

KOMATIITE GENESIS IN THE ARCHAEN MANTLE, WITH IMPLICATIONS FOR THE TECTONICS OF ARCHAEN GREENSTONE BELTS; D. Elthon, Lunar and Planetary Institute, 3303 NASA Rd.1, Houston, TX 77058 and Department of Geosciences, University of Houston — University Park, Houston, TX 77004.

The presence of ultramafic lavas (komatiites) associated with Archaen greenstone belts has been suggested to indicate very high increments (50-80%) of partial melting of the Archean mantle [e.g., 1-3]. Such extensive melting of the Earth's mantle during the Archaen might have profound effects on the early tectonic and chemical evolution of the planet [e.g., 4 & 5], although problems associated with keeping the komatiite liquid in equilibrium with the residual mantle at such high increments of melting has cast doubt upon aspects of extensive melting [e.g., 6 & 7]. Two important aspects of the origin of komatiites are discussed below.

I. WHAT IS THE NATURE OF PRIMARY KOMATIITE LIQUIDS?

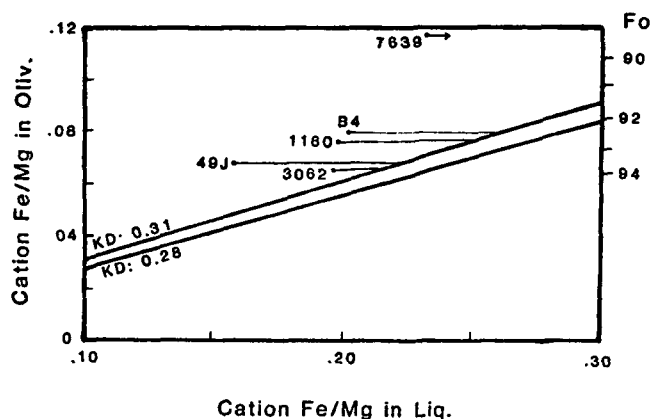
One of the most fundamental aspects of understanding the tectonic and geochemical mode of origin for komatiites is the problem of komatiite primary magmas. The identification of primary komatiite magmas is complicated by the extensive metamorphism that these rocks have typically undergone and by olivine (+ minor spinel) crystallization at low pressures (~1 atm). The crystallization of olivine rapidly depletes a komatiite liquid in MgO, such that the most likely candidates for primary magmas are those with the highest MgO contents.

Previous efforts to evaluate primary komatiitic liquids have proposed that they might contain as much as 33% MgO [2] or 30% MgO [8]. These studies have relied principally on comparison of the compositions of olivines crystallized in high-pressure experimental studies of komatiites with relict olivines found in komatiites (as high as Fo₉₄).

The Fe-Mg exchange between olivine and basaltic-komatiitic liquids has recently been summarized by [9], in which they present equations for calculation of olivine-liquid equilibria over a wide temperature (1074-1600°C) and pressure (1 atm to 25 kbar) range. The KD values for a wide range of komatiites (>20% MgO) were calculated using this equation and range from 0.28 to 0.31 at temperatures of 1450-1650°C at 1 atm. This olivine-liquid equilibrium is shown in Fig. 1 along with the compositions of the most magnesian olivines in komatiites (olivine and komatiite compositions from [8] and references therein). The 1 atm KD values have been used here because the present author considers it most likely that the olivines in komatiites have crystallized at very low pressures (~1 atm); previous investigators [2 & 4] have used KD values from high pressure experiments, which are substantially higher [10 & 11].

The data shown in Fig. 1 (horizontal lines connect the olivine compositions with the liquid from which they could have crystallized) indicate that the komatiite olivines probably have crystallized from liquids with Fe/Mg >0.230. This Fe/Mg (0.230) corresponds to 22-25% MgO in the komatiites, depending upon the FeO content of the liquid. This data indicates that the most magnesian olivines in komatiites could have crystallized from liquids with 22-25% MgO, in contrast to previous estimates of 30-33% MgO. These liquids will have liquidus temperatures of ~1500°C at 1 atm pressure. More MgO-rich komatiites have probably become enriched in MgO as a consequence of olivine accumulation and/or Mg metasomatism.

