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3. Map of Magnetic Anomalies at the Territory of Slovakia and Their Interpretation

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Abstract: The Unified Geomagnetic Map of Slovakia, compiled in 2008, has become the basic map for the interpretation of the sources of magnetic anomalies in the territory of the Slovak Republic. The latest geophysical software Oasis montaj was used to interpret and model magnetic anomalies. The results of the interpretation and modelling of magnetic anomalies provide the basis for geological and tectonic affiliation and petrographic classification of their sources. On the basis of the results obtained, maps of the spatial extent of sources of magnetic anomalies in the pre-Tertiary formations and products of Tertiary and Quaternary volcanism in our territory were compiled. The latest geomagnetic measurements have also revealed the buried volcanoes in various regions of Slovakia, the various types of granitoids (tonalites) and the extensive dimensions of Vepor Stratovolcano have also been distinguished.

Keywords: magnetometry, geomagnetic field of the Earth, magnetic map of Slovakia, geophysical information system SGIDŠ, interpretation of geomagnetic anomalies

3.1 Introduction

Terrestrial geomagnetic measurements of the vertical component of the total intensity of the Earth's magnetic field were made in the 1960s in Eastern Slovakia and in the "Little Podunajská nížina Lowland". In the 70s of the previous century, exploration continued in the Spišsko-gemerské rudohorie Mts., the Ipeľská kotlina Basin and Krupinská vrchovina Upland, the Lučenská and Rimavská kotlina basins, and later in the Spišsko-gemerské rudohorie Mts., the Slovenské rudohorie Mts. and the eastern part of the Nízke Tatry Mts. After evaluating the results of the ground geomagnetic survey, the aeromagnetic mapping of selected areas of Slovakia continued. Until 1992, the territory of Slovakia was covered by geomagnetic measurements by various technological procedures and different instrumentation that responded to the given period. By airborne magnetometry, about 2/3 of the Slovak territory was measured. In the years 2005–2008 the territories without any coverage were complemented by terrestrial geomagnetic mapping with a step of 1–3 points/km^2 (Kubeš, 2008). As they were predominantly mountainous areas, the number of points per km^2 was limited by the terrain. The total magnetic induction vector T was measured. From the geomagnetic data thus obtained, a unified magnetic map of Slovakia (Fig. 3.1) and a magnetic database with a grid of 125 x 125 m were compiled.

The detected magnetic field anomalies were gradually interpreted by various authors and various interpretive techniques that were constantly evolving. Many times, however, the known magnetic properties of rocks in some regions were not interpreted and modelled many times, or there was a lack of knowledge of these properties. Sometimes, even the latest knowledge of the geological setting

