GRAVITY INVESTIGATION AND GEOLOGICAL INTERPRETATION OF THE ULTRAMAFITE COMPLEX OF ÅHEIM, SUNNMØRE, WESTERN NORWAY*

GISLE GRØNLIE & FRANZ ROST

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A gravity survey combined with geological field work has been made of the ultramafite complex of Åheim. The study shows that the exposed ultramafic bodies are in all probability all part of one body which has a depth of about 1 km. The central gneissic mountain, Helgehorn, is probably 'floating' on top of this ultramafic body. The Bouguer anomaly contours suggest an eastward extension of the ultramafic body at depth. The total excess mass of the ultramafite complex is estimated to $1.2–1.5 \times 10^{10}$ tons and the volume is approximately 25–30 km^3.

G. Grønlie, Institutt for geologi, Universitetet i Oslo, Blindern, Oslo 3, Norway.
F. Rost, Mineralogisches Institut der Universität des Saarlandes, 66 Saarbrücken 15, West Germany.

This study is a joint geophysical and geological project undertaken by two research groups, one from Mineralogisches Institut der Universität des Saarlandes, Saarbrücken, and the other from Institutt for geologi, Universitetet i Oslo. The former has for some years been making detailed geological studies in the Åheim area and the latter has recently made a series of geophysical measurements. The large dimensions of the Åheim complex has made it possible to undertake a gravimetric investigation here. The object of this joint study was to try to deduce the total mass of the complex and to confirm the field geologists deductions concerning structures at depth.

The numerous ultramafic bodies occurring in the basal gneiss region in the Sunnmøre–Nordfjord area of western Norway have interested geologists for many years. Early workers in the area were Vogt (1883), Reusch (1884), and Eskola (1921). More recent work has been done by Gjelsvik (1951), Bryhni (1966), and Bryhni & Grimstad (1970), all of whom compiled regional geological maps and looked at the ultramafic bodies in a regional context. Detailed studies on local ultramafic bodies have recently been made by Mysen (1971), Mysen & Heier (1971), and Grønlie et al. (1972).

Field procedure and data reduction

Excellent maps (scale 1:5000, Norwegian Geographical Surveys economic

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map series and scale 1:50 000, series M 711, 1119^{III} and 1218^{IV}) giving station elevations with an accuracy of ± 1.5 m (± 0.3 mgals) were available for this work together with two series of aerial photographs.

180 gravity stations in the area were measured using two gravimeters (types: Worden Master and La Coste Romberg). A complete Bouguer reduction with terrain corrections was made for the whole area. The method of Hammer (1939) was used for the inner zones A–G ($<$ 1 km). The terrain effect from 1 to 22 km (zones H–M) was calculated on a computer using mean heights determined in squares 1×1 km^2 based on the UTM international gridsystem (Grønlie & Ramberg 1973). The terrain corrections varied from 1.4 to 16.0 mgals, but were mostly from 3 to 8 mgals.

The data were reduced to sea level using a density of 2.7 g/cm^3 (mean density of the surrounding gneisses based on 10 samples). The mean density for the ultramafites is 3.22 g/cm^3 (4 samples). The density contrast used is 0.5 g/cm^3.

The Bouguer gravity map

The regional field in the measured area is approximately parallel to the coastline and falls rather steeply (gradient ca. 1 mgal/km) towards the south-east (Fig. 1). This effect is in good agreement with a Moho-discontinuity dipping towards the SE. Superimposed on this regional field is a rather large positive Bouguer anomaly situated over the ultramafite complex of Åheim. The shape of the anomaly generally follows the outcrop boundaries of the dense rocks (Fig. 3). South-east of this anomaly is a positive anomaly belt. The surface rocks in this region are ordinary gneisses with small bodies of eclogite and ultramafites (I. Bryhni, pers. comm.), but the anomaly is probably due to underlying dense rocks. The anomaly ca. 4 km south-west of Åheim is based on only one measured station (which might be in error).

The geological and structural field work

Geological and structural mapping was based on the usual geological field work methods. More than 1000 measurements were made in the ultramafite bodies and the surrounding gneisses to obtain the strike of layering and schistosity and the plunge of fold axes and lineations. A short preliminary abstract is given by Rost (1971).

