

A MAGNETIC INVESTIGATION OF THE LARVIKITE COMPLEX SW OF THE LAKE GJERDINGEN, NORDMARKA*

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The larvikite complex southwest of the lake Gjerdingen has been studied on the basis of its magnetic properties. The mean declination and inclination of the remanent magnetization are 199° and -45° , respectively. A negative magnetic anomaly associated with the larvikite is due to a dominant remanent magnetization within the medium grained larvikite which contains a relatively high concentration of magnetite. The influence of topography on magnetic measurements is discussed.

The magnetic model gives a near vertical extension of surface features to a depth of approximately 1 km where the magnetization contrast vanishes. This implies that the larvikite is either an isolated plug floating in the nordmarkite or the complex widens below this depth.

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The Permian gabbroid plutonic rocks of the Oslo region occur as volcanic necks aligned along the major fault lines or their extensions.

In the northern part of the region younger deep-seated eruptives cut the near N-S direction defined by the necks, beginning with Brandbukampen in the north to Tofteholmen in the south (Ofte Dahl 1960). Within these eruptives there are peculiar circular or semicircular complexes of coarse-grained kjelsosite-larvikite surrounded by a medium grained ring (Sæther 1962). The circular form of the complex is partly destroyed by younger nordmarkite.

The larvikite complex SW of the lake Gjerdingen (Fig. 1), which has most of its circular geometry preserved and is associated with a magnetic anomaly of 1000 gammas, was selected for a detailed magnetic study. A gravity survey has been undertaken by Grønlie (1971).

The paleomagnetic work of van Everdingen (1960) represents the first contribution to a magnetic study of the igneous rocks of the Oslo region. Regional aeromagnetic maps have been published by Norges Geologiske Undersøkelse (N. G. U.) from 1963–1970.

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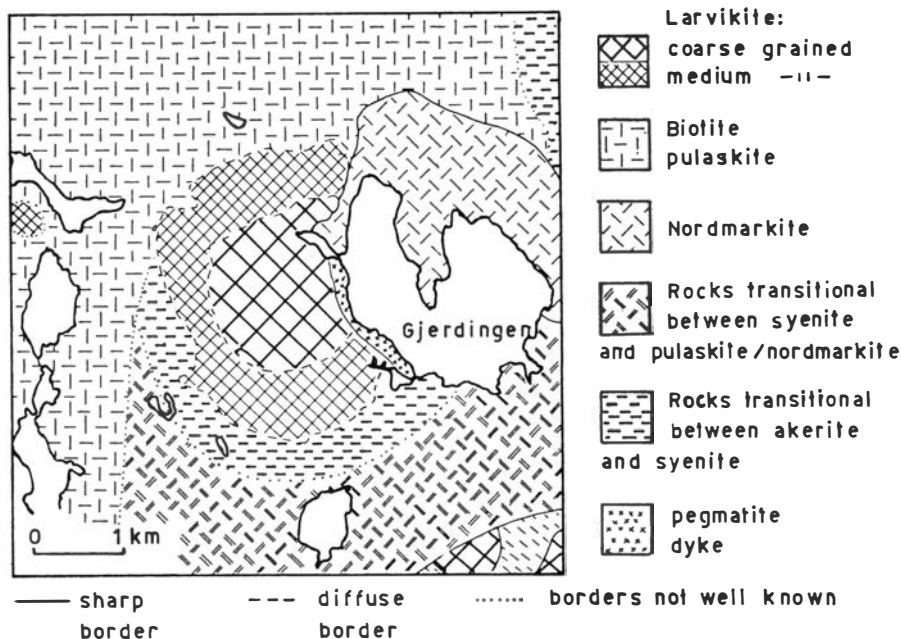


Fig. 1. Local geology, modified from Sæther (1962).

Field and laboratory studies

The vertical component of the magnetic field was measured along three profiles trending NE-SW and spaced 600 m apart (Fig. 2). Observations were made every 10 m within the complex and 25 m elsewhere. Detailed measurements were also done within a 40×40 m area with readings taken every 2 m.

For the investigation of the magnetic properties of the larvikite and the surrounding rocks a total of 76 hand samples were collected, of which 40 were oriented. From the samples 140 cores 19 mm in diameter and 19 mm in length were drilled out and measured. Directions and intensity of the natural remanent magnetization (NRM) were measured by an astatic magnetometer prior to and after alternating field demagnetization in 150 Oe. Absolute values of the susceptibility of 3 specimens were obtained from a calibrated susceptibility bridge at the University of Newcastle. The susceptibilities of the remaining cores were measured relative to these, using a similar instrument. Further measurements of Curie temperatures and saturation magnetization for 10 and 17 specimens respectively, were made with a Curie balance.

Rock magnetic properties

In the larvikite the ore appeared as inclusions in augite and biotite or on the border between these and the feldspar. Examination of 22 polished

