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THE MAGNETIC ANOMALY OF THE IVREA-ZONE

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Abstract. A magnetic field survey has been made in the Ivreazone in 1969/70. This paper shows the results: A significant anomaly of the vertical intensity is found. It follows the basic mainpart of the Ivrea-Verbano zone and continues to the south. The width of the anomaly is about 10 km, the maximum measures about +800 γ. The model interpretation shows that possibly the anomaly belongs to an amphibolitic body, which in connection with the Ivrea-body was found by deep seismic sounding. Therefore the magnetic anomaly provides further evidence for the conception that the Ivrea-body has to be regarded as a chip of earthmantle material pushed upward by tectonic processes. /283**

Key words: Vertical Intensity of Magnetic Field — Smoothed Curves of Anomaly — Wavelength Filtering — Isolines — Basic Mainpart — Twodimensional Modeling — Best Fitting Model Curve — Induced Magnetization — Susceptibility — Amphibolitic Body.

The Ivrea-zone has been investigated very intensely in recent years from a different point of view. More recent papers on the geophysical, geological-tectonic and petrographic structural conditions of this zone have lead to the view of a vast body reaching far into the depths. The concept of a rock-body, which was sheared off in the region of the Moho-Zone and pushed open sharply to the west over sialic material, is shared today by many scientists.

Such an immense, basic to ultra-basic rock-body in sialic environment would probably produce also a noticeable disturbance of the magnetic field. The survey of this magnetic anomaly can make a contribution to the answering of the questions about shape, location, /284
extent and possibly about the material of the Ivrea-body. Several preceding papers confirmed this supposition:

1. The survey of the magnetic field in the Swiss portion of the Ivrea-zone (Weber, et al., 1949) shows anomalies up to + 1200γ, which run mostly parallel to the layer segments.

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2. Rock-magnetic investigations by Pavoni (1968) and Fromm, et al. (1970) indicate that predominantly above the interference zone, induced magnetism is to be expected. Residual magnetization, on the other hand, appears only with far lesser intensity and is very inhomogeneous.

Planning and Carrying-out of the Measurements

A survey of the magnetic field in the Ivrea-zone had to have the following objectives:

1. Representation of the magnetic anomaly of the Ivrea-zone;
2. Information on the carrier substance of the magnetic field disturbances;
3. Comparison of the magnetic model interpretation with other geo-scientific findings.

Can in particular the concept of a sheared off chip from the confines of the earth's crust-mantle be substantiated in the light of magnetism?

On several field trips, a total of 17 profiles lateral to the direction of the Ivrea-body were measured. A coherent longitudinal profile could not be laid because of the difficult terrain conditions. The profiles with a mean length of about 20 km run along streets, or passable roads and paths. Only this way could the measurements be carried out with a tolerable expenditure of time. Certain curtailments in the continual complete covering of the anomaly had to be accepted. By means of some favorable located profiles, the behaviour, however, was also examined outside of the actual interference zone.

The spatial changes of the vertical intensity were measured with an Askania-torsion-magnetometer (GFZ) and a Jalander-nuclear-saturation-magnetometer. The measuring points had to conform to the terrain conditions. Therefore they could not be laid equidistant. However, a mean interval of 50-100 m on the northern and 100-500 m on the southern profiles were strived for. The choice of these measuring point intervals was made with regard to the information possibility of the measurements. For the recording of the large, deep-seated body, larger intervals of 1000-5000 m would have been sufficient. Thereby the information on smaller spatial fluctuations as well as the possibility for the correlation of the calibration curves with petrographic profiles would certainly have been lost. /286 Strong, small spatial fluctuations appear with interbeddings, basic embedments and above meadering zones.

