Comments on "Garnet-bearing ultramafic rocks from the Dominican Republic

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Comments on "Garnet-bearing ultramafic rocks from the Dominican Republic: Fossil mantle plume fragments in an ultra high pressure oceanic complex?" by Gazel et al. [Lithos 125 (2011) 393-404]

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Abstract

The Rio San Juan Complex in the Dominican Republic hosts a suite of enigmatic corundum-bearing garnet peridotite rocks. Two hypotheses for their origin exist, an ultrahigh-pressure (UHP) hypothesis, in which corundum, spinel and garnet crystallised simultaneously at UHP magmatic conditions (>3.2 GPa and >1500°C), and a low pressure (LP) hypothesis, in which the rocks are metamorphosed equivalents of low-pressure plagioclase-bearing cumulates. Distinction between the two is hampered by extensive metamorphic recrystallisation of the rocks under UHP conditions. In a recent paper, Gazel et al. [Gazel, E., Abbott, R.N., Draper, G., 2011, Garnet-bearing ultramafic rocks from the Dominican Republic: Fossil mantle plume fragments in an ultra high pressure oceanic complex? Lithos 125, 393-404] reported trace element data for minerals from a garnet clinopyroxenite rock and used garnet-clinopyroxene partitioning coefficients to demonstrate an ultrahigh formation temperature of the rock, thus supporting the UHP hypothesis. However, the interpretations contained many unwarranted assumptions and were not consistent even with their own new data. This Comment addresses the shortcomings of the paper and demonstrates that (1) the authors' temperature estimates are invalid, (2) their garnet compositional data are best explained by its formation by metamorphic recrystallisation after plagioclase. Therefore, an UHP igneous origin of the rocks is highly unlikely.

Keywords: garnet peridotite, corundum, ultrahigh-pressure metamorphism, REE partitioning, garnet-spinel thermometry, Dominican Republic

1. Introduction

A recent paper by Gazel et al. (2011) reported trace-element data for minerals in corundum-bearing garnet-clinopyroxenite from the northern Dominican Republic and discussed its petrogenesis and tectonic implications. In previous publications by the same group, an ultrahigh-pressure (UHP) magmatic origin was proposed for the rocks based on the co-existence of spinel, garnet and corundum (Abbott et al., 2005; Abbott et al., 2007). The paper by Gazel et al. (2011) aimed to support their earlier interpretation.

An alternative interpretation of the origin of the rocks was published by Hattori et al. (2010a), who proposed that the rock is a metamorphosed ultramafic cumulate that originally crystallized at relatively low pressure (LP). A discussion on the topic (Abbott and Draper, 2010; Hattori et al., 2010b) did not resolve the issue. The Gazel et al. (2011) paper also aimed to further discredit a possible LP origin of the rock.

The main premise of the paper by Gazel et al. (2011) was that garnet-clinopyroxenite contains igneous garnet (Type-1 garnet) as well as garnet isochemically recrystallised from igneous Al-rich clinopyroxene (Type-1' garnet). The trace element distribution between the two types of garnet was used to demonstrate a high temperature of solidification, thus their formation in a mantle plume environment. However, the main hypothesis and interpretations contained unwarranted assumptions and were not consistent even with their own new data. This Comment points out the shortcomings of the paper and demonstrates that (1) the authors' temperature estimates are invalid, (2) their garnet compositional data are best explained by its formation by metamorphic recrystallisation after plagioclase. Therefore, an UHP igneous origin of the rocks is highly unlikely.

Note that the term 'UHP origin' used by Gazel et al. (2011) and in previous papers from the same group (Abbott et al., 2005; Abbott et al., 2007) can be confusing, as the rocks were metamorphosed under UHP eclogitic conditions, which is not disputed. As the authors claim magmatic conditions of >1500°C, the term ultrahigh-temperature (UHT) origin will be used in the Comment.

2. Modification of REE patterns through fluid interaction

Gazel et al. (2011) presented REE abundances of garnet with unusual LREE enrichments. They suggested that the original garnet compositions were re-equilibrated with fluids during

metasomatism, but that the relative abundance (REE partitioning) of the two types of igneous garnet was preserved. The small differences in REE concentrations and patterns were used to infer high temperature solidification of the rock. However, if the scenario were true, REE abundances will reflect the temperature of re-equilibration with fluids, not the original magmatic conditions. Moreover, LREE contents in both garnet types vary by an order of magnitude (shown in Fig. 5 of Gazel et al., 2011; see also **Fig. 1**), indicating that equilibrium has not been achieved. The use of average partitioning patterns will thus provide meaningless equilibration temperatures.

