NGU Report 99.027

# Geophysical investigations: Krokskogen, Oppkuven and Gran, 1998

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# REPORT



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Summary:

During June, 1997, a helicopter geophysical survey was carried out over parts of Krokskogen, Nordmarka, and northward into Hadeland. The sources of many prominent anomalies from the helicopter survey were not immediately evident. Ground visual and geophysical follow-up was necessary in order to identify them. The methods employed were magnetic profiling and magnetic susceptibility measurements, DC resistivity sounding, borehole resistivity logging, VLF profiling, and radiometric profiling. The DC resistivity soundings confirmed the accuracy of resistivities computed from the helicopter EM measurements. The borehole resistivity log provided resistivities for several important lava flow units in the Krokskogen area. Magnetic profiles confirmed a major remanently magnetized dike or series of dikes in Hadeland, and also confirmed minor magnetic anomalies, also most probably dikes. Radiometric measurements confirm that radiometric uranium counts fall off abruptly from west to east near Brandbukampen.

DC resistivity surveys were performed at or near the following locations (WGS84 coordinates): 574250E, 6652300N; 579200E, 6662350N; 574350E, 6654100N (borehole). Magnetic profiles were taken at: 579425E, 6688300N; 584200E, 6686700N; 585600E, 6702050N; 587200E, 6697600N; 583600E, 6673000N; 582800E, 6673000N. VLF and magnetic profiles were taken at 580000E, 6661000N. A radiometric profile was collected at 582800E, 6702700N.



| Keywords: Geofysikk | Radiometri | Magnetometri |
|---|---|---|
| Elektromagnetisk måling | Tolkning | Fagrapport |

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# 1 INTRODUCTION

In June, 1997, a helicopter geophysical survey was carried out over parts of Nordmarka, in the vicinites of Krokskogen, Gran and Oppkuven. The survey area lies between longitudes 10°17′ E and 10°44′ E, and latitudes 59°56′ N and 60°30′ N. The survey area was divided into two zones, a southern zone covering approximately the same area as NGU's Oppkuven map sheet, and a northern zone covering a portion of the Gran mapsheet (Fig. 1). In the south, radiometric, electromagnetic, magnetic, and very low frequency electromagnetic (VLF) data were collected. In the north, only magnetic, radiometric, and VLF data were collected. The primary objective of the helicopter survey was to provide geophysical information in order to enhance geological mapping in the area.

After processing the data and producing geophysical maps of the surveyed areas (Beard, 1998), several anomalies were noted which were not immediately explained by known geological structures. Some of the anomalies include: a major NNE-SSW trending magnetic lineation in the Gran area (labeled D in Figure 1) did not appear on geological maps, smaller magnetic anomalies (E,G,H) in the Gran area, an elliptical magnetic anomaly in Krokskogen (F), a VLF anomaly in Krokskogen (K), and VLF and magnetic anomalies in Oppkuven (I,J). Field follow-up was required to confirm and determine the source of these anomalies. In addition, DC electrical soundings were performed in two selected areas (A,B) in order to better assess the performance of the airborne electromagnetic equipment. Also, a borehole near Sørsætra in Krokskogen was electrically logged (C) to better characterize the electrical properties of some of major geological units in that area. Radiometric measurements were taken near Brandbukampen to better assess the contact between the alum shales and the gneissic units to the east of Brandbukampen (L). These twelve locations are shown in Figure 1.

# 2 METHODS AND EQUIPMENT USED

Direct current (DC) electrical resistivity sounding data were collected at two locations using DC resistivity equipment made at NGU. The Schlumberger array was used to collect these data. A borehole at Sørsætra was logged using DC resistivity equipment made at NGU. A normal logging array was used. Inside the hole a potential and a current electrode were separated by 2.5m. Outside the hole a second pair of potential and current electrodes were each placed about 300m from the hole in opposite directions from each other. Noise levels were low and repeatability good at each of the electrical measurement sites.

Magnetic profiles were collected at 14 different locations. Seven of these were collected across the Gran magnetic lineament (section 3.3 below). A small hand-held total field magnetometer was used. It has a precision of about 10nT. Repeatability was good and noise levels were usually within the precision of the instrument.


Figure 1. Location map for ground geophysical follow-up of helicopter geophysical data. Letters A-L indicate locations where follow-up soundings or profiles referred to in this report were performed. Scale: 1 cm = 2.25 km.

Electromagnetic conductivity data were collected as an auxiliary at some sites to help in interpretation. The instrument used was the 9800Hz Geonics EM-31. Typically, the depth of investigation of the EM-31 is 5-10 meters, but may be more over highly resistive rocks (more than 5000 ohm-m).

Very low frequency EM data (VLF) were collected using a Geonics EM-16.

Radiometric data were collected with a portable Exploranium spectrometer. Channels recorded were total counts, potassium, uranium, and thorium.

Magnetic susceptibility data were collected using a hand-held KT-5 susceptibility meter. The meter is accurate to 0.00001 SI units.

## 3 RESULTS OF GROUND SURVEYS

The results of the ground follow up surveys are grouped below according to the particular anomaly or anomalies examined. Locations are referred to using the WGS84 datum.

### 3.1 DC resistivity soundings—Løvlia and Auretjern

Direct current resistivity soundings were conducted in two locations, both over rhomb porphyry (RP) units. One location, near Auretjern in Krokskogen (location A in Figure 1), was chosen as representative of conductive RP units as judged from the airborne electromagnetic (EM) measurements, about 4000 ohm-m using the 4-kHz horizontal coplanar coils. The second area, near Løvlia in Krokskogen (location B in Figure 1), was chosen as representative of resistive RPs, measured at 30000 ohm-m with the helicopter EM system's 4-kHz horizontal coplanar coils. Inversion of these data produced the geoelectric models shown in Figures 2 and 3. Inversion of the Løvlia data yields resistivities an order of magnitude higher than at Auretjern. These models also agree with resistivity estimates from the airborne data in order of magnitude, and indicate the resistivity estimations from the airborne EM data are trustworthy in at least a relative sense.

### 3.2 DC resistivity borehole logging—Sørsætra

Two geotechnical drill holes are located in the Krokskogen area—one near Auretjern and the other near Sørsætra (location C in Figure 1). We attempted to make DC resistivity logs of both holes. The Auretjern borehole was plugged by debris only 2-3 meters from ground surface, and so it was impossible to obtain a log from this hole. The artesian Sørsætra hole was clear through its entire length, and a resistivity log was successfully obtained from this hole. The Sørsætra hole is inclined 45° to the east and penetrated several rhomb porphyry layers, two dikes, a basalt layer, and other minor units (Løset and Rui, 1998). The logging

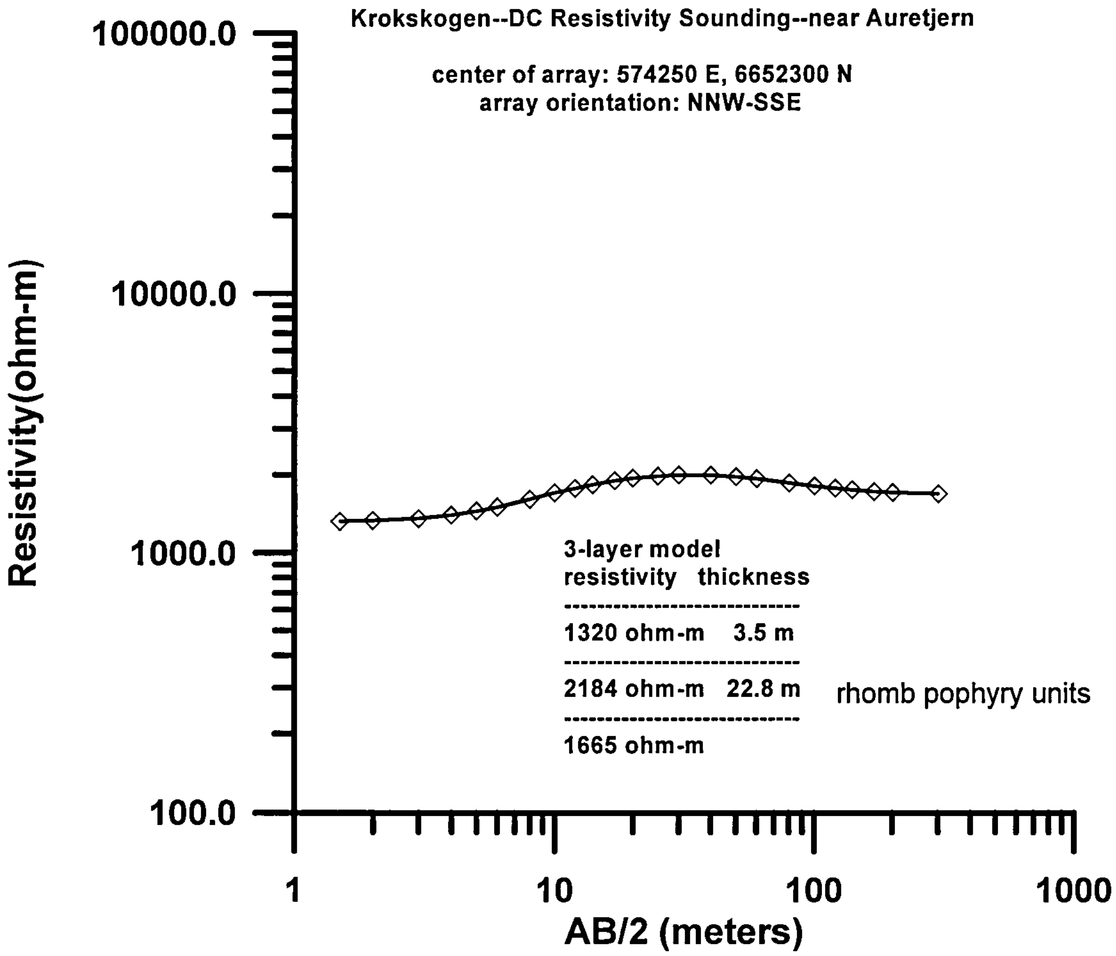


Fig. 2. DC resistivity sounding in an area of Krokskogen judged electrically conductive from helicopter EM survey data.

