Introduction to Science Theme 1B: crust–mantle traverse[1]

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Chapter contents

Crust–Mantle Traverse: Sites CM1 and CM2

From a literal and conceptual distance the boundary between the ocean crust and mantle is simple and defined by mafic and ultramafic rocks formed by the cooling and crystallization of magmas that were produced at an ocean spreading ridge by the decompression partial melting of the underlying mantle peridotite, mostly tectonized harzburgite and dunite. Where gabbroic or mixed gabbroic-ultramafic cumulate rocks occur directly overly mantle harzburgites, the crust/mantle boundary coincides with the Mohorovicic seismic discontinuity. However, the geology exposed in the Samail ophiolite indicates more complicated arrangements with gabbro dikes and sills common within the uppermost mantle rocks and thick (tens to hundreds of meters) layers of ultramafic rocks occurring together with the layered gabbros in complex relationships (e.g., Boudier and Coleman, 1981; Boudier and Nicolas, 1995). In other locations in Oman, the crust/mantle boundary may be faulted (e.g., Wadi Bani Kharus, Wadi Al Abyad). Drilling across the ocean crust–mantle transition targets a number of the primary objectives of the Oman Drilling Project (OmanDP), and our original proposed sites to investigate the crust–mantle transition were in the "Maqsad diapir" (Ceuleneer, 1991; see Site MD1 in Figure F1 in the **Introduction to Science Theme 1A** chapter. At this locality the objectives focused on the relationship between mantle melting and upwelling and mantle melt transport processes, including the role of active mantle diapirism and melt focusing (e.g., Ceuleneer et al., 1988; Jousselin et al., 1998), although it was recognized that these concepts may be difficult to tackle in a few relatively shallow boreholes. Unfortunately, it proved extremely difficult to find suitable sites in the Maqsad region where we could comply with permitting requirements from the Sultanate of Oman Ministry of Regional Municipalities and Water Resources (see Fig. F1).

Consequently, a new location for drilling the crust/mantle boundary was required and reconnaissance efforts focused on the Wadi Tayin Massif, closer to OmanDP Sites GT1 and GT2. Further drilling in Wadi Giddeah was not an option because there is no suitable or easily constructable vehicular access to the peridotites that crop out north of Site GT1 that spudded into lower crustal olivine gabbros and is at least 1000 m stratigraphically above the crust/mantle boundary. There is a well exposed lower crustal to mantle section in Wadi Nassif (e.g., Boudier et al., 1996) ~16 km west of Wadi Giddeah, but this valley hosts a small inhabited village and a falaj in close proximity to the boundary. Further reconnaissance in March 2017 by OmanDP investigators Eiichi Taka-

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zawa, Tomoaki Morishita, and colleagues explored Wadi Zeeb, the next major valley west of Wadi Nassif. Although some distance up the wadi from a graded track and requiring construction of a new metaled road to allow access by heavy machinery, the excellent outcrops of deep crustal and mantle rocks in the wadi and ridges indicated that this would be a good location for sampling a continuous section across the crust/mantle boundary from layered gabbros down to tectonized residual harzburgites.

Geology of Sites CM1 and CM2

Sites CM1 and CM2 are located in Wadi Zeeb in the western side of Wadi Tayin Massif (22.9°N, 58.3°E; Table T3 in the **Methods** chapter; Fig. F1). In the downstream, southern reaches of Wadi Zeeb, the valley passes through abundant outcrops of modally layered cumulate gabbro from the lower part of the crustal section. The layering in these gabbros strikes east-west, with moderate southward dips (range = 30°–55°, although 35°–40° is most common [d/dr 35°/180]). Harzburgite with well-defined tectonized fabrics typical of the uppermost mantle section in Oman is widely distributed in the northern region of Wadi Zeeb (Fig. F2). In these rocks a planar structure is indicated by the alignment of spinels. The strike of this fabric is also approximately east-west and moderately dipping to the south at 48°–58° (d/dr ~ 53°/180). Between these outcrops of distinctly lower crustal and mantle rocks, very black dunite is the dominant rock type with only a few thin layers of gabbro oriented parallel to the planar structures of the overlying gabbros and mantle rocks below. This dunite-rich zone rich with subordinate layered gabbros represents the Crust–Mantle Transition Zone (CMTZ).