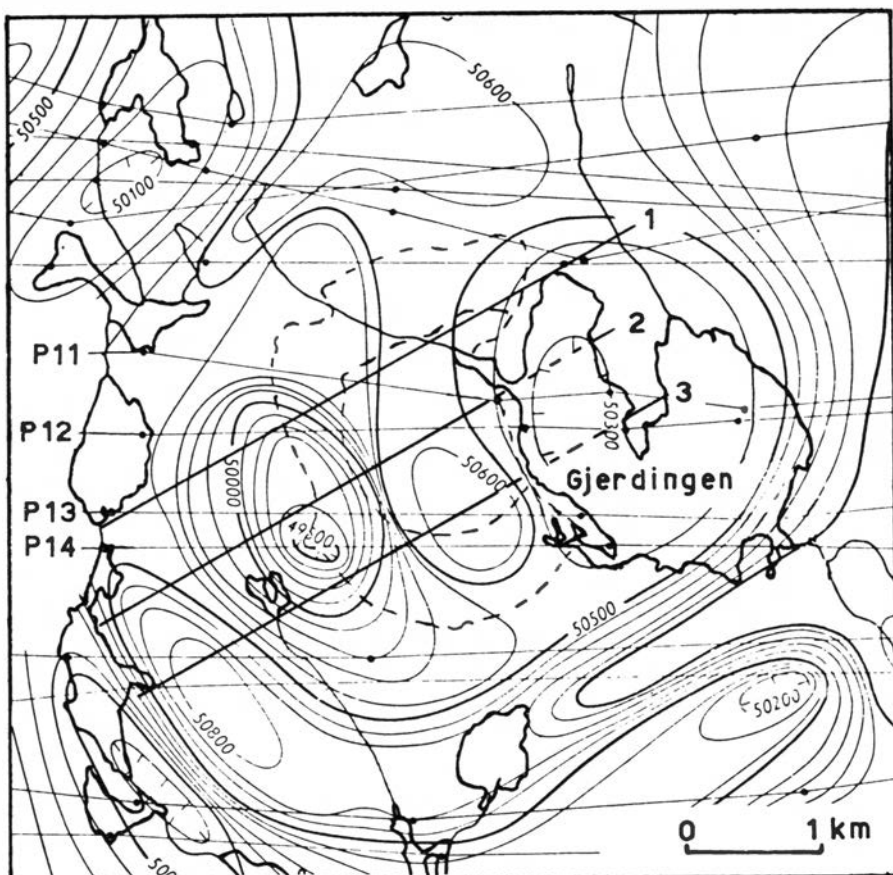


Fig. 2. Aeromagnetic map from N.G.U. sheet 1815 II. Aeromagnetic survey profiles are labelled P11–P14. 1, 2, and 3 are ground observation profiles.

sections showed that grains of an unmixed magnetite-ulvospinel solid solution were dominant. Ilmenite occurred as independent grains but was most common as exsolved lamellae in the magnetite-ulvospinel (Fig. 3). Light anisotropic zones along cracks and grain borders were possibly due to martitization.

The Curie temperatures measured for 10 specimens were found to be in the range 560–585 °C, which implies that the content of ulvospinel in the magnetite amounts to a maximum of 5 % (Nagata 1961).

High values of magnetic susceptibility seem to be related to medium grained larvikite (Fig. 4). However, the change in the susceptibility between the medium grained larvikite and the coarser grained central core takes place within the core rather than across the lithological borders. Between the larvikite and the surrounding nordmarkitic rocks there is a gradual change in the susceptibility except in the southeast.

A difference in magnetic grain size between the medium and coarse grained larvikite may have some influence on the susceptibility (Strangway



Fig. 3. Detail of magnetic grain. The exsolved magnetite-ulvospinel are cut by exsolved ilmenite laths. Light zones are probably due to martitization. Magnification $\times 2000$.

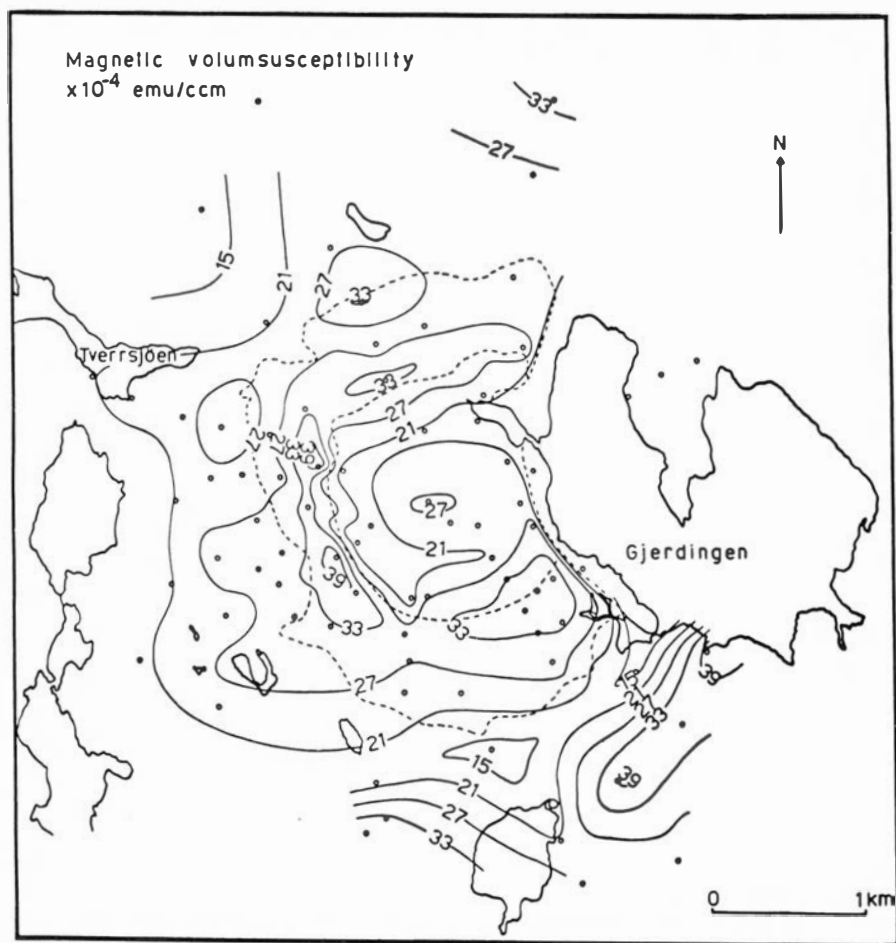


Fig. 4. Variation in susceptibility. Circles show sample localities.

