BUNDESANSTALT FÜR BODENFORSCHUNG

Aeromagnetic Survey in Afghanistan 1968

Text

Airborne Magnetometer Survey

in the

Kingdom of Afghanistan

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Date: February 26, 1968

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BUNDESANSTALT FÜR BODENFORSCHUNG
Hannover

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Summary of the results and conclusions for the exploration on mineral deposits

A. Introduction

By decree of the Bundesministerium für Wirtschaft (Ministry for Economic Affairs of the Federal Republic of Germany) - III A 3 - 96 02 91/6 of December 7, 1965, the President of the Bundesanstalt für Bodenforschung was authorized to arrange for aeromagnetic measurements in the southern part of the Kingdom of Afghanistan, in order to explore the depth of the sedimentary basins and thus to supply data for a possible future exploration on oil.

The airborne magnetometer measurements were performed by the firm of PRAKLA G.m.b.H., Gesellschaft für praktische Lagerstättenforschung, on behalf and under the supervision of the Bundesanstalt für Bodenforschung (BfB) from August until December 1966; subsequently they were interpreted by BfB. This interpretation of the measuring data was done with the most modern methods by using computers.

The present report gives the results of these aeromagnetic measurements. The most important of them is the fact that in the survey area there exist two troughs with especially thick sedimentary fills which preferably may be considered for a future oil exploration. In contrast to earlier concepts it was found that the western part of the Hilmend Depression shows a bedrock lying under but a minor overburden and possibly belonging to an "old block of crystalline rocks". Detailed investigations on occurrences of magnetite ore in the region of the Kuh-i-Khan Nashin did not yield any clues to economically interesting deposits.

B. Contributions of the airborne magnetometer survey to the investigation of the geological structure of Central and South Afghanistan

The interpretation is based on results of supplementary rock-magnetic investigations in the field and the laboratory. According to them, Tertiary volcanites, ophiolites, diorites and partly granites possess higher magnetizations (cf. Table 1). The metamorphic rocks of the epizone and partly also of the mesozone are nonmagnetic, only in the range of the meso/katazone stronger magnetizations can be recorded. Consequently, the interface magnetic/nonmagnetic regionally comprized by the aeromagnetic measurements within the region of the basement approximately corresponds to the interface meso/katazone. For determining the thickness of the sediments from the calculated depth of the magnetic basement (cf. contour maps, Encls. 11 - 16) it is therefore necessary to consider the component of the nonmagnetic crystalline. In the area of the Sharistan Swell, its thickness amounts to about 3 000 m.

The geophysic/geological interpretation of the measuring data, too, is based on the results of the geological mapping in the survey area, which were prevailingly elaborated by the German Geological Mission in Afghanistan. Accordingly, the survey area is divided into the following major units (Fig. 3):

- Zone of Kandahar, situated in the center of the survey area, characterized by sediments of smaller thickness and by the frequent occurrence of magmatic rocks.

- Central region, with two sedimentary basins (Ghor Basin, Rosgan Basin)and swell regions (Central Afghan Swell, Sharistan Swell).

- Southeast Afghan Trough, in the eastern part of the survey area, with a thick sedimentary fill consisting of Tertiary and possibly Mesozoic layers distributed in the deeper underground.

- Hilmend Depression, in the western part of the survey area, a region of large deserts in the South and Southwest of Afghanistan which because of its inaccessibility has not yet been geologically explored to such an extent as the other parts of South Afghanistan. In the Hilmend Depression, in the zone of the earth's surface, loose sediments of the Neogene and the Quaternary are regionally widespread. Before the airborne magnetometer measurements were started, the deeper underground was unknown.

The information on the mentioned geological major units are supplemented by the results of the aeromagnetic measurements in the following way:

The Zone of Kandahar

The plan of isanomalies shows a great number of local anomalies with partly a strong amplitude. A great part of the anomalies is caused by ophiolites, granites and granodiorites, respectively. By means of the course of isanomalies, the boundaries of these intrusive bodies can be given. Important structure lines are the Chaman-line which forms the border to the Southeast Afghan Trough, the Mukur fault and a second structural element running 50 km north parallel to this fault.

The Central Region

A narrow measuring strip taking its course from Kandahar to the Northwest crosses at first the Rosgan Basin, then the Sharistan Swell and the Ghor Basin, and finally ends at the Central Afghan Swell. These individual structures stand out clearly in the map of isanomalies. The calculation of the relief yielded a depth of the magnetic crystalline of approximately 5 000 m below surface in the Rosgan Basin.

As is shown by the method of harmonic analysis, the magnetic field above the Ghor Basin does not contain any components stemming from the deeper underground, i.e. from the magnetic crystalline. Therefore, a quantitative relief computation cannot be made. Thus the magnetic crystalline must lie in so great a depth as to render the detection by measurements impossible. The degree of deepening could be estimated in the area of the Central Afghan Swell. The latter constitutes an upwarping of the magnetic crystalline. In this connection it was found that the crystalline here dips steeply to Southeast as far as to a depth of more than 10 000 m. In the range of the Sharistan Swell, where nonmagnetic metamorphic rocks are exposed, their thickness amounts to about 3 000 m according to the results of interpretation. From the depth position of the magnetic basement, under consideration of the nonmagnetic crystalline, sedimentary thicknesses can be derived which in the Rosgan Basin amount to about 2 000 m only, in the Ghor Basin, however, to about 10 000 m.

The Southeast Afghan Trough

The Southeast Afghan Trough is dominated by a weak large-scale anomaly near Zarghun Shar. The interface of the magnetic crystalline is situated in the deepest part of the trough, approximately 9 000 m below terrain, and ascends to upwarpings of about 6 000 m (below the earth's surface). Considering a nonmagnetic crystalline of 3 000 m as in the Central Region, sedimentary thicknesses of 6 000 m are ascertained in the deepest part of the trough, and of 3 000 m within the region of the strongest upwarping near Zarghun Shar.

Apart from the determination of the sedimentary thicknesses, an essential result of the airborne magnetometer survey is the determination of the course of the deepest part of the trough. Of importance is, additionally, the proof of several intermediate depressions and upwarpings in the zone of the Southeast Afghan Trough.

The eastern boundary of the Southeast Afghan Trough is formed by the strong anomalies in the area of Khost; they have their origin in near-surface bodies (ophiolites) as well as in deeper-seated bodies (crystalline). Consequently, the region possesses features similar to those in the Central Swell of the Indus-Baluchistan Geosyncline called "Zone of Quetta" or "Axial Belt" (cf. Fig. 3). It may be regarded as their continuation to the Northwest. Furthermore, the course of the isanomalies indicates a connection between the Southeast Afghan Trough and the Potwar Basin in West Pakistan farther in the East, which is known by its oild fields.

The Hilmend Depression

The western survey area differs strikingly from those discussed so far. Anomalies with strong amplitudes determine the outer appearance. The evaluation of measurements involves two possibilities for interpretation. In the first case, the interpretation is based on a magnetization of 200 γ, which corresponds to basic rocks. Thereby the interface magnetic/non-magnetic crystalline shows so strong an undulation that it cannot be interpreted as the relief of the basement. On the other hand, this circumstance can be interpreted as an indication of strongly magnetic bodies (basic intrusions) interspersing a "block" of non-magnetic (crystalline) rocks (cf. Fig. 2 b). This interpretation is supported mainly by the appearances of anomalies above old shields such as Canada, Brazil and Scandinavia, which are comparable with the present results of interpretation. The second possibility for interpretation, a minor undulation of the interface magnetic/non-magnetic crystalline at a higher magnetization (400 γ) (cf. Fig. 2 a), is less probable, because metamorphic rocks seldom reach such values of magnetization; it can, however, not be excluded. The depressions and upwarpings of the magnetic basement, calculated in this case, which may indicate sedimentary troughs, would however possess a comparatively small spatial extension.

The first possibility for interpretation is much more likely from the geophysical point of view. With this interpretation it can be assumed that in the region of the Hilmend Depression, under just a thin overburden of about 2 000 m, there exists an "old Block" of crystalline rocks, which means that only minor sedimentary thicknesses of a maximum of 2 000 m are to be expected here.
Most remarkable is the course of ths structure elements (cf. Fig. 13). Their direction is partly N-S, partly E-W, whereas the direction SW-NE predominating in the remaining survey areas is to be observed only subordinately.

C. Conclusions for oil exploration

A comprehensive discussion of oil-geological problems concerning the southern part of Afghanistan will be contained in a special report of BfB. For this reason only geophysical results essential for such a study are dealt with here.

One of the prerequisites for the formation of oil-fields is the presence of large sedimentary troughs with parent and reservoir rocks for hydrocarbons, and a favourable tectonic structure. As is described in detail in chapter 2 of the Main Report, magnetic measurements are apt to give evidence of the position, extension and depth of sedimentary troughs. Likewise statements on the structure and the trend of faults are made possible. On the other hand, the oil prospectivity of a region is restricted by the occurrence of extensive magmatic intrusions and extrusions. For this reason, the knowledge of the regional spread of magmatic rocks is of decisive significance for the valuation of oil-promising areas. In general, these rocks differ from the sediments by their higher magnetization. Thus, regional magnetic measurements such as described in the report are indispensible for the location of position and size of higher-magnetized magmatic rock bodies in the underground.

A compilation of oil-geologically interesting results yields the following: Large sedimentary thicknesses exist, for one, in the region of the Southeast Afghan Trough. Of importance is the course of the deepest part of the trough as shown in Fig. 13. The sedimentary thicknesses in the trough may come up to 3 000 m (in the anticlinal zones), up to 6 000 m (in the synclinal zones). The trough is subdivided into a number of smaller secondary (minor) troughs. Additionally conclusions on possibly existing structures of oil-geological interest in some zones of the Southeast Afghan Trough (near Wazi Khwa, Sarafsar and Urgun) can be derived from weaker anomalies that can be attributed to magnetic sediments.

The most considerable sedimentary thicknesses are to be recorded in the Ghor Basin. The magnetic crystalline in this place has subsided to such a depth that its anomalies lie below the detection limit. Estimations indicate a sedimentary thickness of approximately 10 000 m. In contrast to this, the Basin of Rosgan has a minor sedimentary thickness of only 2 000 m.

In valuating the oil prospectivity of the western survey area, i.e. the area of the Hilmend Depression and that adjacent in the Northwest, two geophysical possibilities for interpretation are to be observed. Following the first more probable one, a "block of crystalline rocks" is situated in the underground below an unessential overburden of about 2 000 m. Such small sedimentary thicknesses exclude, as a rule, the possibility for oil accumulations. A second geophysically less probable possibility lies in the interpretation of measuring results by a great number of deepenings in the crystalline, that is possible sedimentary troughs which, however, reach longer extension only Northeast of Juwain and East of the Kuh-i-Khan Nashin (approximately 50 km x 30 km).

The most important results of airborne magnetic measurements are therefore the proof of large sedimentary thicknesses in the Ghor Basin and in the Southeast Afghan Trough, and the traces indicating crystalline rocks below just a small overburden in the underground of the Hilmend Depression. Accordingly, the Ghor Basin and the Southeast Afghan Trough are the very regions to be suggested for a possible future oil exploration on the basis of results of airborne magnetic measurements.

D. Conclusions for the exploration on ore deposits

In the region of the Kuh-i-Khan Nashin, a detailed survey for potential iron ore occurrences was carried out since here magnetic ore samples (mineralized limestones in volcanic ejecta) were found. The magnetic survey did not yield any indication of an economically interesting occurrence.

In the remaining areas, the emphasis of investigations was laid on the detection of the crystalline underground which conditioned a greater flight height and a larger spacing between profiles. Here, a chance for the proof of profitable magnetite deposits is given only in the immediate vicinity of the profiles. Yet in the region of Kandahar no anomalies have been discovered pointing to such occurrences. It is, however, to be observed that the magnetite and also lead/zinc occurrences known in this region are obviously bound to the magnetic granite massifs (cf. App. 14), so that their magnetic mapping may serve as a basis for a prospection on ore deposits.

An exceptional position has the anomaly of Chakansur in the western survey area. Its amplitude amounts to 1 500 γ at a flight height of about 1 500 m above terrain. For their interpretation, a body with a very strong magnetization must be assumed in the underground. It is possible that a strongly magnetic basic rock, for instance gabbro, is concerned; but in view of the extremely strong anomaly - despite the great flight height - the occurrence of magnetite ores is even more likely. Owing to the considerable spacing between profiles, an exact depth figure cannot be given for the strongly magnetized body. It is to be reckoned with at least 1 000 m depth so that an economic utilization of possibly existing magnetite ores is hardly feasible under the present conditions.

Airborne magnetometer survey in Afghanistan

1. Introduction

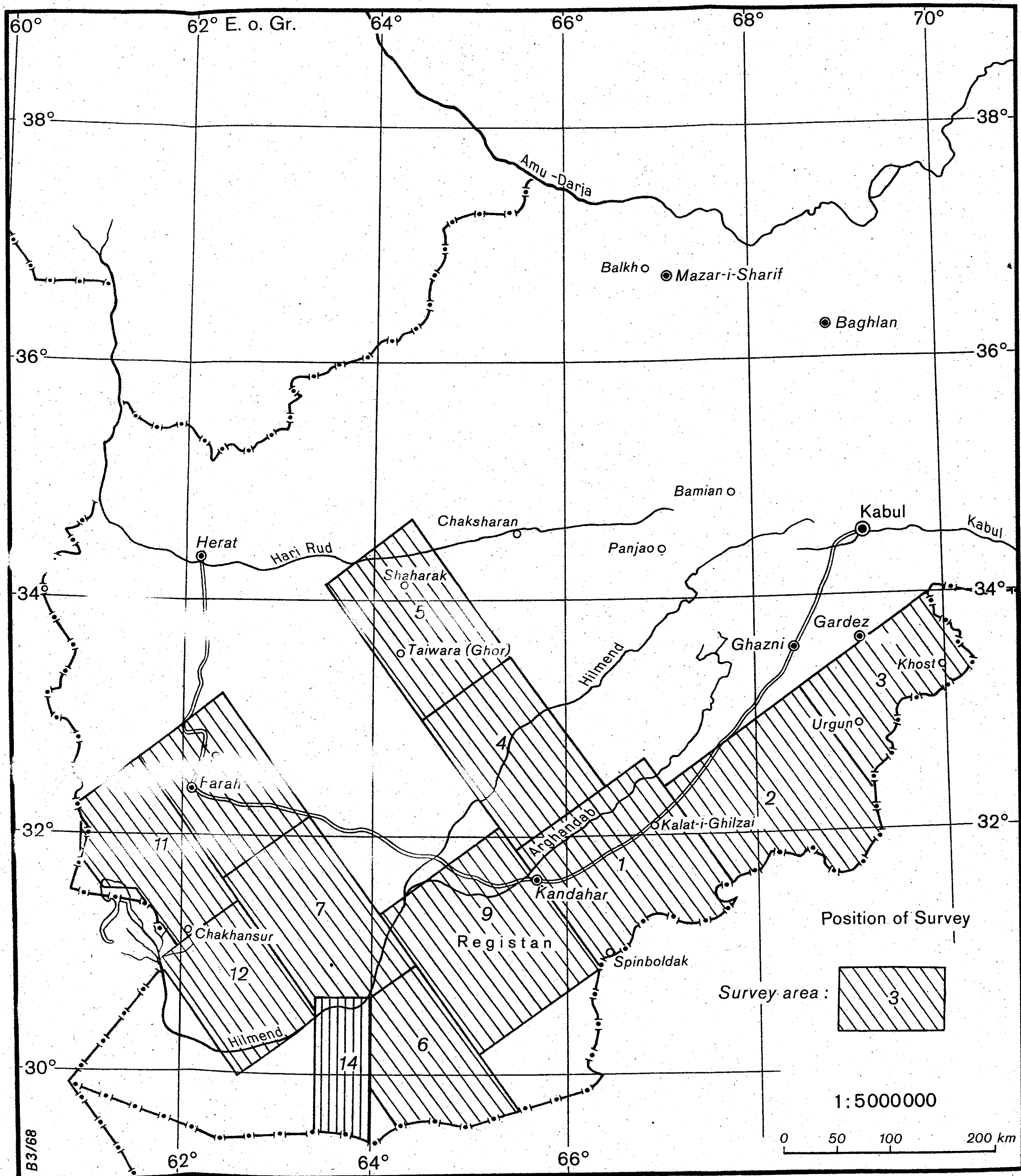
1.1. The order

By decree of the Bundesministerium für Wirtschaft (Federal Ministry for Economic Affairs) the Bundesanstalt für Bodenforschung (BfB) (Geological Survey of the Federal Republic of Germany) was commissioned with the preparation of an airborne magnetometer survey in the southern part of Afghanistan. The principles of this project are contained in the 6th Supplementary Agreement to the agreement of January 31, 1958 - in its form changed by an agreement of June 21, 1965 - between the Government of the Federal Republic of Germany and the Government of the Kingdom of Afghanistan concerning economical and technical cooperation.

