

## 5. Chemical compositions of liquids formed by equilibrium partial melting of pyrolite under water-saturated conditions

### 5.1. Compositions of quenched glasses and equilibrium liquids in experimental runs at 10 kb

#### 5.1.1. 10 kb, 1200°C

The experimental run at 10 kb, 1200°C showed excellent partial melting texture with euhedral olivines (~50%) and uncommon, small chromite crystals in glass. No evidence for quench amphibole or clinopyroxene was found by either optical or X-ray powder diffraction examination. Because of the simplicity of the run products it is possible to deduce a great deal about both the equilibrium partial melting of pyrolite at 10 kb and 1200°C under water-saturated conditions, and about the nature of the quenching process in recovering the sample for petrographic study. While the optical, microprobe and X-ray diffraction identification of quench amphibole and clinopyroxene in lower temperature runs at 10 kb and in runs at 20 kb casts immediate doubt on the glass compositions as those of an equilibrium liquid, this does not obviously apply to the 10 kb, 1200°C and 10 kb, 1100°C runs. Thus these two runs were examined in detail as test cases to establish whether the nature of liquids derived by partial melting of peridotite could be directly determined from the composition of quenched glasses.

Analyses of glass using both stationary beam (giving low Na<sub>2</sub>O values of 0.4% due to volatilization) and with the electron beam kept continually in motion during analysis within larger "pools" of glass (giving higher Na<sub>2</sub>O values of 1.4% but very similar values for other elements) showed that the glass is of high SiO<sub>2</sub> and Ca, and low Mg and Fe character. The glass is strongly quartz normative (20%) and could be broadly classed as andesitic. However the compositions given in tables 1 and 2 show that it is not possible to obtain a mass balance for the original bulk composition of the charge (table 1) if magnesian olivine (table 2, columns 1 or 2) and glass (table 2, column 6) are the only phases present.

The presence of reverse zoning in some large olivine crystals, and analyses of the bulk composition of the run demonstrate that about 30% of the original iron was lost from the sample to the Ag<sub>50</sub>Pd<sub>50</sub> capsule. If this effect is allowed for and a mass balance is attempted using the bulk composition of column 8, table 2 it can be shown that 56% olivine (column 2), 43% glass (column 6), and 1% chromite (column 5) gives reasonable agreement for SiO<sub>2</sub>, TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, CaO and K<sub>2</sub>O but gives high MgO and low FeO figures. Careful analysis of the outer rims of olivine crystals reveal Fe-concen-

trations higher than those in the glass or within the olivine crystals. Analyses of such margins, when corrected for admixture of glass by use of the Ca, Al and Ti contents, yield compositions consistent with thin borders of Fe-rich olivine (e.g. column 3, table 2) as quench outgrowth on the primary crystals. Further evidence for non-equilibrium between glass and olivine crystals is provided by data on Fe/Mg partition between olivine and liquid [21, 22] which predicts that a liquid in equilibrium with olivine (Fo<sub>93</sub>) should itself have 100 Mg/(Mg + Fe<sup>++</sup>) ~ 80. The analysed glass has an Mg-value of 64 (table 2). It is considered that the evidence presented establishes the presence of quench outgrowths of more Fe-rich olivine on the primary crystals, resulting from partial crystallization of the equilibrium liquid during quench cooling. The composition of the residual glass is thus not that of the equilibrium liquid.

Although it has been shown that, even in the deceptively simple run products at 10 kb and 1200°C, it is not possible to determine the composition of the partial melt directly, it remains possible to *calculate* the equilibrium liquid composition by allowing for the effects of iron loss and using the empirically determined partition coefficient between Fe/Mg in olivine and liquid [21, 22]. Residual chromite (1%) will contain most of the chromium in the charge. Knowing the equilibrium olivine composition (Fo<sub>93</sub>) and bulk composition Mg-value of 89.7 after the run and the bulk composition Mg-value of 85.2 before the run, the equilibrium olivine composition, *had there been no Fe-loss*, can be calculated and is Fo<sub>90.1</sub> (column 4, table 2). From the Fe/Mg partition relation for olivine: liquid equilibrium [21, 22], the liquid in equilibrium with olivine of composition Fo<sub>90.1</sub> has 100 Mg/(Mg + Fe<sup>++</sup>) = 73.5. Assuming olivine (Fo<sub>90.1</sub>) chromite (1%) and liquid are the only equilibrium phases in the pyrolite composition at 10 kb and 1200°C, then the charge would be about 54% molten and the liquid would be of composition similar to that in table 2 (column 9) and would be classed as a magnesian, quartz-rich tholeiite (5–7% normative quartz depending on whether Fe<sub>2</sub>O<sub>3</sub> = 0 or 1.5%, respectively). There is a small uncertainty in calculating 100 Mg/(Mg + Fe<sup>++</sup>) of the equilibrium liquid because change in the oxidation state may occur during the run. Analyses for Fe<sup>++</sup> and Fe<sup>+++</sup> for runs in Ag<sub>50</sub>Pd<sub>50</sub> capsules indicate a decrease in Fe<sub>2</sub>O<sub>3</sub>/FeO during runs [23]. In table 2 (column 9) the calculated 100 Mg/(Mg + Fe<sup>++</sup>) value assumes no change in Fe<sub>2</sub>O<sub>3</sub> content and the 100 Mg/(Mg + ΣFe) value assumes all Fe<sup>+++</sup> reduced to Fe<sup>++</sup>. The value for a liquid in equilibrium with Fo<sub>90.1</sub> is 100 Mg/(Mg + Fe<sup>++</sup>) = 73.5 and lies between those values obtained using the assumptions on Fe<sup>+++</sup> discussed above.

