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RE-INTERPRETATION OF THE GRAVITY ANOMALY OF THE ULTRA-BASIC GABBRO MASSIF AT PENNINGBY

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Abstract. The ultra-basic gabbro massif at Penningby on the coast of central Sweden has previously been investigated both geologically and geophysically. Using a recently developed three-dimensional interpretation procedure, the gravity anomaly of the gabbro massif is re-interpreted in this paper. The result is a flat, only partly outcropping body with a deeper root in the central portion.

INTRODUCTION

The ultra-basic gabbro massif at Penningby near Norrtälje on the coast of central Sweden has been the subject of both geological and geophysical investigations. A thorough geological survey was made by Lundegårdh (1943) and the surface contours of the massif given by him are indicated in Fig. 1. The area was geophysically investigated by Vogel (1963, 1964 a, b), who carried out seismic, magnetic and gravity measurements.

The seismic measurements were primarily intended for determinations of depths to the rock surface in covered areas, but some anomalous velocity distributions were also obtained, as indicated in Fig. 4. The relative vertical magnetic field is also shown in this figure. It has a rather irregular shape and is not very suitable for a detailed quantitative interpretation. Some local magnetic highs are probably related to contact zones between different kinds of rocks.

The gravity anomaly shows a well-defined closed contour, Fig. 1. The anomaly was interpreted by Vogel (1963, 1964 a, b) who used a least-squares procedure to fit simple models (vertical cylinder, horizontal plate) to the observed Bouguer anomaly. As larger and faster computers became available, this least-squares procedure, with some modifications to yield stable convergency, was applied to complex two-dimensional models (Dyrelius and Vogel, 1972). Later it was applied also to three-dimensional models (Dyrelius, 1972 b). In the present paper we use this three-dimensional interpretation procedure for a re-interpretation of the gravity anomaly, due to the ultra-basic gabbro massif at Penningby.

THE OBSERVED GRAVITY ANOMALY

The observed Bouguer anomaly, shown in Fig. 1, was obtained after subtraction of the regional trend. For the separation into regional and local Bouguer fields, Vogel (1964 a) used the second derivative of the original field as a guidance. The "zero"-contour line has been omitted in the figure as it is probably more likely to be a result of this method of separation than a reflection of the actual vanishing of the local field.

Several features of the anomaly are apparently due to very local irregularities, as can be seen in the northern and south-western parts. In addition the maximum of the anomaly is very sharp and seems superimposed on the main anomaly. Generally such disturbances do not strongly influence the possibility of obtaining a least-squares solution, but will of course increase the sum of squares of the residuals. When, however, only a domerately detailed interpretation is sought, the tendency of the procedure to fit the model also to such local disturbances might obscure the general trends of the disturbing mass in an undesirable way. To avoid this, we have applied a restricted smoothing of the anomaly. The result is shown in Fig. 2 where the range of the smoothing operator is also indicated. We have used a simple running average, so that the smoothed value is defined by

$$\Delta g'_0 = (2\,\Delta g_0 + \Delta g_1 + \Delta g_2 + \Delta g_3 + \Delta g_4)/6$$

where the points are numbered as in the figure.

Using the methods given by Dyrelius (1972 a) we have calculated the total disturbing mass and the location of its center, from both the smoothed and the unsmoothed anomaly. The results are the same in the two cases. The position of the center is shown in Fig. 2. From this and from the shape of the anomaly one can see that the disturbing body must have a greater horizontal extension than is clear from the surface contours of the massif. This is further supported by the shape of the magnetic anomaly and the areas of anomalously high seismic velocities (Fig. 4).

THE INTERPRETATIONAL MODEL

We have interpreted the gravity anomaly using the automatic model fitting procedure described by Dyrelius (1972 b). To this purpose 88 observation points were chosen to represent the features of the anomaly as well as possible. Most of these points are shown in Fig. 2.

The model is composed of rectangular prisms with known densities and depths to upper surfaces. The depths to the lower surfaces are the unknown parameters. These are adjusted iteratively till the gravity effect of the whole model fits (in the least-squares sense) the observed anomaly.

