Integrated interpretation of gravity and magnetic data of the KTB main well and the surrounding area

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Descriptions and first interpretations of the gravity and magnetic data measured in the pilot and the main well and at the surrounding surface area can be found among others in Bosum, Casten et al. (1993c) and Bosum, Röttger and Schmidt (1993b) in the proceedings of the 6th KTB-Kolloquium as well as in Casten, Heyde and Mühling (1994) and Gobashy, Casten and Neubauer (1993).

1 Surface gravity and Helicopter magnetics

The good correlation between the gravity and magnetic anomalies can be seen by comparing the map of the second vertical derivative of Bouguer anomalies (Fig. 1) with the anomalies of magnetic total intensity (Fig. 2).

In the central part, corresponding NW–SE striking anomalies are evident. They belong to the amphibolite zones of Windischeschenbach and Wildenreuth (see "Geologische Karte des KTB–Umfeldes Oberpfalz 1:50000", Dill et al., 1991). These anomaly areas are limited in the north by the W–E striking Fichtelnaab fault, which is charactrized by minima in Fig. 1 and Fig. 2. North of the Fichtelnaab fault gravity and magnetic anomalies coincide only in the metabasite region, whereas the serpentinites can be distinguished in the magnetic map because of their strong magnetization. In the contrary, the gravity anomalies do not show due to missing density contrast to the adjoining formations. The gravity anomalies, however, extend considerably farther to both NW and SE than the magnetic anomalies. Several outcrop areas suggest interpretation of these anomaly zones as amphibolites. This consequently, indicates an unmagnetic amphibolite type. Also rock magnetic studies in the KTB–well detected types of unmagnetic amphibolite.

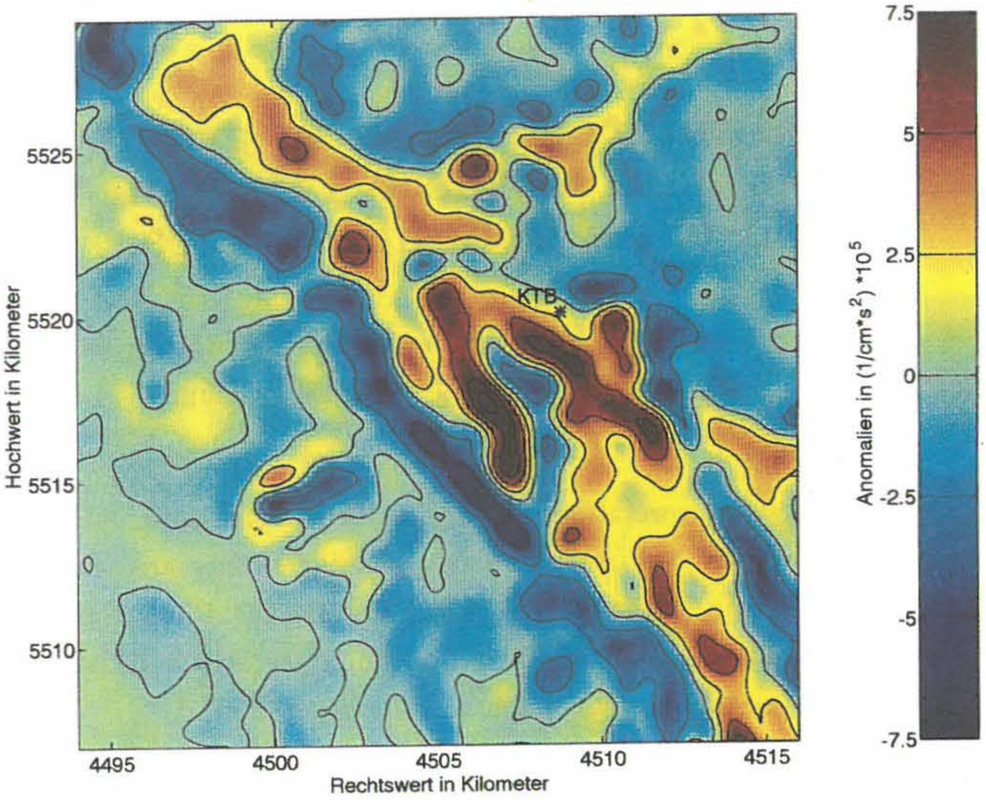

Figure 1: Map of the second vertical derivative of surface gravity data.