From the data in table 2, it is inferred that a liquid produced by 32.5% melting of pyrolite (i.e. 54% melting of pyrolite minus 40% olivine) under water-saturated conditions would have a composition very similar to that of column 9, table 2, leaving residual olivine (Fo<sub>90.1</sub>) and a trace of chromite. The liquid would be a magnesian quartz tholeiite (5–7% quartz). Since olivine is the dominant residual phase, liquids

would become less quartz-normative and then become olivine normative with higher degrees of melting.

### 5.1.2. 10 kb, 1100°C

Optical examination of this run resulted in identification of euhedral olivine and clinopyroxene in a glassy matrix. Tentative identification of rare tabular crystals, with straight extinction and low birefringence, as orthopyroxene [12] was not confirmed by electron microprobe examination which identified only olivine ( $Fo_{89.8}$ ) and low alumina, chrome diopside ( $Ca_{42}Mg_{52}Fe_6$ ). A liquid in equilibrium with olivine of this composition has 100 Mg/(Mg +  $Fe^{++}$ )  $\approx$  73 [21, 22] and this is much higher than the Mg-value of the glass (table 3). As in the 1200°C run, the composition of the glass, which is very similar to that at 10 kb and 1200°C, is considered to result from rapid metastable growth of crystalline phases during quenching. As there are two crystalline phases present, it is not possible to use the data on bulk composition, mineral composition and Mg/Fe partition between olivine and liquid, to calculate the equilibrium liquid composition without specifying the relative proportions of olivine and clinopyroxene. Optical, X-ray and microprobe examination shows that clinopyroxene is a very minor phase relative to olivine.

Analysis of the bulk composition showed slight Fe-loss, taking the Mg-value from 85.2 to 86.4. Thus the composi-

tion of the equilibrium olivine, assuming no Fe-loss, is calculated as  $Fo_{89.0}$  rather than  $Fo_{89.8}$  (table 3). A liquid in equilibrium with olivine ( $Fo_{89.0}$ ) has 100 Mg/(Mg +  $Fe^{++}$ )  $\approx$  71 [21, 22]. In table 3, column 5, the composition of a liquid is calculated by assuming 47% melting of (pyrolite - 40% olivine) and a residual mineralogy of 49% olivine (cf. 45% at 1200°C), 1% chromite, and 3% clinopyroxene. The liquid has an Mg-value of 69.5 - 74, depending on the assumed oxidation state.

The composition of the liquid formed by partial melting of pyrolite at 10 kb 1100°C under water-saturated conditions cannot be specified uniquely by direct melting studies but the composition given in column 5 of table 3 must be a close approximation to the melt composition. It differs from the melt at 10 kb 1200°C in its higher  $SiO_2$  content and in lower Ca/Al, lower MgO and higher  $TiO_2$  and  $K_2O$  contents, and has 9-11% normative quartz (i.e. it may be classified as a basaltic andesite composition). Liquids of this character would be produced by ~28% partial melting of pyrolite leaving clinopyroxene-bearing dunite (olivine ( $Fo_{89}$ ) + chrome diopside + accessory chromite) as residue. The absence of orthopyroxene as a residual phase for these conditions is noteworthy. Orthopyroxene would become even less

TABLE 3

	Analyzed olivine	Calculated olivine	Analyzed clinopyroxene	Glass	Calculated equilibrium liquids derived from initial composition less (49% Ol ( $Fo_{89}$ ) + 1% chromite + 3% Cpx).
$SiO_2$	41.5	40.7	54.0	61.6	56.1
$TiO_2$	-	-	0.4	1.6	2.5
$Al_2O_3$	-	-	1.3	16.3	12.4
$Fe_2O_3$	-	-	-	-	1.7
FeO	9.8	10.7	3.6	3.7	5.8
MnO	-	-	0.1	0.1	0.1
MgO	48.2	48.5	18.8	3.2	9.3
CaO	0.2	0.1	20.5	11.2	9.5
$Na_2O$	-	-	0.2	>1.5	2.0
$K_2O$	-	-	-	0.9	0.5
$Cr_2O_3$	-	-	1.4	-	0.1
" $H_2O$ "				(12.5)	
100 Mg	89.8	89.0	90.4	-	74
Mg + $Fe^{++}$					
100 Mg	89.8	89.0	90.4	60.3	69.5
Mg + $\Sigma Fe$					

Run conditions: 10 kb, 1100°C, 1 hr,  $Ag_{50}Pd_{50}$  capsule. 100 Mg/(Mg +  $\Sigma Fe$ ) of sample after run: 86.4.