This agreement provides for airborne magnetometer measurements in the southern part of Afghanistan, with the aim to explore the depth of the sedimentary basins and thus furnish data that may be of service for future oil exploration.

Following the above-mentioned decree, the order for the practical performance of the airborne magnetometer measurements was issued to the firm of PRAKLA G.m.b.H., Gesellschaft für praktische Lagerstättenforschung, Hannover.

Dr. BOSUM was charged by the President of the Bundesanstalt für Bodenforschung with the technical control and supervision of the measuring programme and with the performance of rock-magnetic investigations in



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Afghanistan. The operations were to be carried out in close cooperation with the Royal Afghan Ministry of Mines and Industries.

1.2. The operations

The airborne magnetic survey of the prospection area (cf. Fig. 1) was carried out by a measuring crew of PRAKLA under the supervision of the engineer Mr. MÜLLER. This crew was stationed in Kandahar. From here they started their survey, and during the period from August 8, 1966, until November 29, 1966, altogether 55 941 km profiles were measured from the air.

Dr. BOSUM of BfB was sent off to Afghanistan for the period of September 8, 1966, until October 17, 1966. He conducted the measuring programme and made rock-magnetic studies on samples picked up in the survey area and in the nearer proximity of it. The rock-magnetic operations which are needed as a basis for the interpretation were supported and promoted by the cooperation of the Messrs. Dr. WITTEKINDT of the German Geological Consultants' Group in Afghanistan, and of the Engineer SAHER of the Royal Afghan Geological Survey. The investigations were particularly carried out in the crystalline of Kabul, in the closer surroundings of Kandahar and in the Central Region (cf. Encl. 1).

The firm of PRAKLA evaluated the measured data and prepared the maps of isanomalies. The results are contained in the report of PRAKLA (Lit. 15). The geophysical-geological interpretation was done in BfB by the

Messrs. Dr. BOSUM, Dr. HAHN, Dipl.-Math. KIND, Dr.WEIPPERT and Dr. GABERT.

Calculation work was carried out on the computers of BfB (IBM 1620), of the Technical University of Hannover (CDC 1604 A) and of the "Deutsches Rechenzentrum Darmstadt" (IBM 7094).

Dr. ECKHARDT arranged for the petrographical analyses. The discussions with a number of colleagues greatly stimulated the geologic-geophysical interpretation. Only the close cooperation between the different branches of geo-sciences rendered possible an interpretation of the airborne-magnetometer survey in the given form.

The work in Afghanistan was supported in a very generous manner by the Royal Afghan Ministry of Mines and Industry. In particular, this applies to motorcraft and personnel placed available. Our special gratitude is due to the President Mr. MIRZAD for his active interest in our work which he supported in every possible way. We also express our sincere thanks to the Governor of the province of Kandahar, Dr. ANAS, to the Royal Afghan airport authorities in Kandahar, in particular Director ETIMADI and Mr. KOHESTANY, as well as all the other Afghan authorities, for their constant readiness to help in the performance of our work.

2. The application of magnetic measurements for the investigation of structural-geologic and oil-geologic problems

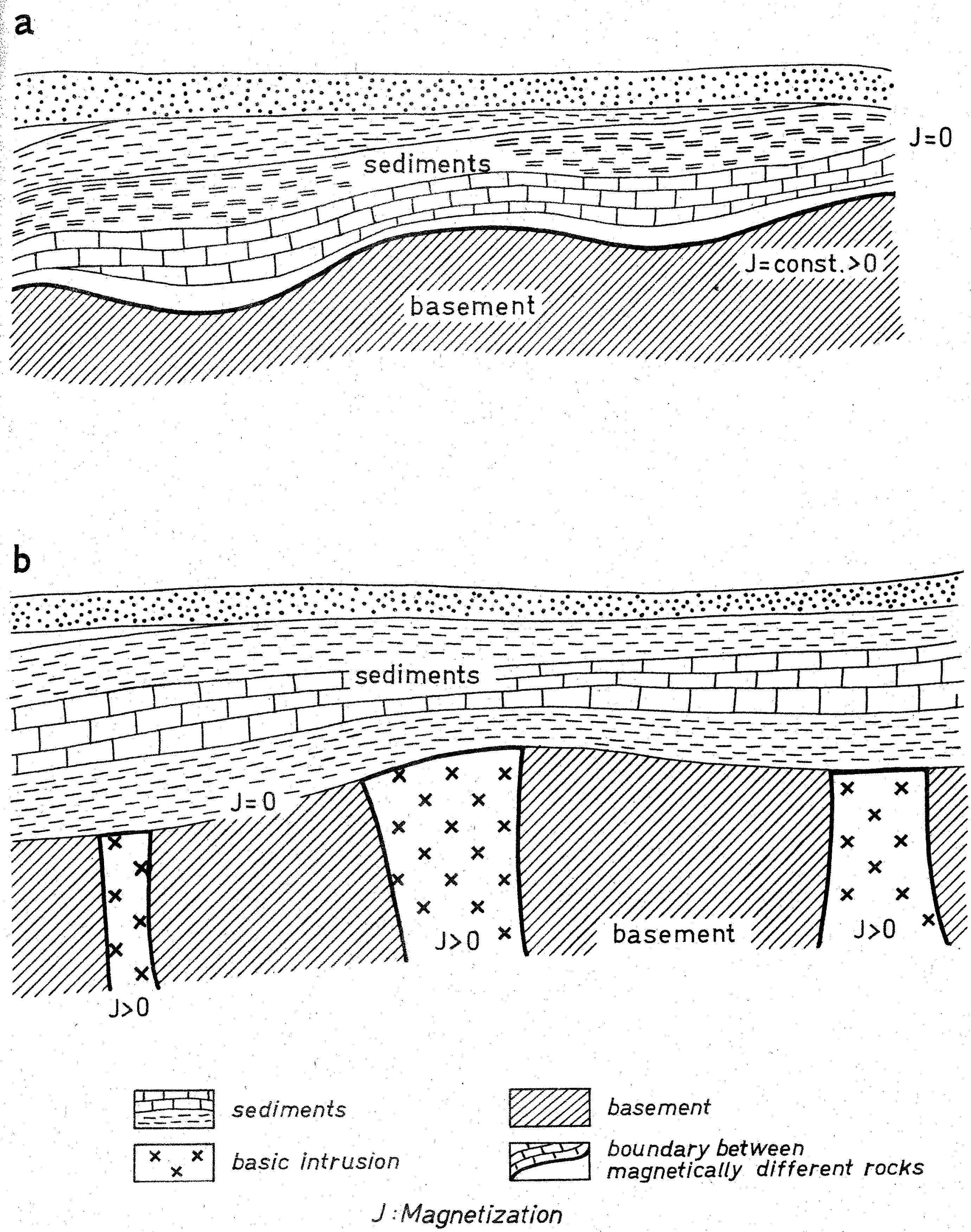
Magnetic measurements as a prospection method can be applied in all places with different magnetizations of interesting rocks or rock complexes. For certain rock types, however, the magnetization is by no means a fixed quantity, it rather varies considerably. The consequence is that a geologic-petrographic interpretation of magnetic measurements in unknown regions is generally not possible, except for anomalies exceeding a certain quantity and therefore most likely being caused by magnetite.

In former times, therefore, the range of application of magnetic measurements was in the first place restricted to iron ore prospection, especially for the proof of magnetitic ore occurrences. Only very recently a change took place, after large coherent areas could be surveyed from the air. For it was then ascertained that a number of rock types within limited regions certainly possess characteristic mean values of magnetization. Such rocks can then be located by magnetic measurements. The conception about the distribution of the magmatic rocks which resulted from magnetic measurements can be used as fundament or supplement for the geological mapping. This realization led to the result that now magnetic, in particular airborne magnetic measurements were carried out to a large extent. From a pure prospection method especially on magnetite ore the magnetic method has changed to a mapping method.

It is a matter of course that for the projecting of a "magnetic mapping programme" certain general presumptions must be fulfilled, one of them being that magnetic rocks must be existing at all. The normal experience is that useful magnetizations occur within magmatic and crystalline rocks. On the average, basic rocks show a stronger magnetization than acid ones, the same as highly metamorphic rocks compared to weakly metamorphic ones. Therefore, a small regional magnetic survey above regions with magmatic or crystalline rocks will always yield anomalies apt to provide indications for the geological structure of the area, especially of the layering conditions of magmatic rocks. A geologic-petrographic interpretation can be provided only by rock-magnetic and petrographic investigations on the rocks of the prospection area and, analogously, its surroundings, and by geological operations which run parallel to airborne magnetometer measurements. In our case, the geological operations had been carried out already by the "GERMAN GEOLOGICAL MISSION in AFGHANISTAN".

On the average, crystalline rocks possess a higher magnetization than sediments which are magnetic in exceptional cases only. There exists, however, also nonmagnetic crystalline which does not differ magnetically from sediments. The airborne magnetometer measurements indicate a physical boundary, namely the boundary magnetic/nonmagnetic. So the boundary crystalline/sediment, i.e. the depths of the sedimentary basins, can be given only when assuming a geological model.

Fig. 2



Two geological models for interpretation of basement-anomalies

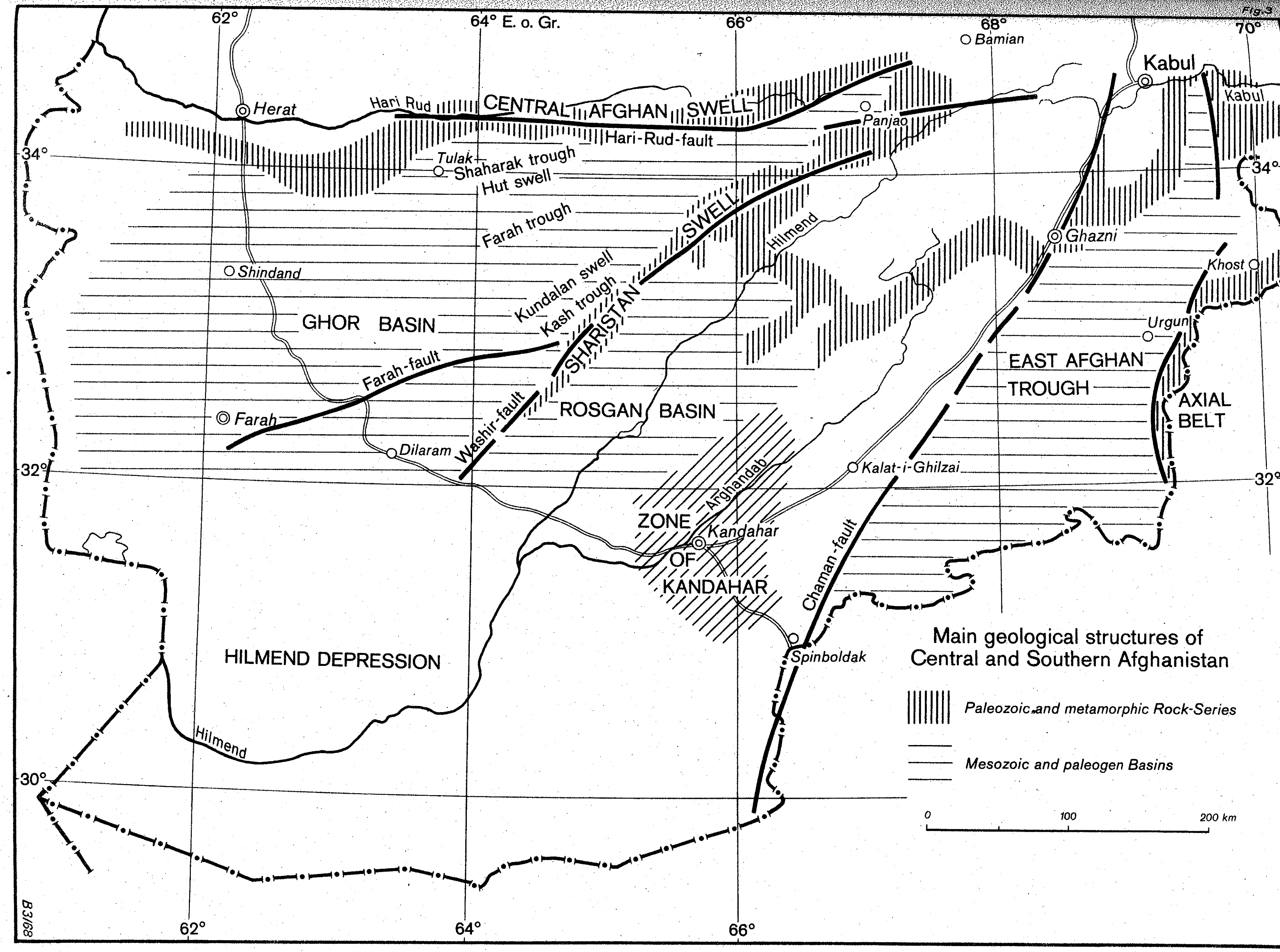
This involves two possibilities for discussion, both being represented in Fig. 2. Fig. 2a shows the case in which the crystalline basement is more or less magnetically homogeneous and altogether stronger magnetized (magnetization $J > 0$) than the sediments ($J = 0$). Therefore, the boundary magnetic/nonmagnetic is identical with the boundary crystalline basement/sediment which we are looking for. It shall be stressed that the boundary may also lie within the basement, if its upper part is nonmagnetic.

In Fig. 2b, the crystalline basement consists of non-magnetic and magnetic zones, e.g. basic intrusions which in "old shields" reach the upper surface of the crystalline basement. An interpretation of the anomalies yields the magnetic bodies. Then the wanted boundary crystalline basement/sediment is given by connecting the tops of the model bodies.

Assuming the above-mentioned conditions position, extension and depths of sedimentary basins can be calculated. Furthermore structures and faults can be detected. Under these aspects the geomagnetic measurements can be applied to oil-geological problems.

