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1 **Highly siderophile element and Os isotope results from the structurally**  
2 **atypical Batin dunite in the Wadi Tayin massif of the Oman ophiolite**

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7 **Key Points**

- 8 1. The Batin dunite is an exceptionally large dunite, interspersed in the mantle section,  
9 discordant to asthenospheric flow.
- 10 2. Its major and highly siderophile element composition becomes progressively less fertile with  
11 increasing height.
- 12 3. Magmas were injected in a late melt pulse at unusual depth, and progressively lost their  
13 reactive capacity as they migrated upward.

14 ***8156 words***

15 **Plain Language Summary**

16 Dunites in ophiolites form by pyroxene dissolution and olivine precipitation during melt-  
17 peridotite interaction. Highly siderophile elements (HSE) and Os isotopes are excellent tracers of  
18 this process. We present structural and geochemical data on dunites and interspersed  
19 harzburgites from borehole BA4A ,of the ICDP Oman Drilling Project in the Batin region (Wadi  
20 Tayin massif) of the Oman ophiolite. This region features an exceptionally large dunite body,  
21 included in the harzburgitic mantle section. This exploratory study of the Batin dunite shows  
22 that it contrasts chemically and structurally with dunites from the Moho Transition Zone and  
23 basal section of the ophiolite, but presents similarities with dunitic veins of the main mantle  
24 section. Nevertheless, its composition changes systematically with height, becoming  
25 progressively less fertile, and depleted in the incompatible HSE, platinum and palladium. We  
26 suggest that the Batin dunite formed by interaction of the preexisting harzburgite with a large  
27 melt pulse that stagnated at ~1200 meters below the Moho. As these melts ascended through  
28 the overlying ~300 meters, their composition was modified through interaction with the  
29 harzburgite, eliminating their undersaturation in pyroxene and thus their capacity to form  
30 dunite. This may explain the upper limit of the dunite at ~900 meters beneath the Moho.

31 ***199 words***

32        **Abstract**

33        Dunites in ophiolites form by pyroxene dissolution and olivine precipitation during melt-peridotite  
34        interaction. We present structural and geochemical data on peridotites from the Batin region (Wadi  
35        Tayin massif) of the Oman ophiolite, where an exceptionally large (~9.5 kilometer long) dunite body  
36        was sampled by the ICDP Oman Drilling Project (BA4A borehole). 900-1200 meters beneath the  
37        petrological Moho, this dunite is overlain by harzburgite hosting pyroxene-depleted and pyroxene-  
38        rich bands. Highly siderophile elements (HSE) and Os isotopes, excellent tracers of melt flow through  
39        peridotites, were measured in dunites and interspersed harzburgites from BA4A borehole. The Batin  
40        dunite is structurally and chemically distinct from dunites from the Moho Transition Zone and basal  
41        section of the ophiolite, resembling instead sparse dunite veins in the main mantle section. Batin  
42        dunites have fairly uniform Os, Ir and Ru abundances, but Pd and Pt contents increasing with depth.  
43        One deep dunite sample has initial  $^{187}\text{Os}/^{188}\text{Os}$  more radiogenic than MORB. Though the limited  
44        number of data demands prudence, we suggest that the Batin dunite formed from a large pulse of  
45        radiogenic melts, whose flow was impeded ~1200 meters below the Moho. As these melts ascended,  
46        they may have lost their radiogenic character and relative Pt and Pd enrichment through interaction  
47        with peridotites, which have much higher HSE contents than melts. Such interaction would also  
48        diminish the under-saturation in pyroxene of the melts, eliminating their capacity to sufficiently  
49        dissolve the pyroxene of the host harzburgite to form dunite, thus explaining the upper limit of the  
50        dunite at ~900 meters.

51        ***250 words***

52        **Keywords**

53        Oman ophiolite, Mantle, Melt, Dunite, Highly siderophile elements, Osmium isotopes

## 54 **1. Introduction**

55 The large and well-exposed Oman ophiolite constitutes an ideal laboratory for studying melt  
56 migration in the uppermost mantle. Its ~15 kilometer thick mantle section is mainly composed of  
57 harzburgite, which hosts a variety of dunite bodies (e.g. Boudier & Coleman (1981)). Ophiolitic  
58 dunites are generally viewed as transport pathways for ascending melts (Büchl et al., 2002, 2004;  
59 Kelemen et al., 1995; O'Driscoll et al., 2012) resulting from complete pyroxene dissolution and olivine  
60 precipitation in the host peridotite by melt-peridotite interactions (Boudier & Nicolas, 1977; Dick,  
61 1977; Kelemen, 1990; Lambart et al., 2009; Morgan & Liang, 2003). An exceptionally large dunite  
62 body, which outcrops in the mantle section in the Batin area (Fig. 1), was sampled by the ICDP Oman  
63 Drilling Project (Kelemen et al., 2020) (<https://www.omandrilling.ac.uk>), and constitutes the only  
64 dunite body within the harzburgitic section with a size allowing mapping at the 1/25000 to 1/100000  
65 scale. The origin of this highly unusual dunite is still unknown.

66 Here, we present structural observations and whole-rock geochemical data on eight samples  
67 collected in the ICDP BA4A cored borehole traversing the Batin dunite body. These samples, which  
68 comprise four dunites each coupled with a nearby host harzburgite, provide information on melt  
69 migration and dunite formation. We focus on the highly siderophile elements (HSE), which include  
70 the platinum group elements (PGE: Os, Ir, Ru, Rh, Pt, Pd) as well as Au and Re. A particular emphasis  
71 is placed on the Re-Os radiometric system, in which  $^{187}\text{Re}$  decays to form  $^{187}\text{Os}$  ( $t_{1/2} = 41.6$  Ga,  $\lambda =$   
72  $1.666 \times 10^{-11}$ ) (Smoliar et al., 1996). While all of the HSE are siderophile and moderately to extremely  
73 chalcophile, they display different bulk behavior during partial melting of the upper mantle (e.g.  
74 Fischer-Gödde et al. (2011)): PPGE (platinum-group PGE: Pt, Pd), Au and Re are slightly to moderately  
75 incompatible, while IPGE (iridium-group PGE: Os, Ir, Ru, Rh) are highly compatible. This contrasting  
76 behavior creates Earth reservoirs with strikingly different Re/Os ratios, which develop with time  
77 distinct Os isotope ratios (Shirey & Walker, 1998). Compared to fertile lherzolites, mantle  
78 harzburgites typically have similar to slightly higher IPGE abundances, lower PPGE, Au and Re  
79 concentrations and unradiogenic Os isotope compositions (cf. summary in Becker & Dale (2016)). In

80 contrast, recycled oceanic crust and sediments have very low IPGE contents, and are relatively  
81 enriched in PPGE, Au and Re, and as a result, are highly radiogenic (Peucker-Ehrenbrink et al., 2003).

82 Osmium isotopes are particularly useful for studying melt migration through peridotites, and more  
83 specifically dunites, because these rocks are very rich in Os compared to typical mantle melts. During  
84 melt migration through dunite, the isotopic and elemental compositions of incompatible elements  
85 (e.g. light rare earth elements) will be rapidly overprinted in the dunite by equilibration with the  
86 magma (Godard et al., 2000; Kelemen et al., 1995), which has much higher concentrations of these  
87 elements. For Os (and the other IPGE), however, the mass balance is reversed, allowing gradual  
88 changes in Os isotope composition to be recorded in the dunite as melt progressively passes through.

89 We explored this process in an earlier contribution based on a large set of structural observations  
90 and geochemical data for peridotites from the Wadi Tayin, Sumail, Nakhl-Rustaq and Haylayn massifs  
91 of the southeastern Oman ophiolite (Klaessens et al., 2021). In this previous study, we identified  
92 three types of dunite, corresponding to the Moho Transition Zone (MTZ), the main and the basal  
93 mantle sections. A strong correlation was observed between the Os isotope compositions of these  
94 three types of dunite and their structural contexts. In contrast, the host harzburgites have Os isotope  
95 signatures spanning the abyssal peridotite range and not varying systematically with setting. Basal  
96 dunites display compositions similar to harzburgite values, while main section dunites have  
97 somewhat more radiogenic compositions. MTZ dunites have highly radiogenic compositions similar  
98 to those of the overlying lower crust (Peucker-Ehrenbrink et al., 2012), requiring extensive  
99 interaction with melts, probably slab-derived, that are more radiogenic than MORB. Such melts  
100 cannot have equilibrated with harzburgite or dunite along the path from the source to the Moho, or  
101 this radiogenic signature would have been erased. This suggests a very rapid transport mechanism  
102 with little melt/rock interaction, possibly hydrofracturing rather than percolation in dunite channels.

103 Our goal in the current contribution is to determine how, or if, the Batin dunite fits into the highly  
104 systematic framework provided by our previous study of dunites from throughout the southeastern  
105 Oman ophiolite. We do this by examining the variation of  $^{187}\text{Os}/^{188}\text{Os}$  and HSE abundances with

106 height in this atypical and large dunite body. The results are interpreted in light of the structural  
107 relationships between the dunite and the overlying and underlying lithologies, with the aim of  
108 understanding the conditions that permitted the formation of such a large mass of dunite within the  
109 mantle section. Nevertheless, this study is only exploratory and a more extensive investigation will  
110 be needed to fully understand the origin of this intriguing feature and whether it relates to crustal  
111 accretion of other processes.

## 112 **2. Geological context**

### 113 **2.1. *The Oman ophiolite: a fast spreading center above a subducted slab***

114 The Oman ophiolite is a 500 kilometer long, 50-100 kilometer wide nappe divided into 13 structurally  
115 continuous massifs (Nicolas, et al., 2000a). It originates from an accretion center in the Neothethys  
116 active ~95 Myr ago (Rioux et al., 2012). The ophiolite is underlain by a thin (0-100 meters),  
117 discontinuous high-temperature metamorphic sole, formed from relics of the oceanic basin over  
118 which the ophiolite was thrust before its obduction onto the continent. This overridden unit has a Lu-  
119 Hf metamorphic age of 104 Myr (Guilmette et al., 2018), which substantially predates the accretion  
120 age of the overlying spreading center. This chronological information, coupled with lava chemical  
121 compositions indicating hydrous magmatic fractionation trends (MacLeod et al., 2013), suggests that  
122 the spreading center parental to the ophiolite was active above a subducting oceanic slab.

123 Low temperature deformation ascribed to ophiolite emplacement is restricted to the first few  
124 hundred meters of the nappe, often at the base of the mantle section. Most of the ophiolite  
125 peridotite section preserves coarse-grained porphyroclastic textures, ascribed to "fossilized"  
126 asthenospheric mantle flow, while in the crust, gabbros have a grain shape preferred orientation of  
127 euhedral crystals, with no superimposed plastic deformation, thus preserving the imprint of  
128 magmatic flow (Nicolas, et al. (2000a) and references therein). Plastic flow lineations in the upper  
129 mantle and magmatic lineations in the lower crust are parallel, demonstrating that these flow

130 structures formed synchronously at the ridge (Nicolas et al., 1994). The sheeted dike complex is  
131 generally near vertical, and the crust-mantle interface (referred to hereafter as the Moho) is nearly  
132 horizontal, gently dipping to the east in the northern massifs, and to the south and south-east in the  
133 southern massifs. The Oman ophiolite can thus be seen as a paleo-oceanic lithosphere, slightly tilted  
134 and dissected by erosion, without any important subsequent deformation (Nicolas, 1989; Nicolas &  
135 Boudier, 1995). Given its continuous crustal section and the rarity of faults, the ophiolite is thought  
136 to derive from a fast spreading center with a permanent magma chamber; a 5 to 10 cm/yr spreading  
137 rate is confirmed by U-Pb dating of zircons from the upper gabbros (Rioux et al., 2012). Systematic  
138 structural mapping of the southern massifs has revealed a paleoridge organization resembling  
139 microplates at the East Pacific Ridge (Boudier et al., 1997). Notably, a distinct change in dike  
140 orientation outlines the limits of a NW-SE spreading center (Fig. 1). Several zones characterized by  
141 plunging mantle lineations and capped by a thick Moho Transition Zone (MTZ) (see next section), are  
142 interpreted as mantle diapirs, underlying the paleo-ridge axis (Jousselin et al., 1998; Nicolas &  
143 Boudier, 1995).

## 144 **2.2. Dunite distribution in the mantle section**

145 The mantle section of the Oman ophiolite is mainly composed of harzburgite but dunitic bodies of  
146 various geometries and structural contexts are also observed. Klaessens et al. (2021) identified three  
147 types of dunite on the basis of field observations in the southeastern part of the ophiolite, each  
148 associated with a specific part of the mantle section. These include:

149 (1) The Moho Transition Zone (MTZ) (Boudier & Nicolas, 1995; Godard et al., 2000; Klaessens et al.,  
150 2021; Koga et al., 2001; Rospabé et al., 2018), a 10-500 meter thick horizontal melt storage and  
151 reaction zone, composed of pure and plagioclase/clinopyroxene-impregnated dunites and situated  
152 just beneath the crust-mantle interface. This zone is thickest above harzburgite diapirs and  
153 represents the largest dunite volume in the ophiolite, as shown on various maps (Glennie et al.,  
154 1974; Ministry Petroleum and Minerals of Sultanate of Oman, 1986; Nicolas, et al., 2000a).



155 (2) Dunitic veins and bands scattered in the harzburgitic main mantle section (MMS) (Bartholomew,  
156 1983; Boudier & Coleman, 1981; Klaessens et al., 2021; Nicolas, et al., 2000b), corresponding to 0-1  
157 meter, rarely up to 5 meters, wide dunitic reaction zones along discordant gabbroic and pyroxenitic  
158 dikes. Most crosscut the peridotite foliation (henceforth referred to as “dunite veins”). In some cases,  
159 the dike fracture closed completely, with all of its melt extracted to shallower levels, leaving only the  
160 dunite reaction zone as an indicator of the magma passage. Rare dunites parallel to the foliation are  
161 also observed in the MMS (henceforth “dunite bands”), possibly representing examples of dunite  
162 veins transposed by mantle flow.

163 (3) The Basal banded unit (BBU) (Boudier & Coleman, 1981; Klaessens et al., 2021; Lippard et al.,  
164 1986), a highly deformed mantle unit near the basal thrust hosting abundant, 0-20 meter thick,  
165 concordant dunitic bands. In some cases, orthopyroxene-depleted harzburgite is found instead of  
166 dunite. While these bands present spectacular outcrops such as near the capital Mascate, they are  
167 difficult to map at scales larger than 1/10000 and represent a minor volume of dunite in comparison  
168 to the MTZ. Their high concentration in the BBU is poorly understood.

### 169 **2.3. Study area: the Batin dunite**

170 The subject of our study, the Batin dunite located in the eastern Wadi Tayin massif (Fig. 1a), does not  
171 fit into any of the three types of dunites defined above. This dunite body is exceptionally large,  $\leq 250$   
172 meter thick,  $\sim 9.5$  kilometer long and 2 kilometer wide (Fig. 1b), dips slightly towards the south-east,  
173 and is elongated perpendicular to the lineation. In this region, the sheeted dike complex is vertical,  
174 striking N-S, and mantle flow is horizontal with a lineation direction of  $\sim N70$ . A mantle diapir has  
175 been mapped at the northern end of the dunite body, centered on  $22^{\circ}57'N-58^{\circ}40'E$  (Ildefonse et al.,  
176 1993), prompting the question of whether the dunite body could correspond to the MTZ above the  
177 diapir. However, the diapir is not centered on this thick dunite body, and our complementary  
178 mapping of the area shows that the Batin dunite is overlain by  $\sim 900$  meters of harzburgite beneath  
179 the Moho (Fig. 1c). A ridge axis (the Khazinah-Batin segment) has been associated with the diapir; its  
180 estimated location based on radiogenic dating, with increasing ages on each side (Rioux et al., 2012),

181 coincides with the structural limit between upper gabbro foliations dipping to the east (east flank) or  
182 dipping to the west (west flank) (Nicolas & Boudier, 2015). This axis is oriented N-S (parallel to the  
183 sheeted dikes), mostly along the 58°37'E longitude; thus placing the Batin dunite 1 (in the north) to 9  
184 (in the south) kilometers east of the axis.

185 Nearly 5 kilometers southeast of the southern tip of the Batin dunite, the Moho dips slightly to the  
186 south, overlying a very thin MTZ (~1-3 meters) (Fig. 1b, southernmost orange observation point, and  
187 Fig. 2a). Heterogeneous harzburgite, containing pyroxene-rich patches as well as pyroxene-depleted  
188 layers (orange dots in Fig. 1b; Fig. 1c), is dominant between this thin MTZ and the Batin dunite.  
189 Dunite crops out near the BA4A borehole in the form of lenses. This dunite is crosscut by numerous  
190 gabbroic and pyroxenitic dikes (Fig. 1c, 2b), and includes some harzburgite clasts (Fig. 2e). To the  
191 north of the BA site, dunite dominates the landscape (Fig. 2c, 2d) and continues to contain coarse-  
192 grained harzburgite clasts (brown dots in Fig. 1b). Further north, beneath the Batin dunite, dunite is  
193 interlayered with harzburgite, in the form of veins, semi-concordant bands, lenses or breccia (purple  
194 dots in Fig. 1b; Fig. 1c, 2d, 2f) until the basal banded unit (located further north off the map). The  
195 Batin dunite was sampled by the ICDP Oman Drilling Project (Kelemen et al., 2020)  
196 (<https://www.omandrilling.ac.uk>) in the BA borehole series (Fig. 1b), mainly dedicated to studies of  
197 serpentinization processes.

### 198 **3. Samples and analytical techniques**

#### 199 **3.1. *BA hole and sample description***

200 The BA site consists of three cored boreholes, BA1B, BA3A and BA4A (Fig. 1b) (Kelemen et al., 2020)  
201 (<https://www.omandrilling.ac.uk>). As the rocks dip gently towards the southeast, the southernmost  
202 hole, BA3A, is closest to the Moho and structurally overlies the middle hole, BA1B, which in turn  
203 structurally overlies BA4A, the hole from which our samples are taken. The 300 meter long BA3A  
204 hole is mainly composed of harzburgite (Fig. 3) overlying the Batin dunite. The 400 meter long BA1B

205 hole begins in dunite, corresponding to a smaller dunitic body with harzburgite intervals located  
206 above the main Batin dunite (Fig. 3); below a depth of ~160 meters, this hole is dominated by  
207 harzburgite, sometimes crossed by dunite veins or lenses (0.05-2 meter thick). The 300 meter long  
208 BA4A hole was drilled ~700 meters to the NW of the BA1B hole, at the southern tip of the large Batin  
209 dunite; in other words, the first meters of the BA4A hole drill the summit of the buried extension of  
210 this dunite. BA4A hole mainly contains dunite, intersected with decametric to metric harzburgite (Fig.  
211 3), with a maximum continuous dunitic thickness of ~26 meters.

212 In this study, we present major element, highly siderophile element (HSE: Os, Ir, Ru, Pt, Pd, Re) and  
213 Os isotopic data for four dunites and four harzburgites (chosen for freshness and very low vein and  
214 crack contents) from the BA4A hole; these "harzburgite/dunite pairs" were collected at ~100 meter  
215 intervals (Table 1 and Fig. 3). Harzburgites were sampled at distances varying from 3 to 20 meters  
216 from their corresponding dunites (Table 1). Batin harzburgites are moderately serpentinized with  
217 coarse-grained porphyroclastic textures. Harzburgite BA4A 10 (near 200 meters depth) is visually  
218 depleted in orthopyroxene, relative to the 20-25% common orthopyroxene content of Oman  
219 harzburgites (Godard et al., 2000), while the shallowest harzburgite BA4A 1 contains aggregates of  
220 small orthopyroxene grains with concave and serrated boundaries, suggesting they are partially  
221 dissolved by circulating melt, as observed in some harzburgite relics in the MTZ (Boudier & Nicolas,  
222 1995). Dunites are moderately to very strongly serpentinized (sample BA4A 2 in particular). They  
223 display high-temperature porphyroclastic and granular textures; dunite BA4A 5 shows annealed  
224 textures with large overgrown olivine crystals (up to 1 centimeter).

### 225 **3.2. Analytical methods**

226 Whole-rock major element concentrations were measured by the SARM at the CRPG laboratory  
227 (Nancy, France) using an ICP-OES iCap6500 (Carignan et al., 2001). Uncertainties vary from <2% for  
228 SiO<sub>2</sub> to <20% for MnO, based on the concentrations presented in Table 1. After chemical separation,  
229 HSE and Os isotopic analyses (Table 2 and Supplementary Tables 1-3) were done at CRPG by MC-ICP-

230 MS (ThermoScientific Neptune +) (Ir, Ru, Pt, Pd and Re), and N-TIMS using a Finnigan MAT262 mass  
231 spectrometer (Os). Details of analytical methods are provided in the [Supplementary Material](#).

## 232 **4. Results**

233 Batin harzburgite major element compositions are coherent with those of other Oman harzburgite  
234 samples (Godard et al., 2000; Hanghøj et al., 2010; Klaessens et al., 2021), except for their slightly  
235 higher water contents (LOI = 12.41-14.01 wt.%) ([Table 1](#)). Their Mg# (0.904-0.911), Al<sub>2</sub>O<sub>3</sub> contents  
236 (0.45-0.74 wt.%) and Os concentrations (3.63-6.1 ppb) are confined to a limited range ([Table 2](#) and  
237 [Fig. 4, 5a](#)). A negative correlation exists between Al<sub>2</sub>O<sub>3</sub> and MgO contents (recalculated on a volatile-  
238 free basis) in [Fig. 4a](#). Batin harzburgites have unradiogenic Os isotopic compositions ( $^{187}\text{Os}/^{188}\text{Os}_{95\text{Ma}} =$   
239 0.1167-0.1286) in the range of those of abyssal peridotites (Day et al., 2017) ([Fig. 5a](#)); all Os isotope  
240 ratios have been corrected for radiogenic ingrowth since ophiolite emplacement at 95 Ma.  
241 Harzburgite CI chondrite (Horan et al., 2003) normalized HSE abundances display mostly flat patterns  
242 broadly similar to Primitive Upper Mantle (PUM) estimates (Becker et al., 2006; Day et al., 2017)  
243 ([Table 2](#) and [Fig. 6a-b](#)). Harzburgite IPGE abundances plot towards the high end of the range  
244 observed elsewhere in the Oman ophiolite (Ahmed & Arai, 2002; Hanghøj et al., 2010; Klaessens,  
245 2021; Lorand et al., 2009), while their PPGE and Re concentrations are more variable. The shallow  
246 harzburgite BA4A 1 shows a moderate enrichment in Pt and Pd and especially in Re. In contrast,  
247 other harzburgites, and particularly BA4A 6 (near 100 meters depth), are depleted in PPGE and Re. In  
248 addition, harzburgite BA4A 6 displays a V-shaped figure for the IPGE Os-Ir-Ru, suggesting the  
249 presence of Platinum Group Minerals (PGM) rich in Ru and Os (e.g. laurite RuS<sub>2</sub> and erlichmanite  
250 Os<sub>2</sub>). This harzburgite also has an unradiogenic Os isotopic composition ( $^{187}\text{Os}/^{188}\text{Os}_{95\text{Ma}} = 0.1167$ ),  
251 arguing for extensive melt extraction more than 1 billion years ago, which could explain its low Re  
252 content.