In addition, the analytical data itself is suspect. It is a challenge to obtain accurate LREE contents of garnet because of their low concentrations compared to other phases. Even small amounts of contamination will result in erroneously high LREE while leaving most other elements unaffected[1]. The garnets in the study by Gazel et al. (2011) are highly fractured and all the laser ablation pits appear to have intersected cracks (see their Fig. 3b). The material in the cracks appears to have contributed LREE to the results because there are strong positive correlations between LREE and other mobile trace element contents, such as Sr and Ba. Garnets with the lowest Sr contents are closest to typical garnet patterns as they show no La-Ce enrichments. Hence, the large range of LREE in garnet observed by Gazel et al. (2011) can at least in part be attributed to contamination instead of disequilibrium. Either way, the use of these patterns to infer crystallisation temperatures is incorrect.

3. Use of inappropriate partitioning coefficients

Gazel et al. (2011) calculated Cpx-garnet equilibrium temperatures using experimentally determined REE partitioning values by Tuff and Gibson (2007). In doing so they ignored the well-documented dependence of partitioning values on the compositions of minerals (e.g., Gaetani and Grove, 1995; Hill et al., 2000). Tuff and Gibson (2007) used augitic Cpx and pyrope low-Ca garnet; both are very different from Tschermakitic Cpx and almandine-grossular in the garnet-clinopyroxenite (Table 1 in Gazel et al., 2011). The use of omphacitic Cpx (Klemme et al., 2002), which has a much steeper REE partitioning slope than augitic Cpx at similar P and T (**Fig. 1**), would have been more appropriate.

Furthermore, the partitioning data from Tuff and Gibson (2007) was incorrectly quoted by

[1] Note that it is not expected to see a decrease in other elements as the volume of the cracks needs to be only very small to increase LREE in garnet and the dilution effect for other elements for such a small volume is negligible.

Gazel et al. (2011) as the REE partitioning pattern in their Fig. 5 differs significantly from the pattern calculated from the Tuff and Gibson (2007) data (**Fig. 1**). Therefore, the estimated temperatures by Gazel et al. (2011) based on Cpx/Grt REE partitioning data are incorrect due to erroneously cited data alone. It appears that Cpx/Grt partitioning data for HREE measured by Gazel ($D^{cpx/grt}$=0.8) are incompatible with any published partitioning data ($D^{cpx/grt} \leq 0.1$), which indicates that Type-1' garnet has re-equilibrated with Type-1 garnet or was in fact not formed from a Cpx precursor.

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

The use of REE partitioning patterns to infer crystallisation temperatures by Gazel et al. (2011) critically depends on the assumption that Type-1' garnet formed from Al-rich igneous Cpx through purely isochemical transformation. If even a small amount of low-Al Cpx is formed during the transformation, REE patterns of newly formed garnet would have been modified due to the large contrast in their affinities for LREE. Low-Al Cpx will be a product of the transformation if the Tschermak component of Al-rich Cpx is less than 50%, which is the case for all Cpx compositions in UHT experiments by Tuff and Gibson (2007) and Milholland and Presnall (1998).

The assumption of isochemical transformation can be tested using elements that prefer Cpx over garnet. Igneous Cpx contains high Na and Sr relative to co-existing garnet (e.g., Klemme et al., 2002; Tuff and Gibson, 2007), but Type-1 and Type-1' garnets contain nearly identical concentrations of these elements. Thus, transformation from Cpx to garnet was not isochemical or Type-1' garnet was in fact not formed from Cpx. Temperatures calculated using garnet-Cpx distribution coefficients between the two types of garnet are therefore meaningless.

5. Invalid application of garnet-spinel thermometry

Gazel et al. (2011) used previously reported spinel-garnet Fe-Mg exchange thermometry results (Abbott et al., 2007) as additional evidence for very high temperatures, although they do not apply the thermometer to the rock from their own study. The garnet-spinel thermometer combined published Mg-Fe exchange calibrations between garnet and olivine and between spinel and olivine (Abbott et al., 2007). Although the concept has merit, there are several problems with its calibration and application.

Firstly, Abbott et al. (2007) ignored the temperature dependence of $K_D^{ol\text{-}sp}$, despite the fact it has been calibrated as a geothermometer (Roeder et al., 1979; O'Neill and Wall, 1987;

Ballhaus et al., 1991). Its temperature dependence is only slightly less than that of $K_D^{ol\text{-}gt}$ (**Fig. 2**) and therefore the temperature dependence of $K_D^{gt\text{-}sp}$ is considerably less than calculated by Abbott et al. (2007). Using temperature-dependent $K_D^{ol\text{-}sp}$ from Ballhaus et al. (1991) will considerably reduce the temperatures calculated by Abbott et al. (2007). For instance, the estimate of 1503°C from sample DR00-3 decreases to 1313°C, whereas the estimate of 1141°C from sample DR10-3b decreases to only 712°C (**Fig. 2**).

Secondly, Abbott et al. (2007) ignored the dependence of $K_D^{ol\text{-}sp}$ on the ferrite component, $(Mg,Fe)Fe_2O_4$. The K_D value for ferrite component is 7±1, much higher than 0.97 for MgAl spinel (Jamieson and Roeder, 1984). Despite the low ferrite component in their spinels, this amount is not trivial because the thermometer is highly sensitive to small changes in K_D. For instance, when taking ferric iron into account, spinel from DR03-10b (Grt and Spl cores, Table 1; Abbott et al., 2007) has $K_D^{ol\text{-}sp}$ value of 1.11 instead of 1.0 used by Abbott et al. (2007), which results in $T_{gt\text{-}sp}$ of 1029°C instead of 1141°C.

