The Punds to Wick of Hagdale

[HP 647 103]–[HP 644 113]

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Introduction

The site lies on the east side of Unst within the Lower Nappe of the Shetland Ophiolite. On the east side is a continuously exposed low-lying cliff section which is of great importance in that it contains the uppermost kilometre of the mantle, the petrological Moho, and a kilometre of the overlying metadunite layer. Inland to the west abundant exposures, ideally weathered, ice-smoothed and lichen-free, reveal in unusual detail the petrography and mineralogy of these rocks. Hitherto, these two units of the ophiolite pseudo-stratigraphy in Unst have received the conventional labels of 'tectonized harzburgite' and 'cumulate dunite' and the latter has been interpreted as the result of the cumulate crystallization of olivine in the base of a magma chamber resting on tectonized mantle at an oceanic constructive plate margin (Gass et al., 1982; Prichard, 1985). However, Flinn (1996) has reached the contrary conclusion that the metadunite is an independent intrusive unit which did not form as a cumulate layer in a magma chamber and that the harzburgite is not tectonized. The site offers a magnificently exposed and easily accessible view of the mantle-lower crust junction.

Description

The rocks to the north of the petrological Moho in (Figure 2.6), representing the uppermost mantle, are dominantly metaharzburgite with lesser amounts of metadunite. Both rocks, being uniformly and extensively altered to hydrous minerals, contain about 13 wt% of water. Lizardite-serpentine, which replaces olivine, weathers to a strong ochrous colour due to a relatively high iron content, while the hydrous minerals replacing pyroxenes weather white and stand slightly proud of the serpentine. Thus the two rocks are easily distinguished, even where intimately mixed. However, adjacent to some of the major shear zones the lizardite-serpentine has been recrystallized to antigorite-serpentine with magnetite and weathers white making it difficult there to distinguish between metaharzburgite and metadunite.

It is apparent that prior to serpentinization the metaharzburgite was composed dominantly of olivine together with 20–30% of orthopyroxene, and about 0.5% of accessory chromite. Thin sections commonly contain about 1% of clinopyroxene. The metadunite was originally almost entirely composed of olivine, with about 1% of accessory chromite. Clinopyroxene is present only very locally (see below). The grain size of the olivine and pyroxene is about 0.5 cm.

The metaharzburgite is rhythmically banded in places. The bands are sharply defined, rectilinear and dip steeply north. They are formed by alternations in olivine/pyroxene proportions, but are ungraded. Olivine-rich and pyroxene-rich pairs are about 30 cm thick, and are parallel to the petrological Moho towards which their persistence and frequency of occurrence increases. Generally, the bands can rarely be followed for more than a few metres, only rarely show signs of disruption or folding and are untectonized. The banding is very well displayed on the coast at The Viels [HP 6444 1108] (Figure 2.7) and on the hillside to the west of the road.

The metaharzburgite is cut by many thin pyroxenite veins filling planar joint-like fractures. The veins are formed of pyroxenite with grain sizes up to one centimetre or more, and much less commonly of olivine-pyroxenite. They are always completely pseudomorphed by fine-grained hydrous minerals. They have been referred to as dykes (Prichard, 1985), but to avoid confusion with the basic dykes forming the quasi-sheeted dyke layer they are referred to here as veins. Many strike parallel to the rhythmic banding, where present, but rarely dip parallel to it; hence they cut the banding. In unbanded areas they have no preferred orientation. In a small number of localities they are seen to have been deformed by cross-cutting early shear zones. Pyroxenite veins are cut by metadunite bodies in the metaharzburgite. Since most orthopyroxene in the metaharzbur-gite is altered to the same secondary minerals as the pyroxenes in the veins, whereas clinopyroxene generally remains fresh, these were probably orthopyroxenite veins. An irregular sheet of fresh, olivine-free orthopyroxenite about 10 cm thick occurs at The Viels [HP 6446 1108].

Metadunite within the metaharzburgite occurs as rare and sporadically distributed bodies that increase in frequency towards the petrological Moho within the northern part of (Figure 2.6). Most are sub-equidimensional bodies or clots a metre or so in diameter with no detectable preferred orientation of their shapes; larger bodies up to a hundred metres or more across also occur and these are commonly of very irregular shape. Several of the larger metadunite bodies contain podiform chromite masses. Parallel-sided sheets of metadunite up to 20 cm thick and several metres in length occur with increasing frequency southward and, for two or three hundred metres north of the petrological Moho, the metadunite clots and sheets are particularly densely distributed, equalling in places the metaharzburgite in volume.