The boundary between layered gabbro and the first major thicknesses of dunite occurs at Point A (see Figs. F2, F3A). This outcrop is composed of layered gabbro associated with some wehrlite, underlain by CMTZ dunite (see Fig. F3). The gabbro layers strike east-west and dip 30°S. This boundary can be traced to the west along the wadi, and the strike of the contact gradually changes to ENE–WSW. Further to the west along the wadi, strongly weathered dunite is widely distributed. CMTZ dunite also crops out in the wadi bed to the north of Point A. The first appearance of harzburgite is ~200 m north of Point A, and these rocks mark the uppermost extent of the mantle section.

From geological mapping and the projection of layers to depth, an offset two-site approach was proposed to sample from layered gabbros, across the crust–mantle transition zone, and into mantle harzburgite. These holes were aligned north-south of each other, with Site CM1 hosted by layered gabbros and Site CM2 in the middle of the CMTZ (Fig. F4).

References

Boudier, F., Coleman, R.G., 1981. Cross section through the peridotite in the Samail ophiolite, southeastern Oman mountains. J. Geophys. Res, 86(B4):2573-2592.

Boudier, F., and Nicolas, A., 1995. Nature of the Moho Transition Zone in the Oman ophiolite. Journal of Petrology, 36:777-796. https://doi.org/10.1093/petrology/36.3.777

Boudier, F., Nicolas, A., and Ildefonse, B., 1996. Magma chambers in the Oman ophiolite: fed from the top and the bottom. Earth Planet. Sci. Lett., 144(1-2):239-250.

Ceuleneer, G., 1991. Evidence for a Paleo-Spreading Center in the Oman Ophiolite: Mantle Structures in the Maqsad Area. In Peters, T., Nicolas, A., Coleman, R.G. (Eds.), Ophiolite Genesis and Evolution of the Oceanic Lithosphere. Petrology and Structural Geology, vol 5: Dordrecht (Springer). https://doi.org/10.1007/978-94-011-3358-6_9

Ceuleneer, G., Nicolas, A., Boudier, F., 1988. Mantle flow patterns at an oceanic spreading centre: The Oman peridotites record. Tectonophysics, 151(1-4):1-26.

Jousselin, D., Nicolas, A., Boudier, F., 1998. Detailed mapping of a mantle diapir below a paleo-spreading center in the Oman ophiolite. JGR Solid Earth, 103(B8):18153-18170.

Figure F1. Location of Wadi Zeeb and the CM sites within the Wadi Tayin block, showing the general geology and Wadi Nassif, Wadi Gideah, Ibra, and other OmanDP drill sites for reference. Small gray dots show the locations of falaj (springs and wells); translucent magenta shaded area shows the 3.5 km buffer zones (no drilling allowed) around these.

