GRAVITY INVESTIGATION OF THE HAREIDLANDET ECLOGITE, WESTERN NORWAY*

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Six structural sections across the Hareidlandet eclogite around Ulsteinvik, Hareidlandet, western Norway are derived from gravity data. The residual gravity anomaly has a maximum of 6.9 mgals and the density contrast is 0.6 g/cm^3. This study, which supports earlier geochemical studies, shows that the eclogite is not connected to the mantle. The folded nature of the eclogite lying in the synform over Ulsteinvik is confirmed, but it shows considerable widening at depth, especially northwards. The eclogite also has less dimensional variation at depth than suggested from surface exposures. The maximum subsurface thickness of the body is generally ca. 300 metres, and the volume of the eclogite is estimated to about 5–6 km^3.

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Geology

The eclogite around Ulsteinvik on Hareidlandet, western Norway (Fig. 1) is an order of magnitude larger than commonly observed for eclogite in amphibolite facies gneiss terrain with an exposed length of about 6 km and a maximum width around 1.5 km (Mysen & Heier 1971). The dimension of the Hareidlandet eclogite, incomparable to other eclogites previously described, has made it possible to undertake a gravimetrical investigation of the eclogite to deduce its total mass and to evidence the three dimensional extensions suggested by the geological evidence. The eclogite generally lies concordantly in the so-called basement gneiss (Bryhni 1966) of western Norway and is folded as a boudinage structure in the synform over Ulsteinvik (Gjelsvik 1951).

The layering generally strikes almost east-west, and dips inward towards the fold axis of the synform. There are larger variations in attitude in the northern than in the southern fold limb. Both the eclogite and the surrounding gneisses exhibit complex tectonic patterns with at least two separate folding phases. The earliest is reflected in tight isoclinal folding in the dioritic gneiss and sometimes in the eclogite, while there is at least one later folding phase giving larger scale flexural folding (Mysen 1971). The fold-axis of the synform plunges moderately ESE (20–30°), and is slightly bent over an axis plunging moderately WSW. The Hareidlandet eclogite consists of

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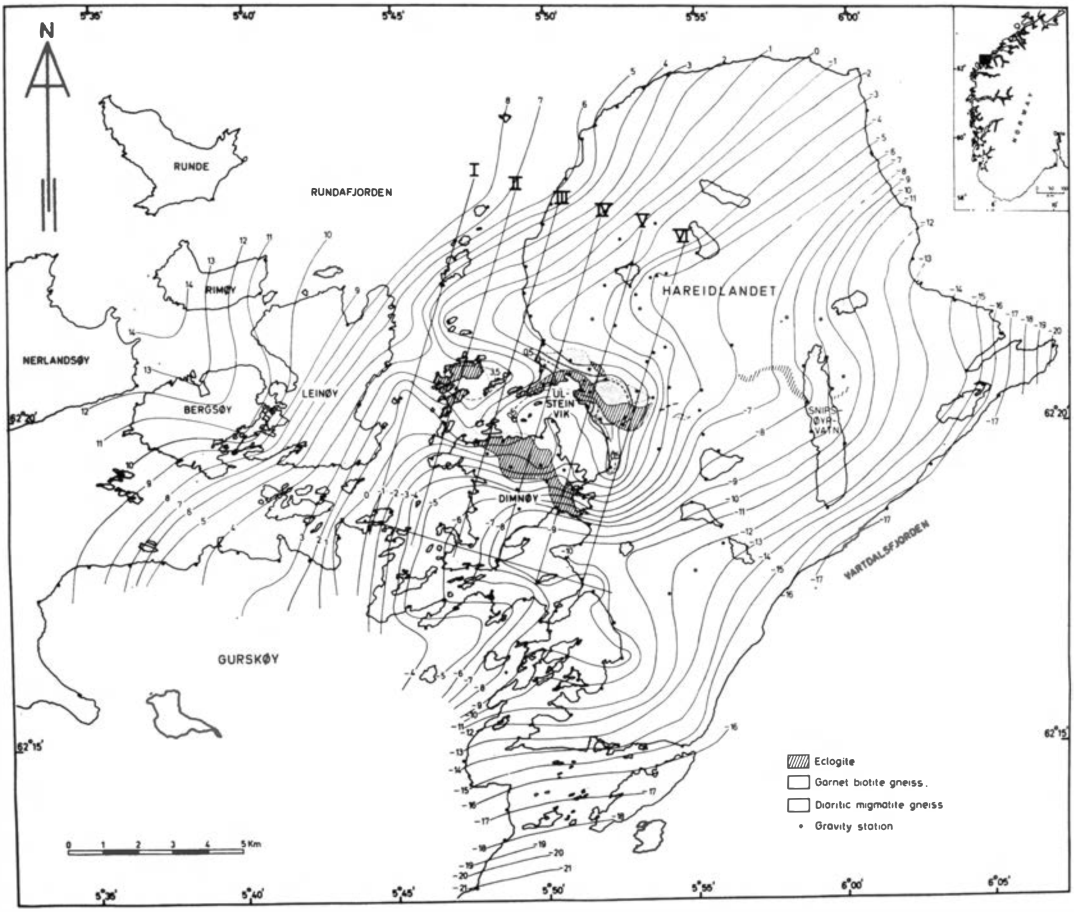