Apart from these calibration issues, the authors assumed that the spinel composition did not change during cooling of the rocks, even though the closure temperature for Mg-Fe equilibrium in spinels is considered to be rather low (Roeder et al., 1979; Barnes, 2000; De Hoog et al., 2004). If during cooling spinel continues to re-equilibrate at lower temperature than the closure temperature of garnet, the difference in Mg# between spinel and garnet would decrease, which would lead to apparent high $T_{gt\text{-}sp}$. This process is aided by the small grain size of spinel relative to garnet. The effect evident in the rock presented in Gazel et al. (2011), as $T_{gt\text{-}sp}$ for Type-1 garnet, the original igneous garnet according to the authors, gives 2072°C (calculated using data from their Table 1 and the formulation by Abbott et al., 2007). This unrealistically high temperature cast doubts on the hot temperatures obtained from other samples.

As an alternative, the formation temperature of garnet, where it co-exists with olivine, may be obtained from its Ni content (Ryan et al., 1996). The Ni contents of garnets from garnet peridotite from the same location (7-48 ppm; Table 3 in Gazel et al., 2011) yield temperatures lower than 750°C, with one exception of 1020°C, which suggests that garnet re-equilibrated or formed at relatively low temperature. Hence, high temperatures based on garnet-spinel thermometry are untenable.

6. Garnet compositions do not support an igneous origin

The only remaining evidence for a UHT origin of the Dominican garnet peridotites is based on phase relationships of co-crystallisation of garnet, corundum and spinel (Abbott et

al., 2005; Abbott et al., 2007; Gazel et al., 2011). The key assumption that these minerals have an igneous origin is difficult to validate, as textural evidence is largely obliterated by subsequent metamorphic recrystallisation. However, geochemical data may be used to determine the origin of minerals.

Gazel et al. (2011) used the sinusoidal REE patterns of garnets to infer their mantle origin. Sinusoidal REE patterns in garnet are typical of harzburgitic garnets from kimberlites and result from extremely high degrees of melt depletion followed by LREE-rich metasomatism (Stachel and Harris, 2008). REE patterns of garnets presented by Gazel et al. (2011) are not strictly 'sinusoidal' as they do not show an increase from Ho to Lu, and only resemble such a pattern because of elevated La-Ce contents, which were due to late-stage re-equilibration with fluids (Gazel et al., 2011) or contamination from cracks (Section 2). Moreover, with high CaO (11-15 wt.%), low Cr_2O_3 (<0.1 wt.%) and low Mg# (<0.4) the garnets are clearly eclogitic, not peridotitic (Schulze, 2003). Eclogitic garnets have a different petrogenetic history and typically do not show sinusoidal patterns (Gonzaga et al., 2010). If they do, it must be related to a secondary process, which has no bearing on a possible mantle origin. Therefore, the attempt by Gazel et al. (2011) to demonstrate a mantle origin based on REE patterns is misleading.

The eclogitic composition of garnet also casts considerable doubts on its igneous origin, as it does not resemble garnet from mantle-derived igneous rocks. Low TiO_2 contents (<0.03 wt.%; Gazel et al., 2011[2]) are particularly striking, as mantle-derived igneous garnets contain high TiO_2 >0.4 wt.% (Schulze, 2003). The compositions are, however, rather similar to garnet porphyroblasts from metamorphosed olivine-rich gabbros (De Hoog et al., 2011).

The only minerals of undoubtedly igneous origin are the Cpx megacrysts (Abbott et al., 2005; Hattori et al., 2010a). The Cpx megacrysts' major and trace element compositions (Cr_2O_3 0.2-0.5 wt.%, TiO_2 0.1-0.8 wt.%, Mg# ca. 88%; Gazel et al., 2011) are similar to those crystallized in mafic magmas (e.g., Elthon et al., 1992; Suhr et al., 2008; Drouin et al., 2009). Gazel et al. (2011) dismiss clinopyroxene compositions as altered because of the presence of amphibole inclusions. However, even if some fluid modification has taken place,

[2] Note that TiO_2 contents by SEM-EDS in Table 1 from Gazel et al. (2011) are probably incorrect based on comparison between SEM-EDS and EPMA data published by Abbott et al. (2006) for similar rocks, as well as TiO_2 results from LA-ICP-MS (<0.02 wt.% for all Type-1' garnets). Cr_2O_3 contents are listed as below detection limit, but values of 0.15-0.51 wt.% for Cpx are reported by LA-ICP-MS (Table 2 in Gazel et al., 2011).

considering their similarity to magmatic Cpx it is unlikely that Cr_2O_3, TiO_2 and Mg# were significantly modified.