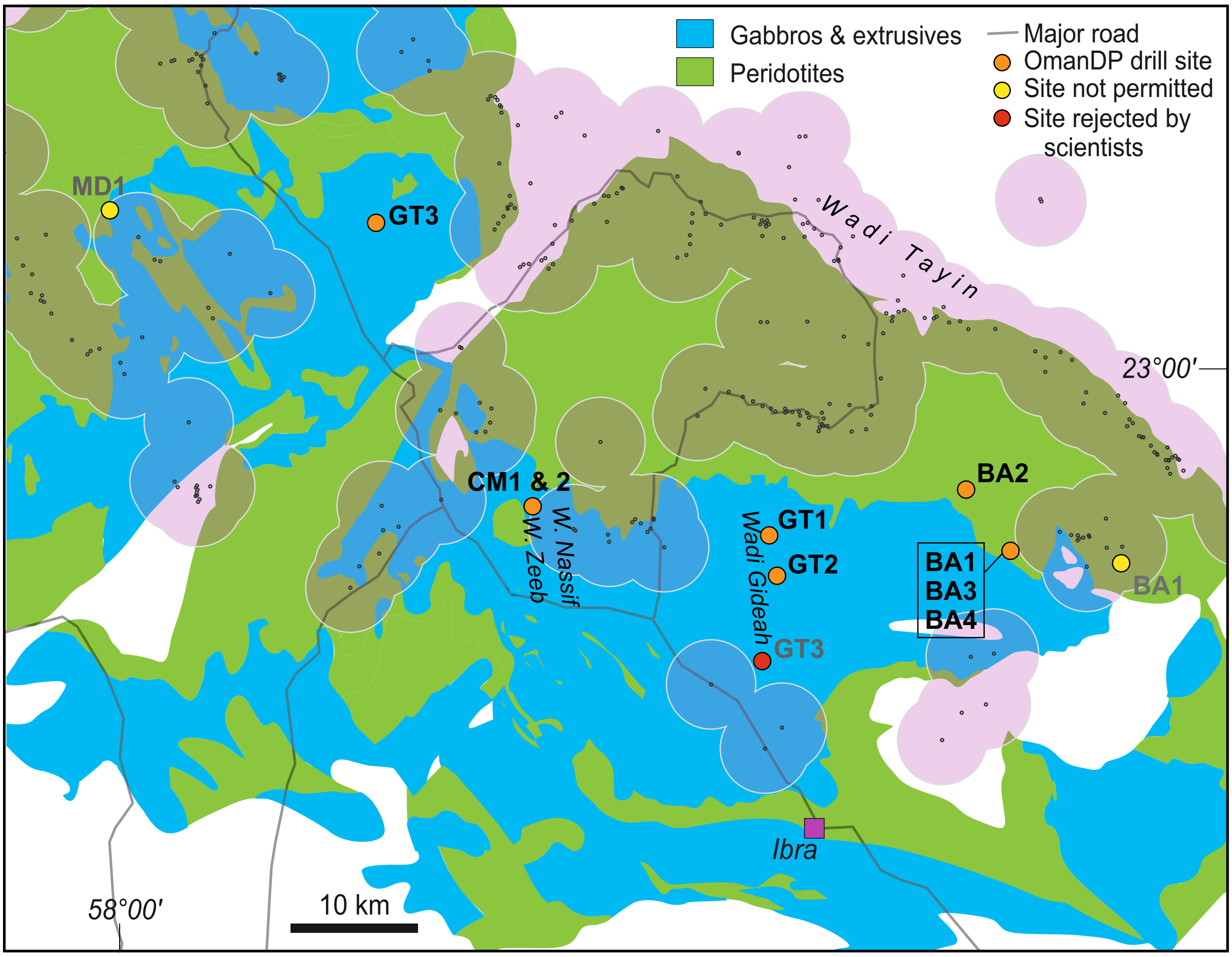

Figure F2. Geological map of the Wadi Zeeb area showing the distribution of layered gabbros and mantle harzburgites and the Crust–Mantle Transition Zone rocks in between. The locations of Sites CM1 and CM2 are shown as is Point A.

