Lithos 134–135 (2012) 335–339

Contents lists available at SciVerse ScienceDirect

Lithos

journal homepage: www.elsevier.com/locate/lithos

Discussion

Reply to Comment on “Garnet-bearing ultramafic rocks from the Dominican Republic: Fossil mantle plume fragments in an ultra high pressure oceanic complex?” by Jan C.M. De Hoog

Esteban Gazel [a,*], Richard N. Abbott Jr. [b], Grenville Draper [c]

[a] Department of Geosciences, Virginia Tech, Blacksburg, VA 24061, United States
[b] Department of Geology, Appalachian State University, Boone, NC 28608, United States
[c] Department of Earth Sciences, Florida International University, Miami, FL 33199, United States

ARTICLE INFO

Article history:
Received 14 November 2011
Accepted 5 December 2011
Available online 10 January 2012

Keywords:
Garnet peridotite
Corundum
Ultrahigh-pressure metamorphism
REE partitioning
Garnet-spinel thermometry
Dominican Republic

ABSTRACT

Two competing hypotheses have been proposed for garnet-bearing ultramafic rocks in the Dominican Republic: (1) The ultrahigh pressure (UHP) – ultrahigh temperature (UHT) hypothesis involves a magmatic protolith of mantle origin, which was then delivered to, and incorporated into deep-subducted oceanic crust (eclogite) at UHP conditions (Abbott et al., 2005, 2006, 2007; Abbott and Draper, 2010; Gazel et al., 2011). (2) The low-pressure (LP) hypothesis involves a plagioclase-bearing, arc-related protolith of crustal origin, which was then subducted to UHP conditions (De Hoog, 2011; Hattori et al., 2010a,b). In both hypotheses, the rocks were uplifted to the surface by an as yet poorly understood mechanism. Here we respond to concerns regarding the integrity of REE analyses, Cpx-Grt REE partitioning, other matters related to the interpretation of the trace element data, and Grt-Spl major-element thermometry. We show that none of the concerns precludes a UHP magmatic origin.

Published by Elsevier B.V.

1. Introduction

We welcome this opportunity to clarify the evidence for a UHP magmatic protolith for these interesting garnet-bearing ultramafic rocks, and in particular the corundum-bearing pegmatitic garnet clinopyroxenite, which is the subject of Gazel et al. (2011). Our principal concern with the comments offered by De Hoog and by Hattori et al. (2010a,b) is that their model fails to recognize or otherwise explain the original, and most compelling, evidence for a UHP *magmatic* origin. We refer of course to basic major-element phase relationships, developed in order to explain an observed sequence of rock types with distinct mineral assemblages, supported by magmatic textures, cross-cutting relationships (dikes, mineral segregations), and decreasing Mg# for spinel and for garnet. The argument is developed in a series of papers (Abbott and Draper, 2010; Abbott et al., 2005, 2006, 2007; and most recently Gazel et al., 2011). To summarize, the sequence of mineral assemblages is consistent with a well-defined liquid line of descent (LLD) in the CMAS system. The relevant phase relationships were derived from the results of 3-GPa melting experiments (Milholland and Presnall, 1998) using standard methods involving Schreinemakers analysis and Alkemade relationships. Taking into account non-CMAS components (Appendix in Gazel et al., 2011), the magmatic conditions are $P > 3.2$ GPa and $T > 1500$ °C, which would indeed constitute UHP–UHT conditions.

In reference to our work, De Hoog's statement, “an ultrahigh-pressure (UHP) *magmatic* origin was proposed for these rocks based on the coexistence of spinel, garnet and corundum,” is not accurate (our italics). (See also the same inaccuracy in the first sentence of Section 6, and last sentence in Section 7 of De Hoog's comments). Nowhere in Gazel et al. (2011) are *magmatic* conditions inferred *solely* from the coexistence of garnet + spinel + corundum. The assemblage Grt + Spl + Crn only indicates very high pressure (VHP), or possibly UHP conditions. However, in the special context of a magmatic origin, the assemblage Grt + Spl + Crn(+Cpx) would not only indicate VHP or UHP conditions, but also UHT conditions.

