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Origin of the dunitic mantle-crust transition zone in the Oman ophiolite: The interplay between percolating magmas and high-temperature hydrous fluids

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Abstract :

Determining which petrological processes build the mantle-crust dunitic transition zone (DTZ) in oceanic spreading settings has a direct impact on our understanding of thermal and chemical transfers on Earth. We report on understated but widespread mineral assemblages present in the DTZ at the top of a mantle diapir (Oman ophiolite), including pargasite, grossular, and pyroxenes of peculiar composition. These minerals are present interstitially between olivines and as inclusions in the disseminated chromite grains, indicating that they are early, high-temperature features. They call for hybridization between the mid-oceanic ridge basalt melts that fed the crustal section and supercritical water saturated with silica. Our synoptic survey (similar to 300 samples collected along 11 cross sections) demonstrates that the DTZ was pervasively infiltrated by such hybrid melts and that the abundance of their crystallization products increases upsection, likely in response to increasing supply of water and decreasing temperature. This indicates that water is involved in the reaction leading to the transformation of mantle harzburgite into dunite in the DTZ. On the basis of field evidence, a hydrothermal origin of the water is a reasonable hypothesis.

INTRODUCTION

In ophiolites, and especially in Oman, the contact between the mantle peridotites and the lower crust is underlined by a horizon as much as several hundred meters thick made essentially of dunite (>95% olivine + minor chromite). The origin of this dunitic transition zone (DTZ) was questioned in the pioneering studies of Moores and Vine (1971) and Greenbaum (1972) and is still debated. The DTZ has been viewed as the shallowest part of the mantle, i.e., a residue of reaction melting between host harzburgite and a percolating melt becoming undersaturated in silica relative to orthopyroxene (Opx) at low pressure (e.g., Moores and Vine, 1971; Dick, 1977; Rabinowicz et al., 1987), or as the deepest part of the crust, i.e., cumulates from Mg-rich melts (e.g., Greenbaum, 1972; Elthon, 1979). We have shown that the two options are not mutually exclusive and that the DTZ can include both residual and cumulative horizons (Abily and Ceuleneer, 2013).

We have performed a systematic sampling of the DTZ in the Maqsad area and, based on our sampling collection (>300 sampling sites), we realized that the DTZ exposes an unexpected abundance of discreet mineral assemblages of enigmatic origin (partly igneous, partly hydrous). The distribution of these mineral assemblages is not random, but vertical within the DTZ. We propose that they are a clue to understand the petrological processes involved in the formation of the DTZ.

GEOLOGICAL SETTING AND FIELD OCCURENCE

The upper Cretaceous Oman ophiolite issued from the Tethys Ocean. It is made of two contrasting magma series: one is a mid-oceanic ridge basalt (MORB) type and the other has a depleted andesitic affinity attributed to subduction and/or thrusting or to hydrated remelting of the shallow lithosphere during spreading (e.g., Pearce et al., 1981; Benoit et al., 1999; Python and Ceuleneer, 2003; Yamasaki et al., 2006; MacLeod et al., 2013).

The Maqsad area (Sumail massif), the focus of our study (Fig. 1), exposes a former asthenospheric diapir that contributed a large amount of melt into the crust (Rabinowicz et al., 1987). It fed a ridge segment extending to the northwest and southeast of the diapir for a distance of ~80 km (Python and Ceuleneer, 2003). It evolved in a MORB igneous environment (Ceuleneer et al., 1996; Benoit et al., 1996; Korenaga and Kelemen, 1997).

A few faults parallel to the paleo-ridge direction (northwest-southeast) affect the DTZ. They consist of breccia with serpentine and carbonate matrix, frequently intruded by gabbroic dikes altered in greenschist facies conditions. They are zones of intense fluid circulation that underwent moderate normal fault movement. Away from them, dunite is weakly serpentinized (<20%); this has preserved its high-temperature mineral assemblages. Above the Maqsad diapir the DTZ was not transposed off axis by mantle corner flow, and the massif as a whole was not affected by late tectonic events (Ceuleneer et al., 1988).

PETROLOGY AND MINERAL CHEMISTRY

We sampled the Maqsad DTZ with a vertical step of 10–20 m along 12 cross sections extending from the mantle harzburgites to the layered cumulates (Fig. 1C). All samples (~300) as well as ~400 silicate inclusions enclosed in chromite grains were analyzed with the electron microprobe.