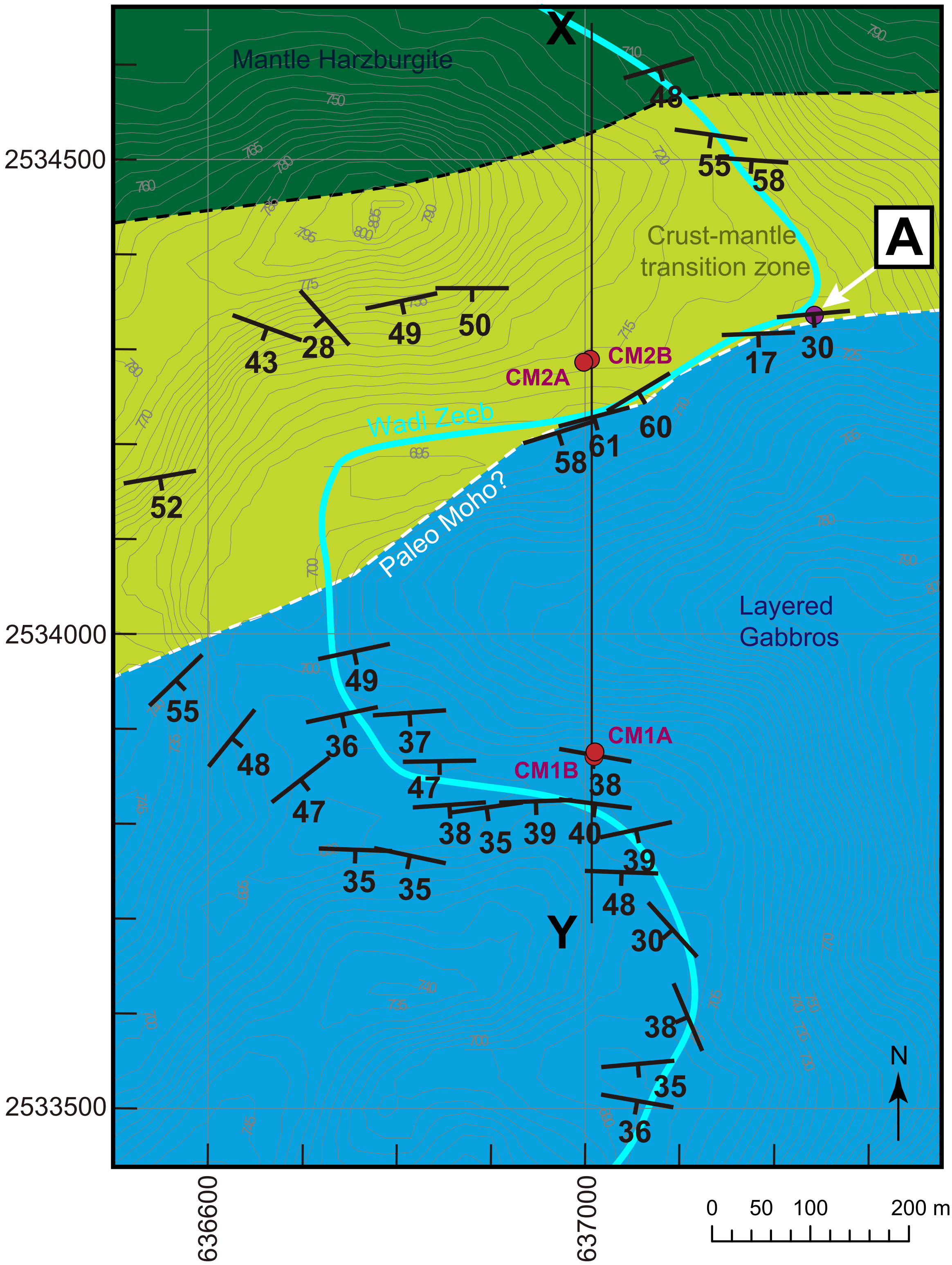

Figure F3. Outcrop photographs of the geology surrounding the CM drill sites in Wadi Zeeb. **A.** Panorama of Sites CM1 and CM2 showing the intervening ridge of south-dipping layered gabbros underlain by ultramafic rocks of the Crust–Mantle Transition Zone (CMTZ). **B.** Mountain slope showing south-dipping layered gabbros underlain by ultramafic rocks of the CMTZ. **C.** Possible "paleo-Moho" where a large outcrop of layered gabbro with black and white stripes is underlain by dunite of the CMTZ. **D.** Aggregation of fragmented blocks of layered gabbro found in the CMTZ. **E.** Complicated penetration relationship between gabbro (white) and ultramafic rock (black). A pen with length 15 cm is included as a scale. **F.** Enlarged view of area squared in E. The tip of gabbro layer has been cut off, probably due to shearing of upper right lateral shift. **G.** Alternation of gabbro and ultramafic layers associated with a normal fault. **H.** Enlarged view of area squared in G showing a folding of gabbro and ultramafic rocks.