Fig. 1. Bouguer gravity anomaly map of the Hareidlandet island, western Norway. Contour interval 1 mgal. The general geology of the area is also shown on the map. Profiles I–VI show location of structural sections in Fig. 2.

garnet and omphacite as major minerals. The omphacite is frequently transformed to diopside + plagioclase symplectite. The symplectitization is probably responsible for the density reduction of the Hareidlandet eclogite ($\sim$3.3 g/cm^3) compared with the value commonly accepted for fresh eclogite ($\sim$3.5 g/cm^3) (Ringwood & Green 1966, Green & Ringwood 1968).

The gneisses surrounding the Hareidlandet eclogite are divided into two groups, garnet-biotite gneiss and dioritic migmatite gneiss. Garnet-biotite gneiss is most frequently exposed to the north while dioritic migmatite gneiss dominates to the east and the south of Ulsteinvik. The garnet-biotite gneiss resembles eclogite chemically and is dominated by garnet, biotite and plagioclase. The chemical composition of the dioritic migmatite gneiss resembles granodiorite and diorite and is dominated by plagioclase, quartz and K-feldspar (Mysen 1971). The more mafic character of the garnet-biotite gneiss is responsible for its higher density (2.9 g/cm^3) compared to the felsic garnet-free gneiss (2.71 g/cm^3).

Field procedure and data reduction

The aim of this geophysical investigation has been to study possible relations between the eclogite and the mantle. We also tried to produce evidence in support of the extension of the eclogite and to calculate its mass.

Close to two hundred gravity stations were measured in the area using two gravimeters (types: Worden Master and LaCoste Romberg). Excellent maps (scale 1:5000, economic map series of Norges Geografiske Oppmåling) were available, giving station elevations with an accuracy of ± 1–$1\frac{1}{2}$ m (± 0.3 mgals).

A complete Bouguer reduction with terrain corrections was made for the whole area. Hammer's (1939) method was used for zones A–G (0–1.5 km). The terrain effect from 1.5 to 22 km (zone H–M of Hammer 1939) was calculated on a computer using mean heights determined in squares 1×1 km^2 based on the UTM international grid system (Lagaaij 1968). Terrain corrections varied from 0.5 to 8.7 mgals, but were mostly from 2 to 4 mgals.

The data were reduced to sea level using a density of 2.71 g/cm^3 (mean density of the surrounding gneisses based on 17 samples). Mean density for the eclogite is 3.31 g/cm^3 (4 samples) and the garnet-biotite gneiss exposed north of Ulsteinvik gave a mean density of 2.90 g/cm^3 (4 samples). The density contrasts used are 0.6 and 0.2 g/cm^3 respectively.

The Bouguer gravity map

The regional field in the measured area is approximately parallel to the coastline and falls rather steeply (gradient ca. -2 mgals/km) in a SE direction (Fig. 1). This effect is in good agreement with a Moho-discontinuity dipping towards SE. Superimposed on this regional field is a rather large positive Bouguer anomaly situated over the Ulsteinvik eclogite and garnet-biotite gneiss area. The shape of the anomaly follows rather closely the outline of the dense rocks.