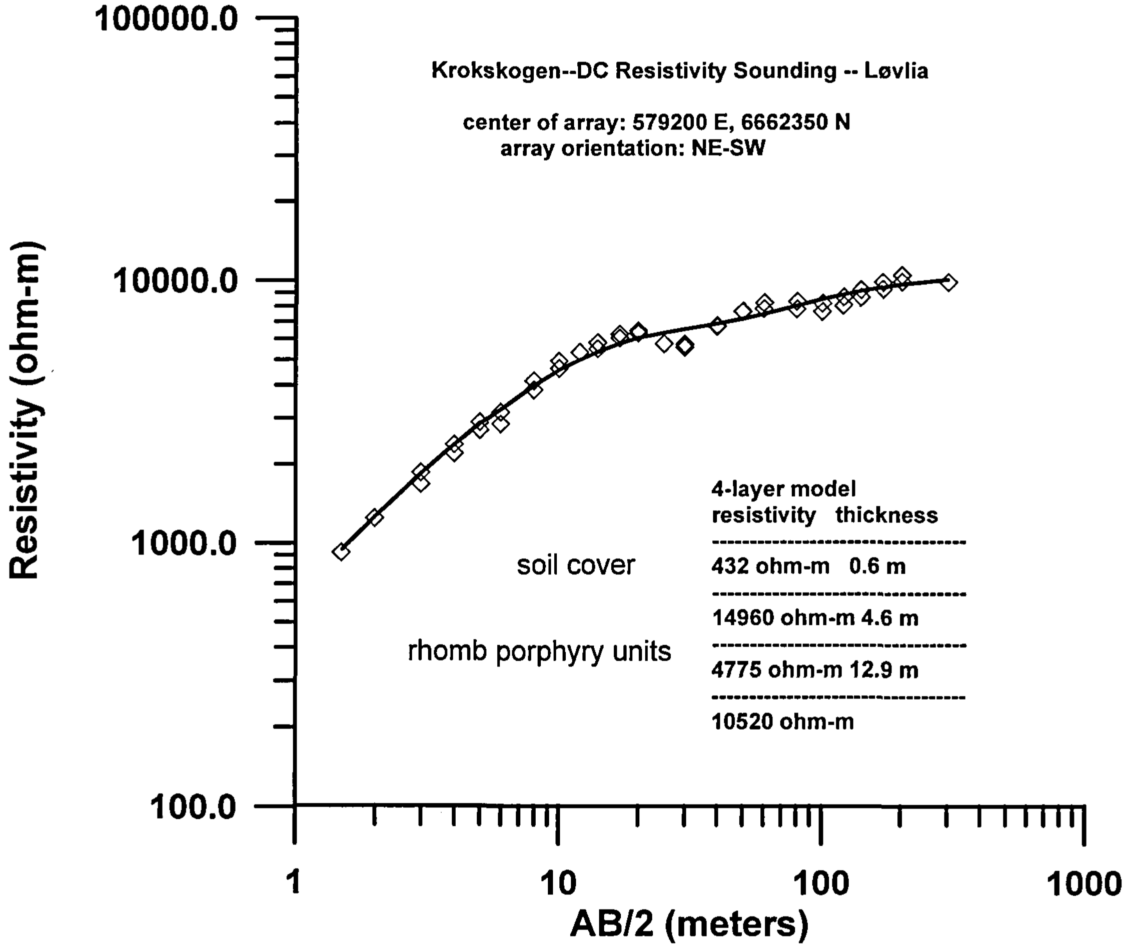


Fig. 3. DC resistivity sounding over area in Krokskogen judged electrically resistive from helicopter EM survey data.

configuration was two in-hole electrodes—one current electrode and one potential electrode—separated by 2.5 m. The other two electrodes were placed on the surface of the earth, each about 300-m distant from the hole and separated from each other by about 500 m. Measurements were collected every 2.5 m in the hole. The results of the two-electrode log are shown in Figure 4. Two zones show resistivities as low as 100 ohm-m. One of these zones, at about 250 m into the hole (about 180 m vertical depth) is described in the driller's log as a fracture zone. The other low resistivity zone, at about 140 m into the hole (about 100 meters vertical depth) is not noted in the drill log, but is probably also a zone of high water content. This zone lies immediately above a porphyritic dike. The rhomb porphyry unit labeled RP5 had resistivities between 200 and 800 ohm-m, whereas the overlying RP8 unit had substantially higher resistivities—700 to 10000 ohm-m.

### 3.3 Gran magnetic lineament

One of the most interesting and distinctive anomalies appearing in the aerial magnetic data is a NNE-SSW trending lineament in the Gran area. The position of the lineament is shown in Figure 1, marked D. The anomaly from helicopter data appears as a linear magnetic low zone with anomaly magnitudes of 10-40 nT along its length. The northern part of the lineament appears to coincide with mapped dikes, but no dike has been mapped in the vicinity of the southern two-thirds of the lineament. Several magnetic profiles were run perpendicular to the anomaly at various locations. Figure 5 shows the 1500-nT negative anomaly from a ground magnetic profile along the road between Stadum and Vien. The anomaly occurs at a roadcut in which dike rock is exposed, located at about 579425E, 6688300N. Susceptibility measurements at the roadcut show wide variation, but most are moderate to high, the highest being 0.04 SI.

The dashed line in Figure 5 represents the computed anomaly a dike model 5-m wide having susceptibility $\chi$=0.015 SI and possessing a strong remanent magnetization (Koenigsberger ratio Q=10) inclined opposite the earth's ambient field direction (ambient field inclination = 60.5°). This remanence direction would be roughly consistent with other Permian age dikes found in this area (Everdingen, 1960). Figure 6 shows small-scale EM-31 and magnetic profiles over the anomaly at the same location. A resistivity high correlates with the magnetic low across the structure, consistent with the hypothesis of a remanently magnetized dike. The anomaly width and shape was consistent at several locations (see Figures A1-A6 in the Appendix). Although exposures are rare along the anomaly's length, a gentle topographic high appears to indicate a dike-like structure. This structure is a major feature and warrants careful geological investigation.

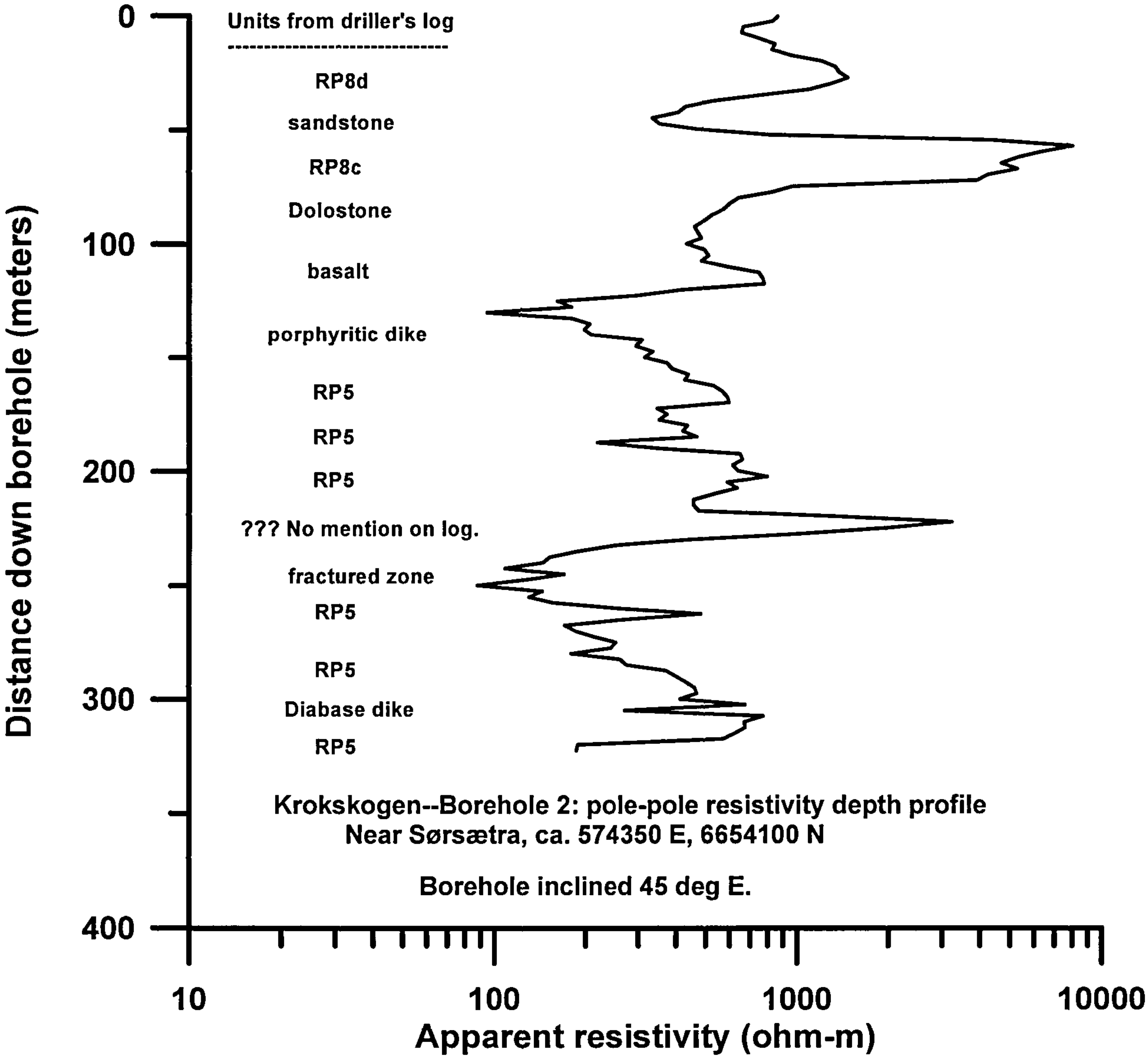


Fig. 4. Borehole dc resistivity log from inclined drillhole near Sørsætra.

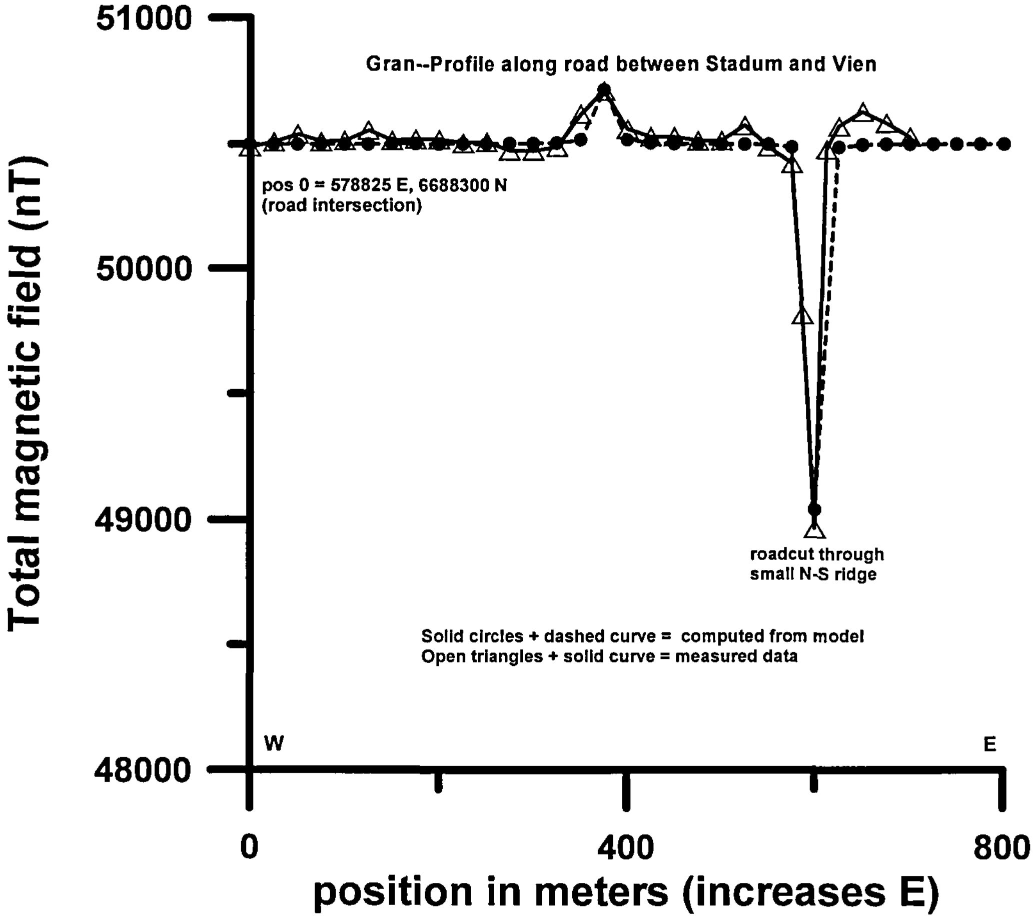


Fig. 5. Magnetic anomaly over Gran magnetic lineament.
Solid line = measured total magnetic field.
Dashed line = anomaly computed using remanently magnetized dike.

