A REGIONAL GRAVITY STUDY OVER THE PERMIAN BÆRUM CAULDRON OF THE OSLO REGION

By

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Abstract. Thirty-five gravity stations were added to a pre-existing gravity net over the Bærum cauldron and the Bouguer anomalies were computed. A positive anomaly lies over the south side of the cauldron. If the effect of the 1000-m-thick B_3 basalt, which is down faulted into the cauldron, is removed, a 10-mgal. negative anomaly is found over the cauldron. This anomaly corresponds to a hypothetical vertical cylinder of nordmarkite 10 km in diameter and 6 km deep. Its top would be about 3 km below the surface. A small negative anomaly associated with contact-metamorphosed sandstones outside the cauldron is ascribed to a subjacent intrusive. A large negative anomaly is found over the nordmarkitic pluton comprising Tryvasshögda.

Introduction.

In 1960 the Geographical Survey of Norway (Norges Geografiske Oppmåling) published a Bouguer gravity map (1:250 000) over the Oslo region. This map, based on 1400 gravity stations, represents a tremendous amount of work; however, since a large area was covered, many features which are interesting to geologists remain undefined due to an insufficient density of stations. The Bærum cauldron was one of these features and was selected for further study because of its general interest and accessibility. Accordingly, 35 more gravity stations were added over the Bærum cauldron and in its vicinity.

The Bærum cauldron in elliptical in plan and measures 8.5 by 12 km across. The southeastern border of the cauldron lies 7 km northwest of the city of Oslo. The terrain consists of rounded, forest-covered hills whose maximum relief is 300 m.

The purpose of the survey was to determine the gravity anomaly associated with the cauldron and to suggest a course for future measurements in the area. The 35 additional stations hardly provide detailed coverage; consequently, the conclusions can only be proportionately exact.

Field Methods and Reduction of Observations.

A Worden gravimeter with a scale constant of 0.09 mgal. was used. Several local base stations were selected from those already established in the area by the Geographical Survey of Norway, and these were tied in with the base gravity station in the Geologisk Museum, Oslo. Gravimeter drift was corrected by returning the instrument to a local base station twice a day.

The main problem of the gravity survey was to establish accurate elevations at gravity stations. Wherever possible, accurately surveyed elevations were used; otherwise, either spot elevations on lakes and farms from rectangle maps of the Geographical Survey of Norway or barometric elevations were used. Spot elevations on more modern maps are accurate to $\pm$ 1 m (O. Trovaag, oral communication). Checks with a Short and Mason barometer between known elevations during a short time interval (one hour or less) showed an accuracy of 2—3 m. Most of the barometric elevations should be within this accuracy; therefore, they may cause an error of 0.6 mgal. in the Bouguer anomalies. Horizontal control was provided by the above-mentioned rectangle maps (1:100 000).

Bouguer anomalies were computed according to NETTLETON, (1940) and a surface density of 2.67 was used for the Bouguer correction. The terrain effect introduces errors up to 3 mgal. at some stations; therefore, terrain corrections, computed using two-dimensional models (HUBBERT, 1942), were applied to most of the stations. These models only approximate the actual terrain but would remove most of the error due to topography. Any error remaining due to terrain effects should not exceed 0.5 mgal. at its greatest.

