GEOLOGICA CARPATHICA, 44, 3, BRATISLAVA, JUNE 1993
135 - 142

CENTRAL EUROPEAN (ALPINE - CARPATHIAN) BELT OF MAGNETIC ANOMALIES AND ITS GEOLOGICAL INTERPRETATION

IVAN GNOJEK[1] and HERBERT HEINZ[2]

[1]Geofyzika a.s., Ječná 29a, P.O. Box 62, 612 46 Brno, Czech Republic
[2]Geologische Bundesanstalt, Rasumofskygasse 23, P.O. Box 154, A-1031 Wien, Austria

(Manuscript received December 12, 1992; accepted in revised form March 31, 1993)

Abstract: Geomagnetic maps of former Czechoslovakia and Poland and the recently compiled aeromagnetic map of Austria reveal significant magnetic anomalies in the area of the Northern Calcareous Alps and in the North Alpine Foredeep, in the region of the Vienna Basin and in the Western Carpathian Foredeep as well as in the Western Carpathian Flysch. From regional point of view the set of anomalies might be regarded as a slightly sagged belt extending for about 700 km, from Innsbruck to Kraków. Magnetic modelling in association with geophysical and geological evidence imply that this belt is an old basement (Protero-Europe?) conserved between the Hercynian consolidated Bohemian Massif and Alpine-Carpathian zone. Rocks representing the remnants of a North Penninic oceanic crust (especially in the western part of the belt) are considered to be a source of some anomalous structures.

Key words: magnetic anomalies, Eastern Alps, Western Carpathians, basement, Proterozoic, Mesozoic, source bodies.

Introduction

The existence of large magnetic anomalies in the central part of former Czechoslovakia (eastern Moravia) has been pointed out in the aeromagnetic map of Czechoslovakia by Man (1968). Striking anomalous structures in the Beskydy mountains of southern Poland were drawn in the map of vertical component by Karaczun & Bilinska (1978). Locally they link with anomalies in the Moravo-Silesian and Slovak Beskydy mountains. The continuation of magnetic anomalies from southern Moravia to Lower Austria has been revealed by the pioneer works of the 1940's, carried out in the course of intensive oil prospection in the Vienna Basin (Bürgl & Kunz 1954). The distinctive Berchtesgaden (magnetic) anomaly west of the city of Salzburg was first found, investigated and analyzed by Gaenger (1954).

The links between anomalies in central Austria and those of Czechoslovakia and southern Poland are shown best in the aeromagnetic map of Austria compiled by Seiberl & Gutdeutsch (1987), published by Heinz & Seiberl (1990a) and Seiberl (1991). These anomalous magnetic structures are regarded as an expression of a fairly continuous belt of geological complexes extending from Innsbruck to the area of Kraków. The main part of this belt lies within Austria (60 %), 25 % in former Czechoslovakia and 15 % in Poland. There are distinct indications for a split of this belt into a northern and southern branch which commences in eastern central Slovakia (Heinz 1992). It is proposed that this extensive feature should be called the "Central European (Alpine-Carpathian) belt of magnetic anomalies", the first complete geological interpretation of which is presented here.

Characteristics of the Central European Belt of magnetic anomalies

The width of the belt ranges from 50 to 120 km. In its westernmost section it covers an area extending from Innsbruck to Steyr (Upper Austria) where it is most continuous. The well known Berchtesgaden anomaly (Gaenger 1954) dominates the pattern in this area with an amplitude of more than 100 nT. Along a line Mittersill-Eisenerz (see Pl. 1) there are several intensive superposed magnetic anomalies; an anomaly group located south of Liezen (Styria) has amplitudes of more than 500 nT (Heinz & Hübl 1988). All of those local magnetic structures have been called "marginal type" anomalies as they generally accompany the northern margins of the Austroalpine crystalline complex (Heinz 1989). Further to the northeast - between Steyr and the northeastern environs of Vienna - the amplitudes of the anomalies become much lower, about one third or even half, the amplitudes of those in its western part. This is not the only one difference as the width of the belt in this area is much smaller; its axis turns slightly into a more southwest - northeasterly direction. In its southern part only a few "marginal type" (sensu Heinz 1989) anomalies have been observed; but its northern part is disturbed by several magnetic structures characterized by high amplitudes and gradients. Whereas the western group of those anomalies is definitely due to relatively shallow sources within the Bohemian Massif (e.g. serpentinites associated with granulites or amphibolites, cf. Wieseneder et al. 1976), the interpretation of the remarkable anomalies along the eastern margin of the Bohemian Massif is still disputable ("Dunkelstein-Moldanubian Belt" in Pl. 1).

The central section of the belt of anomalies, from Mistelbach/Zaya (Lower Austria) to Zlín, contains the most intensive magnetic anomalies with amplitudes of even 500 nT. The general SW - NE trend does not change, but some structures extend in different directions: e.g. near Brno (N - S, NNW - SSE) or in the surroundings of Zlín (W - E). The southwestern margin of the belt is characterized SW of Brno by numerous superposed anomalies of surface or near-surface sources of the Moldanubian and Moravian unit. The generalized picture of this complicated pattern of anomalies in derived aeromagnetic maps, e.g.