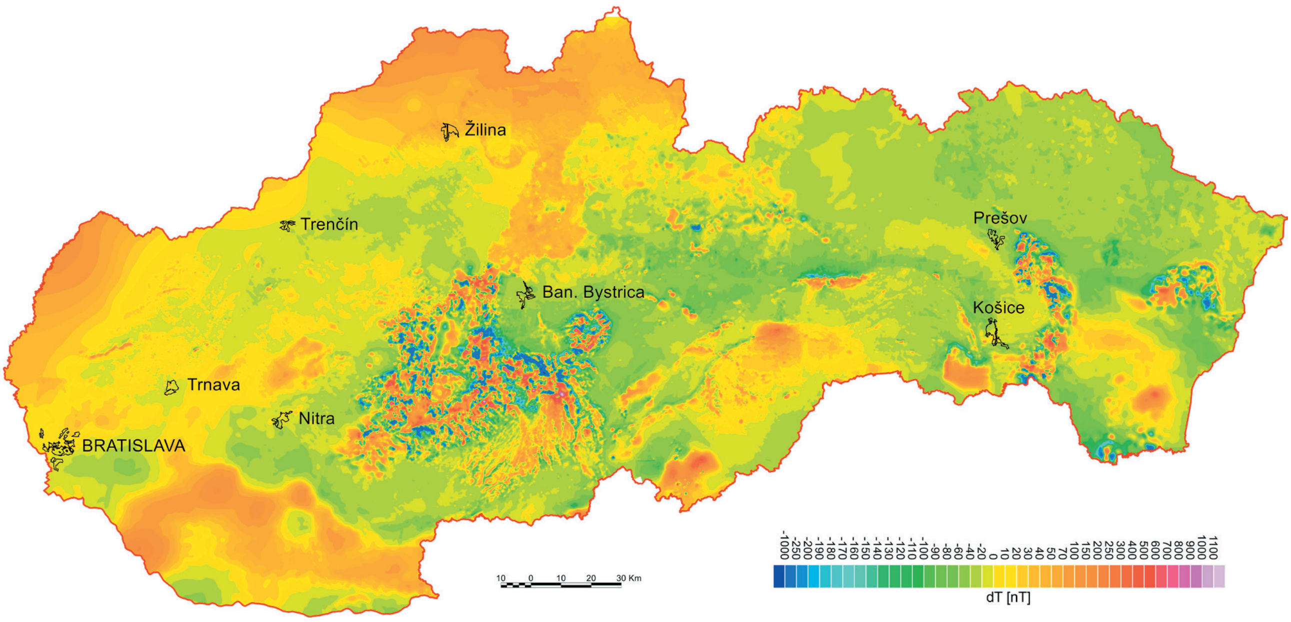

Fig. 3.1 *Unified magnetic map of the territory of Slovakia (Kubeš, 2008), at scale 1 : 500,000*

of Slovakia has not been reflected, which in many cases has led to erroneous interpretations. In interpreting sources of magnetic anomalies from Tertiary or Quaternary volcanism, the situation was also complicated by the existence of rocks with normal and reversed magnetic polarization.

3.2 General characteristic of the Earth's geomagnetic field

3.2.1 Earth's geomagnetic field

Earth's magnetic field study is one of the oldest scientific disciplines. The theory of the Earth's magnetic field depended on the technical achievements and the development of the mathematical apparatus at that time. The first mathematical expression of the earthly geomagnetic field was already presented by Gauss in 1838. Realistic ideas of the emergence of the Earth's magnetic field began to emerge after 1940. One of the most famous theories was developed by E. Bullard (1949) and W. Elsasser. The Bullard model is based on the construction of a body of the earth, the inner core of which is solid and the outer is composed of molten iron, nickel and a small silicate admixture. As a result of the upward and downward movements in the Earth's core and the forces resulting from the rotation of the Earth, the inner layers of the molten core rotate faster than the extern ones. The Earth's mantle rotates faster than its adjacent core layers. Then, Bullard explains the Earth's geomagnetic field as the reflection of all movements and interactions between electromagnetic and mechanical forces. Although this theory is mathematically deeply elaborated and illustrates the emergence of the major dipole magnetic field, the secular variations and continental magnetic anomalies as well as the Western drift, it does not explain the origin of the inversion of the Earth's magnetic field. Experts have suggested a whole bunch of other models, however, they can only be considered as partial solutions to some specific issues of the Earth's magnetic field. Previous knowledge does not make it possible to fully elucidate all the complexities of the geomagnetic field and to verify the ideas about composition and the processes that are taking place there.

3.2.2 Components of the Earth's magnetic field

The Earth's magnetic field at a certain point on the Earth's surface is determined by a vector of magnetic induction (T), which can be decomposed to the vertical (Z) and the horizontal component (H). We can also express the vector T by means of directional parameters, namely magnetic declination (D) and magnetic dip (I). Magnetic declination is the angle between the geographic meridian and the horizontal component H falling in the direction of the magnetic meridian. Dip (inclination) is the angle that generates the total vector T with a horizontal plane (H). Declination can be 0 to 180º (East or West). The dip increases towards the magnetic poles, where it has a value of 90º (in the north + in the south -). The magnitude of the vector of magnetic induction T is about 48,000 nT, dip +65º and declination to +5º.

3.2.3 Structure of the Earth's magnetic field

The resulting magnetic field of Earth consists of a permanent and time-varying magnetic field. The permanent field matches the sum of the effects from:

- the dipole field (the magnetic field of the homogeneously magnetized Earth body),
- the magnetic field of global, or continental anomalies (sources located in about half of the Earth's radius – probably core-mantle interface)
- the magnetic field of regional anomalies (sources are usually located in the upper parts of the Earth's Crust – to a depth of about 35 km);
- the magnetic field of local anomalies (sources are located closer to the surface).

Time variations of the Earth's magnetic field

Time changes of the Earth's geomagnetic field are caused by different sources and have a different duration. These time changes are mainly caused by:

- the processes that take place in the Earth's body (mainly in the Outer Core), so-called secular variations – lasting from a few dozen, hundreds up to hundreds of thousands of years. Their focal points are moving in different directions, mostly westward (drifting). During some geological periods there was an inversion of the Earth's magnetic field polarity with an average period of 400 to 600 thousand years;
- the processes going on in the Sun and in the Earth's atmosphere (they depend on the physical processes running on the surface of the Sun and the mutual position of the Earth and Sun or the Moon). The most important are annual and daily variations.