253 Batin dunites have somewhat higher water contents (LOI = 15.38-17.51 wt.%) than dunites and  
254 harzburgites from elsewhere in the Oman ophiolite (Godard et al., 2000; Hanghøj et al., 2010;

255 Klaessens et al., 2021). Nevertheless, their volatile corrected major element contents fall on trends  
256 defined by peridotites from throughout the ophiolite. Their Al<sub>2</sub>O<sub>3</sub> contents (0.17-0.46 wt.%) and Mg#  
257 (0.890-0.902) (Table 1 and Fig. 4) are lower than those of the harzburgites, and are similar to those of  
258 the MMS dunites. Their Al<sub>2</sub>O<sub>3</sub> and MgO contents correlate negatively along the extension of the  
259 harzburgite trend (Fig. 4a). In contrast with the harzburgites, the position of each dunite on the trend  
260 is a function of the dunite depth, with the lowest Al<sub>2</sub>O<sub>3</sub> and highest MgO contents found in the  
261 shallow dunite BA4A 2, while the highest Al<sub>2</sub>O<sub>3</sub> and lowest MgO contents occur in the deepest dunite  
262 BA4A 14. As they are composed almost exclusively of olivine, Batin dunites, with the exception of  
263 sample BA4A 14, are aligned along the olivine composition line, which assumes that FeO + MgO =  
264 66.67 mol%, in Fig. 4b. Their Os concentrations (3.40-5.46 ppb; Table 2; Fig. 5b) are fairly constant  
265 and in the range of those observed in the Oman MMS and basal dunites (Hanghøj et al., 2010;  
266 Klaessens et al., 2021), but clearly higher than those of the MTZ dunites (Klaessens et al., 2021; Xiong  
267 et al., 2020a, 2020b). The <sup>187</sup>Os/<sup>188</sup>Os<sub>95Ma</sub> ratios of the Batin dunites range from 0.1220 to 0.1373 and  
268 are similar to those of the MMS dunites (Klaessens et al., 2021). Sample BA4A 11 (near 200 meters  
269 depth) is quite different from the other Batin dunites: its Mg# is lower (0.890 vs. 0.898-0.902) (Fig.  
270 4a) and its Os isotopic composition is more radiogenic (<sup>187</sup>Os/<sup>188</sup>Os<sub>95Ma</sub> = 0.1354-0.1373 vs. 0.1220-  
271 0.1302) (Fig. 5b). In harzburgite/dunite pairs, dunites are more radiogenic than their corresponding  
272 harzburgites with the exception of the BA4A 1/BA4A 2 pair located near the surface (Fig. 5c). Because  
273 of sampling constraints, harzburgites and dunites from the same pair were not always collected in  
274 close proximity (3-20 meters separation) (Table 1). As shown by tightly spaced sampling of other  
275 ophiolites (Haller et al., 2021; O'Driscoll et al., 2018; Snortum & Day, 2020) large Os isotope  
276 variations can occur between harzburgites separated by a few meters or even centimeters. The  
277 relatively large separation between each dunite and its paired harzburgite thus implies that the  
278 compositions of the harzburgites do not necessarily represent those of the harzburgites parental to  
279 the associated dunites. Batin dunites display relatively homogenous chondrite normalized HSE  
280 abundance patterns (Table 2 and Fig. 6a-b), which contrast with the great variety of HSE spectra

281 determined for dunites from elsewhere in the ophiolite, including those from the Wadi Tayin massif  
282 (Hanghøj et al., 2010; Klaessens, 2021). Unlike other Oman dunites, the Batin dunites are enriched in  
283 Pd (and Pt); this enrichment increases with depth (Fig. 6c-d). A V-shaped figure for the IPGE Os-Ir-Ru  
284 is also observed with lower Ir abundances and generally higher Os concentrations than estimated  
285 PUM values (Becker et al., 2006) (Fig. 6a-b). Shallow dunite BA4A 2 has, like its adjacent harzburgite,  
286 a higher Re concentration than the other Batin dunites. In contrast, dunite BA4A 5 (near 100 meters  
287 depth) shows the lowest Pt and Re abundances of Batin dunites, consistent with the low abundances  
288 of these elements in its associated harzburgite BA4A 6 (Fig. 6).

## 289 **5. Discussion**

### 290 **5.1. Seawater contamination versus Magmatic process**

291 We first consider whether the radiogenic compositions of some Batin dunites result from  
292 hydrothermal circulation of seawater. Seawater had high  $^{187}\text{Os}/^{188}\text{Os}$  (~0.51–0.57 in the mid-  
293 Cretaceous; Ravizza et al. (2001)), so hydrothermal alteration or serpentinization could potentially  
294 modify  $^{187}\text{Os}/^{188}\text{Os}$  in these oceanic peridotites. Many authors have considered whether such  
295 secondary processes could explain radiogenic compositions observed in peridotite samples;  
296 arguments are summarized in Becker & Dale (2016). Seawater has a very low Os concentration (~10  
297 fg/g) (Levasseur et al., 1998), implying that extremely high water/rock ratios (>1000) are needed to  
298 significantly change Os compositions of peridotites. In ophiolitic peridotites, these ratios are almost  
299 always <100 (McCulloch et al., 1981), so significant modification of  $^{187}\text{Os}/^{188}\text{Os}$  should be rare.

300 Our samples have water contents (LOI < 17.5%, most <15.5%) (Table 1) typical of serpentinized  
301 peridotites, but slightly higher than those of other Oman peridotites (Godard et al., 2000; Hanghøj et  
302 al., 2010; Klaessens et al., 2021). No correlation is observed between this potential indicator of  
303 seawater contamination and Os isotope composition (Supplementary Fig. 1a); moreover, the most  
304 radiogenic dunite BA4A 11 (near 200 meters depth) has the lowest LOI value among the Batin

305 dunites. Another indicator of seawater contamination is the Th/U ratio (e.g. Sanfilippo et al. (2016)),  
306 because the Th/U ratio of seawater ( $\sim 1.5 \times 10^{-6}$ ) is  $\sim 6$  orders of magnitude lower than that of typical  
307 peridotite ( $\sim 3$ ). A simple two-component mixing model (details and parameters in [Supplementary](#)  
308 [Material](#)) was used to determine the variation of  $^{187}\text{Os}/^{188}\text{Os}$  with Th/U in peridotite with increasing  
309 seawater circulation ([Supplementary Fig. 1b](#)). For seawater contamination to raise the  $^{187}\text{Os}/^{188}\text{Os}$   
310 ratio of a dunite with 4 ppb Os from a typical peridotitic value of  $\sim 0.124$  to the most radiogenic  
311 composition measured in the Batin dunites ( $\sim 0.136$ , sample BA4A 11), a water/rock ratio of  $>10\,000$   
312 would be required, which would lower the Th/U ratio of this sample to  $\sim 0.0003$ . Though Th and U  
313 data are unfortunately not available for this sample, [Aupart et al. \(in revision\)](#) analyzed an  
314 immediately adjacent sample (their number BA4A 80-4 (44-49)) and obtained a Th/U ratio of 2.16,  
315 implying very low water/rock ratios in this part of the borehole. Other dunites analyzed by these  
316 authors from the BA4A hole, as well as harzburgites from BA3A and BA1B holes, have Th/U ratios of  
317 0.1-3.8, implying water/rock ratios  $<50$ , which are much too low to significantly modify peridotite  
318  $^{187}\text{Os}/^{188}\text{Os}$  ratios. This is coherent with Th/U results from elsewhere in the ophiolite which imply  
319 water/rock ratios of  $<100$  even in dunites with highly radiogenic Os compositions ([Klaessens et al.,](#)  
320 2021).

321 These considerations argue strongly that the Os isotope signatures of the Batin samples reflect  
322 essentially magmatic processes. While the evidence in favor of stability of PGE abundances during  
323 serpentinization is more equivocal than for Os isotopes, similarity in PGE abundances between  
324 variably serpentinized samples is often used to argue that the effects of this process are minimal  
325 ([Becker & Dale, 2016](#)). Furthermore, sulfides, which are the main PGE host phase, are expected to be  
326 stable under the reducing conditions typical of serpentinization in ophiolites (e.g. [O'Driscoll et al.](#)  
327 (2015)). For these reasons, we will assume, as most previous authors have done, that the PGE  
328 abundances in our peridotites were primarily controlled by magmatic processes. Rhenium  
329 abundances, on the other hand, may be more problematic, as Re is a fluid mobile element. It is thus  
330 possible that the elevated Re contents of some of the Batin samples may result from late Re addition

331 rather than magmatic processes. However, in all cases the  $^{187}\text{Re}/^{188}\text{Os}$  ratios are sufficiently low that  
332 radiogenic ingrowth over the past 95 Ma does not influence interpretation of the Os isotope data.

### 333 **5.2. Record of ancient partial melting event**

334 The Batin harzburgites have major element contents (Fig. 4), Os isotope compositions (Fig. 5) and CI  
335 chondrite normalized HSE abundance patterns (Fig. 6) similar to those of harzburgites from  
336 elsewhere in the Oman ophiolite (Ahmed & Arai, 2002; Godard et al., 2000; Hanghøj et al., 2010;  
337 Klaessens, 2021; Klaessens et al., 2021; Lorand et al., 2009) and more generally, those of abyssal  
338 peridotites (Becker & Dale, 2016; Day et al., 2017). The  $^{187}\text{Os}/^{188}\text{Os}_{95\text{ Ma}}$  ratios of these harzburgites  
339 are slightly ( $\sim 0.128$ ; BA4A 1) to greatly ( $\sim 0.117$ ; BA4A 6) lower than estimates for the PUM ( $\sim 0.1285$   
340 at 95 Ma; Day et al. (2017); Meisel et al. (2001)), indicating that (with the possible exception of BA4A  
341 1) they experienced one or more ancient partial melting events that predated formation of the  
342 ophiolite sequence by hundreds of millions of years. Though the ancient nature of these episodes can  
343 be directly inferred only from their Os isotope compositions, such events would also have modified  
344 the major element and HSE abundance patterns of these samples. Thus, the compositional variations  
345 observed in the harzburgites probably reflect superposition of the effects of melting at the Oman  
346 ridge axis on peridotites that were already heterogeneous. Harzburgite BA4A 6 (near 100 meters  
347 depth) has the lowest  $\text{Al}_2\text{O}_3$  content and highest MgO content of all of the harzburgites studied,  
348 indicating a high degree of melt extraction. This sample displays a marked V-shaped figure for the  
349 IPGE (Os-Ir-Ru) portion of its HSE pattern, coupled with a depletion in PPGE and Re (Fig. 6). These  
350 observations suggest that partial melting of this sample was extensive enough to remove nearly all  
351 base metal sulphides (BMS) and form Ru and Os-rich PGM (e.g.  $\text{RuS}_2$  laurite and  $\text{OsS}_2$  erlichmanite) by  
352 precipitation and/or exsolution. Furthermore, experimental data indicate that Ru, Os and Ir are  
353 moderately compatible in olivine and chromite (Brenan et al., 2016) while Pd, Pt and Re are  
354 incompatible. Thus, it can be hypothesized that, after sulfide exhaustion, Ru and Os were retained in  
355 laurite/erlichmanite, olivine and chromite, Ir was retained mostly in olivine and chromite, while Pt,



356 Pd and Re were largely removed. Nevertheless, this suggestion should be verified by careful *in situ*  
357 studies.

358 The very unradiogenic Os isotopic composition ( $^{187}\text{Os}/^{188}\text{Os}_{95\text{Ma}} = 0.1167$ ) of harzburgite BA4A 6  
359 corresponds to a Re-depletion model age ( $T_{\text{RD}}$ ) of  $\sim 1.7$  Ga (using PUM mantle evolution curve of  
360 Meisel et al. (2001)). This represents a minimum age for the melt extraction event evident in the HSE  
361 and major element systematics of this sample. In Fig. 6c, a rough correlation is observed between the  
362  $^{187}\text{Os}/^{188}\text{Os}_{95\text{Ma}}$  and the Pd/Ir ratios of the Batin harzburgites. It is possible that, at approximately 1.7  
363 Ga, one or more melting events caused the Batin harzburgites to become variably depleted in PPGE  
364 and Re, leading to a correlation between Re/Os and Pd/Ir, and over time to the development of the  
365 observed correlation between Pd/Ir and  $^{187}\text{Os}/^{188}\text{Os}$  by radioactive decay of  $^{187}\text{Re}$ , though we stress  
366 that this interpretation is speculative and based on very few data. These ancient events would be  
367 completely unrelated to the formation of the Batin dunite, which is a late-stage feature, as shown by  
368 its elongation perpendicular to the lineation. Though this correlation may have been modified by  
369 additional melting during formation of the ophiolite sequence at  $\sim 95$  Ma, traces of the original  
370 relationship remain. In theory, it would be more straightforward to consider the relationship  
371 between  $^{187}\text{Os}/^{188}\text{Os}_{95\text{Ma}}$  and Re/Os, and a rough correlation between these parameters in the  
372 harzburgites is indeed observed. However, data are available for only three of the four samples, and  
373 the Re content of harzburgite BA4A 1 is surprisingly high, suggesting that the Re in this shallowest  
374 sample may have been overprinted. Nevertheless, the Re/Os ratio of harzburgite BA4A 6 is indeed  
375 the lowest, as expected.

### 376 **5.3. Systematic chemical variations in the Batin dunite**

377 As the preceding discussion indicates, the Oman harzburgites, including those from the Batin area,  
378 display chemical and Os isotopic compositions similar to those of abyssal peridotites, and no obvious  
379 relationship exists between composition and position of the harzburgites in the ophiolite section. In  
380 contrast, the compositions of dunites from throughout the southeastern part of the ophiolite vary  
381 systematically with structural setting (literature data in Fig. 5b). This is particularly obvious in their Os

382 isotope compositions: BBU dunites, at the base of the ophiolite, have low  $^{187}\text{Os}/^{188}\text{Os}_{95\text{Ma}}$  ratios  
383 indistinguishable from those of nearby harzburgites; MTZ dunites, just below the crust, have highly  
384 radiogenic compositions and low Os concentrations; while dunites from the intervening MMS have  
385 intermediate Os compositions. These differences in Os composition between the three types of  
386 dunites, which are accompanied by more subtle tendencies in major element composition, reflect  
387 variations in the extent of melt-rock interaction experienced by dunites in the different parts of the  
388 mantle section (Klaessens et al., 2021). This systematic variation provides a framework for  
389 interpretation of results from the Batin area.

390 The Batin dunite is exceptionally large with a maximal thickness of 250 meters (Fig. 1). Elsewhere in  
391 the ophiolite, such thick dunite bodies are only found in the MTZ above harzburgite diapirs (Nicolas  
392 et al., 1996). However, thick MTZ dunites typically include chromitite pods and layered gabbroic  
393 lenses, and the underlying harzburgite displays steeply plunging lineations. None of these features  
394 have been reported for the Batin dunite. MTZ dunites (Klaessens et al., 2021; Xiong et al., 2020a,  
395 2020b) have highly variable Mg# (0.897-0.920) and  $\text{Al}_2\text{O}_3$  contents (0.09-1.71 wt.%), but most  
396 samples plot towards the low Mg# and high  $\text{Al}_2\text{O}_3$  ends of these ranges (Fig. 4). This relatively fertile  
397 character cannot be attributed to plagioclase impregnation, as only one of the MTZ dunites is  
398 plagioclase bearing. The MTZ dunites also have low Os concentrations (0.4 to 2.3 ppb) and high initial  
399  $^{187}\text{Os}/^{188}\text{Os}$  ratios (0.132 to 0.149) (Fig. 5b). Dunite Os concentrations are expected to decrease  
400 progressively during melt-rock interaction, after near total exhaustion of base metal sulfides lowers  
401 the bulk rock Os partition coefficient, while  $^{187}\text{Os}/^{188}\text{Os}$  ratios should increase if the melt is more  
402 radiogenic than the peridotite (see Klaessens et al. (2021) for modeling). Thus, the very low Os  
403 abundances, high  $^{187}\text{Os}/^{188}\text{Os}$  and fertile major element compositions of the MTZ dunites suggest  
404 that such interaction processes have been extensive in the MTZ. In contrast, Os abundances in the  
405 Batin dunites are rather high (3.4-5.5 ppb) (Fig. 5b and Table 2), and similar to those of harzburgites  
406 (3.6-6.1 ppb), while their initial  $^{187}\text{Os}/^{188}\text{Os}$  ratios vary from 0.1220 to 0.1373, and so are lower than  
407 those of MTZ dunites (Fig. 5b).

408 Batin dunite chemistry also differs from that of BBU dunites (Klaessens, 2021; Klaessens et al., 2021).  
409 While the  $\text{Al}_2\text{O}_3$  contents of the Batin dunites are similar to those of the basal unit, their Mg# (0.890-  
410 0.902) are distinctly lower than basal dunite values (0.908-0.923) (Fig. 4). The strong PPGE depletion  
411 observed in the BBU dunites is absent in the Batin dunites, and the V-shaped figures for the IPGE Os-  
412 Ir-Ru chondrite normalized abundances are less pronounced (Fig. 6b). Os isotope ratios of Batin  
413 dunites ( $^{187}\text{Os}/^{188}\text{Os}_{95\text{Ma}} = 0.1220\text{-}0.1373$ ) overlap those of the basal dunites (0.1165-0.1280) (Fig. 5b),  
414 but tend to be more radiogenic. Unlike at the base of the ophiolite, where dunites and adjacent  
415 harzburgites have nearly identical Os isotope compositions (Klaessens et al., 2021), the Batin dunites  
416 tend to be more radiogenic than the nearby harzburgites (Fig. 5c).

417 Thus, the Batin dunites display differences with MTZ and BBU dunites of the ophiolite. Instead, they  
418 have major element, HSE and Os isotope compositions similar to those of MMS dunites (Fig. 4-5)  
419 (Godard et al., 2000; Hanghøj et al., 2010; Klaessens, 2021; Klaessens et al., 2021; Xiong et al., 2020a,  
420 2020b). The Os concentrations of the Batin dunites (3.4-5.5 ppb; Table 1) are much less variable than  
421 those observed in the MMS (1.1-11.8 ppb), but this may simply reflect the collection of the Batin  
422 samples in a much more limited zone. This could also explain the limited variability of the Batin  
423 dunite chondrite-normalized HSE abundance patterns (Fig. 6a-b). An affinity with MMS dunites from  
424 elsewhere in the ophiolite is logical as the Batin dunite is indeed located within the main mantle  
425 section. Nevertheless, the Batin body is dramatically larger than the dunite veins and bands seen  
426 elsewhere in the MMS.

427 While the Batin dunites appear to bear some kinship with the MMS dunites from elsewhere in the  
428 ophiolite, they show some particular features. In addition to their high IPGE abundances, Batin  
429 dunites show enrichment in Pd (from 5.4 to 12.8 ppb) and possibly in Pt (from 7.4 to 9.3 ppb)  
430 increasing with depth (Fig. 6). A negative relationship is also observed between  $\text{Al}_2\text{O}_3$  and MgO  
431 contents correlating with depth (Fig. 4a): the deepest dunite BA4A 14 is the richest in  $\text{Al}_2\text{O}_3$  and  
432 PPGE, and the poorest in MgO, while the shallow dunite BA4A 2 contains the lowest  $\text{Al}_2\text{O}_3$  and PPGE  
433 abundances, and the highest MgO contents. The deep dunite BA4A 11 also has a markedly radiogenic

434 Os isotopic composition (Fig. 5b, 6c). The very shallow harzburgite/dunite pair BA4A 1 and 2 (at 10  
435 and 13 meters respectively; Table 1) is enriched in Re relative to other Batin peridotites (Fig. 6a-b).  
436 However, the Re/Os ratio of the dunite is much higher than that of the harzburgite, despite the close  
437 similarity of the  $^{187}\text{Os}/^{188}\text{Os}$  ratios of the two lithologies, strongly suggesting recent enrichment in Re  
438 in these shallow samples.

#### 439 **5.4. Batin dunite formation**

440 The Batin dunite is unique in the Oman ophiolite because of its exceptionally large size and unusual  
441 structural setting, nearly 1 kilometer beneath the Moho. As discussed above, in many respects, the  
442 chemical composition of this body resembles those of MMS dunitic veins and bands (Godard et al.,  
443 2000; Hanghøj et al., 2010; Klaessens, 2021; Klaessens et al., 2021; Xiong et al., 2020a, 2020b).  
444 Nevertheless, not all of the chemical characteristics of the Batin dunite correspond to those of the  
445 small MMS dunitic veins. A chemical evolution is observed within the Batin dunite, with more fertile  
446 compositions (higher  $\text{Al}_2\text{O}_3$  and lower MgO contents, as well as higher Pt and Pd abundances) found  
447 towards the bottom, evolving to less fertile compositions with increasing height (Fig. 4, 6).  
448 Furthermore, orthopyroxene-depleted harzburgite bands instead of dunites are often found in the  
449 harzburgite overlying the Batin dunite and may result from interaction with melts insufficiently  
450 undersaturated in pyroxene to permit complete removal of this phase.

451 We present below a model that may explain many of these observations. This model is unavoidably  
452 speculative, as it is based on a small number of samples. As several studies have shown (Haller et al.,  
453 2021; O'Driscoll et al., 2018; Snortum & Day, 2020), large heterogeneities in Os isotopic composition  
454 and HSE abundances can exist on length scales of a meter or less in ophiolites. Therefore, drawing  
455 conclusions from a few widely spaced samples may be unwise. Nevertheless, we are struck by the  
456 limited variation and surprisingly systematic nature of the dunite HSE patterns, which differ from  
457 those seen in dunites from elsewhere in the massif (e.g. Hanghøj et al. (2010); Klaessens (2021)). This  
458 relative uniformity may suggest that the magma/rock interaction process that produced the dunites  
459 was sufficiently intense to overprint most of the preexisting heterogeneity in the parental

460 harzburgite. We thus suggest that a possible explanation of the existing data is the partial blockage of  
461 a large melt volume during its ascent at ~1200 meters below the Moho, forming the base of the Batin  
462 dunite by dissolution of the orthopyroxene of the host harzburgite. As these melts slowly continued  
463 their migration upwards, their compositions changed through interaction with the harzburgitic  
464 precursors and the formation of the thick dunite body, leading to decreasing Al<sub>2</sub>O<sub>3</sub> and increasing  
465 MgO contents, coupled with a decrease in the degree of melt undersaturation in orthopyroxene. This  
466 change in melt composition is evident in the HSE spectra, which suggest that the initial melts were  
467 relatively enriched in PPGE, and that this enrichment decreased with continued interaction with the  
468 harzburgites as the melts ascended. The elevated <sup>187</sup>Os/<sup>188</sup>Os ratio<sub>95 Ma</sub> of dunite BA4A 11, one of the  
469 two deepest dunites, indicates that these melts were more radiogenic than MORB, and likely similar  
470 to those that interacted with MTZ and MMS dunites elsewhere in the ophiolite (Klaessens et al.,  
471 2021). As these melts interacted with the peridotite during ascent, they would have become less  
472 radiogenic, making them unable to modify the <sup>187</sup>Os/<sup>188</sup>Os ratios of the uppermost peridotites, as  
473 shown by the isotopic similarity between the shallow dunite BA4A 2 and the nearby harzburgite  
474 BA4A 1. If this model is correct, the lack of a systematic, monotonic decrease in <sup>187</sup>Os/<sup>188</sup>Os with  
475 height may reflect the fact that the melt-peridotite interaction was superimposed on precursor  
476 harzburgites that were already heterogeneous (Fig. 5).

