Relationships between geochemistry and structure beneath a palaeo-spreading centre: a study of the mantle section in the Oman ophiolite

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Abstract

The Oman ophiolite exposes a large and well-preserved mantle section beneath a palaeo-spreading centre. The mantle section is mainly composed of extremely refractory harzburgites with relatively homogeneous modal and major element compositions. Nevertheless, our trace element data exhibit variations connected with the main mantle structures, which allow us to define three geochemical and structural domains. The main harzburgitic mantle section, mainly constituted of strongly refractory harzburgites characterised by chondrite-normalised REE patterns that are steadily depleted from HREE to LREE. These rocks are interpreted as mantle residues after \( 15\% \) melt extraction. Their REE signature can be explained by melt transport associated with partial melting. The diapir areas (mainly the Maqsad diapir), defined by plunging lineations. They are constituted of harzburgites with roughly the same modal composition as the main mantle section but distinct, concave-upward REE patterns. The regions of most active upwelling (characterised by sub-vertical lineations) are further distinguished by higher Al\(_2\)O\(_3\)/CaO ratios and TiO\(_2\) contents. This character is ascribed to focused partial melt upwelling. The diapirs are interpreted as local instabilities in upwelling mantle, possibly triggered by feedback mechanisms between deformation and melt percolation. The Maqsad diapir is topped by a thick, dunitic, mantle–crust transition zone (MTZ) that displays the same trace-element signature as the diapir. However, the dunites are distinguished by low Mg\# values and Ni contents. Together with structural evidence, this allows us to interpret the MTZ dunites as diapir harzburgites that were strongly modified by olivine-forming melt–rock reactions at high melt/rock ratios. The MTZ is thought to act as a major collecting zone for mantle melts. The cpx-harzburgites from the base of the mantle section. These rocks are distinguished by high clinopyroxene contents (> 5%), low Al\(_2\)O\(_3\)/CaO and ‘spoon-shaped’ REE patterns. They were individualised from the rest of the harzburgite mantle section by a cpx-forming melt–rock reaction at decreasing melt mass. This reaction probably occurred at near-solidus conditions along the lithosphere–asthenosphere boundary. The formation of these three domains may be integrated in a geodynamic scenario involving the reactivation of an oceanic lithosphere, a process that would be related to the ridge propagator identified in the Oman ophiolite. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

Petrological and geochemical studies of mid-ocean ridge basalts (MORB) and abyssal peridotites, together with geophysical studies, have revealed the complexity of melting and melt migration mechanisms associated with the accretion of oceanic lithosphere (see reviews [1–3]). Yet, the exact nature of melt processes in the upper mantle below spreading ridges is still debated [4–7]. Important issues are whether melting is fractional or at equilibrium (e.g., [8]) and whether melts are transported by pervasive porous flow (e.g., [6,9]) or in chemically isolated conduits (porous flow channels [5] or fractures [4]).

Recent studies have shown that trace element variations in mantle peridotites, coupled with textural and petrographic investigations, and numerical modelling, may be used to evaluate the extent of processes such as melt transport and melt–rock interactions [5,6,10–15]. However, trace element data are scarce for abyssal peridotites because these rocks are rarely exposed and difficult to analyse by traditional analytical methods due to their extreme depletion. Until recently, geochemical data on oceanic lithosphere were mostly restricted to rare earth elements (REE) in clinopyroxenes from abyssal [8,16] and ophiolite [5,15] peridotites and rarely, in whole rock [17–20]. New perspectives have been opened by inductively coupled plasma–mass spectrometry (ICP–MS), which makes it possible to measure a number of trace elements (for instance, U, Th, Nb, Ta plus REE) at the very low concentration levels typical of oceanic peridotites [6,21,22].

Abyssal peridotites make it possible to study mantle processes in present-day oceanic settings (e.g., [6,8,21]), but their sampling is exceptional and limited to the uppermost limit of the oceanic mantle. In contrast, ophiolites expose large mantle sections as well as mantle–crust relationships, and make it possible to study large-scale variations in peridotites [5,15,23]. As such, their study can bring new insights into the understanding of melt processes occurring in the oceanic mantle lithosphere.