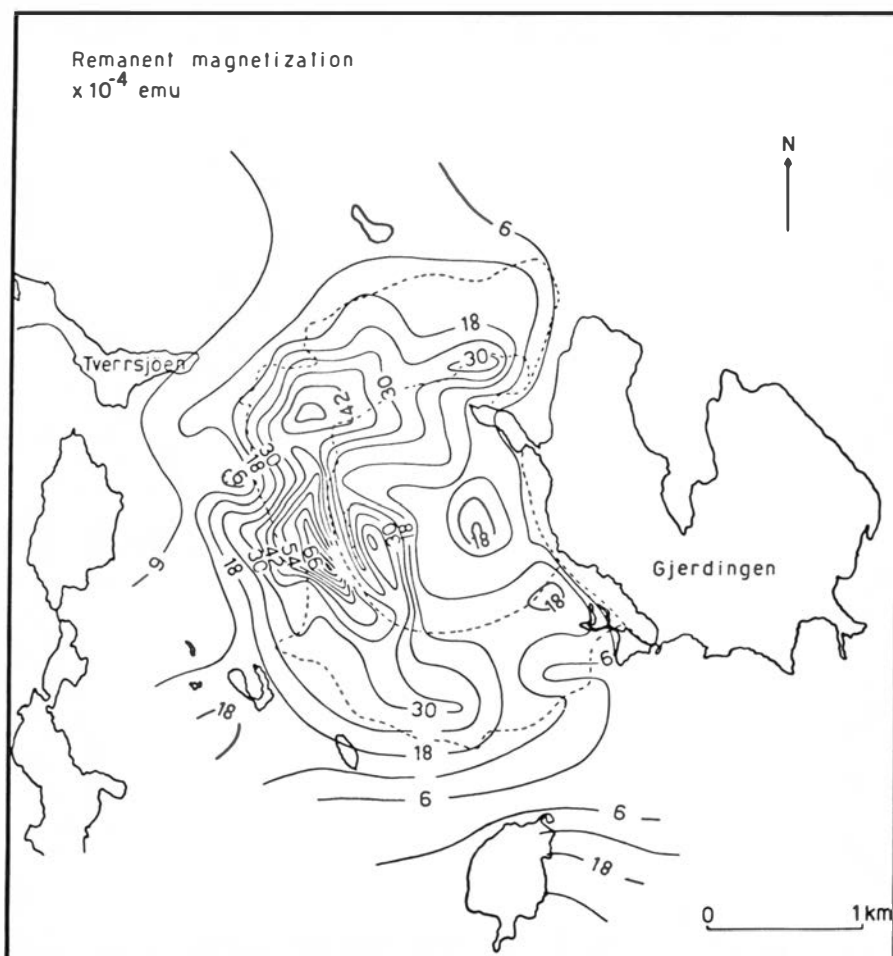


Fig. 5. Variation in intensity of natural remanent magnetization.

1967). However, correlation between magnetic saturation moment and susceptibility did not reveal any distinct effect.

The variations in the susceptibility in Fig. 4 thus reflect the distribution of magnetite within the larvikite complex.

The intensity of natural remanent magnetization shows a pattern similar to that of the susceptibility (Fig. 5). In the coarse grained core there is a high value of NRM to the southwest. This was, however, only based on one sample that did not have a correspondingly high susceptibility. There are considerable variations in the intensity of NRM within the medium grained larvikite with maximum values five times the lowest values.

The directions of NRM in the larvikite have a mean declination of 197° and a mean inclination of -45° after treatment in an alternating field of 150 Oe (Fig. 6).

The Koenigsberger ratio (Q) defined by the relation: $Q = \text{NRM}/\text{Induced}$

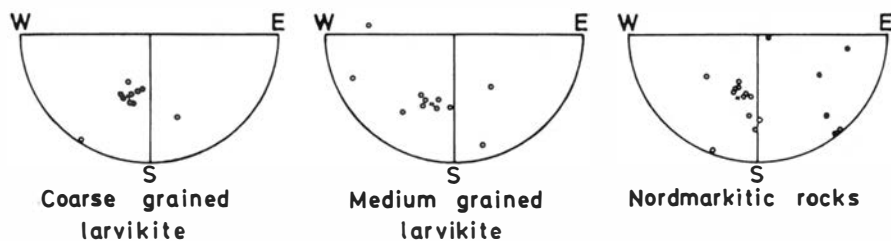


Fig. 6. Stereographic plot of directions of natural remanent magnetization after demagnetization in an alternating field of 150 Oe. Figures from left to right represent coarse grained larvikite, medium grained larvikite and the surrounding nordmarkitic rocks respectively. Open circles are north seeking magnetization in upper half sphere. (Mean value indicated by X.)