477 In this scenario, the top of the dunite may represent the limit above which the melts were no longer  
478 sufficiently undersaturated in pyroxene to fully transform harzburgite into dunite. The pyroxene-  
479 poor harzburgite bands observed above the dunite could have formed from interaction with such  
480 melts. As noted earlier, pyroxene-rich harzburgites are also found above the Batin dunite, which may  
481 suggest that some melts became so enriched in the pyroxene component during melt-rock  
482 interaction that they reached saturation in this phase. Minor changes in conditions and/or melt  
483 composition could then have triggered pyroxene precipitation. Thus, both the pyroxene-depleted  
484 harzburgite bands and the pyroxene-rich harzburgite patches in the region above the Batin dunite

485 could potentially be explained by the intensive melt-rock interaction processes that occurred during  
486 production of the dunite.

487 The reason for melt blockage at depth, sufficient to produce this massive dunite body, is unclear. As  
488 mentioned above, the Batin dunite shows discordant contacts at its upper and lower limits, where  
489 some magmatic breccia are observed (Fig. 2e-f). The NE-SW elongation of this body also crosscuts at  
490 high angle the asthenospheric mantle lineation; it is thus not transposed by mantle flow. These  
491 observations suggest that the giant dunite body was formed when and/or where mantle had stopped  
492 flowing, in near-lithospheric conditions. A possible explanation of the melt ponding depth may be its  
493 correspondence to the lithosphere-asthenosphere boundary. Melt emplacement away from the  
494 accretion center, or as a late magmatic event, during the cooling history of the ophiolite could then  
495 explain the abundance of melt at this level.

## 496 **6. Conclusions**

497 This exploratory study of the large Batin dunite body shows that it contrasts chemically and  
498 structurally with MTZ and basal dunitites of the Oman ophiolite, but presents numerous chemical  
499 similarities with dunitic veins and bands of the main mantle section. Nevertheless, the composition  
500 changes systematically with height, becoming progressively less fertile, and showing decreasing  
501 abundances of the incompatible Platinum Group Elements, Pt and Pd. One interpretation of our field  
502 and analytical data may be that the Batin dunite formed by interaction of the preexisting harzburgite  
503 with a large pulse of melt that stagnated at ~1200 meters below the Moho. As is true elsewhere in  
504 the ophiolite, the dunite-forming melts had more radiogenic Os isotopic compositions than MORB, as  
505 shown by the high  $^{187}\text{Os}/^{188}\text{Os}$  ratio of one of the deepest dunitites. As the melts migrated upwards,  
506 interacting with the harzburgite to form dunite, they would have become less radiogenic and their Pt  
507 and Pd concentrations would have decreased. They would also have become progressively less  
508 undersaturated in pyroxene as they ascended. This suggestion is supported by the bands of

509 pyroxene-poor harzburgites in the zone above the dunite, which likely formed by interaction with  
510 melts that lacked the capacity to fully digest all of the pyroxene present in the original rock.

511 This simple model is based on a very limited number of samples and will surely evolve as more data  
512 become available. Structural and geochemical studies of the lithologies overlying and underlying the  
513 dunite will be particularly valuable for improving our understanding of this intriguing feature in the  
514 Oman ophiolite.

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### 527 **Author Contributions**

528 D. Klaessens, D. Jouselin and L. Reisberg participated in fieldwork and the Oman Drilling Project. D.  
529 Jouselin provided geological context. The Oman Drilling Project Science Team supplies samples. D.  
530 Klaessens completed most of the analyses and wrote the initial manuscript. L. Reisberg supervised  
531 Re-Os analyses. D. Klaessens, L. Reisberg and D. Jouselin discussed the results and their implications,  
532 and assisted in the final revisions to the manuscript.

533 ***CRediT author statement***

534 Delphine Klaessens: Conceptualization, Methodology, Formal analysis, Validation, Investigation,  
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541 **Competing Interests statement**

542 None of the authors have competing interests.

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### 737 **Figure and Table Legends**

738 **Figure 1.** Oman Drilling Project GT, BT, CM and BA borehole locations in the southeastern massifs  
739 (Sumail and Wadi Tayin) of the Oman ophiolite. **(a)** Simplified geological map of the region (after  
740 Nicolas, et al. (2000a)) showing the spatial distribution of the Hawasina sediments, the ophiolite  
741 crustal section, the Moho Transition Zone (MTZ) and large dunite outcrops, the mainly harzburgitic  
742 mantle section and the metamorphic sole. The inferred ridge axis (bold blue lines), mantle diapirs  
743 (stars), main dike orientations (double black lines) and limits of NE-SW dikes (black dashed curves)  
744 are indicated. **(b)** Enlarged view of the Batin region in the northeastern Wadi Tayin massif, where a  
745 large dunite (dark brown) outcrops (after Noël (2018)). Mantle and gabbro lineations (Nicolas, et al.,  
746 2000a), 45° foliation isodip (Ildefonse et al., 1993) and the Khazinah-Batin segment (Rioux et al.,  
747 2012) are shown. BA cored borehole locations (BA1B, BA3A and BA4A) are indicated (large red dots);  
748 studied samples from BA4A hole at the southernmost tip of the exposed part of the dunite body.  
749 Smaller dots show field observation sites where harzburgite (orange dots) or dunite (brown dots) is  
750 dominant or where both lithologies coexist in roughly equal proportions (purple dots). The Moho and



751 underlying rocks dip gently to the south, so that the stratigraphic level deepens towards the north.  
752 **(c)** SE-NW schematic vertical section (corresponding to a traverse from point X to Y in Fig. 1b) based  
753 on field observations in the Batin region, showing the distribution of the lithologies above (point X)  
754 and below (point Y) the Batin dunite.

755 **Figure 2.** Field photographs illustrating the Moho **(a)**, the Batin dunite **(b-d)**, harzburgite clasts  
756 trapped in dunitic vein networks close to this giant dunite **(e-f)** in the study area. **(a)** Moho dipping  
757 slightly to the south and overlying a very thin MTZ (1-3 meters). **(b)** Altered dunite summit crosscut  
758 by numerous gabbroic and pyroxenitic dikes and sills near the BA4A hole. **(c)** View of dunite irregular  
759 summit showing preserved harzburgite clasts (darker) in dunite or indistinguishable depleted  
760 harzburgite (lighter) (delimited contacts). G, gravel. **(d)** Lower part: Batin dunite core with massive  
761 and highly altered dunite, allowing development of a wide Wadi (river) bordered with flat terraces.  
762 Upper part: Batin dunite summit with zones richer in harzburgite, more resistant to erosion, forming  
763 reliefs (purple dots in center of Fig. 1b). **(e)** Pyroxene-rich harzburgite clasts trapped in dunitic vein  
764 network near upper limit of the Batin dunite. **(f)** Dunitic vein network below the Batin dunite  
765 (northernmost observation points of Fig. 1b).

766 **Figure 3.** Stratigraphic cross-sections of ICDP BA3A, BA1B and BA4A cored boreholes in the Batin area  
767 of the Oman ophiolite illustrating lithologies. Borehole locations are shown in insert and Fig. 1; BA3A  
768 hole structurally overlies BA1B, covering BA4A. Data from Kelemen et al. (2020)  
769 (<https://www.omandrilling.ac.uk>). Modified after Aupart et al. (in revision). Samples come from  
770 BA4A hole; their locations and lithologies (light orange for harzburgite and brown for dunite) are  
771 indicated.

772 **Figure 4.** Whole-rock major element compositions of Batin harzburgites and dunites, recalculated on  
773 a volatile-free basis, compared with published peridotite data from the Oman ophiolite. **(a)** Al<sub>2</sub>O<sub>3</sub> vs.  
774 MgO, **(b)** FeO vs. MgO and **(c)** depth vs. Al<sub>2</sub>O<sub>3</sub> (for Batin dunites only). In panel **(b)**, dotted grey lines  
775 represent constant Mg# values and bold dotted black line shows evolution of olivine composition

776 constrained by  $\text{FeO} + \text{MgO} = 66.67 \text{ mol\%}$  following Godard et al. (2000). Published Oman peridotite  
777 data (Godard et al., 2000; Hanghøj et al., 2010; Klaessens et al., 2021) include dunites from the Moho  
778 Transition Zone (MTZ), and dunites and harzburgites from the main mantle section (MMS) and the  
779 basal banded unit (BBU). Attribution of samples from the literature to the three domains defined in  
780 Klaessens et al. (2021) was based on their geographic positions in the mantle section.

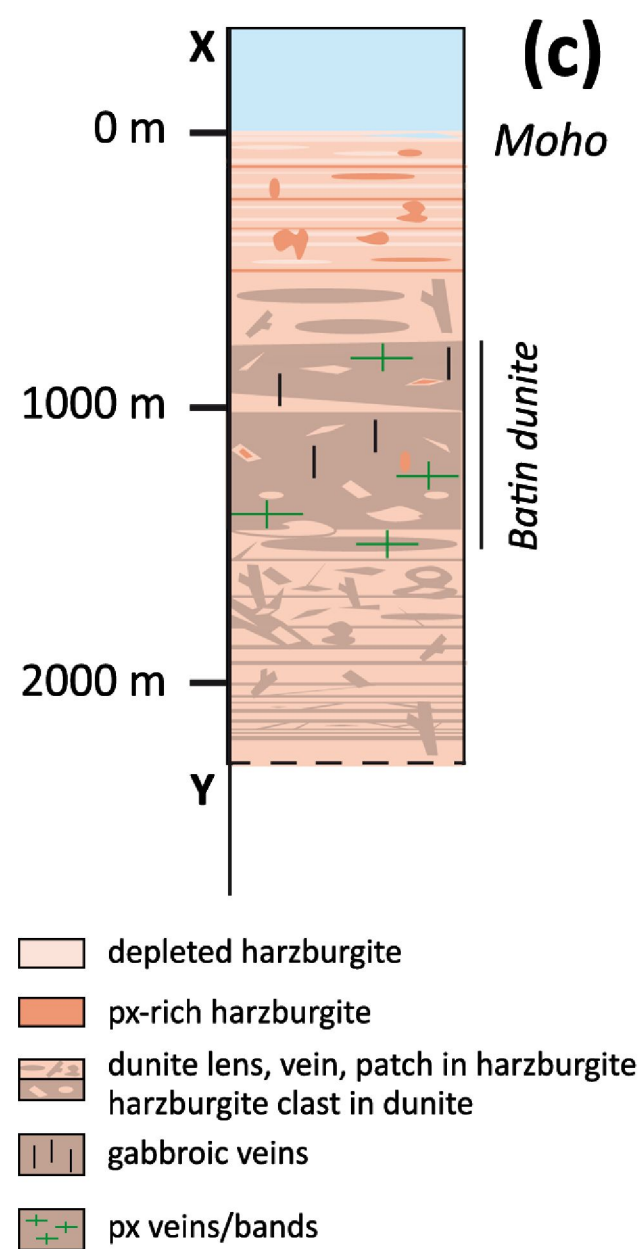
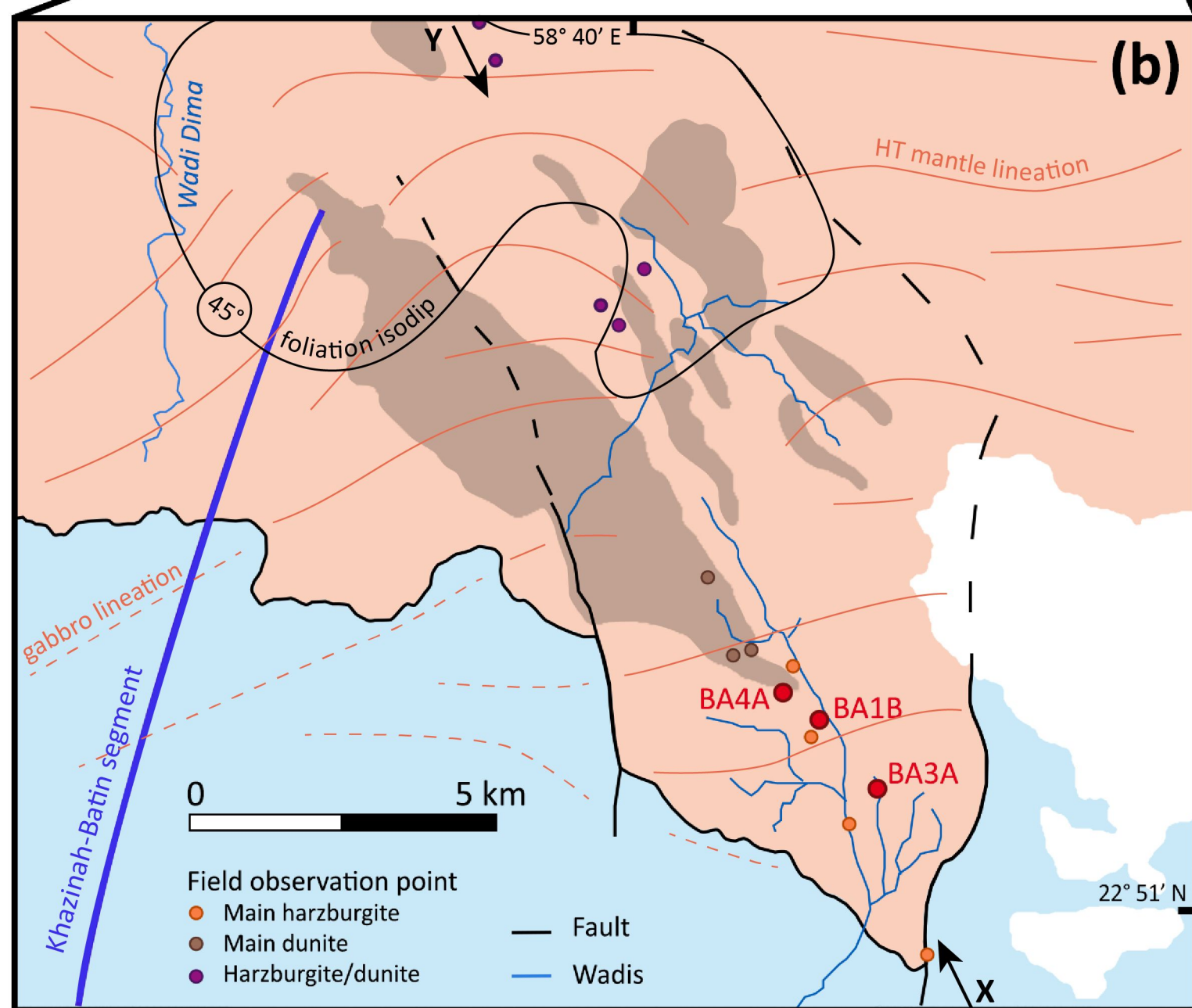
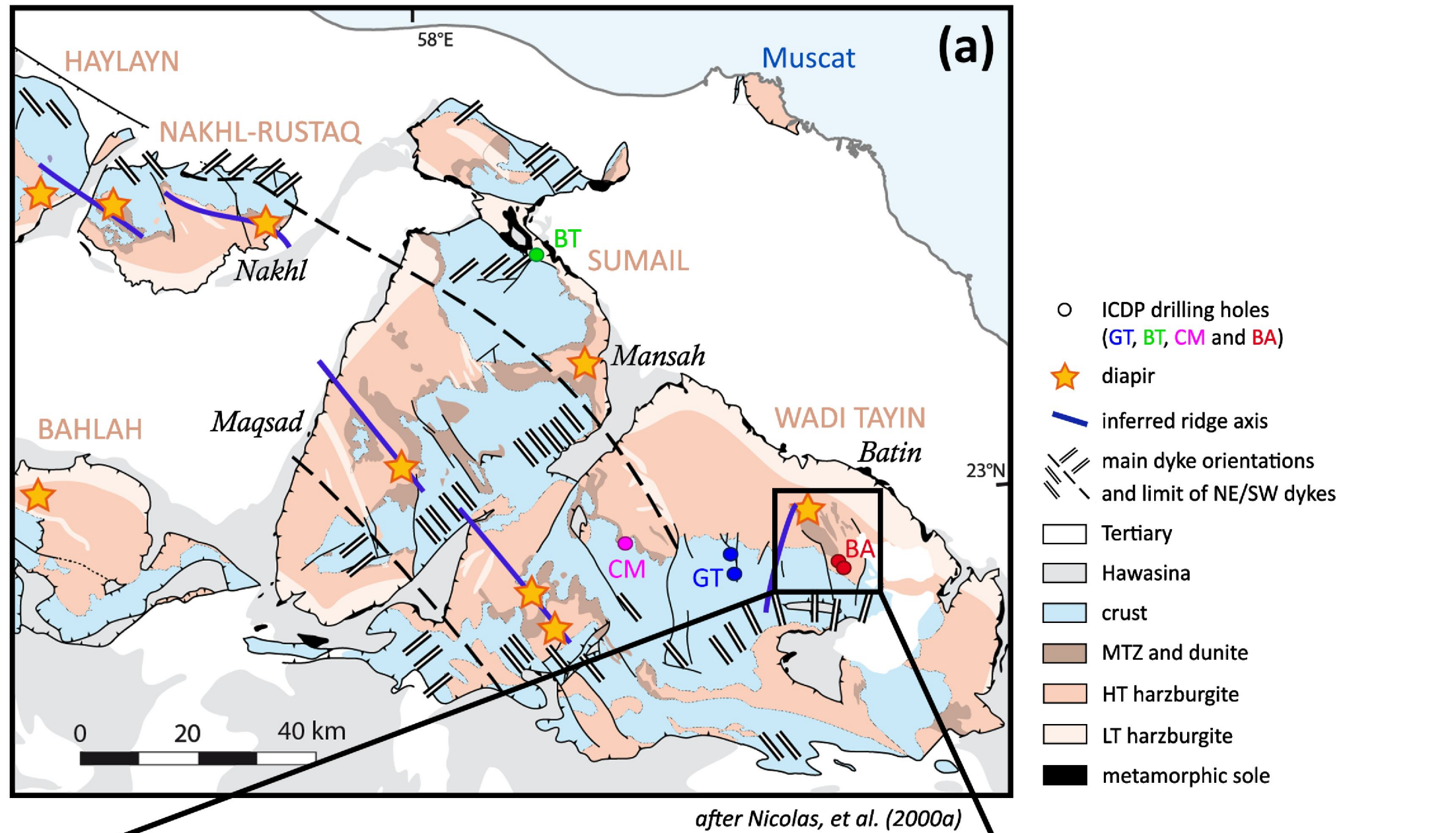
781 **Figure 5.** Os isotope compositions of Batin harzburgites and dunites. **(a)**  $^{187}\text{Os}/^{188}\text{Os}$  vs. [Os] in  
782 harzburgites; **(b)**  $^{187}\text{Os}/^{188}\text{Os}$  vs. [Os] in dunites; **(c)** Variations in  $^{187}\text{Os}/^{188}\text{Os}$  of dunite/harzburgite  
783 pairs (delimited by contours) with depth in BA4A cored borehole. In all panels, pink bands represent  
784 estimated  $^{187}\text{Os}/^{188}\text{Os}$  ratio for the Primitive Upper Mantle (PUM) ( $\sim 0.1289$  at 95 Ma (Meisel et al.,  
785 2001); coherent with  $\sim 0.1285$  at 95 Ma from Day et al. (2017)). Light grey, dark grey and brown  
786 curves on the sides of diagrams show the probability distribution of  $^{187}\text{Os}/^{188}\text{Os}$  ratios for abyssal  
787 peridotites (compilation in Becker & Dale (2016); new data from Day et al. (2017) show a similar  
788 distribution), MORB (MORB sulfide data from Gannoun et al. (2016)) and Oman lower crust (Peucker-  
789 Ehrenbrink et al., 2012) respectively. Published Oman peridotite data are shown for comparison  
790 (Hanghøj et al., 2010; Klaessens et al., 2021; Xiong et al., 2020a, 2020b); symbols as in Fig. 4.  
791 Attribution of samples from the literature to the three domains defined in Klaessens et al. (2021) was  
792 based on their geographic positions in the mantle section. Data for harzburgites and the three types  
793 of dunites from Klaessens et al. (2021) are reported in Supplementary Table 4.