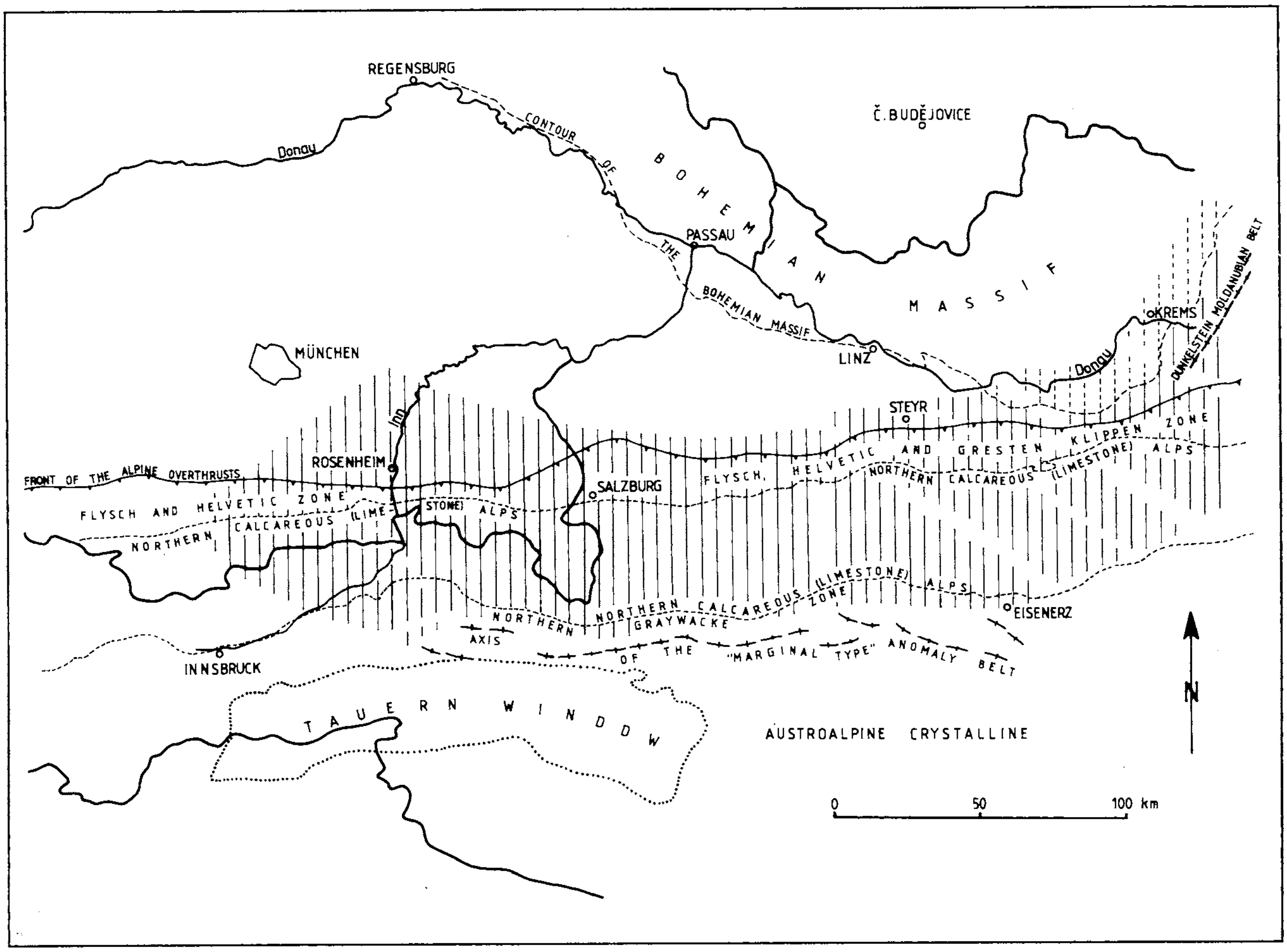


Fig. 1. Extension of the source rocks of the Central European belt of magnetic anomalies - western part.
Dashed line: sources which are definitely due to rocks of the Bohemian Massif.g. 1.

in the analytical upward continuation up to 1000 m above ground (Dědáček et al. 1990), and indicates a prevailing W - E and SW - NE orientation of anomalies associated with deeper sources.

The easternmost part of the belt, in northeastern Moravia (Czech Republic) and southern Poland ("Beskydy", i.e. the area between Zlín and Nowy Sacz, SE of Kraków), is characterized by anomalies with amplitudes of 100 - 150 nT[1)] mostly extending W - E and WSW - ENE. North of the High Tatras Mts., this trend is interrupted by a transversely oriented anomaly attaining amplitudes of more than 200 nT.

Delimitation of the anomaly sources

The parameters of the magnetic anomalies forming the belt in this study include information about the areal extense of the sources (Figs. 1 and 2), so a more detailed quantitative interpretation may yield data on the vertical distribution of magnetically anomalous complexes in the geological section.

The western, mostly Austrian part of the belt between Innsbruck and Vienna indicates the southern margin of the sources which is generally south of the Northern Calcareous Alps and the Northern Greywacke Zone. The rocks inducing the magnetic anomalies occur beneath the entire Calcareous Alps, beneath the Flysch (and related units north of it) and beneath large parts of the Molasse Foredeep (Rosenheim - Vienna). In agreement with Bleil & Pohl (1976) the source of this part of the belt is located at the position according to Fig. 3.

The southeastern margin of the Bohemian Massif is accompanied by a few magnetic structures which remarkably resemble the marginal type anomalies (sensu Heinz 1989) with their limited extension, high gradients and amplitudes. This association of anomalies is depicted in Plate 1 as "Dunkelstein-Moldanubian Belt".

In Moravia the belt attains a width of about 70 km. Its sources are probably quite close to the surface, exceptionally can outcrop. Man (in Blížkovský et al. 1986) interpreted the source of the most distinctive anomaly in Moravia as a subhorizontal slightly sagged body in a depth interval from 2 to 10 km. Bárta & Deščík (in Blížkovský et al. 1986) delineated the sources in Moravia within three depth intervals: 1.5 - 3.5 km, 3 - 10 km and 13 to 20 (25) km.

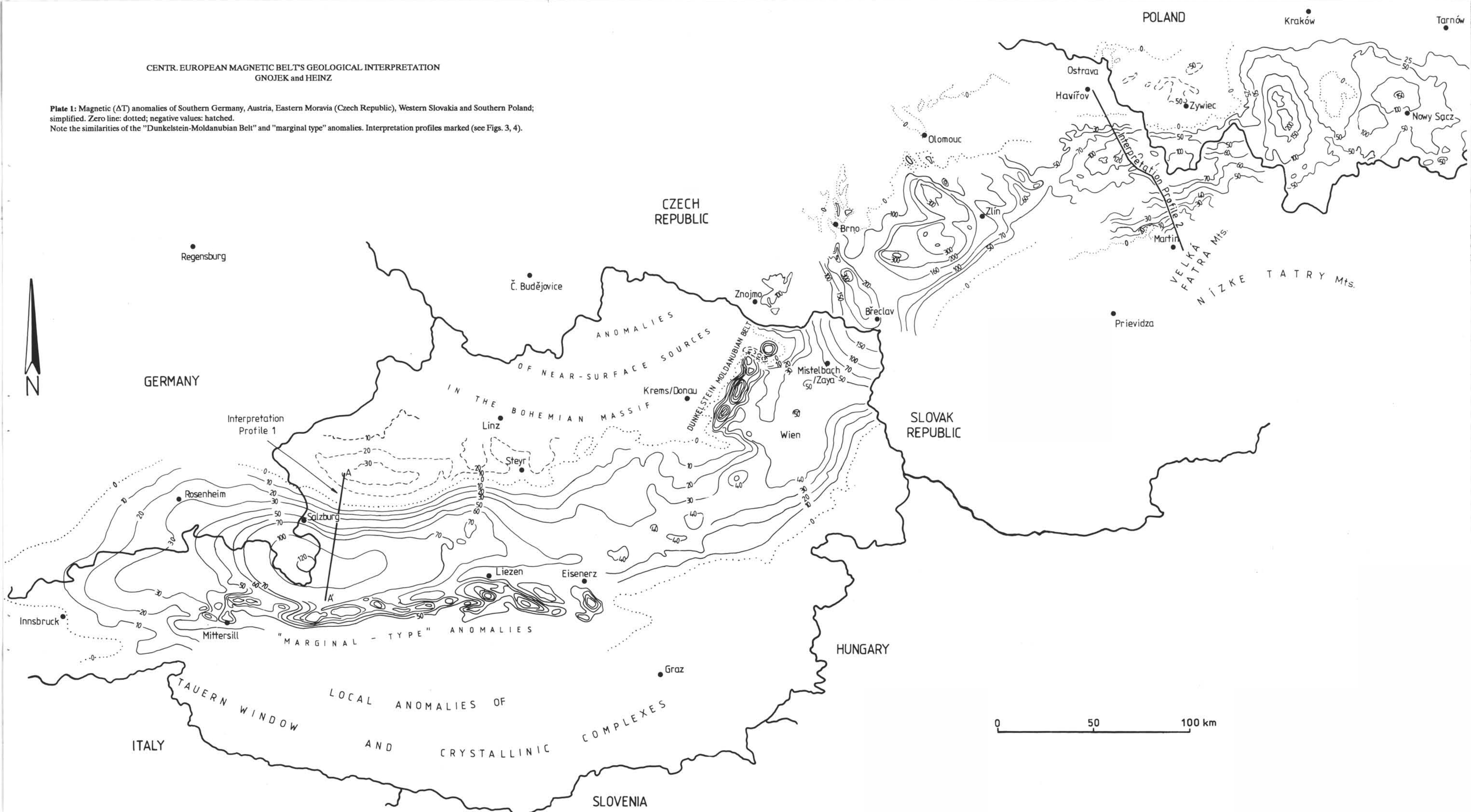
The eastern Beskydy part of the belt suggests complex rock sources mainly beneath the Cretaceous and Paleogene flysch units of the Outer Western Carpathians, in the north beneath