Magnetic properties of minerals and rocks

The magnetic properties of minerals are characterized by some parameters:

- magnetization and magnetic polarization – rocks with magnetic minerals are magnetized in the Earth's magnetic field. In the current magnetic field, rocks obtain the induced magnetization. Rocks can also obtain remanent magnetization, which depends not only on the magnetizing field, but also on other factors existing at a given time when the magnetic field has acted (temperature, chemical reactions, rotation of magnetic poles, etc.)
- magnetic susceptibility (F) and permeability (P) – are dimensionless quantities that characterize magnetic substances (diamagnetic, paramagnetic and ferromagnetic),
- Curie temperature Tc – magnetic susceptibility (or permeability) and magnetization (or magnetic polarization) are temperature dependent. It is the temperature where magnetic substances lose their magnetic properties. Magnetite +578 ºC, hematite and maghemite +675 ºC, pyrrhotite +300 to +325 ºC,
- The temperature (point) of the TT transition – by cooling (e.g. with liquid nitrogen -196 ºC), the magnetic substances become non-magnetic. When reheated, the so-called "magnetic memory" appears; e.g. of hematite when reheated above -23 ºC.

Magnetic properties of rocks depend on the amount of magnetic minerals. The most important magnetic minerals are: magnetite, ulvöspinel, maghemite, hematite, ilmenite and pyrrhotite.

According to the magnitude of the magnetic susceptibility, we divide the rocks into:

- practically non-magnetic: below 300 x 10^{-6} of·SI units,
- very weak magnetic: 300 to 1,000 x 10^{-6} of·SI units,
- weakly magnetic: 1,000 to 10,000 x 10^{-6} of·SI units,
- magnetic: 10,000 to 50,000 x 10^{-6}· of·SI units,
- strongly magnetic: over 50,000 x 10^{-6} of·SI units.

The highest magnetic susceptibility, as well as the natural remanent magnetization, have the magnetite-containing rocks. These are, in particular, the igneous and metamorphic rocks. The lowest magnetic susceptibility have the sedimentary rocks containing hematite.

3.2.4 Magnetic anomalies

Magnetic field anomalies are detected in areas where the measured magnetic field is significantly different from the calculated normal Earth field. They are characterized by a significant change in Earth magnetic field gradients. While the normal field gradient is several nT/km, the gradient of the measured field reaches several tens to hundreds nT/km. The magnitude of the *normal magnetic field* depends on the geographical coordinates and in the past it was determined differently for different epochs and regions, making it impossible to build magnetic maps, for example, for Central Europe. At present, the so-called the International Geomagnetic Reference Field (IGRF) has been adopted, whose calculation is already the basic tool of modern geophysical software.

The magnitude and shape of magnetic anomalies depends on the dimensions (depth of the upper and lower edges of the body, thickness, etc.), structural conditions (dip, magnetic effect from several sources) and magnetic properties of rocks (magnetic susceptibility or direction and magnitude of the magnetization vector both induced and remanent). The subject of magnetic anomaly interpretation is the solution of direct, or inverse magnetometry.

3.3 Level of geomagnetic survey of Slovakia

The first aeromagnetic measurements in Slovakia began at the end of the 1950s at a scale of 1 : 200,000 (Mašín et al., 1963). The map of the isolines was compiled from profile measurements of the total magnetic field strength for a mean flight height of 100 m above the terrain at a profile distance of 2 km. Due to the low resolution of the devices used, the complex morphological conditions and the distance of the measured profiles, the maps are not suitable for further use. Moreover, the measured data does not exist in digital form.

Experimental aeromagnetic measurements at higher altitudes were made in 1966 for a flight height of 500 m above the ground and 2,000 m above sea level in the Central Slovakian Neovolcanites and 300 m above the terrain in the East Slovakian Neovolcanites (Šalanský, 1970, Beneš, 1971). The measured data are also not in digital format.

In the period of 1976 and 1992, the interior of the Western Carpathians was air-mapped. The measured area does not include the Podunajská and Východoslovenská nížina Lowlands, Veľká Fatra, Chočské pohorie, Nízke and Vysoké Tatry mountain ranges and the whole area of the Outer (flysch) Carpathians. The total magnetic field T intensity vector was measured, with a flight height of 80 m above the relief of the terrain. The profile distance was 250 m with a measurement step of 25–55 m (Gnojek & Janák, 1986; Dědáček et al., 1991; Gnojek & Kubeš, 1991; Gnojek, Janák & Nemčok, 1992).