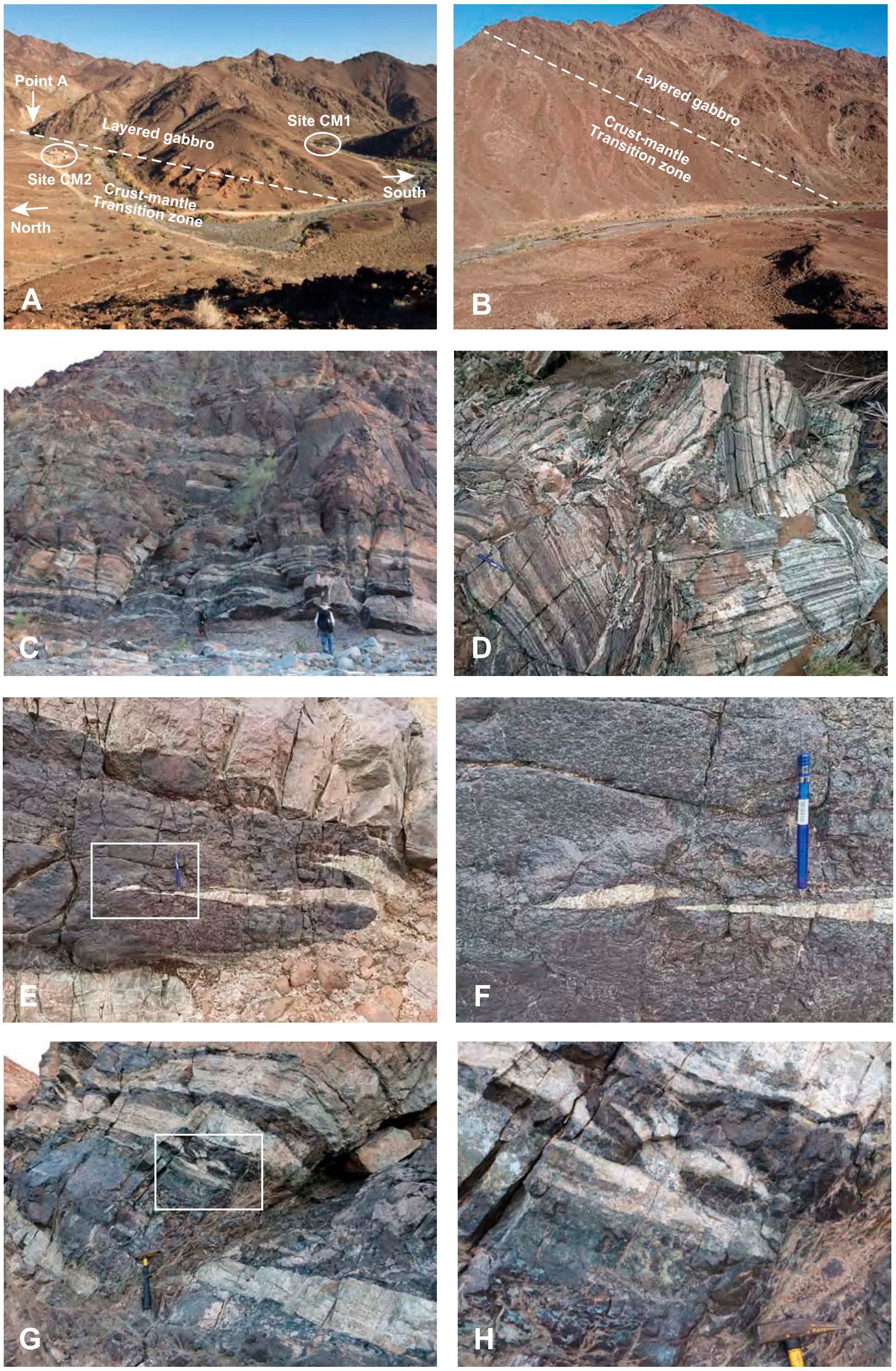

Figure F4. A. North-south cross section through Wadi Zeeb that includes Sites CM1 and CM2, which are directly north-south of each other (see X-Y in Figure F2). This cross section was initially based on field observations of the outcrops exposed along wadi but refined following drilling. The approximate boundaries between the layered gabbro and the top of the CMTZ, and the CMTZ and the mantle harzburgite, dip to the south at ~30°. The thickness of the CMTZ is ~150 m. The slopes of the boundaries are smaller than those of the planar structures of the layered gabbro and the harzburgite.