[1)] The normal field of the map of Z anomalies for Poland differs considerably from those of the maps for Austria and former CSFR, that is, approx. 120 nT. In this study we regard magnitudes of anomalies in Poland as decreased by this value for linking together the maps of anomalous fields of all three countries.

CENTR. EUROPEAN MAGNETIC BELT'S GEOLOGICAL INTERPRETATION

GNOJEK and HEINZ

Plate 1: Magnetic (ΔT) anomalies of Southern Germany, Austria, Eastern Moravia (Czech Republic), Western Slovakia and Southern Poland; simplified. Zero line: dotted; negative values: hatched.
Note the similarities of the "Dunkelstein-Moldanubian Belt" and "marginal type" anomalies. Interpretation profiles marked (see Figs. 3, 4).



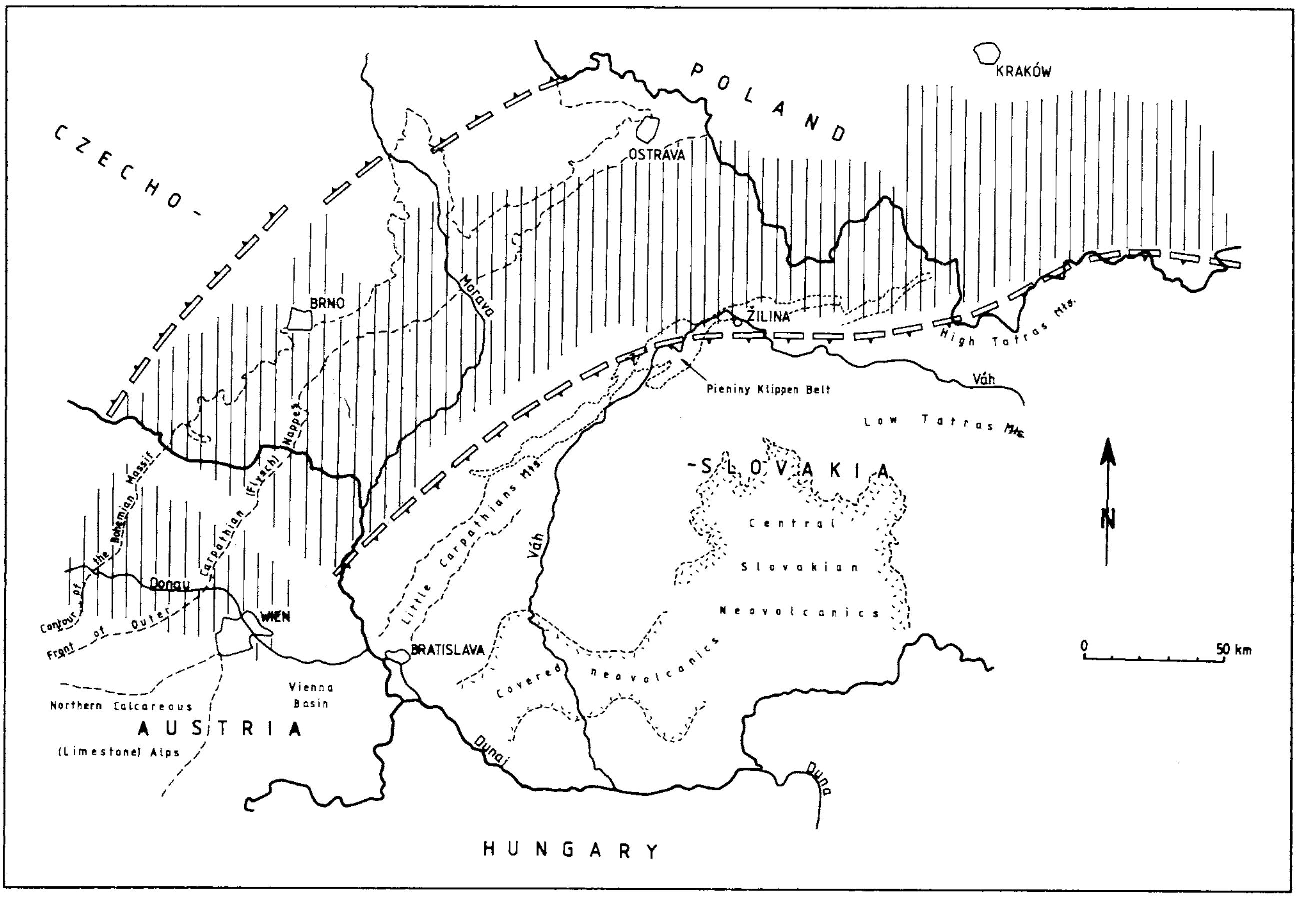


Fig. 2. Extension of the source rocks of the Central European belt of magnetic anomalies - eastern part.
Quadrangles: zones of high conductivities; arrows indicate the direction of dip.

the Miocene of the Western Carpathian Foredeep and in the south beneath the Pieniny Klippen Belt. In these areas the width of the anomaly belt ranges from 50 to 70 km. Models of the Beskydy magnetic source bodies, reported here have been constructed by Šutora & Gnojek (originals in Gnojek & Kubeš 1991). Two models have been offered (see Fig. 4):

1 - an inclined body, 4 to 6 km thick, with susceptibility values corresponding to intermediate or basic rock complexes, i.e. (25) 30 - 40 x 10^{-3} SI;

2 - a slightly upward warped complex within the upper crust, 10 to 15 km thick; susceptibility: 15 x 10^{-3} SI. The top part of the body is: 4 - 7 km below surface over the section but locally may only be 1 - 4 km below surface.

Petrophysical characteristics

In the course of oil, gas and black coal prospection numerous exploratory boreholes have been drilled mainly in the central part of the anomaly belt. Many of these reached the crystalline basement, especially in former Czechoslovakia but some also occur within the Northern Calcareous Alps and the Vienna Basin.

Several boreholes in the Moravo-Silesian Beskydy Mts. revealed intervals of clayey rocks of the Sub-Silesian, Silesian and Magura flysch units, several hundreds or even more than thousand meters in thickness, with effective susceptibilities from 0.3 to 0.45 x 10^{-3} SI. The calculated magnetic effect of such rocks where thickest, i.e. near the Pieniny Klippen Belt (where they are rooted), showed that they may generate magnetic anomalies of max. 8 to 10 nT amplitude. In fact, they induce minor anomalous undulations in the area W of the Pieniny Klippen Belt (up to 10 nT) as shown by Doležal (1985) on the map of DZ magnetic anomalies for eastern Moravia. These undulations are also observable W and NW of Žilina.