South of this anomaly there is another positive anomaly (62°17', 5°50'). The exposed surface rocks are ordinary gneisses, and the anomaly is probably due to underlying dense rocks. If Gjelsvik (1951) was correct in assuming successive syn- and anti-forms with fold axis striking approximately E-W in the area, this positive anomaly might be due to another eclogite body lying in a synform at a rather shallow depth.

Models and interpretation

Six profiles (I–VI) were drawn normal to the strike of the eclogite body at Ulsteinvik and residual anomaly profiles were determined (Figs. 1 and 2). The separation of the residual field from the regional gravity field was done graphically assuming a smooth (almost linear) regional field. Maximum residual anomalies varied from 2.2 (profile I) to 6.9 (profile VI) mgals. The

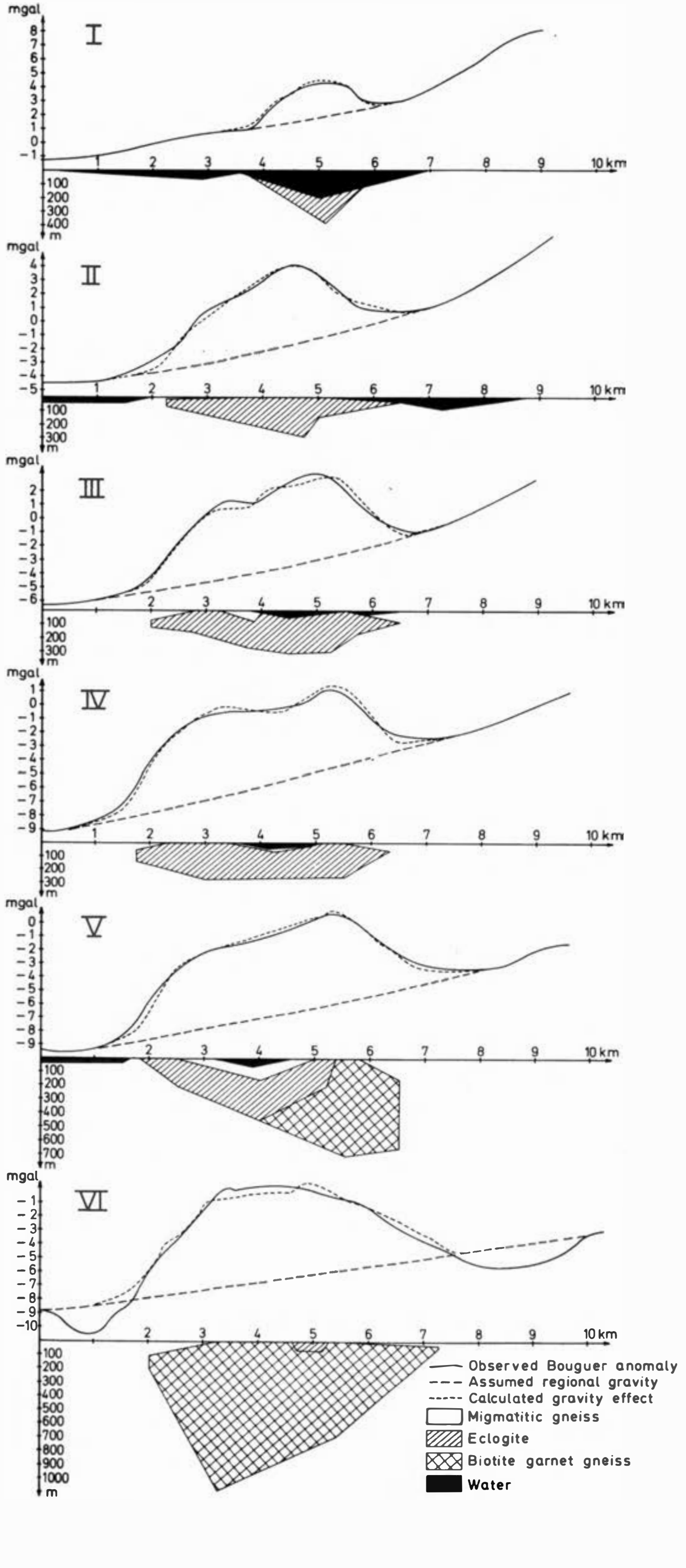

Fig. 2. Profiles I–VI show six structural sections of the Hareidlandet eclogite.

negative residual anomalies on profile VI can probably be explained by a less dense gneiss type (2.62 g/cm^3, 2 samples).

