Synthesis of geophysical data in the Bothnian sea

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SUMMARY

Gravity and magnetic maps covering the Gulf of Bothnia have been compiled. The dominant gravity anomaly along profile 1 is interpreted as a superposition of a Moho trough in the northern part and a mid-crustal diorite pluton just south thereof.

The dominant magnetic anomaly is the maximum observed north of Åland and is interpreted as an upper crustal granitic pluton of relatively high susceptibility. The general magnetic field pattern in the area can be interpreted as a series of upper/middle crustal plutons overlying lower crustal/upper mantle material with rms magnetization about three times higher than that in the upper/middle crust.

1 INTRODUCTION

An integrated geophysical analysis is necessary when the full extent of the tectonic evolution in the area is evaluated. This report describes our first attempt to combine results from the BABEL reflection and refraction data with 3-D modelling of gravity and magnetic data from the Gulf of Bothnia region, in particular the part covered by BABEL lines 1, 6 and 7. Pre-existing potential field data and the high quality reflection recordings enable us to correlate changes in seismic reflectivity with emplaced bodies that cause potential field anomalies.

2 SEISMIC DATA

The final stacks of the reflection seismic data were coherency filtered to emphasize the prominent reflectors and to obtain a more easily interpretable image than it was possible with the previous final stacks. We used a coherency filter based on semblance calculation of adjacent traces within 900 meters. The dip angle ranged between ± 30°. Zones of high and low reflectivity can be distinguished on all sections.

Refraction line 7 was interpreted by 2-D ray-tracing using recordings from stations 701, 703, 704, F21 and F09 (Fig. 1). The data were bandpass-filtered between 3 and 25 Hz and partly deconvolved (station 701) with a predictive operator and a prediction lag of 125 ms. The data show several high amplitude mid-crustal reflectors and refractors and a distinct Moho reflection (PmP). Converted phases (PmS and SmP) and S-waves (SmS) are observed. Preliminary forward modelling by using a ray-tracing algorithm resulted in a crustal depth between 46 and 51 km. The velocities in the uppermost crust lie between 5.8 and 5.9 km/s. High first-arrival velocities from station F09 and upper crustal refractions in the recording of station F21 indicate a layer boundary at 4–6 km depth with a velocity of 6.2 km/s. The velocities in the mid-crustal layer (20–35 km) are between 6.6 and 7.0 km/s and in the lowermost crust between 7.1 and 7.5 km/s. Reflectivity patterns in the crust detected on the CDP profile are difficult to correlate with features in the velocity model. The Moho depths of the CDP data coincide with depths derived from the wide angle data modelling (see Fig. 5). A deconvolution of all available data and an inversion by applying a 2-D damped least-squares method will lead to a more detailed model.

3 GRAVITY AND MAGNETICS

The gravity data used in this study were obtained from two sources, satellite altimetry data processed by Knudsen (pers. comm.) and ordinary land gravity measurements (Huaan Fan, pers. comm.). Whereas the latter data set covers the whole area of Scandinavia, the altimetry data obviously cover only the sea. We used the altimetry data for further modelling, because that data set was more densely sampled (30 km).

The magnetic data are a subset of Scandinavian high altitude measurements (Sveriges Geologiska Undersökning 1983) with a spacing between flight lines of approximately 35 km. Thus the resolution is quite compatible with the gravity map. It should be mentioned that more detailed gravity and magnetic data sets exist. As they do not cover the whole study area, we preferred at the present stage to look only for the most prominent structures and to find reflection patterns in the seismic sections that may support our modelling. Due to the large