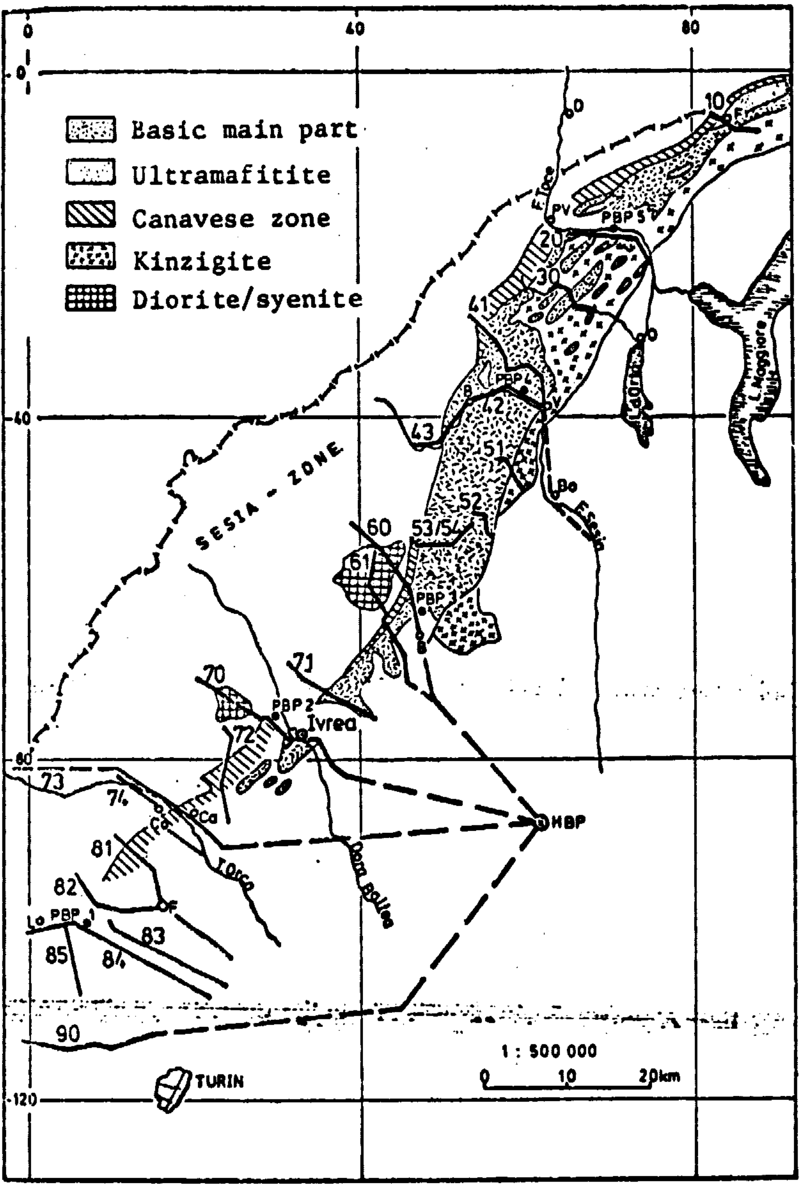

Illustration 1. Geology of the Ivrea-zone and the profile lines of the field measurements.

The individual profiles are entered on the map (Illustration 1).

Preparation and Representation of the Test Data

For the determination of the ΔZ-data from the measured vertical intensity, normal field computations were conducted for several base points within the measuring area. Temporal field interferences were checked by comparisons with variation recordings.

For the representation and interpretation of the magnetic interference field, a separation of the long- and short-wave portions is necessary. Only with adequate distinct anomaly courses can models be constructed and adjusted, which satisfy the test data on the one hand and still convey on the other hand a sufficiently good conception of the body. The data was handled according to two different methods.

1. Smoothing by Convolution with a Triangular Weight Function

With the measurements, not only the test data themselves were observed, but their spatial fluctuations from measuring point to measuring point as well, and afterward their intervals were regulated. With this method there ensues an optimal proportion of information content to the measuring effort.

With the necessary smoothing, the information content should not be lost. A triangular weight function was therefore used which adjusts automatically in its width to the measuring point intervals. With the available data it was deemed necessary and sufficient to cover in each case 11 test points or measuring points per convolution step.

The profile curves smoothed this way are altogether more distinct than the representation of the raw test data. With this smoothing, predominantly foreign interference, in particular, and only very local geological interferences are filtered out. All the important details are preserved for the future and can be better perceived (Illustration 2a, b).

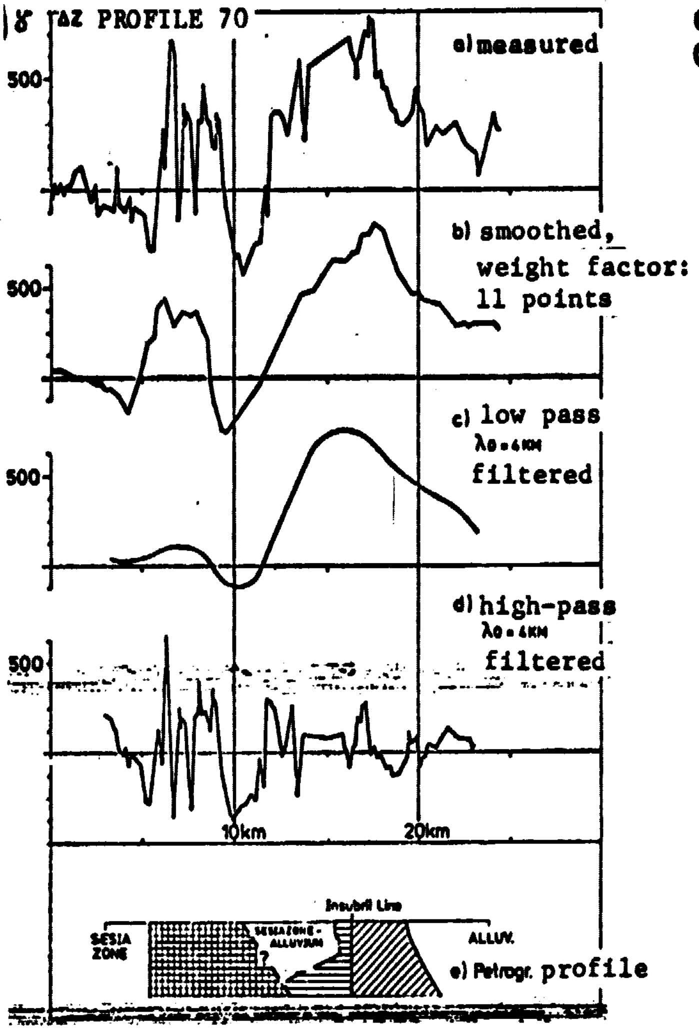

Illustration 2. Comparison of a ΔZ-curve before and after use of different filter methods

2. Smoothing by Filtering

A smoothing of the calibration curve can also be achieved by a wave-length filtering with a low pass filter. With this the short-wave portions of the anomaly are strongly suppressed. It can be shown that this process of the analytical continuation of the potential field upwards is equivalent. With this low-pass filtering and a /287 complimentary high-pass filtering, the separation of the anomaly into its long- and short-wave components can be carried out (Illustration 2c, d).

The smoothing and filtering techniques, requiring intensive computer work, were performed with numerical computer programs which were built for it.

The compilation of the smoothed profiles is rendered in Illustrations 3a and 3b. The individual profiles are drawn under each other from N to S in such a way that the maxima lie on a line. Thus, the /288 alteration of the anomaly curves from N to S are better identifiable.