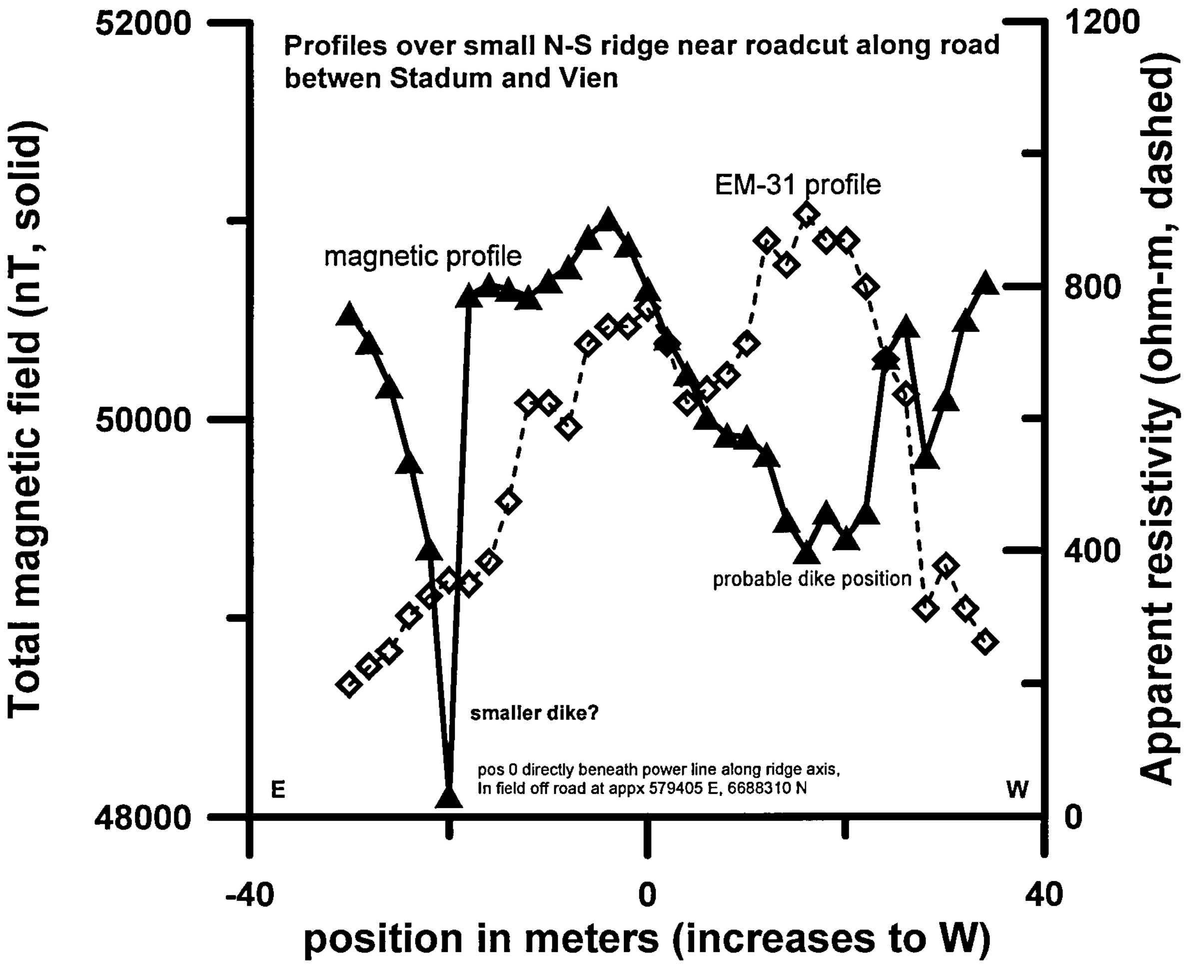


Fig. 6. EM-31 and magnetic profiles over exposed portion of Gran magnetic lineament.

### 3.4 Magnetic anomaly—Skirstad

A minor positive magnetic lineation denoted E in Figure 1, trends NNE-SSW through Skirstad, about 1 km N from Vestby. The location of the strongest part of the anomaly is at approximately 584200N, 6686500E. The anomaly is in the middle of a cultivated field and shows no surface expression. However, the field has not been plowed along the strike of the anomaly, possibly because the underlying rock is very shallow. The sharp peak of the anomaly, shown in Figure 7, indicates a shallow source, probably no more than 10 m below the ground surface. The strike direction of the lineation parallels the Gran magnetic lineament described above. The source of the anomaly is most likely a normally magnetized dike.

### 3.5 Magnetic anomaly—Ristjern

The aeromagnetic anomaly near Ristjern takes the form of an oval-shaped magnetic low (F in Figure 1). We ran a single magnetic profile over the anomaly site to try to confirm the anomaly and determine its source. An east-west profile, shown in Figure 8, ran from 6653800N, 578500E to 6653800N, 579100E across a topographic high about 300 m north from Ristjern. The west end of the profile shows two magnetic low zones separated by a narrow high. Vegetation was dense in the area and topography extreme. There was no obvious source for the anomaly, but the rocks in the vicinity of the westernmost low were breccias. Fractured or brecciated rock often shows a magnetic low as fluid intrusion causes magnetite to oxidize to hematite (Henkel and Guzman, 1977).

### 3.6 Magnetic anomalies—Jølsen and Sørun

Two minor linear magnetic anomalies were examined, one striking NW-SE about 1 km NE from Jølsen (G in Figure 1), which in turn is about 3.5 km from Brandbu. Our profile ran along a logging road and crossed the anomaly at about 6700050N, 585650E. Figure 9 shows the pronounced peak of the anomaly. The form of the anomaly indicates a shallow source, probably a magnetic dike a few meters wide and within a few meters of the surface. There was no geological or topographic expression of the magnetic source rock. Magnetic susceptibility measurements on rocks at the surface showed mostly very low susceptibilities, but a few high susceptibility samples were taken (0.05, 0.06 SI). The magnetic rock samples appeared to be the same rock type (schist) as the non-magnetic samples. A VLF survey over the magnetic anomaly showed no VLF anomaly, making a fault or fracture filled with magnetic material unlikely as the source. The source is probably a buried dike. Along the 2000-m profile several other smaller peaks appeared which could also be related to dike-like intrusions. Access to this anomaly was limited because a locked gate prevented us form getting closer to the anomaly than about 1.5 km. We therefore did not collect EM or other data.

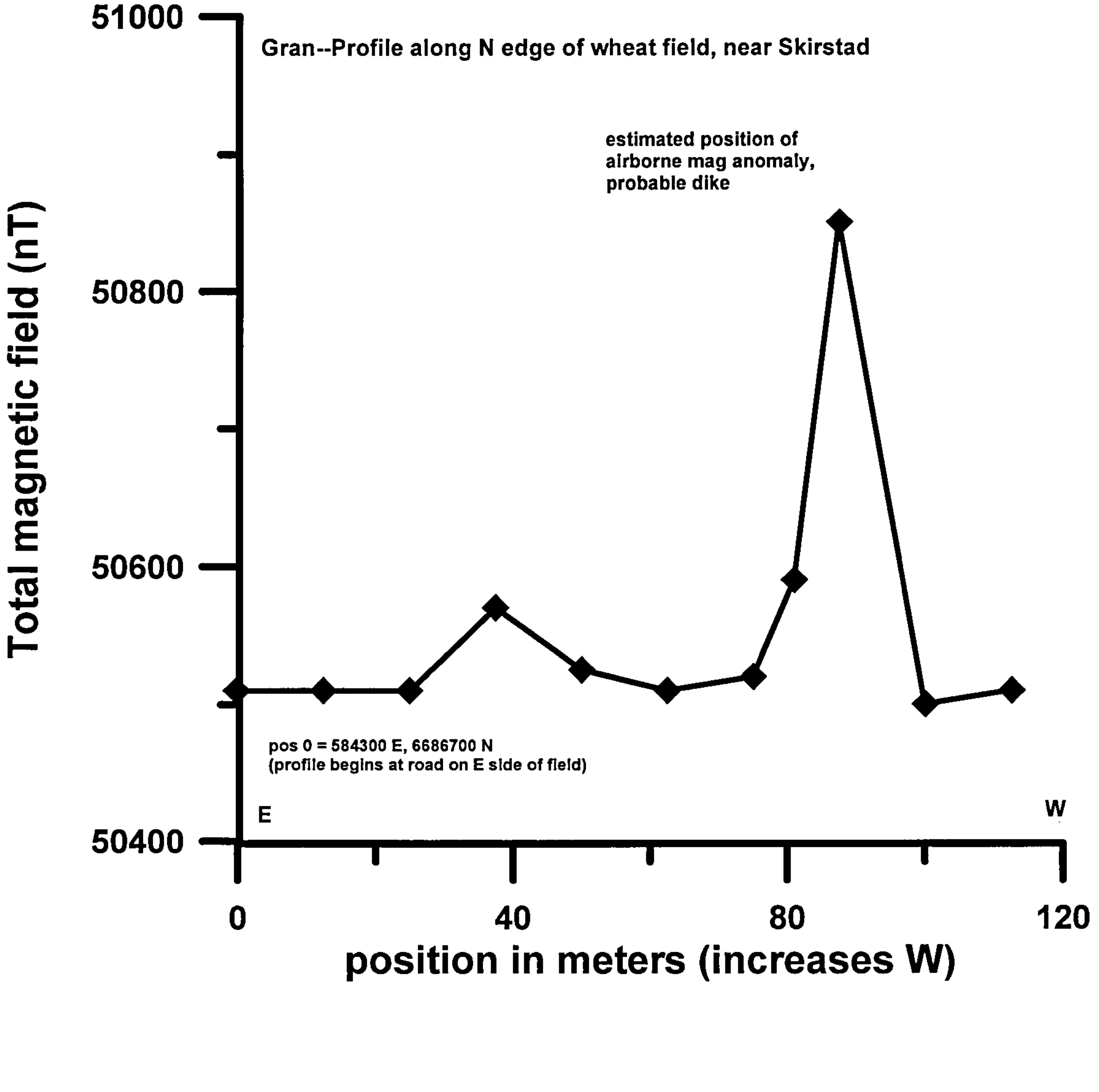


Fig. 7. Magnetic profile over magnetic anomaly from helicopter survey data.