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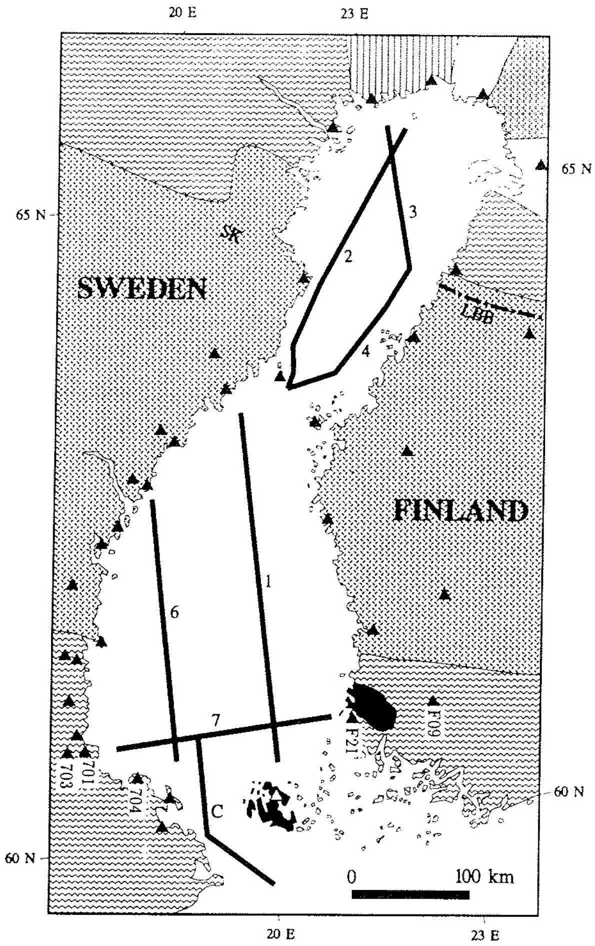

Figure 1. Schematic geological map of the Gulf of Bothnia with location of seismic BABEL profiles and seismic landstations (triangles). Geologic features are outlined after Gorbatschev & Gaal (1987).

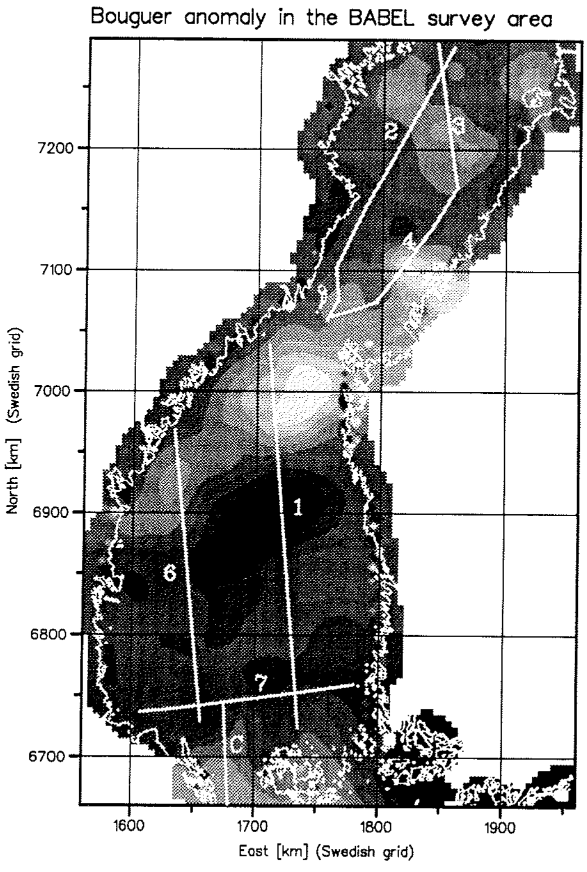

Figure 2. Bouguer anomaly map (in mgal) based on Seasat and Geos-3 altimetry measurements. With permission from Per Knudsen, National Survey and Catastre, Denmark.

