increase in \(\rho^m\) with pressure is significant and cannot be ignored (see Hess, this volume).

References
(1) Stolper et al. \(1981\), JGR, 86, 6261-6271
(2) Nisbet, Walker, \(1982\), EPL, 60, 105-113
(3) Davis, England, \(1964\), JGR, 68, 1113-1113
(4) Akimoto et al. \(1967\), JGR, 72, 679-686
(5) Williams, Kennedy, \(1969\), JGR, 74, 4359-4366
(6) Boyd et al. \(1964\), JGR, 69, 2101-2109
(7) Williams, Kennedy, \(1970\), Am. J. Sci., 269, 431-488
(9) Anderson, Schreiber, \(1965\), JGR, 70, 1462-1471
(10) Boyd et al. \(1963\), JGR, 68, 311-323