The Maqsad DTZ, 200–350 m thick, is made of alternating metric to decametric horizons of pure dunites and dunites containing variable amounts of interstitial clinopyroxene (Cpx) and plagioclase (Fig. 2). The abundance of these interstitial minerals, witnesses of melt percolation, and the degree of differentiation increase upward in most sections, e.g., lower Mg# (100 × Mg/[Mg + Fe_{Total}]) in olivine and Cpx, lower NiO in olivine, and higher TiO_2 in chromite.

In addition to large (millimeter to centimeter) interstitial and poikilitic Cpx compositions (Cr, Al, and Ti rich) consistent with an igneous origin, tiny (tens to hundreds of microns) Cpx crystals underline olivine grain rims (Fig. 3A). They display high Mg# (93 < Mg# < 99) and CaO (>25 wt%) and low Al_2O_3, Cr_2O_3, and TiO_2 contents (see the GSA Data Repository[1]). These compositions are spread between two end members, the igneous Cpx and the diopsides found in hydrothermal diopsidite veins (Python et al., 2011) (Fig. 4A). They are observed in two-thirds of the samples, distributed across the DTZ and particularly abundant at the top of the diapir. Inclusions of Cpx in chromite exhibit the same range of compositions.

Among the other exotic **[[SU: should not be in quotes. “exotic” has specific geological meaning (i.e., foreign or introduced); is meaning here “unusual” or similar?]]** interstitial phases, we observed grossular garnet (37 samples; Fig. 3B), amphibole (pargasites and magnesio-hornblendes) (41 samples; Fig. 3C), and enstatite (Opx, 19 samples; Fig. 3D). Almost all occurrences of amphibole and garnet are in the upper half of the DTZ (>~150 m above its base), and Opx is restricted to its upper part

(>~250 m) (Fig. 2). The vertical distribution of each mineral phase in inclusions in chromite grains perfectly mimics their distribution in the olivine matrix.

Interstitial calcic amphiboles (Fig. 3C) have a lower TiO_2 content (mostly <0.2 wt%) than those in inclusions in chromite (0.2–0.9 wt%) (Fig. 4B). This can be attributed to chemical exchange with the host chromites. All amphiboles (both interstitial and enclosed in chromite) display a common evolution of $(Na^{+}K)_{A}$ element concentration from 0.4 to 1. DTZ Opx forms oikocrysts with lobate contacts with olivine, in obvious contrast to their porphyroclastic texture in mantle harzburgite (Fig. 3D). The composition of the two kinds of Opx is also contrasted (Fig. 4C): DTZ Opx (both oikocrysts and inclusions in chromite) have a much higher TiO_2 content for similar Mg#, reaching 0.37 wt% (average = 0.2 wt%). Among the ~400 analyzed inclusions in chromite (Figs. 3E, 3F), 40% = amphibole (mostly pargasite), 39% = igneous Cpx, 7% = hybrid diopside, 7% = olivine, 3% = mica (Na-rich aspidolite and K-rich phlogopite), 3% = Opx, and 1% = plagioclase and garnet.

INVOLVMENT OF A HYDROUS MELT IN THE GENESIS OF THE DTZ

Variations in the distribution of the interstitial minerals evoke crystallization from a percolating melt in response to compaction (Rabinowicz et al., 1987). In previous studies, the origin of the DTZ has been discussed in a dry igneous system. Interstitial, igneous, Ti-rich Cpx indicates that a MORB melt percolated through the Maqsad DTZ (Abily and Ceuleneer, 2013; this study). This is also evidenced by the composition of the feeding melt channels entrapped in the underlying mantle harzburgite (Kelemen et al., 1995; Ceuleneer et al., 1996; Benoit et al., 1996) and by the composition of the troctolitic-gabbroic sills inside the DTZ (Korenaga and Kelemen, 1997). However, the nature and abundance of the exotic minerals call for pervasive percolation of another water- and silica-rich melt throughout the DTZ that occurred early, as demonstrated by the entrapment of these minerals in the chromite grains. This leads us to formulate the hypothesis that the hydrous melt percolation did not occur after dunite formation, but that it contributed to the process that built the DTZ.

The possibility of a hydrous origin of dunites at a temperature significantly lower than the liquidus of dry basaltic melts was stressed in the seminal work of Bowen and Tuttle (1949). Addition of water to the system triggers the incongruent melting of enstatite into olivine and silica melt. Dunite will form, and excess silica produced by this reaction is exported from the system. Opx will eventually crystallize where this silica-enriched melt accumulates and cools. The absence of Opx in the lower part of the DTZ and its crystallization at its top is elegantly accounted for in this frame.