Fig. 1
Cation Fe/Mg
in olivine
versus cation
Fe/Mg in the
liquid. The
horizontal
lines connect
the composition
of olivines
in komatiites
with liquids
in equilibrium
with these
olivines.



II. WHAT PERCENTAGE OF MELTING IS REQUIRED TO PRODUCE KOMATIITES?

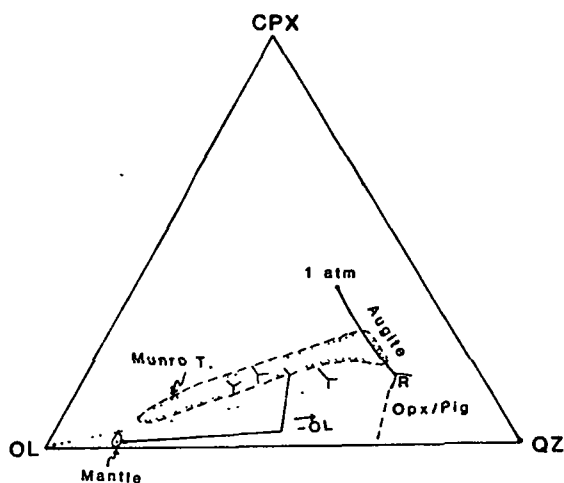
As noted above, it is generally assumed that a very high increment of melting (50–80%) is required in order to generate komatiites from the Earth's mantle. Experimental studies of the melting of reasonable mantle compositions have shown that very magnesium-rich magmas may be produced at high increments of melting [e.g., 11–13]. As outlined below, however, these MgO-rich magmas produced by very large increments (40–80%) of melting within the mantle are NOT komatiites.

A pseudo-liquidus phase diagram for evaluating the petrogenesis of komatiites is shown in Fig. 2. At low pressures (1 atm), some magmas (those above the OL-R join) will crystallize augite as the first pyroxene and others (those below the OL-R join) will crystallize pigeonite or orthopyroxene first. Field and petrographic studies of komatiites have shown that they crystallize augite as the first pyroxene in virtually all instances. Most terrestrial magmas also crystallize augite as the first pyroxene; boninites are an obvious exception. Also shown in Fig. 2 is the field for the compositions of komatiites from Munro Township, which crystallize augite as the first pyroxene [14].

A partially schematic melting path for melting of the mantle is shown in Fig. 2 for melting at 15 kbars. At small to moderate increments of melting (<30%), the primary liquids will lie above the OL-R join, but will lie below the OL-R join at larger increments of melting. The extent of melting required to produce primary magmas below the OL-R join will vary as a function of the composition of the mantle and the pressure of melting, but it is clear that high increments of melting that might produce dunite or OPX-poor harzburgite residues will produce primary magmas that will lie below the OL-R join and will evolve to crystallize orthopyroxene and/or pigeonite before augite. The extent of melting most likely to produce komatiitic magmas is more like 20–25% rather than the 50–80% previously proposed. Although not discussed by the previous authors, this feature is further apparent in the data of [12 & 13].

Spinel from komatiites have Cr/(Cr+Al) from 0.70 to 0.80 [15], which would suggest a slightly higher increment of partial melting of the mantle that occurs in the present-day suboceanic mantle [16], rather than the much higher increments proposed in previous studies.

Fig. 2
Pseudo-liquidus phase diagram
projected from plagioclase [17].
Pseudo-invariant points at
1 atm (R), 10, 15, 20
and 25 kbars are
shown.



In summary, it is suggested that the extent of partial melting that produces komatiite primary magmas is ~20-25% and that these magmas have 22-25% MgO or less. This substantially lower estimate for the extent of melting and eruption temperatures will certainly influence those tectonic characteristics of greenstone belts associated with the dynamics of mantle upwelling and convection.

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