The metadunite sheets within the metaharzburgite adjacent to the petrological Moho are sub-parallel to the rhythmic banding and to the Moho; a high proportion are obliquely cross cutting by 10° or less, while a much smaller proportion cut at much greater angles or are exactly parallel. The clots of metadunite, especially those close to the petrological Moho often have invasive boundaries with thin wedge-like and sheet-like protuberances cutting the enclosing metaharzburgite and giving them an intrusive appearance.

The petrological Moho is taken as the southern edge of the southernmost band of meta-harzburgite. It has an E–W strike parallel to the rhythmic banding, and has a 70–80° dip to the north. It is exposed on the coast (Figure 2.6) and in several inland exposures.

The metadunite layer is dominantly composed of rock indistinguishable from the metadunite forming bodies and sheets within the metaharzburgite layer. Thin sections reveal equidimensional olivine grains about half a centimetre in size forming a triple-junction grain-boundary network, but which have been extensively replaced by iron-rich mesh-type serpentine so that the rock weathers to a bright ochrous colour, lacking the white-weathering altered pyroxenes characteristic of the metaharzburgite. The metadunite is lithologically uniform and texturally isotropic, except for the local presence of chromite and clinopyroxene.

Chromite, in both the metadunite layer and in the metadunite sheets and bodies within the metaharzburgite, occurs as disseminated accessory grains no more than 1 mm in size and as coarser grains several millimetres in diameter forming band- or vein-like concentrations that locally expand into podiform bodies. Some accessory chromite forms schlieren, typically several centimetres thick and ten times as long, in which the individual chromite grains are several millimetres apart. Schlieren are well exposed on the coast just south of the Moho in (Figure 2.6) but occur more commonly in the metadunite to the west of the road. The bands formed of more concentrated coarsely crystalline chromite cannot be studied as extensively. They were used by prospectors as guides to the presence of podiform masses and have almost all been excavated, leaving pits, trenches and spoil heaps to mark their previous existence. The best remaining locality for the study of in-situ banded chromite occurs in the cliffs 100 m east of Boat Geo [HP 6456 1030]. The spoil heaps of some chromite pits are a good source of banded chromite, but the waste heaps of the famous Hagdale Quarry have been despoiled by collectors and carried away for infill. Specimens remaining in waste heaps elsewhere in Unst reveal bands of chromite cut by metadunite. The presence of angular fragments of massive chromite floating in metadunite and the folding of the chromite bands indicate that fracturing and deformation of the deposits took place while the dunite was still mobile. Disseminated accessory chromite is also present in the meta-harzburgite, though much less abundantly than in the metadunite.

Clinopyroxene occurs locally and rarely as sub-millimetre, isolated, interstitial fresh grains. It may be either uniformly distributed or form schlieren in the metadunite layer but it never occurs in metadunite within the metaharzbur-gite. Both types of occurrence of clinopyroxene are to be found closely associated with similarly occurring chromite on the coast of the Wick of Hagdale in the 200–300 in to the south of the petrological Moho (Figure 2.6) and inland elsewhere. Interstitial clinopyroxene occurs most commonly in the top of the metadunite layer close to wehrlite–clinopyroxenite masses. An example is indicated in the SE corner of (Figure 2.6) but this relationship is better displayed in the Skeo Taing to Clugan GCR site.

Interpretation

The metaharzburgite has been recognized as infertile mantle (Gass *et al.,* 1982; Prichard, 1985), on the basis of its composition and by analogy with other ophiolite complexes (Gass, 1980). This makes its boundary against the metadunite layer to the south the upper limit of the mantle and therefore the petrological Moho (Figure 2.2).

The metaharzburgite resembles that of many other ophiolites in the presence of the enclosed metadunite bodies, the pyroxenite veins, the rhythmic banding and the accessory chromite. Harzburgite in ophiolites is generally held to have been tectonized by convectional flow at a constructional plate margin before obduction and the tectonite nature of the harzburgite has been cited as evidence of the ophiolitic nature of the Shetland complex by the above mentioned authors. Bartholomew (1993) reported the occurrence throughout the metaharzburgite of two vertical foliations intersecting at high angles. These foliations were recognized in the field by the flattening of the accessory chromite grains and were confirmed in thin-section by a pre ferred orientation of grain shapes, interpreted by Bartholomew as arising from simple shear during mantle flow. However, Flinn (1996) found no trace of the two foliation directions and reported only that, in a number of places, a slight flattening of the chromite grains parallel to the plane of schlieren is present, but never in two widely different directions in the same area. He also noted that pyroxene grain-shapes are clearly etched out by weathering and show no grain-shape preferred orientation, even in rhythmically banded areas. The tectonite status of the metaharzburgite therefore remains controversial.

