

EXPERIMENTAL MELTING STUDIES ON A MODEL UPPER MANTLE COMPOSITION AT HIGH PRESSURE UNDER WATER-SATURATED AND WATER-UNDERSATURATED CONDITIONS

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The solidus of a model pyrolite composition is sensitively dependent on water content and has been determined experimentally up to 40 kb, for water-saturated (6% H₂O) and water-undersaturated (0.2% H₂O) conditions. Pargasitic hornblende is a major subsolidus phase to 29 kb and its breakdown at higher pressure has the effect of sharply depressing the solidus for (pyrolite + 0.2% H₂O) from ~1150°C to ~1020°C between 25 and 29 kb. Experiments have been carried out above the solidus to determine the nature of the partial melting process, particularly the nature and composition of the residual phases at a specific pressure, temperature and water content. The presence of siliceous (>58% SiO₂), low-magnesium glasses, broadly of andesitic or dacitic character, in experiments quenched at both 10 kb and 20 kb, is shown to be due to growth during quenching of olivine, clinopyroxene, amphibole and mica. However, it is possible in some experiments to use the compositions of the starting mix and analyzed residual phases to calculate the composition of the *equilibrium liquid* and degree of melting at the particular condition. High degrees of melting under water-saturated conditions at 10 kb yield magnesian, quartz-normative basaltic andesites ~10% Qz, (1100°C, 28% melting) to quartz tholeiite magmas 5-7% Qz, (1200°C, 32.5% melting), and at 20 kb, yield olivine tholeiite magmas (1100°C, 27-30% melting). Andesitic or dacitic magmas are not products of equilibrium partial melting of pyrolite at $P > 10$ kb under water-saturated conditions but may be derived from parental olivine-poor tholeiites, quartz tholeiites or basaltic andesites ($P < 10$ kb) by crystal fractionation. Parental magmas of the island arc tholeiitic magma series may originate by partial melting of upper mantle peridotite (pyrolite or residual peridotite of the lithosphere) under water-saturated conditions at ~5-20 kb.

1. Introduction

In a recent paper, Kushiro et al. [1] report the results of experimental melting [7] of a peridotitic composition (Iherzolite inclusions from Salt Lake Crater, Hawaii) at 20 kb and 26 kb under water-saturated conditions (30% H₂O). With high degrees of melting (~20%), glass was obtained among the run products, together with olivine, orthopyroxene and clinopyroxene. The compositions of the latter phases were quite different from those of the starting material, providing evidence that reaction to a new equilibrium assemblage has occurred under the experimental conditions. The composition of the glass, analyzed by electron microprobe, was high in SiO₂, Al₂O₃ and CaO and also apparently contained ~13% H₂O. The authors noted

that their glass composition was broadly andesitic or dacitic in character and not basaltic. These experimental data were thus taken to support models of direct derivation of siliceous magmas (>55% SiO₂) by partial melting of mantle peridotite under water-saturated conditions [1, 8, 9].

In this laboratory, melting experiments on a model pyrolite composition under water-saturated conditions yielded very similar data to those described above. However, it can be shown that the glass obtained is metastable, with a composition determined by growth of quench amphibole, mica olivine and pyroxene, and does not correspond to the composition of a liquid in equilibrium with olivine, orthopyroxene and clinopyroxene. The data presented in this paper support and are complementary to studies by Nicholls and Ringwood

[2] which have shown that quartz-normative liquids (including quartz tholeiite, andesite, dacite) do not have olivine as a liquidus phase at pressures > 20 kb, even for water-saturated conditions, and thus cannot be direct partial melts of a peridotitic source rock.

2. Experimental methods

Experiments were carried out in a piston-cylinder apparatus using welded Ag₇₅Pd₂₅ and Ag₅₀Pd₅₀ sample capsules containing known quantities of water. The composition investigated was a model pyrolite [4] as shown in analysis 1, table 1. To diminish the dominance of olivine and consequent high proportions of crystals to liquid under conditions of partial melting, a composition equivalent to pyrolite minus 40% olivine (Mg_{91.6}Fe_{8.1}Mn_{0.1}Ni_{0.2}) was used in all experiments [5, 6]. Sample weights of 15 mg were used with a water content of 10%. The water was added by microsyringe and checked by weighing before and after welding. With such a large water content, piercing of the capsule after the run yielded small droplets of water and drying of the opened sample at 110°C showed that 7–9% water was 'free' after quenching of the sample. These techniques also readily identified any runs in which capsule failure has caused loss of water.