Similar magnetic susceptibility values (0.3 to 0.8 x 10^{-3} SI), with effective values of 0.5 x 10^{-3} SI on average, were found in drill cores of Early and Late Carboniferous silt- and claystone series, but the thicknesses of the rock sequences are much smaller than those of the flysch sequences mentioned above. The calculated magnetic effect induced by the Carboniferous rocks is negligible (2 or 3 nT).

Table 1: Representative susceptibility values from the Carpathians and their Foredeep, after Uhmann (1973) and Kadlečík et al. (1983).

Rocks	Susceptibilities (x 10^{-3} SI)
Miocene sediments of the Carpathian Foredeep	0.18
Paleogene and Cretaceous sediments of flysch units	0.21
Late Carboniferous sediments	0.25
Early Carboniferous sediments (Culm facies)	0.35
Devonian sediments (mainly carbonates)	0.11
crystalline basement	0.5 - 41

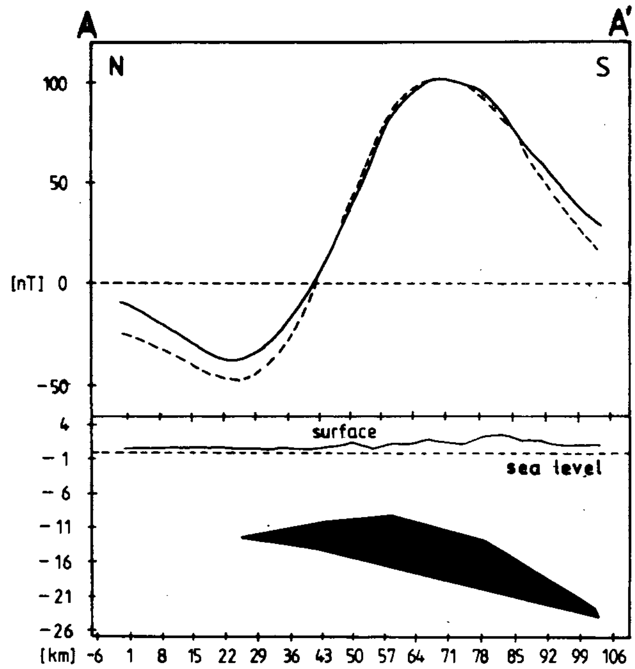


Fig. 3. Section across the large scale magnetic structure S of Salzburg (Austria), after Hübl (1991). Location see Pl. 1.
Model data: susceptibility: 0.0028 [SI], gradient x = 0, gradient y = 0, inclination (rem.) = 89°, declination (rem.) = 1°.
Field data: inclination = 63°, declination = 1°, field strenght: 47. 214 nT. Direction of cross-section: 175° S. Full line - observed, dashed line - calculated.

Recently, Ondra & Hanák (1989) published susceptibility values for a rather limited area (Snežnica Beds, Pieniny Klippen Belt). They range from 0.5 to 1.1 x 10^{-3} SI. Neither these layers nor any of the previously described sedimentary sequences are able to induce magnetic anomalies of hundreds of nT. Only thin and rarely occurring lenses of pelosiderites have susceptibilities from 0.1 to 3 x 10^{-3} SI and cannot act as even minor contributors to the generation of an extensive belt of anomalies.

The anomalies in the area could be affected by volcanic rocks: Diabase porphyrites of Devonian age were found in only one borehole (Nítkovice 2, approximately 40 km E of Brno) between depths of 1130 and 1200 m, with susceptibilities exceptionally attaining 12.6 x 10^{-3} SI. Another local occurrence of diabases intercalated into sediments of Late Carboniferous age, was found in the borehole Čeladná SV-6 (approximately 30 km S of Ostrava) between depths of 1300 and 1360 m, with susceptibilities of only 0.4 x 10^{-3} SI units. Those rare manifestations of Devonian and Carboniferous volcanism, though not quite negigible, obviously cannot substantially influence the magnetic field in the area.

More important magnetic contributors are teschenitic volcanites occurring in the Cretaceous sediments of the Silesian nappes in the Beskydy part of the belt in both former Czechoslovakia and Poland. They have been recorded from several boreholes in northeastern Moravia at depths of about 940 m below the surface, with maximum thicknesses of tens of meters. They have also been studied recently in outcrops by Kudělásková (1987) and Narebsky (1990). The effective magnetic susceptibility measured on core samples of those rocks were as high as 70 x 10^{-3} SI units. There are the most probable sources of some high amplitude anomalies with short wavelenghts in near surface and surface occurrences only in the Cretaceous Těšín-Hradište series of the Silesian nappes. The limited occurrences at depths of several hundreds of meters are not likely to influence the surface magnetic field.

The susceptibilites of the crystalline basement, obtained from borecore samples often range from 0.5 to 41 x 10^{-3} SI units. But almost all of them were strongly weathered and the amount of drill core material may not be fully representative. Nonetheless effective susceptibilities of 10 to 25 x 10^{-3} SI units and in some exceptions 30 to 45 x 10^{-3} SI units suggest that the crystalline complexes are the most like sources for the magnetic anomalies. They extend down to approximately 20 km and are thus the most significant sources of the belt in the Carpathian Foreland. According to the Geological Atlas of the Western Carpathians and their foreland seven boreholes reached the crystalline basement in the territory of Poland (Poprawa & Nemčok 1989), but no information is available about geophysical parameters for this area.

As already mentioned the geological background of the western section of the magnetic belt is mainly represented by the carbonatic masses of the Northern Calcareous Alps, by sedimentary sequences of the Rhenodanubian Flysch, the Helvetic unit, as well as (partly) the Greywacke Zone and the Austroalpine crystalline unit.

Table 2: Representative susceptibility values from the area of the Berchtesgaden anomaly. The sediments with magnetite represents merely thin layers which are not likely to produce anomalies of substantial magnitudes.

Rocks	Susceptibilities (x 10^{-3} SI)
Limestones of the NCA	0.13 - 0.21
Dolomites of the NCA	0.17 - 0.30
Rhenodanubian flysch (marls)	0.13 - 0.18
Rhenodanubian flysch (sandstones)	0.12 - 0.15
Sediments of the foredeep with magnetite as opaque fraction	> 3.94 - 10.70(!)

Table 3: Representative susceptibility mean values from Alpine metamorphites, volcanites and basites (partly according to: Weber et al. 1983). Additional values from selected rock types of the (South) Penninic Tauern Window have been published by Heinz & Pestal (1988).