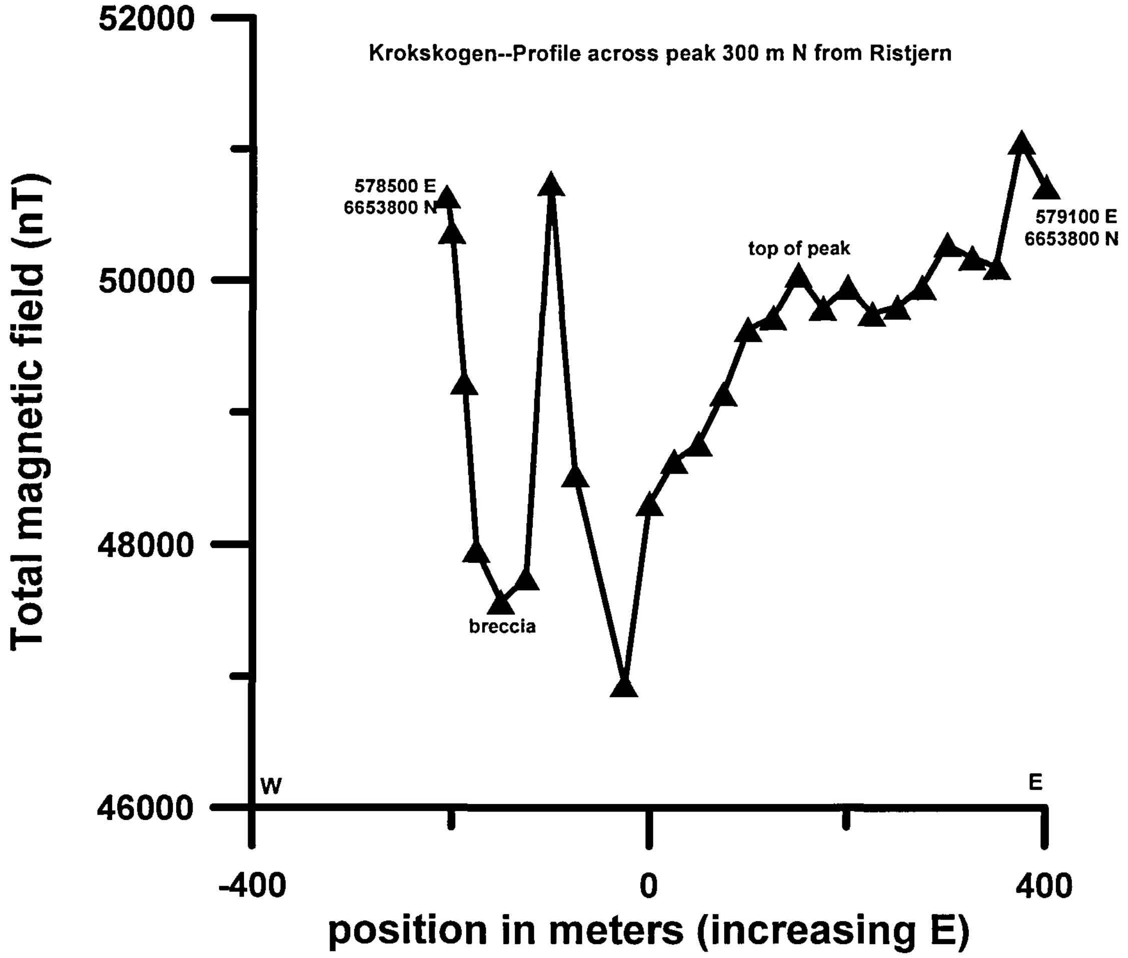


Fig. 8. Magnetic profile over aerial magnetic low near Ristjern.

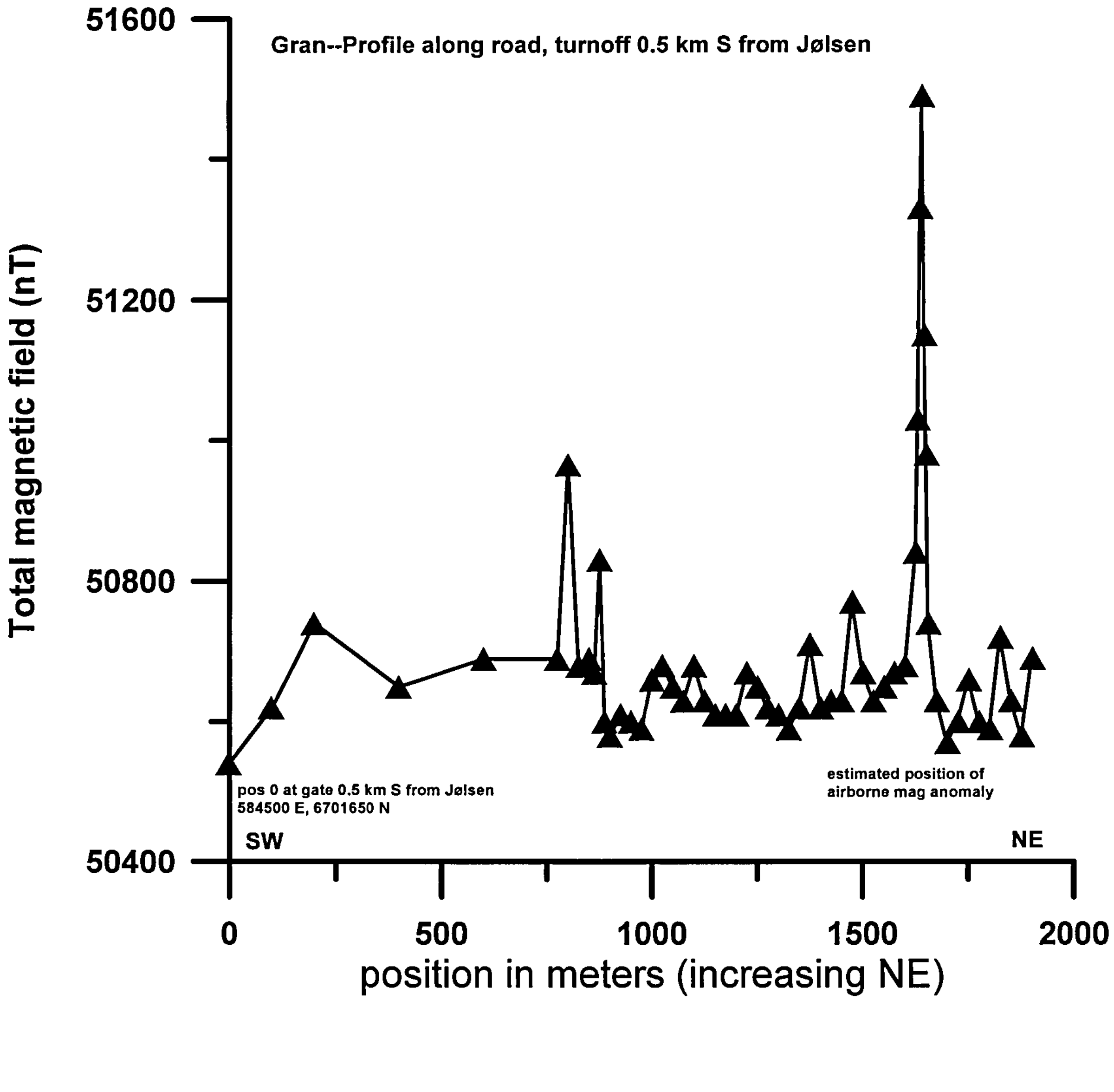


Fig. 9. Magnetic profile over magnetic anomaly identified in helicopter survey data.

The second anomaly, denoted H in Figure 1, is located about 0.75 km south from Sørum, which is itself 2 km north from Jaren. The aeromagnetic lineation trends NE-SW. Our ground profiles—magnetics and EM-31—crossed the anomaly at about 6697550N, 587150E. The magnetic profile shows a pronounced peak at the same location as the EM-31 shows a resistivity high (Figure 10). This suggests a shallow dike, as the EM-31 senses no deeper than 5-10 m, even in fairly resistive rock. No topographic or geological evidence suggested a source for the anomaly. Magnetic susceptibilities of the schistose rocks near the anomaly were uniformly low—near zero—with a single highly magnetic exception ($\chi$=0.035 SI).

### 3.7 Magnetic profiles—Pershusfjellet and Sinderbrenna

Two north-south trending magnetic anomalous highs lie on either side of Sinderdalen, about 7 km southeast from Jevnaker. The anomaly east of Sinderdalen, denoted I in Figure 1, appears to coincide with Pershusfjellet. A east-to-west magnetic profile from Skarpvatnet, east from Pershusfjellet shows a magnetic field decrease as Pershusfjellet is approached, opposite the airborne anomaly trend (Figure 11). The decrease could result from increasingly thick talus as the steep face of the peak is approached. Air pockets in the talus could cause a decreasing anomaly. Results from this profile are therefore inconclusive.

The north-south anomaly to the west from Sinderdalen (J in Figure 1) does not correlate with any particular topographic feature. However, an east-to-west ground magnetic profile shows a sharp increase in magnetic field in the same location as the helicopter survey (Figure 12). The syenitic rocks in this location were noticeably redder in color than other rocks along the profile. If the red color is related to increased iron content in the rock, that could explain the increased magnetic field. Magnetic susceptibility measurements of the red syenites show susceptibilities of about 0.018 SI, a fairly high value for syenites. In addition, syenites outside the red zone had susceptibilities nearly as high. The source of the anomaly remains unclear. Two hand samples (Ole Lutro, NGU, #98240, 98241) collected inside the area of the magnetic high appear to be rather ordinary specimens of syenite.

### 3.8 VLF and magnetic profiles—south from Løvlia

Helicopter data from Krokskogen showed several VLF anomalies trending approximately SW-NE. The source of these anomalies was unclear. We therefore conducted ground VLF and magnetic profiles across one of the anomalies south from Løvlia (K in Figure 1) to confirm the aerial VLF anomaly and to identify it's source, if possible. The curve produced by the ground VLF survey, shown in Figure 13, does not closely match the aerial data. However, this is likely a result of different parameters being measured by the different systems. The ground and airborne data do agree in that both show a high gradient 'crossover' in the same location. VLF crossovers occur when a receiver passes over a narrow conductive