The Illustrations 4a and 4b show the corresponding isoline maps of the vertical intensity.

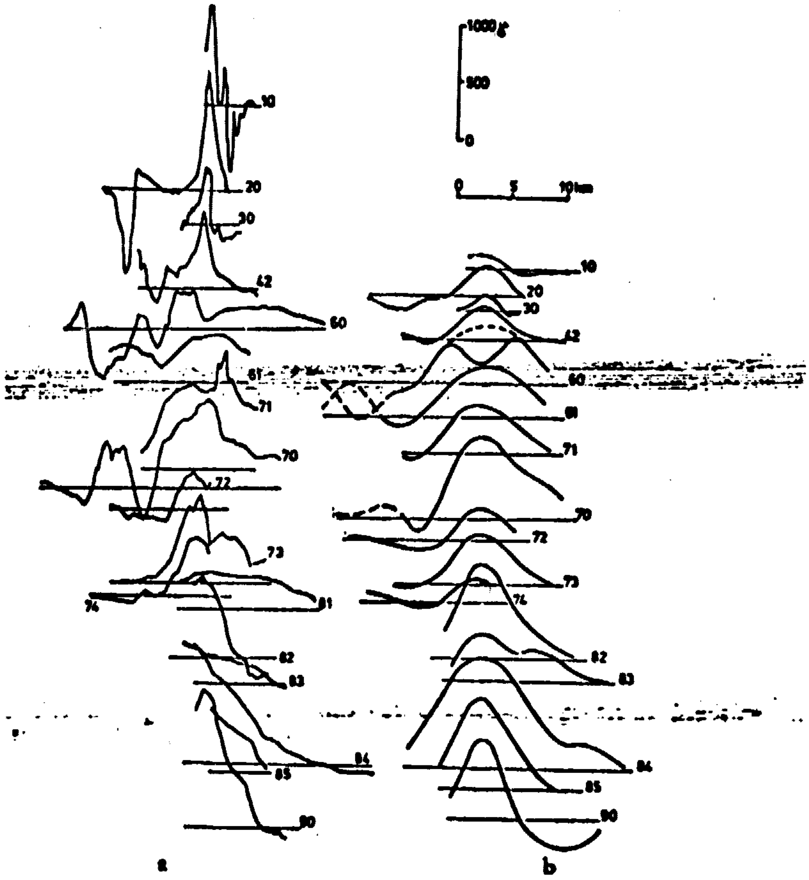

Illustration 3a. Smoothed ΔZ-curves. Weight factor: 11 points

Illustration 3b. Low-pass filtered ΔZ-curves. Limit wave length $\lambda_0 = 4$ km

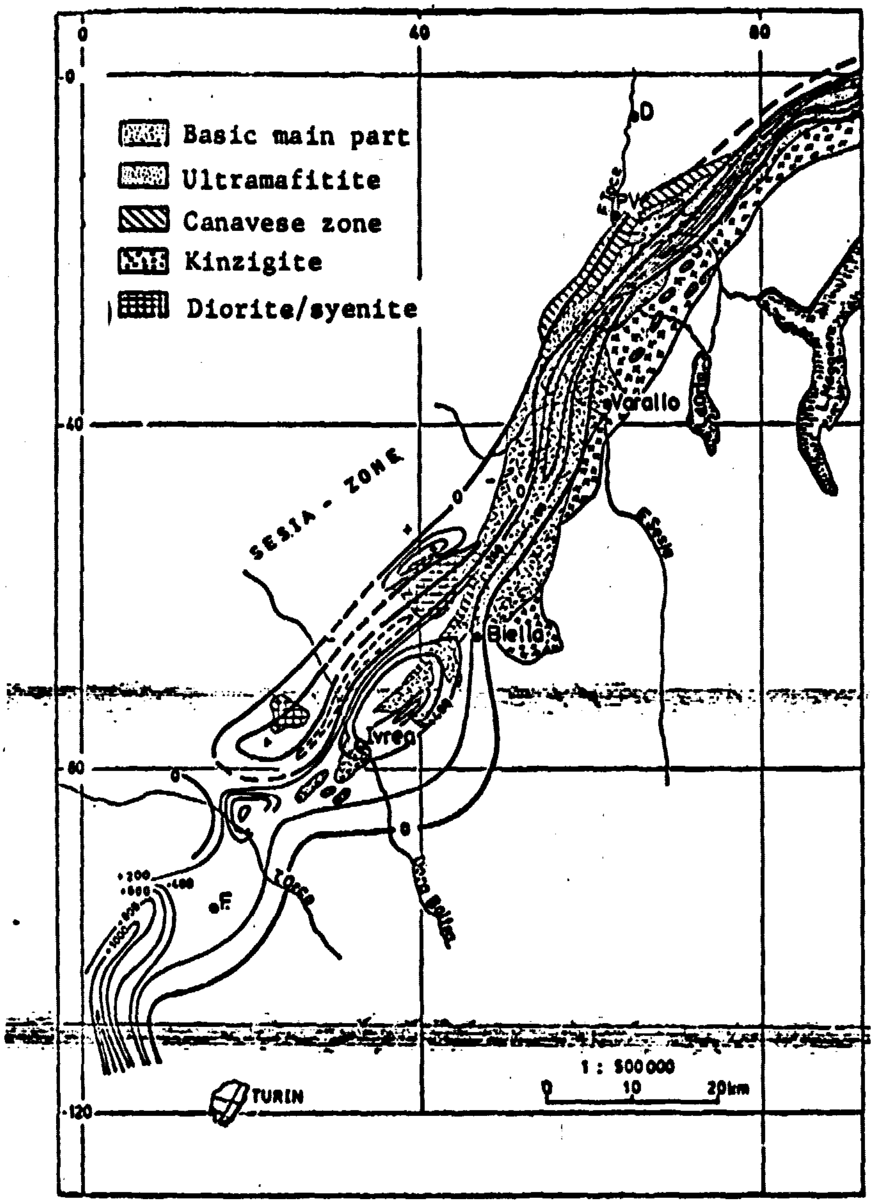

Illustration 4a. Isolines of the smoothed data.