A basic requisite for the formation of oil-fields is the existence of sedimentary basins with the relevant parent- and reservoir rocks and a favourable tectonic structure.

Oil possibilities of an area are restricted by extensive magmatic intrusions and extrusions. Therefore, the knowledge of the stratification of magmatic rocks is



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important for valuating the oil possibilities of an area. Generally these rocks possess a higher magnetization than the sediments. Thus they can be detected by magnetic measurements.

The proof of sedimentary basins, the statements on structures and faults and the delineation of areas of magmatite rocks give evidence of the important rôle played by airborne magnetic measurements in oil exploration.

3. Geological general view

In Central and South Afghanistan crystalline schists of pre-Ordovician and alpidic metamorphism, Paleozoic, Mesozoic and Tertiary sediments as well as loose sediments of the Quaternary are exposed, also magmatites of Mesozoic, Tertiary and - in minor distribution - Quaternary age. The older strata including the Lower Tertiary rock series have been folded and faulted. Faults have also displaced Upper Tertiary and Quaternary rock units. The directions SW-NE to W-E are to be recognized as the predominating trend of strike in the presently existing structures; subordinately occur, in the oldest rock series, N-S striking fold axes.

Central and South Afghanistan is divided into geological units which differ from one another by their thickness and facies conditions and are arranged from NW to SE in the following way (cf. Fig. 3):

1) the Central Afghan Swell
2) the Ghor Basin
3) the Sharistan Swell
4) the Rosgan Basin
5) the Zone of Kandahar
6) the Southeast Afghan Trough
7) the Central Swell ("Axial Belt") of the Indus Baluchistan Geosyncline

The Hilmend Depression (8) is situated in SW-Afghanistan.

The Central Afghan Swell extends from the eastern part of Central Afghanistan as far as up to the area of Herat in the West. It is characterized by an old central core consisting of pre-Ordovician, possibly pre-Cambrian gneisses, mica schists and phyllites which, however, are exposed only locally. In partial areas, this old core is overlain by Paleozoic sediments of minor thickness (some 100 m), but is also interspersed by younger plutonites of Mesozoic and Tertiary age. A zone of tectonical displacements, the Hari Rud Fault, follows the region of the swell with an E-W strike.

The Ghor Basin adjoining in the South - in publications sometimes referred to as "Central Afghan Trough" - is characterized by its Jurassic and Cretaceous sediments, probably of more than 6 000 m thickness (argillaceous and marly slates, calcareous sandstones and limestones). A thick series composed of sandstones, conglomerates and volcanites (up to 2 000 m thick) of Lower Tertiary age (?) covers large areas in the western part of the basin; in the eastern part of the Ghor Basin it appears only sporadically in synclines and small-scale basins. These (?) Lower Tertiary formations rest unconformably upon Cretaceous sediments, yet have been folded in their turn.

The Ghor Basin is subdivided into a number of special basins and swells being arranged according to the main direction of the folds:

Shaharak Trough in the North
Hut Swell
Farah Trough
Kundalan Swell
Kash Trough in the South

Only within the zone of the Kundalan Swell locally argillaceous slates and quartzites of presumed Paleozoic (Carboniferous ?) age are exposed below the Jurassic sediments. Apart from this, no information concerning the deeper underground of the Ghor Basin is available at present.

In the central and southwestern part of the Ghor Basin granite and granodiorite plutons have become known. They probably intruded during Middle Cretaceous to Older Tertiary times. In some regions - especially in the course of the Farah Fault - basic lavas and tuffs of Cretaceous age have been found.

The Sharistan Swell striking SW-NE, can be pursued from the Girishk region in the Southwest in NE direction as far as to the Eastern Central part of Afghanistan. It separates the Ghor Basin from the Rosgan Basin lying in the South of this swell. In the swell region, again metamorphic rocks (phyllites) are cropping out; they are unconformably overlain by younger, possibly Upper Paleozoic argillaceous slates and quartzites with limestones intercalations. Along the Washir Fault accompanying the Sharistan Swell, locally basic intrusions and extrusions took place during the Cretaceous.

The Rosgan Basin, too, contains a Jurassic/Cretaceous sequence, this, however, showing a total thickness of 1 000 m to 2 000 m only. In the Northeast of the basin, Permo/Triassic limestones underlying Jurassic/ Cretaceous sediments crop out in broad extension.

Also in the Zone of Kandahar, deposits of only 1 000 m to 2 000 m thickness (limestones, argillaceous slates, sandstones with conglomerate layers) of Jurassic and Cretaceous age are exposed. They are intercalated by expansive granite and granodiorite bodies of Middle Cretaceous age. Basic, secondarily also acid lavas of Upper Cretaceous age are regionally spread. In tectonic highs at the northern border of the zone of Kandahar, Paleozoic sediments and metamorphic rocks crop out in small areas.

The Southeast Afghan Trough forms the northwestern half of the alpidic Indus Baluchistan Geosyncline which is lying in front of the older mountains of Central Afghanistan and the Himalaya as their southern foreland. A swell region, the "Axial Belt" (also referred to as "Zone of Quetta") separates the Southeast Afghan Trough from the southern half of the geosyncline. In Afghanistan, within the region of the

"Axial Belt", Mesozoic (thickness more than 1 000 m ?), possibly also Paleozoic sediments and (?) Upper Mesozoic peridotites are exposed. The Southeast Afghan Trough is separated from the older sedimentation areas in Central Afghanistan by the striking Chaman Fault, which is accompanied by numerous occurrences of basic and ultrabasic intrusions ("ophiolites", Cretaceous/ Lower Tertiary).
In the trough itself, sediments of Lower Tertiary age (argillaceous slates as well as sandstones with conglomerates) - more than 4 000 m thick - crop out underlain presumably by Mesozoic and Paleozoic sediments. Altogether the sedimentary fill of the Southeast Afghan Trough may reach 6 000 m according to geological mapping. The folding of Lower Tertiary beds forming NNE-, NE- and ENE-striking structures with widely stretched synclines and steep anticlines took place in the Oligocene.

Whilst in the areas described so far, Upper Tertiary and Quaternary deposits are of minor importance, compared to the older rocks, in the Hilmend Depression almost exclusively Upper Tertiary to Quaternary clastic sediments are exposed reaching a thickness of some 100 m, possibly even more. The geological structure of the basin fill and its whole thickness is practically unknown. So also for the deeper underground of the Hilmend Depression, only vague assumptions can be made. Ejecta of Pliocene to Pleistocene volcanoes in the southern part of the depression as well as the presence of older rocks in the marginal zones indicate an - at least local - occurrence of (?) Lower Tertiary sandstones and Upper Mesozoic limestones below the Upper Tertiary sediments.

4. Geophysical investigations

4.1. Rockmagnetic measurements

As was already explicitely described in Chapter 2, a combined geologic-geophysical interpretation presumes the knowledge of the magnetic properties of the individual rock types. This applies in particular to the determination of the depth of the "basement" for problems concerned with oil exploration. For this reason, rockmagnetic studies were initiated in the field as well as in the laboratory (Rock-magnetic Laboratory of the BfB in Göttingen). The Petrographic Laboratory of BfB analysed mineral composition and rock type.

Of special interest in this connection was the magnetic behaviour of the "Crystalline Basement". In the prospection area itself, this basement is exposed at only few places and in partly untypical condition. In the immediate neighbourhood, however, there exist large areas with crystalline rocks, so for instance in the region around Kabul and of the Central Afghan Swell. Here, measurements on crystalline rocks were carried out and the results obtained were used for the interpretation of the aeromagnetic survey.

A further object for investigation was the magnetic behavior of the magmatic rocks which appear to a large extent in the region of Kandahar. Here, the ophiolites, granodiorites and granites were investigated.

Measurements on rocks from the region of the Kuh-i-Khan Nashin in the South of the desert Registan, which had been picked up by members of the German Geological

Mission in Afghanistan, served the interpretation of detail measurements under special consideration of the question for possible magnetic iron ore occurrences.

4.1.1. Measuring equipment

For the purpose of determining the magnetization in the field, a "SCHMIDT field balance" (Askania Gf6) was made use of. Samples are brought near to this instrument and the deflection is measured. It is proportional to the susceptibility. A remanent magnetization is ascertainable by a relevant measuring arrangement. The disadvantage of the lesser accuracy in the measurement with the SCHMIDT field balance is compensated by the advantage to be able to investigate a great number of samples in the field in the shortest time possible and thus to obtain representative mean values. In addition, samples of special interest are selected for laboratory tests.

The equipment used in the laboratory consists of the FÖRSTER probe (fluxgate Magnetometer) (sensitivity 10^{-5} cgs) and the astastic magnetometer after HELLBARDT (sensitivity 10^{-7} cgs, Lit. 11). Susceptibility and remanent magnetization (according to quantity and direction) are determined.

4.1.2. Measuring results

The results of the rockmagnetic investigations have been compiled in Table No. 1. The position of the several sample localities is to be found in Encl. No. 1. Altogether about 500 samples were investigated in the field, and 50 in the laboratory.

First,results of specimens originating from the crystalline basement near Kabul shall be discussed. According to the geological and petrographical knowledge the deepest zone of the crystalline basement in the Afghan region lies exposed here (mesozone to katazone). As is indicated by the Table, the greatest part of the samples has only a small magnetization in the order of magnitude 0γ - 2γ, which means that the rocks can but produce anomalies of the geomagnetic field reaching a maximum of 10γ. Greater magnetizations have been recorded with samples Nos. 3, 4, 10, 12 and 13. With the exception of specimen No. 10, which originates from a fault zone, these specimens belong to the deeper part of the crystalline basement. The induced magnetization amounts, on an average, to 60γ. The remanent magnetization comes into the same order of magnitude according to laboratory measurements, so that a total magnetization of about 100γ may be assumed. There is to be paid particular attention to the increase of the magnetization in the specimens Nos. 1 to 4, for it is in correlation with an increase of metamorphism in this direction (according to ANDRITZKY, Lit. 1).

The samples Nos. 40 - 43 are collected from the range of the Sharistan Swell. The rocks are but slightly metamorphic (epizone); their magnetization amounts to 0γ - 4γ.

The result is that great parts of the crystalline basement (in the eastern survey area) are nonmagnetic, and they are obviously those parts that belong to the upper zones (epizone to mesozone). Greater magnetizations are to be recorded only in the deeper zone (mesozone to katazone). They are in the order of magnitude of 100γ (induced + remanent magnetization). Transferring this result to the geological models discussed in Chapter 2, one does not detect, in the case of Fig. 2a (relief of a magnetically uniform crystalline basement) the boundary between crystalline basement and sediment, but another one within the crystalline basement (possibly in the range of the boundary mesozone to katazone), which would be overlaid by nonmagnetic crystalline basement. Its thickness shall be discussed in Chapter 4.2.4.2.2. in connection with the interpretation results.

The measuring results obtained in magmatic rocks originating from the region of Kandahar and from the central region are shown in the second and third part of Table No. 1. As could be expected the basic extrusive and intrusive rocks (diabases, ophiolites) and the Tertiary volcanic rocks with an induced magnetization (J_i) amounting, on an average, to 60γ or 40γ, respectively, have proved to be magnetic. Remanent magnetism (J_r) is in the same order of magnitude; in particular cases it reaches a multiple of this value (for example, sample No. 56). One therefore can assume a total magnetization of 120γ - 200γ for these rocks.

It is remarkable that also the granodiorites and granites show relatively high magnetizations, namely, on an average, of 20γ of induced magnetization and an approximately equally large remanent magnetism, i.e. a total magnetization of about 50γ. This result is very important for an interpretation of the anomalies in the region of Kandahar, as many of them may be assumed to have been caused by granites. Therefore one can indicate the boundary of these massifs according to the maps of isanomalies. However, besides magnetic granites there were also observed single nonmagnetic granites (e.g. sample No. 39). Apart from the granite massifs, detected by the magnetic survey, there may also exist other ones consisting of nonmagnetic granite.

The highest values of magnetization ($J_i = 200\gamma$) show basic veins in a granite body (samples No. 30 and No. 60).

The investigations carried out on the porphyries or the porphyrites, resp., and on the tuffs from the Kuh-i-Khan Nashin yielded two magnetic types, i.e. a strongly magnetic one ($J_i = 80\gamma$, $J_r = 200\gamma$) and the other one weakly magnetic ($J_i = 8\gamma$, $J_r = 5\gamma$). Besides, there have been found magnetically mineralized limestones, which showed strong magnetizations.

Summarizing it can be said that high values of magnetization are to be found in the region of Southeast and Central Afghanistan with basic volcanic rocks ($J = 120\gamma$ - 200γ), granites, diorites ($J = 50\gamma$) and highly metamorphic crystalline rocks ($J = 100\gamma$), which can be taken as a basis for interpreting the magnetic anomalies that have been detected there.

4.2. Airborne magnetic measurements

4.2.1. Arrangement of the survey

The position of the prospection area can be taken from Fig. 1. The 12 partial survey areas bear the serial numbers 1 - 9, 11 - 12 and 14. The following geological and morphological units are concerned in the survey: The southeastern and southern trough of the Indus Baluchistan Geosyncline with its marginal zones, the area between Kandahar and the Central Afghan Swell, the deserts in the South and Southwest.

The survey lines were oriented normal to the general strike. In all regions, except for No. 14, their direction is N 130° E (NW-SE). The spacing and the flight height were chosen corresponding to the problem. For the purpose of detecting the structure of the deeper underground, a distance of 5 km is sufficient, with a height above ground of about 1 000 m. It is to be considered, however, that the anomalies of near-surface bodies (depth smaller than 2 000 m below flight level) are not fully detected and that in such cases, when interpreting the maps of isanomalies, the position of survey lines in relation to the anomalies must also be considered (this applies in particular to the region of Kandahar). Control lines were flown rectangular to the survey lines with a spacing of 20 km.

The flight level was constantly barometric, but variable in the individual survey areas because of greater topographic elevations. It was as follows:

Regions 3 and 5: constantly 3 400 m above mean sea level
Regions 2 and 4: constantly 3 000 m above mean sea level
Region 1 : constantly 2 600 m above mean sea level
Regions 6,7,8,9,11,12: constantly 2 000 m above mean sea level

In region No. 14 a detailed measurement was done for the purpose of investigating possible iron ore occurrences in the proximity of the Kuh-i-Khan Nashin. Here the survey lines run N-S with a spacing of 1,2 km, control lines normal to these with a spacing of 10 km. The flight level was predominantly 1 500 m above mean sea level, within the region of higher mountains 2 000 m above mean sea level.

4.2.2. Magnetometer

The magnetometer used was a proton-precession magnetometer of the type PRAKLA PM 24. It possesses an absolute accuracy of $\pm 1\gamma$ with a measuring interval of 0.9 sec.

4.2.3. Further instruments, technical information and evaluation of the measuring data

A detailed information on other instruments, on the airplane, on the technical performance of measurements and the evaluation of the measuring data and the preparation of the maps of isanomalies incl. are to be found in the report of PRAKLA (Lit. 15).