The Oman ophiolite contains the largest and one of the best-preserved sections of oceanic lithosphere [4,24,25]. In this paper, we present a systematic study of major and trace elements in the mantle peridotites of this ophiolite. Our purpose is to characterise the composition of the mantle section and to combine geochemical and structural data to place constraints on melt processes in the oceanic upper mantle.

2. Geological setting

The mantle section of the Oman ophiolite is mainly composed of harzburgite tectonites with coarse-grained porphyroclastic textures inherited from high-temperature (T > 1200°C) deformations associated with asthenospheric mantle flow [24,25]. It also contains a few centimetre- to metre-thick dunite bands, discordant to the harzburgite foliation. Near the base and top of the mantle section, the dunite bands become parallel to the foliation.

As illustrated in Fig. 1, this study is focused on the south-eastern massifs of Nakhl, Sumail and Wadi Tayin, where the mantle section can reach a thickness of 12 km below the Moho (in the north-eastern part of Wadi Tayin [24,25]). In this region, structural studies have revealed the existence of a complex ridge system [26,27] and diapir areas characterised by concentric plunging peridotite lineations [28]. In the Sumail and Wadi Tayin massifs, diabase dyke directions define two ridge systems that are interpreted as the opening of a NW–SE propagator in a slightly older lithosphere, characterised by NE–SW diabase trajectories [26,27]. In the Sumail and Nakhl massifs, the peridotite foliation is generally parallel to the Moho, except in diapir areas. Diapirs are kilometre-scale concentric structures (∼10×10 km²), characterised by steep vertical foliations (> 45°) and lineations (> 30°). They are observed...
mostly along the NW–SE ridge system [27]. Thick dunite mantle–crust transition zones (MTZ – up to 800 m thick) are observed at the top of the diapiric structures [29]. MTZ contain diffuse segregations of clinopyroxene and plagioclase (‘impregnated’ dunites) as well as numerous gabbro sills. At the base of the ophiolite slab, the high-temperature deformation is overprinted by a low-temperature (1100–900°C) deformation, responsible for a fine-grained porphyroclastic texture in the harzburgites [24]. The low-temperature deformation is ascribed to the early detachment of the ophiolite [25,30].

3. Sampling

The 29 peridotites analysed for this study are described in Table 1. Twenty-four peridotites were sampled within the limits of the NW trending propagator (Fig. 1). These include two harzburgites from the vicinity of the small Nakhl diapir (95OA77, 93OF101) and 16 samples from the Maqsad diapir area, in the western part of the Sumail massif. Among the Maqsad samples, 11 are harzburgites from the diapir area (defined by lineations ≥30°) and three are dunites (devoid of ‘impregnation’ features) from the thick transition zone set above the diapir. The two other Maqsad peridotites represent the transition from the main harzburgitic sequence (96OF59B) to the dunitic MTZ (96OF59). The five remaining peridotites are from the north of the Wadi Tayin massif. They were sampled by Boudier and Coleman [24] and have already been studied by Kelemen and co-workers [5]. Two samples are dunites...
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see overleaf for more information.
from 7–8 km below the Moho, and three are harzburgites from the low-temperature deformation zone (10–12 km below the Moho). These last three harzburgites are clinopyroxene-rich (cpx > 5%), compared with the other Oman harzburgite. In the following, they will be referred to as cpx-harzburgites.

4. Geochemistry of the Oman ophiolite peridotites

The samples were analysed as whole rocks for major, minor (Ni, Cr) and trace elements (REE, Cs, Rb, Ba, Th, U, Pb, Nb, Ta, Zr and Hf). Trace element concentrations were determined on a VG-PQ2 Turbo+ ICP-MS (ISTEEM, Montpellier) following the method described in the EPSL Online Background Dataset. Analytical results are given in Table 1.