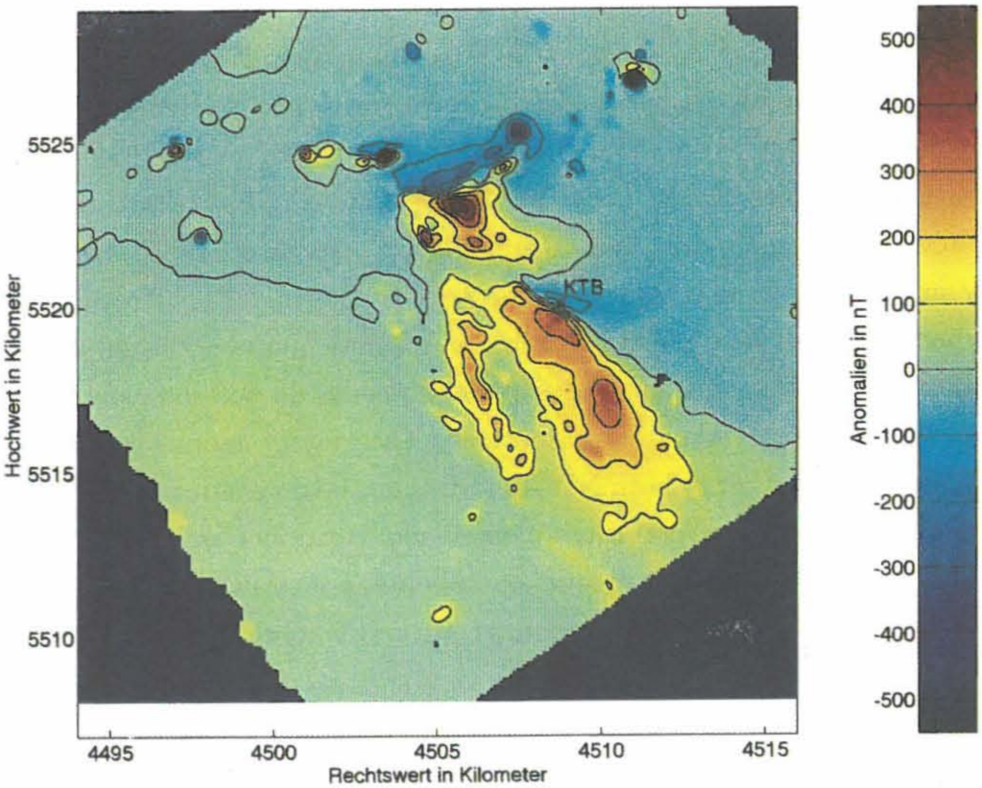

Figure 2: Map of BGR helicopter magnetic data.

2 Spectral analysis of surface anomalies

As a first step of interpretation a Fourier analysis of the magnetic as well as the gravity anomalies was carried out. The results are presented in Fig. 3.

For the surroundings of the KTB area data from the aeromagnetic regional survey of the FRG (elevation 1500 m above sea level) and from the gravity survey were used. For the KTB area (area of the ISO89 experiment) data of the detailed helicopter magnetic survey were used. The coinciding indication of the magnetic and the gravity data to geophysical discontinuities in (statistic average) depths of 3.4–3.5 km below ground (see Fig. 3a, 3b) and 1.4–1.8 km below ground (see Fig. 3b, 3c) becomes evident. The deeper discontinuity can be explained by the upper boundary of the amphibolite unit drilled at depths of 3150 m respectively 3500 m in the main well. Concerning the magnetic field, however, this can be interpreted as the lower boundary of the magnetic disturbing body of Erbendorf (see below) also. The discontinuity in shallow depth can be explained as the (statistic average) top sides of the amphibolitic disturbing bodies close to the surface.

3 Results of the borehole gravity survey

Borehole measurements provide important additional information for the interpretation of surface data. The left-hand side of Fig. 4 shows the Bouguer anomaly log measured in the main well.

The log clearly shows the alternating gneiss/amphibolite succession of the lithological profile. The continuous decrease of the anomalies below 3500 m gives indication to the statement that the amphibolite is not drilled through to the profile end at 6000 m. The apparent density log calculated from the borehole gravity values (Fig. 4, right) is distinctly lower than the cutting density in the depths of the amphibolites. This suggests that the borehole has been drilled nearby the flank of the amphibolite complex. This coincides with the location of the drill site with regard to the surface anomalies (refer to Fig. 1).