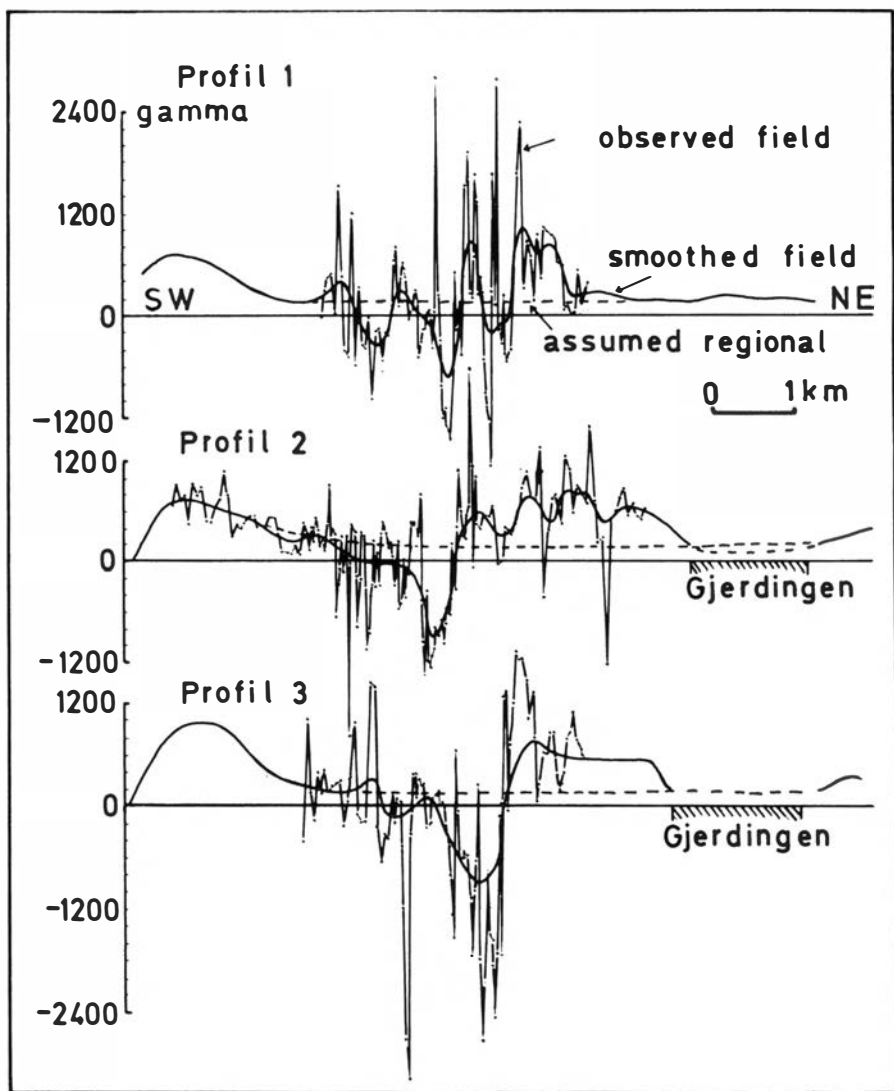


Fig. 7. Observed vertical component of the magnetic field. Zero line is arbitrarily chosen.

magnetization, is 2.0 or more within most of the medium grained larvikite thereby indicating that the magnetic anomaly of the larvikite complex is principally due to the natural remanent magnetization.

The magnetic field

The total intensity map compiled by N.G.U. is based on E-W trending aeromagnetic profiles measured at an altitude of 150 m (Fig. 2). Large field gradients occur in the area of strong remanent magnetization.

Ground measurements of the vertical field component show a very irregular feature (Fig. 7). The plotted values are corrected for geomagnetic time variations. As the magnetic terrain correction demands knowledge of the magnetic susceptibility and remanence in the vicinity of the observing point its evaluation is very time consuming. To establish its significance the terrain correction was calculated in 19 observation points. For the strongly magnetized areas, magnetization being greater than 10^{-3} emu, the correction is up to 700 gammas with the accuracy being 100 gamma. This fact calls for procedures which by reasonable assumptions reduces the amount of work, but still gives reliable results.

For the case that the geological body can be represented magnetically by an infinite line pole, point pole, an infinite line dipole or point dipole, Paul & Roy (1967) give a quantitative procedure for reducing the vertical field component to a horizontal plane. Unfortunately, discrimination between topographic influence and real anomalies are not obtained by this method.

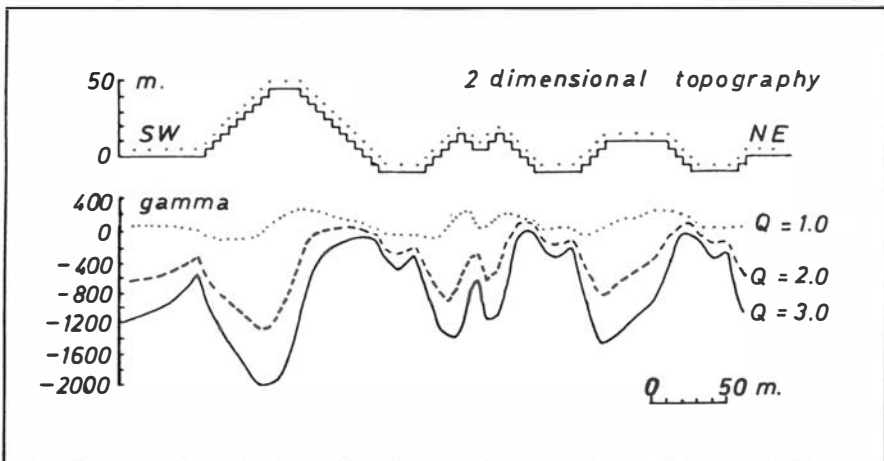


Fig. 8. Model of 2-dimensional topography. Dots above topography indicate points where the influence of topography is calculated. Curves show calculated variation in the vertical component of the magnetic field due to topography only for different values of Q and magnetization of the terrain.