Isoanomalous Maps of the Smoothed Profiles

The anomaly chart (Illustration 4a), which was obtained by convolution, should also contain information on the sources of interference closer to the surface, and therefore it should be correlatable with the geological map of the area. It is recognized that the magnetic anomaly follows the basic main part within the entire zone, indeed somewhat displaced to the SE. As was expected, a detailed chart /291 of the anomaly was obtained by this method. It is organized into

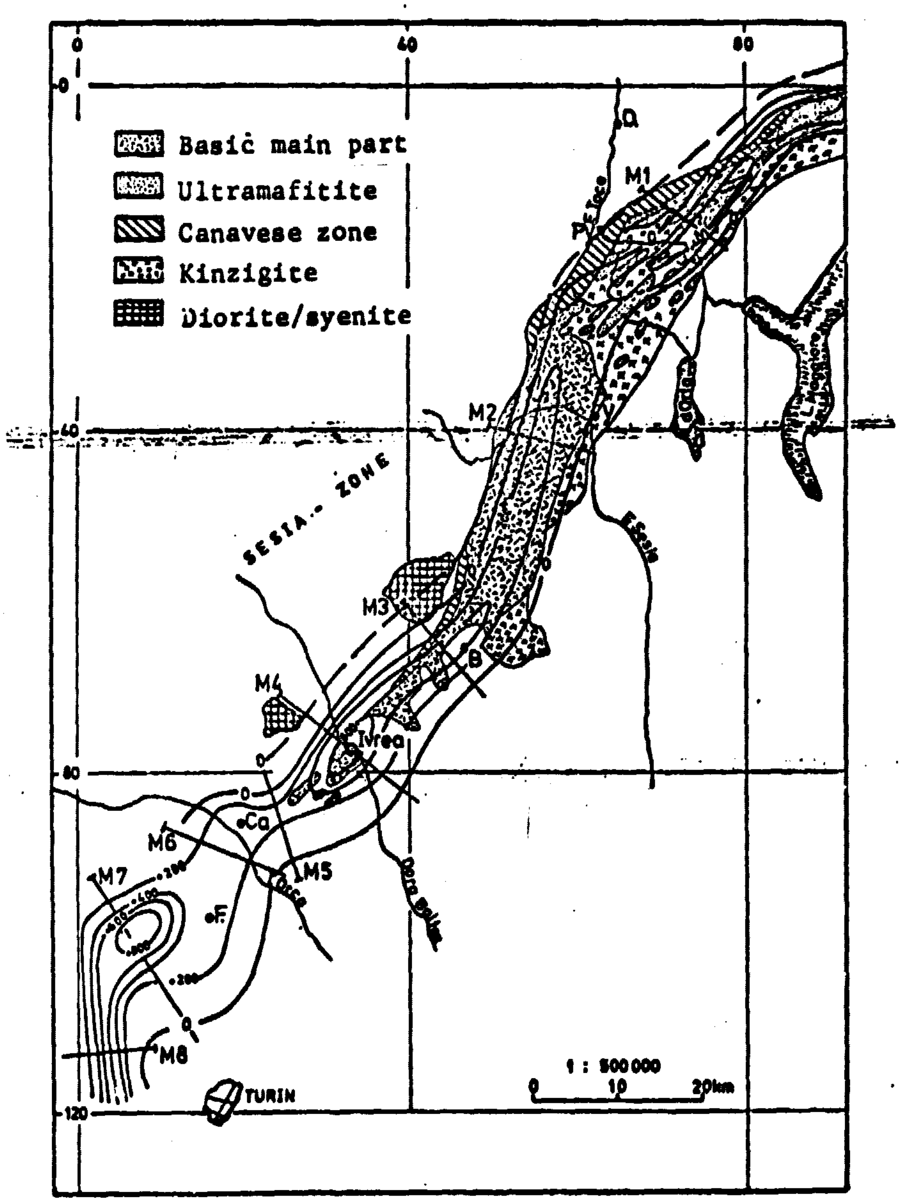

Illustration 4b. Isolines of the low-pass filtered profile curves

four zones:

1. A very homogeneous disturbance (NE-SW direction) forms the northern most part of the anomaly. It reaches from the Swiss boarder to south of Varallo. The maximum value lies at + 600γ. The width amounts to 3-4 km. In the direction of the ends, this partial anomaly is slightly bent and spreads there to over 6 km.

2. After a narrower transitional zone again, an elliptical anomaly area connects between Biella and Ivrea. The maximum value here lies at + 1000γ. With it there appears a shift of the maximum to the SE. From 0 to + 600γ the interference has a strong gradient in the NW and a flat flank in the SE. The data from + 800γ to + 1000γ are superimposed as humps on the disturbance and, therefore, they must be ascribed to an asymmetry on the upper edge of the body.

In this area the negative pre-anomaly in the NW is clear, into which a positive interference is thrust. The pre-anomaly can be considered as an indication of a flatter entry of the Ivrea-body. The positive interference correlates with the syenite of Biella and the diorite of Traversella. The union of the isolines suggests a connection of these two related mineralogical types of rock.