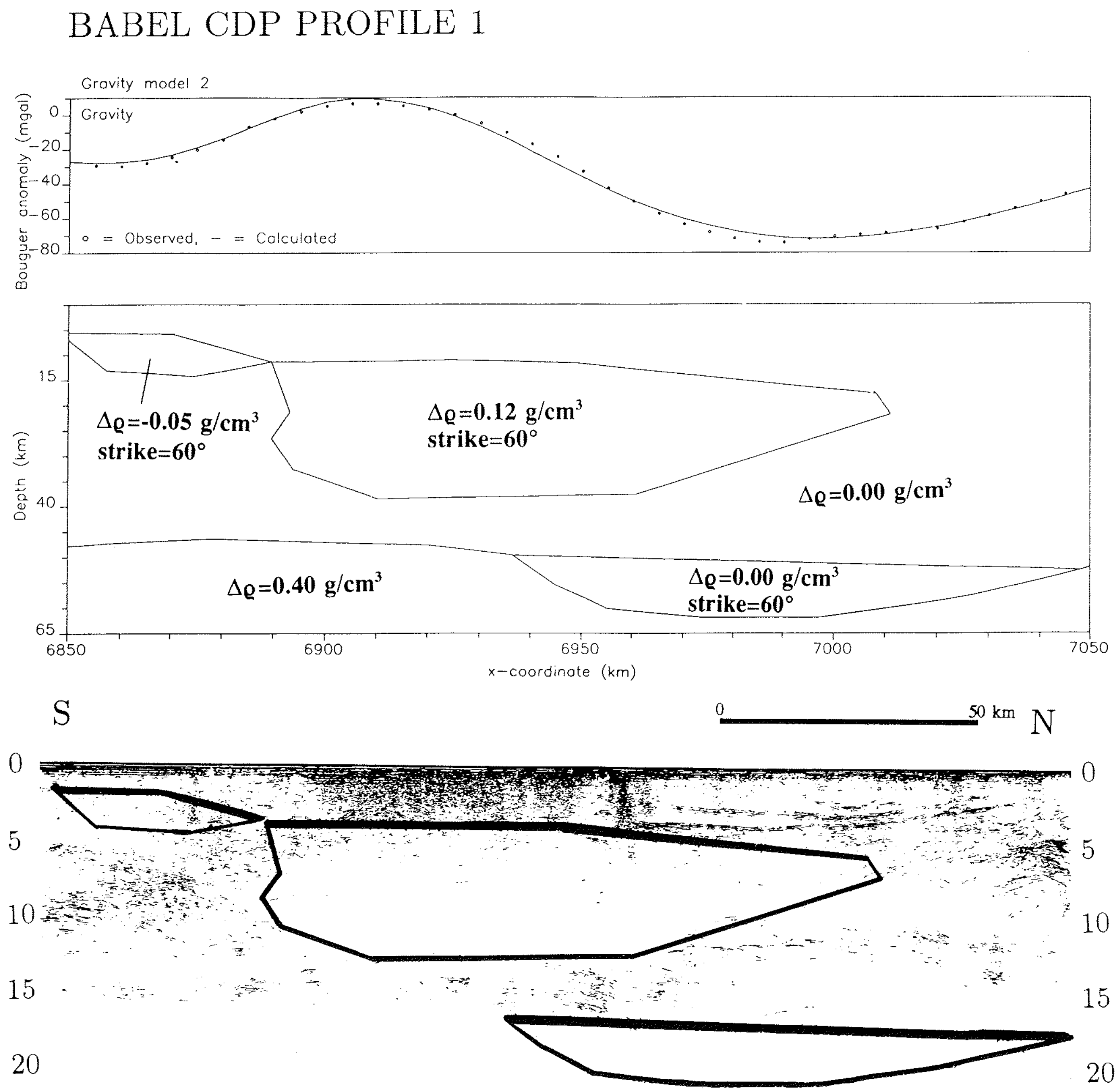

Figure 3. $2^1/_2$-D Bouguer gravity model along profile 1.

distances between the sampling points, we exclude anomalies of wavelengths smaller than about 60–70 km. This, however, does not imply that earth structures below that threshold will be ignored. If they are sufficiently powerful, even "point" sources may be resolved from the potential field maps.