$Q = 1.0$: Susceptibility: $k = 2.5 \cdot 10 \text{ emu/cm}^3$ and NRM = $1.25 \cdot 10 \text{ emu/cm}^3$.
 $Q = 2.0$: $k = 3.6 \cdot 10 \text{ emu/cm}^3$ and NRM = $3.6 \cdot 10 \text{ emu/cm}^3$.
 $Q = 3.0$: $k = 3.0 \cdot 10 \text{ emu/cm}^3$ and NRM = $4.5 \cdot 10 \text{ emu/cm}^3$.

An upward continuation of the magnetic data (Grant & West 1965, Oldham 1967) would attenuate the shorter wavelengths, but simultaneously decrease the resolution power.

For practical reasons, the topographic effect is removed from the magnetic data by filtering (Breen 1967). The filter can in its most simple form be defined as:

$$Z_m = \frac{1}{L} \int_{-L/2}^{L/2} Z \, dx$$

where Z_m is the mean value of the vertical field component in the interval L along a profile. Variations in Z of wavelengths $2L$ will be attenuated effectively leaving greater wavelengths relatively undisturbed.

In Fig. 8 the calculated effect of a 2 dimensional topography along a profile oriented parallel to the actual observed ones is shown. For the Permian igneous rocks of the Oslo region the NRM is nearly antiparallel to the induced magnetization giving a change in phase between topography and its corresponding magnetic signature depending on Q and the general intensity of magnetization in the area.

The calculated curves clearly show that the amplitude in the vertical field component may exceed 1000 gammas due to topography alone in areas where magnetization is greater than 10^{-3} emu/cm³. Also the interval L used in the filtering procedure must vary according to the corresponding wavelengths in topography. However, care must be taken when long wavelengths are involved.

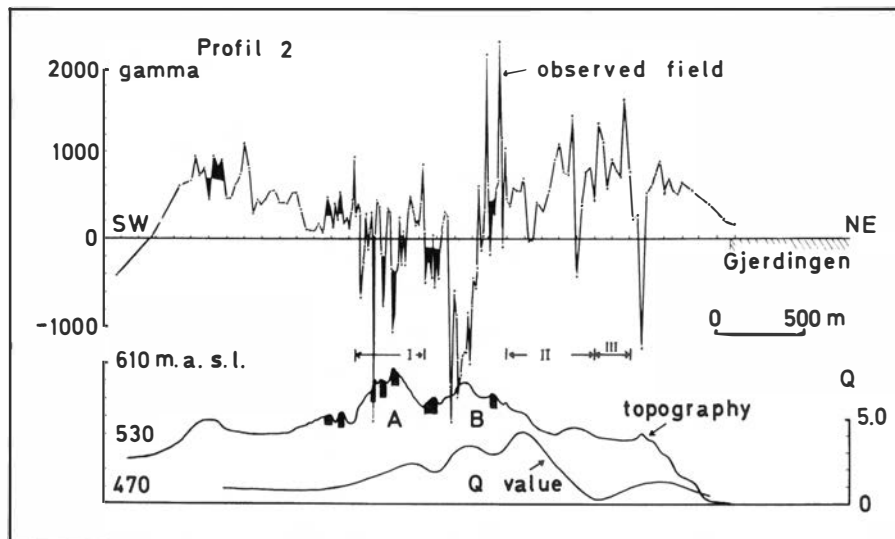


Fig. 9. Correlation of observed vertical component and topography based on the results from Fig. 8. Shaded parts of anomaly curve and topography indicate corresponding features.

The results of Fig. 8 have been used for a qualitative identification of the topographic effect on the measurements in the observed profile 2 (Fig. 9).

The shorter wavelengths of Z have a clear relation to topography. In the interval I a decrease in the amplitude of the long wavelength of Z can be expected if the topographic ridge A is taken into consideration. The same is the case for ridge B. Interval II represents a V-shaped valley where utilization of model calculations is impossible. In interval III when a peat bog is crossed it is interesting to notice variations as large as 600 gammas.

As far as the aeromagnetic measurements are concerned a topographic correction is considered to be of minor importance as long as the maximum difference in elevation within the area is less than the survey altitude.