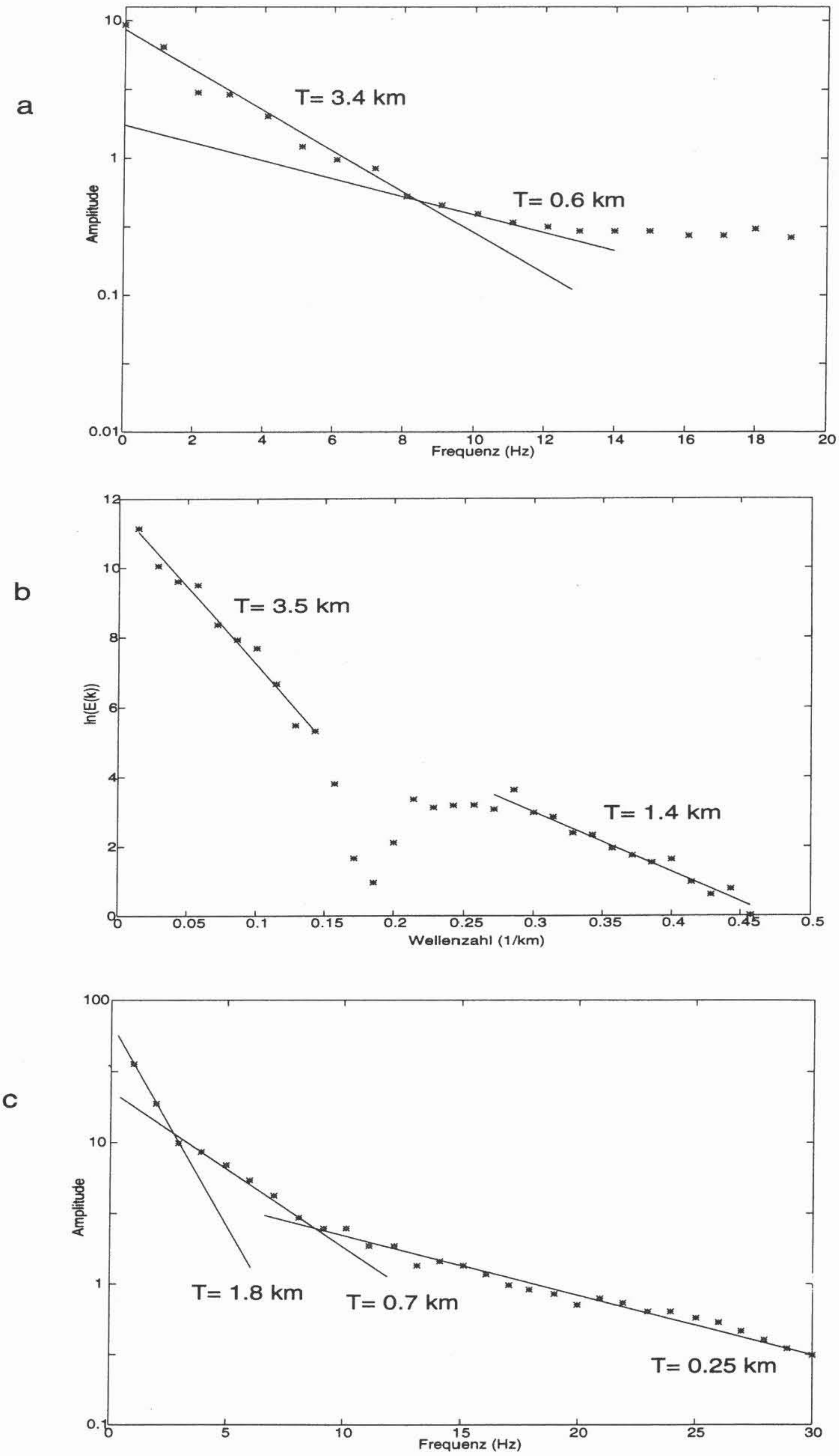

Figure 3: Spectral depths a) of the aeromagnetic data, b) of the gravity surface data and c) of the helicopter magnetic data in the KTB area.

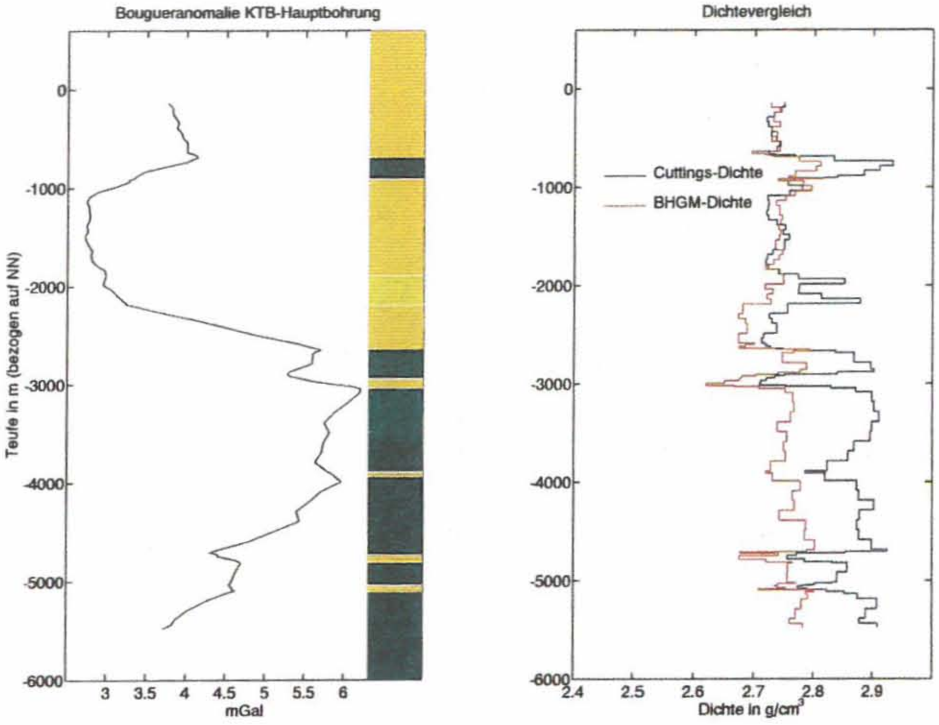

Figure 4: (left) Bouguer anomalies of the main hole together with a simplified lithological profile. Dark sections mark metabasites; bright areas gneisses.
(right) Comparison of the apparent density log and the cuttings density of the main hole.

4 Forward modeling of the gravity data

The gravity data were interpreted by forward modeling. Fig. 5 shows the present preliminary 2D model crossing the KTB location. It follows in its general built-up the geological model of Hirschmann (1994). It considers the drilling results concerning rock densities and lithological successsion as well as the reflectors SE1 and SE2 determined from the ISO89 data. The fit to measured Bouguer anomalies and to observed density log is very good (Fig. 6).

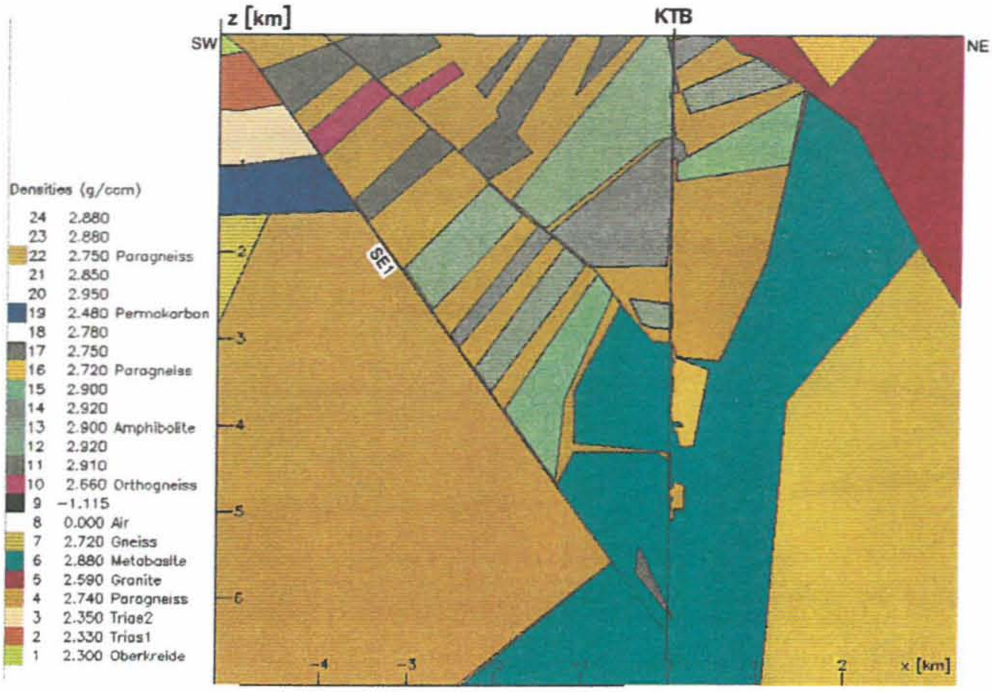

Figure 5: 2D model of the direct borehole vicinity. The sediments in the SW, the ZEV, consisting of gneisses and metabasites and the granite in the NE can be distinguished.