3. A wide transitional zone follows then. A triangular disturbence of + 800γ is centrally located near Castellamonte.

4. The southern most zone was not completely recorded. It is in the center presumably 12 km wide (6 km from the maximum value + 1200γ up to the zero line), provided that it is built up symmetrically vertical to the feature. The symmetry is suggested by the + 800γ and + 1000γ line. It shows a bending of the northern end similar to the northern most zone.

The filtering with the cutoff wavelength $\lambda_0 = 4$ km produces the isoline chart of Illustration 4b. The isolines coincide roughly with those of Illustration 4a. The entire phenomenon is indeed more uniform with the simple smoothed profiles. The compactness of the anomaly is more strongly manifested. However, here too the structuring into the four zones is possible as described above.

Conspicuous is an apparent propagation of the first zone and a diminution of the width in the second zone. This effect may not be ascribed, however, to a forming effect of the filter. In this regard investigations were conducted. They showed that with the filtering, only the interferences by sources in a small volume and close to the surface are filtered out, while the long-wave disturbance /292 field is only negligibly altered. By the selection of a digital filter, which cuts off very sharply, the long- and short-wave portions of the calibration curve could be separated so loss-free that with a trial addition of the two components, nearly the original calibration curve could be obtained again.

In the analysis of the high-pass filtered profiles (see below) it is determined, in addition, that the northern calibration curves and their high-pass filtered ΔZ-curves show strong structural similarities. This indicates that there the main portion of the interference is caused by sources which are in a small volume and close to the surface. The deep body produces only a relatively weak but widely blurred, hence long-wave interference field. Since it can be assumed that the deep body is formed relatively homogeneous, a rather constant width of the anomaly appears understandable.

Summarizing, the following assessment of the long-wave anomaly can be given:

The zero line surrounds the entire anomaly. Likewise, the + 200γ line can be drawn continuously. The partial disturbances, as they were described above, have to be considered, therefore, as a closed whole anomaly. The pattern which is being produced in these representations could be contingent upon a tectonic shearing of the body. The bends in the direction of the anomaly and the symmetry behaviour point this out. Also a variable strong collapse of the partial bodies could cause this pattern.

While the first and second zone in the middle follow the same feature direction, the fourth runs in a N-S direction. This strong bending begins in the wide transitional zone 3. The small enclosed disturbance there indicates a fragment. A possible existing vertical shearing (the model computation must furnish the proof) takes place presumably in several small fissures. Obviously there is also a rotation of horizontal shift, as the sharp bending of the fourth zone demonstrates.

Both representations confirm the information of the seismic and gravitational methods in that here an extended, relatively intense anomaly is likewise found. The magnetic interference is, however, somewhat displaced to the SE. In addition, a stronger disturbance pattern can be identified. This applies in particular to the upper part of the body.

Information of the High-Pass Filtered Profiles

The high-pass filtering is an interpretation aid for the isoline charts. In this connection the knowledge is utilized that the test data fluctuations in magnetically disturbed zones become large, chiefly in the fringe areas. The short-wave ΔZ-curves give some /293 information on sources which are adjacent or lie close below the Earth's surface. In addition, this component of the calibration curve can shed light on the character of the upper edge of the body.

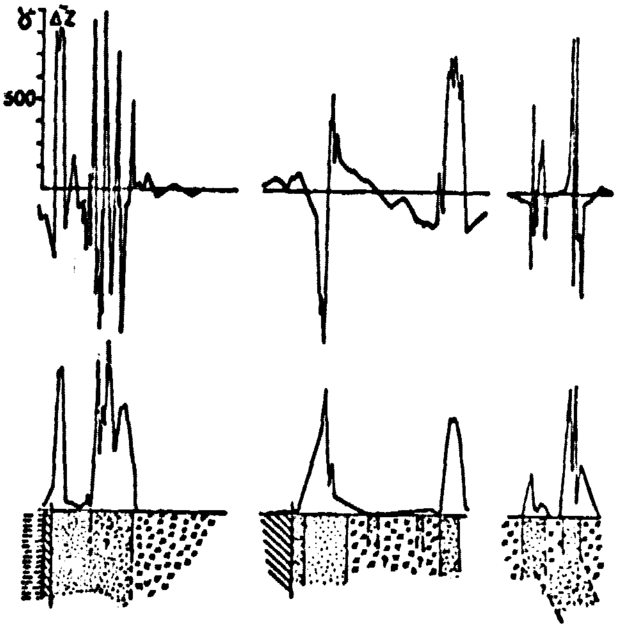

Illustration 5. Example of three high-pass filtered profiles (above) and correlation of the effective value curve with the petrographic profile (below

☐ Basic main part
▭ Ultramafitite
▨ Canavese zone
▦ Kinzigite
▤ Sesia zone

Illustration 5 shows three typical representatives of these short-wave profile curves. Under each other were plotted the high-pass filtered ΔZ-profile, an effective data representation of this curve and the corresponding petrographic profile.

As a restriction it must be said, that the high-pass filtered profile curves contained all the test and evaluation errors and falsifications of test data.

The northern profiles 10-74 show a similar structure as the calibration curves. From this, the conclusion can be drawn that they contain essential information on the body and the shape of the upper edge.