De Hoog acknowledges the UHP conditions, so we will focus on issues regarding UHT magmatic conditions ($T \geq 1500$ °C) for the protolith. We are the first to admit that the garnet-bearing ultramafic rocks suffered greatly from retrograde metamorphism during decompression and late, low-pressure hydration. This is the challenge in identifying any “memory” at all of UHT conditions. Our efforts with Grt-Spl thermometry and REE partitioning between type-1′ Grt (proxy for high Al-Cpx) and type-1 Grt are intended to test consistency with very high temperatures. The determination by these means of actual

---

[*] Corresponding author. Tel.: +1 540 231 2296; fax: +1 540 231 3386.
E-mail addresses: egazel@vt.edu, abbottrn@appstate.edu (E. Gazel), abbottrn@appstate.edu (R.N. Abbott), draper@fiu.edu (G. Draper).

0024-4937/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.lithos.2011.12.002

solidus temperatures was never intended. The results of our tests and De Hoog's concerns simply do not preclude UHT conditions.

2. Modification of REE patterns through fluid interaction?

Gazel et al. (2011) recognize that the LREEs could be partially re-equilibrated, and for this reason we emphasized the importance of the HREEs. We do not dispute problems with the LREEs, however we think that the humped character of the REE patterns is original and thus a fundamental characteristic (Sulu and DR samples, Figs. 5b and c in Gazel et al., 2011). The problem of re-equilibration does not seem to have affected the HREEs, where there is no overlapping of otherwise very narrow and distinct ranges of values for type-1, type-1′ and type-2 garnets. Gazel et al. (2011) emphasized that the different types of garnet are distinct in terms of texture, major elements and REEs. The REE patterns for type-1′ garnet and type-1 garnet actually cross one another at element Tb (see Gazel et al., 2011, Fig. 5b). We take this to mean that the different types of garnet acquired their REEs in fundamentally different ways, (1) in the case of type-1 Grt as magmatic garnet, (2) in the case of type-1′ Grt as magmatic high-Al Cpx, and (3) in the case of type-2 Grt as late garnet associated hydration and the growth of hornblende.

De Hoog calls into question the analytical data and invokes contamination by “cracks.” This seems to us an unwarranted criticism that could be lodged casually on any set of laser ablation data. Every precaution was taken to avoid “cracks,” mineral inclusions, and other such impurities. Data streams showed no irregularities. Also, De Hoog states, “all ablation pits appear to have intersected cracks…” This observation is incorrect, inasmuch as there are no ablation pits in the image to which De Hoog refers. The image was captured before the laser ablation analyses were performed.

We attribute the broad range of LREE values for the various types of garnet to late re-equilibration with respect to aqueous fluids, very likely also related to the late formation of hornblende and type-2 Grt. De Hoog alludes to interesting Sr systematics. We point out here that while the ranges are broad for Sr in type-1′ and type-1 garnets, the average value in type-1′ Grt (9.53 ppm) is more than twice the average value in the type-1 Grt (4.62 ppm), and the maximum values are respectively 43.6 ppm (type-1′) and 12.48 ppm (type-1). Therefore, we take this to mean that the Sr systematics do not preclude our interpretation that the type-1′ Grt was derived more or less isochemically from a high-Al Cpx predecessor.

3. Use of inappropriate partitioning coefficients?

De Hoog is correct in pointing out an error in our representation of the Cpx/Grt partitioning data of Tuff and Gibson (2007). This was an unfortunate drafting error, the correct Tuff and Gibson (2007) is now in Fig. 1.

Nevertheless, it is important to clarify that Gazel et al. (2011) didn't “calculate” temperatures using data from Tuff and Gibson (2007). Gazel et al. (2011) used the data, along with the data of Schmidberger and Francis (2001), to show that the REE partitioning for Cpx/Grt decreases with increasing temperature for the LREEs, and increases with increasing temperature for the HREEs, such that the slope of the pattern decreases with increasing temperature. We take this to mean only that REE partitioning between type-1′ Grt and type-1 Grt is consistent with the nature of very high temperature partitioning between Cpx and Grt. Once again, for the sake of clarification, we proceed from the general principle that partitioning (D or K_D) approaches unity with increasing temperature. In the case of the REE partitioning, this is why the slope flattens and the partitioning approaches unity with increasing temperature. In Fig. 1, with regard to the HREEs, the slope of our data is flatter and more closely approaches unity than even the 1425–1475 °C Cpx/Grt REE-partitioning data from Tuff and Gibson (2007).