ORIGIN OF WATER

A water-saturated melt can have different origins: (1) a mantle source hydrated in a subduction setting (e.g., MacLeod et al., 2013), (2) a shallow lithospheric source hydrated by hydrothermal fluids and undergoing remelting in response to the rise of a mantle diapir (Benoit et al., 1999), (3) an extreme degree of fractional crystallization of a dry (actually water poor) MORB, and (4) hybridization of a MORB with hydrothermal fluids.

In the first two hypotheses, the mantle source is depleted in incompatible elements, including Ti. Primitive cumulates rich in Opx are widespread in the ophiolite but crystallized from highly depleted melts (Benoit et al., 1999; Python and Ceuleneer, 2003; Akizawa and Arai, 2009). High Mg# in interstitial Opx in dunite seems to

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contradict MORB involvement (e.g., Wang et al., 2016) but not the high Ti content. Moreover, the successive occurrences of garnet, amphibole, and then Opx upsection (Fig. 2) are not in accordance with a deep-water source, which should have delivered hydrated melt across the DTZ. The third hypothesis is difficult to reconcile with the high Mg# of Opx and the abundance of amphibole: even if we consider that the Mg# is partly buffered by high-forsterite olivine, the degree of fractional crystallization necessary to reach water saturation should be far too high (Gillis and Meyer, 2001).

This led us to explore the fourth hypothesis. The percolation of high-temperature hydrothermal fluids in the Oman lower oceanic crust is well documented (e.g., Coogan, 2003; Bosch et al., 2004; Akizawa et al., 2011; Koepke et al., 2014). The distribution of hydrous minerals in the DTZ is consistent with the involvement of hydrothermal water. The fact that Cpx composition spreads between igneous and hydrothermal end members (Fig. 4A) is strong evidence for hybridization. We propose that the hybrid melt is a blend between supercritical hydrothermal fluids rich in silica, i.e., trondhjemitic melt issued from hydrous melting of the country rocks (Amri et al., 1996), and variably evolved MORB.

Synmagmatic faults are present at the base of the Maqsad lower crust and were main avenues for seawater penetration down to the Moho (Abily et al., 2011). The brittle features affecting the DTZ may be the late expressions of faults that were active earlier. They mainly affect the top of the DTZ and are, with the hydrous mineral distribution (Fig. 2), consistent with a water supply from above. The presence of Opx and amphibole in layered gabbroic cumulates in present-day oceanic lower crust was also explained by the involvement of hydrothermal fluids (Gillis and Meyer, 2001) and by the extraction from the mantle of heterogeneous batches of slightly evolved and unmixed melt (Gillis et al., 2014).

THERMAL AND CHEMICAL GEODYNAMIC IMPLICATIONS

Interstitial hydrous minerals described in this study crystallized early, as shown by similar phases enclosed in chromite grains. Purely hydrothermal alteration followed the magmatic activity, as indicated by Cpx and amphibole alteration products (Fig. 4B) and the presence of hydrogrossular and serpentine (see also Gregory and Taylor, 1981), but obviously did not totally overprint the high-temperature features. This suggests a high cooling rate of the DTZ, consistent with previous geothermometric studies of the base of the Oman lower crust (VanTongeren et al., 2008) and uppermost mantle section (Dygert and Liang, 2015).

Below a 5–6-km-thick crust, the stability field for Opx and amphibole after fractionation from a primitive (virtually dry) to a highly evolved (water-saturated) MORB may imply temperature decrease to ~950 °C (pressure of 0.2 GPa) (Berndt et al., 2005). High-temperature conditions of crystallization of diopside from hybrid melts are supported both by their entrapment in chromite and their coexistence with igneous Cpx. Regarding the composition range pointing toward igneous Cpx, the crystallization temperature of diopside seems to be higher than the 600–800 °C previously estimated for a pure hydrothermal frame (Python et al., 2007; Arai and Akizawa, 2014). Although the garnet stability field is variable (300–800 °C) (e.g., Bach and Klein, 2009; Newton and Manning, 2007), inclusions of andradite and grossular in chromites show that they also fractionated at a high temperature. Considering that a dry MORB injected at Moho level during the rise of the Maqsad diapir reached 1230 °C (Ceuleneer et al., 1996), the mineralogical distribution through the DTZ (Fig. 2) points toward a thermal gradient of about few hundreds degrees in only few hundred meters, making the Moho a clear rheological transition between the hot ductile mantle above the diapir and the lower crust.