Because of its very low Cr_2O_3, TiO_2 and Mg#, garnet cannot have been in equilibrium with Cpx with such composition, which further argues against its igneous origin. Type-1' garnet, considered by Gazel et al. (2011) to be the isochemical equivalent of primary igneous Cpx, also has low Cr_2O_3, Na_2O and TiO_2 (all <0.05 wt.%), and very low Mg# (0.2), which is dissimilar to those of any reported igneous Cpx, including high-PT experiments on natural compositions (e.g., Tuff and Gibson, 2007). Its trace element geochemistry is remarkable similar to Type-1 garnet. Hence, the notion of an igneous Cpx precursor for Type-1' garnet by Gazel et al. (2011) seems inconsistent with the compositional data presented in their paper.

A metamorphic origin of garnet is supported by positive Eu anomalies in Type-1 and Type-1' garnets (Fig. 5B in Gazel et al., 2011). They occur in all these garnets, including those with low Sr and LREE contents, and therefore Eu anomalies are a primary feature and not the result of contamination from cracks (Section 2) or fluid interaction (Gazel et al., 2011). They can be explained by growth of garnet during the breakdown of a mineral with a positive Eu anomaly, such as plagioclase (Mazzucchelli et al., 1992). Similar REE patterns were reported from garnet porphyroblasts in metamorphosed olivine-rich gabbros (De Hoog et al., 2011). The occurrence of different garnet types in the rock is best explained by growth in different microdomains in the rock (e.g., Rebay and Powell, 2002), their composition reflecting various precursor minerals (olivine, plagioclase, clinopyroxene, hornblende), and by subsequent retrograde modification (e.g., Janák et al., 2006).

A metamorphic origin for garnet in Dominican peridotites was previously proposed by Hattori et al. (2010a); the new data presented by Gazel et al. (2011) thus appears to support that interpretation. Gazel et al. (2011) argued that a LP origin of the rocks (Hattori et al., 2010a) was unlikely as the rocks showed only small positive or no Eu anomalies. A similar argument was used by Abbott and Draper (2010), who argued that Eu anomalies were probably introduced by late-stage fluids. However, olivine gabbros need not have positive Eu anomalies, as the size of that anomaly depends on the ratio of plagioclase to Cpx, the latter being much richer in REE (e.g., Godard et al., 2009). Hattori et al. (2010a) estimated that the protolith, if formed at LP, would have contained about equal proportions of plagioclase and Cpx. Hence, bulk rock Eu anomalies are expected to be small or non-existent in these rocks and thus the lack thereof provides no evidence as to a UHT or LP origin.

7. Other corundum-spinel-garnet ultramafic rock occurrences

Gazel et al. (2011) repeated the claim by Abbott et al. (2005) that the Dominican garnet peridotites were the first reported occurrence of co-existing corundum-spinel-garnet, but the assemblage is well-known from alkremite and corgaspinite xenoliths in kimberlites (Nixon et al., 1978; Padovani and Tracy, 1981; Mazzone and Haggerty, 1989). Garnets in these rocks have distinctively different compositions than those from the Dominican garnet peridotites.

Corundum and spinel inclusions in garnet were reported by Vrabec (2007) and De Hoog et al. (2011) in UHP garnet peridotites from Pohorje, Eastern Alps (**Fig. 3**). The Pohorje garnet peridotites contain pseudomorphs after former plagioclase and are the metamorphosed equivalents of olivine-rich gabbroic cumulates (De Hoog et al., 2011). Garnet formed after (altered) plagioclase and spinel upon subduction to UHP conditions (4 GPa, 900°C). Therefore, the assemblage corundum-spinel-garnet is no proof of an UHT origin of rocks unless the magmatic origin of these minerals can be demonstrated.

8. Conclusions

- Temperature estimates based on garnet-'cpx' REE partitioning are invalid because of a variety of reasons: disequilibrium between garnet grains, contaminated values of LREE, erroneously quoted mineral partitioning data, ignoring the effects of mineral compositions on partition values, and the unreasonable assumption of isochemical transformation of Al-rich Cpx to garnet.
- Unrealistically high temperatures obtained from the garnet-spinel geothermometry are considerably overestimated due to flaws in the thermometer calibration and by low-temperature re-equilibration of spinel below the closure temperature of garnet. This is supported by Ni-in-garnet thermometry for garnet in nearby garnet peridotites, which formed or re-equilibrated at temperatures <1020°C.
- Garnet compositions (very low Cr_2O_3, TiO_2 and Mg#, peculiar REE patterns) are best explained by its formation by metamorphic, not magmatic, processes. Positive Eu anomalies of garnets suggest a Eu-rich precursor, most likely plagioclase. Hence, the geochemical data presented by Gazel et al. (2011) support the metamorphic origin of garnet proposed by Hattori et al. (2010a).
- In light of the new geochemical data presented by Gazel et al. (2011), a UHT mantle origin of the ultramafic rocks is highly unlikely.

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References

Abbott, R.N., Draper, G., Keshav, S., 2005. UHP magma paragenesis, garnet peridotite, and garnet clinopyroxenite: An example from the Dominican Republic. International Geology Review 47, 233-247.