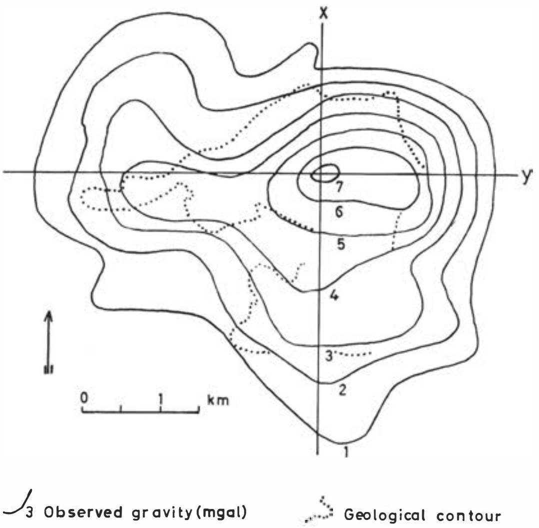

Fig. 1. Bouguer anomaly (after A. Vogel) and simplified geological contour (after P. H. Lundegårdh) of the ultra-basic gabbro massif at Penningby.

According to Vogel (1963) the density contrast between the gabbro and the surrounding lighter granites is 0.26 g/cm^3. This value has been used for all prisms of the final interpretational model. Naturally some uncertainty is associated with this value, especially when considering the richness of gabbro varieties in the massif (Lundegårdh, 1943). Therefore several models with different density contrasts have been tried. The results at least

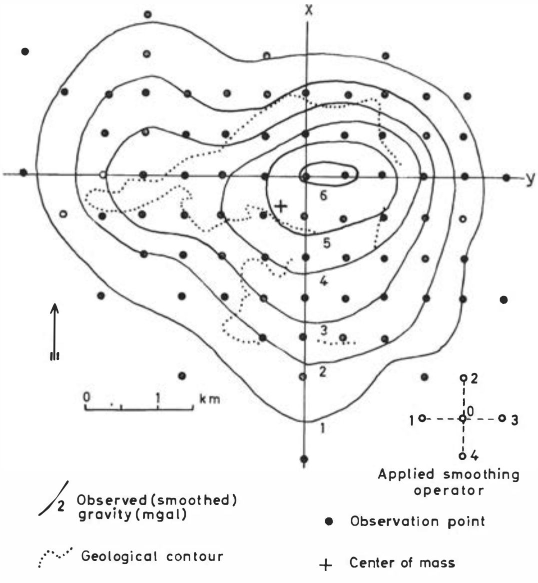

Fig. 2. Smoothed Bouguer anomaly.

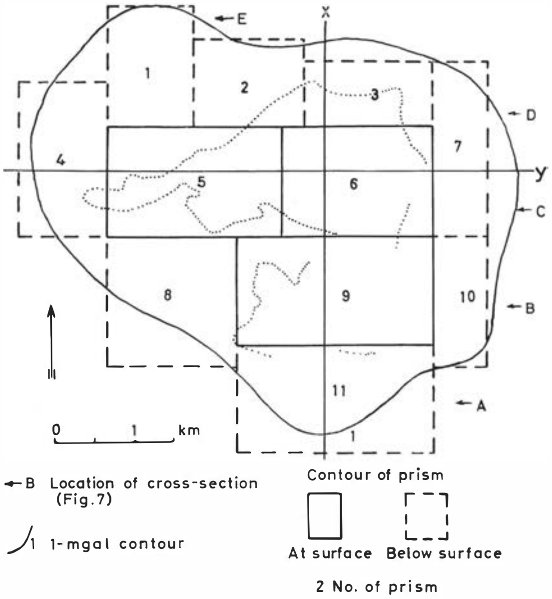

Fig. 3. Distribution of prisms in the final interpretational model.

showed that considerably different values do not yield satisfactory fits to the observed anomaly.

The slopes of the anomaly indicate how to distribute the prisms and chose the depths to the upper surfaces. The latter are also fixed with respect to the geological mapping, so that most prisms outcrop inside the contour of the massif. Since the prisms are necessarily too large for a close approximation of the irregular contour, compromises between these different considerations are unavoidable.

The final model was found after successive tests with different distributions of prisms, depths to upper surfaces and density contrasts. For these rearrangements of the model, the distribution of residuals (i.e. differences between observed and calculated gravity) obtained from a solution, served as a guidance. The different solutions were compared using the mean error m as a measure of the goodness of fit. $m = \sqrt{S/(N-M)}$ where S is the sum of squared residuals, N is the number of observation points and M is the number of prisms. Thus a smaller value of m generally corresponds to a better solution.