Extreme values of the vertical field component Z are often observed in

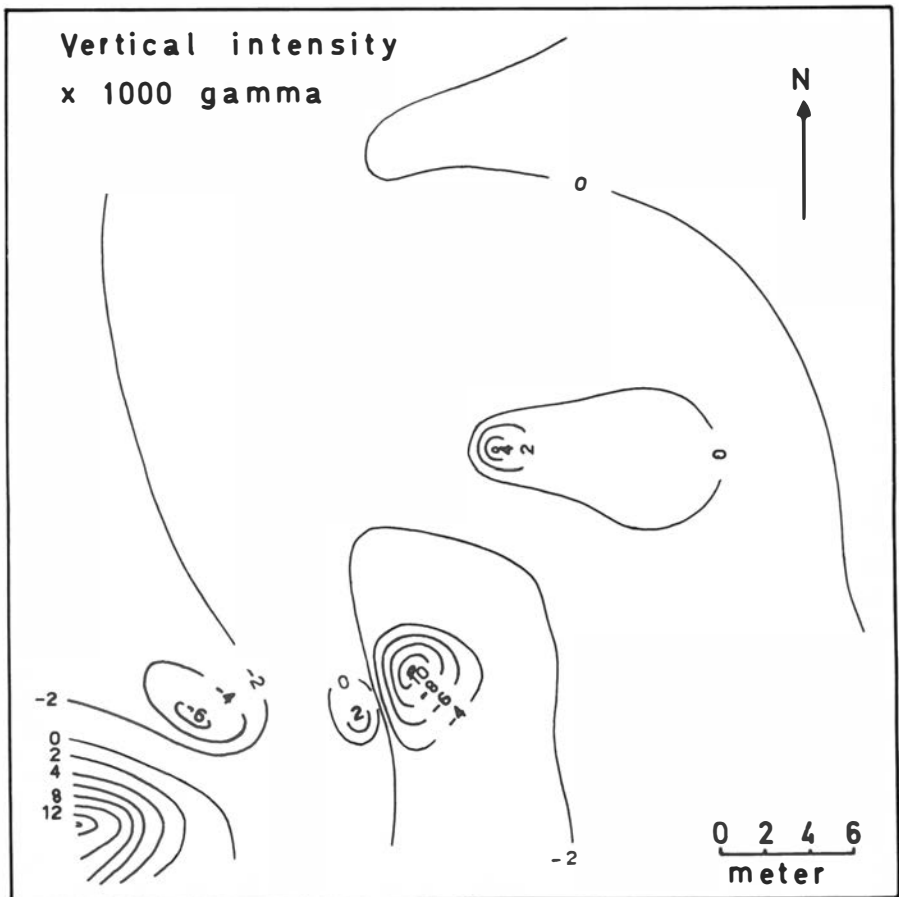


Fig. 10. Detailed survey of vertical component of the magnetic field within a rectangle 40×40 m. Note the mixed polarity and strictly local character of the anomalies. Zero level is arbitrarily chosen.

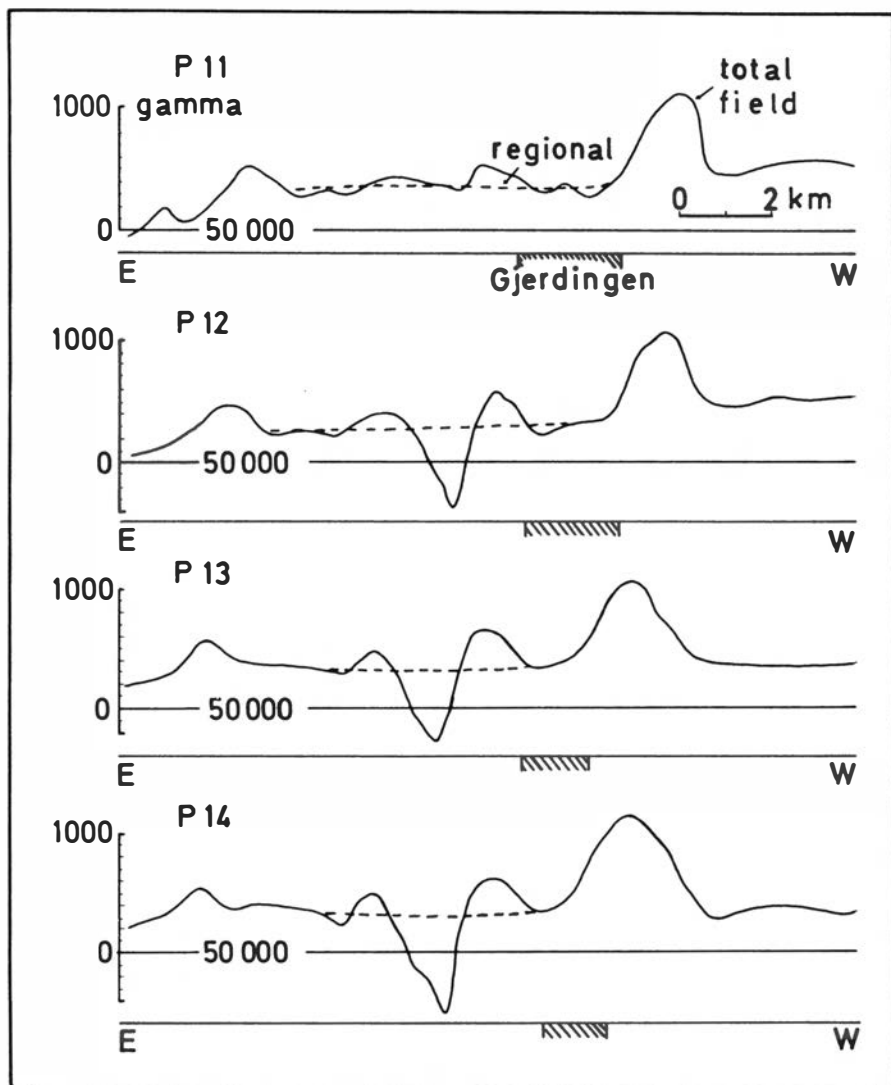


Fig. 11. Aeromagnetic profiles. N.G.U. survey October 1964. For location see Fig. 2.

ground measurements. A detailed survey of a 40×40 m area on a hillock is shown in Fig. 10. In two places the field exceeds 10,000 gammas. No inclusions of basic material were found in the area and any influence of chemical remanent magnetization acquired in the weathering process was not observed in the samples. The frequent occurrence of these extreme intensities on topographic highs suggests that they might be due to strokes of lightning which are known to cause anomalous remanent magnetization (Nagata 1961).