CONCLUSIONS

We propose that the formation of the DTZ bears witness to transient processes attributable to the meeting, at Moho level, of an ascending front of mantle partial melts and a descending front of hydrothermal fluids. This specific context triggers the formation of hybrid melts out of equilibrium with their country rocks, which contribute to deeply modify the mineralogical and geochemical composition of the shallow mantle and deep crust. Furthermore, hydrous melts are well known to be particularly efficient in mobilizing metals, such as Cr, in the formation of chromitite ore bodies (Borisova et al., 2012). Our results suggest that the DTZ is among the most reactive interfaces on Earth. Its formation may be a major factor in the global chemical transfer and redistribution between the mantle, the crust, and the ocean, and can condition the cycle of carbon, halogens, and gases such as hydrogen and methane.

Our views, although challenging, do not fully contradict previous models for the genesis of the DTZ, but reconcile different pieces of evidence in a more general scenario.

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REFERENCES CITED

Abily, B., and Ceuleneer, G., 2013, The dunitic mantle-crust transition zone in the Oman ophiolite: Residue of melt-rock interaction, cumulates from high-MgO melts, or both?: Geology, v. 41, p. 67–70, doi:10.1130/G33351.1.

Abily, B., Ceuleneer, G., and Launeau, P., 2011, Synmagmatic normal faulting in the lower oceanic crust: Evidence from the Oman ophiolite: Geology, v. 39, p. 391–394, doi:10.1130/G31652.1.

Akizawa, N., and Arai, S., 2009, Petrologic profile of peridotite layers under a possible Moho in the northern Oman ophiolite: An example from Wadi Fizh: Journal of Mineralogical and Petrological Sciences, v. 104, p. 389–394, doi:10.2465/jmps.090622a.

Akizawa, N., Arai, S., Tamura, A., Uesugi, J., and Python, M., 2011, Crustal diopsidites from the northern Oman ophiolite: Evidence for hydrothermal circulation through suboceanic Moho: Journal of Mineralogical and Petrological Sciences, v. 106, p. 261–266, doi:10.2465/jmps.110621b.

Amri, I., Benoit, M., and Ceuleneer, G., 1996, Tectonic setting for the genesis of oceanic plagiogranites: Evidence from a paleo-spreading structure in the Oman ophiolite: Earth and Planetary Science Letters, v. 139, p. 177–194, doi:10.1016/0012-821X(95)00233-3.

Arai, S., and Akizawa, N., 2014, Precipitation and dissolution of chromite by hydrothermal solutions in the Oman ophiolite: New behavior of Cr and chromite: American Mineralogist, v. 99, p. 28–34, doi:10.2138/am.2014.4473.

Bach, W., and Klein, F., 2009, The petrology of seafloor rodingites: Insights from geochemical reaction path modeling: Lithos, v. 112, p. 103–117, doi:10.1016/j.lithos.2008.10.022.

Benoit, M., Polvé, M., and Ceuleneer, G., 1996, Trace element and isotopic characterization of mafic cumulates in a fossil mantle diapir (Oman ophiolite): Chemical Geology, v. 134, p. 199–214, doi:10.1016/S0009-2541(96)00087-3.

Benoit, M., Ceuleneer, G., and Polvé, M., 1999, The remelting of hydrothermally altered peridotite at mid-ocean ridges by intruding mantle diapirs: Nature, v. 402, p. 514–518, doi:10.1038/990073.

Berndt, J., Koepke, J., and Holtz, F., 2005, An experimental investigation of the influence of water and oxygen fugacity on differentiation of MORB at 200 MPa: Journal of Petrology, v. 46, p. 135–167, doi:10.1093/petrology/egh066.

Borisova, A.Y., et al., 2012, A new view on the petrogenesis of the Oman ophiolite chromitites from microanalyses of chromite-hosted inclusions: Journal of Petrology, v. 53, p. 2411–2440, doi:10.1093/petrology/egs054.

Bosch, D., Jamais, M., Boudier, F., Nicolas, A., Dautria, J.M., and Agrinier, P., 2004, Deep and high-temperature hydrothermal circulation in the Oman ophiolite—Petrological and isotopic evidence: Journal of Petrology, v. 45, p. 1181–1208, doi:10.1093/petrology/egh010.

Bowen, N.L., and Tuttle, O.F., 1949, The system MgO-SiO_2-H_2O: Geological Society of America Bulletin, v. 60, p. 439–460, doi:10.1130/0016-7606(1949)60[439:TSM]2.0.CO;2.