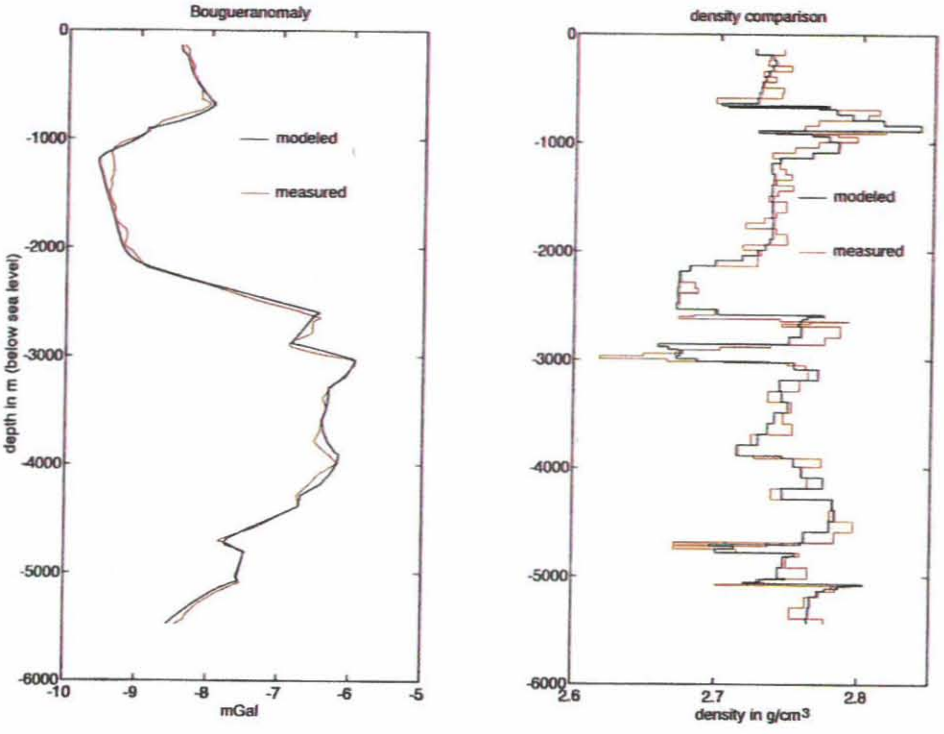

Figure 6: Comparison of measured and modeled Bouguer anomalies (left) and apparent density logs (right).

Fig. 7 shows the central vertical plane of the current 3D model covering a more extensive area.

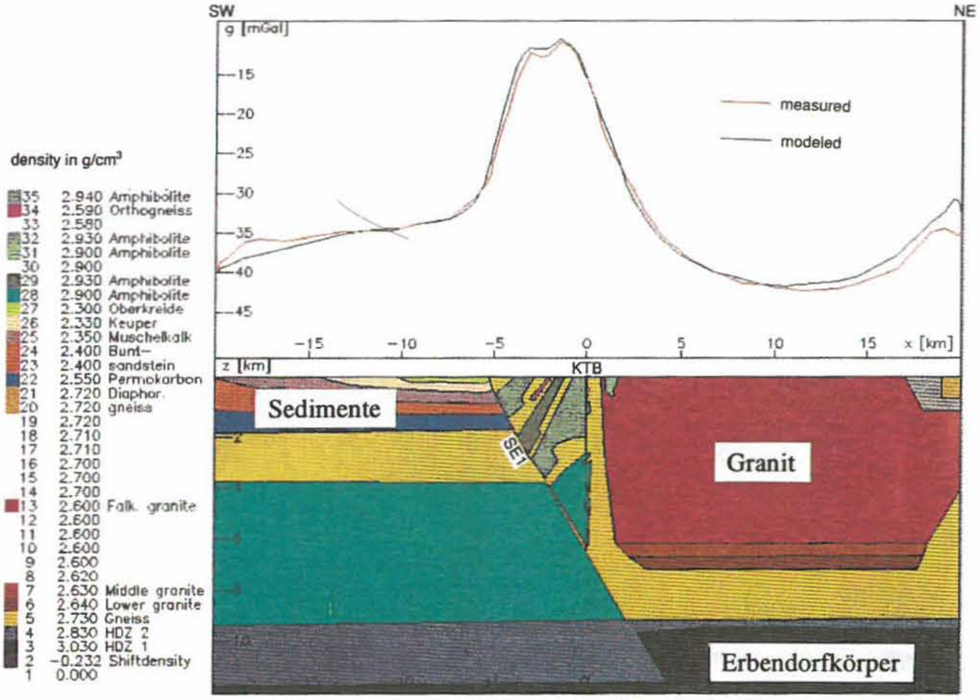

Figure 7: Central vertical plane across the drilling location of the 3D model.

The main structural units are the Falkenberg granite in the NE, the ZEV in the middle and the sediments southwest of the Franconian line. In addition the deep situated so-called Erbendorfbody is considered. The fit to the measured surface Bouguer anomalies is very good, whereby it is necessary to assume a large body of higher density (amphibolite ?) below the sediments. Until now there are a number of discrepancies between the 2D and 3D models, e.g. the allocation of the amphibolite bodies in the direct borehole vicinity and the eastern granite margin. These differences are probably caused by the 2D character of the borehole model.