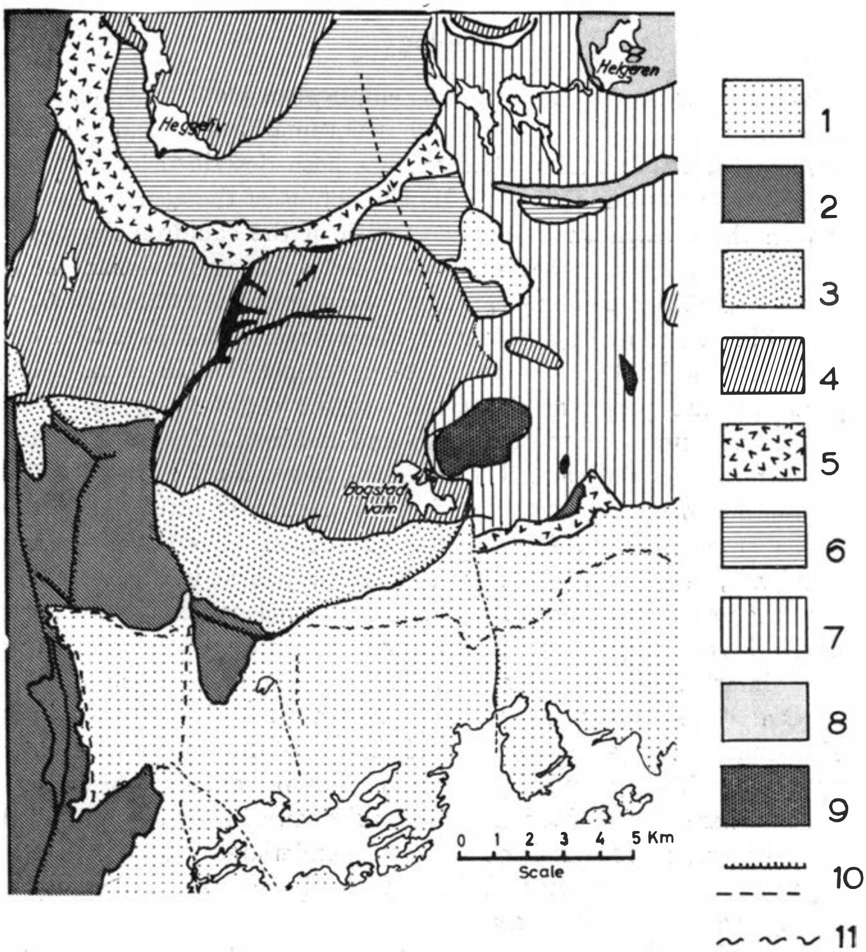

Fig. 1. Geological map of the Bærum cauldron and vicinity (Generalized after Holtedahl and Dons 1952).

Cambrian to lower Devonian sedimentary rocks. Permian supracrustal rocks (with some hypabyssal rocks): 1. Cambrian to lower Devonian sedimentary rocks. 2. Lower rhomb porphyries and B_1+B_2 basalt, 3. B_3-basalt with beds of agglomerate and sandstone, 4. Felsite and syenite porphyry and upper rhomb phorphyries. *Permian intrusive rocks:* 5. Akerite (syenodiorite), 6. Larvikite and Kjelsåsite, 7. Nordmarkite, 8, Ekerite (aegerine granite), 9. Biotite granite. Solid black indicates the large syenitic to granitic (ring) dikes circumscribing the cauldron. 10. Faults and other prominent fractures. 11. Limits of contact metamorphism.

Geology.

The Bærum cauldron is a block, elliptical in plan, that has sunk down inside a ring fault along which a nordmarkitic to granitic dike is emplaced. This Permian cauldron has been described by SÆTHER (1945) and OFTEDAHL (1953, 1960). The details of the geology can be seen on the geologic map (Fig. 1). South of the cauldron lie folded Cambro-Silurian limestones and shales and a Lower Devonian sandstone which have a combined stratigraphic thickness of about 1500 m. The sedimentary rocks are contact metamorphosed adjacent to the cauldron. The Krokskogen lava plateau, composed of Permian basaltic and rhomb porphyry flows, borders the cauldron to the west. Larvikitic plutons lie to the north and nordmarkitic plutons with some granite to the east. The subsided block itself is cut by the eastern nordmarkitic pluton, a fact of particular interest for the gravity interpretation. According to OFTEDAHL (1960), the vertical subsidence, based on the stratigraphic lava sequence, is 1000—1500 m along the southern border. In contrast to the single ring dike elsewhere, the northern end of the subsided block has been intruded by a swarm of nordmarkite dikes as far as 2 km from the marginal fault. The elliptical block has probably subsided into a magma chamber. This subsidence may have been caused by „withdrawal of magmatic support" within the underlying magma chamber or by explosive volcanism whereby the block simultaneously sank into space provided by the extrusion of lava. If the cauldron is underlain by a nordmarkitic to granitic pluton, the mass deficiency of this body should be detectable by means of gravity measurements.

The subsided block is composed of a layered sequence of lava flows and conformable felsite intrusions or ignimbrites which dip northward at 10—30°. The most prominent unit is the B_3 basalt, which attains a maximum thickness of at least 1000 m (SÆTHER, 1945). SÆTHER emphasizes that this is not a plateau basalt but is an extremely heterogeneous unit. It is composed of many small flows with pockets of basaltic clastics and is cut by numerous glassy, basaltic dikes. He calls the B_3 basalt unit a shield volcano. The basalt is visibly metamorphosed. The other rocks in the subsided block are rhomb porphyries and trachytes.

Rock Densities.

The densities of the various rock types were determined by weighing them in air and in water with a balance. Before weighing in water, the samples were allowed to stand in water under a vacuum for 15 minutes. The precision of the method was $\pm$ 0.01.

