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Experimental petrology of peridotites, basalts and C,H,O–a window on the Earth's upper mantle

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For over 50 years the use of high pressure piston/cylinder apparatus combined with an increasing diversity of microbeam analytical techniques has enabled study of mantle peridotite compositions and of magmas derived by melting in the upper mantle. The experimental studies are guided by the petrology and geochemistry of peridotites from diverse settings and by the remarkable range of mantle-derived magma types. Water and carbon (as carbon dioxide, carbonate, diamond or graphite, or methane) exercise major controls on the mantle melting behaviour. The phase relationships of lherzolite + H_2O explain the Lithosphere/Asthenosphere rheological contrast essential for thin plate tectonics. Recent experimental study using FTIR spectroscopy to monitor water content of minerals has shown that fertile lherzolite (MORB-source upper mantle) at $\sim$1000°C can store 200 ppm H_2O in defect sites in nominally anhydrous minerals (NAMs) (olivine, pyroxenes, garnet, spinel). Higher water contents stabilise pargasite at <3GPa. The hydrous mineral pargasite is the major site of H_2O-storage in the fertile uppermost mantle lherzolite but pargasite is unstable at pressure (P) >3 GPa (>90-100 km depth) causing a sharp drop in water storage capacity from >2000 to $\sim$200 ppm. Water in excess of 200 ppm appears as an aqueous vapour phase at >3 GPa, 1000°C. The vapor-saturated solidus (water-rich vapor) of fertile lherzolite increases in temperature (T) from a minimum of 970°C at 1.5 Gpa, through 1010°C at 2.5 GPa, 1210°C at 4GPa and 1375°C at 6 GPa. Both immediately below and above the solidus, the H_2O-content in residual lherzolite is $\sim$200 ppm retained in NAMs at 2.5 and 4 GPa. Because of pargasite stability, the solidus at <3 GPa is the dehydration or vapour-undersaturated solidus for small H_2O-contents (<4000 ppm approximately). This solidus temperature decreases sharply at $\sim$90 km (3 GPa) depth and the vapour-undersaturated solidus of fertile lherzolite provides the basis for understanding the asthenosphere and source regions for MORB and intraplate magmas.
In oceanic intraplate settings, the geotherm passes from subsolidus pargasite-bearing lherzolite to garnet lherzolite with incipient melting, creating the rheological boundary between Lithosphere and Asthenosphere. The Asthenosphere becomes geochemically zoned with the 'enriched' intraplate basalt source (>500 ppm H_2O) overlying the 'depleted' MORB source ($\sim$200 ppm H_2O). From the study of liquidus temperatures of primitive MOR picrites and their conditions of segregation from residual peridotite, the modern mantle potential temperature for MORB petrogenesis is $\sim$1430°C. The intersection of the 1430°C adiabat with the vapour-saturated lherzolite solidus at $\sim$230 km suggests that upwelling beneath mid-ocean ridges begins around this depth. Upwelling for intraplate magmas begins from shallower depths and lower temperatures but the upwelling lherzolite is enriched in water, carbonate and incompatible elements. Magmas from olivine melilitites, olivine nephelinites, basanites, alkali-picrites to tholeiitic picrites are consequences of increasing melt fraction and decreasing pressure at melt segregation in diapiric upwelling from the upper part of the asthenosphere.