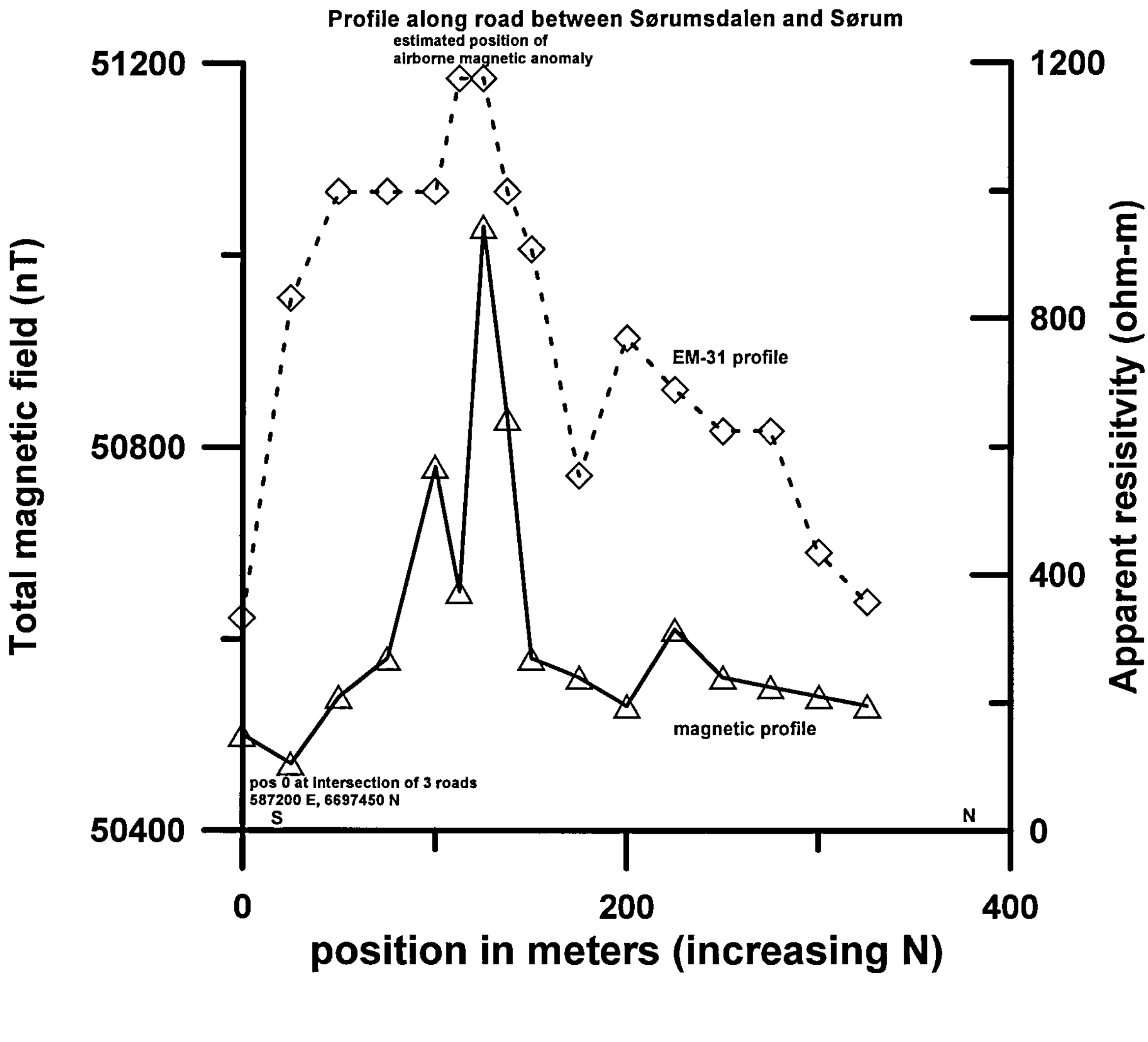


Fig. 10. EM-31 and magnetic profile over magneic anomaly identified in helicopter survey data.

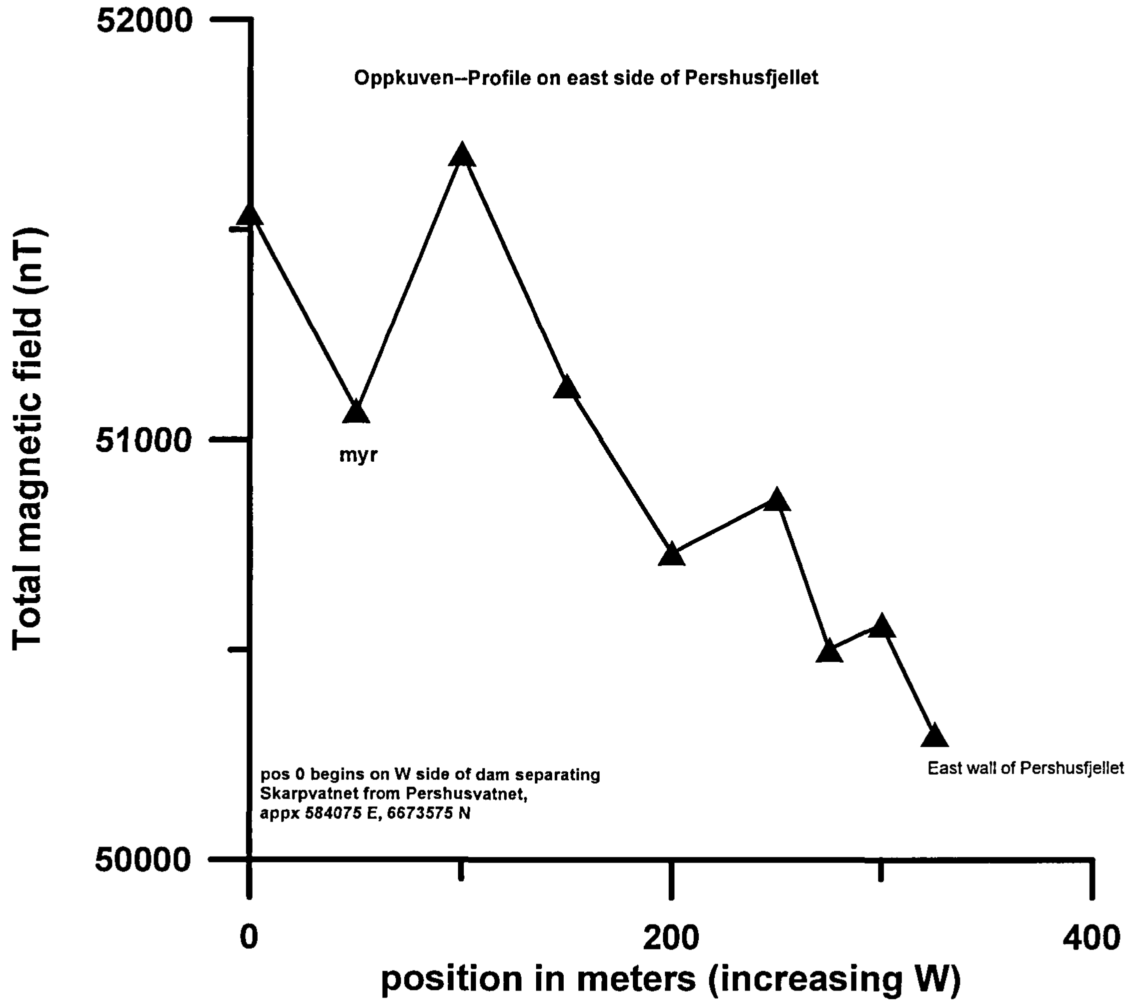


Fig. 11. Magnetic profile, east to west, from Skarpvatnet to Pershusfjellet.

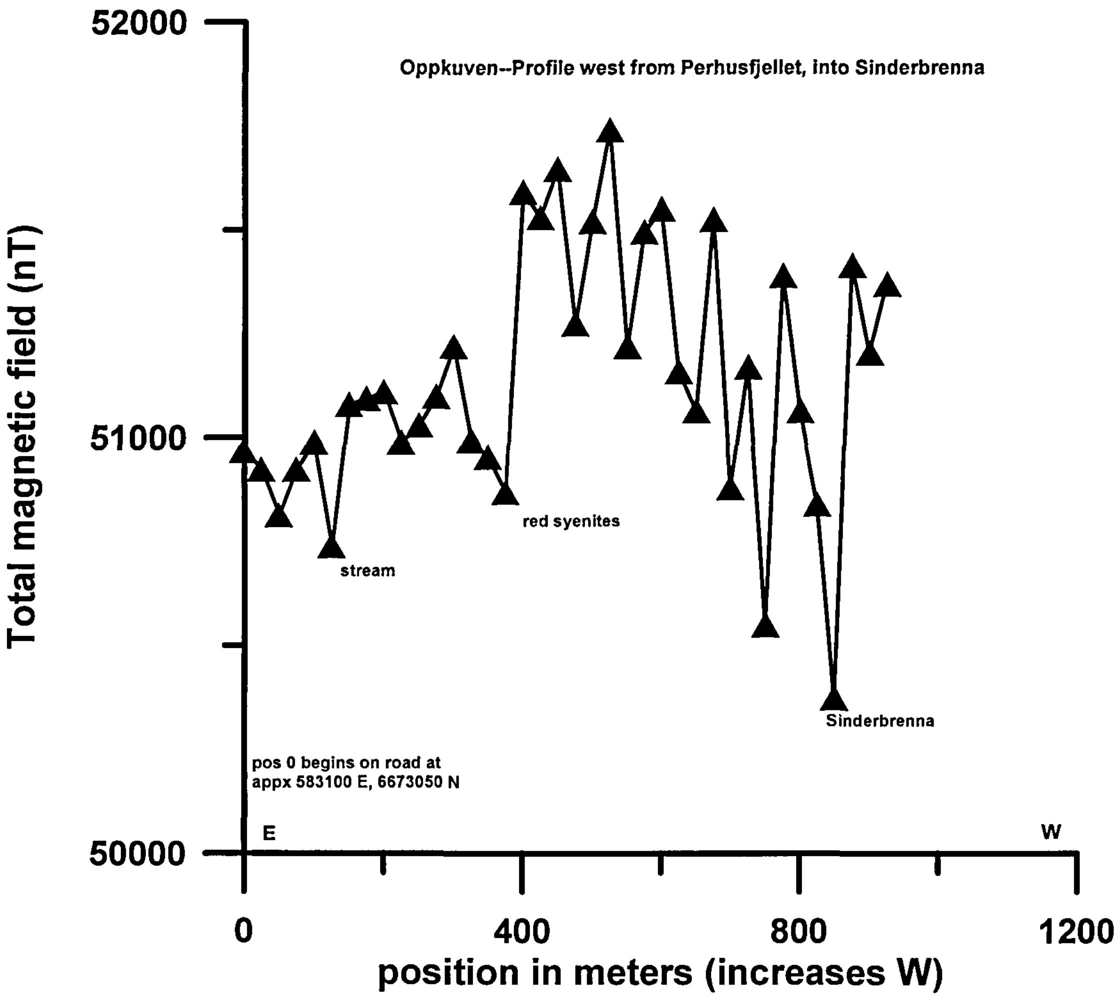


Fig. 12. Magnetic profile, east to west, from Pershusfjellet to Sinderbrenna.