4.1. Major and minor elements

The analysed samples plot near the most depleted end of the mantle fractionation array on the MgO/SiO2 vs. Al2O3/SiO2 diagram (Fig. 2a). Similar to the most refractory abyssal peridotites [6,21,31], the Oman peridotites display low Al2O3/SiO2 ratios (0.01–0.03). They also have high MgO/SiO2 ratios typical of refractory mantle rocks and, except for the addition of water, do not display any of the major element variations occasionally associated with oceanic alteration (e.g., MgO depletion [6,32]). The harzburgite composition in Fig. 2a is consistent with the evolutionary trend—parallel to the mantle array—shown by Southwest Indian Ridge and Western Alps peridotites.

Similar to other suites of mantle rocks, the Oman peridotites show a broad positive correlation between Al2O3 and CaO (Fig. 2b). However, in contrast to dominantly lherzolitic suites (e.g., Western Alps peridotites) that show nearly constant Al2O3/CaO ratios close to primitive mantle estimates, the Oman peridotites show important variations of this ratio. Al2O3/CaO tends to decrease with increasing fertility (i.e., cpx content) in the main harzburgite sequence, down to very low values (0.53–0.69) in the cpx-harzburgites from the base of the mantle section. In contrast, the harzburgites from the most actively upwelling areas in the Maqsad diapir (inner zones, with lineation dip > 40°), as well as the MTZ dunites and the harzburgite 96OF59B collected close to the Maqsad MTZ, are distinguished by higher Al2O3/CaO ratios (0.94–1.17). These samples are also enriched in TiO2 (0.07–0.08) compared with the other peridotites (TiO2 < 0.02).

With the exception of the MTZ dunites, the studied peridotites have a narrow range of MgO and FeO contents (Fig. 2c). The Mg# ratio (100×(Mg+Fe_total)/SiO2) of these samples (90.8 ± 0.3) does not show significant variations as a function of peridotite fertility, from the dunites of the main mantle section to the cpx-harzburgites. In contrast, the MTZ dunites display variable MgO and FeO contents, and lower Mg# values (87.8–
90.1) than the other peridotites. The MTZ samples are further distinguished by lower Ni contents (6150 ppm) than the other Oman peridotites (1923–2530 ppm, this study and unpublished data).

4.2. Trace elements

The normalised REE and trace element patterns of the analysed samples are shown in Figs. 3 and 4, respectively. Similar to other ophiolitic refractory peridotites (e.g., [18,22,33]), the Oman peridotites are strongly depleted in lithophile trace elements, with whole rock concentrations well below chondritic and primitive mantle (PM) values (mostly <0.1×PM).

The harzburgites from the main mantle section display relatively linear REE patterns (Fig. 3a), characterised by a steady decrease of normalised REE abundances from heavy (HREE) to light (LREE). The harzburgites from the Maqsad diapir area are distinguished by concave-upward REE patterns (Fig. 3b), with a steep HREE segment from Gd to Lu, and a relatively flat LREE segment from La to Gd. In addition, diapir harzburgites are characterised by strikingly homogeneous HREE contents. It is worth noting that the two harzburgites from the Nakhl diapir area...
and the harzburgite 96OF59B collected close to the Maqsad MTZ (Fig. 3a) also have concave-upward REE patterns, very similar in shape to those observed in the Maqsad diapir. The dunites have almost linear or slightly concave REE patterns (Fig. 3c), without significant differences between dunites from the main mantle section and those from the MTZ. The cpx-harzburgites are clearly distinguished from the other peridotites by ‘spoon-shaped’ REE patterns. They show a convex-upward distribution of middle REE (MREE) and HREE, from Nd to Lu, and a slight enrichment of La and Ce. These REE patterns are very similar in shape to those obtained by Kellenen et al. [5] on clinopyroxenes from the same samples (OMB14, OMB23 and OMB27 analysed by SIMS). In addition, the cpx-harzburgites display the highest HREE contents (Yb = 0.4×chondrites), but almost the lowest LREE abundances (Ce = 0.004–0.015×chondrites), among the studied peridotites.