4.2.4. Interpretation of the magnetic anomalies

4.2.4.1. Interpretation methods

4.2.4.1.1. Interpretation of isolated anomalies

Isolated anomalies, chiefly those which are caused by bodies near the surface, are interpreted by two-dimensional (mathematical term for a body infinitely extended in the strike) and three-dimensional bodies. Initially, one takes on profiles the magnetic field values normal to the preferred strike of the anomalies. Appropriate two-dimensional model bodies (circular cylinder, infinite and finite thin plate, broad dike, step) are presumed, their anomalies are compared with the measured one and their form varied until the calculated and the measured graph correspond sufficiently well.

The iteration method just described is programmed for computers according to the method of least squares and proceeds fargoing automatically (Lit. 3). The computer generally determines depth, form and magnetization (or equivalent quantities, respectively, for instance the product thickness times magnetization for the thin plate etc.) of the body. If further details are asked for, such as a plunging, a traversing of the body etc., or if already from the form of the anomaly can be taken that a two-dimensional body would not furnish a satisfying interpretation, one constructs, after a preceding two-dimensional approximation, a three-dimensional body, computes its field and approximates it to the measured anomaly. This is done with a computer programme which is written for a body of arbitrary magnetization - bordered by planes. The programme produces, in connection with an automatic plotting machine (Graphomat) the picture of the isanomalies. The results are plotted in the interpretation maps in the customary way, for instance by indicating the strike, dip and depth of the bodies.

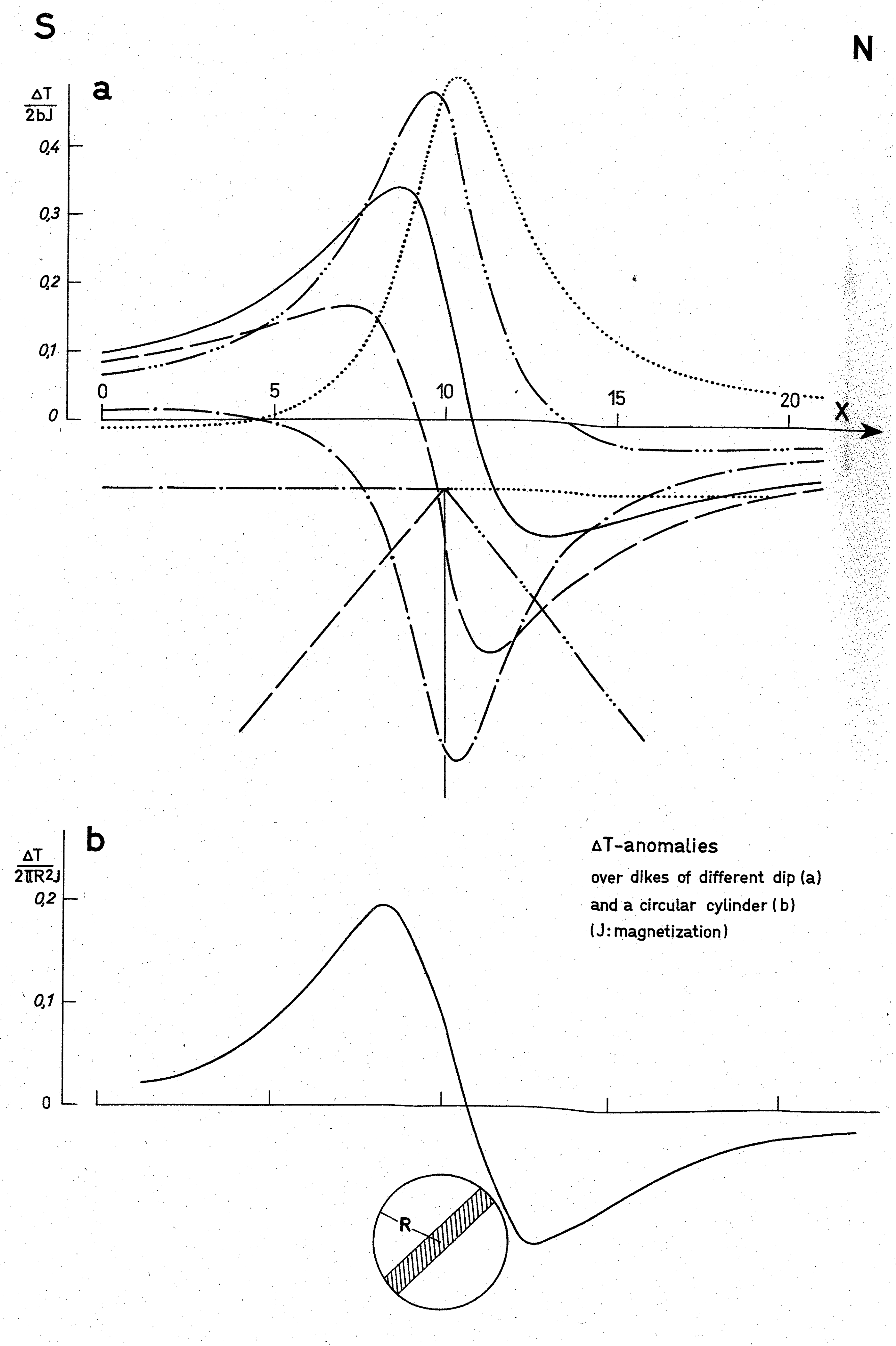
4.2.4.1.2. Interpretation by the surface relief of a magnetized layer

In this method, the computation runs directly from the measured field to the relief (Lit. 10). Merely to be entered into the calculation is a mean depth and the contrast of magnetization at the relief plain which in general is equal to the magnetization of the lower layer. The process of calculation is as follows: The magnetic field is represented by a two-dimensional finite Fourier's-series. The partial waves are continued separately into the projected interpretation depth and used for the construction of the relief. The resulting relief represents a model, which interprets the pre-given field completely. This method has the following equivalence: the product of relief amplitude and magnetization contrast is practically constant. If, e.g., with a magnetization contrast of 200γ a relief amplitude of 3 km is calculated, a magnetization contrast of 100γ would involve a relief amplitude of 6 km.

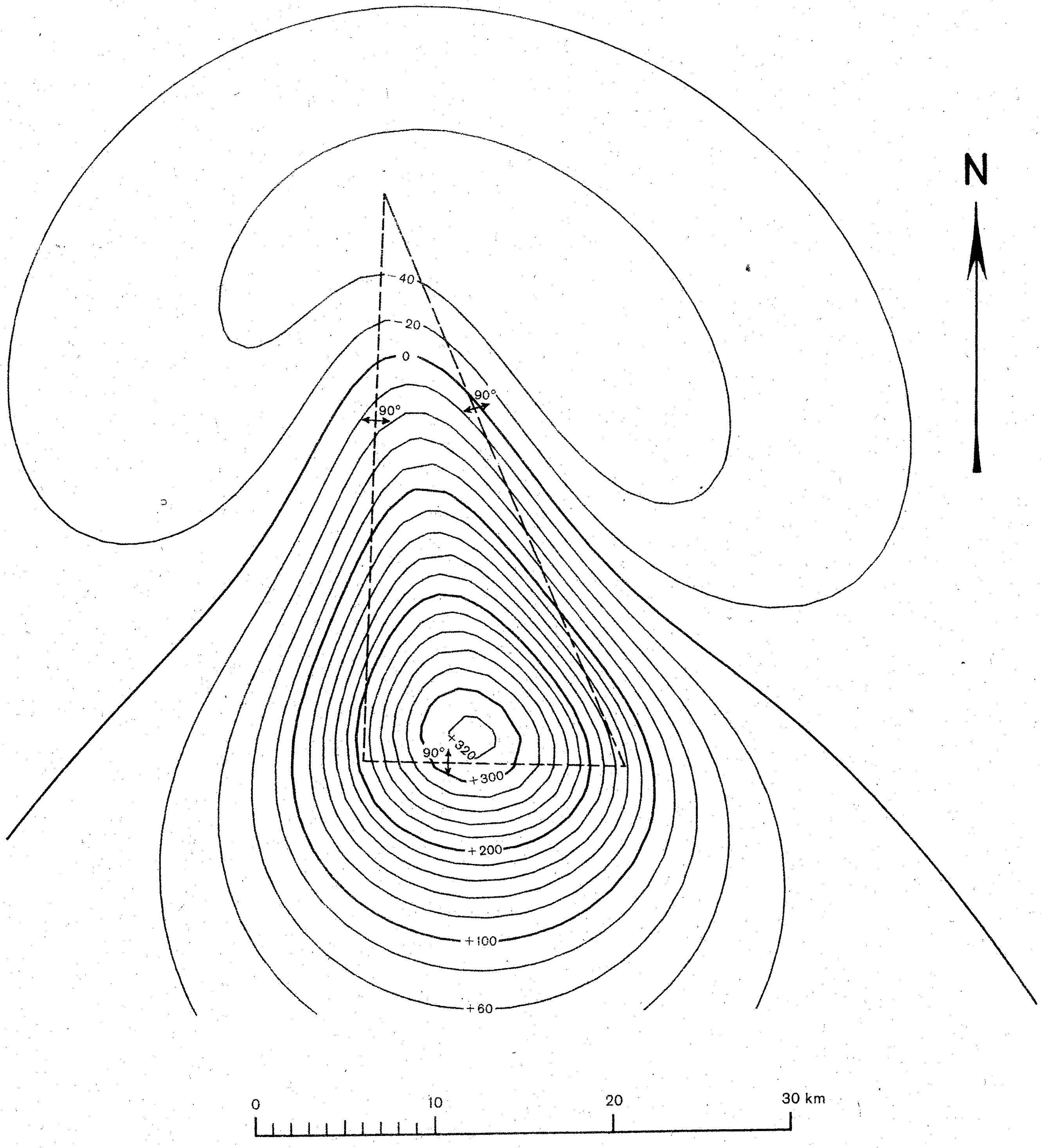
4.2.4.2. Results of interpretation

The results of interpretation are contained in the maps of interpretation (cf. Encls. No. 11 - 16). The scale is 1 : 500 000, so that they can directly be compared with the plans of the isanomalies (cf. Encls. No. 5 - 10) and with the geological maps of the German Geological Mission in Afghanistan which are presently available as manuscript (Lit. 4). A detailed representation has been given of the localization of the bodies resulting from the interpretation of profiles, the depth contours traced in accordance with the relief calculation as well as so-called structure lines. These latter ones have immediately been derived from the plan of isanomalies. They result from characteristical forms of the isanomalies, from a displacement of maximum lines of the anomalies etc. Their meaning cannot be given in a general way. For instance, the structure lines may be fault zones or lineaments. But they may also characterize boundaries between rock complexes of different magnetic feature. They often allow a subdivision of several regions. The structure lines thus are intended to indicate all of these different points of view to the geologist and to possibly complete his concepts on the geological structure of the area resulting from the mapping. In specific cases one can modify their course by using the plans of the isanomalies.

For the detection of anomalies of near-surface bodies (depth smaller than 2 000 m below flight level) the spacing is too extensive. The drawing of the anomalies, therefore, depends on the position of the survey lines. They have been plotted on the maps of the isanomalies on a scale of 1 : 200 000 in Encls. Nos. 11 - 44 of PRAKLA (Lit. 15). As has been mentioned above, the field of these bodies has not been determined completely; consequently the course of the isanomalies is not secured.



ΔT-anomalies
over dikes of different dip (a)
and a circular cylinder (b)
(J: magnetization)