Rocks	Susceptibilities(x10^{-3}SI)
Austroalpine	
orthogneisses	0.42 - 1.12
amphibolites	0.35 - 1.28
mica schists	0.6
paragneisses	0.4 - 0.5
Penninic system	
marbles	<0.1
sericite phyllites	~1
serpentinites	36 - 40, up to 160
amphibolites	3 - 32
greenschists	0.7
gabbro (3 occurrences only)	295
Volcanic sequences	
Miocene (andesitic)	2 - 40
Pliocene (basalts)	12 - 22

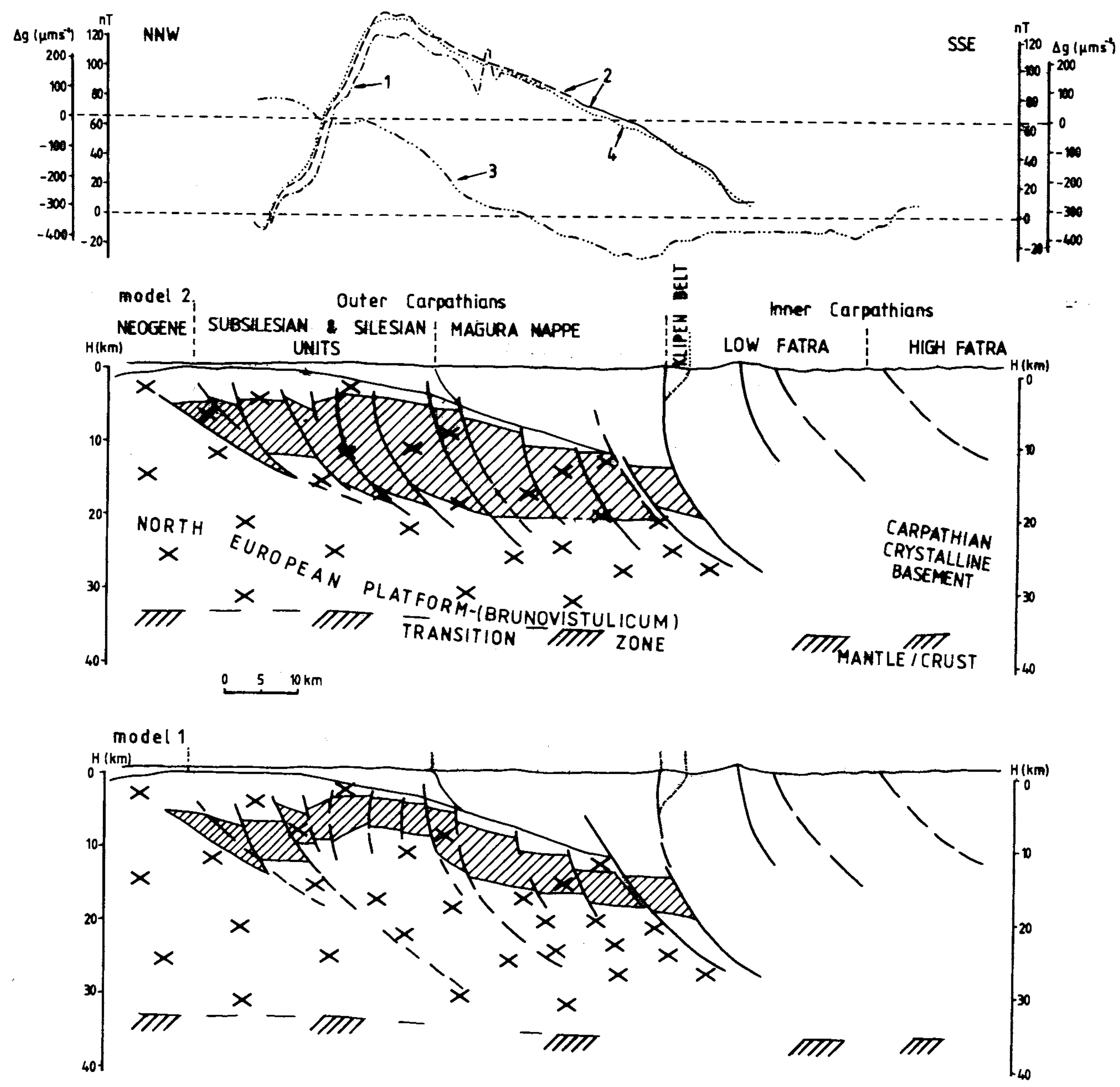


Fig. 4. Interpretation profile 2 (location see Pl. 1). The synoptic cross-section shows the magnetic sources (marked) of the Beskydy part of the Central European belt of magnetic anomalies using geological and gravimentric/density data as well.
Geophysical indications (upper part): 1 - vertical component magnetic anomalies ΔZ; 2 - total vector magnetic anomalies ΔT (full line - measured, dashed line - calculated from ΔZ values); 3 - Bouger gravity anomalies Δg; 4 - calculated effects of both magnetic and gravity models.
Crosses: crystalline complex between Variscides of the Bohemian Massif and the "Lower Carpathian Crust" - Brunovistulicum.

None of the outcropping rocks are likely to produce anomalies of the magnitude and extension shown in Pl. 1 or Figs. 1 and 2.

The source bodies for the "marginal type" of anomalies are mainly due to ultrabasic and related rocks. These magnetic structures dominate both the interior of the Tauern Window and the boundary between Austroalpine Crystalline and the northern units (cf. Fig. 1). Some of the source rocks are exposed (within the Tauern Window and SE of Liezen; Heinz & Hübl 1988; Heinz & Pestal 1988), or are located at very shallow depths (cf. Fig. 2 in Heinz 1989). The susceptibility values (Tab. 3) prove that solely rocks from the (Southern) Penninic domain should be regarded as being sources of the "marginal type" of magnetic anomalies.

Additional geophysical knowledge

Besides magnetometric data some gravity, seismic and geoelectrical data can be used for structural studies. Interpreting the Berchtesgaden magnetic anomaly across a SSW - NNE section Bleil & Pohl (1976) drew attention to a partial positive gravity anomaly (270 ms^{-2}) superimposed on the smooth deep Alpine gravity low of about - 1500 ms^{-2} south of the city of Salzburg, i.e. in the area of the anomaly source. For the model of the magnetic source body the differential density of 0.1 or 0.2 gcm^{-3} had been applied and the actually measured gravity effect of 270 ms^{-2} had been obtained. This coincidence of both gravity and magnetic effects gives strong evidence for the reliability of the geophysical interpretation of the anomaly source in the Berchtesgaden area.

In the map of Bouguer anomalies for the Vienna Basin and the both Czech and Slovak parts of the Outer Western Carpathians where the gravity low attains -400 to -600 ms^{-2}, no comparable partial positive anomalies are superimposed to the northern branch of the Carpathian gravity low. However in close vicinity to the Outer Carpathian margin independent local gravity elevations are observable with amplitudes of 150 to 250 ms^{-2}. They belong to a belt of gravity anomalies which is 80 to 100 km wide, accompanying the eastern margin of the Bohemian Massif. Its approximate axis follows a line Krems/Donau - Znojmo - Brno - Ostrava, situated between Central Bohemian and Outer Carpathian gravity lows. Thus, it is parallel and partly identical with the belt of magnetic anomalies in that area. The gravity anomalies are shown in a generalized form by Ibrmajer (1981) in a map of regional Bouguer anomalies in former Czechoslovakia. It has been also presented by Beránek & Dudek (1981) in a map of the zero contours of the second derivative.