The terrestrial magnetic measurements began in eastern Slovakia in 1960 (Man, 1961). The vertical component of the total vector of the magnetic field with a density of 4–6 points per km^2 was measured.

The next ground geomagnetic measurements were carried out in 1962 in the Podunajská nížina Lowland. The vertical component of the magnetic field was measured with a density of 1 point/km^2 and the values were processed to a scale of 1 : 200,000 (Man, 1962).

Bárta commenced in 1962 the field magnetic measurements at a scale of 1 : 25,000. The vertical component of the magnetic field in the Spišsko-gemerské rudohorie Mts. region with a density of 10–12 points/km^2 was measured (Bárta, 1969).

In 1974 the area of Ipeľská and Krupinská vrchovina Highlands was the subject of measurement. Šefara et al. carried out field measurements of ΔZ at a scale of 1 : 25,000 with a density of 5–15 points per km^2 (Šefara et al., 1974).

In the Lučenská and Rimavská kotlina Basins measurements were carried out with a density of 10–12 points/km^2 in the years 1969–1970. The component of the Earth's total vector of the magnetic field with the output to the maps was 1 : 25,000 and 1 : 50,000 (Bodnár, 1979).

In 1980, Obernauer completed the ground measurement in the western part of the Slovenské rudohorie Mts. and in the eastern part of the Nízke Tatry Mts. with a density of 10–12 points per km^2 at a scale of 1 : 25,000. The partial component of the total vector of magnetic induction of the geomagnetic field and also the magnitude of the total vector T (Obernauer, 1980) and the wider area of Bratislava – Malé Karpaty area, SE part of Záhorská nížina Lowland and NW part of the Podunajská nížina Lowland were measured. Output maps contained the ΔT isolines at a scale of 1 : 25,000 (Bárta et al., 1988).

In 2005–2008, terrestrial magnetic mapping covered large areas of territories until then without any magnetic field measurements (Kubeš, 2008). Geographically, they fall (according to Mazúr and Lukniš, 1980) within: Bukovské vrchy Mts., Laborecká vrchovina Upland, Ondavská vrchovina Upland, Busov, Čergov and Beskydské predhorie Mts. The area of interest in the Inner Carpathians is located in the Žilina Region in the north of Slovakia. The region includes Skorušinské vrchy, Chočské vrchy, Veľká Fatra, Vysoké Tatry, Nízke Tatry Mts., Podtatranská kotlina Depression and Kozie chrbty Mts. Geomagnetic survey coverage is shown in Fig. 3.2.

Fig. 3.2 *Geomagnetic survey coverage of the territory of Slovakia (Kubeš, 2008)*

From previous measurements a database of geomagnetic measurements was created (Kubeš, 2008). For the creation of the database measurements were used in the sense of Table 3.1. Existing database of magnetometric data of Slovakia was compiled on the basis of airborne (Gnojek, 1986; Gnojek, 1991; Gnojek, 1992) and ground magnetometry outputs (Man, 1962; Možný, 1963; Man, 1961; Kubeš, 2008).

Basic data on aeromagnetic measurements

Airborne magnetometry in M 1 : 25,000 covers approximately 70% of the territory of the Slovak Republic. The base flight profiles were 250 m apart and 2,500 m perpendicular bridging profiles. Sampling of all measured values took place at a frequency of 1 sec. Flight height ranged from 70 to 100 m above terrain, at flight speeds around 120 to 130 km x hour^{-1}. Aircraft equipment was carried by helicopters (predominantly Mi-8) in all areas of neovolcanites, core mountains and intermountaineous depressions vessels, only in the southern part of the Východoslovenská panva Basin, in the Orava area and Levočské vrchy Mts. it was transported by biplane AN-2.

The entire volume of aviation magnetometry was measured by the proton magnetometer G-801/3B of the Company Geometrics (USA). When helicopters were used, the magnetometer detector was in the subframe, in the case of AN-2 aircraft, the detector was at the outer edge of the wing.

The bulk of aerial measurements (until 1982) were locally documented by a video record of the flight path by the Company Sony. Subsequent confrontation of a video with a detailed 1 : 25,000 topography map was then the basis for determining the point data of each flight profile. Only in the Juhoslovenská panva Basin, in the Orava area and Levočské vrchy Mts. was the location of the air data measured by Motorola's Mini Ranger III positioning system (USA). The terrain's flight height was measured by a radio shader with the same one-second frequency. The continuous recording of all data on board aircraft was digital.