The values obtained appear in Table 1.

Rock Type	No. of Samples	Av. Sp. Gr.
Nordmarkite (Sørkedalen, Vettakollen, Grorud)	6	2.59
Felsites and trachytes in the subsided block ..	5	2.70
Rhomb prophyry (RP_1)	1	2.71
Shale and shaley limestone	4	2.72
Larvikitic rocks (Sørkedalen)	3	2.74
B_3 basalt	3	3.03

The above figures show that the rocks of the subsided block with the exception of the B_3 basalt have about the same density as the rocks outside the cauldron. An average density of 2.73 is used for the country rocks and 2.59 for the nordmarkite plutons.

The low density of nordmarkite is striking; it may be explained by the drusy character of these rocks, first noted by Brögger (1890). The low density of nordmarkite certainly affirms the stoping power of nordmarkite magma. Its lower density would allow it to stope its way into all but rather porous sedimentary rocks.

Gravity Interpretation.

A Bouguer gravity map (Fig. 2) shows the vertical intensity of the earth's gravity field after the Bouguer correction has been made at each station. The Bouguer anomalies represent the interplay of local and regional anomalies, superposed on each other. Local and regional are only relative in denoting any particular areal extent; however, regional anomalies are usually due to larger, deeper features, and local anomalies to shallower ones. The anomalies are caused by the horizontal variation of density distributions associated with geologic features, i.e. folds and faults in layers of different density or plutons whose density is different from that of the country rock. The problem

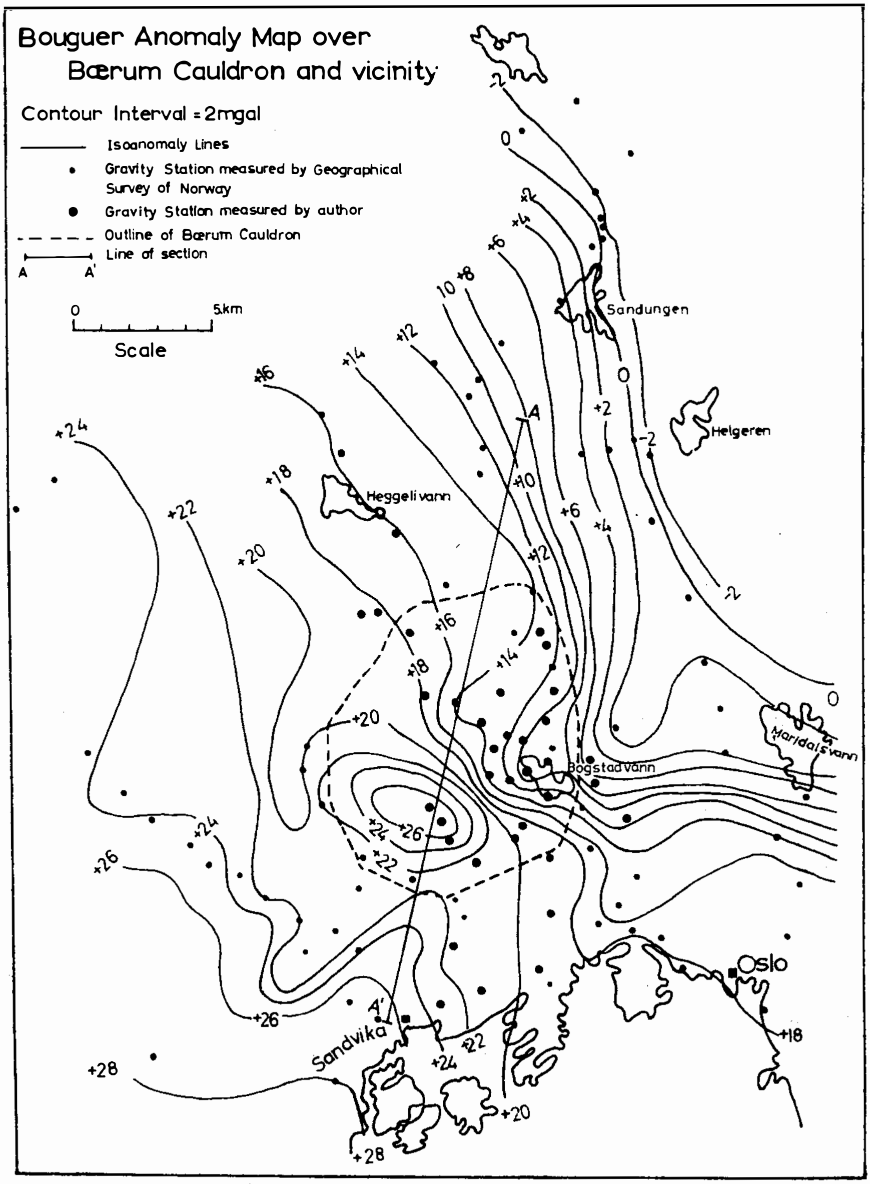

Fig. 2. Bouguer gravity anomaly map.