The depths of the crystalline basement, which are important for interpreting the location and shape of the source bodies, are derived from seismic data (Kocák, Kadlečík, Mayer, Jan Novák, Josef Novák - Geofyzika Brno, pers. comm.). At the boundary Western Carpathian Foredeep/front of Carpathian flysch nappes the crystalline basement has been found at depths of 1.5 to 2.5 km, but, east of Brno, are only at a depth of 0.5 km (which is due to the Ždánice elevation). Near the frontier former Czechoslovakia/Poland the top of the crystalline basement is 2.5 km below surface. Close to the front of the Magura Nappes, about 10 to 30 km SE of the foredeep the crystalline basement inclines steeply to the E, SE and S, from depths of 3 down to 7 km. Further to the SE (over a distance of about 10 km) the basement plunges abruptly for another 3 km down to 10 km depth. In the vicinity of the Pieniny Klippen Belt there are almost no seismic indications concerning the basement, only in northwestern Slovakia (near Žilina) has the top of the crystalline basement been interpreted at depths of 11 to 13 km.

This general descent of the crystalline basement from the Carpathian Foredeep towards the Central Carpathians determines the position of sources of the magnetic anomalies. To the NW of the Carpathian Foredeep a slight plunge of the marginal segment of the basement crystalline underneath the Bohemian Massif is probable; this has been confirmed e.g. in the vicinity of Brno where Tomek (in Blížkovský et al. 1990; Profile 8 HR) interpreted NW - dipping reflection elements at depths of 4 to 7 km as overthrust faults within the Bohemian Massif.

Beránek (1971) defined a zone of high velocity seismic waves (6.5 kms^{-1}) while interpreting the results of the International Deep Seismic Sounding Profile (DSS-VI), which crossed the belt of the magnetic anomalies studied. The zone ascends from average depths of 20 km in the Western Moldanubian unit and down to 25 km beneath the Pannonian Basin, up to only 10 km in places. It consequently marks an uparching of lower crust masses of relatively high densities into the upper crustal levels.

Near the margins of the belt two geoelectric inhomogeneities of regional to continental significance have been found in former Czechoslovakia and Poland (Praus et al. 1981; Jankowski et al. 1984; Hvožďara et al. 1986). These extensive crustal conductivity zones are several hundreds of km long and extend down to a depth of 20 km. This "Carpathian Geoelectric Anomaly" (see Fig. 2) has very distinct physical manifestations. It extends from the eastern part of the Vienna Basin along the Pieniny Klippen Belt into the Tatra part of southern Poland. There it turns ESE, crossing northeastern Slovakia, the Transcarpathians towards Romania. Its thickness ranges from 1 to 7 km; it dips to the S (SE, SW) and the source is located in depth intervals of 7 (10) to 20 (25) km. The increased electric conductivity has been explained by the cited authors as:

- large thicknesses of permeable sediments along the front of the Central Carpathian mountains
- mineralized waters in these sediments
- high temperature of the waters
- partial melting of rocks (subductive processes).

A different geoelectric inhomogeneity (high conductivity zone) has been located (according to the same authors) close to the uncovered part of the southeastern margin of the Bohemian Massif (Fig. 2). It could be traced from the Czech/Austrian frontier area (SE Moldanubicum) to the NE along the eastern margin of the Třebíč Syenite Massif and to the northern part of the Drahanská Vrchovina Upland Culm. It continues to the Hornomoravský úval depression and into the center of the Nízký Jeseník (Niederes Gesenke) Culm as far as Silesia (Poland). The physical manifestations of this zone are, in places, less distinct than those in the "Carpathian Zone of high Conductivity".

The source of this anomaly has been interpreted as an 8 to 10 km wide body, increasing in width to 30 km in the area of Nízký Jeseník Mts. The depth of the source body reaches 12 to 22 km, and it dips to the W or NW respectively.

Geological interpretation - Discussion

In the previous chapters it has been demonstrated that there is no surficial evidence for any source rocks of the magnetic belt especially in its western part at least in the area between Innsbruck and Steyr (except for the very narrow chain of "marginal type anomalies along its southern margin). There is no doubt that Bohemian Massif rocks are traceable relatively far to the south e.g. "von Buch - Granite", borehole Aurach 1 - about 60 km SW of Linz etc., but the Bohemian Massif does not account for the magnetic sources (Fig. 1, Pl. 1).

For these and geodynamic reasons a model is presented, which suggests anomaly sources obducted as ophiolitic sequences below the outer units of the Eastern Alps (Heinz 1989; Heinz & Seiberl 1990; Oberhauser 1991). The existence of oceanic crust north of the Tauern Window - whose interior definitely has to be considered as a Southern Penninic (Piemontaisian) element - has been postulated by Frisch (1979, 1981) who evolved logically consistent geodynamic history of the Alpine system. Furthermore the results of the aeromagnetic survey of Switzerland (Commission Suisse de Géophysique 1983) provides evidence for the continuation of the "marginal type" anomalies to the west, but not for counterparts of the large scale anomalies of the Central European anomaly belt. The belt is obviously cut off by the "Engadin - Loisach - Lineament" (Tollmann 1977), which is traceable far to the northeast parallel to the NE - SW directed segment of the 10 nT- isoline W of Rosenheim (Pl. 1). Moreover, it is remarkable that Frisch (1979; especially Figs. 3 and 4) delimits the North-Penninic ocean at a transform fault in a similar position to this lineament. A detailed discussion about the (mainly nomenclature) consequences for Alpine terms which arise from this two-ocean-model has been initiated by Heinz & Seiberl 1990.

Borehole evidences from crystalline basement in former Czechoslovakia has been evaluated by Dudek (1980); more recently this has been worked on by Jiříček (1991) who put emphasis on the "Moravian Hercynides". Both compiled valuable maps of the crystalline basement in eastern Austria, western Slovakia and eastern Moravia. The crystalline basement of the southern part of Poland has been described in detail by Poprawa & Nemčok (1989). Dudek (1980) defined an independent crystalline unit, called Brunovistulicum, based on geological research, drilling and geophysical evidence. The age of metamorphism in this crystalline rocks and the age of magmatism in this area have been determined as 550 to 660 m.y., corresponding to the Cadomian consolidation of the Brunovistulicum, by Dudek & Melková (1985).

From the geophysical data as well as the interpretative cross sections (Fig. 4) it is deduced that the rocks producing the central part of the anomaly belt are part of the old crystalline basement unit. The magnetically anomalous rocks within this unit reach their highest level in the vault-shaped structure of the basement, north of the maxima of magnetic anomalies. From the top part of this vault structure they plunge, mainly by overthrust mechanisms, towards the W and NW beneath the Bohemian Massif. The southeastern flank of the vault structure is built up by the magnetic rocks first slightly and then steeply dropping down into the collision zone between the North European Platform and a Carpatho-Pannonian (sub)plate in which they have been consumed at a depth from over 20 (30) km. Due to the substantial changes in the physical conditions of this deep crustal level the basement rocks lost their magnetic properties. This crustal segment, formed in the Cadomian and filled by Brunovistulic rocks, can be interpreted generally as a rigid ridge (elevation of the Proterozoic basement) which formed an obstacle for the Moldanubicum and Lugicum progressing to the SE. Later, during the Alpine orogeny, it was an obstacle in the N (NW)-ward movement of the Carpathian/Pannonian plate as well. These subsequent antagonistic events were responsible for shaping this continental part of Proto-Europe into an antiform now being buried at depths of several km.