TABLE 1

Compositions of pyrolite [16] and pyrolite minus 40% olivine (Olivine of composition Mg_{91.6}Fe_{8.1}Ni_{0.2}Mn_{0.1}). The latter composition is that used in experimental runs

	Pyrolite	Pyrolite minus 40% olivine	Spinel lherzo- lite Kushiro et al. [1, 7]
SiO ₂	45.2	47.8	48.3
TiO ₂	0.7	1.2	0.2
Al ₂ O ₃	3.5	5.9	4.9
Fe ₂ O ₃	0.5	0.8	—
FeO	8.0	8.2	10.0
MnO	0.1	0.1	0.1
MgO	37.5	28.7	32.5
CaO	3.1	5.1	3.0
Na ₂ O	0.6	0.95	0.7
K ₂ O	0.13	0.22	0.07
P ₂ O ₅	—	—	—
Cr ₂ O ₃	0.4	0.7	0.3
NiO	0.2	0.2	—
<u>100Mg</u>			
Mg + Fe ⁺⁺	89.2	86.5	85.2
<u>100Mg</u>			
Mg + ΣFe	88.9	85.2	85.2

As there is > 10% olivine present in all experiments reported in this paper, the water content of 10% added to the olivine-depleted pyrolite is equivalent to an experimental study of standard pyrolite with 6% water added. In addition to experiments with excess water, the pyrolite solidus and melting relationships for $p_{H_2O} < P_{total}$ were determined using a composition (pyrolite minus 40% olivine plus 0.3% H₂O) equivalent to (pyrolite plus 0.2% H₂O). In studying the water-undersaturated melting relationships in pyrolite it is necessary to add accurately the very small quantities of water. To overcome the weighing error and practical difficulty of weighing or micropipetting 0.03 mg H₂O to a 10 mg sample, large capacity runs [100 mg (pyrolite minus 40% olivine) + 0.3 mg H₂O] were carried out at 15 kb, 1000°C for 6 hr. This produced fine-grained assemblages of olivine + amphibole + pyroxenes in which the water is locked in amphibole. This material was finely ground and mixed, and 10 mg portions were re-run under various *P*, *T* conditions using sealed Ag₇₅Pd₂₅ Ag₅₀Pd₅₀ or Pt capsules (Pt at *T* > 1250°C at 30 kb or *T* > 1150°C at 5 kb). The experimental method is equivalent to a study of pyrolite + 0.2% H₂O, or, in mineralogical terms, of hornblende peridotite containing 15–20% pargasitic hornblende (compared with a maximum pargasitic hornblende content of about 30% for pyrolite composition [12] with excess water and subsolidus conditions at about 10 kb).

Experimental charges were examined microscopically in transmitted light and polished mounts were also prepared. The latter method enabled close observation of the textures of melting and subsolidus runs, the recognition of glass by its low reflectivity and interstitial habit, the distinction between quench and primary phlogopite, and the recognition of abundant and evenly distributed gas-phase bubbles. Solid phases were analyzed using an electron microprobe and non-dispersive X-ray analytical system, based on the TPD microprobe [10]. Full details of the instrument and analytical procedures will be described elsewhere by Reed and Ware [30]. Conditions of analyses are as described previously [11] but several features of this instrument are particularly important for the present investigation. Firstly, the specimen current of 3–5 nA is an order of magnitude lower than that for most electron microprobe systems but in spite of this, careful investigation by I.A. Nicholls showed that highly siliceous and water-rich glasses suffered specimen damage and Na-volatilization by the electron beam during 100 sec analysis-time at each point. Thus the analyses of glass were carried out, where possible, by continuously moving the beam on an area of glass or by counting for 10 sec on each of 10 glass spots. This resulted in an increase of apparent Na content from ~ 0.5% to 1.5% Na₂O but it is recognized that these figures may still be low. It was possible to analyze simultaneously for Na, Mg, Si, P, K, Ca, Ti, Cr, Mn, Fe at each point and this permitted the identification and analysis of quench amphibole and quench clinopyroxene, as well as primary phases. The analytical method also identified real compositional variations within the glass, although for such "point" analyses, Na-figures are not reliable. In the TPD instrument the high quality optics and ability to view the sample while