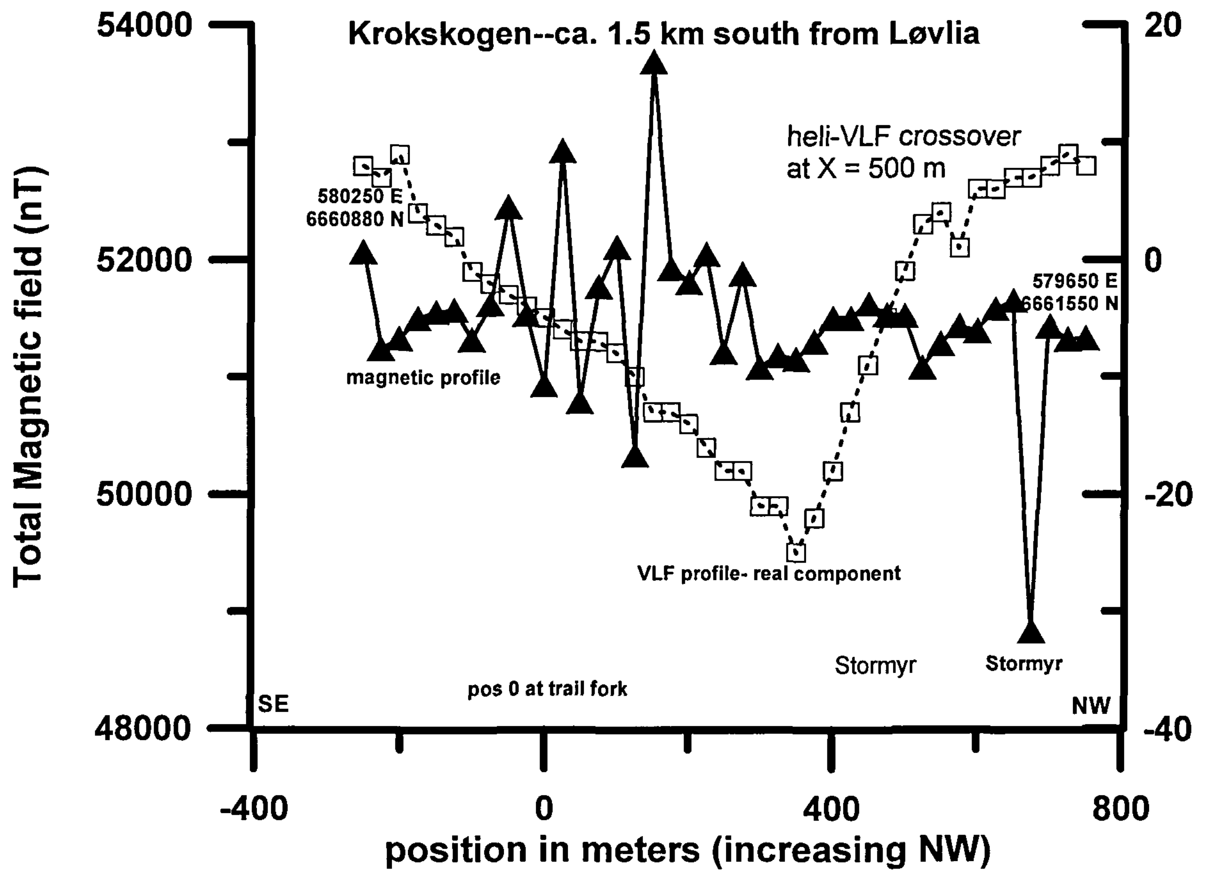


Fig. 13. VLF and magnetic profiles over helicopter VLF anomaly.

structure. This occurs near X = 450 m in Figure 13. A sharp 500-nT drop in the total magnetic field appears at the same location, at the edge of a marsh called Stormyr. The aerial VLF anomaly appears to coincide with a stream flowing southward from Stormyr. The aerial magnetic data also shows a subtle anomalous trend paralleling the VLF anomaly. The VLF anomaly may thus indicate a fractured zone in which rock has altered to a slightly less magnetic state than the surrounding rock.

### 3.9 Radiometeric profile—Brandbukampen

Maps made from helicopter radiometric data collected in the 1997 survey show an abrupt falloff in radiometric counts from west to east in the vicinity of Brandbukampen. A radiometric ground profile was performed, beginning on the east side of Brandbukampen and moving northeastward parallel to a road to Eggebråtån. We hoped the radiometric data would indicate a sharp contrast across the contact between the radiometric alum shales (Andersson et al., 1985) nearest Brandbukampen and the gneisses further east. To reduce the influence of soil cover, measurements were made on exposed rock. Figure 14 shows an abrupt falloff in radiometric counts in the uranium channel. Possibly only the first point was located in the alum shale unit. This abrupt falloff from west to east also occurs in the helicopter radiometric data.

## 4 DISCUSSION AND CONCLUSIONS

Layered earth inversion of the surface DC electrical soundings at Auretjern and Løvlia show that the half-space resistivities derived from the aerial electromagnetic data can be trusted as reliable relative indicators of conductive and resistive zones. The DC borehole log gave accurate resistivity estimates of major rhomb porphyry units as well as other rock units in Krokskogen. These units have lower than anticipated resistivities on the order of 100s rather than 1000s of ohm-m, indicating high porosity.

A 20-km long linear magnetic anomaly discovered in the 1997 helicopter survey was confirmed by several ground magnetic profiles. The source of the anomaly appears to be a poorly exposed remanently magnetized dike or series of dikes trending roughly NNE-SSW. The remanent magnetization yields the anomalous magnetic low. The Gran magnetic lineation may indicate a major structural zone of weakness and warrants careful geological follow up.

Of the minor magnetic lineations profiled, none were exposed. However, these appear to be normally magnetized dikes. These, and other anomalies investigated, are summarized in Table1.

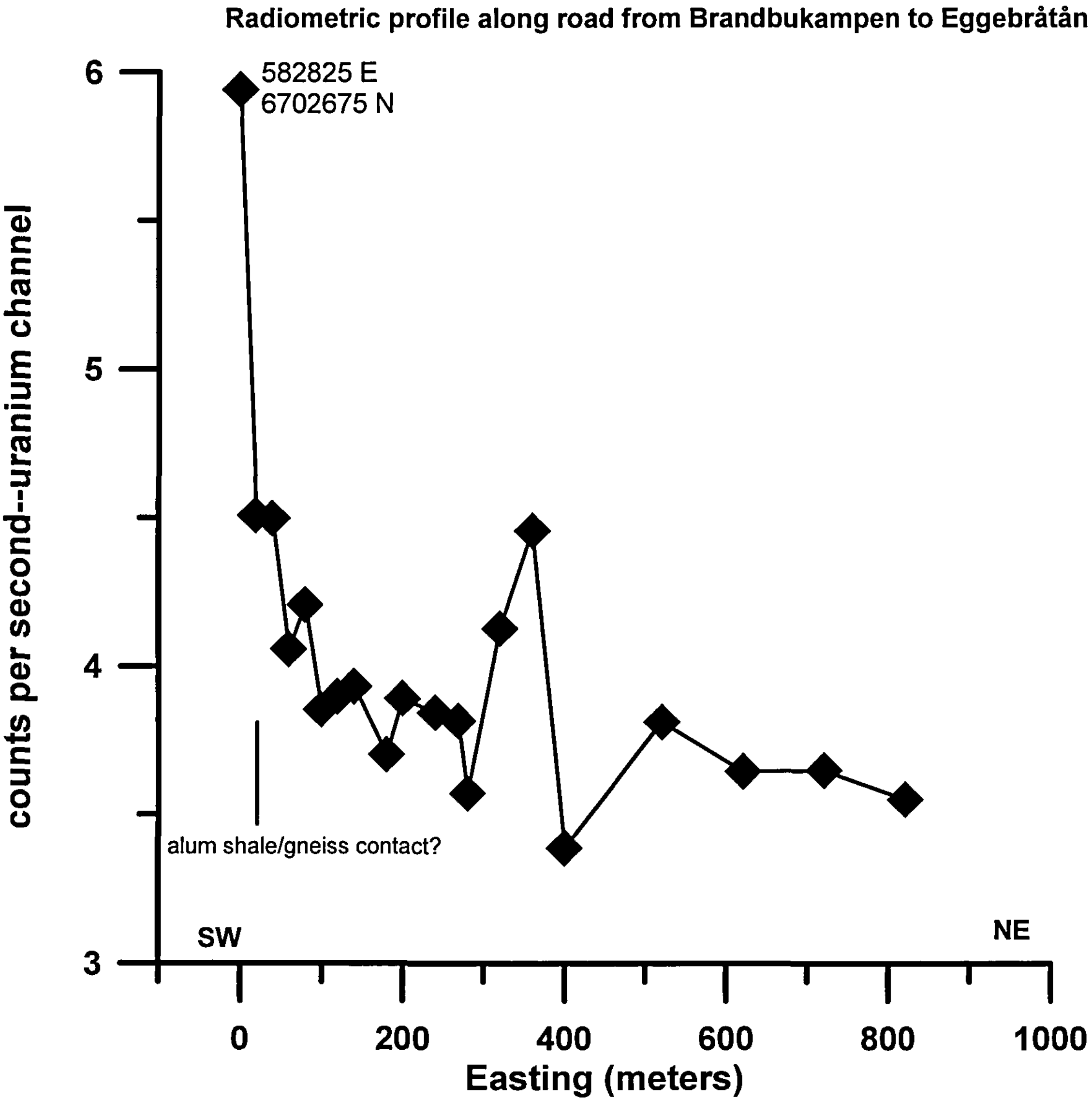


Fig. 14. Uranium anomaly at Brandbukampen.

## TABLE 1. SUMMARY OF GEOPHYSICAL ANOMALIES

| ANOMALY LETTER | LOCATION | ANOMALY TYPE | POSSIBLE SOURCE |
|---|---|---|---|
| A | Auretjern, Krokskogen 574250E, 6652300N | Electromagnetic conductive zone | Dense, high porosity RP units |
| B | Løvlia, Krokskogen 579200E, 6662350N | Electromagnetic resistive zone | Low porosity RP units |
| C | Sørsætra, Krokskogen 574350E, 6654100N | Borehole low and high resistivity zones | Porosity and permeability varations in RP and other rock units |
| D | 7 km N from Jevnaker 579425E, 6688300N | Linear magnetic low | Reversely magnetized dike or series of dikes. Poorly exposed. |
| E | 3 km W from Lunner 584200E, 6686700N | Linear magnetic high | Normally magnetized dike. |
| F | Ristjern, Krokskogen 578600E, 6653800N | Oval-shaped magnetic low | Unknown, but corresponds to brecciated zone. |
| G | 3 km NE from Brandbu 585600E, 6702050N | Linear magnetic high | Normally magnetized dike? No exposure. |
| H | 2 km NE from Jaren 587200E, 6697600N | Linear magnetic high | Normally magnetized dike? No exposure. |
| I | Pershusfjellet, Nordmarka 583600E, 6673000N | Linear magnetic high | Magnetic rock (mapped as syenite) near crest of Pershusfjellet. |
| J | Sinderbrenna, Nordmarka 582800E, 6673000N | Linear magnetic high | Iron rich syenites? |
| K | 1.5 km S from Løvlia 580000E, 6661000N | Linear VLF anomaly | Fracture zone? No exposure. Small associated magnetic anomalous low. |
| L | W side of Brandbukampen 582800E, 6702700N | Abrupt radiometric change | Contact between alum shales and gneisses. |

## 5 ACKNOWLEDGMENTS

Natalia Artemieva assisted in collecting magnetic, VLF, and radiometric data at some of the Gran area locations.

## 6 REFERENCES

Andersson, A., Dahlman, B., Gree, D.G., & Snall, S. 1985: The Scandanavian Alum Shales. *Sver. Geol. Unders.* Ca56, 1-50.

Beard, L.P. 1998: Data acquisition and processing—helicopter geophysical survey, Oppkuven and Gran, 1997: NGU Report 98.079.

Everdingen, R.O.v. 1960: Studies in the igneous rock complex of the Oslo region; XVII, Palaeomagnetic analysis of Permian extrusives in the Oslo region, Norway. Skrifter- Norske Videnskaps Akademi i Oslo, 80pp.

Henkel, H. and Guzman, M., 1977: Magnetic features of fracture zones: Geoexploration, 15, 173-181.

Løset, F. and Rui, I. 1998: Ringeriksbanen: resultater av kjerneboring: NGI report 971021-2.

## 7 APPENDIX—Magnetic profiles over Gran magnetic lineament

This appendix shows the results of six ground magnetic profiles taken at various locations across the Gran magnetic lineament, shown by the line denoted D in Figure 1. Figures A1 through A6 show that the magnetic lineament maintains its reversely magnetized character at each of the six locations.