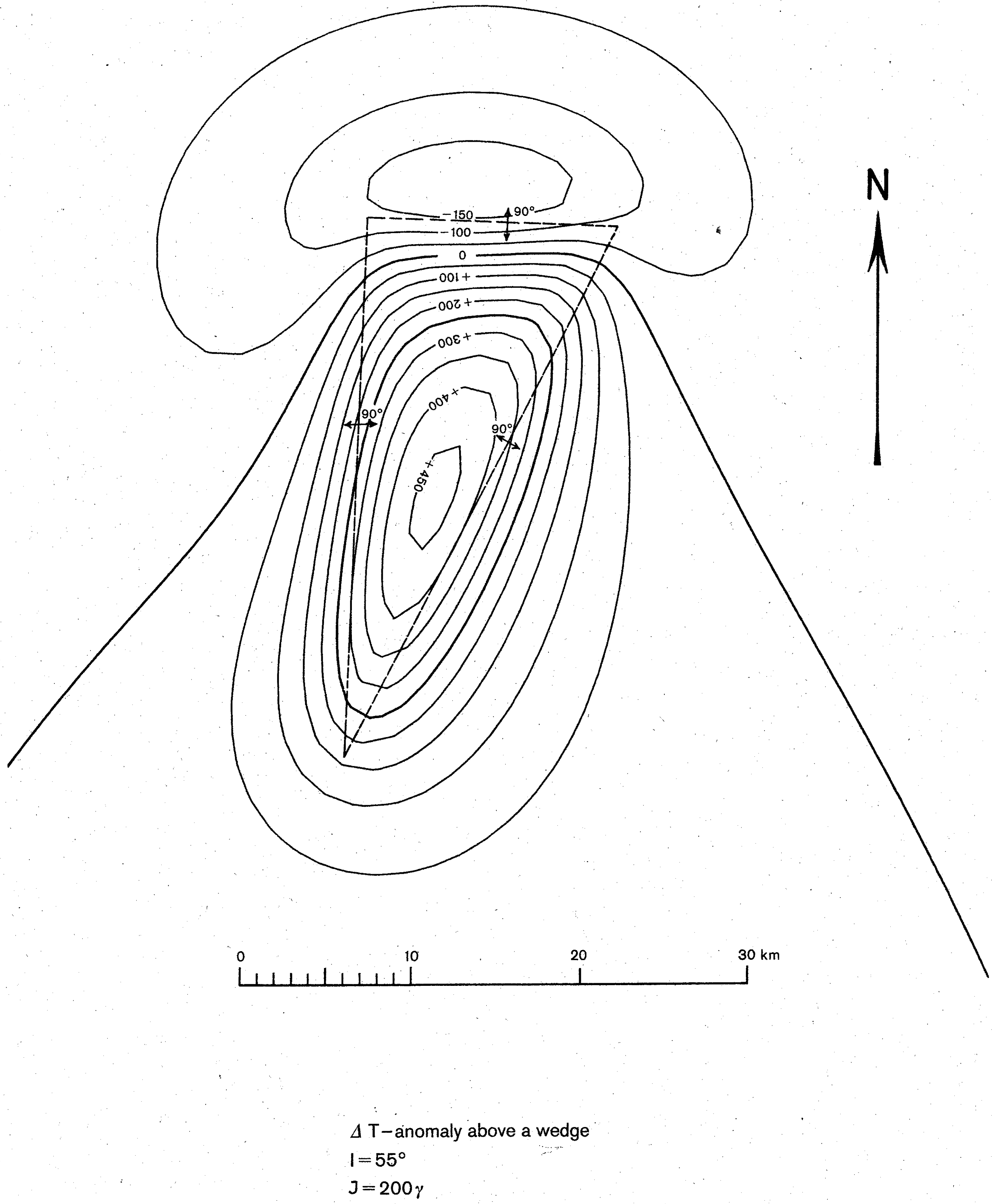
ΔT-anomaly above a wedge

I = 55°

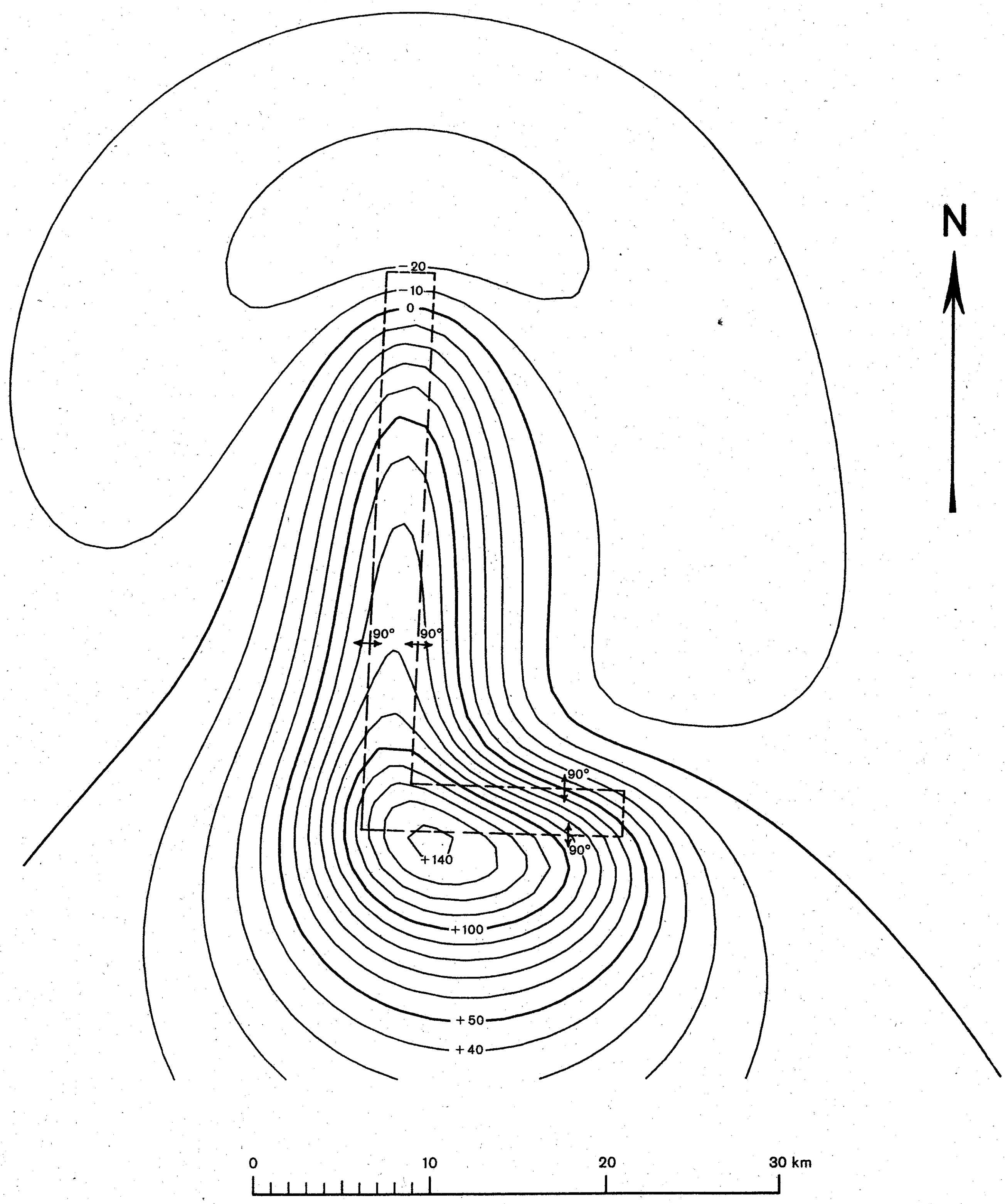
J = 200 γ

depth of the upper face 6000 m

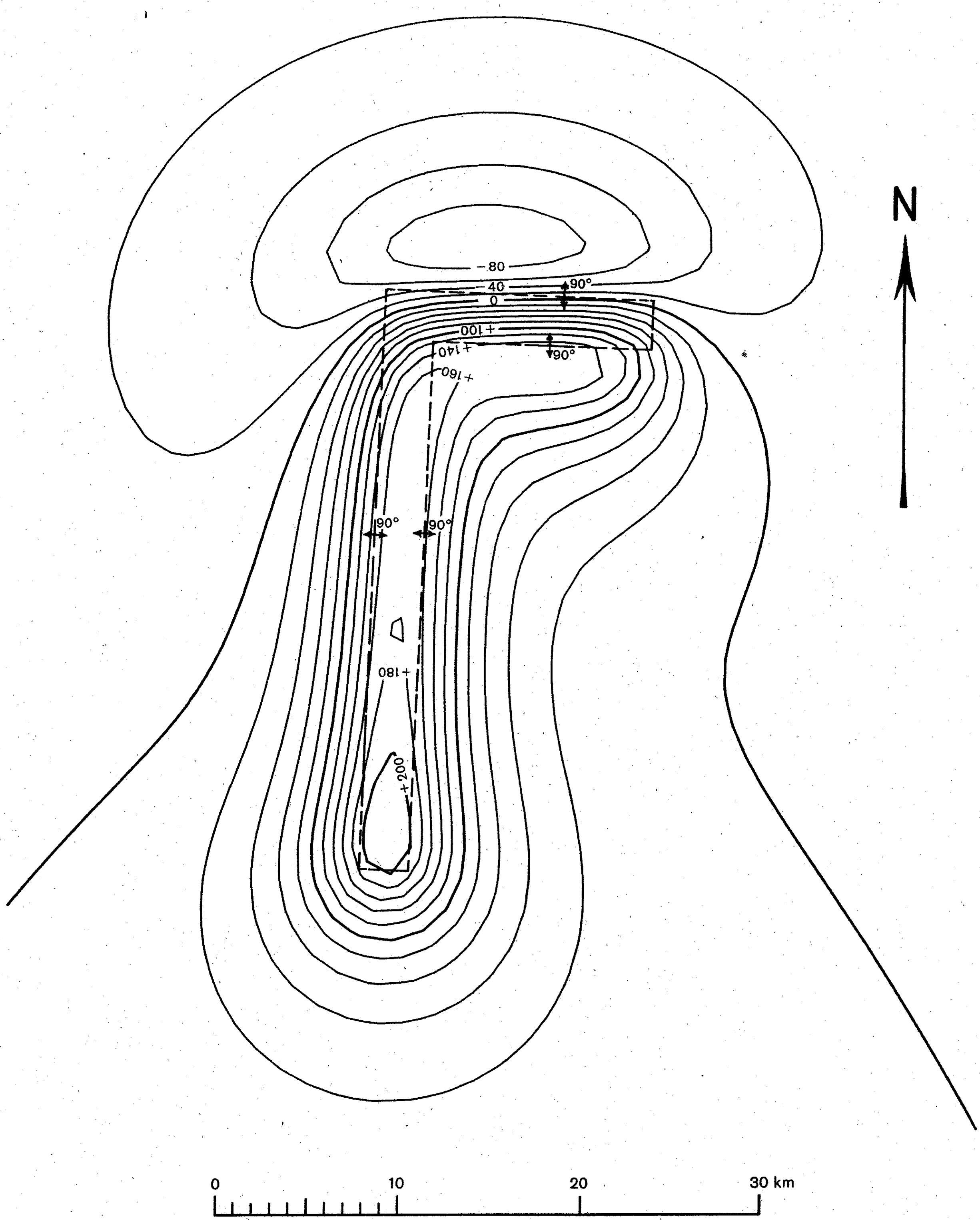
depth of the under face 22000 m



Δ T−anomaly above a wedge
I = 55°
J = 200 γ
depth of the upper face 3400 m
depth of the under face 19400 m



ΔT – anomalies above 3-dimensional
dike-like bodies (rectangular arranged)
$I = 55°$
$J = 200\ \gamma$
depth of the upper face 6000 m
depth of the under face 22000 m



ΔT – anomalies above 3-dimensional
dike-like bodies (rectangular arranged)
I = 55°
J = 200 γ
depth of the upper face 3400 m
depth of the under face 19400 m

For an analysis of the maps of isanomalies it will be appropriate to have in view the form of the anomalies above different model bodies to reach a first qualitative interpretation. Therefore, several theoretical curves have been represented in Figures Nos. 4 - 8 above two-dimensional (Fig. 4) and three-dimensional (Figs. 5 - 8) model bodies.

If not stated otherwise, a homogeneous magnetization has been presupposed parallel to the earth-magnetic field (inclination $i = 55^{o}$).

Fig. No. 4a shows the ΔT-anomalies above a dike of different dip (0^{o}, 50^{o} N, 90^{o}, 50^{o} S). Thereby, the model for a dip of 0^{o} means, in practice, a step of a magnetic sheet which, in the one case, is situated in the South of the body and, in the other case, in the North of it. As can be recognized, the relation of the maximum to the minimum of the magnetic anomaly is altered with the changing angle of dip of the dike. Predominantly positive anomalies mean a northern dip, whereas predominantly negative anomalies mean a southern dip.

Fig. No. 4b shows the anomaly above a circular cylinder. Geologically this mathematical model means a body whose extensions are small compared to its depths. Thus it may, for instance, be a dike-like body of small extension, as has been indicated by hatchings in Fig. No. 4b.

The Figures Nos. 5 - 8 show the anomalies above three-dimensional bodies. In the one case (Figs. 5 - 6), they strike N-S, altering their thickness in this direction. Thus they have the form of a wedge. In the other case (Figs. 7 - 8), they show a bending-over from N-S strike into E-W strike. Essential features are given by the position of the extreme values and the bending-over of the isanomalies.

These models shall give a fundamental approximation to anomalies, which show a typical bending-over of their strike or a typical increase of breadth. On the one hand they are to be found in the region of Kandahar. They may here be caused by acid or basic intrusive bodies. On the other hand they are to be observed in the western part of the survey area near Farah, where they furnish indications to faults.

An analysis of the map of the isanomalies in connection with the geological and morphological divisions is suggesting the following subdivision of the survey area:

1. the center with the Zone of Kandahar
2. the Central Region, Northwest of the Zone of Kandahar up to the Central Afghan Swell
3. the Northeast, i.e. the Southeast Afghan Trough of the Indus Baluchistan Geosyncline
4. the western survey area, i.e. the region of the Hilmend Depression and the area Northwest of it.

The results of interpretation will be discussed in accordance with this division.

4.2.4.2.1. The Zone of Kandahar

The zone of Kandahar (cf. Encls. 7, 8, 10, 13, 14, 16) is situated in the center of the survey area. It has been included because all important magmatic rocks occur here. Therefore it could be expected that representative values about their magnetic behavior may be obtained. The map of isanomalies shows a very unsteady picture. The anomalies are caused by magmatic rocks that crop out at the surface or that are situated underneath a minor overburden, further by granites, granodiorites and ophiolites which, for the greater part, are magnetic (see Table No. 1).

Through a correlation of the geological and magnetic maps as well as in consideration of the petromagnetic results it is possible to associate the greater anomalies to certain rock complexes. In this way there result "the possible magmatic intrusions" that have been plotted on the map of interpretation. The biggest ones are situated near the places (from N to S) Nish, Gunda/Kundilan, and North of Salim, East of Khurgiani, Northwest of Spin Baldak, near Buka Khan and North of Bismillah.

Beside these strong extensive anomalies there are to be observed subordinate narrow anomalies striking SW-NE. They could be caused, for a large part, by basic dikes - in part also by bodies of some greater extension - which, according to Table No. 1, are characterized by high magnetizations. The anomalies are in part strongly negative. The strike over long distances, which is interrupted several times, may additionally indicate pronounced fault lines. There are two such lines that have been plotted on Encls. 13 and 14. The northern one approximately takes its course in the valley of the Arghandab from NE to SW up to about 80 km distance beyond Kandahar; the southern line runs parallel to the first one at a distance of 50 km. It contacts the places Mishin Khan and Takhta - pul Post. In its middle part it coincides with the important Mukur fault, which is ascertained by the geological mapping over a long extension, so that it may be interpreted as caused by this fault. According to the map of isanomalies, the Mukur fault would then extend in the indicated way in SW up to the characteristic anomaly situated 30 km West of Walham, and in the NE up to 30 km Northeast of Pannah.

Beside these structure lines that are indicated directly by string-like anomalies two other ones can be recognized indirectly. One of these lines represents the boundary of the magnetically strongly disturbed Zone of Kandahar toward the magnetically smooth field in the SE. It can be followed up from Chaman in the SW up to Alak in the NE, i.e. as far as the survey goes. In part it coincides with the Chaman fault, which may be extended, in accordance with the map of isanomalies, to NE in the indicated way.

Along this zone there are to be recognized relatively narrow anomalies that persist in strike over a long extension. Presumably these are basic bodies. In several cases, dip (under the assumption of normal magnetization+)) and depth have been determined.

+) normal magnetization: magnetization parallel to the recent earthmagnetic field.

(The depth is reckoned positively downwards. Zero lies in the mean sea level). The values have been plotted on the map of interpretation. Whereas for the anomaly East of Buka Khan a flat dip of about 40° toward SE was calculated, there resulted for the northern anomalies of the Chaman line (Encl. 10) a steep dip of about 80° toward NW. Such a dip has incidentally been calculated in the majority of cases for the magnetic rock bodies ("dikes") in the region of Kandahar.

The delimitation of the Zone of Kandahar in NW possesses a very irregular shape. The anomalies end Southeast of the Hilmend. A but slightly disturbed magnetic field follows to the NW.

With regard to the strong anomalies of near-surface bodies statements about a possibly existing deeper basement cannot be made. Neither can the question be decided whether a swell exists here (the so-called Kandahar Swell). If, however, one compares the anomalies of the Zone of Kandahar with the interpretable anomalies above the Sharistan Swell and the Central Afghan Swell (see farther below) and if, further, by relying on the magnetic map, one pays attention to the immediate transition from the Zone of Kandahar into the Basin of Rosgan (situated to the Northwest), one is inclined not to assume here a swell comparable with the afore-mentioned ones.

In the area North of Kandahar small magnetite occurrences are known. Three of them are plotted in the interpretation map Encl. 14. The airborne magnetometer survey did not prove anomalies, which indicate an unknown greater magnetite deposit. All anomalies can be interpreted as being caused by known granites and ophiolites. Magnetite occurrences, on the other hand, cannot be excluded but they may only be small deposits. It should be noticed, however, that - with a spacing of 5 000 m and a flight height of about 1 000 m above ground by which a detection of the magnetic crystalline is guaranteed - not the whole magnetic field of near-surface bodies is comprised. Ore bodies lying between the survey lines may be ignored.

4.2.4.2.2. The central region

Northwest of the Hilmend River (cf. Encls. 8, 9, 14, 15) a large magnetically smoothed region begins. It is characterized by a zone of anomalies, SW-NE striking approximately in the middle of the survey strip and by the anomalies hit upon in the NW. In-between a few smaller local anomalies are situated that partly also were arranged in a strike.

The calculation of a relief for the southern half of the region has been carried out with a magnetization of 150 γ. This corresponds to the magnetization of the highly metamorphic crystalline basement of Kabul (see Table No. 1, Chapter No. 4.1.2.). As is shown by the relief (small changes of altitude by small magnetization), the geological model of Fig. No. 2a can be taken as a basis for interpretation, i.e. the calculated relief represents the relief of the magnetic crystalline basement.

At the southern border of the area of interpretation the depth of the relief amounts to about 3 000 m below mean sea level. There is a slight ascent by only a few hundred meters forming a swell, which can be recognized in the plan of the isanomalies as a chain of anomalies on the line Deh Baba-Khuni-Anorara. Toward NW then follows, after a slight decline, a steep rise to about 1 000 m below mean sea level. This upwarping of the crystalline basement coincides with the so-called Sharistan Swell, which represents an important tectonical element, as can be seen also from the map of isanomalies.

