

Dating of zircon from Ti-clinohumite-bearing garnet peridotite: Implication for timing of mantle metasomatism: Comment and Reply

COMMENT

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Katayama et al. (2003) dated zircon in some ultramafic rocks dominated by garnet and titanite clinohumite (hereafter Ti-clinohumite rocks) from the Kokchetav ultrahigh-pressure (UHP) metamorphic terrane, and interpreted that the zircon cores formed in the mantle in the Proterozoic and the zircon overgrowths formed as a result of UHP metamorphism and mantle metasomatism by slab-induced fluids/melt during the early Paleozoic. However, the data presented in this and their foregoing papers (Muko et al., 2002; Okamoto et al., 2000) cast considerable doubt about their interpretation and conclusions.

Metasomatism of mantle peridotite by crustal materials adds Si (and conceivably Ti, Al, Fe, Ca, Na, K, and large ion lithophile elements), and removes Mg (and conceivably Cr, Ni, and Co). The mantle metasomatism proposed by Katayama et al. (2003) does not explain why the rocks are even more depleted in Si, Na, and K than garnet peridotites (Muko et al., 2002) (Fig. 1), or how the enormous amount of Al, an element known to be relatively immobile in fluid and melt, could be added into a peridotite to produce abundant garnet. Garnet rims in the Kokchetav Ti-clinohumite rocks are significantly higher in Mg relative to the cores (Muko et al., 2002), suggesting that the rocks were enriched in Mg rather than Fe before or during UHP metamorphism.

Katayama et al. (2003) suggested that large amounts of Ti and other high field strength elements (HFSE) were added into a peridotite protolith by metasomatism, based on the experiments by Iizuka and Nakamura (1995) at 80 kbar. The pressure estimates for the Kokchetav UHP rocks are mostly ≤ 60 kbar, although Okamoto et al. (2000) argued for ≥ 60 kbar. At these conditions, fluid derived from crustal materials is not enriched in Ti but in Si, causing olivine to transform into pyroxene (Iizuka and Nakamura, 1995). The high HFSE and H₂O contents in Ti-clinohumite rocks do require metasomatism, but not necessarily of garnet peridotite in the subduction zone. In contrast, Scambelluri and Rampone (1999) demonstrated that the Ti-clinohumite-bearing rocks from western Liguria (Italy) were derived from Fe-Ti gabbros by Mg metasomatism in an oceanic crust and subsequent high-pressure metamorphism. A Ti-clinohumite rock similar to the Kokchetav ones occurs in the Chinese Su-Lu UHP metamorphic terrane (Yang, 2003). In terms of MgO, CaO, Fe₂O₃, and Al₂O₃ compositions, the Ti-clinohumite rocks are intermediate between ultramafites and unaltered Fe-Ti gabbros (Fig. 1). Mg metasomatism of a Fe-Ti gabbroic protolith by fluids from a contacting mantle-derived ultramafic rock in the crust may explain the enriched feature of Ti (and other HFSE), Fe, Al, Mg, Cr, Co, Ni, and volatiles and the depleted feature of Si, Ca, and Na in the Su-Lu Ti-clinohumite rock (Yang, 2003). Subsequent UHP metamorphism at a mantle depth transformed the altered gabbro into assemblages characterized by garnet + Ti-clinohumite + pyroxene + zircon + apatite. It is likely that similar chemical and tectonic processes took place in the Kokchetav Ti-clinohumite rocks, because these also better explain their chemical features.

The Proterozoic zircon cores are interpreted by Katayama et al. (2003) to have formed at depths where plagioclase or spinel was stable. The zircon cores contain high U and some also contain high Th (Table 1 in Katayama et al., 2003), suggesting that they may have formed in crustal materials. The

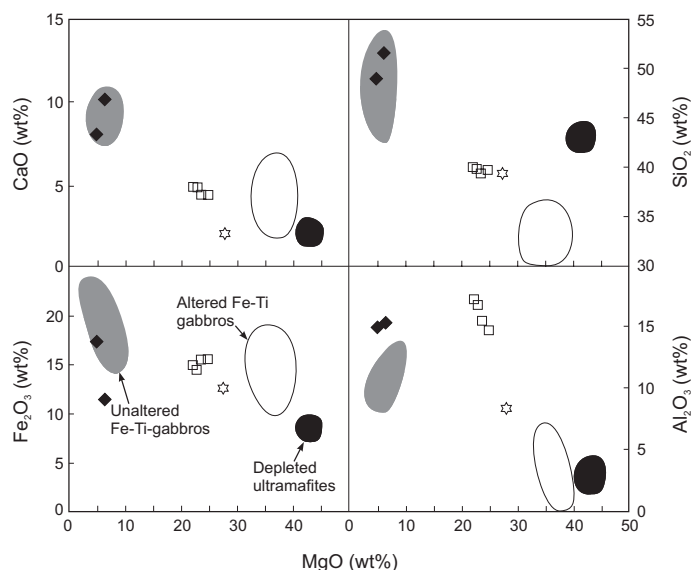


Figure 1. Al₂O₃, SiO₂, CaO, and Fe₂O₃ versus MgO plots for Ti-clinohumite rocks from both Kokchetav (open squares) (Muko et al., 2002) and Su-Lu (star) (Yang, 2003) terranes, along with composition ranges of unaltered and altered Fe-Ti gabbros and depleted ultramafites from literature. Filled diamonds stand for eclogites from Su-Lu locality.

zircon overgrowths contain much lower U and Th, indicating involvement of mantle components. This is consistent with the Mg metasomatism-UHP metamorphism scenario proposed above, but not with the corner convection hypothesis (Katayama et al., 2003). Moreover, pristine mantle peridotites are known to be depleted in Zr and can hardly contain zircon (Bea et al., 2001, and references therein). On the other hand, zircon could be abundant in gabbroic rocks, and it could continue to grow while the rocks transform into Ti-clinohumite rocks during subduction.