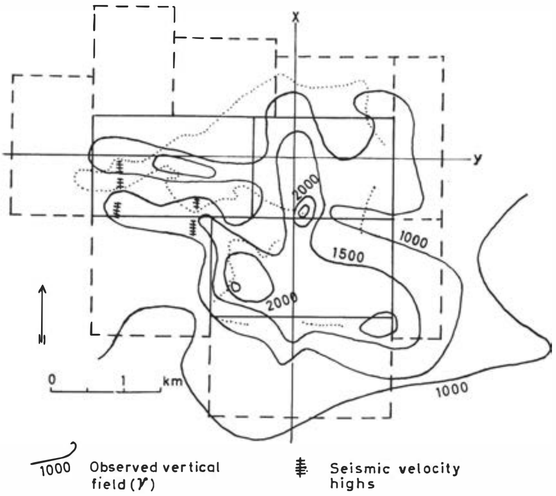

Fig. 4. Relative magnetic vertical field and locations of anomalously high seismic velocities (after A. Vogel).

FINAL RESULTS AND DISCUSSION

The final model, composed of 11 prisms, is shown in Fig. 3, in which each prism has been assigned a number. The least-squares solution for this model was obtained after five iterations and is illustrated in Figures 5—8.

The gravity effect of the model is seen, in Fig. 5, to fit the observed anomaly rather closely. Since

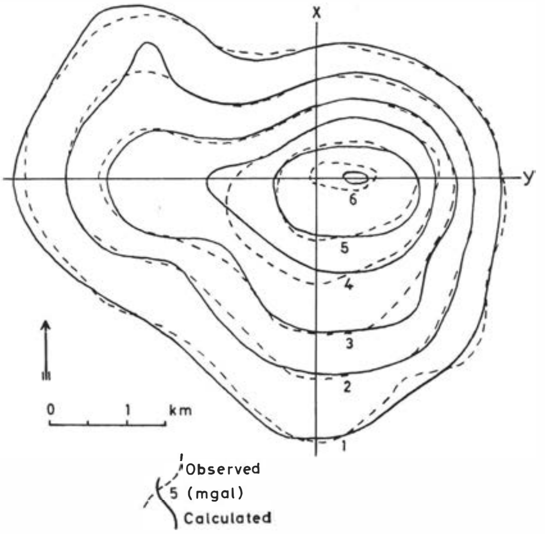

Fig. 5. Gravity effect of best fitting model and observed (smoothed) Bouguer anomaly.

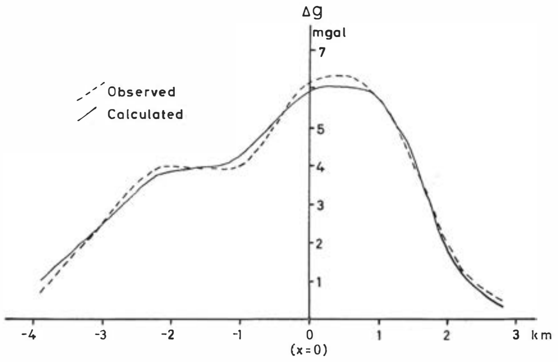

Fig. 6. Profile along y-axis (Fig. 5).

the distance between the contour lines is dependent upon the slope of the anomaly a further illustration is given in Fig. 6, showing a profile along the y-axis. The mean error, m, is 0.18 mgal (cf. $m = 1.3$ mgal for the horizontal plate used by Vogel (1964)).

The fitted model is shown in the form of vertical cross-sections in Fig. 7 and in divided perspective in Fig. 8. In addition, depths of the prisms are tabulated below.

Prism No.	Depth to upper surface (meters)	Depth to lower surface with mean error (meters)
1	165	465 ± 25
2	140	220 ± 15
3	140	415 ± 25
4	140	330 ± 20
5	0	385 ± 15
6	0	885 ± 30
7	110	435 ± 30
8	165	325 ± 15
9	0	290 ± 15
10	140	345 ± 25
11	165	345 ± 20

The fitted model is seen to be a rather flat "mushroom-shaped" structure where the central part (prism no. 6) reaches a depth of about 900 meters. Fitting the model to the unsmoothed anomaly, we have found that the mean error increases to about 0.3 mgal but the depths are not altered significantly.

The centre of mass of the model is in good agreement with that found from the anomaly (Fig. 2). The total mass shows a larger deviation. This is most easily explained as being due to the flat shape of the body. This shape implies a considerable overestimate of the depth used to correct the calculation of the mass from the anomaly (Dyrelius, 1972 a). Replacing, in this correction, by the depth to the center of the obtained model, the two masses agree completely. It is also possible to increase the mass of the model by decreasing the density contrast, since this would lengthen the prisms considerably. This, however, has shown to give a worse fit to the anomaly.