Besides the calculation of a relief, several anomalies have been interpreted by isolated, dike-like model bodies. As can be concluded from this detail interpretation the magnetic crystalline basement rises in the region of the Sharistan Swell from SW to NE by 3 000 to 4 000 m. For instance a sudden rise takes place at the structural element 10 km NE of Dera (see Encl. 15) as follows from the depths plotted on both sides of the structural line (200 m, -1 100 m, resp.).

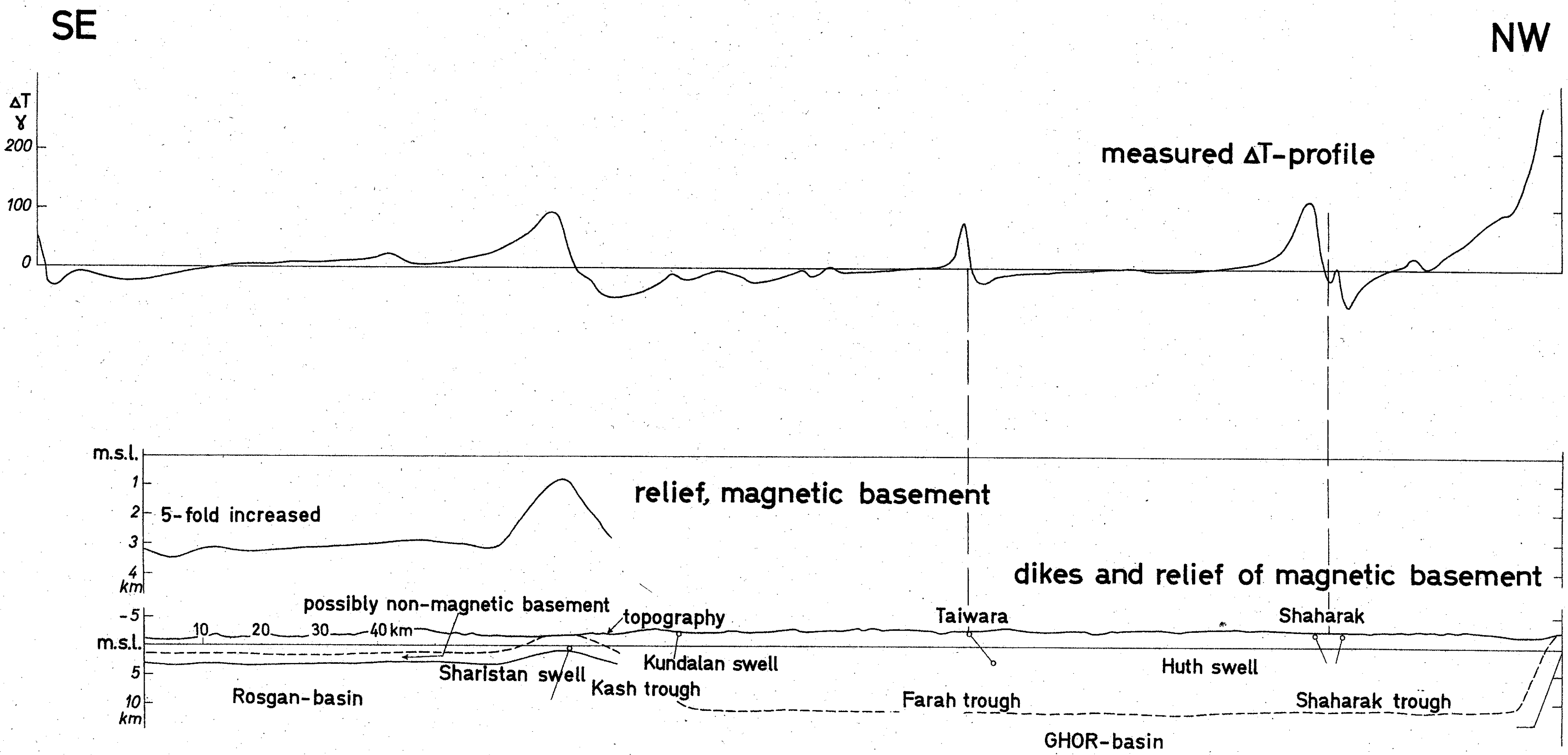
Beside this part of the anomaly, which originates from the deeper bottom (1 000 m and more), another one is recognizable in the region of the Sharistan Swell (12 km NW of Dera), whose cause is to be sought near the surface. The interpretation yielded a dike-like body, which has been plotted on the map of interpretation immediately to the Northwest of the swell. Possibly it corresponds to known basic volcanic rocks.

To the Northwest of the discussed Sharistan Swell a smoothed field follows again, with only a few groups of anomalies. A relief calculation did not show any result, as there apparently is no information at hand from the deeper bottom in the surveyed magnetical field. The cause must probably be sought for in a very deep subsidence of the magnetic crystalline basement, whose magnetization is relatively weak anyway. In the NW anomalies are again recognized. They indicate the Central Afghan Swell. In order to get some estimate of the depths of the magnetic crystalline basement "two-dimensional steps" have been calculated there. But it must be taken into account that the anomaly is not completely measured toward NW. From this model may be derived that the magnetic crystalline basement dips steeply at an angle of about 70° toward SE as far as to a depth of approximately 13 000 m below mean sea level (cf. Encl. No. 15).

The region under discussion is called the Ghor Basin. Proceeding from SE to NW it is subdivided into the Kash Trough, Farah Trough, and Shaharak Trough, as can be seen from profile D in Figure No. 9. These troughs or the pertaining swells are corresponding, in the map of the isanomalies, to the isolated anomalies caused by near-surface bodies. According to the geological mapping they can be attributed to Tertiary volcanic rocks. The association of the anomalies relating in the one case to swells (for example the Kundalan Swell) and in the other case to troughs (for example the Farah Trough) is not so readily understandable.

Fig.9

Profile D



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A few structure lines have been derived from the map of the isanomalies and have been plotted on the map of interpretation (Encl. 15). One of them takes its course to the West of the anomaly of Shaharak. It can possibly be extended as far as to the western delimitation of the anomaly of Taiwara. As will be noted, the two basic occurrences of volcanic rocks near Shaharak and Taiwara are very similar in the form of their isanomalies and represent the most remarkable anomalies of the Ghor Basin. Moreover shorter structure lines have been detected as the eastern delimitation of the anomaly of Shaharak with an NNW-SSE strike, and in the range of the Central Afghan Swell.

Profile D in Figure No. 9 shows a section across the region under discussion, and summarizes the results of interpretation. The magnetic profile is to be found in the upper part of the Figure; below, there is the relief of the magnetic crystalline basement, 5-fold increased, and at the bottom the relief as well as the isolated bodies are to be found in a 1 : 1 proportion.

As had been mentioned above, the depth of the magnetic crystalline basement within the range of the southwestern part of the Sharistan Swell amounts to about 1 000 m below mean sea level. The crystalline basement cropping out at the surface is nonmagnetic according to the rock-magnetical investigations (see Table No. 1, samples Nos. 40 - 43). The topographical altitude in this region amounts to about 2 000 m above mean sea level. From this a thickness of the nonmagnetic crystalline basement of about 3 000 m may be inferred. Under this assumption the dotted line (possibly nonmagnetic basement) has been plotted on the profile.

As can further be seen from Fig. 9, the Ghor and Rosgan Basins essentially differ from one another because of the depths of the magnetic crystalline basement. Whereas its depth in the Rosgan Basin amounts to about 5 000 m below terrain, it may reach 10 000 - 15 000 m below terrain in the Ghor Basin. Under consideration of a nonmagnetic crystalline basement of approximately 3 000 m, thicknesses of the sediments of about 2 000 m would ensue in the Rosgan Basin, and of 7 000 to 12 000 m in the Ghor Basin. There further exists a characteristical difference between the two basins in the fact that local anomalies, owing to basic volcanic rocks, solely are to be observed in the Ghor Basin. This phenomenon can be explained by a difference in depth of the crystalline basement, yet may possibly also be an indication of a difference in tectonics in both basins.

4.2.4.2.3. The region of Southeast Afghanistan

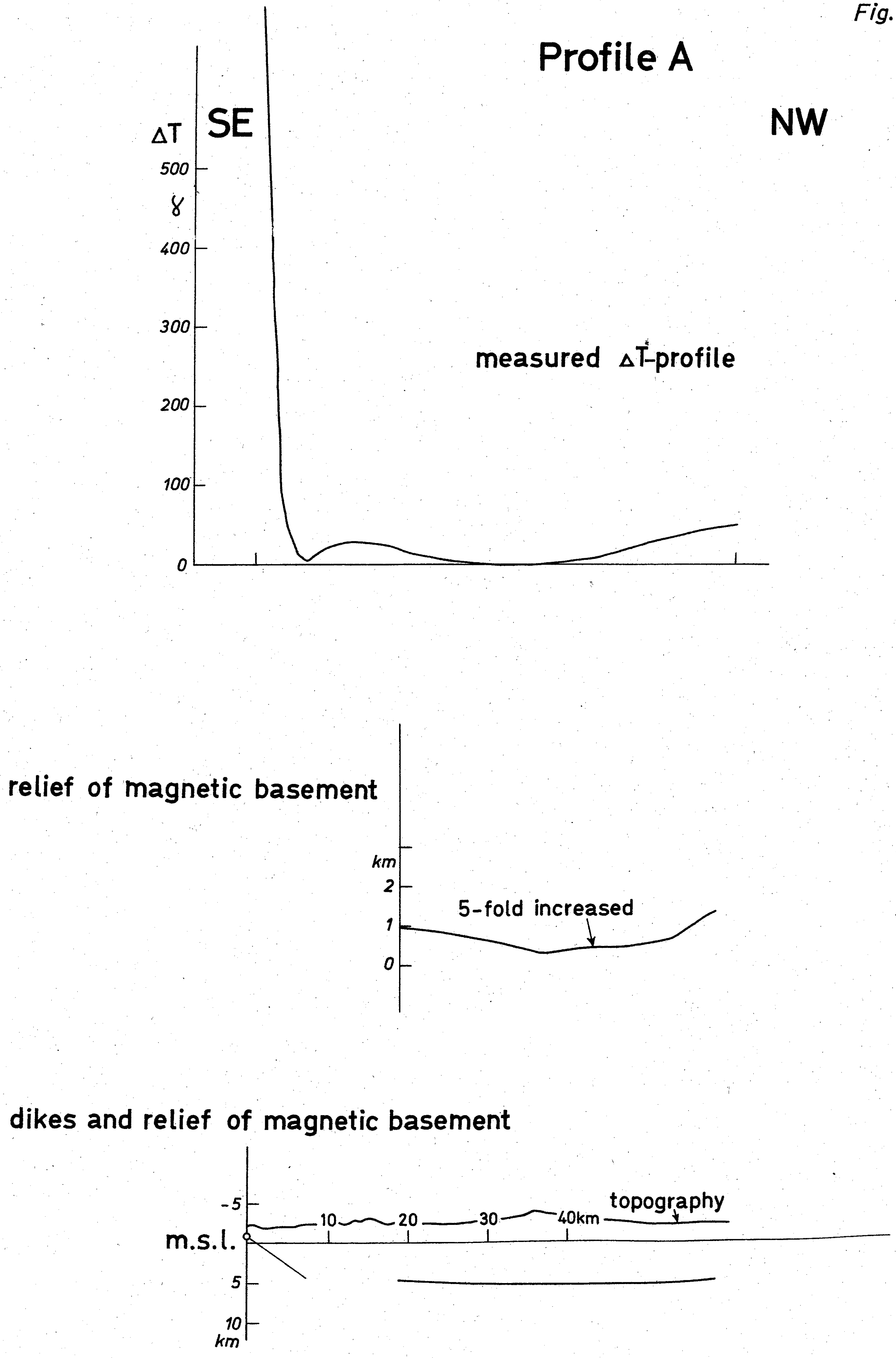
Magnetically the region East of the Chaman line, and Southeast of the Mukur fault (cf. Encls. 10 and 16) is completely different from the Zone of Kandahar. The course of the isanomalies is very smoothed. The anomalies scarcely reach 100 γ. The field is dominated by a large anomaly, whose maximum is located near Zarghun Shar and whose decline extends over the whole of the area striking about SW-NE. This anomaly has a continuation in the NE which is represented by several small maximums. The other isanomalies also show predominantly SW-NE striking.

The anomalies have been interpreted by the relief of a magnetized layer. For the magnetization 150 γ were presumed which, according to Table No. 1, corresponds to a highly metamorphic crystalline basement. The result is shown in the map of interpretation, (Encl. 16). The depths are given in m below mean sea level+). A remarkable trough extends across the whole of the area from SW to NE. This zone represents the greatest depth of the Southeast Afghan Trough which belongs to the Indus Baluchistan Geosyncline. The greatest depth amounts to about 6 000 m below mean sea level. The greatest extension in width of this trough is to be found in the SW. Toward the NE the relief rises in the trough zone to approximately 5 000 m below mean sea level within the range of an intermediate swell near Quala-i-Babakar. Farther to the NE the relief drops again. In the farther continuation there appear several intermediate troughs and swells. They are in detail the troughs Southeast of Urgun, near Sarafsar and near Melan. The intermediate swells are very small, only about a few hundred meters.

Greater upwarpings of this relief are to be recognized only near Zarghun Shar and Northeast of it. Here the depths amount to about 3 000 m below mean sea level. Thus ensues a total amplitude of the relief of about 3 000 m from the swell as far as to the trough. (The relief amplitude in first approximation is inverse proportional to the magnetization. For instance a magnetization of 100 γ would yield a relief amplitude of about 4 500 m).

+) The topographic heights amount from (1 000 m-) 2 000 m to 3 000 m.