Other model calculations were carried out to evaluate the effect of a cataclastic zone of lower density drilled from 6200 m to 6400 m (below sea level), which corresponds to the SE1. The Bouguer anomalies and apparent density log were calculated down to a depth of 9000 m. Moreover the effects of the possible thrust faulting of the Erbendorfbody with a throw of 2 km in the NE of the drilling (Wiederhold, 1992) on the borehole gravity profile were calculated (Fig. 8).

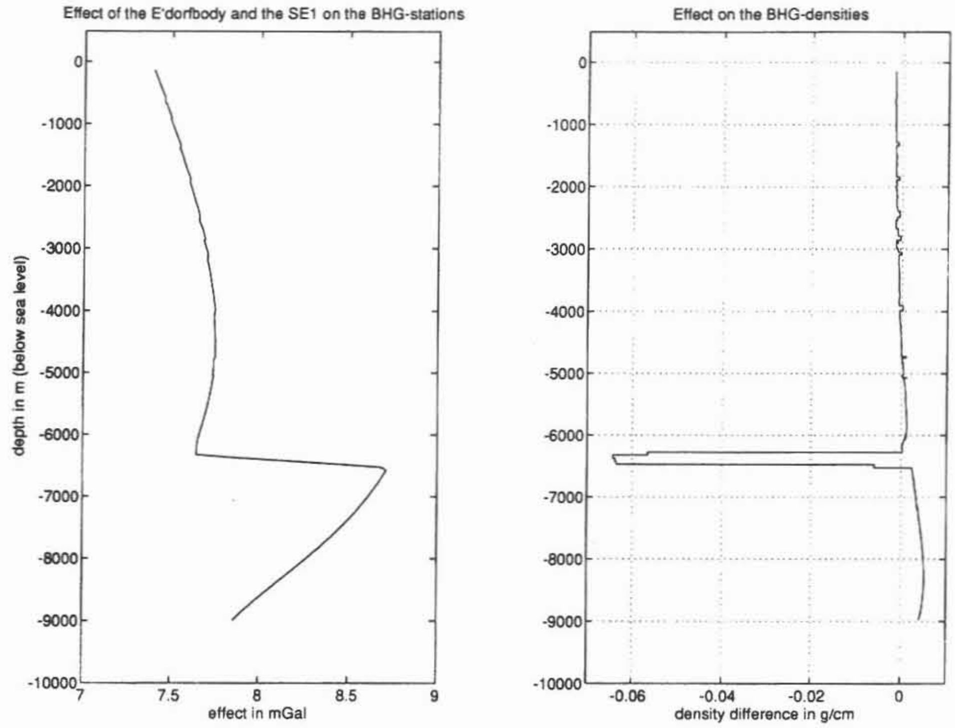

Figure 8: Model calculations of the effect of the SE1 fault zone and the thrust faulting of the Erbendorfbody on the Bouguer anomalies (left) and the apparent density log (right) of the main hole down to a depth of 9000 m.

The results show that it should be possible to separate these structures in a borehole gravity profile conducted from the present 6000 m to the final depth. As a consequence valuable indications concerning the nature of the Erbendorfbody could be expected from a prolongation of the borehole gravity survey.

5 Magnetic model calculations

To interpret the magnetic anomalies profiles normal to the general strike were considered. 2D models were constructed and calculated, whereby normal direction of magnetization was assumed (Bosum et al., 1993a). Fig. 9 presents the model crossing the KTB drilling site.

That model follows the geological/lithological results of the drilling (Hirschmann and Kohl, 1991) in combination with the interpretation of the 3D borehole magnetometer survey (Bosum et al., 1992).

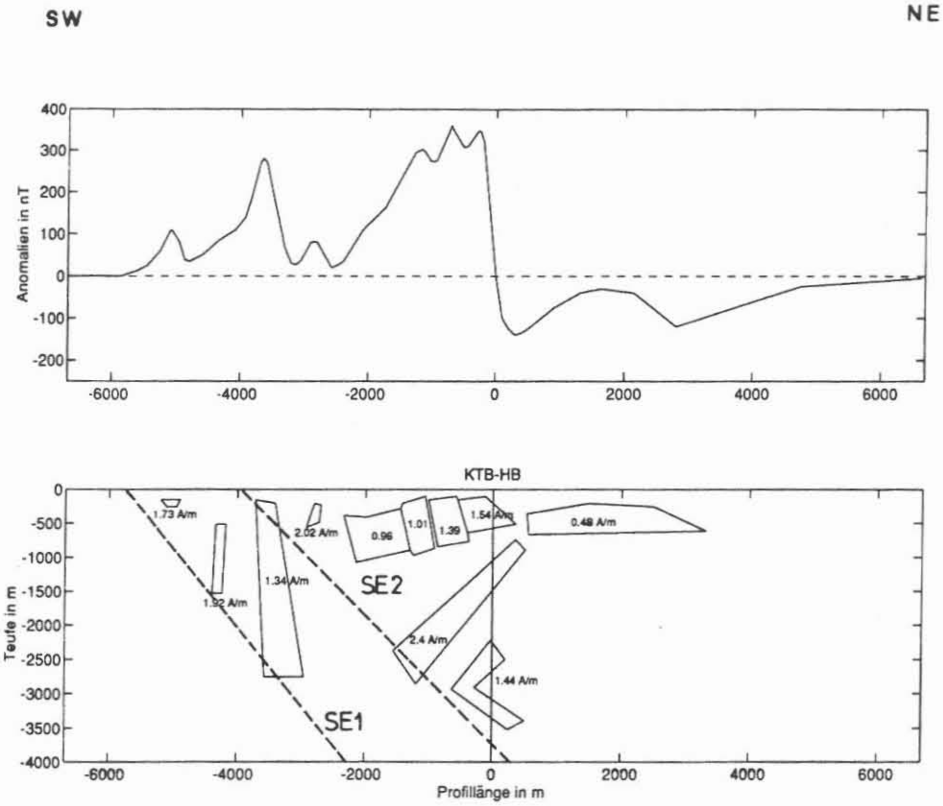

Figure 9: 2D magnetic model along a profile crossing the drill site. In addition the seismic reflectors SE1 and SE2 are marked.