794 **Figure 6.** HSE abundances and Os isotope compositions of Batin harzburgites and dunites. **(a-b)** CI  
795 chondrite (Horan et al., 2003) normalized HSE abundances of harzburgites **(a)** and dunites **(b)**. **(c)**  
796  $^{187}\text{Os}/^{188}\text{Os}_{95\text{Ma}}$  vs. Pd/Ir. **(d)** [Pd] vs. [Pt]. **(e)** Variations in Batin dunites of Pd content with depth in  
797 BA4A cored borehole. In all panels, pink fields represent estimated  $^{187}\text{Os}/^{188}\text{Os}$  ratio and HSE  
798 abundances for Primitive Upper Mantle (PUM) from Meisel et al. (2001) and Becker et al. (2006)  
799 respectively, while violet fields represent HSE estimates for PUM from Day et al. (2017).  
800 Harzburgite/dunite pairs are shown with same colors (filled symbols for harzburgites; open symbols  
801 for dunites). Light and dark grey fields in panels **(a-b)** show HSE abundances for harzburgites and

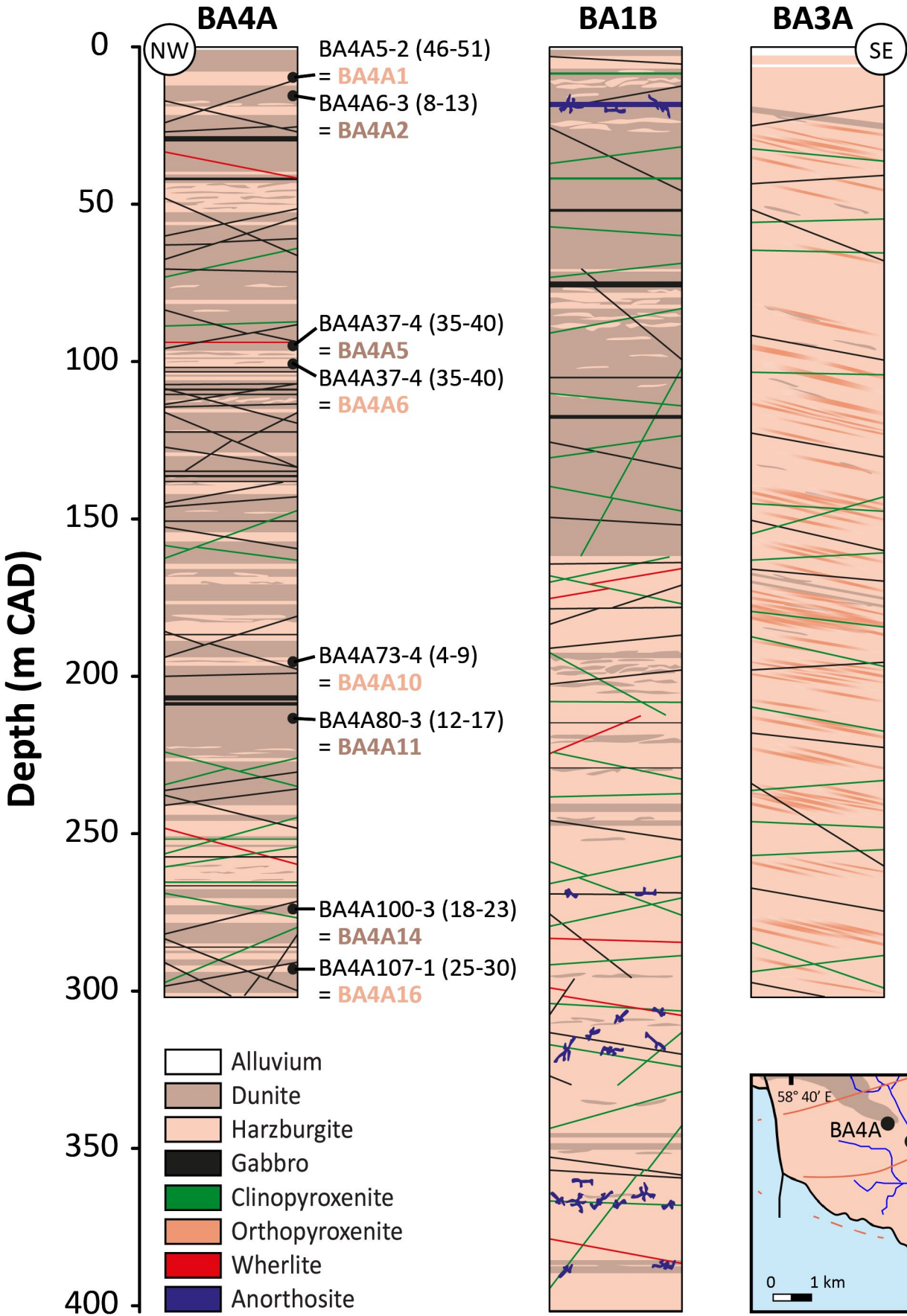
802 dunites from the Oman main (MMS) and basal mantle sections (partially covered by translucent  
803 MMS fields) respectively (Klaessens, 2021). In panels **(c-d)**, blue arrows indicate Batin dunite  
804 enrichment in Pd and more limited enrichment in Pt increasing with depth. In panel **(c)**, blue dotted  
805 line highlights correlation between Pd/Ir and  $^{187}\text{Os}/^{188}\text{Os}$  in harzburgites, consistent with radiogenic  
806 ingrowth since ancient partial melting. Published Oman peridotite data are shown for comparison  
807 (Hanghøj et al., 2010; Klaessens, 2021; Klaessens et al., 2021) (symbols as in Fig. 4). Attribution of  
808 samples reported in the literature to the three domains defined in Klaessens et al. (2021) was based  
809 on their geographic positions in the mantle section. Osmium isotope and HSE data of Klaessens  
810 (2021) and Klaessens et al. (2021) are reported in [Supplementary Tables 4-5](#).

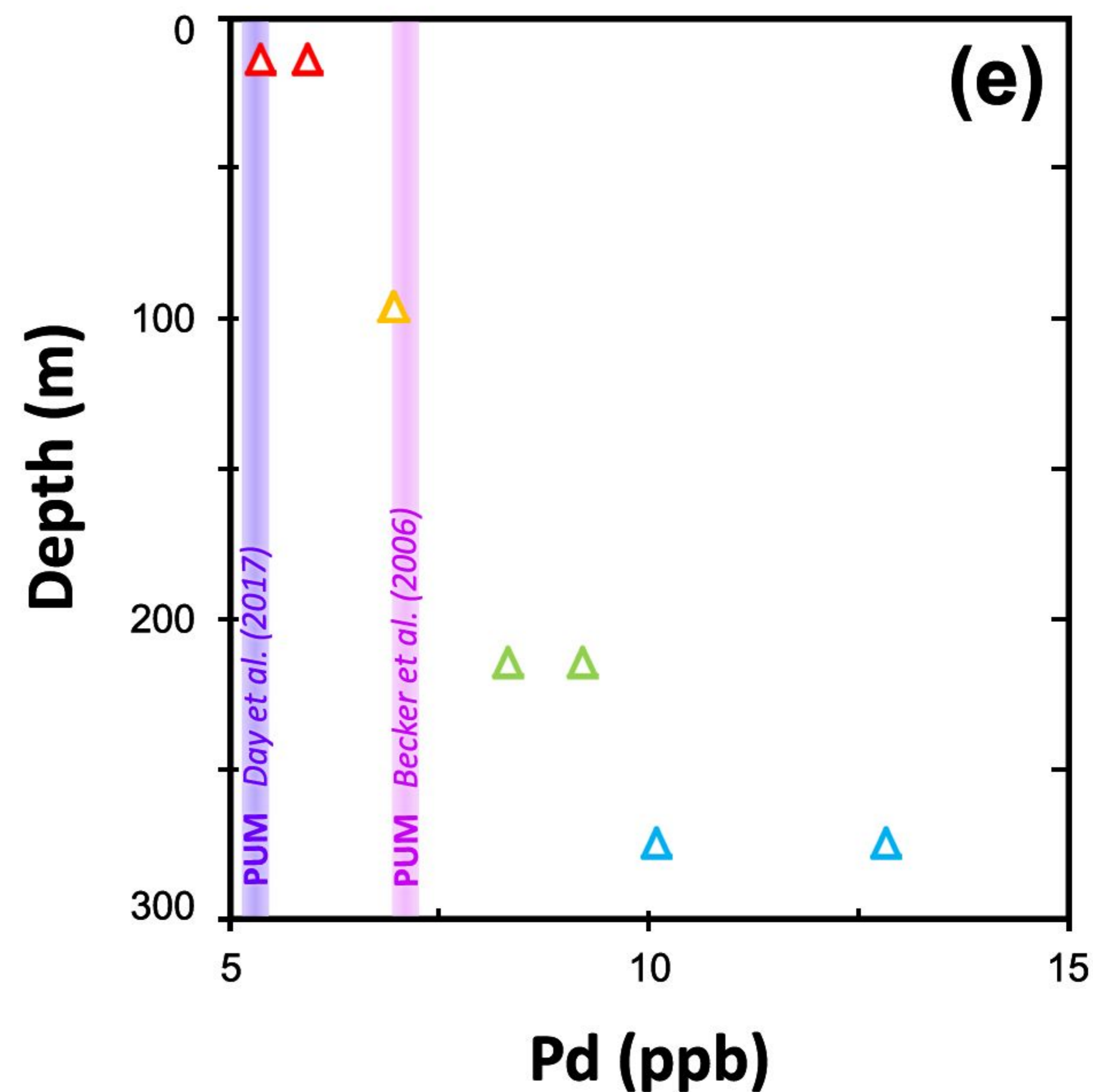
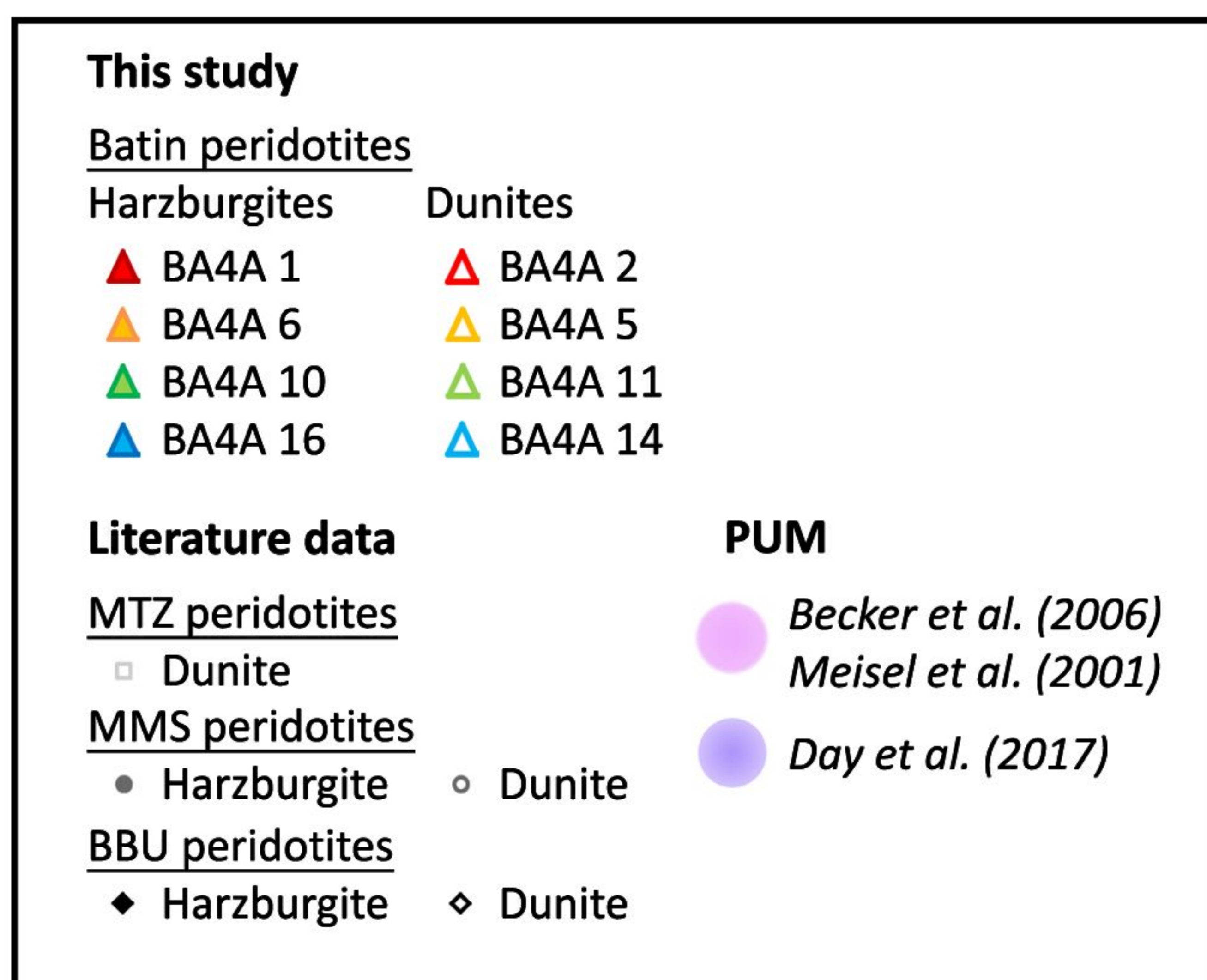
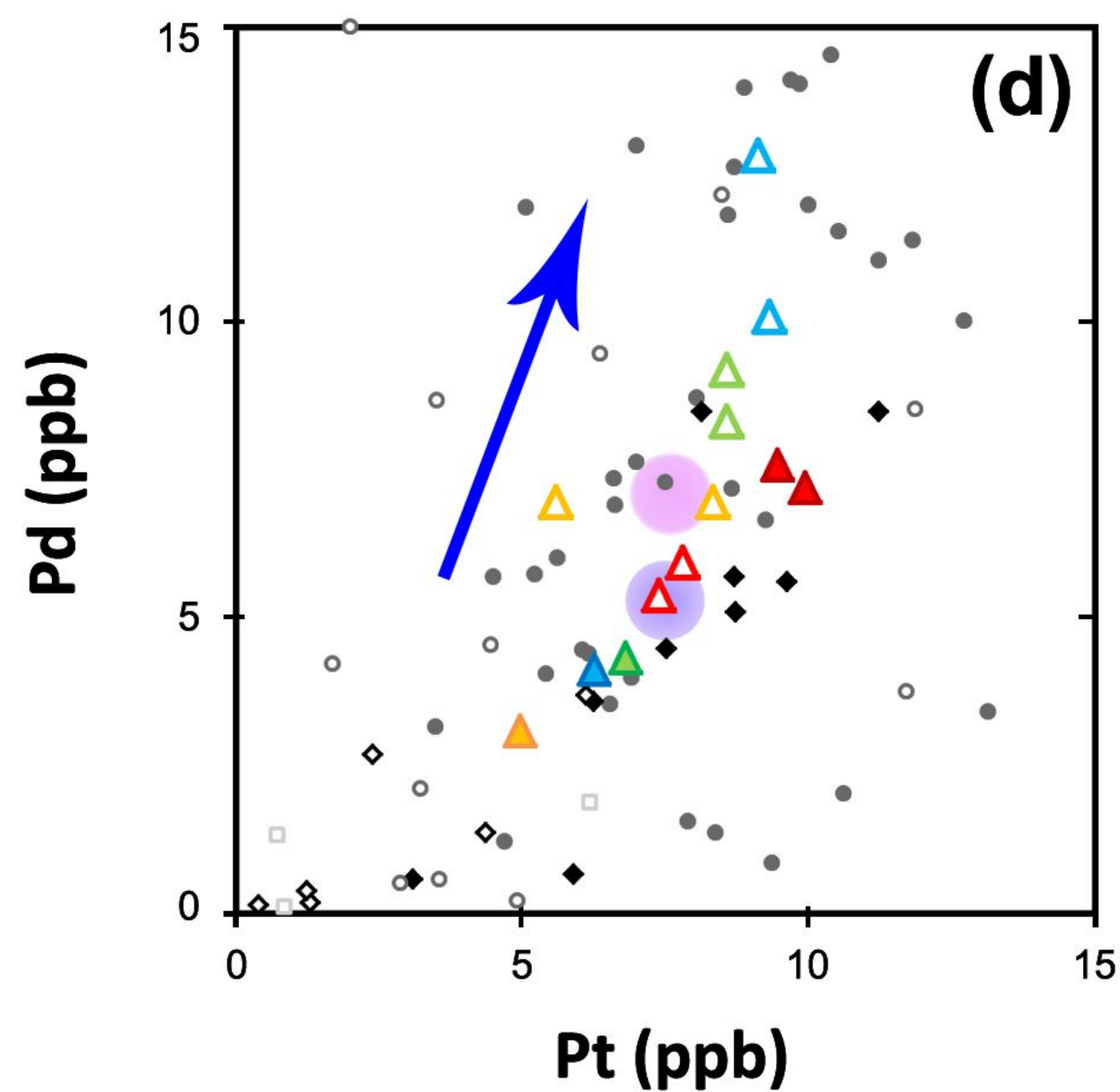
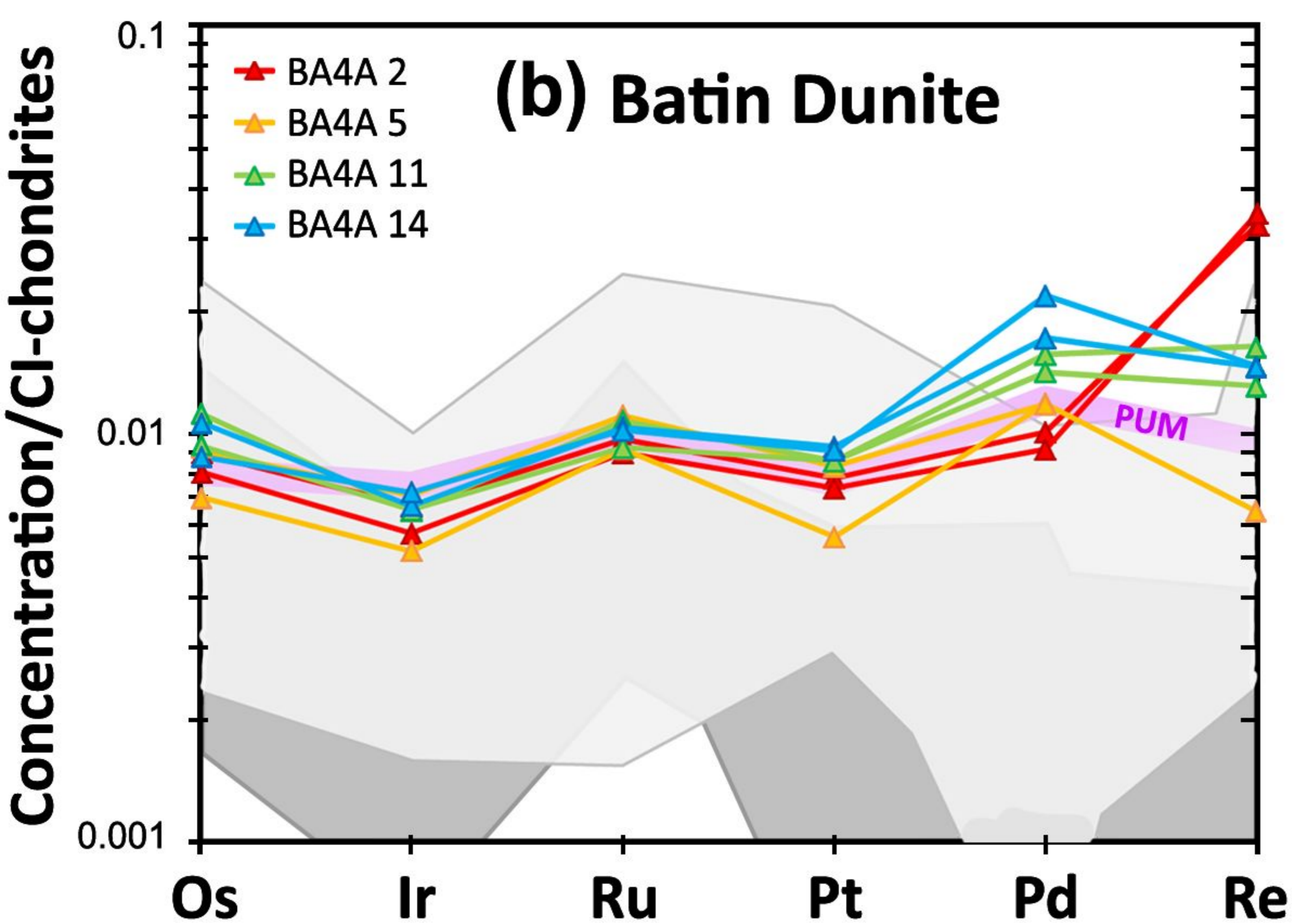
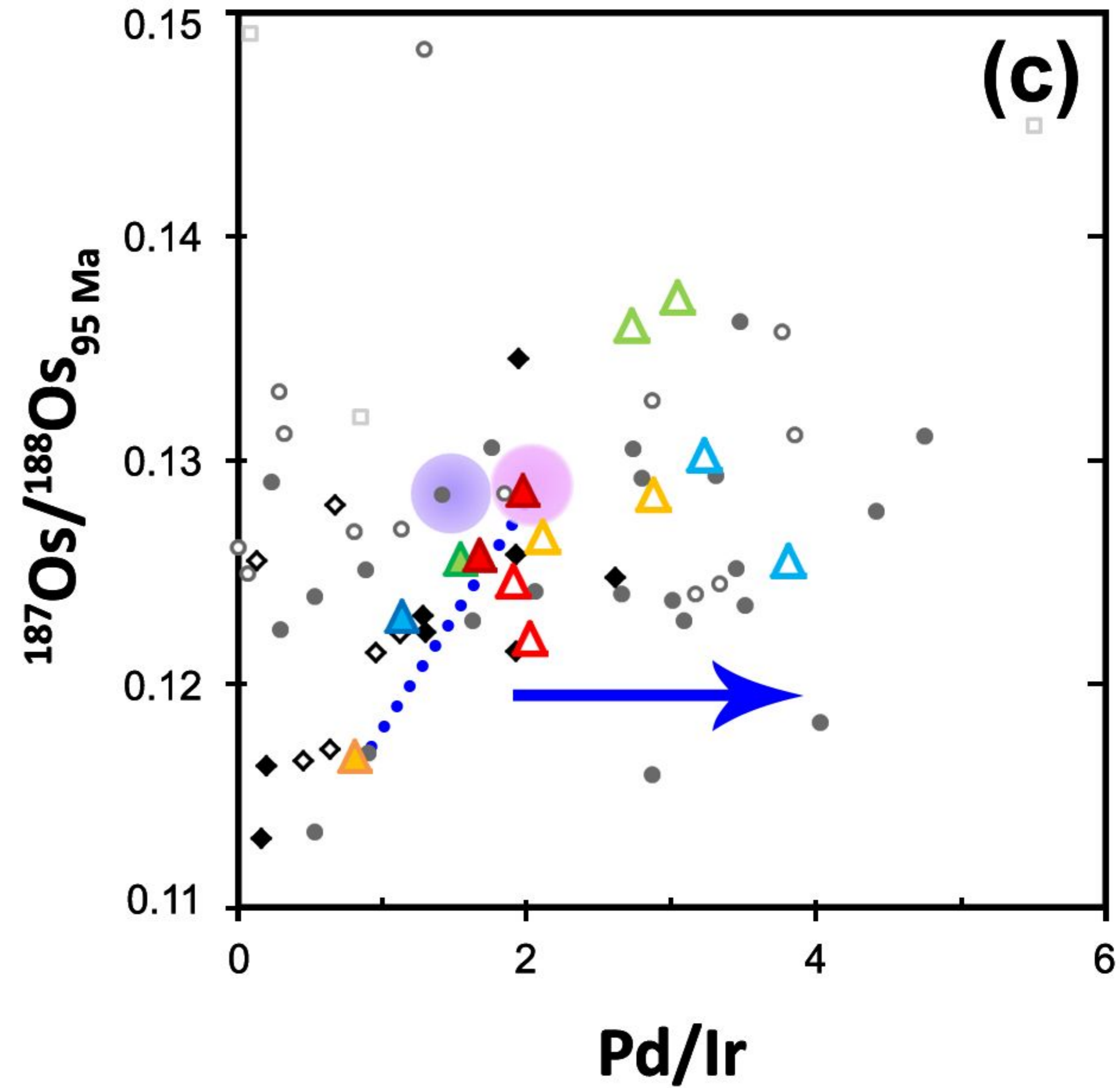
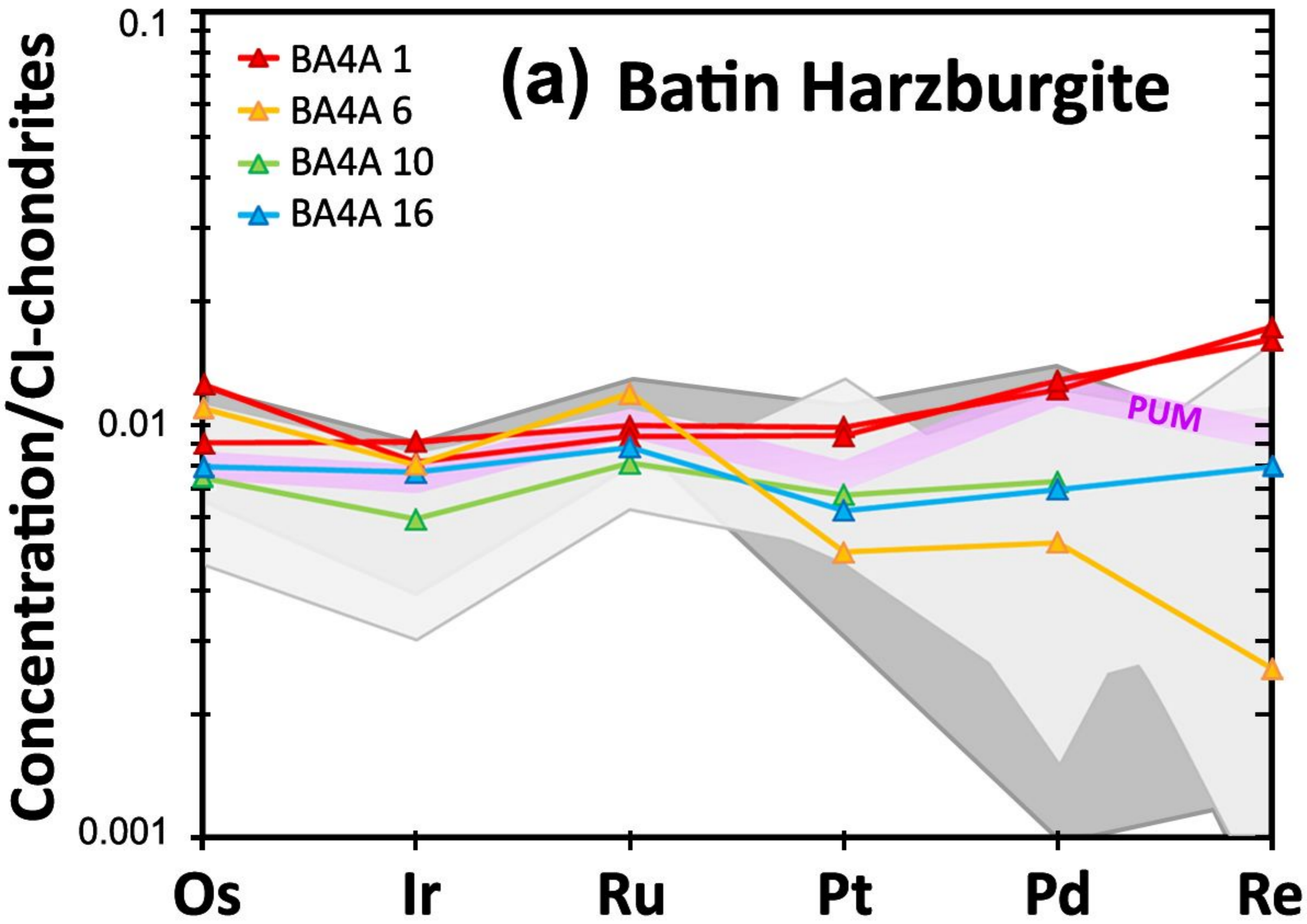
811 **Table 1.** Whole-rock major element compositions of the studied Batin peridotites