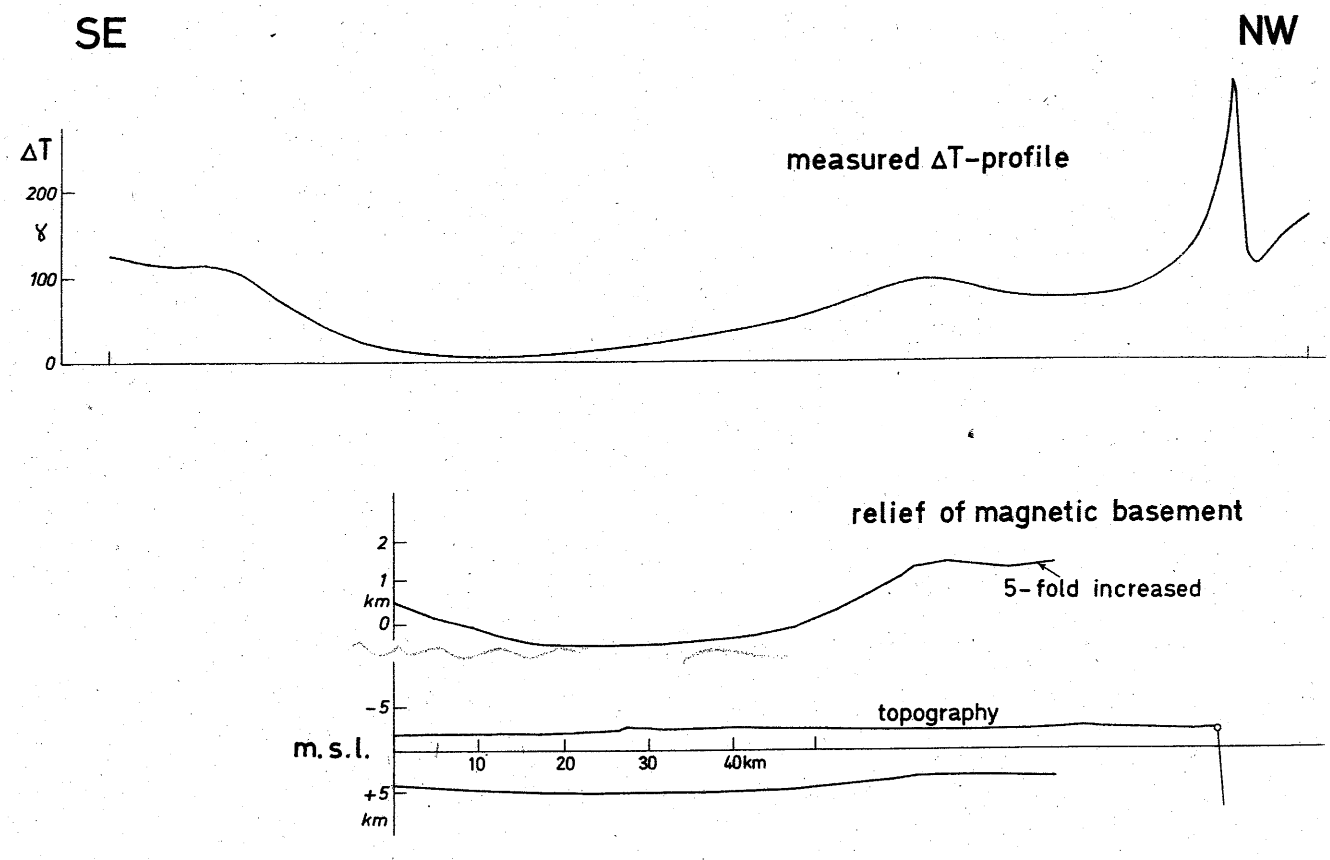
Fig.1(



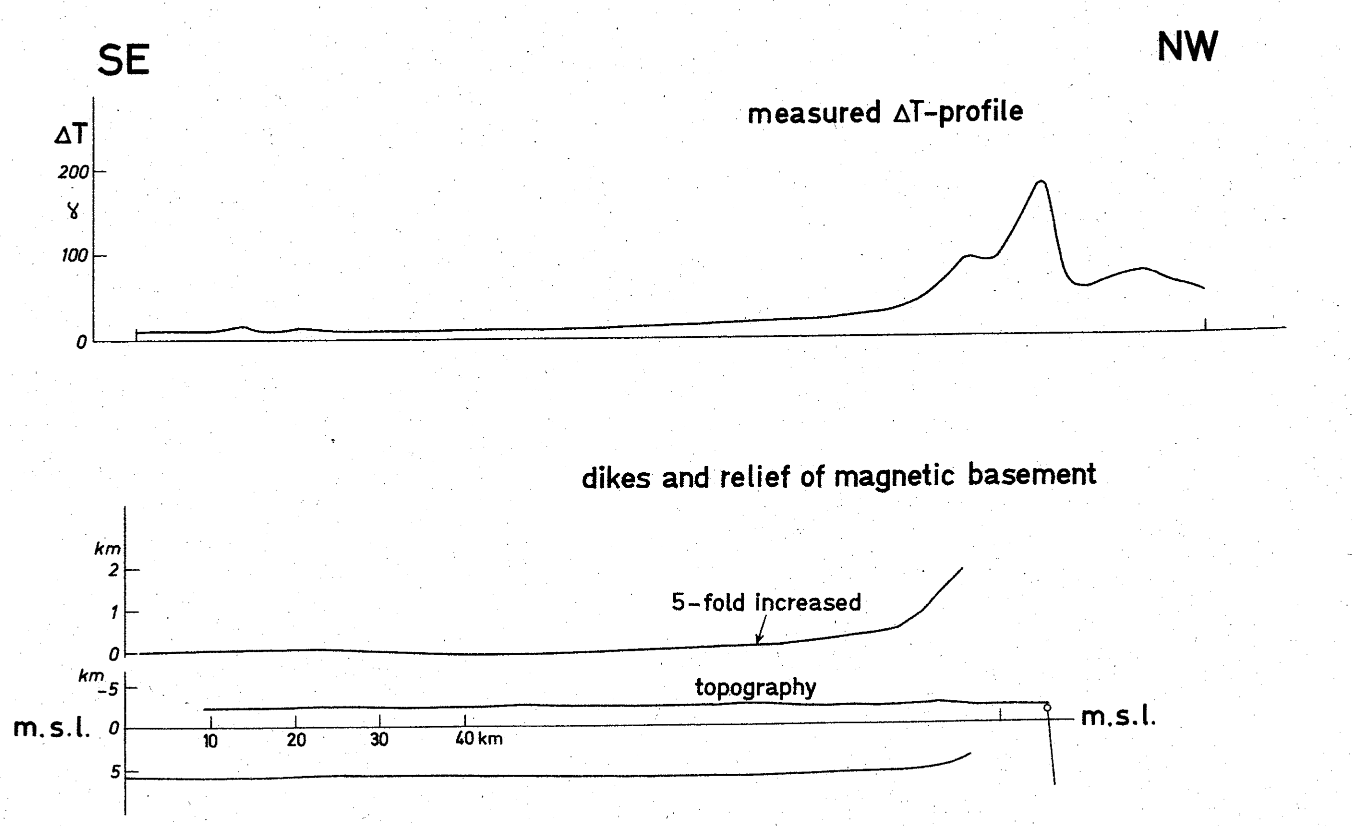
Profile A
SE
NW
ΔT
500
γ
400
300
200
100
0
measured ΔT-profile
relief of magnetic basement
km
2
1
0
5-fold increased
dikes and relief of magnetic basement
-5
m.s.l.
5
10
km
10
20
30
40km
topography

Fig.

Profile B



Profile C



At the boundary of the interpretation areas toward NW and SE a rise of the relief is discernible. It is possibly simulated by the neighbouring anomalies of near-surface bodies. (The parts of the relief lying within the dotted and the solid boundary line may be deformed the stronger, the nearer they lie to the outer boundary.)

The three profiles A, B and C (cf. Figs. 10 and 11) illustrate the conditions described. They show a section through the northern partial trough (profile A), through the intermediate swell (profile B) and through the southern partial trough (profile C). In each case the figures show, from top to bottom, the magnetical profile, the relief fivefold increased and the relief with altitude and length in the same scales.

The moderate undulation of the relief, in spite of a low magnetization, points to the geological model in Fig. 2a. As has been outlined in Chapter 4.1.2. greater magnetizations have been observed with metamorphic rocks. So, contrary to Fig. 2a, not the boundary sediment/crystalline has been determined by evaluation of the measuring data, but a boundary in the crystalline basement, probably within the boundary meso-/katazone. So the question arises, how much nonmagnetic crystalline may lie upon this relief plain. An exact answer cannot be given. But it may be referred to the region of the Sharistan Swell (cf. Chapter No. 4.2.4.2.2.), where the thickness of the nonmagnetic basement may amount to 3 000 m.

In the area SE of Wazi Khwa the course of the isanomalies shows a strong curling. The weak anomalies indicated in this way only have a small "maximum-minimum distance". So they must be caused by near-surface bodies within the Tertiary sediments. According to O. GANSS sediments are known here that contain intercalations of magnetite. They may be the cause for these weak anomalies. Similar anomalies are to be found near Sarafsar and near Urgun.

East of the area under discussion once more strong anomalies can be recognized with a center near Khost (zone of Khost, Fig. 13). Partly they have their origin in near-surface bodies, which means in the well-known basic rocks, the ophiolites; partly, however, the cause is to be found in a greater depth. Thus there have been calculated depths of about 4 000 m below mean sea level, for example for the model bodies between the places Gabar and Muhammed Khel. Likewise the anomaly West of Matun furnishes a depth of this order of magnitude.

If these deeper-lying magnetic bodies are correlated to the basic crystalline, there yields an upwarping of about 2 000 m of the magnetic basement in relation to the deepest part of the trough in the West. So this region represents a swell zone. Following the course of the isanomalies - particularly the magnetic minimum extending beyond Gabur - the Southeast Afghan Trough can be connected, across this swell, with the Potwar Basin in West Pakistan, which is known by its oil-fields.

The geological interpretation of the zone may be given by referring to the paper of O. GANSS (Lit. 7). The Zone of Quetta mentioned here is marked by basic rocks and represents the central swell between the South-east Afghan Trough and the shelf trough of the Indus Baluchistan Geosyncline. As has been said before, basic rocks determine also the Zone of Khost. Therefore, it can be assumed that the zone of Khost is the continuation to NW of the Zone of Quetta.

4.2.4.2.4. The western survey area

The maps of isanomalies of the western survey area (see Encls. Nos. 5 and 6) show an entirely different picture than those of the eastern regions. Moreover it is not possible to correlate anomalies of both regions. This is the case particularly with the continuation of the Sharistan Swell, which cannot be coordinated to any anomaly in the West.

The maps of isanomalies are determined by large-area anomalies that extend over tens of kilometers. Their strike is predominantly E-W. The tops of the bodies causing these anomalies reach altitudes of about 2 000 m below mean sea level, i.e. approximately 3 000 m below terrain.

Now it could be assumed that the anomalies of this area are caused by bodies of a kind similar to that in the region of Kandahar, with the only difference that magmatic rocks crop out there, while in the considered area they are subsided in greater depth. In this case, however, the anomalies in the region of Kandahar should have a greater amplitude. But in point of fact, the anomalies of both areas are lying in the same order of magnitude (some 100 γ). To illustrate these circumstances the magnetic field measured around Kandahar has been continued upwards for 7 000 m (cf. Encl. 2), a procedure which resulted in a considerable decrease of the amplitudes. It can be concluded, therefore, that the western survey area differs magnetically essentially from the other areas.

Besides these anomalies of deep-lying bodies there are anomalies that must have been caused by bodies cropping out at the surface or lying near the surface. From the rockmagnetic data (see Chapter 4.1.2., Table No. 1) and by comparison with the geological map in the region of Farah, it can be concluded that for a great part Tertiary volcanic rocks, possibly also granites, are causing these anomalies. Local anomalies in the South are to be ascribed to volcanic rocks of the Kuh-i-Khan Nashin and of the Kuh-i-Arbu as well as to ophiolites which are known also from the region of Kandahar.

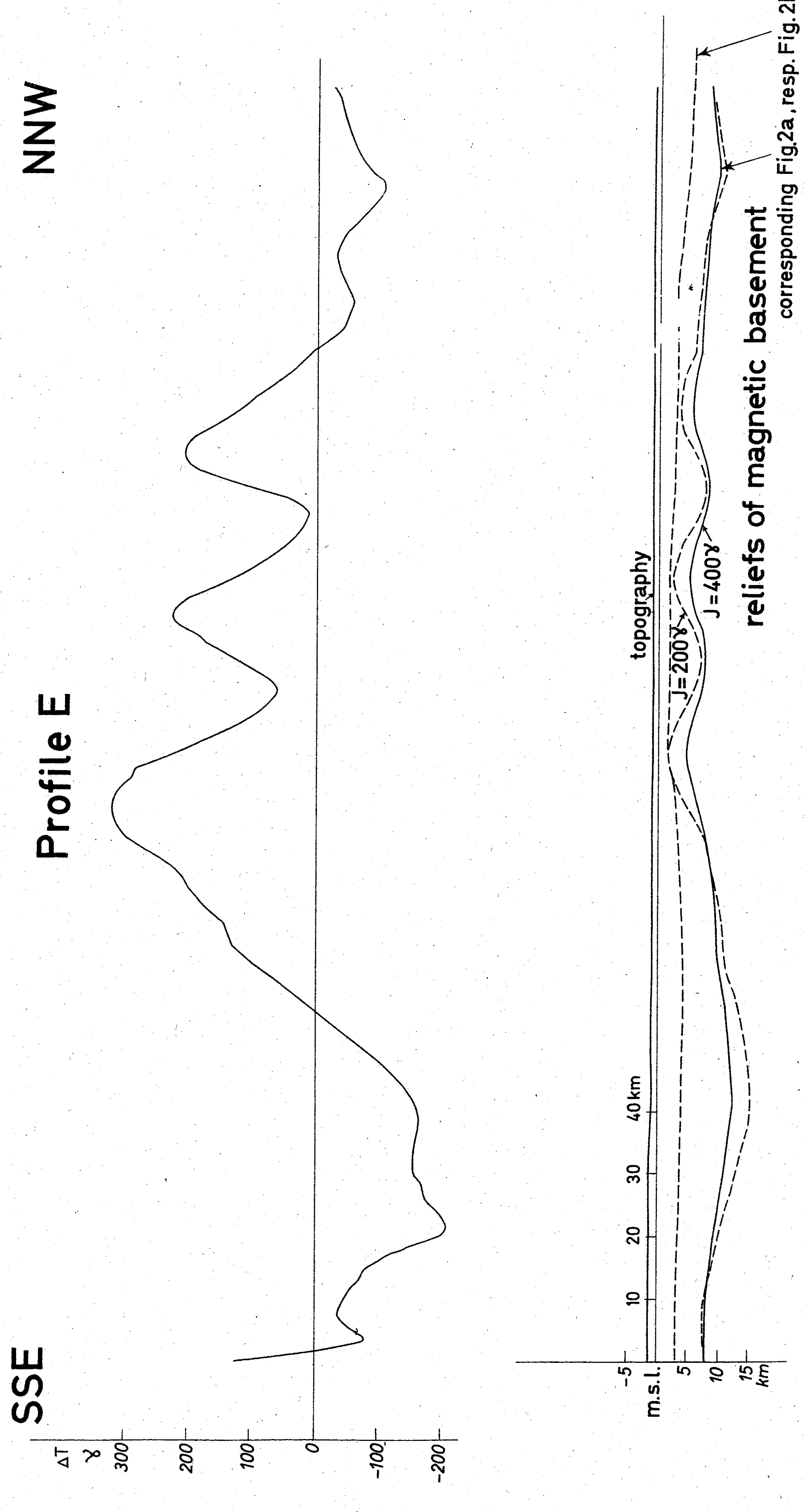
Interpreting the map of isanomalies one first has to separate the two groups of anomalies originating in different storeys. The anomalies of the deeper storey primarily determine the magnetic field, whereas the upper storey can be recognized only locally. Further the method of harmonic analysis permits suppression of certain anomalies by a kind of filter effect. So it is possible, to a certain extent, to separate the influence of both storeys from one another.

The deeper storey has been interpreted by the method of harmonic analysis (see Chapter 4.2.4.1.2.). If one presumes a magnetization of 150 γ, as in the eastern regions, the method is divergent+). Thus it is necessary to use a higher magnetization. A calculation of the relief has been tried with a magnetization of 200 γ. In this case divergences have been observed within the anomalies near Chakansur and North of Juwain; they disappeared assuming a magnetization of 400 γ. On the other hand a magnetization of 400 γ applying all over an area of such an extension seems to be rather improbable. As can be derived from Table No. 1, such magnetizations have been observed but in basic dikes. One thus rather will assume a regional mean magnetization of 200 γ; locally, however, within the range of the above-mentioned anomalies, it will be necessary to take into consideration higher magnetizations, for instance, 400 γ. A mean regional magnetization of 200 γ is shown by basic rocks, for instance, basalt, diabase, gabbro.