In the Bouguer anomaly map of the Gulf of Bothnia (Fig. 2), two gravity anomalies are dominant. A gravity low exists in the northern part of profile 1 and a gravity high just north of the centre of the profile. By examining CDP profile 1, a large body with almost no reflectivity is observed, coinciding with the location of the observed gravity maximum. There is also evidence for crustal thickening toward the northern part of the profile, in agreement with the recent Moho map of Scandinavia by Luosto *et al.* (1991). A gravity model of the area is provided in Fig. 3. The transparent body contains a density contrast of +0.12 g/cm^3 to the surrounding area. A contrast of +0.40 g/cm^3 is used for the upper mantle. The density of the transparent block corresponds to that of a dioritic pluton. Henkel *et al.* (1990) name this as "basement culminations" that, for instance, can be observed on land in Uppland with densities on average of 2.81 g/cm^3. There is no evidence for a small body in the upper crust with a slightly negative contrast, but it is included to obtain a better fit to the observed data.

The magnetic anomaly map (Fig. 4) reveals a strong maximum north of Åland. An examination of CDP profile 7 shows a doming structure that could be interpreted as an intrusion. To model the magnetic data, one profile crossing the centre of the anomaly and one profile 20 km north of the centre (a–a') were extracted

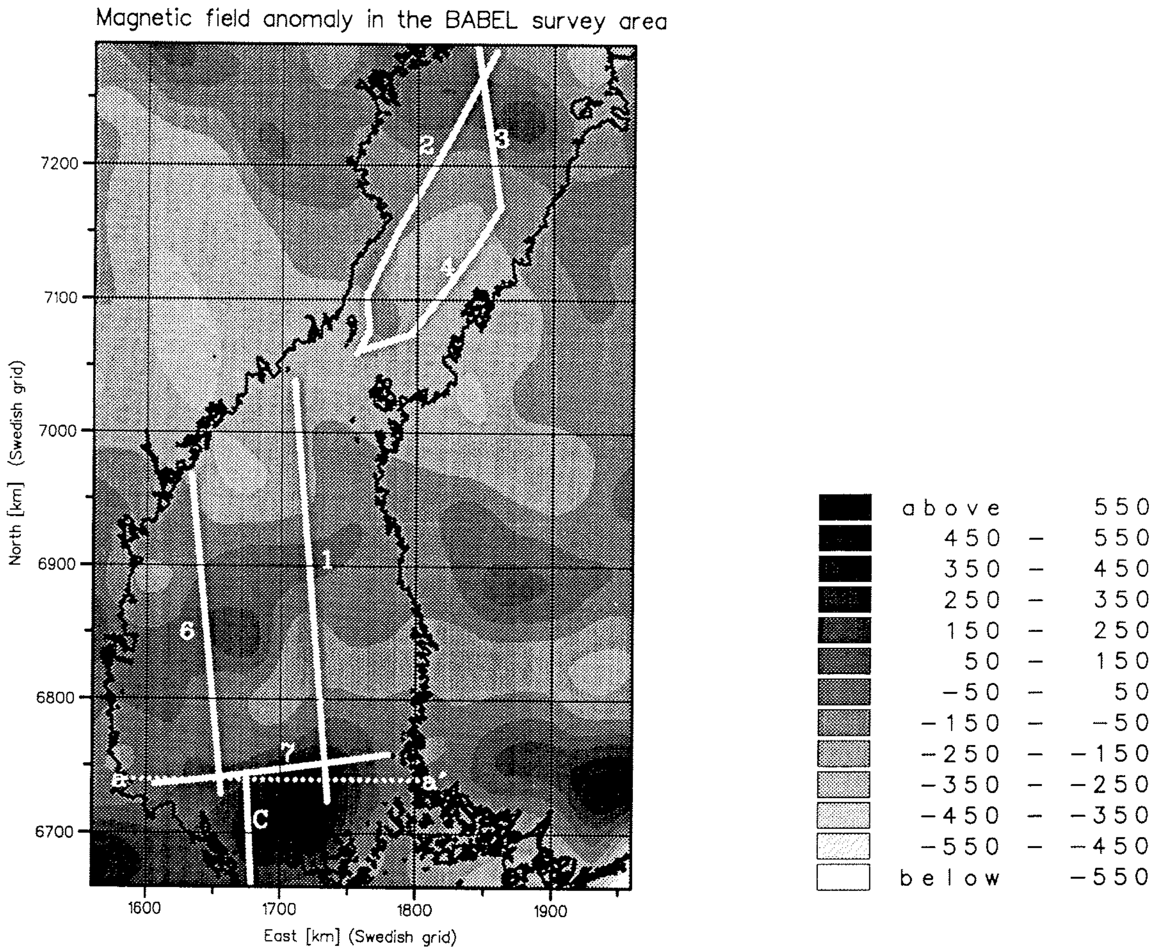

Figure 4. Total magnetic field intensity (in nT) reduced after IGRF 1965, revision 1987. High altitude magnetic field measurements (3000 m). With permission from Sveriges Geologiska Undersökning, Sweden.

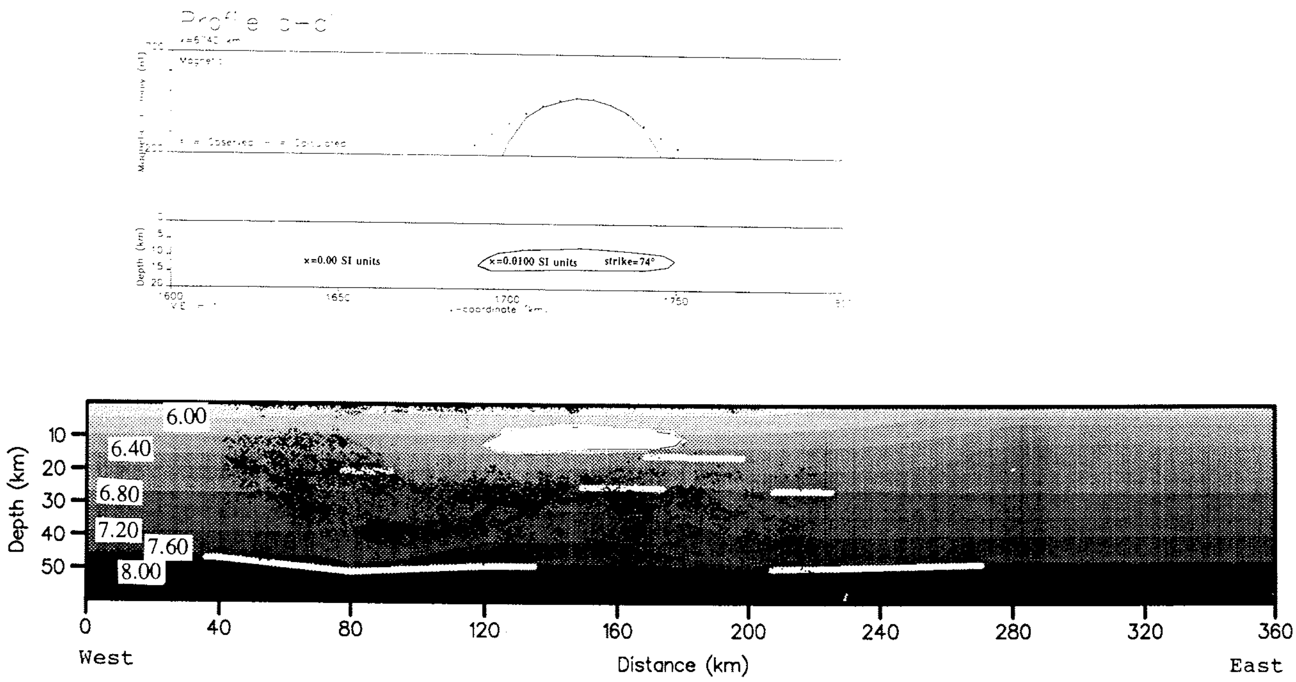

Figure 5. 2½-D magnetic model and P-wave velocity model along profile 7 superimposed on the CDP stack using a conversion velocity of 6.35 km/s. The thick white lines represent the images of reflected phases observed in the wide angle data.