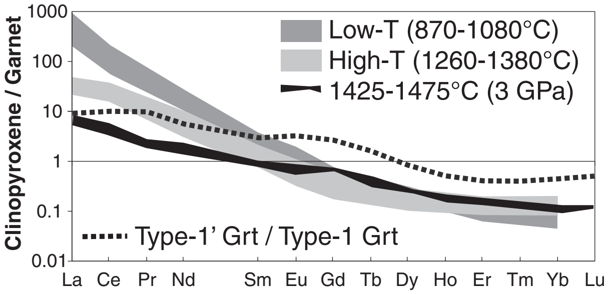

Fig. 1. REE partitioning between the average type-1′ garnet and the average type-1 garnet of the garnet-clinopyroxenite (DR03-12). Shaded regions represent high temperature (1260–1380 °C) and low temperature (960–1080 °C) clinopyroxene/garnet REE partitioning from mantle xenoliths (Schmidberger and Francis, 2001) and 1425–1475 °C (3 GPa) experimental data (Tuff and Gibson, 2007). Notice how the REE partition between type-1′ garnet (formed nearly isochemically from magmatic high-Al clinopyroxene) and type-1 garnet is flatter than high T natural samples and has a slope similar to experimental data (Tuff and Gibson, 2007). We interpret this to support VHT conditions for the formation of the garnet-clinopyroxenite.

De Hoog is concerned that, “Cpx/Grt partitioning data for HREE measured by Gazel ($D^{cpx/grt} = 0.8$) are incompatible with any published partitioning data ($D^{cpx/grt} < 0.1$).” But, the influence of very high-Al in Cpx is simply not known. Again, we only point out that the nature of the partitioning between type-1′ Grt and type-1 Grt is broadly consistent with expected behavior for partitioning of REEs between Cpx and Grt at a very high temperature (flat slope, not absolute values).

4. Transformation of Al-rich Cpx into garnet was not isochemical?

Milholland and Presnall (1998) reported Al-Cpx with tschermak-content ($CaAl_2SiO_6$) in excess of 50 mol% for Al-Cpx coexisting with garnet and an Al-saturating phase (sapphirine) at 1550 °C and 3 GPa. According to Boyd (1970), Cpx coexisting with garnet and corundum has nearly 50 mol% tschermak-content at 1200 °C and 3 GPa. Between a solidus temperature of ~1500 °C and a subsolidus temperature of 1200 °C, the Cpx coexisting with Grt + Crn is nearly isochemical with garnet. Actually, there is a temperature between 1200 °C and 1500 °C where the Cpx is exactly isochemical with Grt. Under these conditions, the *principal* mass transfer affecting the assemblage Grt + Cpx + Crn + Spl is Cpx = Grt (Abbott and Draper, 2010). Low-Al Cpx coexisting with Grt + Crn is not possible in this temperature range (Fig. 4 in Gazel et al., 2011).

Using Na and Sr, De Hoog offers a way to test the isochemical transformation of Al-Cpx to type-1′ Grt. As noted in Abbott and Draper (2010), before the late formation of hornblende, these garnet-bearing ultramafic rocks had to have been extremely depleted in Na, to the extent that none of the minerals, Grt, Cpx, Spl, Crn and Ol, contained appreciable Na. With regard to Sr, we dispute De Hoog's statement, “type-1 and type-1′ garnets contain nearly identical concentrations of these elements.” As noted in Section 2 here, statistically, Sr-values are distinctly higher (more than 2 times higher) in type-1′ garnet than in type-1 Grt. In any event, the nature of partitioning of Sr between garnet and very high-Al Cpx is not known, thus the Sr (and Na) systematics simply do not preclude isochemical or near-isochemical transformation of high-Al Cpx to Grt under the relevant conditions.

5. Invalid application of garnet-spinel thermometer?

Abbott et al. (2007) expressed caution that their derived, admittedly simplistic, Grt-Spl thermometer applies only to olivine-bearing assemblages (i.e., Grt peridotite) at high temperatures, ideally T > 1300 °C. They used only monomineralic inclusions of spinel in garnet, because the olivine in the Grt peridotite is demonstrably re-