The conventionally accepted origin (Prichard, 1985) for the metadunite bodies within the metaharzburgite and the metadunite above the petrological Moho is that they crystallized out of basic magma, produced by adiabatic melting deep in the mantle, as it rose to form a magma chamber above the mantle. However, field evidence from this and the Skeo Taing to Clugan GCR site has been interpreted as showing that the metadunite layer above the mantle is an intrusive unit and not a layer accumulated on the floor of a magma chamber (Flinn, 1996).

In support of his interpretation Flinn cited Kelemen *et al.* (1995) who have suggested that MORB (mid-oceanic ridge basalt) magma produced by adiabatic melting deep in the mantle would be pyroxene undersaturated and would rise through the mantle by intergranular flow. Such magma would dissolve the pyroxene grains in the mantle and so become focused into conduits made more porous than the surroundings, the conduits thus becoming columns of dunite. It is possible that the enhanced porosity of the dunite in the MORB conduits (a MORB : dunite ratio of 1:10, according to Kelemen *et al.,* 1995) could so lower the cohesion of the olivine grains that the rising MORB would fluidize the dunite. The fluidized dunite would then flow up its conduits through the mantle giving rise to the observed invasive relationships of the dunite relative to the enclosing harzburgite, and including the sheet-like injections close to the Moho. The upward flowing dunite accumulated above the mantle as an intrusive layer several kilometres thick and when flow ceased the conduits within the mantle broke up into independent bodies.

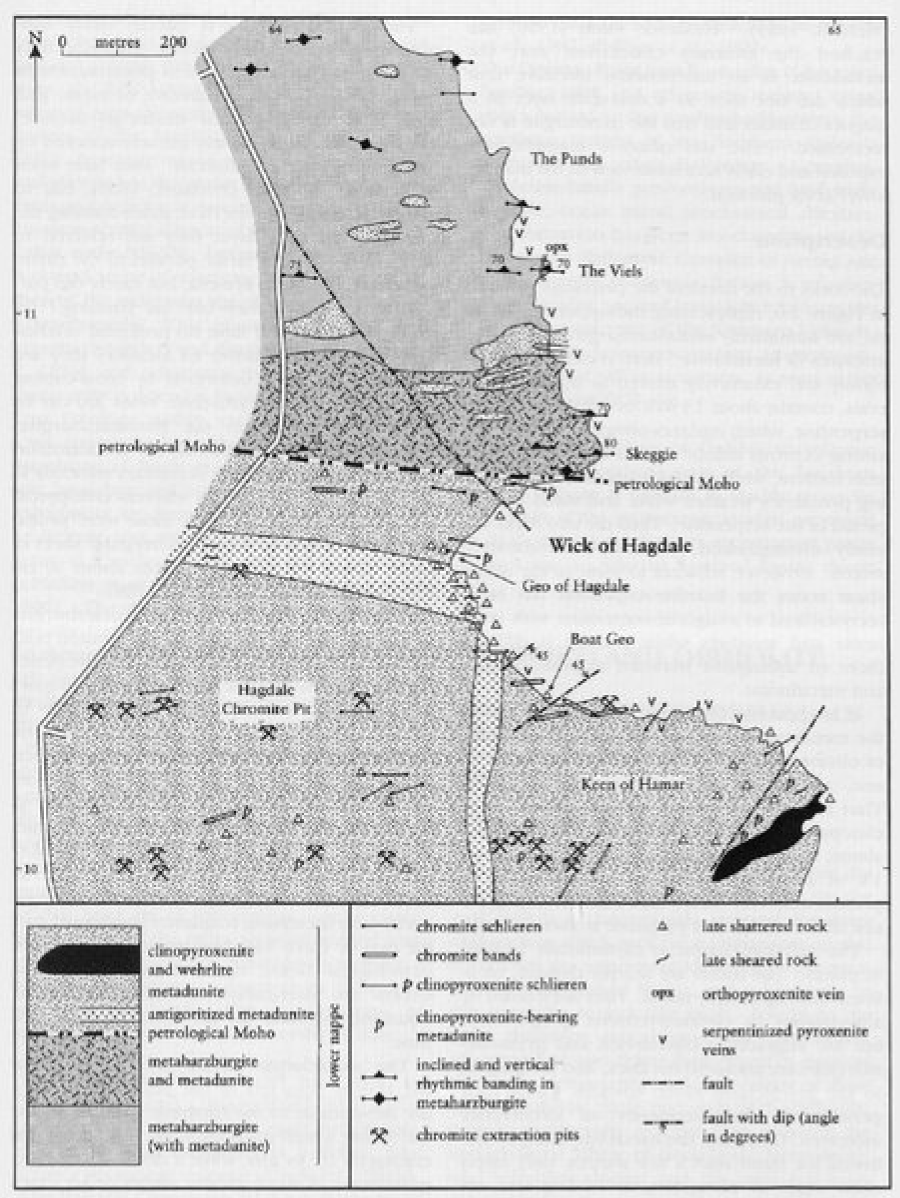
Neither the conventional account of the origin of the metadunite bodies within the mantle (Prichard, 1985), nor that of Kelemen *et al.* (1995) provide an adequate explanation for the presence of podiform masses of chromite in some of the metadunite bodies within the mantle in Unst, whereas other, nearby and larger bodies contain only sparsely distributed accessory chromite grains. Nor do they account for the apparent random distribution of the chromite podiform masses in the metadunite layer above the mantle, or the fact that they are indistinguishable from those nearby within the mantle. Possibly the podiform masses were formed at depth in the mantle and carried up to their present positions in Unst in the mobilized dunite.