Similar to refractory peridotites from other mantle suites [14,21,22,34,35], the Oman peridotites are characterised by U-shaped normalised trace element patterns (Fig. 4). These patterns reflect the depletion of LREE, Zr and Hf relative to HREE, and the selective enrichment of highly incompatible elements (Cs to Ta) relative to LREE (e.g., Th/Ce = 0.9–9.1×PM). However, the trace element patterns show prominent Sr spikes which are reflected in extremely high Sr/Ce ratios (up to 390×PM). In addition, U, Nb and Ta are enriched relative to the neighbouring elements Th and LREE. The U/Th ratio, for instance, is in the range of 1.1–5.3×PM. The Nb/Ta ratio is generally close to PM estimates (20.7±2.6, compared with PM = 17.6 [36]), except for the inner zone of the Maqsad diapir and the two samples from the Nakhl diapir area. Being strongly depleted in Ta relative to Nb, these samples are distinguished by high Nb/Ta values, up to 78 (Figs. 4 and 5). Zr shows variable, but systematic,
depletion relative to MREE and Hf. The Zr/Hf ratio (10.8–25.3) is lower than PM estimates (36.25 [36]).

5. Discussion

The mantle unit of the Oman ophiolite is composed of refractory peridotites with extremely low trace element contents. However, the samples are much less depleted in LREE relative to MREE and HREE than generally expected for mantle residues after partial melting (e.g., [17,18,33,37]). Some samples from the diapir areas and the cpx-harzburgites from the base of the mantle unit even show subtle LREE enrichment on normalised diagrams (Fig. 3). Furthermore, all samples are enriched in highly incompatible elements (Rb to Ta) relative to LREE (Fig. 4).

LREE enrichment in ophiolitic peridotites is generally attributed to secondary processes such as serpentinisation, oceanic alteration or contamination by crustal fluids during ophiolite obduction (Fig. 5).
tion [33,37]. However, similar to geochemical parameters hardly affected by alteration (e.g., MREE/HREE ratio, and Al₂O₃ and TiO₂ concentrations), LREE/MREE and LREE/HREE ratios in Oman peridotites show variations related to mantle structures. The (Ce/Sm)₈ ratio, for instance, is in the range 1.35–1.43 in the Maqsad diapir area, compared with 0.65–1.11 in the main harzburgite section. Clearly, such a relationship is not consistent with secondary contamination. In addition, trace element enrichment involves elements such as Th, Nb and Ta, which are reputedly immobile during alteration. In fact, the paradox of incompatible trace element enrichment in refractory peridotites is not specific to the ophiolites. Virtually all harzburgitic mantle rocks for which trace element data are available show similar enrichment marked by U-shaped trace element patterns ([34] and references therein, [14,21,22]). In several cases, the enrichment is observed in peridotites that are totally devoid of alteration, as well as in acid-leached mineral separates [35,38]. For these reasons, we consider that the U-shaped trace element patterns of the analysed samples (Fig. 4) represent a mantle signature. In detail, however, the distribution of the alkaline and alkaline-earth elements (Cs, Rb, Ba and Sr), and particularly the positive Sr anomaly, might result from secondary processes. Yet, no correlation is observed between the serpentinisation degree and, for instance, Sr/Ce.

Based on the distribution of the less mobile elements, including REE, our data define three geochemical domains, broadly coinciding with major structural features: (1) a main harzburgite section, (2) a diapiric domain, including the Maqsad and Nakhl diapir harzburgites as well as the MTZ dunites, and (3) a basal section constituted of cpx-harzburgites. In the following, we discuss the role of melt processes in the individualisation of these three domains, as well as their geodynamic significance.