Three magnetic units can be distinguished:

- the uppermost one down to a depth of about 500 m with a magnetization of 1.54 A/m (metabasites b1/b2),
- the one in the middle at about 1100 m to 1600 m (metabasite b2),
- the lowest one at about 2500 m to 3500 m (metabasites b3 (b4?)).

The seismic reflectors SE1 and SE2 are limiting the distribution of the magnetic disturbing bodies.

The results of this interpretation suggest, like the results of the gravity interpretation, the marginal location of the KTB site with regard to the magnetic complex of Erbendorf (see also Fig. 2). Attention should be drawn to the northern horizontally bedded disturbing body with a magnetization of 0.48 A/m. The body is situated within a muscovite-biotite gneiss area in hornfels facies and can be explained by contact-magnetization through the underlain granite. Integrating the 2D models along the separate profiles, 3D bodies were constructed and interactively modeled. The resulting isanomalic contour map (Fig. 10) reflects the prominent measured anomalies (refer to Fig. 2).

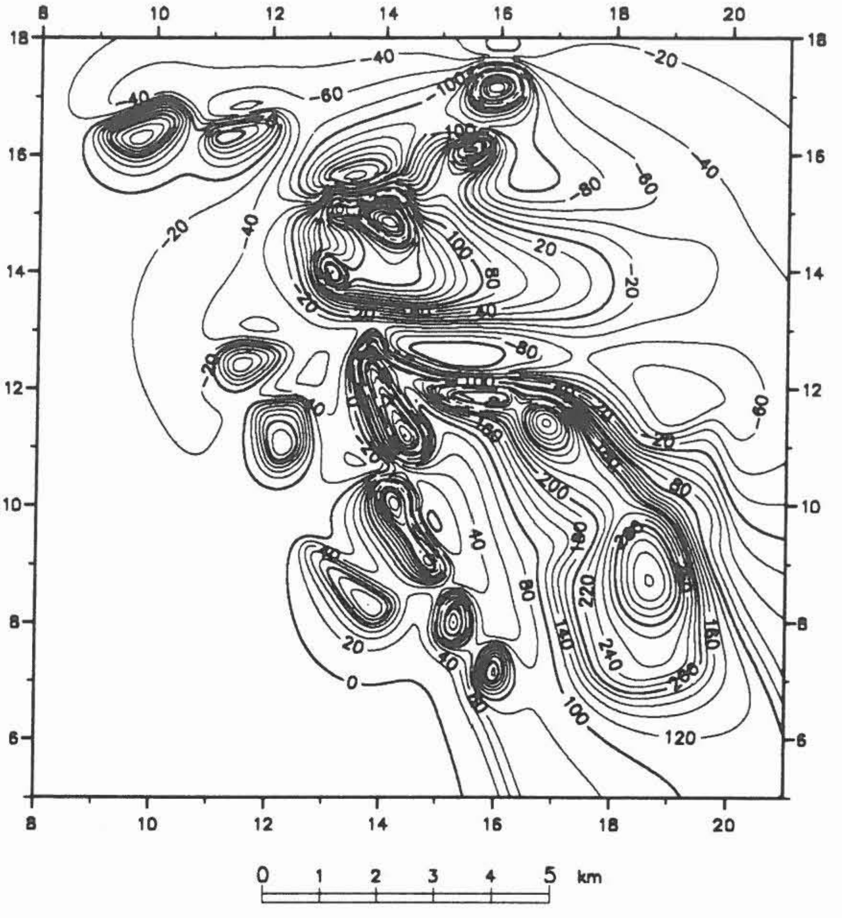

Figure 10: Anomalies of the magnetic total intensity field in the KTB area resulting from the 3D model (compare with Fig. 2).

The 3D model shows that the Erbendorf anomaly could be interpreted by magnetic intercalations in the upper 3000 m. The magnetic discontinuity in a depth of 3.4 km, mentioned above, could therefore be explained by the lower boundary of these magnetic disturbing bodies. Interpretation as the upper surface of the amphibolite body drilled at a depth of 3150 m respectively 3500 m would require an increase of magnetization of this body towards SW, because it has only weak magnetization around the drillhole.

Evidence concerning deeper magnetic structures are provided by borehole magnetometer measurements (Fieberg and Kuhnke, 1993). These show an anomalous increase of the magnetic field strength with depth (Fig. 11). Explanation by a layer of stronger magnetization at greater depth is not possible in this simple way, since a horizontal extended magnetic layer would not cause an anomaly. Anomalies, however, could be found at the edges of such layers as shown in Fig. 12.