The correlation of these high-pass filtered ΔZ curves and their effective data with the petrographic profiles reveals a clear coordination of the areas of large data fluctuations with ultramafitite and, especially, with basic rock. The insubric line is portrayed particularly clearly in the effective data. /294 From this it must be concluded again that in the north, the Ivrea-body reaches up more closely to the surface, ultimately up to the ultramafitite body of Finero. Also, these short-wave ΔZ-curves do not permit a uniform anomaly to be identified, but rather only areas of stronger or of increased fluctuations which correlate with the basic main part. From a magnetic view, this signifies an irregular top edge of the body. Above the compact body, intrusions and chips can be found. The adjacent ultramafitate lenses seem to have them also (Lensch, 1968a).

The effects found decrease in intensity from north to south. Since it can be discerned, however, with the profiles 10-74 that the high-pass filtered ΔZ curves are smooth above the Sesia and Canavese zone and above the sediments of the Po plane, maxima and peaks of the effective data can be interpreted as reference to the coarseness of the body surface for the lesser pronounced southern profiles.

According to these findings, the magnetic Ivrea-body has to be accepted as being frayed, splintered, and alternating with the adjacent material. This agrees with the conceptions on the upper edge of the body which were derived by Lensch (1968a) from petrographic findings.

Model Calculation

Up to now only the phenomenon of the magnetic anomaly was presented and discussed. Now it is only a matter of combining this with the remaining indications of the disturbance zone to complete the picture of the Ivrea-body. From all available knowledge and from the anomaly image of the magnetic data, the shape and the intial parameters of a model body are established.

Basically, we have to make a distinction between two groups of parameters:

1. geometric parameters which affect the character of the anomaly curve, and

2. material parameters which affect the amplitude — hence the intensity of the anomaly.

In regard to 1. The relative large longitudinal dimensions of the anomaly permits a two dimensional model treatment. If the position of the seismic (Berckhemer, 1968) and gravimetric (Kaminski and Menzek, 1968) models and that of the magnetic anomaly according to Illustrations 4a and 4b are considered, then it is conspicuous that the magnetic field interference forms only above the east flank of the Ivrea-body. A simple computation shows that the seismic and gravimetric models, considered as magnetic bodies, would produce a substantially wider anomaly (about 25 km) than the measured one (about 10 km). Since a substantial deviation from the normal field is not discernable northwest of the found anomaly, the magnetically effective portion of the body complex must be less powerful and has to be sought on the southeast flank. Altogether, we can proceed from a basic form of a diagonally placed slab. As initial data of the geometric parameters, the width with 2.5 km on the upper edge, the depth position of the upper edge and the angle of inclination corresponding to the seismic and gravimetric models, were assumed. /295

The intensity of the magnetization is proportional to the susceptibility of the material in question. For this, different data can be assumed.

For peridotite, a value can be computed according to a relation between the composition of the material and of the susceptibility which was stated by Nagata (1961). These data for the tests, which were analyzed by Lensch (1968b) range between $\varkappa = 9 \cdot 10^{-3}$ (pyroxenite) and $25 \cdot 10^{-3}$ (olivine-pyroxenite). Hornblende-peridotite and phlogopite-peridotite have susceptibilities of about $23 \cdot 10^{-3}$. They correspond to literature data which can be found in other references.

Rock magnetic investigations (Fromm et al., 1970) show, on the other hand, for peridotite of the Ivrea-zone only susceptibility data of $0{,}12 \cdot 10^{-3}$. With these low values, a very powerful body as source of the measured anomaly would have to be assumed. These disturbances, which can be computed in this manner, would be, however, far wider than the measured ones. Also, for the computable susceptibility data, no satisfactory models and anomaly curves can be attained. These data again are somewhat too high.

For biotite-amphibolite, susceptibility values of $10 \cdot 10^{-3}$ were measured by Fromm (1970). For gabbrodiorite, Pavoni (1968) alleges an equally large value.

Along with the composition of the rocks, the temperature also exercises an influence on the magnetization. With a normal temperature gradient the Curie point will be exceeded at a depth of about 20 km. This consideration leads to a limitation of the magnetic effective body downward.

A computer program enables the automatic adjustment of the model parameters by way of comparison of the respective model anomaly with the measured disturbance. This computer system is based on a work of Bosum (1968). The basic principle lies in an adjustment on the basis of the smallest least square sums. In every case, optimization is performed using the partial derivatives of the parameters. Inclination of the slab, thickness of the slab, depth of the upper edge and position of the middle of the upper edge in the profile are adjusted. /296

The position of the body relative to the profile was fixed after a few optimization steps. Thus, the deviations of the computed and measured anomaly affected the remaining important parameters. For the relative inaccurate purported susceptibility, it was calculated with fixed data $(1\cdot10^{-3}, 5\cdot10^{-3}, 10\cdot10^{-3}, 15\cdot10^{-3})$. The geometric parameters are very definable from the standpoint of the method, but they have to be seen and assessed within the framework of the relatively inaccurate assumptions and presuppositions of the total situation. The comparison with the overall picture of the anomaly allow the found models to appear defendable.

Results of Model Calculation

Illustration 6 shows the individual model curves in comparison to two smoothed profile curves. It can be very clearly recognized that the susceptibility data $5\cdot10^{-3}, 10\cdot10^{-3}, 15\cdot10^{-3}$ can be considered as being equally justified. For $1\cdot10^{-3}$, there results generally a very large body; an adequate agreement with the measured anomaly will, however, by no means be attained. The good adjustment with three susceptibility values does not make it possible to narrow down the geometry of the body more. For the depth of position of the upper edge, there appears, however, with all the profiles a slight freedom of movement. The angle of inclination can be considerly largely as constant.