then, in gravity interpretation, is to isolate the local anomaly and calculate the form for a disturbing mass that corresponds to this anomaly.

A variety of density distributions located at different depths can each cause the same gravity anomaly; therefore, gravity interpretations are inherently ambiguous. The more geological information is known, the more unique the gravity solution becomes.

The geology of the Bærum cauldron indicates that the subsided block is underlain by a nordmarkite pluton. The common association of gravity „lows'' and granitic plutons is well known (ROMBERG and BARNES, 1944; GARLAND, 1950, 1953; BOTT, 1956). The presence of contact metamorphism on the southern rocks of the cauldron (SÆTHER, 1945) suggests that the present depth of the pluton is not great. If the cauldron is underlain by a nordmarkitic to granitic pluton, the mass deficiency of this body should be detectable with gravity measurements. One would expect, therefore, that a „low'' could be detected over the cauldron.

The Bouguer gravity map (Fig. 2) shows no such association. On the contrary, a gravity high is situated over the south end of the cauldron. This „high'' coincides with the outcrop of the B_3 basalt. When the thickness (about 1000 m), high density (3.03), and shallow position of the B_3 basalt are considered, it is not surprising that positive or zero local anomalies occur over the cauldron. Consequently, the effect of the deeper nordmarkite pluton is masked by that of the basalt.

Logically, the next step is to determine the gravity field after the removal of the effect of the basalt. To do this, a N—S profile of the gravity field was drawn through the cauldron (Fig. 3). The regional gravity gradient is expressed in the general slope of the profile outside the limits of the cauldron. The basalt is considered to be a disc dipping northward at 20°, and its attraction is computed at points along the profile. These values are subtracted from the measured gravity at each point to determine a new curve that represents the gravity field if the basalt were replaced by a layer of average density (2.72). The difference between the curve obtained and the regional gradient is the anomaly caused by the pluton at any particular point.

It should be noted that a radius of 4 km was used for the basalt disc. This presupposes that the basalt is intersected in depth by the pluton and does not extend completely across the cauldron. There are

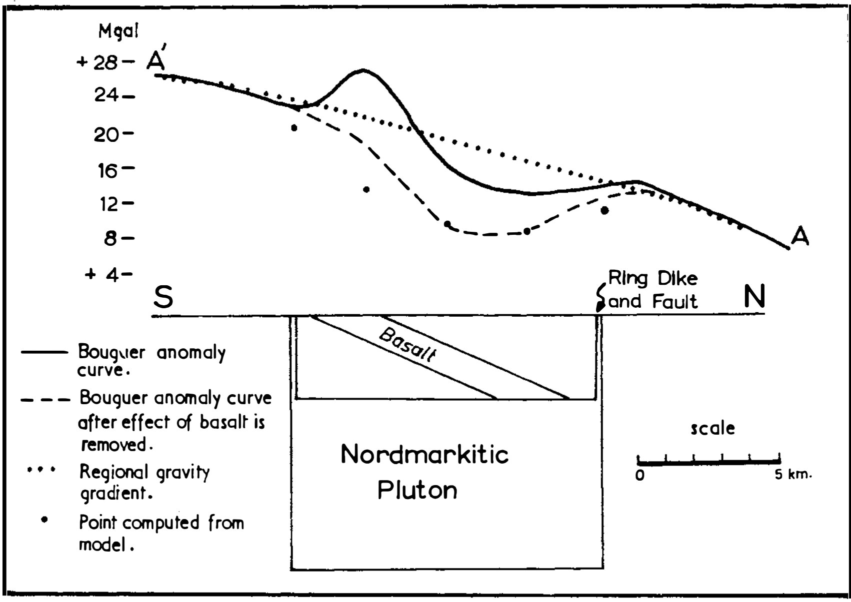

Fig. 3. Profile of gravity field and computed model of nordmarkitic pluton.

two reasons for this supposition: 1) The contact metamorphism suggests a shallow depth of the pluton. 2) The most suitable model can be computed on this basis.