The ultramafite complex is composed of three main bodies or lenses. The largest one (the Almklovdalen body) outcrops in the bottom of the valley between the lake near Gusdal (Gusdalsvatnet) and Hellebost farm (Figs. 2 and 3). It is more than 1 km wide and 4 km long. A large sinuous outcrop occurs south of the Almklovdalen body (Rødkleiva–Sunndalen body). It can be traced from the south-eastern corner of lake Gusdalsvatnet where it strikes NW–SE to Rødkleiva where the strike becomes NE–SW, S of Halse it returns to NW–SE and finally turns east–west near Sunndalen

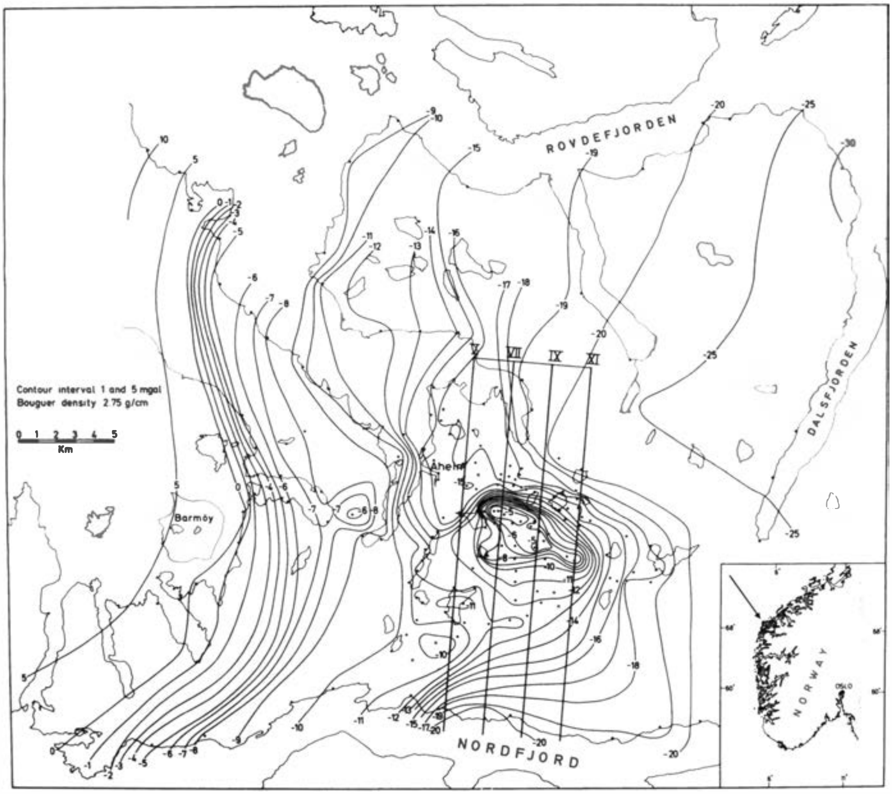

Fig. 1. Bouguer gravity anomaly map of the ultramafite complex of Åheim, Sunnmøre, western Norway.

farm. Near the lake Gusdalsvatnet, layering and schistosity generally dip steeply or are perpendicular. In Rødkleiva hill both dip approximately 60–70° to the SE, and this same dip is seen in the northern part of the body between Halse and Sunndalen. From the middle part to the S and SE the angle of dip decreases (40–30° to the E) and SW of Sunndalen it is almost horizontal.

A connection between the bodies of Halse/Sunndalen and the WE striking body south of the mountain Helgehorn (the Helge body) was long time in doubt. N of Sunndalen outcrops of ultramafic rocks are absent in the broad valley plain, as indicated in Fig. 2 by omission of the dotting. However, the geological situation and the morphology point to a continuation of the Sunndalen body to the Helge body. The latter shows a very distinct change in strike from EW to NS SW of Helgehorn. This seems to be in conformity with the NS strike of the Rødkleiva ultramafites. A NS striking fault from Sunndalen to the N is a possible alternative explanation.

The ultramafite body S of Helgehorn (the Helge body) strikes WE as already mentioned. In the eastern part it fingers out between intercalations of gneisses and finally disappears in the valley near Hellebost. The dipping in the Helge body is generally perpendicular or very steep to the N or the S.