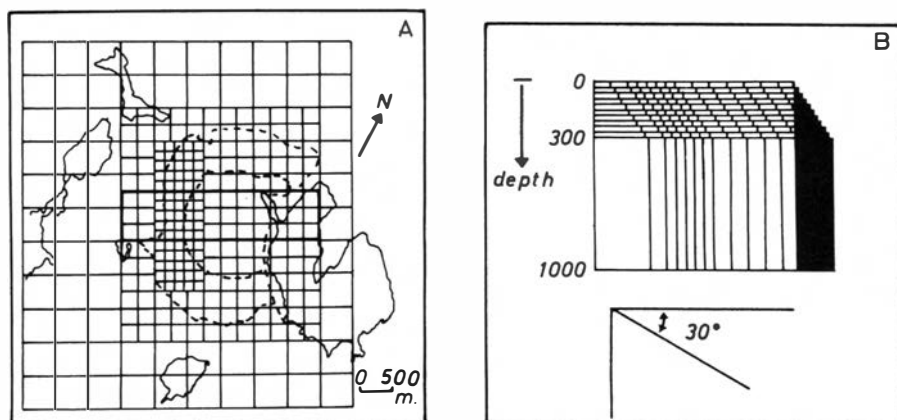


Fig. 12 A. Grid system used for model calculations. Refined model has a straight vertical downward extension of surface magnetic features except in central rectangle indicated by heavy lines.

B. Detail of area within rectangle of refined model. Prisms to the far right which are added have no influence due to low magnetization in NNE.

Magnetic anomalies

Separation of an anomaly from the observed magnetic field is impossible unless the distance between two neighboring magnetic bodies is greater than $2 \times$ the depth, defined as the distance from magnetometer to top of body (Bosum 1970). The larvikite complex, however, causes a well-defined anomaly in the magnetic field. A graphical method was utilized for the separation shown in Fig. 11.

Model calculations

A model is only valid for the distribution of magnetic minerals. It was necessary to assume that the contrast in intensity of magnetization at the surface was constant with depth. Other statements would be too speculative. The method outlined by Sharma (1966) for calculation of the magnetic field at an arbitrary point from a rectangular prism was used. Appropriate attention to the large lateral variations in magnetization was given by using a grid system (Fig. 12). Prisms with a cross section equal to the corresponding grid approximated the shape of the magnetic body.

Each prism had a susceptibility and NRM defined as the mean value within the grid. For an area 15×15 km surrounding the grid system a constant susceptibility of 2.0×10^{-3} emu/cm³ and a NRM of 6.0×10^{-4} emu/cm³ is used.

Tentative calculations indicated deviations from a straight downward extension of the surface magnetization features in the strongly magnetized area. The model also appeared to be relatively shallow.

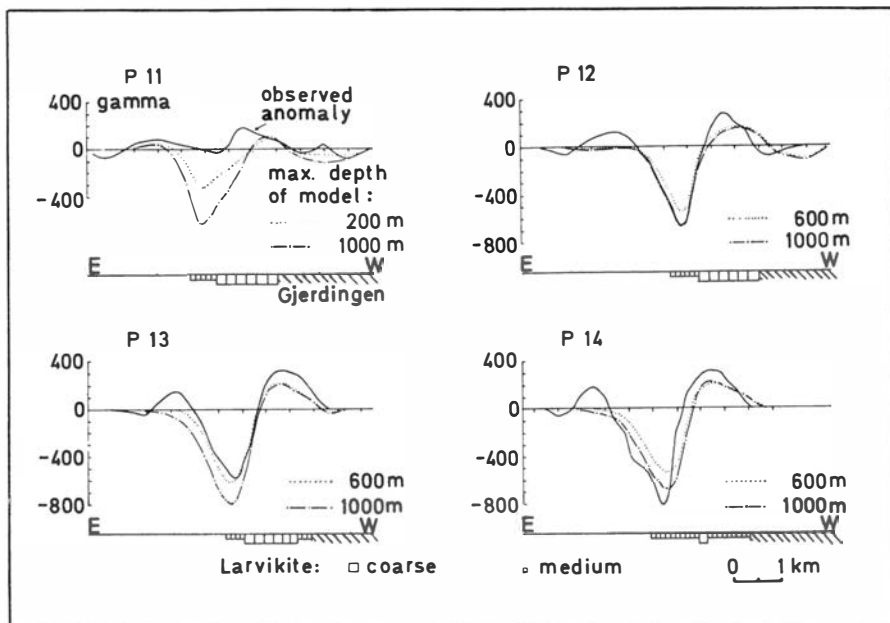


Fig. 13. Aeromagnetic profiles versus calculated values for models of different depth extent.

The refined model is shown in Fig. 12b. Within the black rectangle of Fig. 12a a dip of 30° NE of the upper 300 m was simulated by a computing procedure indicated in the vertical cross section Fig. 12b. All the prisms outside the black rectangle are vertical to a depth of 1000 m. Fig. 13 gives the calculated total intensity anomaly. The calculated curves fit the observed anomaly reasonably well in the profiles P12 and P14. P13, however, is better satisfied with a model which has a maximum depth of 600 m. The discrepancy between calculated and observed anomaly in P11 is striking. Even the disappearance of the magnetization contrast at 200 m below the surface gives an amplitude too large. A weaker magnetization will give a deeper model in better agreement with profile P12 which is parallel to P11 350 m further south.

There is a marked misfit between calculated and observed anomalies from ground measurements of the vertical field component in profiles 1, 2 and 3 (Fig. 14), not only in details, but of a more general character. This reveals weaknesses of the assumed model in the area, a fact which is also seen in P13 and P14. Interpretation from the ground measurements only would yield a rather detailed model. However, for a rock complex like larvikite where only the gross features are of primary interest aeromagnetic anomalies seem to be the most useful for interpretation. As the distance from the geological body equals the flight elevation at the minimum these measurements are less sensitive to local magnetic inhomogeneities.