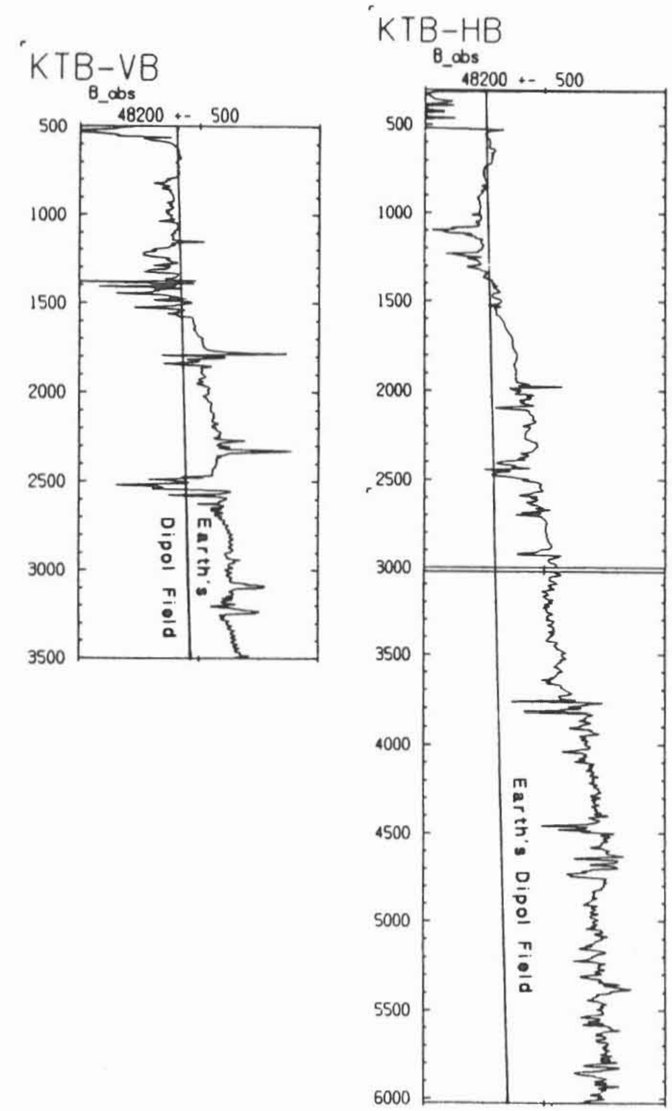

Figure 11: The magnetic field measured in the KTB main hole in comparison with the normal terrestrial magnetic field (after Fieberg and Kuhnke, 1993).

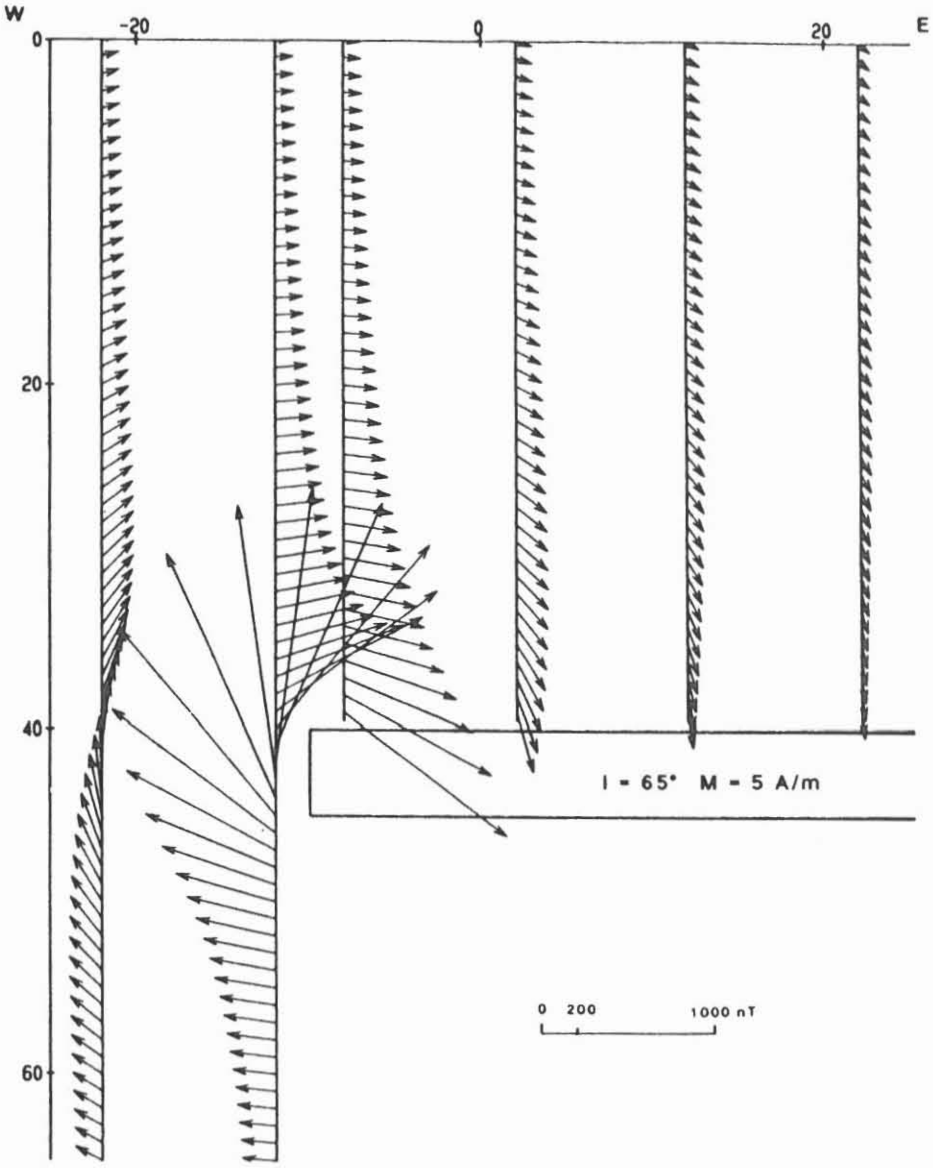

Figure 12: Magnetic anomaly vectors along vertical drillings at the edge of a horizontal magnetic plate.

This model possesses strong analogy with the gravity model of the Erbendorfbody (Fig. 7). To verify this boreholemagnetometer measurements at greater depths are of particular importance.

6 Geophysical thematic mapping by multivariate analysis

Interpretation of gravity and magnetic data could be improved by adding further geophysical parameters using multivariate analysis methods. Additional radiometric and electromagnetic data of the detailed helicopter survey in the KTB area were considered to conduct an integrated lithological/geophysical interpretation in combination with the geologic map (Dill et al., 1991). In detail, the following data were used and included: magnetization (calculated for the surface near area), Bouguer anomalies and their second vertical derivative, U–, Th–, K–radiation and the apparent resistivity for different frequencies.