This model also explains some features of the conductivity zone at the southeastern margin of the Bohemian Massif which actually occurs at the northwestern margin of the buried Proterozoic basement elevation. This deep geoelectric anomaly is regarded as a conductivity feature of tectonized rocks due to the thrustplane Moldanubicum/Moravicum and, of both units, over Brunovistulicum. In the southwestern part close to the Czech Rebublic/Austria frontier the source may occur at a shallower crustal level (compared with the central and northern Moravian part). This zone is much older than the Carpathian Conductivity Zone and was repeatedly deformed by the NW-SE directed Labe fault system. Seismic, gravity and magnetic data indicate that the Cadomian complex has been built up by relatively heavy rocks similar to ocean type crust. This old and primary continental basement presumably did not fully resist the force which triggered the NW - SE discontinuities in the Central European crust. This is shown by the discontinuous prolongation of the belt to the S and SW of Vienna, where the Danube fault system was active; in the Central Moravian area the Labe fault system played an important role. Late Alpine transpression influenced the rigid basement as well (western margin of the Vienna Basin, western part of Beskydy Mts. area; rather unclear in the anomaly maps, but confirmed by seismic data).

Following Ádám & Pospíšil, the Carpathian Conductivity Zone which accompanies the magnetic anomaly belt is interpreted as an expression of the deep parts of the collision zone between the Carpatho-Pannonian (sub)plate and the North European Platform. The loss of magnetic properties of the platform rocks descending beneath the Curie-isograde-plane is an additional feature of this conductivity zone. An additional contributor to its origin are the large thicknesses of flysch sediments rich in mineralized water, creating a large accretionary wedge in the collision zone. The almost parallel axis of the Carpathian gravity low, as a response to the biggest thickness of the flysch, demonstrates the close relation of these phenomena.

Conclusions

The Central European belt of magnetic anomalies represents the most striking geophysical phenomenon in the Eastern Alps and Western Carpathians. It is homogeneous in respect of its physical appearance but is obviously built up by sources of different geodynamical importance and age. The source for the western part is considered to be a remnant of a North Penninic ocean (oceanic crust) which has been obviously limited in both time and space. The North Penninic oceanic crust has been obducted partly onto the northern continent ("Stable Europe"). This event was completed in the Late Eocene "second continent-continent collision" according to Frisch (1979, 1981). The "marginal anomaly" type accompanying the belt in the south is due to remnants of a South Penninic oceanic realm, which was consumed before the "first continent-continent collision" (Early Upper Cretaceous). The shape of the source bodies of the "marginal type" is due to their involvement into two continent-continent collisions (Heinz 1989; Heinz & Seiberl 1990). The time ranges mentioned simultaneously mark the initiation and then the entire consumption of the North Penninic ocean.

In contrast to the Eastern Alps the source rocks of the anomalous magnetic belt in the Western Carpathians are due to a much older geodynamic element. The drillholes reaching the Outer Carpathian basement brought evidence that mostly granodioritic, dioritic to gabbro rocks of Cadomian origin, pertaining to the Brunovistulic unit defined by Dudek (1980), are the dominating sources of the belt between Vienna and Olomouc. The eastern Beskydy part of the belt is mainly due to crystalline complexes (gneisses, amphibolites) with evidence of intermediate to basic plutonites (diorites or gabbros) as well. The age of these rocks is also considered to be Cadomian. The eastern termination of the belt in the vicinity of Nowy Sacz is probably influenced by a NW-SE tectonic lineament parallel or associated with the Tornquist lineament.

These almost completely buried Proterozoic complexes, consolidated by Cadomian tectogenesis, seem to have a slightly vaulted shape which might be the result of two orogenic processes. The first and older one was the Variscan orogeny forming the Bohemian Massif which influenced the W and NW side of the Proterozoic "core rocks". The younger and probably more intensive one was the Alpine-Carpathian orogeny which formed the S (SE) slope during the obduction of the Inner Carpathians. Deep seated (high) Conductivity Zones bordering the Cadomian source rocks both from the N (NW) and from the S (SE) could define the tectonic margins of this covered Proterozoic structure.

The Vienna Basin originated within the weakened zones of the Danube fault system is thus a key area hiding the original tectonic pattern of the contact of the Eastern Alps with the Western Carpathians. Great thicknesses of younger sediments and long distance movements along several strike-slip faults complicate the understanding of the extension of the Penninic realm and the termination or continuation of the buried Central European Proterozoic core.

Acknowledgements: The authors wish to thank Dr. Dudek and Prof. Tarling for comments on the script.

References

Ádám A. & Pospíšil L., 1984: Crustal Conductivity Anomalies in the Carpathian Region. *Acta Geodaet., Geophys. et Montanist. Hung.*, 19 (1-2), 19 - 34.

Bárta R. & Deščík M., 1986: Three dimensional model of the geomagnetic field - vertical component in Southeastern Moravia. In: Blížkovský M. (Ed.): *Geophysical model of the lithosphere.* Internal issue of the Geophys. Inst. Czechoslov. Acad. Sci., Geophys. Inst. Slovak Acad. Sci. and Geofyzika Brno (in Slovak).

Beránek B., 1971: Study of the velocity conditions in the Earth's Crust in the regions of the Bohemian Massif and the Carpathian System along International Profiles VI and VII. *Stud. geophys. geod.* (Praha),15, 316 - 330.

Beránek B. & Dudek A., 1981: Geological interpretation of the transformed gravity fields in the Bohemian Massif and in the West Carpathians. *Sbor. Geol. Věd, užitá Geofyz.*, 17, 47 - 59 (in Czech).

Bleil U. & Pohl J., 1976: The Berchtesgaden Magnetic Anomaly. *Geol. Rndsch.*, 65, 756 - 767.

Buday T., Pospíšil L. & Šutora A., 1986: Geological significance of some boundaries delimited by Landsat data in Western Slovakia and Eastern Moravia. *Miner. slovaca* (Bratislava), 18, 6, 481 - 499 (in Czech).

Bürgl H. & Kunz B., 1954: Magnetische Messungen im Wiener Becken. *Geol. Jahrbuch (Hannover)*, 70, 7 - 41.

Commission Suisse de Géophysique, 1983: Carte aéromagnetique de la Suisse 1/500 000, Carte 9, Wabern.

Dědáček K., Mašín J., Pokorný L., Procházka J., Štovíčková N. & Veselý V., 1990: Airborne geophysical mapping and its geological interpretation in Southwest Moravia. Manuscript. Arch. Geofyzika Brno (in Czech).

Doležal J., 1985: Vertical component magnetic intensity map of the Eastern Moravia, scale 1 : 200.000. Manuscript. Arch. Geofyzika Brno (in Czech).

Dudek A., 1980: The crystalline basement block of the Outer Carpathians in Moravia: Bruno-Vistulicum. *Rozpr. ČAV.* (Praha).

Dudek A. & Melková J., 1975: Radiometric age determination in the crystalline basement of the Carpathian Foredeep and of the Moravian Flysch. *Věst. Ústr. úst. geol.* (Praha), 50, 257 - 264.