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REPLY

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We welcome the comments by Yang, who proposed that the Kokchetav ultramafic rocks have an Fe-Ti gabbroic protolith based on whole-rock major element chemistry (Muko et al., 2002), and have been subjected to a Mg metasomatism at crustal depths. The Kokchetav Ti-clinohumite-rich rocks described in our paper contain abundant volatile and high field strength element (HFSE)-bearing minerals. Combined with zircon U/Pb dating and trace element characteristics, we interpreted these features as fluid-infiltrated mantle metasomatism at a subduction zone.

The Kokchetav ultramafic rocks have clearly experienced long and complex metamorphic evolution that consequently buries their original histories as well as compositions. They contain abundant serpentine and amphibole minerals along secondary veins that resulted from later stage overprinting during exhumation. The whole-rock analysis would therefore include an effect of such alteration, and to use major chemistries to correlate the nature of protolith for metasomatic rocks, as shown by Yang, could be greatly misleading. However, examination of mineral inclusion and compositional zonation of refractory minerals, such as garnet and zircon, can reveal evidences prior to such overprintings (e.g., Schertl et al., 1991; Zhang et al., 1997; Katayama et al., 2000).

Compositions of garnet from the Ti-clinohumite-bearing ultramafic rocks compared with those from different rock types are shown in Figure 1. The analyzed garnet has similar composition to that of orogenic peridotites in the Dabie Mountains (Zhang et al., 1995), but is significantly different from those of associated eclogites and diamond-bearing pelitic gneisses from the same locality (Shatsky et al., 1995; Zhang et al., 1997; Okamoto et al., 2000). The garnet displays a pronounced zonation with increasing pyrope content from core (51–56 mol%) to rim (58–63 mol%); this is probably associated with the reaction of $\text{Chl} + \text{En} = \text{Fo} + \text{Prp} + \text{H}_2\text{O}$. The pyrope-rich rim contains abundant inclusions of Ti-clinohumite, ilmenite, zircon, and apatite; in contrast, the garnet core includes green spinel, amphibole, and phlogopite. The absence of Ti-bearing phases in the garnet core suggests that Ti enrichment occurred during high-pressure recrystallization. This fact is not consistent with the suggestion of the Fe-Ti gabbroic protolith enriched in Mg during magnesium metasomatism prior to subduction as proposed by Yang. Trace element abundance of stubby-shaped zircon separated from the ultramafic rocks (see Figure 3 in Katayama et al., 2003) also indicates that they recrystallized at high pressures where garnet is stable. The zircon rare earth element abundances display significantly different patterns from those of associated eclogite and country gneisses, but are similar to the characteristics reported in kimberlite. The calculated pressure (>35 kbar) required for the coexistence of low-F Ti-clinohumite, olivine, and ilmenite is consistent with our proposed model.

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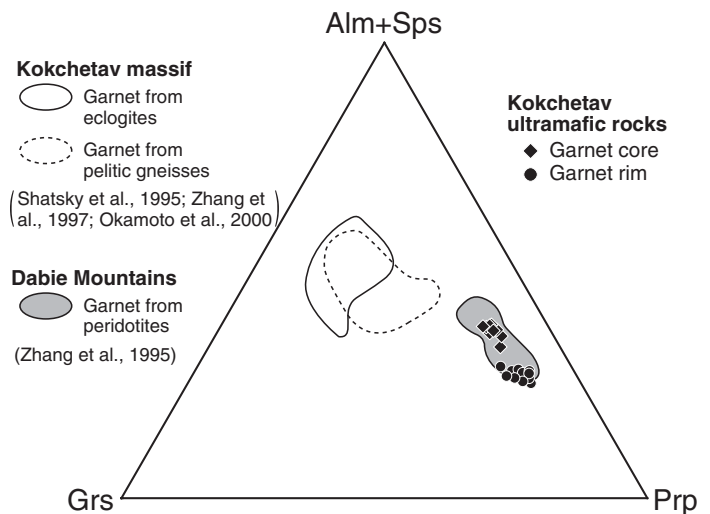


Figure 1. Composition of garnets from Ti-clinohumite-bearing ultramafic rocks in the Kokchetav massif. Compositional fields of garnets from associated eclogites and pelitic gneisses in same locality, and from garnet peridotites in the Dabie Mountains, are shown for comparison.

These lines of evidence preserved in refractory minerals favor that HFSE-rich metasomatism of garnet-bearing peridotites took place at mantle depths rather than Fe-Ti enrichment and Mg metasomatism in gabbroic rocks at crustal depths. The Kokchetav ultramafic rocks also contain rare inherited zircons of Proterozoic ages with pronounced heavy rare earth element enrichment. Large differences for the radiogenic ages and trace element characteristics, including U and Th concentrations, raise a plausible interpretation that the inherited zircons formed during one or more Proterozoic events and subsequently resided in the mantle environment. These zircons served as seeds for zircon growth during the HFSE-rich metasomatic processes.

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