5.1. The main harzburgite section: melt extraction versus melt transport

Away from diapir areas and at some distance (> 2 km) above the base of the ophiolite slab, the main harzburgite section is composed of refractory peridotites with relatively homogeneous modal and major element compositions. To account for these compositions, melting of a pristine mantle source requires a high degree of melt extraction, in the range 15–30% (Fig. 6 [39,40]). Such values are significantly higher than melting degrees inferred for MORB (5–15% [2]) and high-Ti magmas such as those forming the dyke complex and the MORB-like Geotimes lava sequence in Oman [25]. Present-day intermediate and fast-spreading ridges show a similar discrepancy between melting degree inferred from residual mantle and that inferred from lava (e.g., [6,16]). This paradox is generally solved by considering that abyssal peridotites represent only the shallowest part of the mantle column affected by partial melting and thus record the highest melting degrees. In contrast, MORB are thought to represent integrated melts from the whole melting column and thus record average melting degrees. In
Oman, however, the main harzburgite section does not show any change that would indicate decreasing melting degree at depth, down to about 10 km from the Moho. In terms of cpx content, the basal section of the mantle unit is more fertile than the main harzburgite section. However, as discussed below, this feature results from secondary fertilisation rather than from a lesser degree of melt extraction.

In fact, melt extraction fails to account for two notable features of the Oman harzburgites: (1) their relatively linear REE patterns (Fig. 3), with no trace of the strong LREE depletion predicted by the standard melting models (e.g., [8]) and (2) the high olivine proportion (75–85%) observed in several samples (Fig. 6). The relatively unfracti- onated REE distribution may simply result from melt transport through molten peridotites (e.g., [10–12,41]), a process which was also referred to as ‘open-system melting’ [42]. During this process, the most incompatible elements (LREE) tend to be ‘buffered’ by percolating melt while the less incompatible elements (HREE), similar to major elements, are governed by melting reactions [13,41,43]. As noted by Vernière et al. [41], this process would account for negative correlations between LREE/HREE ratios and peridotite fertility, as commonly observed in heterogeneous peridotite suites ([34] and references therein). However, melt transport alone cannot explain olivine proportions higher than predicted by melting reactions [39,40]. This feature is indicative of olivine-forming reactions between residual peridotites and infiltrated melts ([3,44] and references therein).

With respect to incompatible trace elements, reactive porous flow at increasing melt mass is virtually indistinguishable from partial melting coupled with melt transport. On the other hand, these two processes can be readily distinguished from standard melting models, as well as from reactions at decreasing melt mass [41]. In Fig. 7 are compared two numerical experiments performed with the plate model of Vernière et al. [41]. The first one (Fig. 7a) simulates standard incremental melting [8] and produces strongly LREE-depleted peridotite residues, quite different in shape from the Oman harzburgites. In this experiment, the presence of trapped melt in the residue – due to inefficient melt extraction – does not provide a better fit to the data (Fig. 7c). The second experiment (Fig. 7b) simulates reactive porous flow at increasing melt mass and produces peridotite residues that are only moderately depleted in LREE. Moreover, with a small amount of trapped melt (0.5–1%), this experiment generates linear REE patterns comparable to those of the main harzburgite section.

These results suggest that the Oman harzburgites were pervasively traversed by diffuse melt flow. Porous flow associated with partial melting would account for the observed REE patterns. However, the harzburgites probably underwent more reactive melt flow at a shallow level, which contributed to their olivine enrichment. Crosscutting dunites are widespread throughout the main harzburgite section and would represent end products of the inferred olivine-forming reaction [44]. The dunites were probably individualised by channelled percolation [3,5] at the top of the melting column.

It should nevertheless be noted that interactions of the harzburgites with MORB melts could hardly explain the selective enrichment of highly incompatible elements in these rocks (Fig. 4). The enrichment of Th, Nb and Ta relative to LREE, for instance, suggests that the mantle section was belatedly percolated by small fractions of volatile-rich fluids (see below).