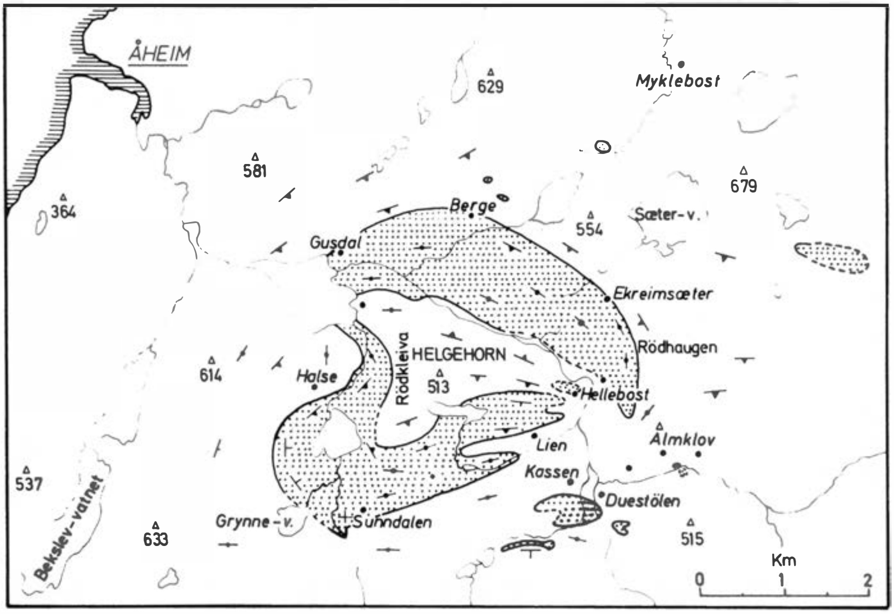

Fig. 2. Geological map of the ultramafite complex of Åheim.

A connection between the Helge body and the southern end of the Almklovdalen body is possible but not proven.

The Helgehorn gneissic body lies in a central position surrounded by these three ultramafite bodies. The dipping of the gneiss schistosity of the

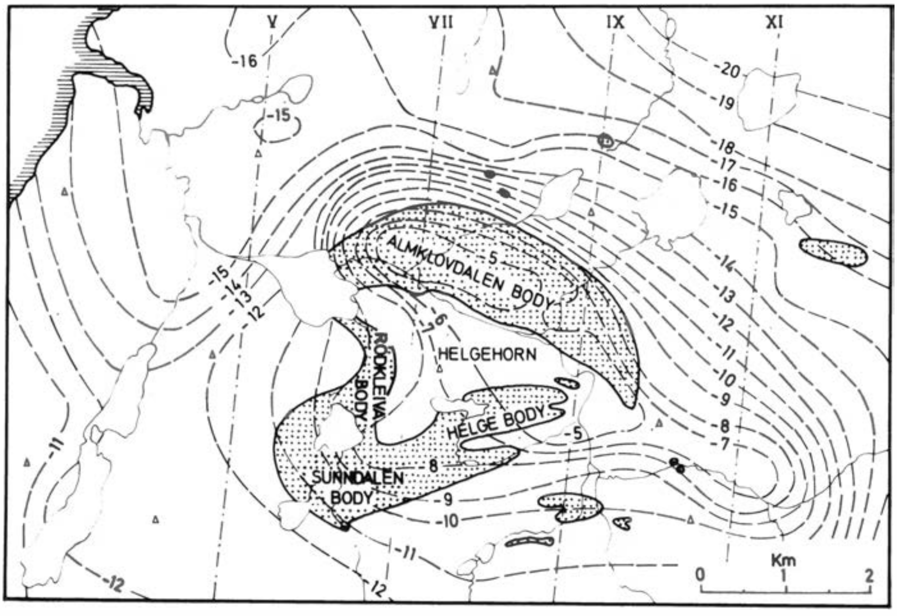

Fig. 3. Simplified geological map with Bouguer gravity anomaly contours of the ultramafite complex of Åheim.

Helgehorn body seems to indicate a strongly compressed steep fold which plunges nearly WE. The question as to whether this gneissic body is underlain by ultramafic rocks is difficult to answer. The geophysical evidence is in favor of this (as is shown later), but the geologic evidence disfavors the idea.

Model study and discussion

The results of the geophysical investigation and the geological and structural field work are presented on the map in Fig. 3. This demonstrates that the anomaly lines do not follow the outlines of the outcropping ultramafite complex of Åheim very closely. They mark the borders of the ultramafite only along the northern and western sides of the Almklovdalen body. The interpretation of this must be that the Almklovdalen body dips along the northern border very steeply or perpendicularly to a depth which we have calculated to be approximately 1 km, and that it ends abruptly to the N and in the lake Gusdalsvatnet.

The Bouguer anomaly isogals cross the borders of the other two exposed bodies. This can be interpreted in two ways: (1) the bodies are very shallow and (2) the exposed ultramafite bodies are part of a larger body with varying thickness. Alternative 2 is the most likely because the exposed bodies are lying completely within the anomalous gravity area, which must be due to a rather large accumulation of dense rocks.

We have made five two-dimensional models by the method of Talwani et al. (1959) over the ultramafites of the Åheim complex, in order to study the three-dimensional extent of the bodies (Fig. 4). Three of the profiles cross exposed ultramafic rocks (VIII, VIIa, IX) and two do not (V, XI). The profiles were drawn almost parallel to the regional gravity gradient and the separation of the residual field from the regional gravity field was made graphically assuming a smooth, almost linear regional field. Maximum residual anomalies vary from 8.6 (profile V) to 13.3 (profile XI) mgals.