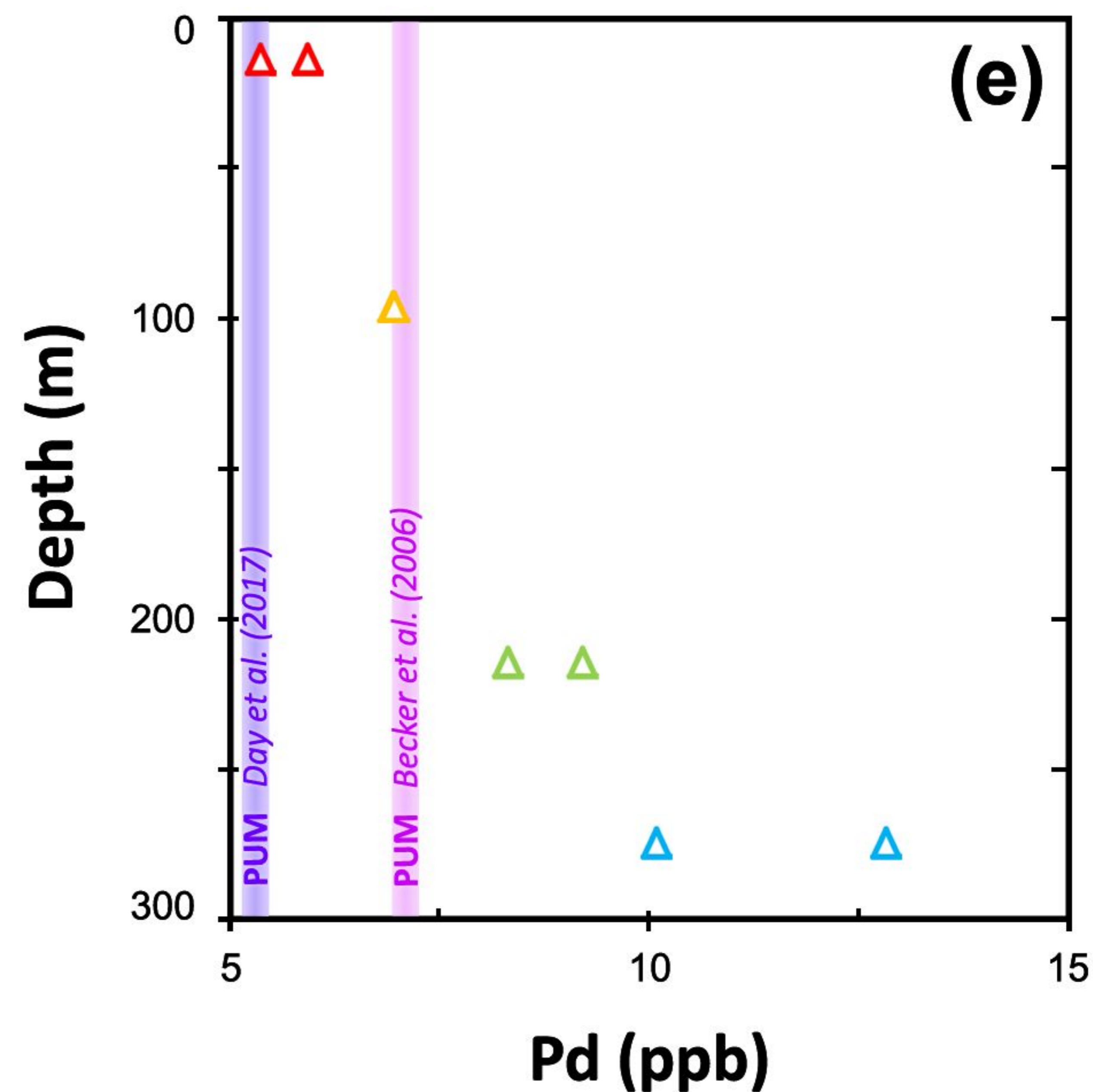
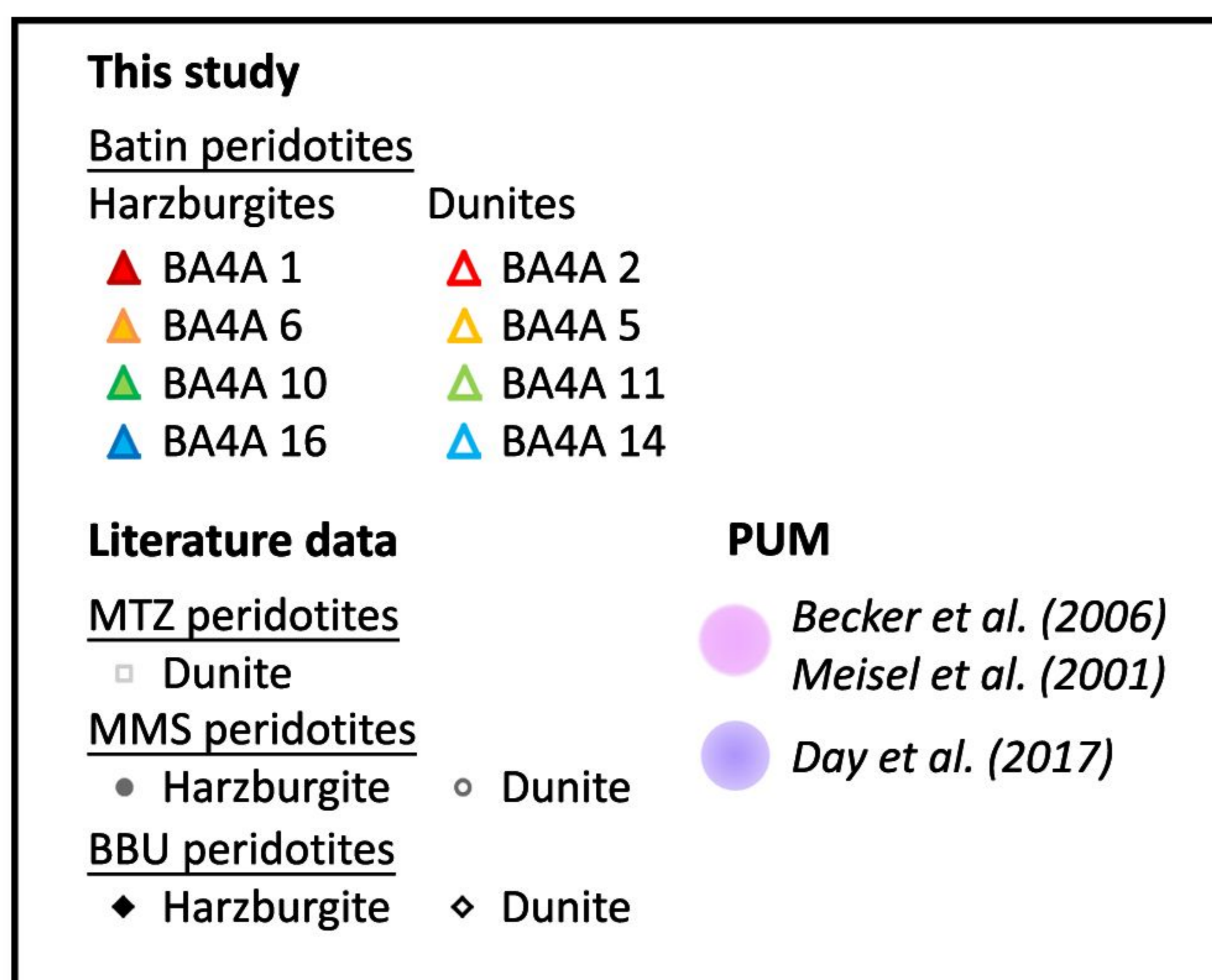
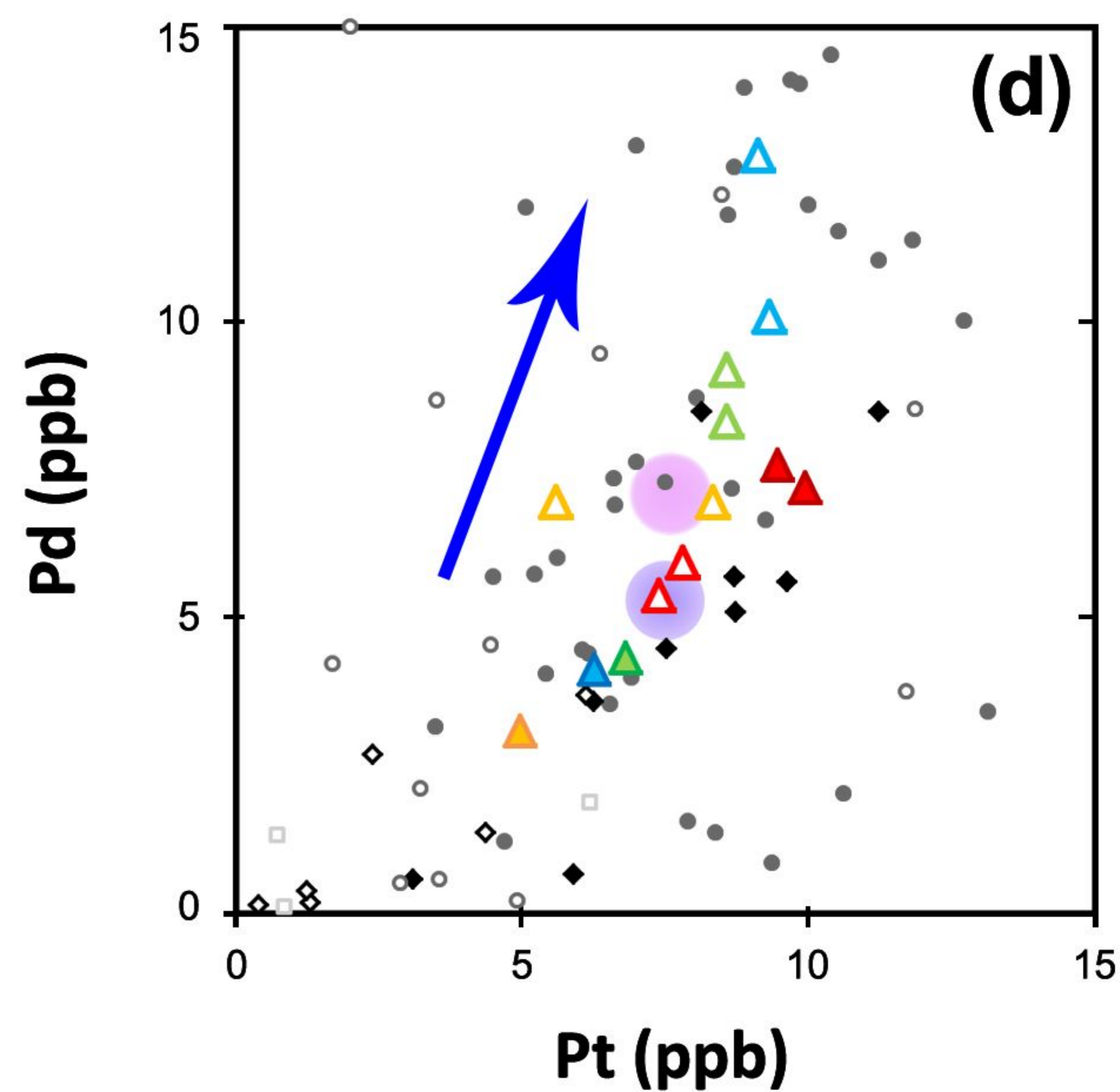
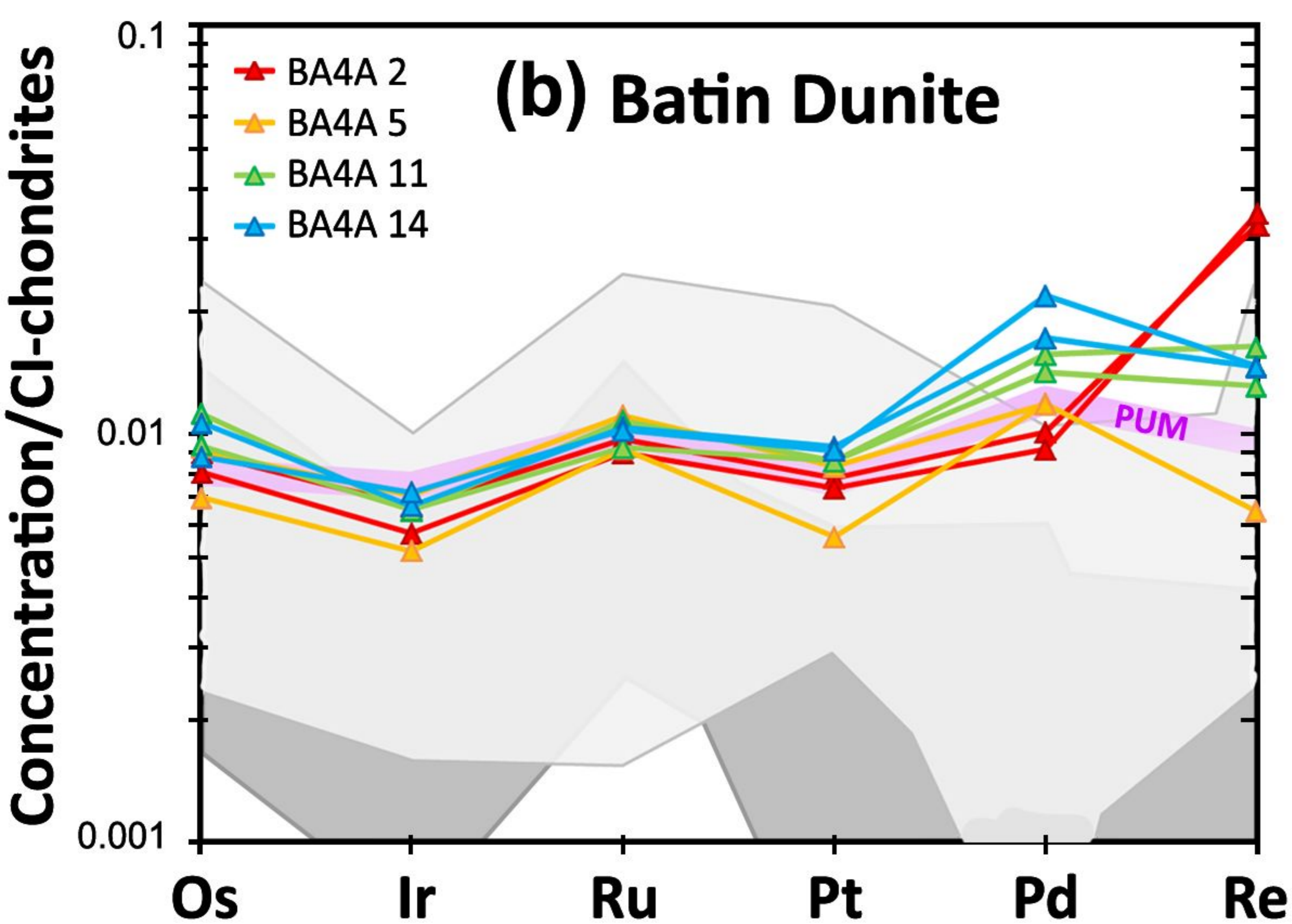
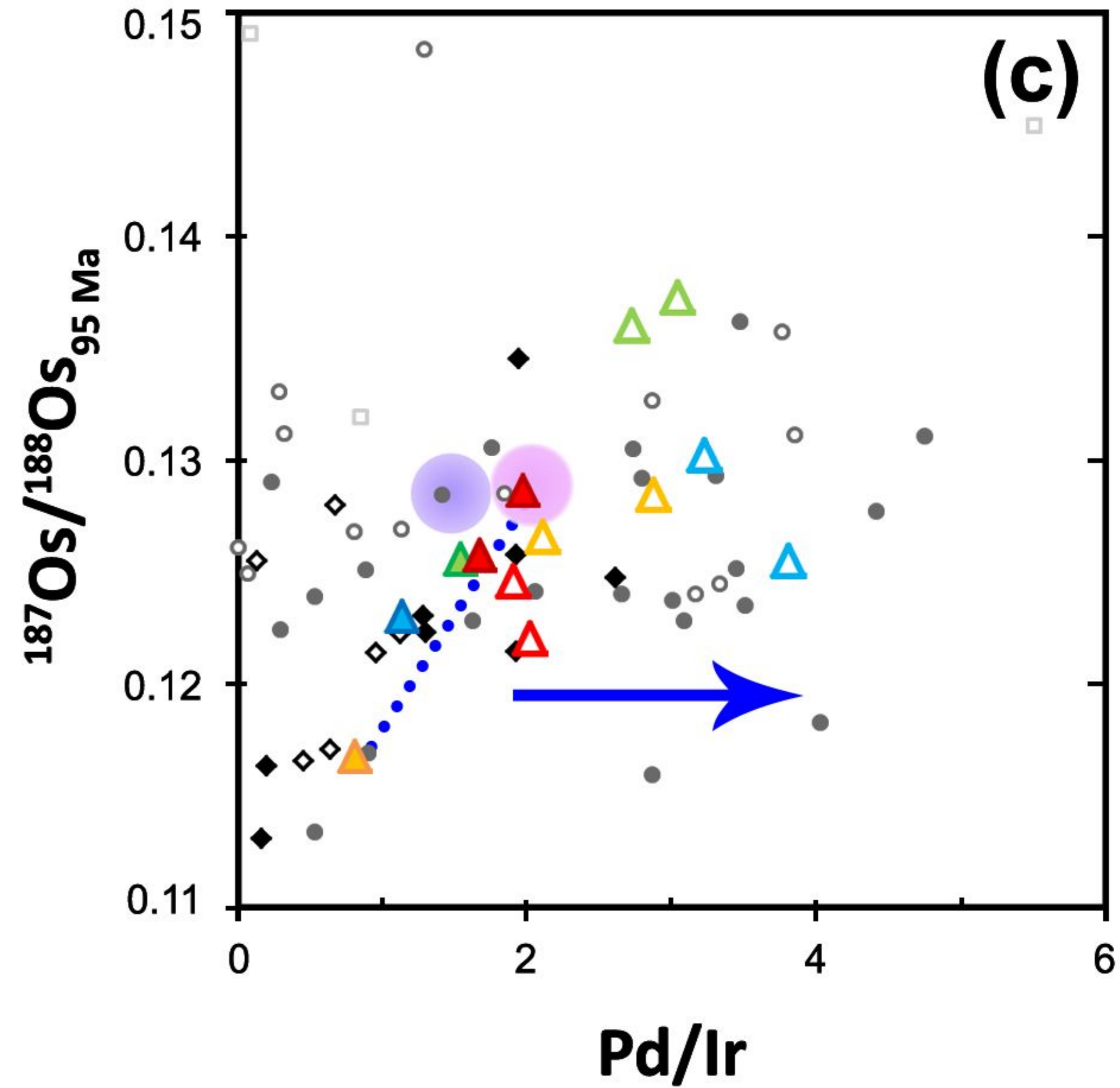
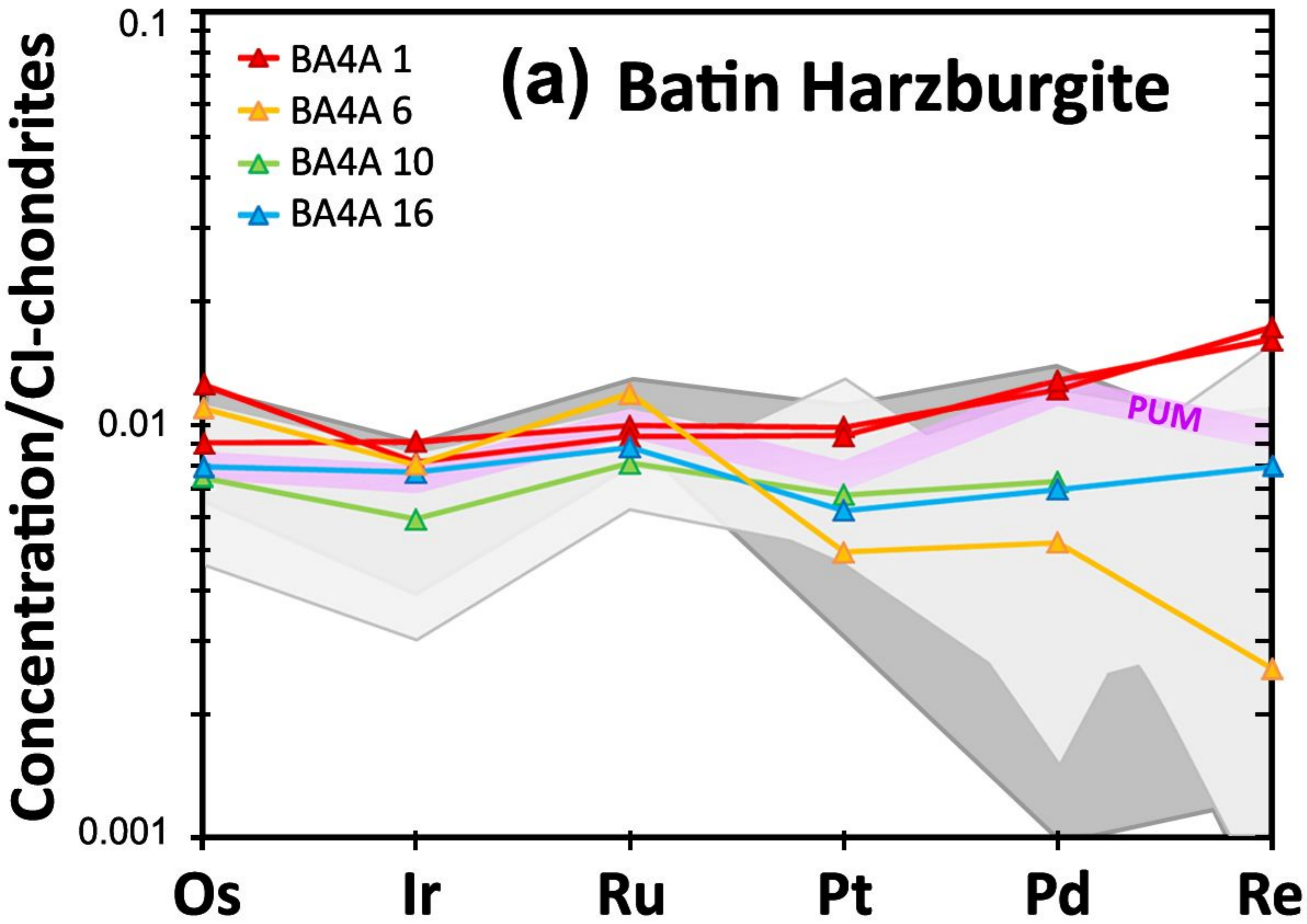
812 **Table 2.** HSE concentrations and Os isotope compositions of the studied Batin peridotites and UB-N  
813 and MUH-1 standards