Using the two-dimensional method of Talwani et al. (1959), models were calculated for all six profiles. The models presented (Fig. 2) indicate that the eclogite at depth shows a wider and more regular shape than at the surface.

Profile I. The whole profile is in water, and consequently no rocks are exposed. The water cover varies from a few metres to ca. 200 m. The positive anomaly is probably caused by a broad U-shaped eclogite body directly under the water cover with a maximum thickness of ca. 180 m

Profile II. The profile is partly on land and in shallow water (less than 110 m). The eclogite body is exposed for a total length of ca. 1.5 km where the maximum residual anomaly is also found. A much wider subsurface extension (ca. 4.0 km) of the eclogite body has to be assumed in order to explain the gravity anomaly. The maximum thickness of the eclogite is ca. 300 m.

Profile III. The profile is partly on land and partly in shallow water (less than 60 m). The eclogite is exposed for a total length of ca. 1.5 km. The anomaly confirms the synformal shape with ca. 0.75 km of exposed gneiss in the middle. In order to match the anomaly we have to extend the eclogite body ca. 0.8 km to the SW and ca. 2.0 km to the NE. The body has a maximum depth of ca. 300 m.

Profile IV. The profile is very similar to profile III. The eclogite lies in a synform with partly exposed gneiss on top. Shallow water covers the rocks. The eclogite body (exposed length ca. 1.5 km) has to be extended 0.5 km to the SW and 0.75 km to the NE in order to match the anomaly. The maximum thickness is ca. 250 m.

Profile V. The profile is situated mostly on land. The eclogite is exposed for a total length of ca. 3 km with gneiss on top. A ca. 0.5 km-wide band of garnet-biotite-rich gneiss borders the eclogite to the NE. The SW contact apparently dips 30° to the NE. In order to explain the gravity effect the garnet-biotite gneiss has to be extended ca. 0.5 km to the NE. The eclogite and the garnet-biotite gneiss bodies have a maximum thickness of ca. 250 m and ca. 400 m respectively.

Profile VI. The profile is situated entirely on land. The eclogite is only ca. 0.5 km wide, and is bordered on both sides by exposed garnet-biotite gneisses having a total width of 2.25 km. This width has to be extended ca. 1.25 km to the NE to explain the gravity effect. The maximum thickness of the eclogite is probably ca. 60 m and that of the garnet-biotite gneiss ca. 900 m.

Discussion

The models show that the eclogite body is wider at depth than the surface exposures indicate. The residual anomalies are somewhat larger to the NE on most of the profiles, indicating that the eclogite body has more of its mass on its NE than on its SW side.

The residual anomalies also increase to the SE along the major fold axis, which implies that the maximum thickness of the eclogite (and also the surrounding garnet-biotite gneiss) is found to the SE, consistent with the southeastward plunge of the major fold axis of the synform over Ulsteinvik.

The eclogite seems to wedge out along the fold axis, towards NW, and ends rather abruptly to the SE where these is a steep gravity gradient (ca. -4 mgal/km). A connection between the Ulsteinvik eclogite body and the long and thin eclogite body at the lake Snipsøyrvatn is possible, but not likely. A small gravity anomaly is associated with this eclogite, indicating a very shallow body.

Models II, III and IV show a widening of the eclogite body, much different from the narrow body exposed at the surface. The dip at the exposed contacts varies, but is always inward (Mysen 1971). This has to change rather abruptly to an outward dip, giving the body the structure shown in the models.

Comparing neighbouring profiles (II, III and IV) it is seen that the shape and amplitude of the residual anomaly are almost the same. For this reason we have assumed the gneiss lying on top of the eclogite in profiles III, IV and V to be rather shallow.

By the use of the Gauss theorem the excess mass of the anomaly is calculated to ca. 3.4×10^9 tons, or a volume of the eclogite of 5–6 km^3 assuming a density contrast of 0.6 g/cm^3.

The limited extent of the anomaly over the Hareidlandet eclogite and the small calculated mass exclude the possibility of the eclogite being connected in any way with the mantle.

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