5.2. Diapir domains: high melt flow areas

5.2.1. Mantle diapirs: instabilities created by partial melt upwelling

The Maqsad diapir area is distinguished from the main harzburgite section by concave-upward REE patterns, and low and homogeneous HREE content (Fig. 5a). Moreover, the inner zone of the diapir (lineation dip > 40°) is characterised by elevated Al₂O₃/CaO and Nb/Ta ratios, and high TiO₂ contents (Fig. 5b–d). However, while being closer to PM values in terms of Al₂O₃/CaO, the diapir shows a significant departure from PM with respect to Nb/Ta.

Their homogeneous REE composition indicates that the diapir harzburgites were extensively re-
equilibrated with a pervasive melt [10,13,41]. Likewise, the distinctly higher Al$_2$O$_3$/CaO ratio and TiO$_2$ content of the inner zone are indicative of relatively pristine melt composition, suggesting that the diapir has focused partial melt upwelling. A similar interpretation was recently proposed for refractory peridotites characterised by a high Ti content in minerals [23]. Nb/Ta fractionation is not well understood in this scheme. A possible interpretation is to consider that the melt that flowed through the diapir was enriched in volatiles [22,45–47].

Compositional differences between the Maqsad diapir and the main harzburgite section suggest that the diapir intruded a pre-existing oceanic lithosphere, diapiric upwelling being probably associated with the opening of the NW–SE ridge system. Although radial lineations around the Maqsad diapir suggest a widespread radial solid flow outwards [48], only the MTZ dunites and three harzburgite samples collected in the vicinity of the Maqsad and Nakhl diapirs, close to the MTZ, have geochemical compositions akin to the inner zone of the Maqsad diapir (i.e., high
Al$_2$O$_3$/CaO ratio and TiO$_2$ content, and fractionated Nb/Ta ratio and HREE segment). Therefore, outward flow from diapirs was probably restricted to the shallowest part of the mantle section (mostly the MTZ), with limited extension away from diapir areas.

Dynamic models of mantle upwelling have pointed to the major role of feedback relationships between melt and solid flows (e.g., [49]). The distinctive geochemical composition of the diapirs suggests that they represent instabilities triggered by partial melting and were probably rooted in a larger molten region that is not seen in the ophiolite.

### 5.2.2. Mantle–crust transition zone: melt accumulation at the Moho

The MTZ dunites are distinguished from the other Oman peridotites by lower Ni contents, and lower and more variable Mg# ratios (87.8–90.1, compared with 90.3–91.3 – Fig. 2). In addition, they often show cpx and plagioclase impregnation textures (although not in the studied samples – Table 1). Because of these features, the MTZ was first interpreted as the lowest part of the crustal cumulate sequence [25]. However, the MTZ olivine crystals display the same high-temperature deformation as in the other Oman peridotites. Moreover, the low Ni and Mg# values, as well as the impregnation textures, can be explained by peridotite–melt interaction at a high melt/rock ratio (e.g., [50]). Melt–rock reactions would involve olivine precipitation (to form the dunites), followed by melt consumption (to form the impregnated dunites).

Our data indicate that the MTZ dunites share with the Maqsad diapir several major and trace element characteristics, such as high Al$_2$O$_3$/CaO and Nb/Ta ratios, and high TiO$_2$ contents. Together with the structural observations of Boudier and Nicolas [29], this suggests that the MTZ originates from the inner part of the diapirs, strongly modified by low-pressure melt–rock reactions. Melt accumulation at the Moho would focalise outward solid flow from the diapirs against the mantle–crust boundary. In turn, deformation and/or melt–rock reaction might enhance the role of the MTZ as a collecting layer for partial melts tapped from mantle diapirs.

### 5.3. Cpx-harzburgites: melt freezing at the asthenosphere–lithosphere boundary

In addition to their location at the base of the ophiolite slab, the cpx-harzburgites are distinguished by high cpx contents (> 5% – Table 1) and distinctive ‘spoon-shaped’ REE patterns (Fig. 3). The presence of less refractory peridotites in the lower mantle section is relatively common in harzburgitic ophiolites. It was described in the eastern Mediterranean Tethyan ophiolites [51] and in the Bay of Islands ophiolite, in Newfoundland, for instance [15,23]. These rocks are generally ascribed to a lower degree of melt extraction, the deeper peridotites being supposedly less affected by pressure-release partial melting [15,23].