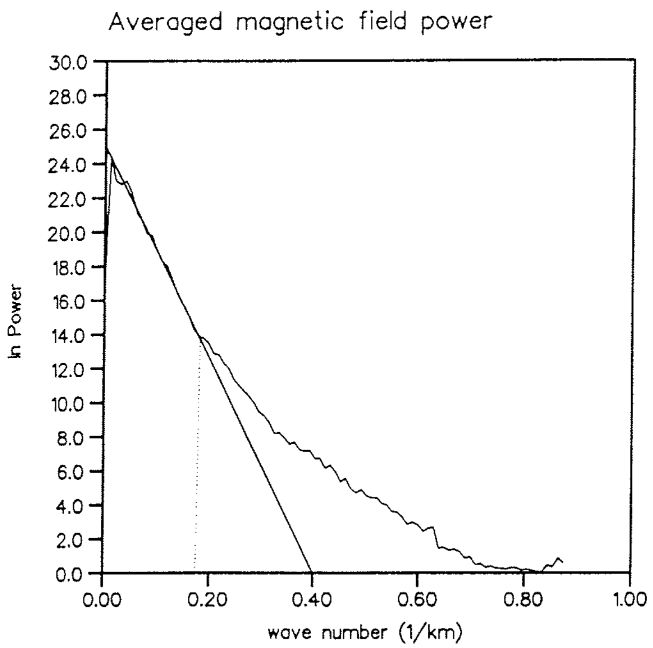

Figure 6. Power spectrum of magnetic field from the Bothnian Sea and surroundings corresponding to map in Figure 4. Stippled line indicates maximum wave-number beyond which noise dominates. Straight line shows the slope of the dominant shallow ensemble down to 31 km depth.

from the interpolated grid (Fig. 4). The geometric dimensions of the magnetized body are constrained by the CDP section and it was assigned a strike length of 70 km. We chose a susceptibility of 0.01 – a typical value for a post-orogenic granitoid pluton in the central Scandinavian Granite–Porphyry Belt (Dyrelius 1980).

A simple sandwich magnetic model of the Svecofennian province can be obtained by calculating the power spectrum of the magnetic field (Fig. 6) (Pedersen 1991). The dominant slope of the spectrum reveals a layer boundary at about 31 km depth. By combining this result with information from heat flow studies of the area (Bauman 1990) in which the Curie depth is estimated to be approximately 62 km, a simple two-layer sandwich model is obtained. An approximate rms magnetization ratio of 1:3 between the upper and lowermost layer can also be derived from the power spectrum. This is in agreement with previous results showing that the lower crust is more magnetized than the upper crust (Pozzi & Dubuisson 1992). Using this ratio between the rms magnetizations, the two-layer magnetized model shown in Fig. 7 is obtained. Notice that the mean magnetization in each layer is zero. Any constant magnetization may be added without perturbing the magnetic field.

Figure 7. (overleaf)

4 DISCUSSION

The gravity anomaly along the northern part of line 1 can well be explained by the most recent Moho map (Luosto, pers. comm.) and the transparent zone observed on the near-offset seismic data. The layered sequence overlying the transparent zone (see Fig. 3), believed to represent metagreywackes, probably has a density similar to that of the background Svecofennian rocks and can be ruled out as a candidate for explaining the positive gravity anomaly.

The magnetic anomaly north of Åland on line 7 does not seem to be directly related to the Rapakivi granites on Åland, which generally are much less magnetic than inferred from this modelling study giving a susceptibility of 0.01. The transparent zone in line 7 coinciding well with the magnetic body could thus be interpreted as a granitic pluton of a different generation than the Åland Rapakivi granites.