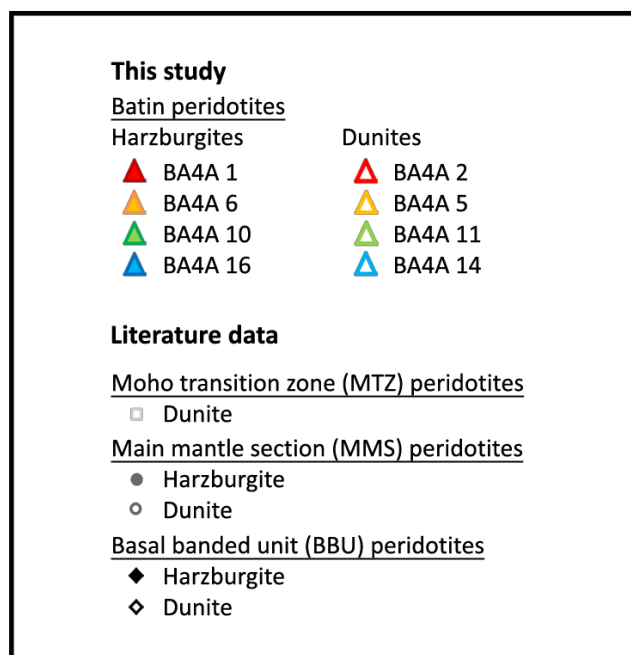
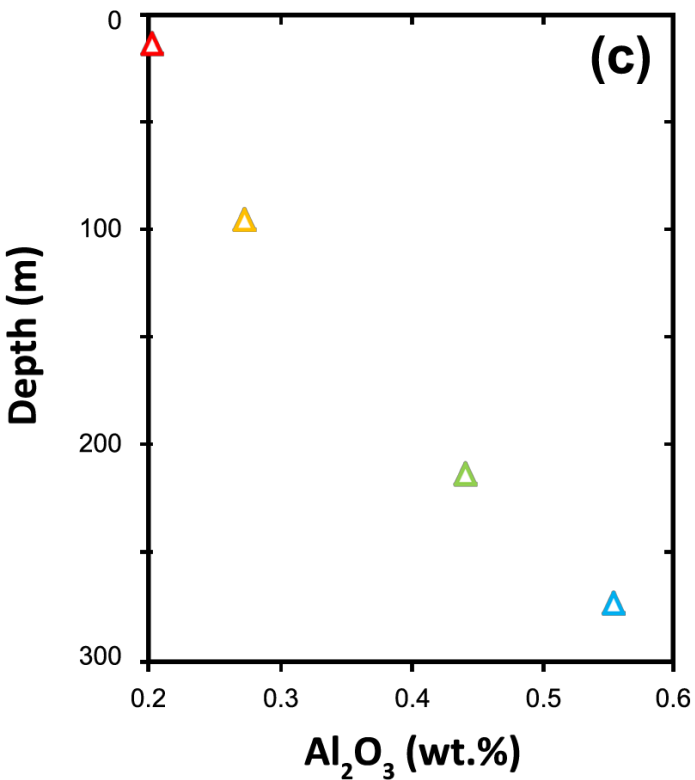
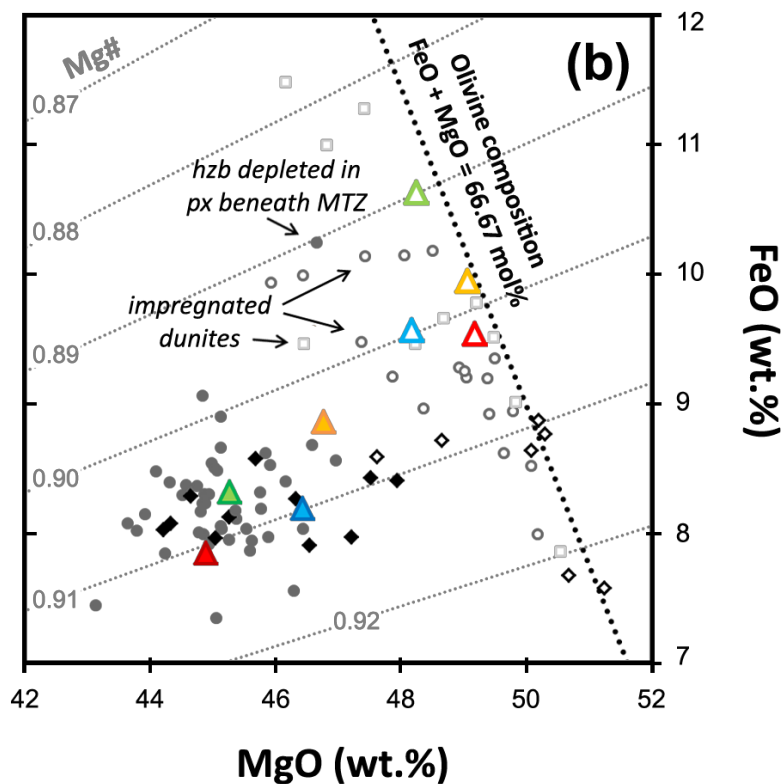
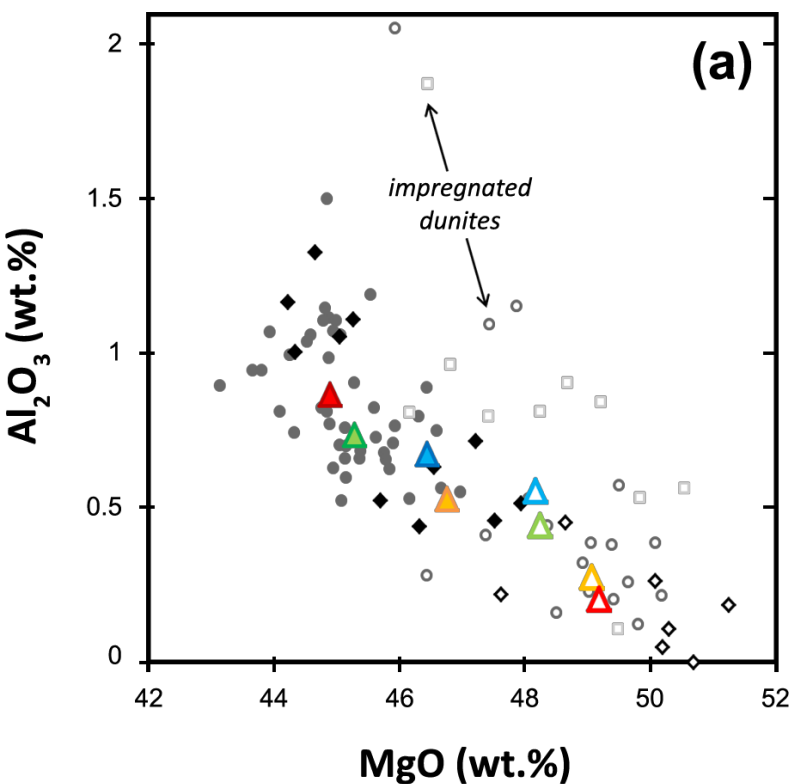


after Noël (2018)

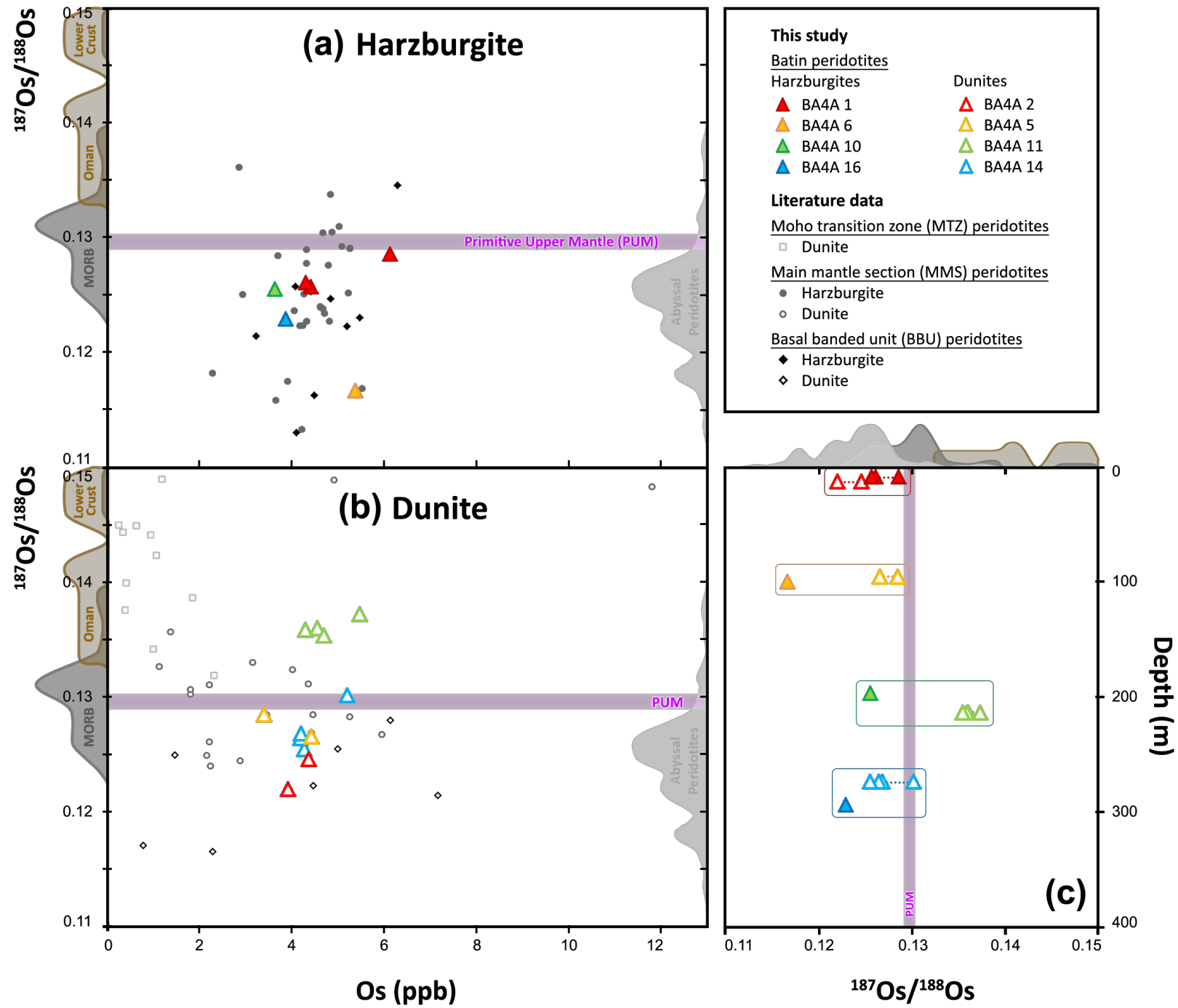












**Table 1.** Whole-rock major element compositions of the studied Batin peridotites

Sample	Lithology	Oman DP reference	Depth (m)	Hzb/Dun pair distance (m)	SiO <sub>2</sub> (wt.%)	Al <sub>2</sub> O <sub>3</sub>	FeO*	MnO	MgO	CaO	Na <sub>2</sub> O	LOI	Total	Mg#
BA4A 01	hzb	5-2 (46-51)	10.16	3.175	39.09	0.74	6.76	0.11	38.65	0.73	b.d.l.	12.41	98.49	0.911
BA4A 02	dunite	6-3 (8-13)	13.33		33.12	0.17	7.73	0.12	39.85	0.04	b.d.l.	17.51	98.53	0.902
BA4A 06	hzb	39-2 (74-79)	100.24	4.620	36.71	0.45	7.53	0.12	39.75	0.44	b.d.l.	14.01	98.99	0.904
BA4A 05	dunite	37-4 (35-40)	95.62		33.06	0.23	8.17	0.13	40.29	0.25	b.d.l.	16.23	98.35	0.898
BA4A 10	hzb	73-4 (4-9)	197.20	16.965	37.88	0.63	7.09	0.11	38.58	0.92	b.d.l.	13.87	99.07	0.907
BA4A 11	dunite	80-3 (12-17)	214.17		33.31	0.37	8.84	0.14	40.08	0.32	0.04	15.38	98.47	0.890
BA4A 16	hzb	107-1 (25-30)	293.98	19.770	37.48	0.58	7.02	0.11	39.80	0.71	b.d.l.	13.42	99.11	0.910
BA4A 14	dunite	100-3 (18-23)	274.20		34.08	0.46	7.92	0.13	39.86	0.31	b.d.l.	15.43	98.18	0.900

Whole-rock major element compositions were analyzed by the SARM (Service d'Analyse des Roches et des Minéraux) at the CRPG laboratory in Nancy (France) using ICP-OES iCap6500. K<sub>2</sub>O, TiO<sub>2</sub> and P<sub>2</sub>O<sub>5</sub> contents are below detection limit of the instrument. Oman DP references include section unit and sample interval (cm).

\*Total Fe as FeO.

Mg# =  $Mg/(Mg+Fe)_{at}$ ; LOI = Loss On Ignition; b.d.l. = below detection limit; Hzb = harzburgite; Dun = dunite.

**Table 2.** HSE concentrations and Os isotope compositions of the studied Batin peridotites and UB-N and MUH-1 standards

Sample	Lithology	Depth (m)	[Os] (ppb)	[Ir] (ppb)	[Ru] (ppb)	[Pt] (ppb)	[Pd] (ppb)	[Re] (ppb)	$^{187}\text{Re}/^{188}\text{Os}$	$(^{187}\text{Os}/^{188}\text{Os})_m$	2 $\sigma$ error	$(^{187}\text{Os}/^{188}\text{Os})_{95\text{Ma}}$	2 $\sigma$ error
BA4A 1	hzb	10.155	4.41	4.30	6.93	9.96	7.19	0.641	0.701	0.12682	0.00057	0.12571	0.00057
BA4A 1-d <sub>1</sub>			6.12	3.83	6.51	9.49	7.57	0.599	0.471	0.12936	0.00145	0.12861	0.00145
BA4A 1-d <sub>2</sub>			4.30					0.564	0.633	0.12710	0.00054	0.12610	0.00054
BA4A 2	dunite	13.330	4.35	3.12	6.69	7.81	5.93	1.203	1.331	0.12669	0.00055	0.12459	0.00055
BA4A 2-d			3.92	2.67	6.20	7.38	5.38	1.277	1.572	0.12450	0.00059	0.12201	0.00060
BA4A 6	hzb	100.245	5.38	3.79	8.28	4.97	3.07	0.096	0.086	0.11684	0.00052	0.11671	0.00052
BA4A 5	dunite	95.625	4.42	3.31	7.67	8.34	6.96	0.239	0.260	0.12696	0.00053	0.12655	0.00054
BA4A 5-d			3.398	2.42	6.35	5.60	6.95			0.12762	0.00062	0.12846	0.00063
BA4A 10	hzb	197.205	3.63	2.80	5.62	6.83	4.31			0.12548	0.00053	0.12552	0.00054
BA4A 11	dunite	214.170	5.46	3.04	7.44	8.59	9.20	0.606	0.535	0.13812	0.00124	0.13728	0.00124
BA4A 11-d <sub>1</sub>			4.55	3.06	6.39	8.59	8.32	0.485	0.514	0.13682	0.00054	0.13601	0.00055
BA4A 11-d <sub>2</sub>			4.69					0.631	0.649	0.13641	0.00053	0.13538	0.00053
BA4A 11-d <sub>3</sub>			4.29					0.496	0.559	0.13675	0.00051	0.13586	0.00051
BA4A 16	hzb	293.975	3.86	3.63	6.14	6.27	4.13	0.295	0.368	0.12354	0.00054	0.12296	0.00054
BA4A 14	dunite	274.205	5.19	3.13	7.17	9.32	10.09	0.539	0.501	0.13097	0.00061	0.13018	0.00061
BA4A 14-d <sub>1</sub>			4.27	3.37	7.06	9.13	12.82	0.542	0.612	0.12644	0.00055	0.12547	0.00055
BA4A 14-d <sub>2</sub>			4.18					0.507	0.584	0.12736	0.00051	0.12644	0.00051
BA4A 14-d <sub>3</sub>			4.20					0.483	0.554	0.12769	0.00053	0.12681	0.00053
<i>Standards</i>													
MUH-1			4.10	2.61	5.65	20.99	8.93	0.276	0.325	0.12658	0.00052		
UB-N 1			3.44	2.76	5.88	6.75	10.44	0.243	0.341	0.12725	0.00055		
UB-N 2			3.30					0.240	0.351	0.12780	0.00052		
UB-N 3			3.43					0.191	0.269	0.12690	0.00051		

HSE concentrations and Os isotopic compositions in whole rock powders were analyzed at the CRPG laboratory in Nancy (France) using MC-ICP-MS (Neptune +) and N-TIMS (Finnigan MAT 262) (Os). All uncertainties are 2SE and include all recognized sources of uncertainty, including in-run analytical precision, reproducibility of standard analyses, uncertainties related to blank variability, uncertainties related to age correction (95 Ma). Duplicate analyses were performed for several samples (noted "-d") and the UB-N standard. Details are presented in the [Supplementary Tables 1-3](#). Hzb = harzburgite.

# Supplementary material

## 1. Analytical methods

### 1.1. *Major element compositions*

Whole-rock major element concentrations (Table 1) were measured by the SARM at the CRPG laboratory (Nancy, France; <http://helium.crpq.cnrs-nancy.fr/SARM/>). Loss on Ignition (LOI) was determined by mass loss after calcination at 1000°C. The anhydrous residue was fused with LiBO<sub>2</sub> flux then digested in acid prior to major element analysis using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES iCap6500). Detailed technique description can be found in Carignan et al. (2001). Uncertainties vary from <2% for SiO<sub>2</sub> to <20% for MnO, based on the concentrations.

### 1.2. *Highly siderophile element abundances and Os isotopic compositions*

Highly siderophile element abundances and Os isotopic compositions were analyzed at CRPG. Sample powders (1.5-2g) were spiked with a mixed tracer solution containing <sup>190</sup>Os, <sup>101</sup>Ru, <sup>191</sup>Ir, <sup>196</sup>Pt, <sup>105</sup>Pd and <sup>185</sup>Re, and digested in a solution of concentrated HCl:HNO<sub>3</sub> (2:5 for samples and 1.5:5 for blanks) in a High Pressure Asher (HPA-S; Anton Paar) for 16 hours at 100 bars and 285°C. This procedure brings all of the Os to its most oxidized form (OsO<sub>4</sub>), assuring spike-sample equilibration. Osmium was chemically extracted from the sample solution into liquid bromine, for which OsO<sub>4</sub> has a strong affinity, and purified by microdistillation, using techniques adapted from Birck et al. (1997). Following Os extraction, other HSE were separated from the residual acidic solution by anion-exchange column chromatography using the method of Rehkämper & Halliday (1997). For several of the replicate analyses, only <sup>187</sup>Os/<sup>188</sup>Os ratios and Os and Re concentrations were determined. In these cases, Re was separated using AG1 X8 resin columns from the residual solution.

Rhenium, Pd, Ru, Pt and Ir isotopic compositions used for concentration determinations by isotope dilution were analyzed by MC-ICP-MS (ThermoScientific Neptune +). Given that Rh and Au are monoisotopic elements, it was not possible to analyze them by this method. Instrumental mass

25 fractionation was corrected by standard bracketing, assuming  $^{187}\text{Re}/^{185}\text{Re} = 1.6738$ ,  $^{108}\text{Pd}/^{106}\text{Pd} =$   
26  $0.9236$ ,  $^{102}\text{Ru}/^{99}\text{Ru} = 2.4726$ ,  $^{194}\text{Pt}/^{195}\text{Pt} = 0.9744$  and  $^{191}\text{Ir}/^{193}\text{Ir} = 0.5949$  for the standard. Osmium  
27 isotopic compositions were determined by Negative Thermal Ionization Mass Spectrometry (NTIMS)  
28 (Creaser et al., 1991; Völkening et al., 1991) using a Finnigan MAT 262 mass spectrometer. Isotopic  
29 ratios of  $\text{OsO}_3^-$  masses were obtained by peak jumping on an ETP electron multiplier. Corrections for  
30 heavy oxides, spike contributions and instrumental mass fractionation were made off-line, assuming  
31 a natural  $^{192}\text{Os}/^{188}\text{Os}$  ratio of 3.08271.