Abbott, R.N., Draper, G., Broman, B.N., 2006. P-T path for ultrahigh-pressure garnet ultramafic rocks of the Cuaba Gneiss, Rio San Juan complex, Dominican Republic. International Geology Review 48, 778-790.

Abbott, R.N., Broman, B.N., Draper, G., 2007. UHP magma paragenesis revisited, olivine clinopyroxenite and garnet-bearing ultramafic rocks from the Cuaba Gneiss, Rio San Juan Complex, Dominican Republic. International Geology Review 49, 572-586.

Abbott, R.N., Draper, G., 2010. Comments on "Corundum-bearing garnet peridotite from northern Dominican Republic: A metamorphic product of an arc cumulate in the Caribbean subduction zone," by Hattori et al. [Lithos 114 (2010) 437-450]. Lithos 117, 322-326.

Ballhaus, C., Berry, R.F., Green, D.H., 1991. High-pressure experimental calibration of the olivine-ortho-pyroxene-spinel oxygen geobarometer - Implications for the oxidation-state of the upper mantle. Contributions to Mineralogy and Petrology 107, 27-40.

Barnes, S.J., 2000. Chromite in komatiites, 2. Modification during greenschist to mid-amphibolite facies metamorphism. Journal of Petrology 41, 387-409.

De Hoog, J.C.M., Hattori, K.H., Hoblitt, R.P., 2004. Oxidized sulfur-rich mafic magma at Mount Pinatubo, Philippines. Contributions to Mineralogy and Petrology 146, 750-761.

De Hoog, J.C.M., Janak, M., Vrabec, M., Hattori, K.H., 2011. Ultramafic cumulates of oceanic affinity in an intracontinental subduction zone: ultrahigh-pressure garnet peridotites from Pohorje (Eastern Alps, Slovenia), in: Dobrzhinetskaya, L., Faryad, S.W. et al. (Eds.), Ultrahigh-Pressure Metamorphism: 25 years since the discovery of coesite. Elsevier, Amsterdam, pp. 399-439.

Drouin, M., Godard, M., Ildefonse, B., Bruguier, O., Garrido, C.J., 2009. Geochemical and petrographic evidence for magmatic impregnation in the oceanic lithosphere at Atlantis Massif, Mid-Atlantic Ridge (IODP Hole U1309D, 30^{o}N). Chemical Geology 264, 71-88.

Elthon, D., Stewart, M., Ross, D.K., 1992. Compositional trends of minerals in oceanic cumulates. Journal of Geophysical Research-Solid Earth 97, 15189-15199.

Gaetani, G.A., Grove, T.L., 1995. Partitioning of rare-earth elements between clinopyroxene and silicate melt - crystal-chemical controls. Geochimica et Cosmochimica Acta 59, 1951-1962.

Gazel, E., Abbott, R.N., Draper, G., 2011. Garnet-bearing ultramafic rocks from the Dominican Republic: Fossil mantle plume fragments in an ultra high pressure oceanic complex? Lithos 125, 393-404.

Godard, M., Awaji, S., Hansen, H., Hellebrand, E., Brunelli, D., Johnson, K., Yamasaki, T., Maeda, J., Abratis, M., Christie, D., Kato, Y., Mariet, C., Rosner, M., 2009. Geochemistry of a long in-situ section of intrusive slow-spread oceanic lithosphere: Results from IODP Site U1309 (Atlantis Massif, 30°N Mid-Atlantic-Ridge). Earth and Planetary Science Letters 279, 110-122.

Gonzaga, R.G., Lowry, D., Jacob, D.E., LeRoex, A., Schulze, D., Menzies, M.A., 2010. Eclogites and garnet pyroxenites: Similarities and differences. Journal of Volcanology and Geothermal Research 190, 235-247.

Hattori, K.H., Guillot, S., Saumur, B.M., Tubrett, M.N., Vidal, O., Morfin, S., 2010a. Corundum-bearing garnet peridotite from northern Dominican Republic: A metamorphic product of an arc cumulate in the Caribbean subduction zone. Lithos 114, 437-450.

Hattori, K.H., Guillot, S., Tubrett, M.N., Saumur, B.M., Vidal, O., Morfin, S., 2010b. Reply to Comment on "Corundum-bearing garnet peridotites from northern Dominican Republic: A metamorphic product of an arc cumulate in the Caribbean subduction zone" by Richard N. Abbott and Grenville Draper. Lithos 117, 327-330.

Hill, E., Wood, B.J., Blundy, J.D., 2000. The effect of Ca-Tschermaks component on trace element partitioning between clinopyroxene and silicate melt. Lithos 53, 203-215.

Jamieson, H.E., Roeder, P.L., 1984. The distribution of Mg and Fe^{2+} between olivine and spinel at 1300°C. American Mineralogist 69, 283-291.