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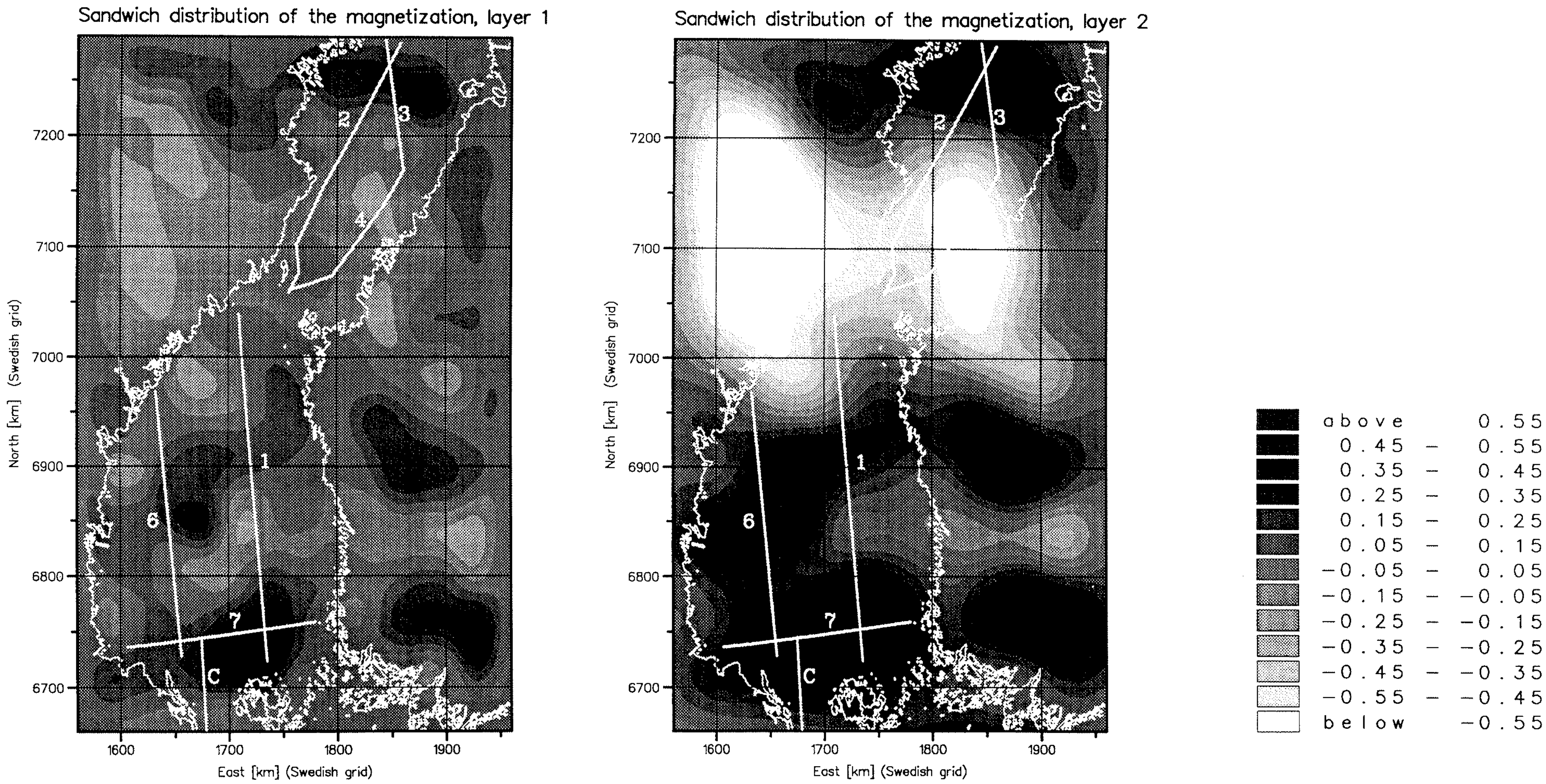

Figure 7. Magnetic sandwich model for the northern BABEL area. Both layers have a thickness of 31 km. Magnetizations are relative and given in units of A/m.