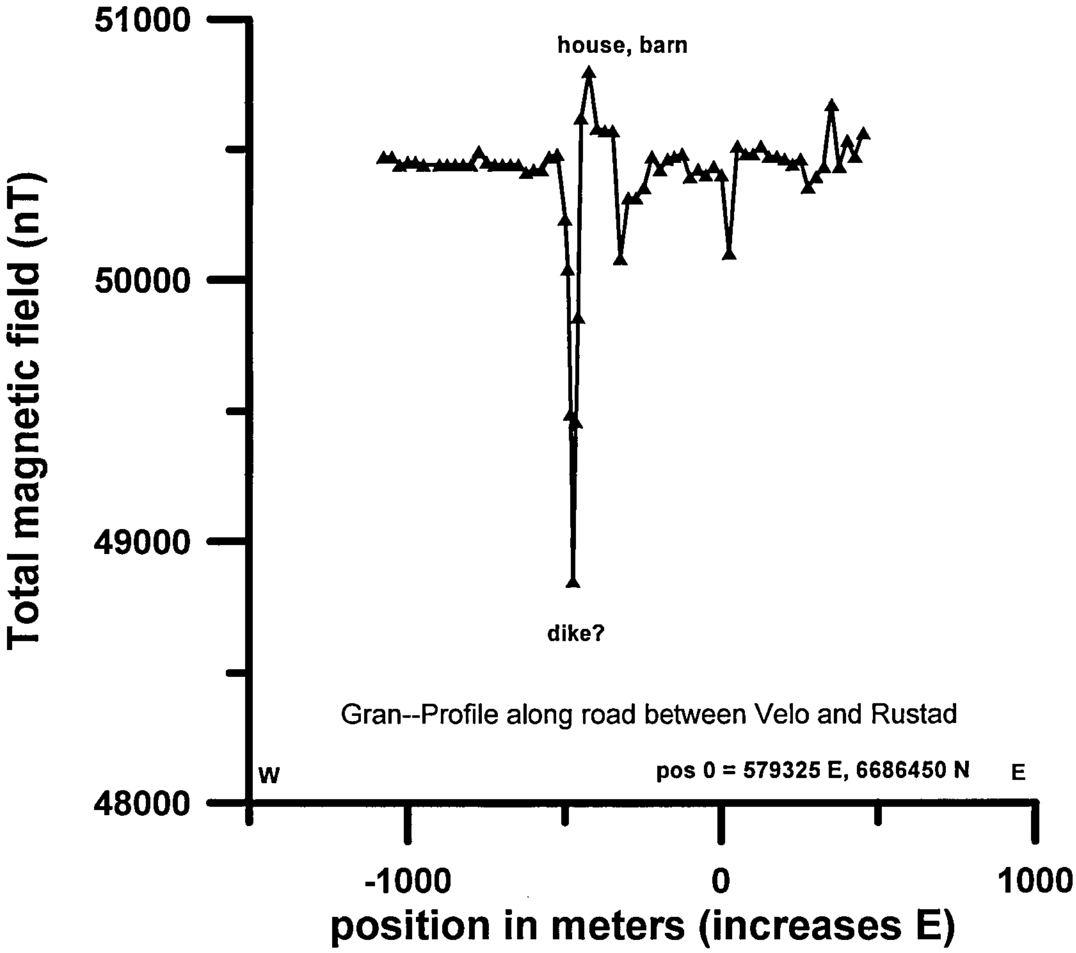


Fig. A1. Magnetic profile across Gran magnetic lineament.

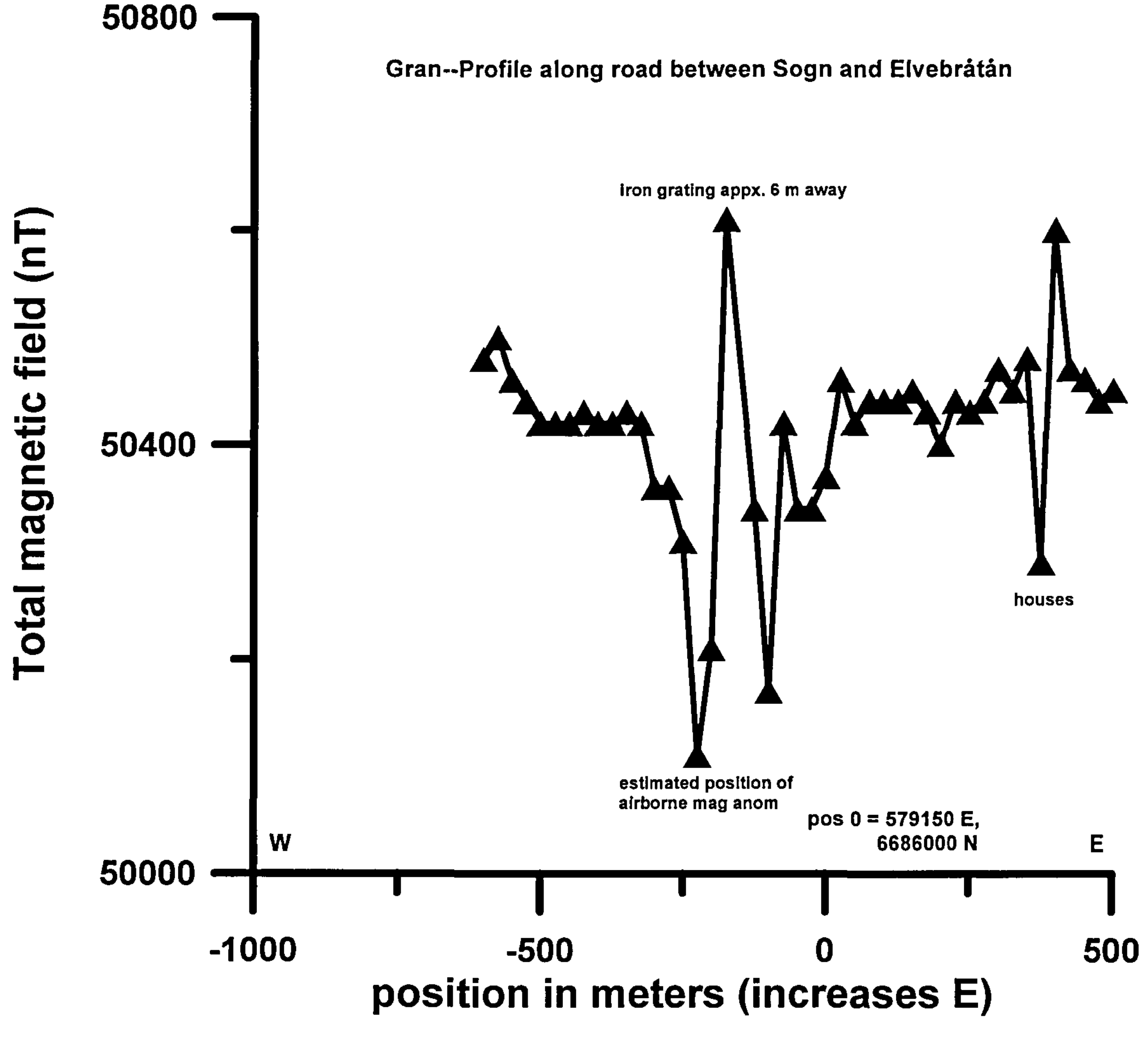


Fig. A2. Magnetic profile over Gran magnetic lineament.

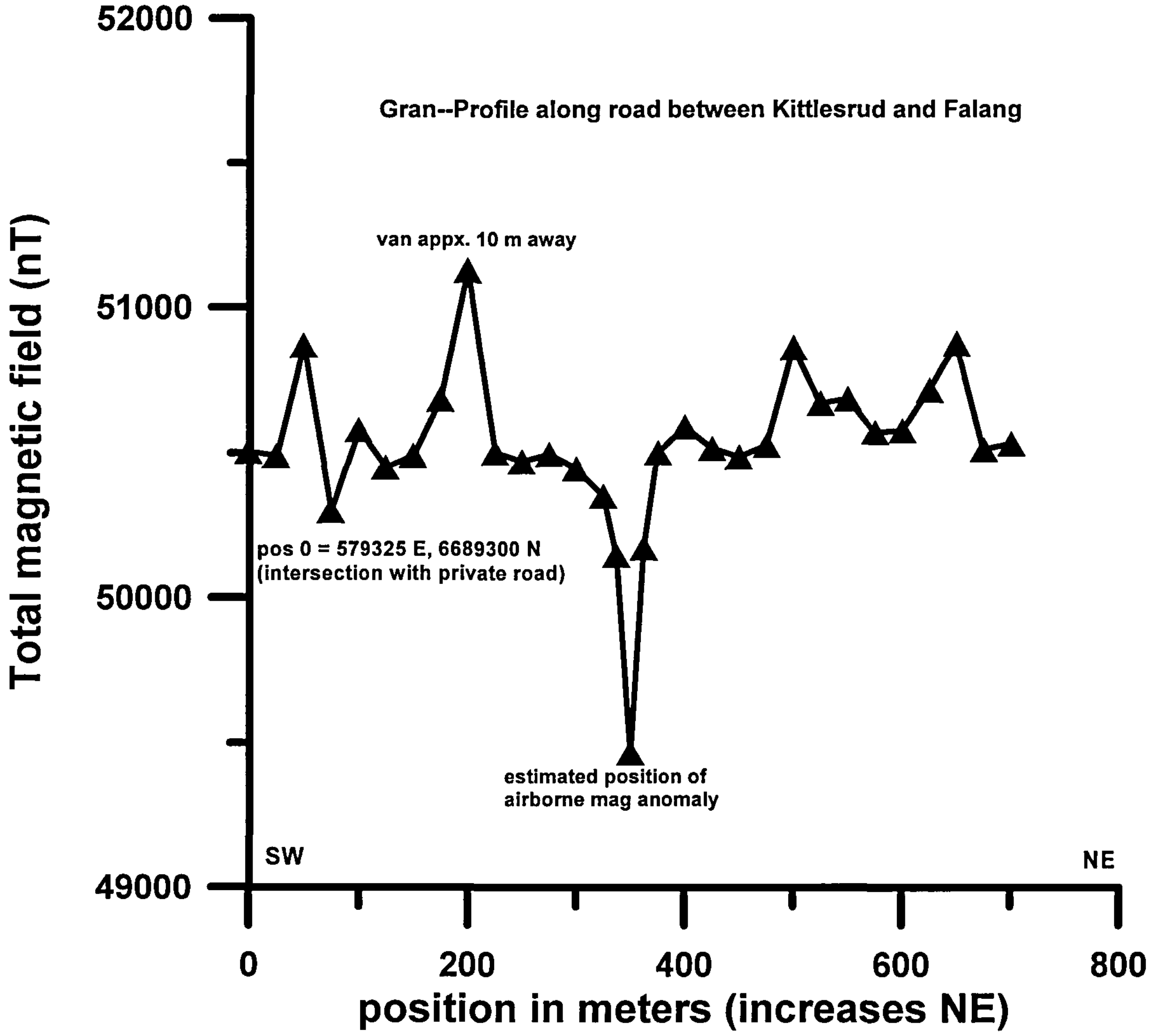


Fig. A3. Magnetic profile over Gran magnetic lineament.