It is a different matter with the width of the body. Here the magnetization ratios is reflected in the first approximation in the inverse sense. That has to be expected, too, from the physical standpoint. While the character (gradient of the anomaly flanks, symmetry, minimum to maximum relation) is determined by the slab's angle and depth, magnetization (as factor) and width (massiveness) affect the intensity of the anomaly. The width also possesses a forming influence.

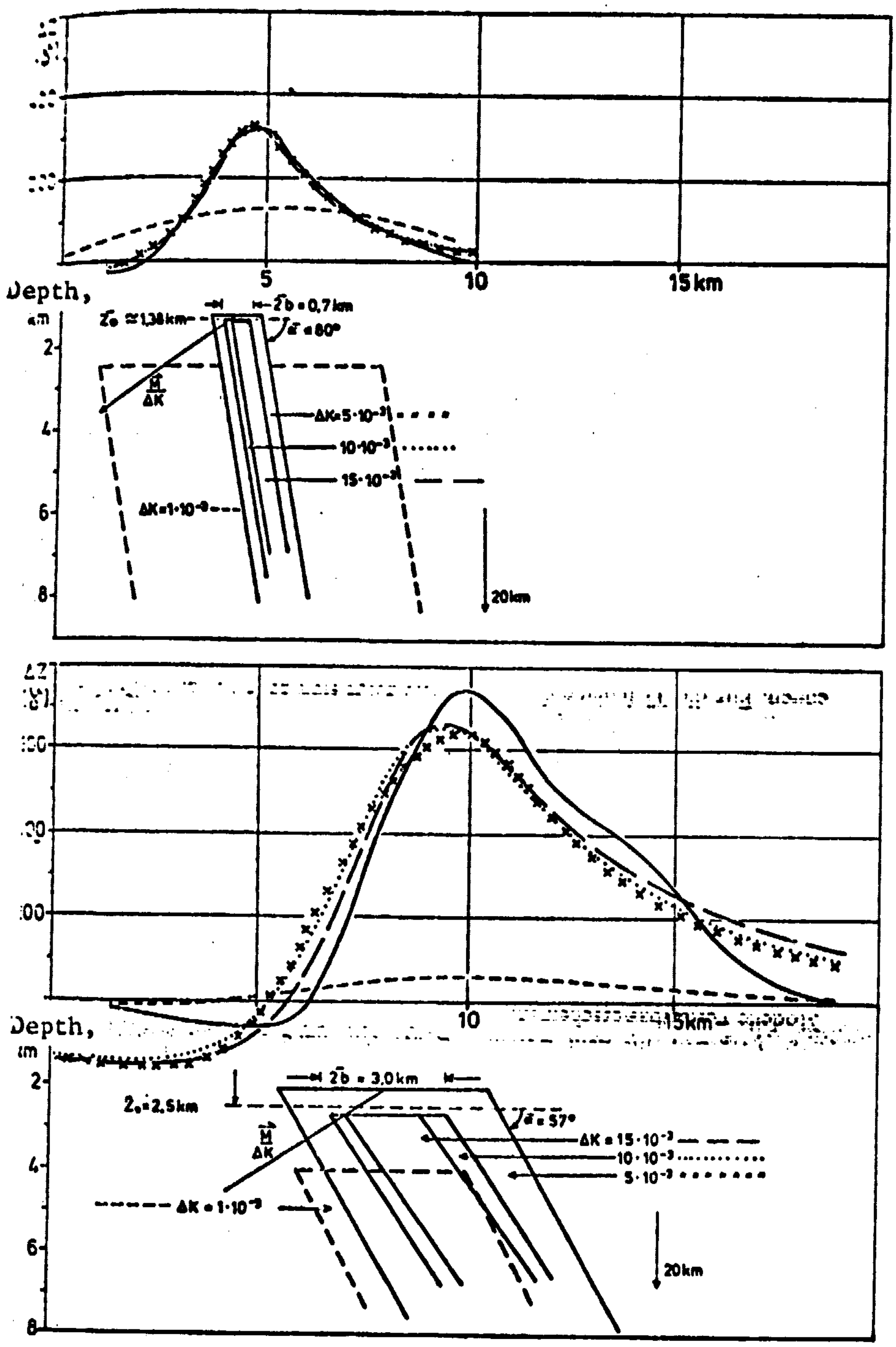

Figure 6, a and b. Models with magnetic field

According to these results and considerations, depth, angle of inclination, and position of the body are determined relatively exactly. For the magnetization and width, on the other hand, only the range of a possible value can be stated. Likewise, the lower limitation of the body takes are uncritical at 15 or 20 km.

The model is a relatively narrow, steep, upright slab. The upper edge and width show light fluctuations. From north to south a trend of increasing depth and width is unmistakable. The body is /298 limited downward by the Curie temperature which is exceeded at a depth of 15 - 20 km. This picture becomes discernible in the representation of the depth contours (Illustration 7). The tipping over of the slab between profile M5 and M6 is striking. In this area a distinct interference in the isoline diagram is identified.

Summarizing Assessment

The clearly identifiable magnetic anomaly agrees with the basic main part, the geologic anomaly, both in its long-wave and in the short-wave components. It can therefore be assumed that in the south of the test area, basic to ultrabasic material can be found under the alluvial sediments. The isoline charts of the anomaly permit, within the limited framework, limited information on structure and position of the body which is closely connected with the adjacent material. The model calculation shows a closed body lying at a depth of 2 - 3 km, presumably out of amphibolite. It can be traced magnetically to about 20 km.

The deviation of the seismic from the magnetic body, which was established above, was underlined by the computed model slabs. Even with the large fluctuation range of the possible susceptibilities, no magnetic body can be found which coincides with the seismic and gravimetric models. How can a connection be established nevertheless?