32 Highly siderophile element abundances and Os isotope data are presented in [Table 2](#) and  
33 [Supplementary Tables 1-2](#). All uncertainties are 2SE and include all significant recognized sources of  
34 uncertainty (in-run analytical precision, standard reproducibility, uncertainties related to variability  
35 of the amount and isotopic composition of the analytical blank, uncertainties related to the Re/Os  
36 ratio and the ensuing age correction). These different uncertainty components are listed for each  
37 sample in [Supplementary Table 3](#). The total analytical blanks varied between the two main analytical  
38 periods of the study: Os =  $0.0007 \pm 0.0002$  ng,  $^{187}\text{Os}/^{188}\text{Os} = 0.209 \pm 0.122$  ( $n = 3$ ), Re =  $0.042 \pm 0.078$   
39 ng, Ir =  $0.001 \pm 0.002$  ng, Pt =  $0.015 \pm 0.023$  ng, Ru =  $0.018 \pm 0.045$  ng, Pd =  $0.014 \pm 0.022$  ng ( $n = 4$ )  
40 (first period, including all full HSE analyses); Os =  $0.0010 \pm 0.0000$  ng ( $n = 2$ ),  $^{187}\text{Os}/^{188}\text{Os} = 0.2204 \pm$   
41  $0.0058$  ( $n = 1$ ), Re =  $0.022 \pm 0.003$  ng ( $n = 2$ ) (second period; comprising those replicates analyzed  
42 solely for  $^{187}\text{Os}/^{188}\text{Os}$  and Re and Os concentrations); all uncertainties  $2\sigma$ . The total  $2\sigma$  uncertainties,  
43 including the blank variability, on the initial  $^{187}\text{Os}/^{188}\text{Os}$  ratios of all samples are  $< 1.2\%$ . UB-N and  
44 MUH-1 reference materials ([Table 2](#) and [Supplementary Tables 1-3](#)), which like our samples are  
45 serpentinized peridotites, were analyzed concurrently with the samples, yielding mean  $^{187}\text{Os}/^{188}\text{Os}$   
46 ratios of  $0.1273 \pm 0.0005$  ( $2\sigma$ ) ( $n = 3$ ) and  $0.1266 \pm 0.0005$  ( $2\sigma$ ) ( $n = 1$ ) respectively, in agreement with  
47 the accepted values (MUH-1: Snortum & Day (2020); UB-N : Meisel et al. (2003)). Duplicate analyses  
48 were performed for all dunites ( $n = 2$  for BA4A 2,5 and 4 for BA4A 11,14) and harzburgite BA4A 1 ( $n =$   
49 3).

## 50 **2. Seawater alteration of peridotite - mixing model**

51 To exclude a contamination of our samples with seawater, we simulate a simple two component  
52 mixture between seawater and a common peridotite in Klaessens et al. (in revision) (Supplementary  
53 Fig. 1), similar to the model used by Sanfilippo et al. (2016), using the following equations:

54 (1) 
$$[Os]_{mix} = (f \cdot [Os]_{seawater}) + ((1 - f) \cdot [Os]_{per})$$

55 (2) 
$$({}^{187}Os/{}^{188}Os)_{mix} = \frac{1}{[Os]_{mix}} \cdot (f \cdot [Os]_{seawater} \cdot ({}^{187}Os/{}^{188}Os)_{seawater}) + ((1 - f) \cdot [Os]_{per} \cdot ({}^{187}Os/{}^{188}Os)_{per})$$

56 Th and U concentrations are calculated in the same manner as Os concentration, using Equation A.1.

57 where:  $[Os]_{per}$ : concentration in Os of the peridotite

58  $[Os]_{seawater}$ : seawater concentration in Os

59  $[Os]_{mix}$ : concentration in Os of the mixture, including seawater and peridotite

60  $({}^{187}Os/{}^{188}Os)_{per}$ :  ${}^{187}Os/{}^{188}Os$  ratio of the peridotite

61  $({}^{187}Os/{}^{188}Os)_{melt}$ :  ${}^{187}Os/{}^{188}Os$  seawater ratio

62  $({}^{187}Os/{}^{188}Os)_{mix}$ :  ${}^{187}Os/{}^{188}Os$  ratio of the mixture, including seawater and peridotite

63  $f$ : seawater fraction

64 We use the following compositions for the peridotite and Cretaceous seawater endmembers:

65  $({}^{187}Os/{}^{188}Os)_{per} = 0.124$   $({}^{187}Os/{}^{188}Os)_{seawater} = 0.55$

66  $[Os]_{per} = 4$  ppb  $[Os]_{seawater} = 10^{-5}$  ppb

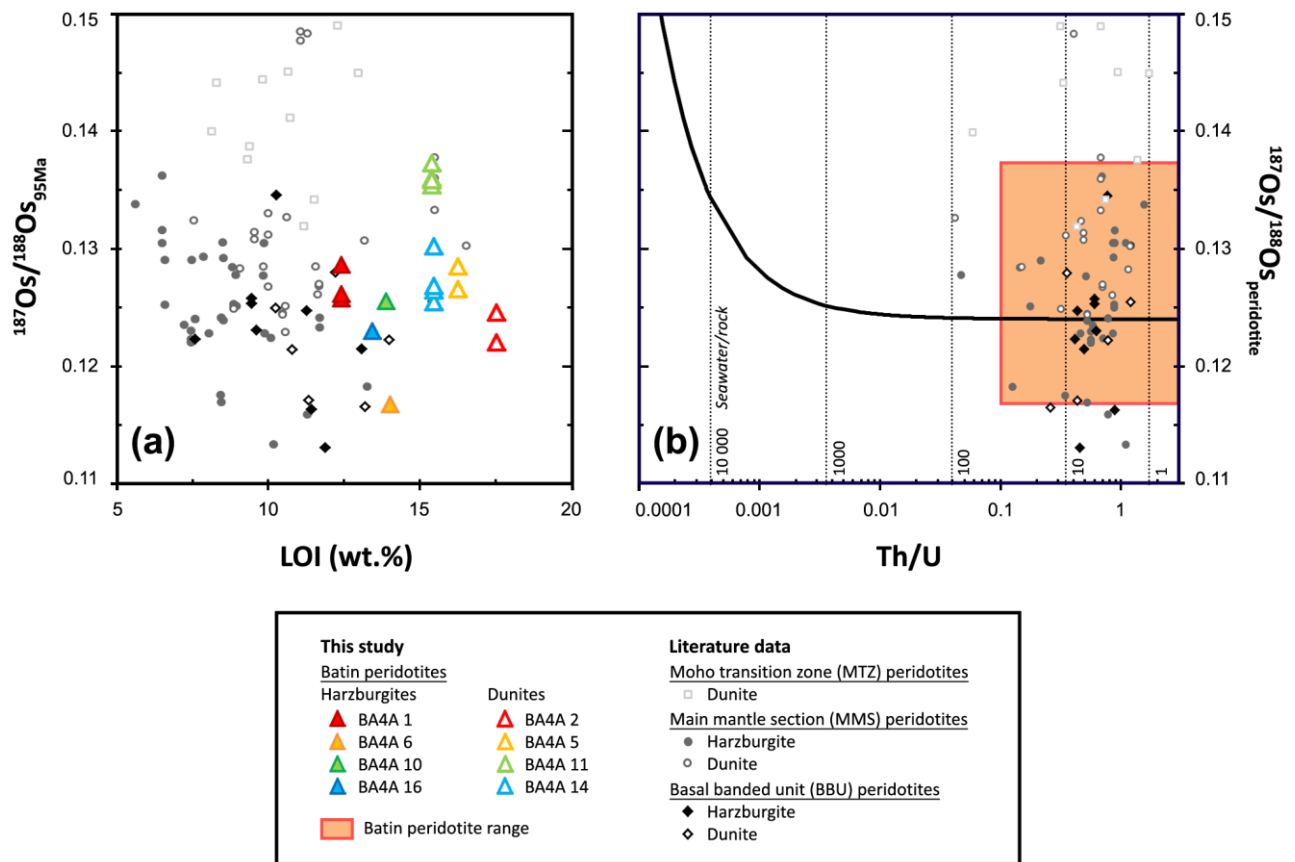
67  $[Th]_{per} = 13$  ppb  $[Th]_{seawater} = 5 \times 10^{-6}$  ppb

68  $[U]_{per} = 4.5$  ppb  $[U]_{seawater} = 3.3$  ppb

69 For the peridotite, the  ${}^{187}Os/{}^{188}Os$  ratio chosen is typical of Oman harzburgites, as well as of abyssal  
70 peridotites, and its Os concentration of 4 ppb is typical of dunites and harzburgites from the Batin  
71 area (Table 1, main text). The peridotite Th and U concentrations are those of the depleted peridotite  
72 reference material PCC-1 (Govindaraju, 1994). Seawater Os, Th and U contents are the same as those  
73 used in the model of Sanfilippo et al. (2016). The seawater  ${}^{187}Os/{}^{188}Os$  ratio is from Ravizza et al.  
74 (1999).

75 This mixing model shows that seawater contamination sufficient to produce radiogenic Os  
76 compositions similar to that of the most radiogenic Batin sample, dunite BA4A 11 ( $^{187}\text{Os}/^{188}\text{Os}_{95\text{Ma}} \sim$   
77 0.136), would require water/rock ratios  $>10000$ , and would lower corresponding peridotite Th/U  
78 ratios to  $\sim 0.0003$ . In another study of the ICDP Oman Drilling Project BA borehole samples, Th/U  
79 ratios of dunites from the same hole used in our study (BA4A; some collected in close proximity with  
80 our samples) and of harzburgites from the BA3A and BA1B holes were analyzed (Aupart et al., in  
81 revision). These Th/U ratios (0.1-3.8) are all several orders of magnitude higher than 0.0003, implying  
82 that seawater contamination was much less important than that required to explain our results by  
83 this process. The dunite sample BA4A 80-4 (44-49) of Aupart et al. (in revision) was collected just  
84 next to our radiogenic dunite BA4A 11 and has an almost unperturbed Th/U ratio of 2.16.  
85 [Supplementary Fig. 1](#) shows the Os composition and Th/U ratio range of Batin peridotites in  
86 comparison with the mixing model curve and other published Oman peridotite data (Godard et al.,  
87 2000; Hanghøj et al., 2010; Klaessens et al., 2021; Xiong et al., 2020a, 2020b). These data, in addition  
88 to the absence of correlation between LOI values and Os isotope composition in our Batin peridotite  
89 samples, argue that they have preserved the Os isotope signatures of essentially magmatic  
90 processes.

## Figures



92

93 **Supplementary Fig. 1.** Initial osmium isotope composition vs. tracers of seawater contamination (**a**,

94 LOI and **b**, Th/U ratio) for Batin harzburgites and dunites.  $^{187}\text{Os}/^{188}\text{Os}_{95\text{Ma}}$  vs. **(a)** LOI, **(b)** Th/U ratio. In

95 panel **(b)**, the black curve represents the compositions of a mixture of Os, Th and U from seawater

96 ( $^{187}\text{Os}/^{188}\text{Os} = 0.55$ ;  $[\text{Os}] = 10^{-5}$  ppb;  $[\text{Th}] = 5 \times 10^{-6}$  ppb;  $[\text{U}] = 3.3$  ppb) and peridotite ( $^{187}\text{Os}/^{188}\text{Os} =$

97  $0.124$ ;  $[\text{Os}] = 4$  ppb;  $[\text{Th}] = 13$  ppb;  $[\text{U}] = 4.5$  ppb). Black dotted lines indicate seawater/rock ratios of

98 1, 10, 100, 1000 and 10 000. The orange area represent Os compositions (this study) and Th/U ratio

99 (Aupart et al., in revision) range of Batin peridotites. In all panels, published Oman peridotite data are

100 shown for comparison (Godard et al., 2000; Hanghøj et al., 2010; Klaessens et al., 2021; Xiong et al.,

101 2020a, 2020b): dunites from Moho transition zone (MTZ), dunites and harzburgites from main (MMS)

102 and basal mantle sections (BBU). Attribution of samples reported in the literature to the three

103 domains defined in Klaessens et al. (2021) was based on their geographic positions in the mantle



104 section. No correlation is observed between initial Os isotope ratios, LOI, whole-rock Th/U ratios and  
105 the Th/U model curve. This curve shows that seawater/rock ratios >10 000 would be required to  
106 produce  $^{187}\text{Os}/^{188}\text{Os}$  ratios comparable to those of the MTZ dunites and Batin dunite BA4A 11, and  
107 these would be associated with Th/U ratios much lower than the observed values. Thus, seawater  
108 contamination cannot explain the radiogenic initial  $^{187}\text{Os}/^{188}\text{Os}$  ratios of these samples.

109

## Tables

110 [Supplementary Table 1](#). Re and Os concentrations and Os isotope compositions of the studied Batin  
111 peridotites and UB-N and MUH-1 standards

112 [Supplementary Table 2](#). HSE concentrations of the studied Batin peridotites and UB-N and MUH-1  
113 standards

114 [Supplementary Table 3](#). Different components of the uncertainties on HSE concentrations and Os  
115 isotope compositions entering into the total uncertainties

116 [Supplementary Table 4](#). Re and Os concentrations and Os isotope compositions of Oman  
117 harzburgites and the three types of dunites and of the reference materials (Klaessens, 2021;  
118 Klaessens et al., 2021)

119 [Supplementary Table 5](#). HSE concentrations of Oman harzburgites and the three types of dunites  
120 and of the reference materials (Klaessens, 2021; Klaessens et al., 2021)

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Supplementary Table 1. Re and Os concentrations and Os isotope compositions of the studied Batin peridotites and UB-N and MUH-1 standards

Sample	Lithology	Depth (m)	Mass (g)	[Os] (ppb)	2 $\sigma$ error	[Re] (ppb)	2 $\sigma$ error	<sup>188</sup> Os (M/g)	2 $\sigma$ error	<sup>187</sup> Re/ <sup>188</sup> Os	2 $\sigma$ error	( <sup>187</sup> Os/ <sup>188</sup> Os) <sub>m</sub>	2 $\sigma$ error	( <sup>187</sup> Os/ <sup>188</sup> Os) <sub>95 Ma</sub>	2 $\sigma$ error
BA4A 1	harzburgite	10.155	2.01412	4.411	0.000	0.641	0.039	3.08E-12	2.22E-14	0.701	0.043	0.12682	0.00057	0.12571	0.00057
BA4A 1-d <sub>1</sub>			2.00379	6.123	0.000	0.599	0.039	4.27E-12	1.90E-13	0.471	0.037	0.12936	0.00145	0.12861	0.00145
BA4A 1-d <sub>2</sub>			1.54518	4.295	0.000	0.564	0.005	3.00E-12	1.91E-14	0.633	0.007	0.12710	0.00054	0.12610	0.00054
BA4A 2	dunite	13.330	2.00336	4.354	0.000	1.203	0.039	3.04E-12	1.75E-14	1.331	0.044	0.12669	0.00055	0.12459	0.00055
BA4A 2-d			1.51420	3.916	0.000	1.277	0.052	2.73E-12	1.54E-14	1.572	0.064	0.12450	0.00059	0.12201	0.00060
BA4A 6	harzburgite	100.245	2.00763	5.375	0.000	0.096	0.039	3.76E-12	1.64E-14	0.086	0.035	0.11684	0.00052	0.11671	0.00052
BA4A 5	dunite	95.625	2.00897	4.416	0.000	0.239	0.039	3.08E-12	1.40E-14	0.260	0.042	0.12696	0.00053	0.12655	0.00054
BA4A 5-d			1.52049	3.398	0.000			2.37E-12	3.05E-14			0.12762	0.00062	0.12846	0.00063
BA4A 10	harzburgite	197.205	2.00718	3.630	0.000			2.53E-12	1.11E-14			0.12548	0.00053	0.12552	0.00054
BA4A 11	dunite	214.170	2.08374	5.463	0.000	0.606	0.038	3.81E-12	9.90E-14	0.535	0.036	0.13812	0.00124	0.13728	0.00124
BA4A 11-d <sub>1</sub>			1.52127	4.552	0.000	0.485	0.051	3.17E-12	1.78E-14	0.514	0.054	0.13682	0.00054	0.13601	0.00055
BA4A 11-d <sub>2</sub>			1.54478	4.686	0.000	0.631	0.002	3.27E-12	3.71E-14	0.649	0.008	0.13641	0.00053	0.13538	0.00053
BA4A 11-d <sub>3</sub>			1.62985	4.286	0.000	0.496	0.002	2.99E-12	3.17E-14	0.559	0.006	0.13675	0.00051	0.13586	0.00051
BA4A 16	harzburgite	293.975	2.00632	3.861	0.000	0.295	0.039	2.70E-12	1.24E-14	0.368	0.049	0.12354	0.00054	0.12296	0.00054
BA4A 14	dunite	274.205	2.03097	5.191	0.000	0.539	0.039	3.62E-12	3.90E-14	0.501	0.036	0.13097	0.00061	0.13018	0.00061
BA4A 14-d <sub>1</sub>			1.55373	4.269	0.000	0.542	0.050	2.98E-12	1.61E-14	0.612	0.057	0.12644	0.00055	0.12547	0.00055
BA4A 14-d <sub>2</sub>			1.56883	4.185	0.000	0.507	0.002	2.92E-12	1.87E-14	0.584	0.004	0.12736	0.00051	0.12644	0.00051
BA4A 14-d <sub>3</sub>			1.52166	4.198	0.000	0.483	0.002	2.93E-12	2.42E-14	0.554	0.005	0.12769	0.00053	0.12681	0.00053
<i>Standards</i>															
MUH-1 4			1.53566	4.096	0.000	0.276	0.051	2.86E-12	9.46E-15	0.325	0.060	0.12658	0.00052		
UB-N 5			2.00186	3.436	0.000	0.243	0.039	2.40E-12	1.26E-14	0.341	0.055	0.12725	0.00055		
UB-N 6			1.61348	3.298	0.000	0.240	0.002	2.30E-12	9.59E-15	0.351	0.003	0.12780	0.00052		
UB-N 7			1.53837	3.426	0.000	0.191	0.010	2.39E-12	9.16E-15	0.269	0.014	0.12690	0.00051		

Re and Os concentrations and Os isotopic compositions in whole rock powders were analyzed at the CRPG laboratory in Nancy (France) using MC-ICPMS (Neptune +) and N-TIMS (Finnigan MAT 262) (Os). All uncertainties are 2  $\sigma$  and include all recognized sources of uncertainty, including in-run analytical precision, reproducibility of standard analyses, uncertainties related to the variability of the blank and its isotope composition, uncertainties related to the age correction (95 Ma). Duplicate analyses were performed for several samples (noted "-d") and the UB-N standard.

Supplementary Table 2. HSE concentrations of the studied Batin peridotites and UB-N and MUH-1 standards

Sample	Lithology	Depth (m)	Mass (g)	[Os] (ppb)	2 $\sigma$ error	[Ir] (ppb)	2 $\sigma$ error	[Ru] (ppb)	2 $\sigma$ error	[Pt] (ppb)	2 $\sigma$ error	[Pd] (ppb)	2 $\sigma$ error	[Re] (ppb)	2 $\sigma$ error	Ir/Os	Ir/Ru	Pd/Ir	Re/Os
BA4A 1	harzburgite	10.155	2.01412	4.411	0.000	4.305	0.002	6.931	0.023	9.960	0.012	7.194	0.011	0.641	0.039	0.98	0.62	1.67	0.15
BA4A 1-d <sub>1</sub>			2.00379	6.123	0.000	3.834	0.002	6.508	0.023	9.488	0.013	7.566	0.011	0.599	0.039	0.63	0.59	1.97	0.10
BA4A 1-d <sub>2</sub>			1.54518	4.295	0.000									0.564	0.005				0.13
BA4A 2	dunite	13.330	2.00336	4.354	0.000	3.115	0.001	6.691	0.023	7.809	0.012	5.931	0.011	1.203	0.039	0.72	0.47	1.90	0.28
BA4A 2-d			1.51420	3.916	0.000	2.672	0.001	6.205	0.030	7.383	0.016	5.379	0.015	1.277	0.052	0.68	0.43	2.01	0.33
BA4A 6	harzburgite	100.245	2.00763	5.375	0.000	3.787	0.001	8.283	0.023	4.972	0.012	3.069	0.011	0.096	0.039	0.70	0.46	0.81	0.02
BA4A 5	dunite	95.625	2.00897	4.416	0.000	3.314	0.001	7.671	0.023	8.344	0.012	6.965	0.011	0.239	0.039	0.75	0.43	2.10	0.05
BA4A 5-d			1.52049	3.398	0.000	2.419	0.001	6.349	0.030	5.599	0.016	6.948	0.015			0.71	0.38	2.87	
BA4A 10	harzburgite	197.205	2.00718	3.630	0.000	2.797	0.001	5.620	0.023	6.830	0.012	4.312	0.011			0.77	0.50	1.54	
BA4A 11	dunite	214.170	2.08374	5.463	0.000	3.035	0.001	7.439	0.022	8.588	0.012	9.205	0.011	0.606	0.038	0.56	0.41	3.03	0.11
BA4A 11-d <sub>1</sub>			1.52127	4.552	0.000	3.055	0.002	6.390	0.030	8.587	0.016	8.320	0.015	0.485	0.051	0.67	0.48	2.72	0.11
BA4A 11-d <sub>2</sub>			1.54478	4.686	0.000									0.631	0.002				0.13
BA4A 11-d <sub>3</sub>			1.62985	4.286	0.000									0.496	0.002				0.12
BA4A 16	harzburgite	293.975	2.00632	3.861	0.000	3.630	0.001	6.139	0.023	6.271	0.012	4.129	0.011	0.295	0.039	0.94	0.59	1.14	0.08
BA4A 14	dunite	274.205	2.03097	5.191	0.000	3.127	0.001	7.174	0.023	9.324	0.012	10.088	0.011	0.539	0.039	0.60	0.44	3.23	0.10
BA4A 14-d <sub>1</sub>			1.55373	4.269	0.000	3.372	0.002	7.058	0.030	9.127	0.016	12.816	0.015	0.542	0.050	0.79	0.48	3.80	0.13
BA4A 14-d <sub>2</sub>			1.56883	4.185	0.000									0.507	0.002				0.12
BA4A 14-d <sub>3</sub>			1.52166	4.198	0.000									0.483	0.002				0.12
<i>Standards</i>																			
MUH-1 4			1.53566	4.096	0.000	2.613	0.001	5.654	0.030	20.991	0.015	8.931	0.015	0.276	0.051	0.64	0.46	3.42	0.07
UB-N 5			2.00186	3.436	0.000	2.756	0.001	5.882	0.023	6.746	0.012	10.436	0.013	0.243	0.039	0.80	0.47	3.79	0.07
UB-N 6			1.61348	3.298	0.000									0.240	0.002				0.07
UB-N 7			1.53837	3.426	0.000									0.191	0.010				0.06

HSE concentrations in whole rock powders were analyzed at the CRPG laboratory in Nancy (France) using MC-ICPMS (Neptune +) and N-TIMS (Finnigan MAT 262) (Os). All uncertainties are 2  $\sigma$  and include all recognized sources of uncertainty, including in-run analytical precision, reproducibility of standard analyses, uncertainties related to the variability of the blank and its isotope composition, uncertainties related to the age correction (95 Ma). Duplicate analyses were performed for several samples (noted "-d") and the UB-N standard.