Compared to the previous interpretations (Vogel, 1963, 1964 a, b) we have obtained a more

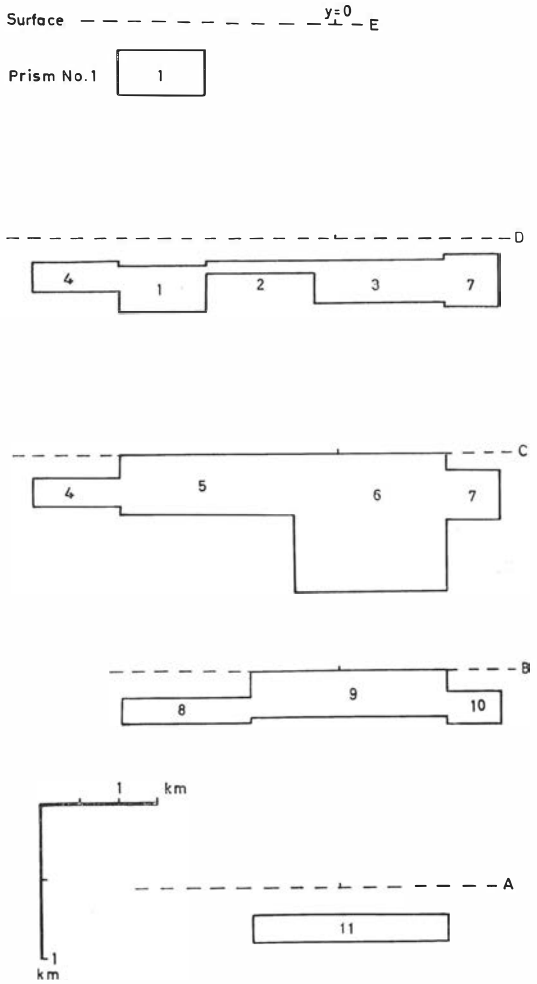

Fig. 7. Vertical cross-sections of best fitting model. Lettering of the sections and prism Nos. refer to Fig. 3.

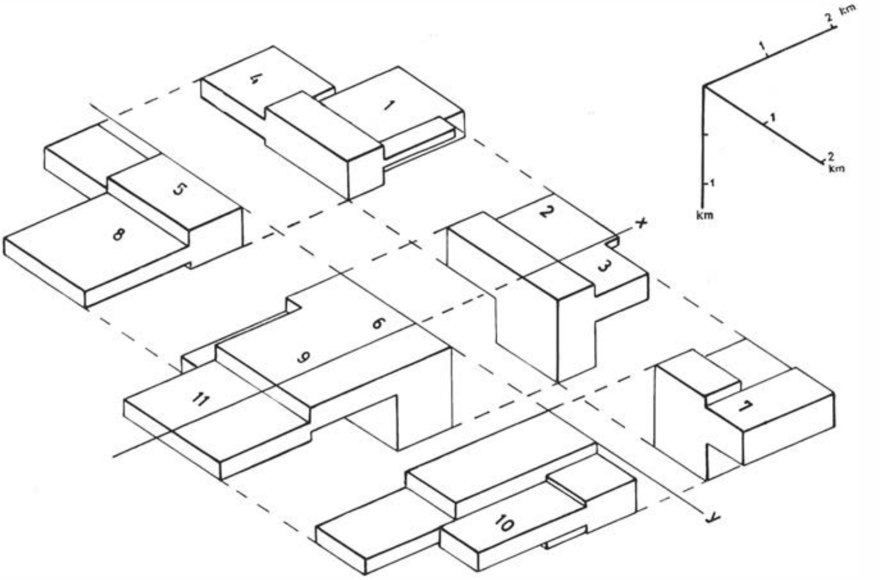

Fig. 8. Perspective of best fitting model, elucidated by division into six separated blocks. Prism Nos. refer to Fig. 3.

detailed and better fitting model with a much greater horizontal extent than is indicated by the geological mapping. As was mentioned before, this model is further supported by the magnetic and seismic data (see Fig. 4). In addition the magnetic anomaly has a maximum inside the deepest part of the model, close to the southern edge of prism no. 6. This is to be expected if the magnetization of the gabbro is induced by the Earth's present field. Vogel (1964 a) did not find any detectable remanent magnetization in samples from the massif and concluded that the magnetic anomaly is mainly due to induced magnetization.

Some possible errors of the interpretation have already been discussed; for example the uncertainty both in the estimates of the depths to the upper surfaces and in the choice of the density contrast. Additional geophysical data and density sampling might reduce these uncertainties. The interpretational model can be further improved by allowing variable upper surfaces and irregular contours of the prisms (Dyrelius, 1972 b). This is to a great extent a matter of the capacity of the computer used for the iterative model fitting procedure.

ACKNOWLEDGEMENTS

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