With this question, the zone of recent Anatexis, which was postulated by Giese (1968) and Berckhemer (1968), to the northwest

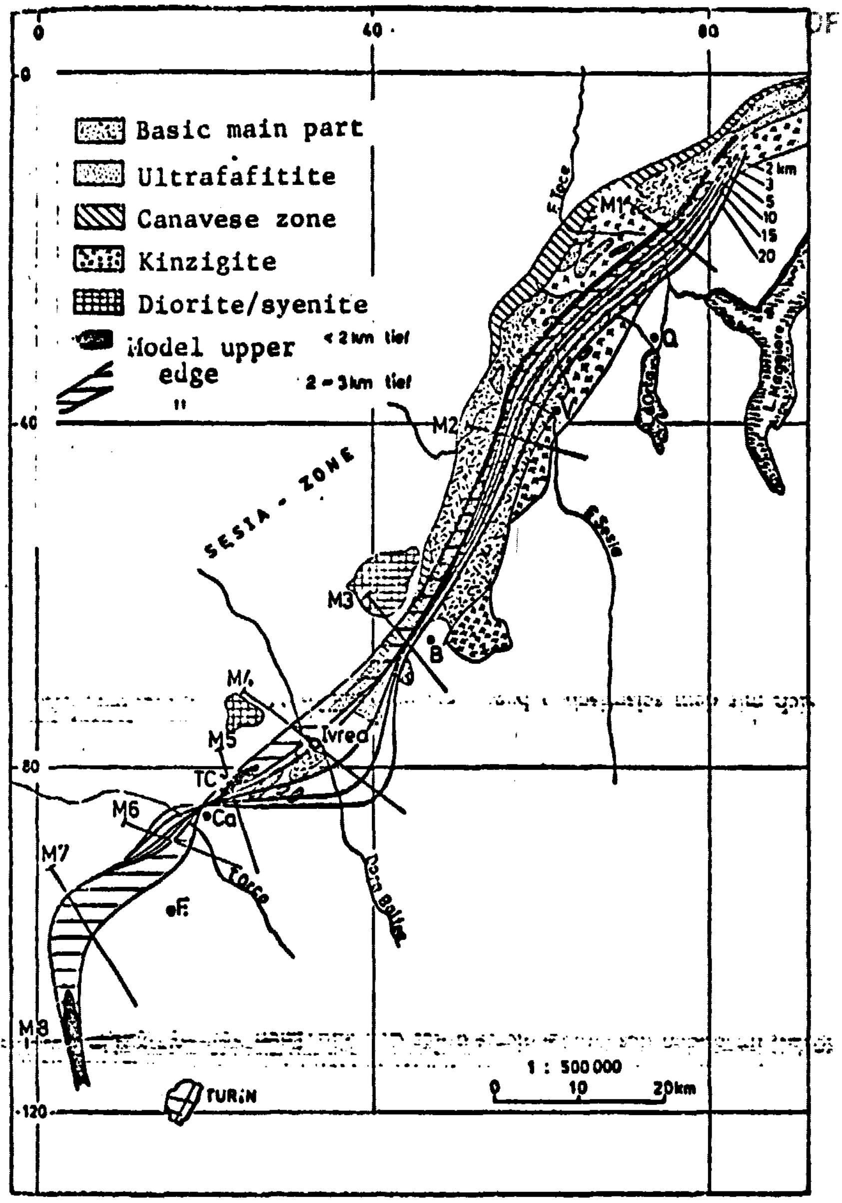

Illustration 7. Depth contour plan of the mean magnetic Ivrea-body

under the Ivrea-body, may not be left out of account. At over 700° C, the northwest flank of the Ivrea-body would possess a temperature above the Curie point and thus also would not be magnetically effective. It appears nevertheless questionable whether the seismically found body alone for this reason would be reduced to the found magnetic model body. This explanation appears too speculative.

The problem is solved quite directly, on the other hand, if biotite-amphibolite is considered as the source of the magnetic interference. This material furnishes for the susceptibility the desired value (see above), and amphibole and hornblende-peridotite appear predominantly on the SE flank of the seismic disturbance zone. Comparable widths (Schmin in Lensch, 1968a) are also found in adjacent areas with the found models.

The magnetic anomaly is applied by this means to a certain component of the whole body complex. This does not contradict the results obtained seismically and gravimetrically, since these are /300 related particularly to the high densities and seismic velocities characteristic of the ultrabasites. The magnetism confirms therewith the hypothesis of a steep Earth crust section and furnishes clues for the structure of the lower crust. An interspersing, scaling, or interbedding of peridotite with amphibolite can be identified from the deviating inclination of the slab from the seismic boddy (Illustration 7).

The isoline and depth contour charts indicate that the slab shows signs of tectonic stress, which are also confirmed by the models by tipping over.

The model slab can be considered only as a basic model. The upper edge in particular will in reality be substantially more multiform than it is assumed in the model. The short-wave portions allow magnetic material to be identified also above the body up to the Earth's surface.

This investigation was conducted within the framework of the stressed program "Project Earth Mantle" with financial support by the German Research Association. The suggestion for this paper originated from Professor Dr. H. Berckhemer, whom I also thank for the critical reading of the text. The first test results were obtained in 1969 on the occasion of a field trip of the Frankfurt University Institute for Meteorology and Geophysics. Mr. K. Lorenzen and Mr. N. Mertz participated in further field work. I thank Mr. W. Mahler for the completion of the drawings. Further details on the test data and method of treatment can be found in

the diploma thesis of the author, which was submitted at the Institute for Meteorology and Geophysics of the University of Frankfurt (1973).

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