Janák, M., Froitzheim, N., Vrabec, M., Ravna, E.J.K., De Hoog, J.C.M., 2006. Ultrahigh-pressure metamorphism and exhumation of garnet peridotite in Pohorje, Eastern Alps. Journal of Metamorphic Geology 24, 19-31.

Klemme, S., Blundy, J.D., Wood, B.J., 2002. Experimental constraints on major and trace element partitioning during partial melting of eclogite. Geochimica et Cosmochimica Acta 66, 3109-3123.

Mazzone, P., Haggerty, S.E., 1989. Peraluminous xenoliths in kimberlite - metamorphosed restites produced by partial melting of pelites. Geochimica et Cosmochimica Acta 53, 1551-1561.

Mazzucchelli, M., Rivalenti, G., Vannucci, R., Bottazzi, P., Ottolini, L., Hofmann, A.W., Sinigoi, S., Demarchi, G., 1992. Trace-element distribution between clinopyroxene and garnet in gabbroic rocks of the deep crust - an ion microprobe study. Geochimica et Cosmochimica Acta 56, 2371-2385.

Milholland, C.S., Presnall, D.C., 1998. Liquidus phase relations in the CaO-MgO-Al_2O_3-SiO_2 system at 3.0 GPa: The aluminous pyroxene thermal divide and high-pressure fractionation of picritic and komatiitic magmas. Journal of Petrology 39, 3-27.

Nixon, P.H., Chapman, N.A., Gurney, J.J., 1978. Pyrope-spinel (alkremite) xenoliths from kimberlite. Contributions to Mineralogy and Petrology 65, 341-346.

O'Neill, H.S.C., Wood, B.J., 1979. Experimental study of Fe-Mg partitioning between garnet and olivine and iIts calibration as a geothermometer. Contributions to Mineralogy and Petrology 70, 59-70.

O'Neill, H.S.C., Wall, V.J., 1987. The olivine ortho-pyroxene spinel oxygen geobarometer, the nickel precipitation curve, and the oxygen fugacity of the Earth's upper mantle. Journal of Petrology 28, 1169-1191.

Padovani, E.R., Tracy, R.J., 1981. A pyrope-spinel (alkremite) xenolith from Moses Rock Dike - first known North-American occurrence. American Mineralogist 66, 741-745.

Rebay, G., Powell, R., 2002. The formation of eclogite facies metatroctolites and a general petrogenetic grid in Na_2O-CaO-FeO-MgO-Al_2O_3-SiO_2-H_2O (NCFMASH). Journal of Metamorphic Geology 20, 813-826.

Roeder, P.L., Campbell, I.H., Jamieson, H.E., 1979. Re-evaluation of the olivine-spinel geothermometer. Contributions to Mineralogy and Petrology 68, 325-334.

Ryan, C.G., Griffin, W.L., Pearson, N.J., 1996. Garnet geotherms: Pressure-temperature data from Cr-pyrope garnet xenocrysts in volcanic rocks. Journal of Geophysical Research-Solid Earth 101, 5611-5625.

Schulze, D.J., 2003. A classification scheme for mantle-derived garnets in kimberlite: a tool for investigating the mantle and exploring for diamonds. Lithos 71, 195-213.

Stachel, T., Harris, J.W., 2008. The origin of cratonic diamonds - Constraints from mineral inclusions. Ore Geology Reviews 34, 5-32.

Suhr, G., Hellebrand, E., Johnson, K., Brunelli, D., 2008. Stacked gabbro units and intervening mantle: A detailed look at a section of IODP Leg 305, Hole U1309D. Geochemistry Geophysics Geosystems 9, Q10007.

Tuff, J., Gibson, S.A., 2007. Trace-element partitioning between garnet, clinopyroxene and Fe-rich picritic melts at 3 to 7 GPa. Contributions to Mineralogy and Petrology 153, 369-387.

Vrabec, M., 2007. Petrology of ultrahigh-pressure metamorphic rocks from Pohorje. Ph.D. Thesis, University of Ljubljana, Slovenia, Ljubljana.

FIGURE CAPTIONS

Figure 1 Clinopyroxene/garnet REE distribution coefficients for Dominican garnet peridotites using Type-1' garnet as a proxy for Al-rich Cpx (after Gazel et al., 2011). Experimental data from eclogite (yellow squares; Klemme et al., 2002) shows a pattern rather different from experimental Fe-rich picrite at similar P and T (yellow diamonds; Tuff and Gibson, 2007) indicating a large mineral compositional effect ignored by Gazel et al. (2011). Gazel et al. (2011) presented average partitioning data (thick dotted line), but the range of distribution coefficients calculated from all analyses in their dataset spans an extremely wide range (purple field) especially for LREE, which makes comparison of their data with experimental data rather ambiguous. Also note that data for 1475°C and 3 GPa from Tuff and Gibson (2007; red diamonds) is quite different than presented by Gazel et al. (2011) in their Figure 5 (narrow red field).