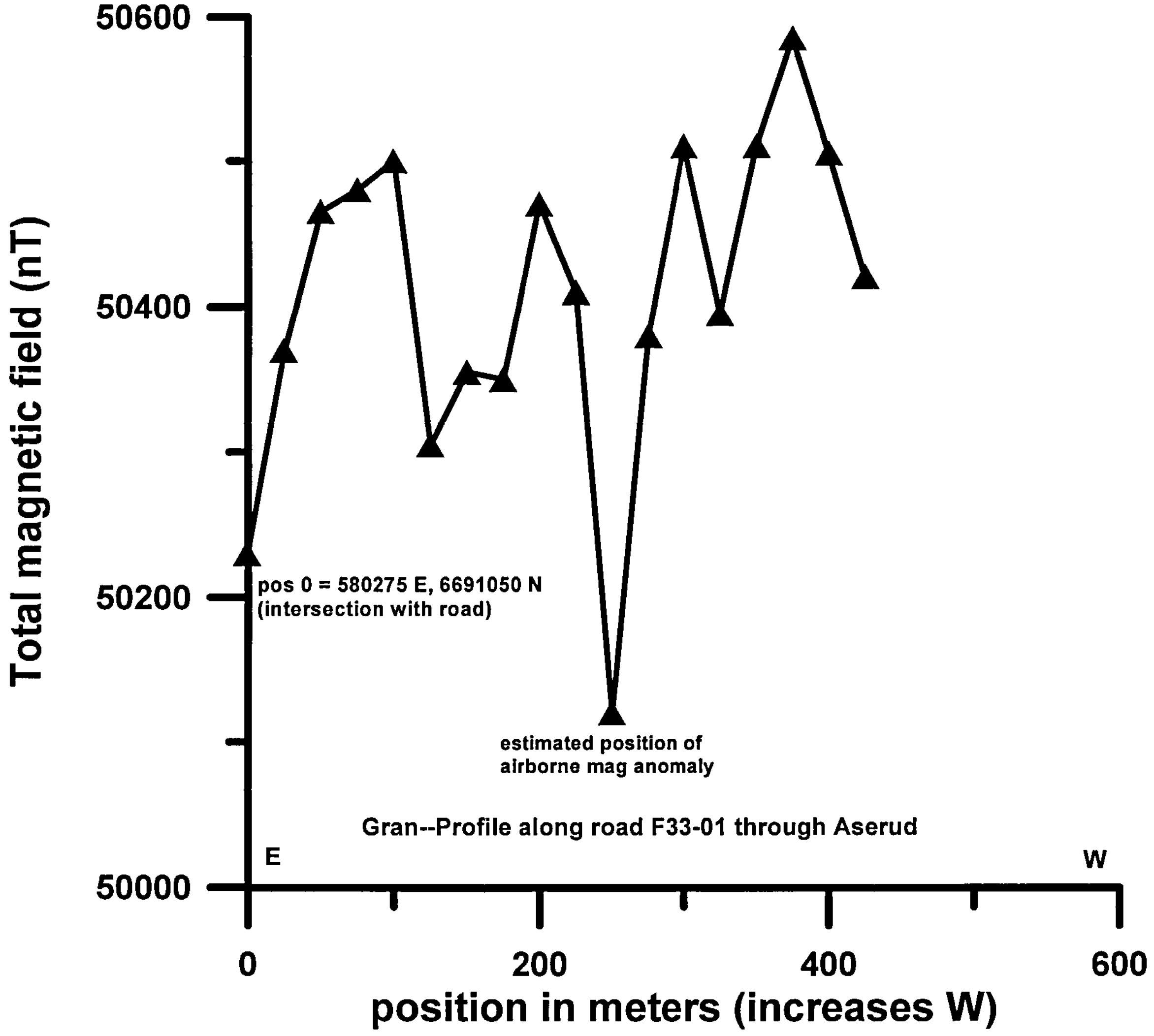


Fig. A4. Magnetic profile over Gran magnetic lineament.

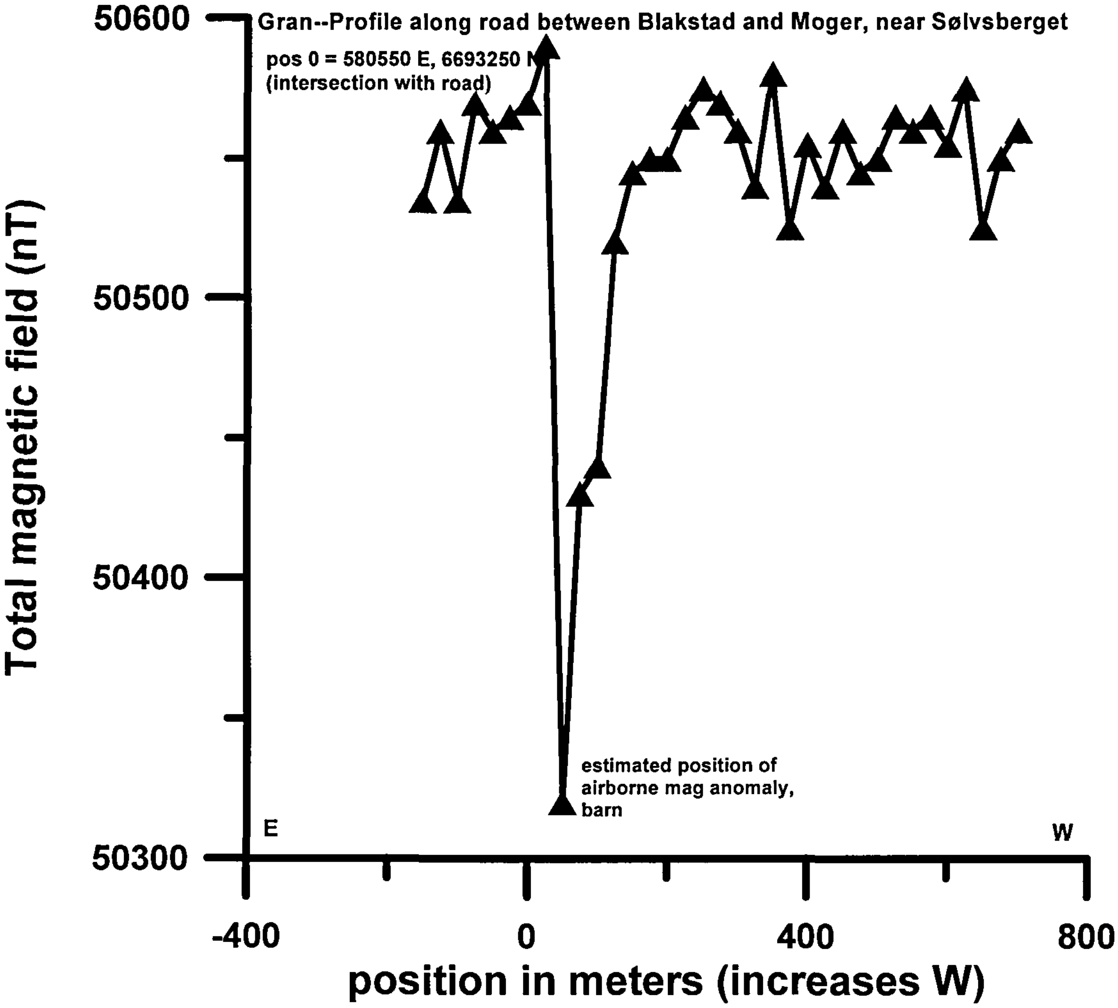


Fig. A5. Magnetic profile over Gran magnetic lineament.

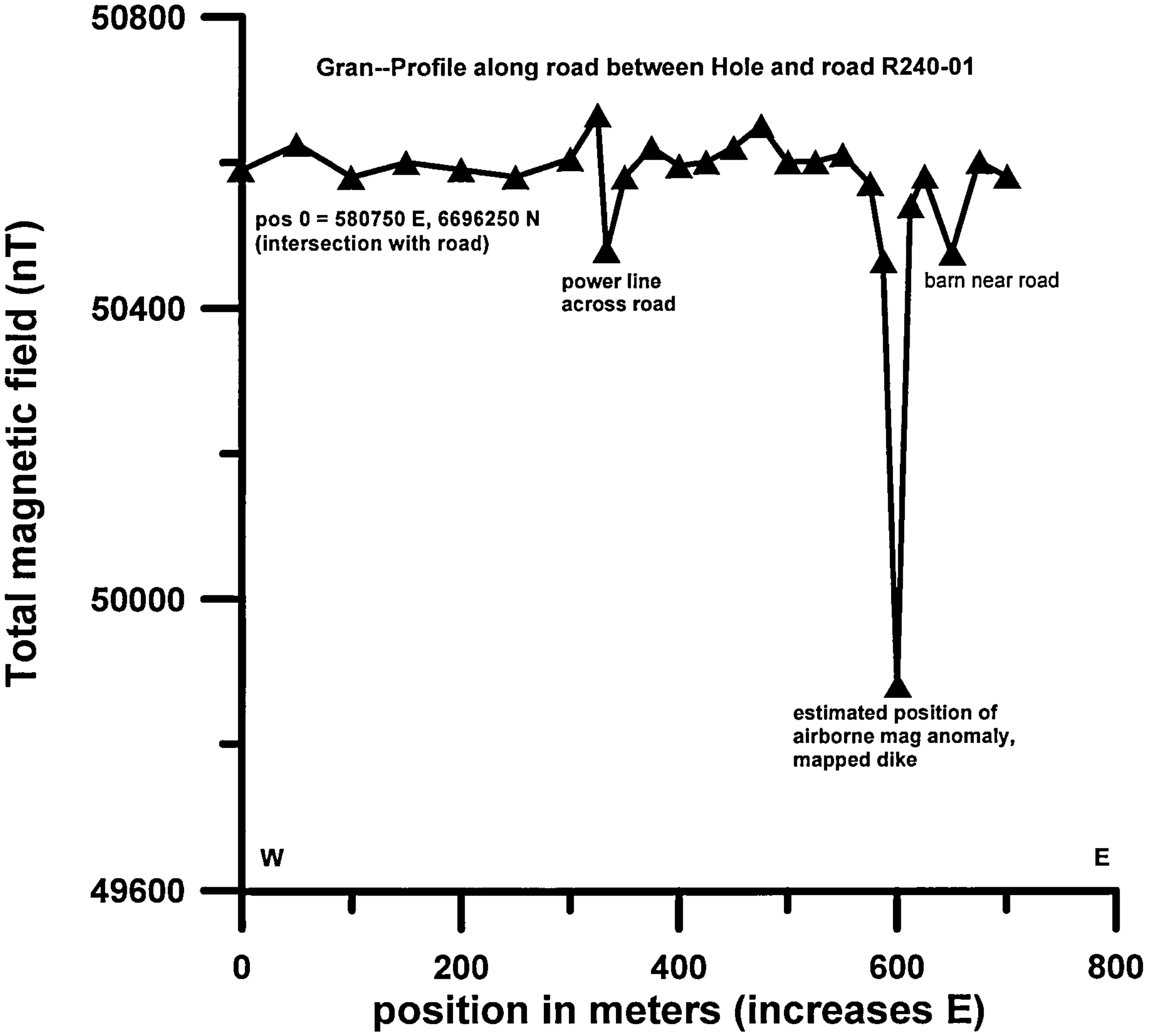


Fig. A6. Magnetic profile over Gran magnetic lineament.