Fig. 13 presents the result of a cluster analysis (K-MEAN CLUSTER) for ten rock units.

- Apart from the amphibolite zones of Windischeschenbach and Wildenreuth an additional amphibolite with an average lower magnetization can be distinguished, which strikes NW–SE in the West bending towards East in the South of the mapping area. It is best marked at the marginal zone of the granites in the E. A comparable amphibolite type was already mentioned while discussing the gravity and magnetic anomaly maps.
- Occuring granites can be in principle classified in four groups: type 1 and 2 represent the Steinwald/ Friedenfels granites in the N. Type 3 and 4 describe mainly the granites of Falkenberg and Leuchtenberg in the E.
- Granodiorites and/or diorites cover an extended area in the transition zone of the Falkenberg granite complex to the amphibolites in the vicinity of the KTB to amphibolites in the vicinity of the KTB location.

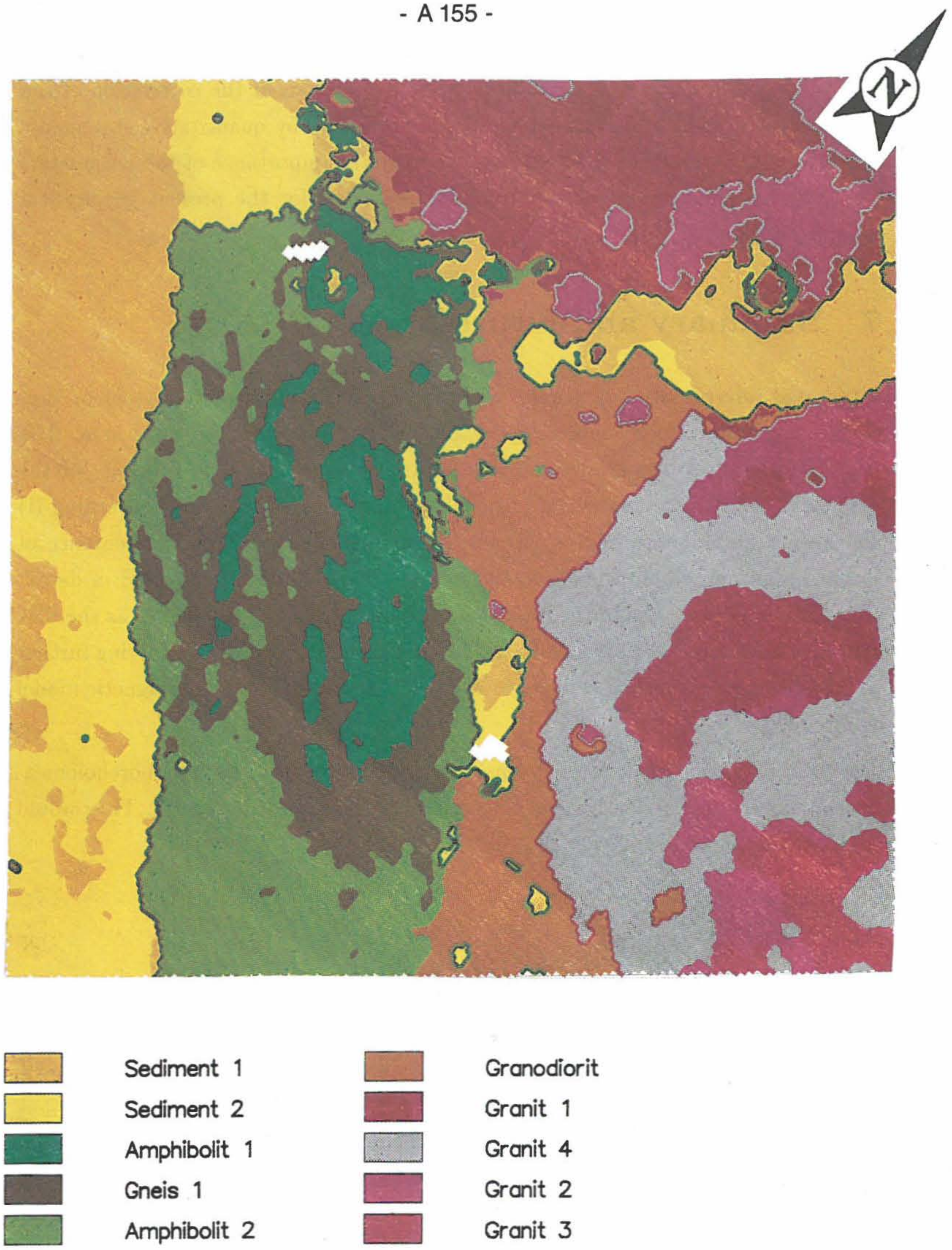

Figure 13: Result of a (K-MEAN) cluster analysis for 10 rock units under consideration of 7 parameters compared with the geological map 1:50000 (after Dill et al., 1991).

Additional information was yielded by the factor analysis of the correlation of the different parameters and the analysis of discrimination by quantitative statements concerning the quality of classification. Thereby the importance of the parameters Th–radiation, magnetization and Bouguer anomalies for the present geophysical mapping is pointed out.

7 Summary and future plans

Integrated interpretation of gravity and magnetic data provides consistent or supplementary information concerning the geological structure of the KTB area. The geophysical models essentially coincide with geologic ideas. The lithology of the drilling is clearly represented. Additional information was obtained concerning (i) the deeper amphibolite bodies, (ii) the Erbendorfbody and (iii) the occurence of granites and amphibolites close to the surface. This has to be discussed in detail. Correlation consists also in the position of prominent seismic structures, as the SE1 and SE2 reflectors. The 3D models will be continously improved considering further geophysical and geological results. In particular a joint 3D gravity/magnetic model is intended.

For the exploration of the deeper crustal region gravity and magnetic boreholemeasurements to the final depth are of essential importance as stated above. They would also reduce the ambiguities of the current models.

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