Frisch W., 1979: Tectonic progradation and plate tectonic evolution of the Alps. *Tectonophysics*, 60, 121 - 139.

Frisch W., 1981: Plate motions in the Alpine region and their correlation to the opening of the Atlantic ocean. *Geol. Rndsch.*, 70, 402 - 411.

Gaenger R., 1954: Regionale magnetische Untersuchungen in den Berchtesgadener Kalkalpen und ihrem Vorland. Thesis, Univ. München, 1 - 62.

Gnojek I. & Kubeš R., 1991: Airborne geophysical mapping and its geological interpretation in Northwest Slovakia. Manuscript. Arch. Geofyzika Brno (in Czech).

Heinz H., 1989: Aeromagnetic measurements in the Eastern Alps: the area east of the Tauern Window. *Tectonophysics*, 163, 25 - 33.

Heinz H., 1992: Magnetische Strukturen in Mitteleuropa. *Frankfurter geowiss. Arb.*, 11, 228 - 229.

Heinz H. & Hübl G., 1988: Magnetische Anomalie am Lärchkogel (Steiermark). *Jb. Geol. B.-A.* (Wien), 131/2, 279 - 283.

Heinz H. & Pestal G., 1988: Geologisch-geophysikalische Analyse von Ultrabasiten aus den zentralen Hohen Tauern. *Jb. Geol. B.-A.* (Wien), 131/2, 285 - 289.

Heinz H. & Seiberl W., 1990a: Bewertung und Problematik Aerogeophysikalischer Anomalien im Österreichischen Bundesgebiet. *Abhandl. Geol. Bundesanstalt* (Wien), 44/1990, 1 - 244.

Heinz H. & Seiberl W., 1990b: Magnetic structures of the Eastern Alps west of the Tauern window. *Mém. soc. géol. France* (Paris), 156, 123 - 128.

Hvožďara M., Petr V., Pěčová J. & Praus O., 1986: Delimination of the main geoelectric inhomogeneities in the territory of the CSSR based on magnetovariation measurements. In: Blížkovský M. (Ed.): *Geophysical model of the lithosphere.* Internal issue of the Geophys. Inst. Czechoslov. Acad. Sci., Geophys. Inst. Slovak Acad. Sci. and Geofyzika Brno (in Czech).

Ibrmajer J., 1981: Geological interpretation of gravity maps of Czechoslovakia. In: Zátopek A. (Ed.): *Geophysical syntheses in Czechoslovakia. VEDA*, Publ. House Slov. Acad. Sci., Bratislava.

Jankowski J., Petr V., Pěčová J. & Praus O., 1984: Geoelectric anomaly in the Czechoslovak-Polish section of the Carpathians on the basis of geomagnetic and magnetotelluric soundings. *Acta Geodet., Geophys. Montanist. Hung.*, 19, (1-2), 81 - 91.

Jiříček R., 1991: The problem of the eastern termination of the Moravian Hercynids. *Zem. Plyn Nafta* (Hodonín), 1, 36, 3 - 40 (in Czech).

Kadlečík J., Doležal J., Čekan V., Uhmann J. & Filková V., 1983: Comprehensive processing of geophysical data in the Carpathian Foredeep and in Flysch Belts of the West Carpathians. Manuscript. Arch. Geofyzika Brno (in Czech).

Karaczun K. & Bilinska M., 1978: Vertical component magnetic intensity map of Poland, scale 1:500.000. *Wydawnictwa Geologiczne*, Warszawa (in Polish).

Kudělásková J., 1987: Petrology and geochemistry of selected rock types of teschenite association, Outer Western Carpathians. *Geol. Zbor. Geol. carpath.* (Bratislava), 38, 5, 545 - 573.

Man O., 1968: Aeromagnetic Map of Czechoslovakia (1:1, 000.000). *Central Geol. Institute (ÚÚG)*, Prague.

Man O., 1986: Interpretation of magnetic anomalies situated between the Bohemian Massif and the Inner West Carpathians. In: Blížkovský M. (Ed.): *Geophysical model of the lithosphere.* Internal issue of the Geophys. Inst. Czechoslov. Acad. Sci., Geophys. Inst. Slovak Acad. Sci. and Geofyzika Brno (in Czech).

Narebski W., 1990: Early rift stage in the evolution of Western part of the Carpathians: geochemical evidence from limburgite and teschenite rock series. *Geol. Zbor. Geol. carpath.* (Bratislava), 41, 5, 521 - 528.

Oberhauser R., 1991: Zum Zuschub des Penninikums der Ostalpen aus der Kenntnis ihrer westlichen Flysche von der Kreide- zur Eozänzeit. *Abstract SGG*, Chur.

Ondra P. & Hanák J., 1989: Petrophysical correlation in the Raca flysch unit in Eastern Moravia and Northwest Slovakia. *Čas. min. geol.* (Praha), 34,1, 31 - 43 (in Czech).

Poprawa D. & Nemčok J., 1989: Geological atlas of the Western Outer Carpathians and their Foreland. *Panst. Inst. Geol.* Warszawa, *Geol. Inst. D. Štúr* Bratislava; *Geol. Survey* Praha.

Praus O., Pěčová J., Petr V., Pěč K., Hvožďara M., Červ V., Pek J. & Lastovičková M., 1981: Electromagnetic induction and electrical conductivity in the Earth's body. In: Zátopek, A. (Ed.): *Geopyhsical syntheses in Czechoslovakia. VEDA*, Publ. House Slov. Acad. Sci., Bratislava.

Seiberl W., 1991: Aeromagnetische Karte der Republik Österreich 1:1,000.000. *Geologische Bundesanstalt*, Wien.

Seiberl W. & Gutdeutsch R., 1987: Aeromagnetic map of Austria, preliminary data processing compilation. Manuscript. Geologische Bundesanstalt/Universität, Wien.

Tollmann A., 1977: Die Bruchtektonik Österreichs im Satellitenbild. *Jb. Geol. Paläont. Abh.* (Stuttgart), 153.

Tomek Č., Dvořáková L., Ibrmajer I., Jiříček R. & Koráb T. 1987: Crustal profiles of active continental collisional belt: Czechoslovak deep seismic reflexion profiling in the West Carpathians. *Geophys. J. Roy. Astr. Soc.*, 89, 383 - 388.

Tomek Č., Dvořáková L., Ibrmajer I., Mayerová M., Mitrenga P., Nakládalová Z. & Slavík R., 1990: Results obtained by the new seismic sounding. In: Blížkovský M. (Ed.): *Geophysical research of the Earth crust* ... (Period 1985 - 1990). Manuscript. Arch. Geofyzika Brno (in Czech).

Uhmann J., 1973: Physical properties of rocks in Neogene Foredeep and Flysch Belts of the West Carpathians. Manuscript. Arch. Geofyzika Brno (in Czech).

Weber F., Schmöller R. & Walach G., 1983: Jahresbericht 1982 über die geophysikalischen Untersuchungen im Rahmen des Teilprojektes S15/15. *Jber., Hochschulschwerpunkt*, 15, Graz.

Wieseneder H., Freilinger G., Kittler G. & Tsambourakis G., 1976: Der kristalline Untergrund der Nordalpen in Österreich. *Geol. Rndsch.*, 65, 2, 512 - 525.