However, the Oman harzburgites do not show a gradual decrease of their refractory character from the top to the base of the mantle section, as would be expected in this model. Instead, the mantle sequence shows a rapid transition (within less than a few kilometres) from the main harzburgite section to the basal cpx-harzburgites. Besides, the cpx-harzburgites are virtually indistinguishable from the other Oman harzburgites with respect to their Mg# ratios and olivine proportions (Figs. 2 and 6). In fact, their more ‘ferile’ character is mainly reflected in higher cpx/opx ratios (Fig. 6), suggesting that they were individualised from the other harzburgites by a melt–rock reaction involving precipitation of cpx at the expense of opx [52]. A similar reaction was recently described in the Ronda massif and interpreted as a near-solidus melt–freezing reaction occurring at the boundary of a partial melting domain developed at the expense of the lithospheric mantle [53]. A similar scenario may be envisioned for the formation of the cpx-harzburgites at the base of the Oman ophiolite, which is thought to have preserved the base of the oceanic lithosphere [30]. In this scheme, cpx precipitation in the Wadi Tayin basal harzburgites would underline the lower boundary of pre-existing oceanic lithosphere thermally eroded by upwelling, partially molten
asthenosphere. This process would be related to the opening of the NW–SE propagator identified in the Oman ophiolite [27].

Several studies have proposed that melt-consuming reactions occurring at the base of the lithosphere would release volatile- and LILE-enriched small melt fractions that may pervasively infiltrate large volumes of relatively cold lithospheric mantle [38,54]. Although this process was generally invoked for subcontinental lithosphere, it is strongly suggested in Oman by the existence of fertilised harzburgites at the base of the ophiolite and the pervasive enrichment of highly incompatible elements observed throughout the mantle section.

6. Conclusion

The mantle section of the Oman ophiolite exposes refractory peridotites characterised by relatively homogeneous modal and major element compositions. However, trace elements display significant variations related to geological structures (revealed by high-temperature mantle deformation) and distance from the Moho. Our data distinguish three structural and geochemical domains and provide constraints on their origin:

1. The main harzburgitic mantle section is composed of strongly refractory harzburgites interpreted as mantle residues after >15% melt extraction. Their REE signature can be explained by melt transport associated with partial melting. Their olivine-rich composition may partly result from an olivine-forming melt–rock reaction at shallow level.

2. The diapir areas (mainly the Maqsad diapir) show distinctive trace element compositions ascribed to focused upwelling of partial melts. They are interpreted as instabilities in upwelling mantle, triggered by partial melting and probably enhanced by feedback relationships between deformation and melt percolation. The diapirs are topped by a thick, dunitic, MTZ that displays the same trace element signature as the diapirs. The MTZ is considered to be a major collecting zone for mantle melts.

3. The cpx-rich harzburgites from the base of the mantle section were individualised from the rest of the harzburgite mantle section by a cpx-forming, melt–rock reaction. This reaction probably occurred as a near-solidus melt–freezing reaction at the boundary between oceanic lithosphere and partially molten, upwelling mantle.

These three domains may be integrated in a geodynamic scenario involving the reactivation of an oceanic lithosphere, a process that would be related to the ridge propagator identified in the Oman ophiolite. The main harzburgite section would represent pre-existing oceanic lithosphere whereas the diapir areas would represent newly accreted oceanic lithosphere. In this scheme, the cpx-harzburgites would underlie the base of the pre-existing lithosphere thermally eroded by upwelling mantle and fertilised by partial melts via a melt-consuming reaction. Small-volume melts, residual after this reaction, probably percolated throughout the oceanic lithosphere and would account for pervasive enrichment of highly incompatible elements in the whole mantle section.

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