Figure 2 Diagram of ln $K_D^{Fe/Mg}$ versus 1000/T (K) for garnet-spinel (red line) calculated from spinel-olivine (green line; Ballhaus et al., 1991) and garnet-olivine (purple line; O'Neill and Wood, 1979). The garnet-spinel thermometer by Abbott et al. (2007) is the same as garnet-olivine because of their assumption $K_D^{Fe/Mg\ sp\text{-}ol} = 1$. Garnet-spinel temperatures calculated with temperature-dependent $K_D^{Fe/Mg\ sp\text{-}ol}$ (large dots) are considerably lower than those using the Abbott et al. (2007) calibration (small dots).

Figure 3 Spinel and corundum in garnet from meta-olivine gabbros metamorphosed under UHP conditions from Pohorje, Slovenia, Eastern Alps (Janák et al., 2006; Vrabec, 2007; De Hoog et al., 2011). A. Photograph of rock section showing the main mineral assemblage of olivine (Ol), clinopyroxene (Cpx), garnet (Grt), chromian spinel (Chr) and Ca-rich amphibole (Cam). B. Backscatter electron image of spinel (Spl) and corundum (Crn) inclusions in garnet (Grt).

FIGURES

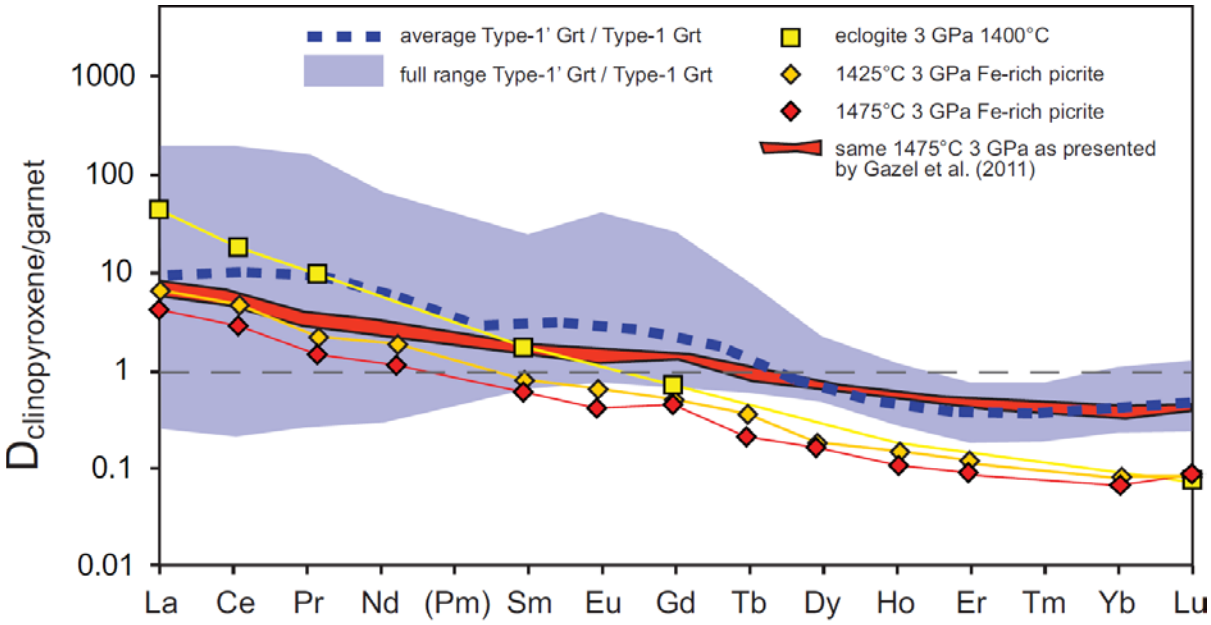

Fig. 1 De Hoog (comment on Gazel et al., 2011)