One relief each has been calculated for a magnetization of 200 γ and 400 γ. The results have been represented in the maps of interpretation (see Encls. 11, 12 and 13). (The differing magnetizations are indicated by a double marking of the isolines.) The location of the model bodies, the swells and trough axes can be derived from the maps of interpretation. Special attention should be paid to a potential upwarping in the region of Farah as well as to another one North of the big Hilmend bend near Khairabad both E-W striking.

+) Divergence means in this case that the undulation of the relief exceeds certain plausible limits.

Fig.12



Profile E
SSE
NNW
ΔT
γ
300
200
100
0
-100
-200
-5
m.s.l.
5
10
15
km
10
20
30
40 km
topography
J = 200γ
J = 400γ
reliefs of magnetic basement
corresponding Fig.2a, resp. Fig.2b

With a magnetization of 200 γ the relief gets strong amplitudes reaching up to 10 000 m. A magnetization of 200 γ , however, is essentially much more plausible than one of 400 γ because of the rockmagnetic results. So the geological model of Fig. No. 2b is suggested.

The basis for this model had been the conception of a rock complex of weakly magnetic components, which is interspersed by comparatively strongly magnetical (basic) rock bodies. Using this model for interpretation of the western survey area, the boundary sediment/ crystalline basement is approximately given by a connection of the tops of the model bodies. Such a relief is shown in Encl. No. 3.

Regarding the anomalies of near-surface bodies, which will chiefly originate in basic volcanic rocks, partly in granites, they are determined definitely by the structure of the deeper bottom. Therefore structural elements of the deeper bottom, which can be derived from the map of isanomalies, should in particular also be important for the structure of the overburden.

The most interesting structural elements are the lines that can be observed in the region of Farah and Khermalik. They are striking approximately SSW-NNE parallel to each other over a length of about 150 km. The two central lines end in the North at two characteristic very similar anomalies, whose type is interpreted in the Figs. Nos. 5 - 8. Vertical to them a further structure line has been plotted, approximately W-E striking. It crosses Farah and then joins the so-called Farah line. At the intersection points of these lines greater anomalies stand out that indicate potential intrusive bodies.

The structural elements described seem to determine essentially the geological structure of the north-western survey area. They should be taken into account for the preparing of the geological maps.

Further structure lines are to be recognized within the range of the deserts Registan and Dasht-i-Margo (cf. Encls. 5, 7, 8, 11, 13, 14). They strike N-S and E-W, respectively. But they are not developed as distinctly as those from the region of Farah, which had been discussed previously.

In particular there should be pointed to the anomaly of Chakansur. With an amplitude of about 1 500γ it is the strongest one of the whole survey. The anomaly was interpreted once by the relief of a magnetized layer with a magnetization of 600γ . As is shown by the result in Encl. 12, the upper surface of the magnetic body lies 500 m below mean sea level+). An equivalent interpretation by two-dimensional models yielded a dike-like body with a maximum depth of 5 700 m below mean sea level as it is plotted in Encl. 12. (A statement of the depth more exact than the range indicated by the two interpretation methods (500 m, 5 700 m, respectively) is not possible because of the rather considerable spacing of the survey lines.) The model "thin plate" does not prove the magnetic properties of the rock, because the interpretation yields only the product thickness (b) x magnetization (J). In this case the product had been calculated to $b \, . \, J = 6.10^6$ (m.γ). So the anomaly may be caused, for instance, by magnetite ore with a magnetization of 2 000γ and a thickness of 3 000 m, or by a strong

+) The topographic heights amount to 500 m to 1 000 m above mean sea level.

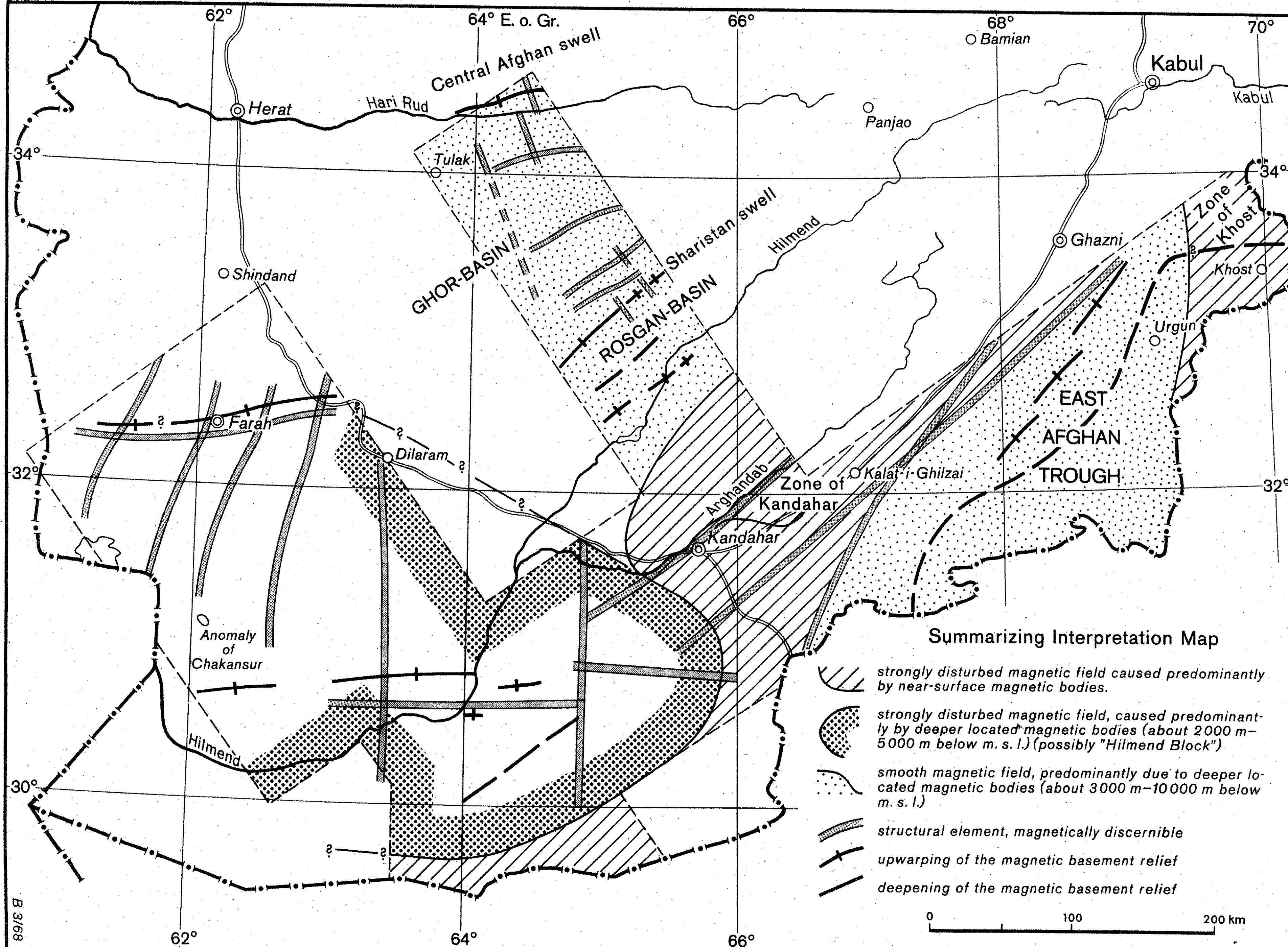
magnetic basic rock of a magnetization of 600 γ and a thickness of 10 000 m.

Remarkable is the deep minimum of the anomaly, which is twice as strong as the maximum. This speaks for the fact that the direction of magnetization deviates from that of the recent earthmagnetic field. Under the assumption of a finite, dike-like body the direction of the remanent magnetization results to: azimuth N 10° E, inclination $+10^{\circ}$. Calculating the relevant pole position and comparing it with paleomagnetic data (Lit. 2), a Tertiary age of the body results. Of course this is valid only for the body causing the anomaly of Chakansur, not so for the whole western survey area. Within this region the anomaly of Chakansur takes in a unique position and it seems to be very likely that this anomaly indicates a later "intrusion" into an already consolidated block.

The anomalies in the region of the Kuh-i-Khan Nashin show the well-known volcanoes of probably Quaternary age. They rest on a large-area anomaly of E-W strike.

Similar anomalies are to be found near the Kuh-i-Arbu in the South (see Encls. 45 - 52 in the PRAKLA report, Lit. 15). An interpretation using two-dimensional bodies shows Encl. 4. The southern anomalies should have been caused by basic rocks. This detailed survey had been made for the purpose of searching for magnetite iron ore occurrences. As can be seen from the maps of isanomalies there do not exist any anomalies that point to greater occurrences of magnetite in a small depth, namely such of economic interest.

Fig. 13



Aeromagnetic survey Afghanistan 1968

Bundesanstalt für Bodenforschung

For the geological interpretation of the western survey area it is important to stress the fact that the magnetic field shows a great similarity with those found above old shields. They have become known, among others, in Scandinavia, Canada and Brazil. Thus it can also here be assumed - particularly in view of the uniform character of the magnetic field - that within the range of the great Afghan deserts, i.e. in the Hilmend Depression, there exists an old block in the substratum below a partly minor overburden of not more than 2 000 m.

Hannover, February 26, 1968

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Tabelle 1 - Table 1

Ergebnisse gesteinsmagnetischer Untersuchungen -

Results of rockmagnetic investigations

Spalte 1	geographische Koordinaten (°)
Spalte 2	Aufschluß Nr. (s.Encl. 1)
Spalte 3	Geologisch-petrographische Klassifizierung
	Messungen an der Schmidt'schen Feldwaage Gf6:
Spalte 4	Probenanzahl
Spalte 5	induzierte Magnetisierung (γ)
Spalte 6	Remanenz (+: nachgewiesen)
	Messungen im Labor:
Spalte 7	Probenanzahl
Spalte 8	Suszeptibilität $\varkappa \cdot 10^6$
Spalte 9	Remanenz (γ)
Spalte 10	Deklination der Remanenz (°)
Spalte 11	Inklination der Remanenz (°)

1	2	3	4	5	6	7	8	9	10	11
<u>Kristallin bei Kabul</u>										
68,920 34,451	1	Glimmerschiefer (Epi-Mesozone)	10	0		4	0,08	0,05	276	32
68,850 34,370	2a	Gneis (Mesozone ?)	20	10		2	0,1	0,03	145	7
68,850 34,370	2b	Gneis (Mesozone ?)	8	1		2	2	0,4	250	27
68,853 34,324	3	körniger Granit mit Amphibolit-Linsen	12	60		5	160	50		
68,835 34,270	4	körniger Granat-Gneis	8	45		2	120	84		
68,812 34,256	5	Orthogneis	5	0						
	6	Glimmerschiefer	7	1						
	7	phyllitische Tonschie- fer und Quarzite	6	0						
69,038 34,516	8	Glimmerschiefer Amphibolit	6 5	3 6						
69,038 34,534	9	Glimmerschiefer	15	2						
69,031 34,538	10	Gneise mit Myloniten	7	190		1	600	160		
69,029 34,543	11	Gneis	8	2						
69,031 34,549	12	Augen-Gneis;Glimmer- schiefer	9	65						
69,029 34,549	13	Gneis	7	90	+					
69,041 34,545	14	Gneis	8	1						
69,075 34,543	15	Gneis, z.T. mit bas. Ganggestein	15	1						
69,125 34,535	16	Glimmerschiefer; Gneis	12	0						
68,570 34,447	17	Gneis	9	0						

1	2	3	4	5	6	7	8	9	10	11
68,566 34,445	18	Hornblende - Granat Gneis	5	0						
68,473 34,424	19	Grünschiefer-Phyllite	6	0						
68,462 34,423	20	Grünschiefer	5	2						
69,217 34,482	21	Kabuler Bändergneis	4	0						
69,211 34,462	22	Plagioklas-Amphibolit	6	4						
69,205 34,454	23	Granat-Glimmerschiefer	3	2						
69,198 34,441	24	Granat-Glimmerschiefer	7	6						

Magmatische und metamorphe Gesteine aus der Umgebung von Kandahar

65,98 31,38	25	Diabas	6	30						
66,03 31,33	26	Diabas	10	20						
66,03 31,33	27	Diabas	8	55						
66,27 31,14	28	Aplitgänge	10	20						
66,27 31,14	29	Hornblende-Biotit-Granit	5	35		2	74	16		
66,29 31,12	30	Hornblende-Biotit-Granit	5	40						
		basische Gänge i.Granit	3	220						
66,37 31,08	31	Hornblende-Biotit-Granit	3	35		1	190	350	60	58
65,72 31,63	32	Tuffe	5	150		1	500	225	14	26
65,74 31,64	33	Tuffe	5	70		1	320	100	240	71

1	2	3	4	5	6	7	8	9	10	11
65,53 31,65	34	Granodiorit-Dazit	8	9	+					
65,50 31,67	35	Andesit Ophiolit	4	110						
65,52 31,67	36	Granodiorit	6	6						
65,43 31,90	37	Diorit	6	45		2	25	13		
65,45 31,93	38	Aplit Granit	14	15		2	80	10		
65,21 31,70	39	Hornblende - Biotit Granit	7	5		1	2	1		
64,64 32,64	40	Granit	6	0		1	1	0,04		
64,65 32,69	41	Gabbro (basische Intrusion)	8	2						
64,69 32,69	42	Granatführende Glimmerschiefer (Granat Amphibolit)	5	0		1	6	0,2		
		basisches Ganggestein	4	4						
		Glimmerschiefer	4	1						
64,61 32,51	43	Diabas	7	1		1	31	9		
Magmatische und metamorphe Gesteine im Zentralgebiet										
62,94 32,49	44	Kontaktgesteine im Hangenden des Granits	5	1						
62,91 32,50	45	Granit-Kontakt	7	5		2	16	2		
62,90 32,51	46	tertiäre Vulkanite	7	160		2	200	150	316	38
62,88 32,54	47	Labrador Andesit	9	4		2	20	4		
62,82 32,60	48	bas.Vulkanite (alttertiär)	5	1		1	9	5		
62,39 33,18	49	Granit	8	20		2	35	10		

1	2	3	4	5	6	7	8	9	10	11
63,07 34,46	50	Granit	8	20						
63,11 34,47	51	Hornblende-Granit	6	10						
63,92 34,33	52	Kristallin	8	1						
64,21 34,10	53	tertiäre Vulkanite	6	4	+	2	4	27		
64,19 34,08	54	Tuff	7	20						
		Vulkanite	2	75						
64,43 34,31	55	bas.Vulkanite	7	5						
64,45 34,32	56	bas.Vulkanite	8	10	+	2	7	130		
64,46 34,34	57	Granit	7	1						
64,51 34,39	58	Gabbro - Diorit	3	10	+					
		Granit	2	15						
		Gneis	1	1						
64,50 34,36	59	Granit	8	30		1	53	12		
65,46 34,52	60	Granit	5	0						
		basische Intrusion	1	200						
	61	Granit	5	2						
	62	Granit	6	2						
	63	Granit	6	4						