Orthopyroxene and the Ocean Crust

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Orthopyroxene is normally a minor constituent of the ocean crust. In mid-ocean ridge basalt (MORB), orthopyroxene crystallizes after olivine, plagioclase and clinopyroxene, at Mg numbers ($Mg/(Mg+Fe^{2+})$) less than about 70, very late in the crystallization sequence. Only in arc boninites is orthopyroxene a primary liquidus phase. These lavas do not occur at mid-ocean ridges.

There is a problem in the MOR lower crust however. In recent years, there have been several observations of primitive orthopyroxene-bearing lower crustal gabbros and gabbronorites with Mg#>80. The localities include the East Pacific Rise at Pito Deep (Perk, et al 2007) and at Hess Deep (Gillis et al., 2013), the FAMOUS area of the Mid-Atlantic Ridge (Nonotte, et al 2005). These are are neither crystallized from associated basalts, nor from any known MORB composition (Nonotte, et al, 2005). Crystallization experiments of MORB have not produced such primitive gabbronoritic assemblages, nor can reasonable theoretical models of MORB (using e.g. MELTS). Neither of the existing explanations: hydrous partial melting of a harzburgitic mantle body by water of unknown non-subduction origin (Nonotte et al, 2005) nor shallow equilibration of melts with upper mantle (Gillis et al 2013) makes much sense.

There are now two further plausible solutions. First, our conception of the ~10% mantle partial melting process for primitive MORB is based only on the most primitive erupted lavas, a kind of circular reasoning. At high potential temperatures corresponding to ~20% adiabatic partial melting, orthopyroxene is driven higher on the liquidus of the resulting aggregate melt, sufficient to explain the gabbronorites. The result however is an ocean crust 12-15 km thick. Large Igneous Provinces (LIPs) may be that thick but so far no known samples of LIP lower crust exist.

A better explanation is a mantle assimilation fractional crystallization (AFC) process (see Sen et al, this meeting) where a primitive MORB dissolves upper mantle while crystallizing just at the crust-mantle interface. The resulting AFC solid line of descent produces a noritic olivine-orthopyroxene sequence. The spinel co-crystallized from this reaction series also shows dramatic enrichment in Cr and Ti once plagioclase enters the AFC assemblage.

This reaction also explains the Ti enrichment in plagioclase bearing abyssal peridotites, a ubiquitous feature of oceanic matle rocks. Also as a non-hydrous model for gabbronorite formation it removes the necessity for subduction to explain the existence of gabbronorites in the lower crust of ophiolites.