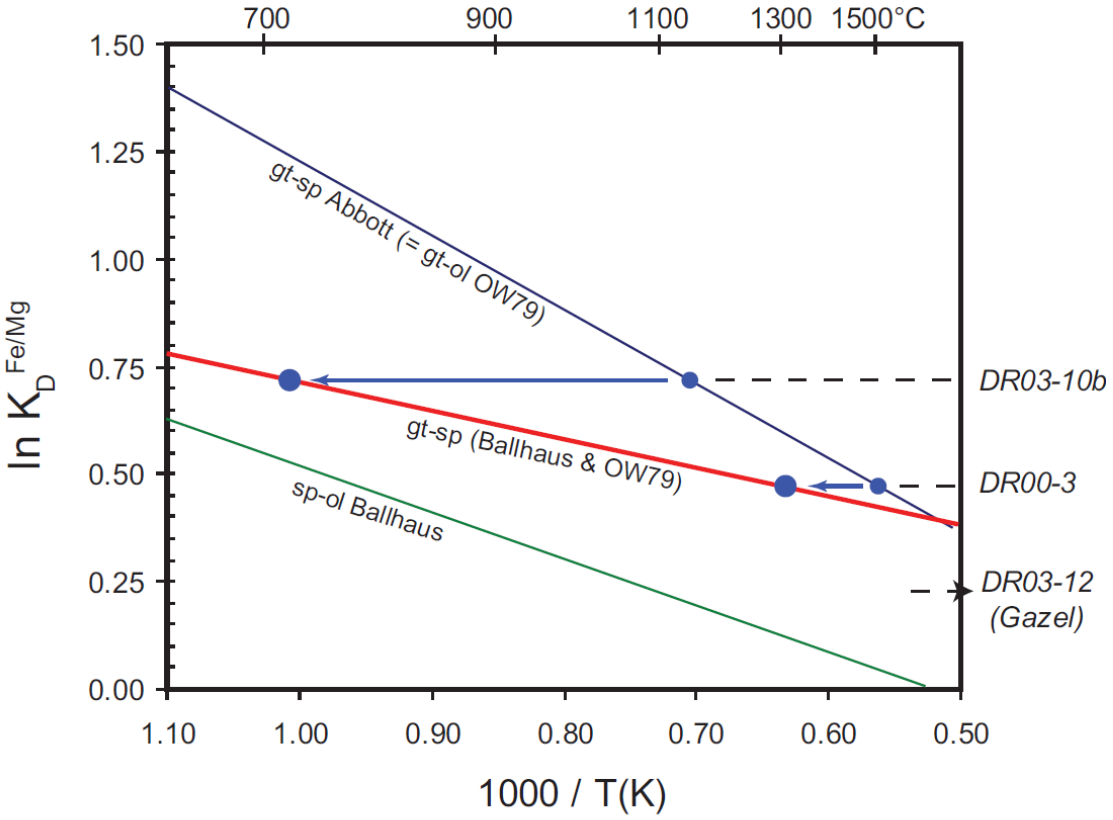

Fig. 2 De Hoog (comment Gazel et al. 2011)

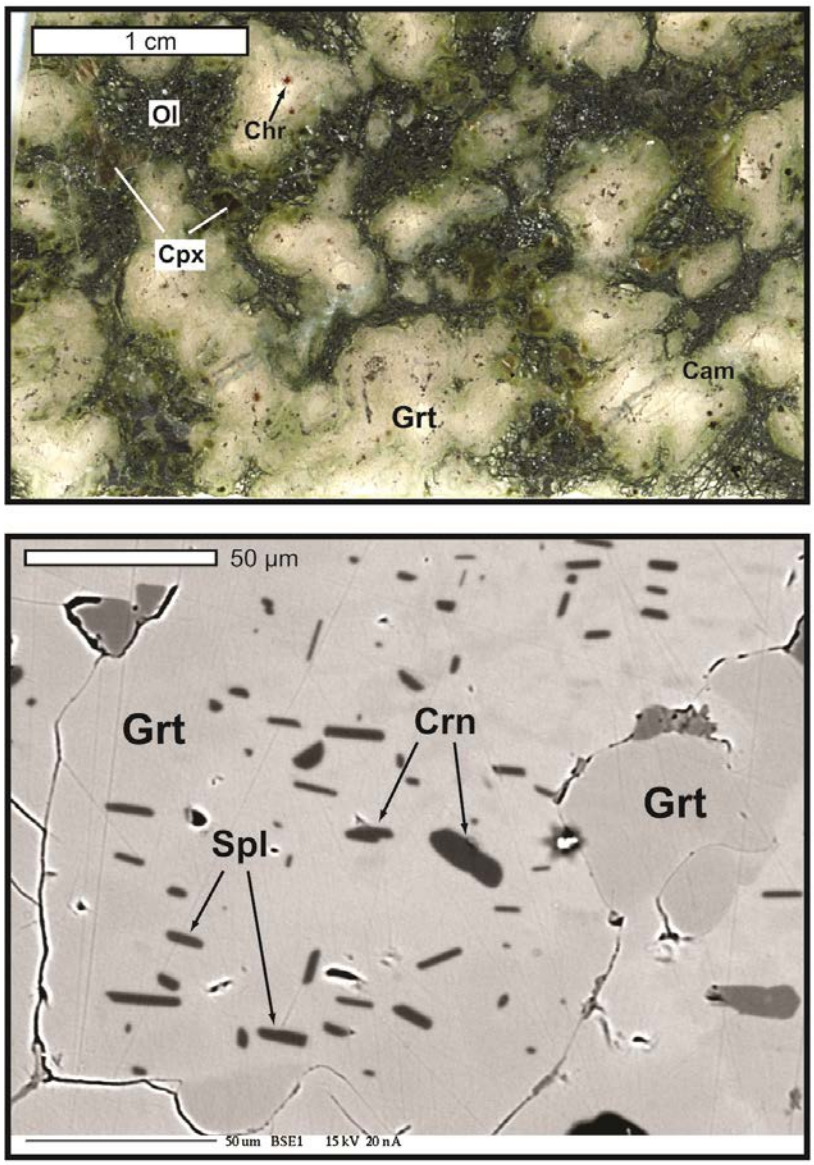

Fig. 3 De Hoog (comment Gazel et al. 2011)