After the effect of the basalt is removed, an anomaly of 10 mgal. appears over the center of the cauldron. This anomaly upholds the geological supposition that a nordmarkite pluton underlies the cauldron. Accordingly, a cylindrical model was used to compute a theoretical anomaly, which was compared with the actual anomaly. A density contrast of 0.14 (2.73 minus 2.59) between surface rocks and nordmarkite was used, and it was assumed that this density contrast exists in depth. A 6-km-deep cylinder of nordmarkite whose top is 3 km below the earth's surface and whose radius is 5 km causes a negative anomaly of 10 mgal.

The attraction of the cylinder at different points along the profile was computed and plotted. Fig. 3 shows that the points near the edge of the cauldron depart from the anomaly curve. This departure is caused by approximate nature of the assumptions used; the data available do not warrant more exact calculations.

A nordmarkitic to granitic pluton that cuts across a small part of the cauldron's east side offers an interesting possibility to check the postulated thickness of the subsided block. This is probably an extension of the pluton underlying the cauldron; therefore, the local anomaly over this extension is a function of the thickness of the subsided block. In this case, the anomaly associated with a 2-km-wide outcrop is the local anomaly, and the gravity field along a 12 km profile furnishes the regional gradient. The maximum negative anomaly over the projection of the pluton east of Bogstadvann is 4 mgal. An average density of 2.82, based on the relative thicknesses of basalt and felsite flows, was used for the subsided block and, again, 2.59 for the intrusion. A half-cylinder approximates the form of the intrusion because it is a semi-rounded projection from a much larger nordmarkitic to granitic pluton that borders the east side of the cauldron. This model, extending to a depth of 3 km, causes a negative anomaly of 4.3 mgal. as compared with measured anomaly of 4 mgal. The close agreement between the two calculations is striking, but they are not completely independent because the average density of the subsided block is necessarily based on depth assumptions. It is, in fact, probably accidental that the two figures agree so well, but, even a somewhat poorer agreement would imply that the depth to the underlying pluton is on the order of 3 km.

Some features of the Bouguer anomaly map require further explanation. The marked positive anomaly over the B_3 basalt around Muren is not expressed to the east where the basalt is also exposed. This fact may be explained by a thinning of the basalt in this direction. For all calculations a constant thickness of 1000 m was used, and departures from this thickness would affect the calculations. A denser net of gravity stations could give information regarding the thickness and would be advisable over the basalt cutcrop and its vicinity.

A traverse northwest from Sandvika in west Bærum includes several relatively low readings that coincide with an area of contact-metamorphosed Cambro-Silurian sedimentary rocks. This „low" is reflected in the southwest trending embayment of the isoanomaly contours 3 km northwest of Sandvika. No plutons are exposed in the area. BOTT (1956) has invoked a large, unexposed granitic intrusion to explain a large negative anomaly over a mineralized region in England. The presence of a granitic intrusion is strongly suggested for this area by the coincidence of an apparent low and the contact metamorphism; however, more gravity stations are needed to define the anomaly.

The most distinctive feature of the gravity map is the „low" shown by an embayment in the contours over Tryvasshögda. This represents a large „low" superimposed on the southwest-northeast regional gradient. This „low" corresponds to the outcrop of a large pluton of nordmarkite and granite and would be another worthwhile project for further study.

Conclusions.

The gravity data corroborate the geological supposition that the Bærum cauldron subsided into a magma chamber. As determined by the geological information used, the cauldron is underlain by a cylindrical pluton whose top is about 3 km below the surface and whose „base" is 9 km deep. The „base" is defined as the lower limit of the density contrast between the pluton and country rock; „base" is not used to indicate whether the pluton or the country rock is terminated at that depth. The calculations indicate a considerable size for the pluton; however, the depth to its top is undoubtedly more accurate than the depth to its „base".

This regional survey suggests that an unexposed granitic pluton underlies an area in west Bærum northwest of Sandvika and shows a fairly large negative anomaly over the Tryvasshögda nordmarkites. Both areas require more detailed gravity measurements, and a detailed gravity net would also be advisable over the cauldron area. Because of the marked low density of nordmarkite, nordmarkitic areas are particularly suitable for gravity surveys even when in contact with plutons of medium composition, i.e. larvikite. In a geologically complicated area such as the Oslo region, detailed surveys are practically mandatory. These surveys should be planned with a consideration of geological features and an anticipation of the anomalies caused by them.

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