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Ceuleneer, G., Nicolas, A., and Boudier, F., 1988, Mantle flow patterns at an oceanic spreading centre: The Oman peridotites record: Tectonophysics, v. 151, p. 1–26, doi:10.1016/0040-1951(88)90238-7.

Ceuleneer, G., Monnereau, M., and Amri, I., 1996, Thermal structure of a fossil mantle diapir inferred from the distribution of mafic cumulates: Nature, v. 379, p. 149–153, doi:10.1038/379149a0.

Coogan, L.A., 2003, Contaminating the lower crust in the Oman ophiolite: Geology, v. 31, p. 1065–1068, doi:10.1130/G20129.1.

Dick, H.J.B., 1977, Evidence of partial melting in the Josephine Peridotite, *in* Dick, H.J.B., ed., Magma Genesis 1977: Proceedings of the American Geophysical Union Chapman Conference on Partial Melting in the Earth’s Upper Mantle: State of Oregon Department of Geology and Mineral Industries, p. 59–62.

Dygert, N., and Liang, Y., 2015, Temperatures and cooling rates recorded in REE in coexisting pyroxenes in ophiolitic and abyssal peridotites: Earth and Planetary Science Letters, v. 420, p. 151–161, doi:10.1016/j.epsl.2015.02.042.

Elthon, D., 1979, High magnesia liquids as the parental magma for ocean floor basalts: Nature, v. 278, p. 514–518, doi:10.1038/278514a0.

Gillis, K.M., and Meyer, P.S., 2001, Metasomatism of oceanic gabbros by late stage melts and hydrothermal fluids: Evidence from the rare earth element composition of amphiboles: Geochemistry, Geophysics, Geosystems, v. 2, 1012, doi:10.1029/2000GC000087.

Gillis, K.M., et al., 2014, Primitive layered gabbros from fast-spreading lower oceanic crust: Nature, v. 505, p. 204–207, doi:10.1038/nature12778.

Greenbaum, D., 1972, Magmatic processes at ocean ridges: Evidence from Troodos massif, Cyprus: Nature, v. 238, p. 18–21, doi:10.1038/physci238018a0.

Gregory, R.T., and Taylor, H.P., 1981, An oxygen isotope profile in a section of Cretaceous oceanic crust, Samail Ophiolite, Oman: Evidence for $\delta^{18}O$ buffering of the oceans by deep (>5 km) seawater-hydrothermal circulation at mid-ocean ridges: Journal of Geophysical Research, v. 86, p. 2737–2755, doi:10.1029/JB086iB04p02737.

Kelemen, P.B., Shimizu, N., and Saltersi, V.J., 1995, Extraction of mid-ocean-ridge basalt from the upwelling mantle by focused flow of melt in dunite channels: Nature, v. 375, p. 747–753, doi:10.1038/375747a0.

Koepke, J., Berndt, J., Horn, I., Fahle, J., and Wolff, P.E., 2014, Partial melting of oceanic gabbro triggered by migrating water-rich fluids: A prime example from the Oman Ophiolite, *in* Rollinson, H.R., et al., eds., Tectonic evolution of the Oman Mountains: Geological Society of London Special Publication 392, p. 195–212, doi:10.1144/SP392.10.

Korenaga, J., and Kelemen, P.B., 1997, Origin of gabbro sills in the Moho transition zone of the Oman ophiolite: Implications for magma transport in the oceanic lower crust: Journal of Geophysical Research, v. 102, p. 27,729–27,749, doi:10.1029/97JB02604.

MacLeod, C.J., Lissenberg, C.J., and Bibby, L.E., 2013, “Moist MORB” axial magmatism in the Oman ophiolite: The evidence against a mid-ocean ridge origin: Geology, v. 41, p. 459–462, doi:10.1130/G33904.1.

Moores, E.M., and Vine, F.J., 1971, The Troodos massif, Cyprus and other ophiolites as oceanic crust—Evaluation and implications: Royal Society of London Philosophical Transactions, ser. A, v. 268, p. 443–467, doi:10.1098/rsta.1971.0006.

Newton, R.C., and Manning, C.E., 2007, Solubility of grossular, $Ca_3Al_2 Si_3O_{12}$, in H_2O-NaCl solutions at 800° C and 10kbar, and the stability of garnet in the system $CaSiO_3$-Al_2O_3-H_2O-NaCl: Geochimica et Cosmochimica Acta, v. 71, p. 5191–5202, doi:10.1016/j.gca.2007.08.021.