The origins of the clinopyroxene in the metadunite layer and of the wehrlite–clinopyroxenite masses in the upper part of the metadunite layer south of (Figure 2.6) are more conveniently discussed in the context of the Skeo Taing to Clugan GCR site.

Conclusions

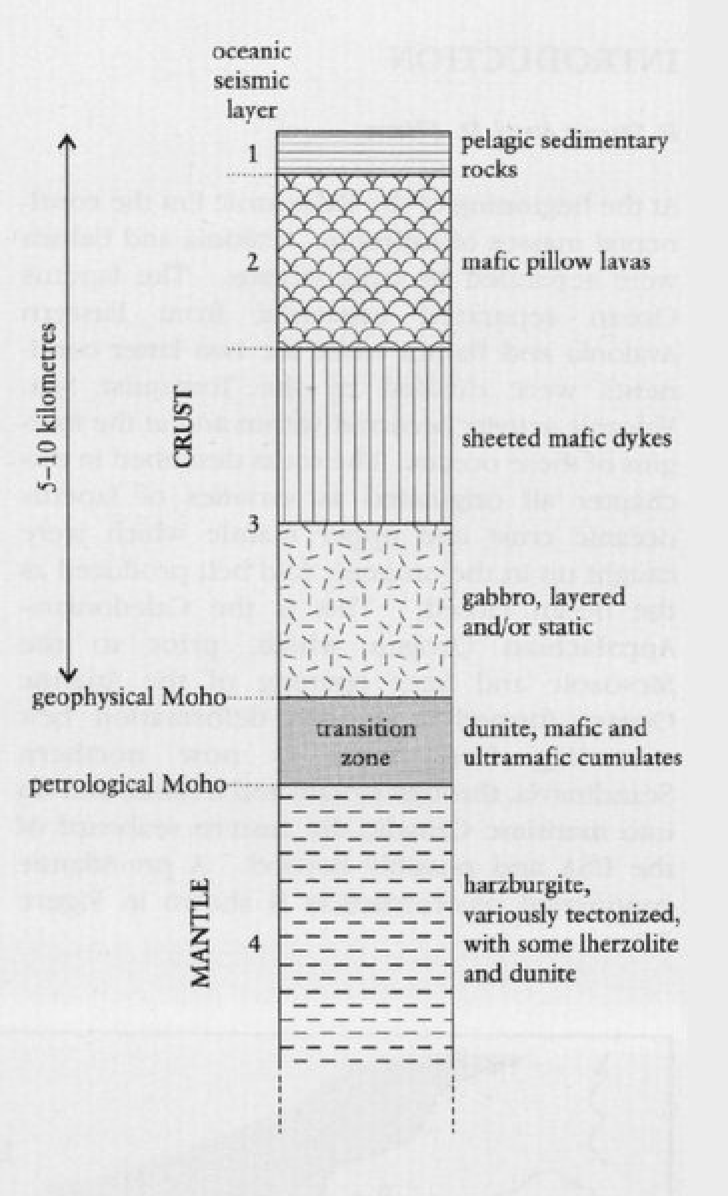
The Punds to Wick of Hagdale GCR site features an uninterrupted passage through the top kilometre of the mantle and the bottom kilometre of the overlying lower crustal succession. The profusion of glacially smoothed exposures makes the area ideal for the study of the environment of the petrological Moho, thus providing a rare opportunity of international importance in ophiolite geology. In particular, the site allows close investigation of the controversial intrusive relationship of the dunite to the mantle.

References



(Figure 2.6) Map of the Wick of Hagdale area, Unst.

(Figure 2.7) Rhythmic banding in the metaharzburgite at The Viels [HP 6444 1108] close to the petrological Moho. The hammer is 37 cm long. (Photo: D. Flinn.)



(Figure 2.2) An idealized ophiolite succession compared to the seismic structure of oceanic crust and mantle (after Coleman, 1977). As an indication of scale, beneath the oceans the depth to the geophysical moho is between 5 and 10 km.