Supplementary Table 3. Different components of the uncertainties on HSE concentrations and Os isotope compositions entering into the total uncertainties

Sample	Mass (g)	Associated blank		[Os] uncertainty			<sup>188</sup> Os uncertainty			Measured <sup>187</sup> Os/ <sup>188</sup> Os uncertainty				
		Os	Re	measurement (2σ-m) (ppb)	due to blank variability (2σ)	Total (2σ)	measurement (2σ-m) (M/g)	due to blank variability (2σ)	Total (2σ)	measurement (2σ-m)	due to variability of blank <sup>188</sup> Os (2σ)	due to variability of blank <sup>187</sup> Os/ <sup>188</sup> Os (2σ)	due to long term reproducibility of standard (2σ)	Total (2σ)
BA4A 1	2.01412	a	a	0.032	0.000	0.032	2.22E-14	8.95E-17	2.22E-14	0.00026	0.00000	0.00001	0.00050	0.00057
BA4A 1-d <sub>1</sub>	2.00379	a	a	0.273	0.000	0.273	1.90E-13	8.99E-17	1.90E-13	0.00136	0.00000	0.00001	0.00050	0.00145
BA4A 1-d <sub>2</sub>	1.54518	b	b	0.027	0.000	0.027	1.91E-14	1.23E-18	1.91E-14	0.00020	0.00000	0.00000	0.00050	0.00054
BA4A 2	2.00336	a	a	0.025	0.000	0.025	1.75E-14	8.99E-17	1.75E-14	0.00022	0.00000	0.00001	0.00050	0.00055
BA4A 2-d	1.51420	a	a	0.022	0.000	0.022	1.54E-14	1.19E-16	1.54E-14	0.00032	0.00000	0.00001	0.00050	0.00059
BA4A 6	2.00763	a	a	0.023	0.000	0.023	1.64E-14	8.97E-17	1.64E-14	0.00014	0.00000	0.00001	0.00050	0.00052
BA4A 5	2.00897	a	a	0.020	0.000	0.020	1.40E-14	8.97E-17	1.40E-14	0.00019	0.00000	0.00001	0.00050	0.00053
BA4A 5-d	1.52049	a	a	0.044	0.000	0.044	3.05E-14	1.18E-16	3.05E-14	0.00037	0.00000	0.00002	0.00050	0.00062
BA4A 10	2.00718	a	a	0.016	0.000	0.016	1.11E-14	8.98E-17	1.11E-14	0.00018	0.00000	0.00001	0.00050	0.00053
BA4A 11	2.08374	a	a	0.142	0.000	0.142	9.90E-14	8.65E-17	9.90E-14	0.00114	0.00000	0.00001	0.00050	0.00124
BA4A 11-d <sub>1</sub>	1.52127	a	a	0.026	0.000	0.026	1.78E-14	1.18E-16	1.78E-14	0.00021	0.00000	0.00001	0.00050	0.00054
BA4A 11-d <sub>2</sub>	1.54478	b	b	0.053	0.000	0.053	3.71E-14	1.23E-18	3.71E-14	0.00018	0.00000	0.00000	0.00050	0.00053
BA4A 11-d <sub>3</sub>	1.62985	b	b	0.045	0.000	0.045	3.17E-14	1.16E-18	3.17E-14	0.00011	0.00000	0.00000	0.00050	0.00051
BA4A 16	2.00632	a	a	0.018	0.000	0.018	1.24E-14	8.98E-17	1.24E-14	0.00020	0.00000	0.00001	0.00050	0.00054
BA4A 14	2.03097	a	a	0.056	0.000	0.056	3.90E-14	8.87E-17	3.90E-14	0.00035	0.00000	0.00001	0.00050	0.00061
BA4A 14-d <sub>1</sub>	1.55373	a	a	0.023	0.000	0.023	1.61E-14	1.16E-16	1.61E-14	0.00022	0.00000	0.00001	0.00050	0.00055
BA4A 14-d <sub>2</sub>	1.56883	b	b	0.027	0.000	0.027	1.87E-14	1.21E-18	1.87E-14	0.00008	0.00000	0.00000	0.00050	0.00051
BA4A 14-d <sub>3</sub>	1.52166	b	b	0.035	0.000	0.035	2.42E-14	1.25E-18	2.42E-14	0.00018	0.00000	0.00000	0.00050	0.00053
<i>Standards</i>														
MUH-1 4	1.53566	a	a	0.014	0.000	0.014	9.45E-15	1.17E-16	9.46E-15	0.00016	0.00000	0.00001	0.00050	0.00052
UB-N 5	2.00186	a	a	0.018	0.000	0.018	1.26E-14	9.00E-17	1.26E-14	0.00023	0.00000	0.00001	0.00050	0.00055
UB-N 6	1.61348	b	b	0.014	0.000	0.014	9.59E-15	1.18E-18	9.59E-15	0.00015	0.00000	0.00000	0.00050	0.00052
UB-N 7	1.53837	b	b	0.013	0.000	0.013	9.16E-15	1.23E-18	9.16E-15	0.00010	0.00000	0.00000	0.00050	0.00051

Supplementary Table 3 (suite). Different components of the uncertainties on HSE concentrations and Os isotope compositions entering into the total unce

Sample	[Re] uncertainty			Total <sup>187</sup> Re uncertainty (2σ) (M/g)	<sup>187</sup> Re/ <sup>188</sup> Os uncertainty (2σ)	Effect of <sup>187</sup> Re/ <sup>188</sup> Os uncertainty on <sup>187</sup> Os/ <sup>188</sup> Os age (2σ)	Total uncertainty initial <sup>187</sup> Os/ <sup>188</sup> Os (2σ)	Total <sup>187</sup> Os/ <sup>188</sup> Os uncertainty (%)
	measurement (2σ-m) (ppb)	due to blank variability (2σ)	Total (2σ)					
BA4A 1	0.005	0.039	0.039	1.32E-13	0.043	0.00007	0.00057	0.45
BA4A 1-d <sub>1</sub>	0.004	0.039	0.039	1.32E-13	0.037	0.00006	0.00145	1.13
BA4A 1-d <sub>2</sub>	0.004	0.002	0.005	1.54E-14	0.007	0.00001	0.00054	0.43
BA4A 2	0.003	0.039	0.039	1.31E-13	0.044	0.00007	0.00055	0.44
BA4A 2-d	0.003	0.052	0.052	1.74E-13	0.064	0.00010	0.00060	0.49
BA4A 6	0.000	0.039	0.039	1.31E-13	0.035	0.00006	0.00052	0.45
BA4A 5	0.001	0.039	0.039	1.31E-13	0.042	0.00007	0.00054	0.43
BA4A 5-d	0.000	0.000	0.000				0.00063	0.49
BA4A 10	0.000	0.009	0.009				0.00054	0.43
BA4A 11	0.000	0.038	0.038	1.26E-13	0.036	0.00006	0.00124	0.90
BA4A 11-d <sub>1</sub>	0.000	0.051	0.051	1.73E-13	0.054	0.00009	0.00055	0.40
BA4A 11-d <sub>2</sub>	0.001	0.002	0.002	6.21E-15	0.008	0.00001	0.00053	0.39
BA4A 11-d <sub>3</sub>	0.001	0.002	0.002	5.78E-15	0.006	0.00001	0.00051	0.38
BA4A 16	0.000	0.039	0.039	1.31E-13	0.049	0.00008	0.00054	0.44
BA4A 14	0.000	0.039	0.039	1.29E-13	0.036	0.00006	0.00061	0.47
BA4A 14-d <sub>1</sub>	0.000	0.050	0.050	1.69E-13	0.057	0.00009	0.00055	0.44
BA4A 14-d <sub>2</sub>	0.000	0.002	0.002	5.97E-15	0.004	0.00001	0.00051	0.40
BA4A 14-d <sub>3</sub>	0.001	0.002	0.002	6.15E-15	0.005	0.00001	0.00053	0.42
<i>Standards</i>								
MUH-1 4	0.000	0.051	0.051	1.71E-13	0.060	0.00009	0.00053	0.42
UB-N 5	0.001	0.039	0.039	1.31E-13	0.055	0.00009	0.00056	0.44
UB-N 6	0.000	0.002	0.002	5.79E-15	0.003	0.00000	0.00052	0.41
UB-N 7	0.010	0.002	0.010	3.32E-14	0.014	0.00002	0.00051	0.40





[Supplementary Table 3 \(suite\)](#). Different components of the uncertainties on HSE concentrations and Os isotope compositions entering into the total uncertainties

*Notes:*

*Column C:* Os blanks associated with two different analytical periods: a)  $0.0007 \pm 0.0002$  ng,  $^{187}\text{Os}/^{188}\text{Os} = 0.209 \pm 0.122$  ( $n = 3$ ); b)  $0.0010 \pm 0.0000$  ng ( $n = 2$ ),  $^{187}\text{Os}/^{188}\text{Os} = 0.220 \pm 0.006$  ( $n = 1$ ); uncertainties  $2\sigma$

*Column D:* Re blanks associated with two different analytical periods: a)  $0.042 \pm 0.078$  ng ( $n = 4$ ); b)  $0.022 \pm 0.003$  ng ( $n = 2$ ); uncertainties  $2\sigma$

*Column E:* Based on in-run uncertainty on  $^{190}\text{Os}/^{188}\text{Os}$  used in isotope dilution calculations

*Column F:* From difference between [Os] corrected using Os blank +  $2\sigma$  and [Os] corrected using Os blank -  $2\sigma$

*Column G:* Total uncertainty on [Os] based on combination of uncertainties in columns C and D (square root of individual values squared)

*Column H:* Based on in-run uncertainty on  $^{190}\text{Os}/^{188}\text{Os}$  used in isotope dilution calculations

*Column I:* From difference between  $^{188}\text{Os}$  corrected using Os blank +  $2\sigma$  and  $^{188}\text{Os}$  corrected using Os blank -  $2\sigma$

*Column J:* Total uncertainty on  $^{188}\text{Os}$  based on combination of uncertainties in columns F and G

*Column K:* In-run uncertainty on  $^{187}\text{Os}/^{188}\text{Os}$

*Column L:* From difference between  $^{187}\text{Os}/^{188}\text{Os}$  corrected using  $^{188}\text{Os}$  blank +  $2\sigma$  and  $^{187}\text{Os}/^{188}\text{Os}$  corrected using  $^{188}\text{Os}$  blank -  $2\sigma$ ; blank  $^{187}\text{Os}/^{188}\text{Os}$  held constant at mean value

*Column M:* From difference between  $^{187}\text{Os}/^{188}\text{Os}$  corrected using  $^{187}\text{Os}/^{188}\text{Os}$  blank +  $2\sigma$  and  $^{187}\text{Os}/^{188}\text{Os}$  corrected using  $^{187}\text{Os}/^{188}\text{Os}$  blank -  $2\sigma$ ; blank  $^{188}\text{Os}$  held constant at mean value

*Column N:* Long-term  $2\sigma$  reproducibility of in-house liquid standard run by peak jumping on an ETP electron multiplier

*Column O:* Total uncertainty on  $^{187}\text{Os}/^{188}\text{Os}$  based on combination of uncertainties in columns I through L

*Column P:* Based on in-run uncertainty on  $^{187}\text{Re}/^{185}\text{Re}$  used in isotope dilution calculations

*Column Q:* From difference between [Re] corrected using Re blank +  $2\sigma$  and [Re] corrected using Re blank -  $2\sigma$

*Column R:* Total uncertainty on [Re] based on combination of uncertainties in columns N and O (square root of individual values squared)

*Column S:* Total uncertainty on  $^{187}\text{Re}$  - proportional to total uncertainty on [Re]

*Column T:* Total uncertainty on  $^{187}\text{Re}/^{188}\text{Os}$  based on combination of uncertainties in columns H and Q

*Column U:* Uncertainty on age (95 Ma) corrected value of  $^{187}\text{Os}/^{188}\text{Os}$  related to  $^{187}\text{Re}/^{188}\text{Os}$  uncertainty.

Uncertainties on age correction related to  $^{187}\text{Re}$  decay constant, ophiolite age and spike calibration are not considered as they should be very small and systematic for all samples (i.e., they cannot produce inter-sample variability)

*Column V:* Total uncertainty on initial  $^{187}\text{Os}/^{188}\text{Os}$  based on combination of uncertainty on measured value (column M) and uncertainty related to age correction (column S)

*Column X:* Based on in-run uncertainty on  $^{191}\text{Ir}/^{193}\text{Ir}$  used in isotope dilution calculations

*Column Y:* From difference between [Ir] corrected using Ir blank +  $2\sigma$  and [Ir] corrected using Ir blank -  $2\sigma$

*Column Z:* Total uncertainty on [Ir] based on combination of uncertainties in columns I and J (square root of individual values squared)

*Column AA:* Based on in-run uncertainty on  $^{102}\text{Ru}/^{99}\text{Ru}$  used in isotope dilution calculations

*Column AB:* From difference between [Ru] corrected using Ru blank +  $2\sigma$  and [Ru] corrected using Ru blank -  $2\sigma$

*Column AC:* Total uncertainty on [Ru] based on combination of uncertainties in columns L and M (square root of individual values squared)

*Column AD:* Based on in-run uncertainty on  $^{194}\text{Pt}/^{195}\text{Pt}$  used in isotope dilution calculations

*Column AE:* From difference between [Pt] corrected using Pt blank +  $2\sigma$  and [Pt] corrected using Pt blank -  $2\sigma$

*Column AF:* Total uncertainty on [Pt] based on combination of uncertainties in columns O and P (square root of individual values squared)

*Column AG:* Based on in-run uncertainty on  $^{108}\text{Pd}/^{106}\text{Pd}$  used in isotope dilution calculations

*Column AH:* From difference between [Pd] corrected using Pd blank +  $2\sigma$  and [Pd] corrected using Pd blank -  $2\sigma$

*Column AI:* Total uncertainty on [Pd] based on combination of uncertainties in columns R and S (square root of individual values squared)



Supplementary Table 4 (suite). Re and Os concentrations and Os isotope compositions of Oman harzburgites and the three types of dunites and of the reference materials (Klaessens, 2021; Klaessens et al., 2021)

Sample	Massif	Lithology	Hzb/Dun pairs	Normalized height in the section	Mass (g)	[Os] (ppb)	2σ error	[Re] (ppb)	2σ error	<sup>188</sup> Os (M/g)	2σ error	<sup>187</sup> Re/ <sup>188</sup> Os	2σ error	( <sup>187</sup> Os/ <sup>188</sup> Os) <sub>m</sub>	2σ error	( <sup>187</sup> Os/ <sup>188</sup> Os) <sub>95 Ma</sub>	2σ error	T <sub>RD</sub> age (Ga)
<i>Reference materials (UB-N, MUH-1, HARZ-01 and OKUM)</i>																		
UB-N 1					1.52295	2.805	0.007	0.191	0.057	1.96E-12	1.11E-14	0.328	0.098	0.1279	0.0007	0.1274	0.0007	0.2
UB-N 2					1.71621	3.908	0.006	0.232	0.051	2.73E-12	1.39E-14	0.286	0.062	0.1274	0.0006	0.1270	0.0006	0.3
UB-N 3					2.00842	3.533	0.005	0.208	0.043	2.46E-12	8.70E-15	0.283	0.059	0.1272	0.0006	0.1268	0.0006	0.3
UB-N 4					2.04999	3.995	0.005	0.211	0.042	2.79E-12	1.99E-14	0.254	0.051	0.1272	0.0006	0.1268	0.0006	0.3
UB-N 5					2.00186	3.436	0.000	0.243	0.039			0.341		0.1273	0.0005	0.1267	0.0006	0.3
MUH-1 1					2.01885	4.111	0.005	0.222	0.043	2.87E-12	1.51E-14	0.260	0.050	0.1275	0.0006	0.1271	0.0006	0.3
MUH-1 2					2.00321	5.624	0.005	0.177	0.043	3.92E-12	1.70E-14	0.151	0.037	0.1271	0.0005	0.1269	0.0005	0.3
MUH-1 3					2.01237	5.808	0.005	0.186	0.043	4.05E-12	1.79E-14	0.154	0.036	0.1265	0.0005	0.1263	0.0005	0.4
MUH-1 4					1.53566	4.096	0.000	0.276	0.051			0.325		0.1266	0.0005	0.1261	0.0005	0.4
HARZ-01 1					2.03967	3.540	0.005	0.073	0.043	2.47E-12	1.16E-14	0.099	0.058	0.1261	0.0006	0.1259	0.0006	0.5
HARZ-01 2					2.02701	4.261	0.005	0.561	0.043	2.97E-12	3.14E-14	0.634	0.049	0.1273	0.0007	0.1263	0.0007	0.3
HARZ-01 3					2.01448	5.082	0.005	0.110	0.043	3.55E-12	2.57E-14	0.105	0.041	0.1259	0.0005	0.1257	0.0006	0.5
HARZ-01 4					2.01454	3.776	0.003	0.068	0.009	2.63E-12	8.27E-15	0.087	0.012	0.1278	0.0013	0.1276	0.0013	0.3
OKUM 1					2.00675	0.864	0.005	0.568	0.043	5.92E-13	4.59E-15	3.223	0.247	0.2630	0.0014	0.2579	0.0014	-22.1
OKUM 2					2.01264	1.030	0.005	0.541	0.043	7.08E-13	1.78E-13	2.572	0.680	0.2455	0.0011	0.2414	0.0015	-18.7

Re and Os concentrations and Os isotopic compositions in whole rock powders were analyzed at the CRPG laboratory in Nancy (France) using MC-ICPMS (Neptune +) and N-TIMS (Finnigan MAT 262) (Os). All uncertainties are 2 σ and include all recognized sources of uncertainty, including in-run analytical precision, reproducibility of standard analyses, uncertainties related to the variability of the blank and its isotope composition, uncertainties related to the age correction (95 Ma). Duplicate analyses were performed for several samples (noted "-d") and the reference materials (UB-N, MUH-1, HARZ-01 and OKUM). Samples belonging to harzburgite/dunite pairs collected in close proximity (<1 meter) are indicated. For each sample, an approximate estimation of its height in the mantle section was obtained by normalizing to the total section height to compare samples from different cross-sections. Re-depletion model ages (T<sub>RD</sub>) were calculated by comparing measured <sup>187</sup>Os/<sup>188</sup>Os values directly with the mantle evolution curve. They represent minimum ages of melt extraction and should not be equated with true ages.

\* For 10 OM 5C sample, (<sup>187</sup>Os/<sup>188</sup>Os)<sub>95 Ma</sub> was calculated using Re compositions of its duplicate.

Hzb = harzburgite; Dun = dunite; Px = pyroxene; Opx = orthopyroxene; Cpx = clinopyroxene; Pl = plagioclase.



Supplementary Table 5 (suite). HSE concentrations of Oman harzburgites and the three types of dunites and of the reference materials (Klaessens, 2021; Klaessens et al., 2021)

Sample	Massif	Lithology	Hzb/Dun pairs	Normalized height in the section	Mass (g)	[Os] (ppb)	2σ error	[Ir] (ppb)	2σ error	[Ru] (ppb)	2σ error	[Pt] (ppb)	2σ error	[Pd] (ppb)	2σ error	[Re] (ppb)	2σ error	Ir/Os	Ir/Ru	Pd/Ir	Re/Os
<i>Reference materials (UB-N, MUH-1, HARZ-01 and OKUM)</i>																					
UB-N 1*					1.52295	2.805	0.007	1.497	0.011	5.025	0.329	6.808	0.138	6.119	0.081	0.191	0.057	0.53	0.30	4.09	0.07
UB-N 2*					1.71621	3.908	0.006	2.749	0.015	5.730	0.287	7.231	0.123	5.687	0.029	0.232	0.051	0.70	0.48	2.07	0.06
UB-N 3					2.00842	3.533	0.005	3.157	0.024	5.804	0.012	6.549	0.078	5.674	0.309	0.208	0.043	0.89	0.54	1.80	0.06
UB-N 4					2.04999	3.995	0.005	3.650	0.025			7.256	0.077	5.368	0.305	0.211	0.042	0.91		1.47	0.05
UB-N 5					2.00186	3.436	0.000	2.756	0.001	5.882	0.023	6.746	0.012	10.436	0.013	0.243	0.039	0.80	0.47	3.79	0.07
MUH-1 1					2.01885	4.111	0.005	3.951	0.027			8.134	0.080	9.570	0.343	0.222	0.043	0.96		2.42	0.05
MUH-1 2					2.00321	5.624	0.005	2.943	0.022	9.809	0.020	7.350	0.080	8.230	0.314	0.177	0.043	0.52	0.30	2.80	0.03
MUH-1 3					2.01237	5.808	0.005	3.915	0.012	5.846	0.008	25.628	0.084	8.359	0.306	0.186	0.043	0.67	0.67	2.14	0.03
MUH-1 4					1.53566	4.096	0.000	2.613	0.001	5.654	0.030	20.991	0.015	8.931	0.015	0.276	0.051	0.64	0.46	3.42	0.07
HARZ-01 1					2.03967	3.540	0.005	2.319	0.021	6.731	0.010	9.438	0.200	7.372	0.321	0.073	0.043	0.66	0.34	3.18	0.02
HARZ-01 2					2.02701	4.261	0.005	2.317	0.011	5.075	0.007	10.511	0.076	4.998	0.304	0.561	0.043	0.54	0.46	2.16	0.13
HARZ-01 3					2.01448	5.082	0.005	2.717	0.012	5.574	0.008	8.795	0.076	5.680	0.306	0.110	0.043	0.53	0.49	2.09	0.02
HARZ-01 4					2.01454	3.776	0.003	3.409	0.013	5.170	0.019	8.771	0.077	13.127	0.308	0.068	0.009	0.90	0.66	3.85	0.02
OKUM 1					2.00675	0.864	0.005	0.909	0.011	4.387	0.023	14.607	0.078	11.638	0.315	0.568	0.043	1.05	0.21	12.81	0.66
OKUM 2					2.01264	1.030	0.005	1.032	0.013	5.916	0.022	13.135	0.081	11.343	0.313	0.541	0.043	1.00	0.17	10.99	0.53

HSE concentrations in whole rock powders were analyzed at the CRPG laboratory in Nancy (France) using N-TIMS (Finnigan MAT 262) (Os), MC-ICP-MS (Neptune +) and Q-ICP-MS (XSERIES). All uncertainties are 2 σ and include all recognized sources of uncertainty, including in-run analytical precision, reproducibility of standard analyses, uncertainties related to the variability of the blank and its isotope composition. Duplicate analyses were performed for several samples (noted "-d") and the reference materials (UB-N, MUH-1, HARZ-01 and OKUM). Samples belonging to harzburgite/dunite pairs collected in close proximity (<1 meter) are indicated. For each sample, an approximate estimation of its height in the mantle section was obtained by normalizing to the total section height to compare samples from different cross-sections.

\* Analyses using Q-ICP-MS XSERIES.

Hzb = harzburgite; Dun = dunite; Px = pyroxene; Opx = orthopyroxene; Cpx = clinopyroxene; Pl = plagioclase