Pearce, J.A., Alabaster, T., Shelton, A.W., and Searle, M.P., 1981, The Oman ophiolite as a Cretaceous arc-basin complex: Evidence and implications: Royal Society of London Philosophical Transactions, ser. A, v. 300, p. 299–317, doi:10.1098/rsta.1981.0066.

Python, M., and Ceuleneer, G., 2003, Nature and distribution of dykes and related melt migration structures in the mantle section of the Oman ophiolite: Geochemistry, Geophysics, Geosystems, v. 4, 8612, doi:10.1029/2002GC000354.

Python, M., Ceuleneer, G., Ishida, Y., Barrat, J.A., and Arai, S., 2007, Oman diopsidites: A new lithology diagnostic of very high temperature hydrothermal circulation in mantle peridotite below oceanic spreading centres: Earth and Planetary Science Letters, v. 255, p. 289–305, doi:10.1016/j.epsl.2006.12.030.

Python, M., Yoshikawa, M., Shibata, T., and Arai, S., 2011, Diopsidites and rodingites: Serpentinisation and Ca-metasomatism in the Oman Ophiolite mantle, *in* Srivastava, R.K., ed., Dyke swarms: Keys for geodynamic interpretation: Berlin, Springer-Verlag, doi:10.1007/978-3-642-12496-9_23.

Rabinowicz, M., Ceuleneer, G., and Nicolas, A., 1987, Melt segregation and flow in mantle diapirs below spreading centers: evidence from the Oman ophiolite: Journal of Geophysical Research, v. 92, p. 3475–3486, doi:10.1029/JB092iB05p03475.

VanTongeren, J.A., Kelemen, P.B., and Hanghøj, K., 2008, Cooling rates in the lower crust of the Oman ophiolite: Ca in olivine, revisited: Earth and Planetary Science Letters, v. 267, p. 69–82, doi:10.1016/j.epsl.2007.11.034.

Wang, C., Liang, Y., Dygert, N., and Xu, W., 2016, Formation of orthopyroxenite by reaction between peridotite and hydrous basaltic melt: An experimental study: Contributions to Mineralogy and Petrology, v. 171, 77, doi:10.1007/s00410-016-1287-z.

Yamasaki, T., Maeda, J., and Mizuta, T., 2006, Geochemical evidence in clinopyroxenes from gabbroic sequence for two distinct magmatisms in the Oman ophiolite: Earth and Planetary Science Letters, v. 251, p. 52–65, doi:10.1016/j.epsl.2006.08.027.

FIGURE CAPTIONS

Figure 1. A: Location of the Oman ophiolite. B: Geological map of the southeast massifs of the Oman ophiolite showing the Maqsad paleo-ridge segment (red outline) and the inferred position of the paleo-spreading axis (red dotted line) (Python and Ceuleneer, 2003). C: Enlargement of the Maqsad diapir area; orange lines indicate the positions of our cross sections.

Figure 2. Synthetic lithological log showing the vertical distribution of the mineral assemblages along the dunitic transition zone (DTZ) in the vicinity of the Maqsad diapir, Oman. Pl—plagioclase; Ol—olivine.

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Figure 3. Photomicrographs showing the texture of the various minerals constituting the dunitic transition zone dunites and phases enclosed as inclusions in chromite grains. A: 500 μm clinopyroxene (tiny diopside) underlying olivine grains. B: Interstitial grossular garnet (sporadically associated with hydrogrossular and andradite; see the Data Repository; see footnote 1). C: Interstitial pargasite (frequently associated with magnesiohornblendes and rare magnesio-hastingsites). D: Oikocrystic orthopyroxene in dunite showing lobate contacts with olivine. E, F: Inclusions of garnet, clinopyroxene, hybrid diopside, orthopyroxene, and amphibole in chromite.

Figure 4. Major element compositions of clinopyroxene (cpx), amphibole (amph), and orthopyroxene (opx) observed interstitially in dunite and in inclusion in chromites. A: Al_2O_3 and TiO_2 versus Mg# in clinopyroxene. B: TiO_2 versus Al_2O_3 and $(Na^+K)_A$ versus Al_{IV} in amphiboles. C: TiO_2 versus Mg# in orthopyroxene.

[1]GSA Data Repository item 2017xxx
, is available online at
http://www.geosociety.org/datarepository/2017/ or on request from
editing@geosociety.org.