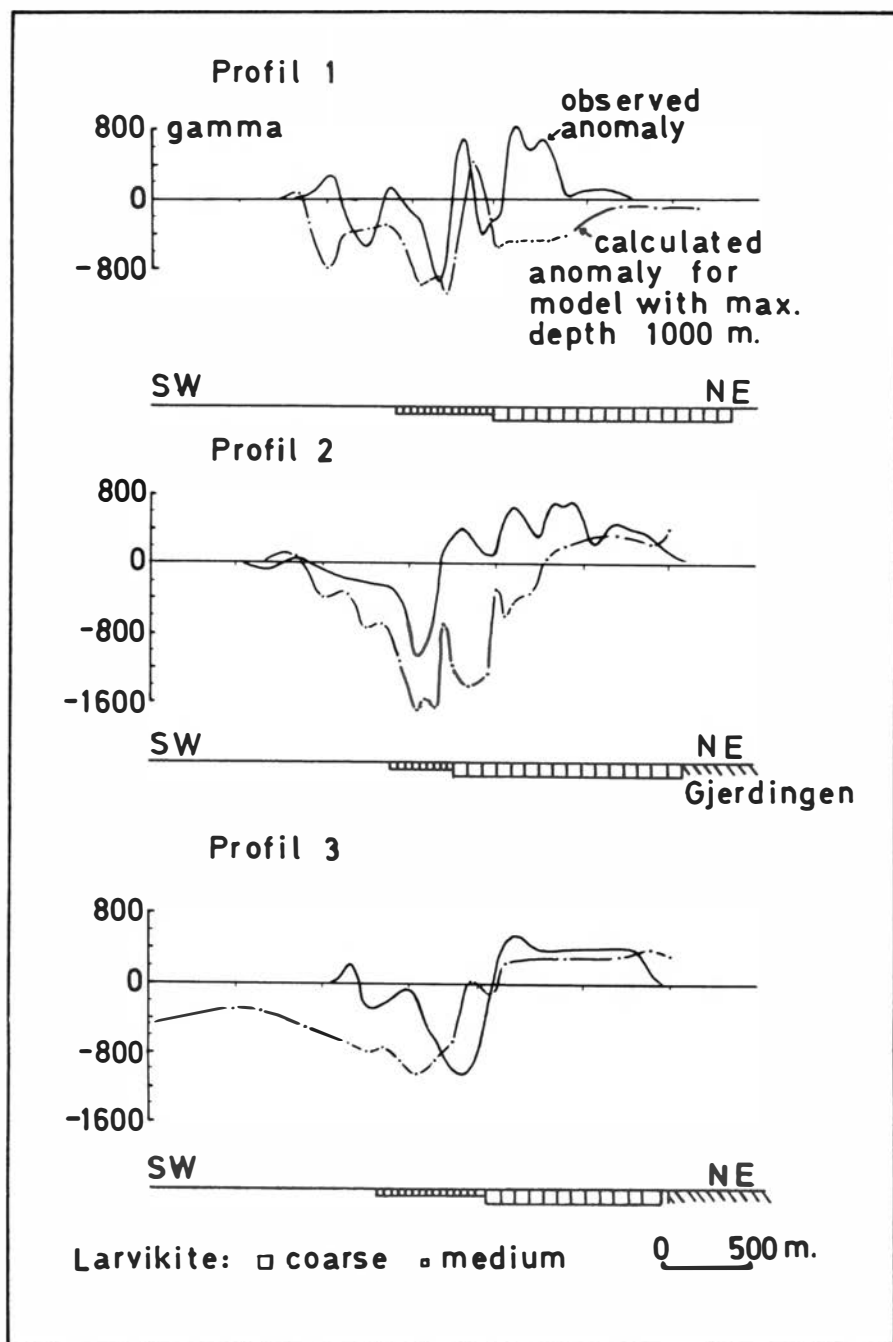


Fig. 14. Observed profiles of vertical intensity versus calculated values for a model of maximum depth of 1000 m.

Discussion

The calculations gave a magnetic model which has its lower boundary at a depth of 1000 m based on the assumption that the observed magnetization at the surface does not change with depth. Variations, however, are most likely to occur. As seen in Figs. 4 and 5, the distance between neighboring maxima in the magnetization at the surface is greater than 700 m. It seems reasonable that a similar variation in the vertical might be the case, which would give a slight correction to the depth estimate.

Geologically the magnetic model satisfies several alternatives:

The magnetite content in the larvikite diminishes below a depth of 1000 m which will actually give an infinite vertical extension of the complex.

The cross section of the larvikite complex decreases drastically below the 1000 m level and later widens giving an hourglass-shaped structure.

A plug of larvikite 'floating' in younger eruptives.

Widening of the larvikite complex below 1000 m will remove the contrast in magnetization.

The first two alternatives are possible solutions which cannot be rejected by this investigation alone. They are, however, not compatible with the results of Grønlie (1971).

An interpretation where the larvikite is considered an isolated 'plug' or laccolith is fully justified from a geophysical viewpoint alone.

However, widening of the larvikite complex below a depth of 1000 m not only meets the geophysical conditions, but supplies a simple geological explanation also. The magnetization – as well as the density contrast of the larvikite relative to the surrounding rocks seen at the surface will then disappear. A connection at this depth with the larvikite plug 3 km to the west at the lake Tverrsjøen, and the larvikite complex at the lake Katnosa 3–4 km to the south and southwest then seems possible. Two separate intrusions of larvikite have most likely occurred to give the observed field relations of the larvikite complex.

The existence of a relatively small amount of ilmenite laths together with ulvospinel indicates a larvikite magma with low oxygen fugacity (Buddington & Lindsley 1964, Carmichael & Nicholls 1967).

Whether or not a subsidence of the central core has taken place during the intrusion of the medium grained larvikite and/or there has been a subsidence of the entire larvikite massif at the time of the invasion of the younger syenites cannot be settled from the existing evidence.

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