The corresponding models (Fig. 4) indicate a rather thick central section of the ultramafite complex, ranging from ca. 500 to 1000 m for the different profiles. (The exposed body in profile IX at 10.5 km is probably not connected to the main body since the computed curve does not match the observed curve.)

The models indicate that the different ultramafic bodies exposed at the surface most likely connect to form one body at depth. From the geophysical data it is most likely that the gneiss complex of Helgehorn is 'floating' on top of an ultramafic body. This also simplifies the explanation of the continuation of the Bouguer anomalies to the E in the upper Almklovdalen. As model XI (Fig. 4) indicates, it is explained as an elongation of the main body.

We have also considered the possibility that the gneissic mountain Helgehorn divides two different ultramafic bodies (model VIIa). The fit between

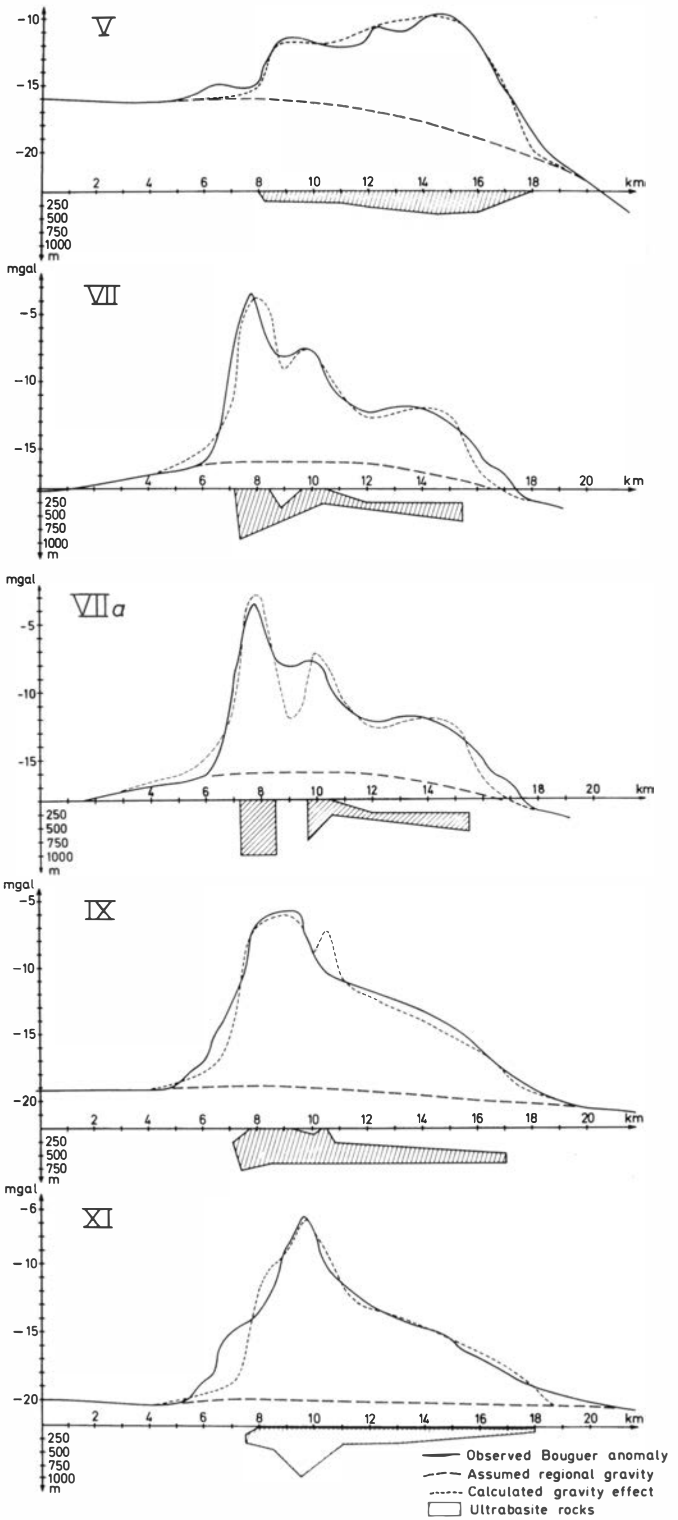

Fig. 4. Gravity profiles and geophysical models across the ultramafite complex of Åheim.

the observed gravity anomaly and the calculated effect from this model is not good at all. We cannot totally exclude the possibility of such a solution being the correct one, but must say that it does not seem likely on the basis of the gravity results. From the geological field results it still seems to be an acceptable possibility.

A rough estimate of the excess mass gives 1.2–1.5 $\times 10^{10}$ tons and the volume of the ultramafite is approximately 25–30 km^3.

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