In the processing of aviation magnetic data, correction was applied to daily variations of the geomagnetic field. These variations were largely measured by their own portable variation station, located in the airport, where the base of the measuring group was. Only in cases of natural magnetic field interference by electrified railways the values of daily variations were taken from the Geomagnetic Observatory in Hurbanovo. The actual calculation of the delta T anomalies was then carried out by reduction to the normal field, which was determined for the Carpathian part of the Czechoslovak Socialist Republic by O. Man to the epoch 1974, 3.

From the resultant values of the observed geophysical parameters – the ΔT anomalies obtained along the individual flight paths, a regular square network of 125 m x 125 m dimensions was formed mathematically, oriented in the direction of the kilometre network of the Gauss-Krüger geographic coordinate system. The average measurement error was not defined.

Basic data on ground magnetic measurements

In all three cases (A – C), the vertical component of the intensity of the magnetic field Z was measured. In the Podunajská nížina Lowland, the density of the measurement was 1 point/km^2, in the Východoslovenská nížina Lowland 4-6 points/km^2. The density of the points in the Vienna Basin and the West Carpathian Flysch is not mentioned, but it is assumed to be 1 point/km^2. As reported by the authors of the reports, additional supplementary measurements (densifying) were performed in anomalous areas. The mean measurement error was within 3 nT.

In the case of Regions V and Z, magnetic induction of the total vector of the geomagnetic field of the Earth was measured in a step of 1 to 3 points/km^2. The mean measurement error was calculated to 1 nT.

3.3.1 Unified magnetic map of Slovakia

In 2001, work was completed on the project "Atlas of Geophysical Maps and Profiles" (Kubeš, 2001) and in 2008 "Magnetic Map of Slovakia" (Kubeš, 2008).

The objectives of these projects were:

- to compile a unified magnetic map of Slovakia at a scale of 1 : 500,000 and 1 : 200,000;
- to build a grid database of 125 x 125 m (the ability to build a magnetic map at a scale of 1 : 50,000) from the geomagnetic measurements and implement it into the GfIS (Geophysical Information System);
- to compile the maps of magnetic sources in the pre-Tertiary subsoil and the products of Tertiary and Quaternary volcanism with determination of their types, polarity and age for individual apparatuses, or bodies;
- to comprehensively evaluate and model more significant sources of magnetic anomalies;
- for selected magnetic anomalies to build a geological-geophysical source model, supplemented by a petrophysical characteristic;
- to summarize and evaluate the magnetic properties of rocks and rock complexes with regard to sounding measurements in selected wells (mainly reaching the pre-Tertiary basement).

To assemble a unified magnetic map of Slovakia aeromagnetic measurements with an average flight height of 80 m above the terrain relief were used. The results of ground measurements of the vertical component of the magnetic field obtained at the beginning of the 1960s in the Podunajská nížina and Východoslovenská nížina Lowlands and the western part of the Outer flysch zone were linked to these magnetically measured magnetic data. The Z-component magnetic field values were recalculated by magnetic field dip data (taken from Hurbanovo observatory) to total magnetic field induction T values. Supplementary geomagnetic measurements were performed between 2005 and 2008. T values were corrected on the normal field with International Geomagnetic Reference Field (IGRF – 1995, part of the Oasis montaj software). They were recalculated then on the altitude level of aviation measurements. Since the territory of Slovakia is located at the regional magnetic minimum, the calculated values of ΔT are in most cases in negative values. To get a picture of the course of the magnetic field (as we know it from older magnetic maps), all ΔT values were increased by +140 nT constant. This value was determined by statistical comparing the parameters of significant magnetic anomalies in old and newly created magnetic maps.

This way, a magnetometric database was obtained covering almost the entire territory of Slovakia in the form of grids in a regular network of 125 x 125 m, which corresponds to the requirements for creation of maps at scale 1 : 50,000 and a unified magnetic map of Slovakia was compiled (Kubeš, 2008; Fig. 3.1).

3.3.2 Geophysical information system (GfIS) – magnetometry

GfIS for magnetometry contains simultaneously 4 information levels:

1. Information level SK500,000, which includes:
   - coverage by GDB survey (magnetometric survey);
   - mag_125.GRD (ΔT grid field of the SR territory, 125 x 125 m);
   - mag_SK500,000.MAP (ΔT field map territory SR, M 1 : 500,000.
2. Information level JTSK200,000 – includes magnetometric data sorted by the 13 map sheets of the Basic Map of SR at scale 1 : 200,000:
   - Nr. Mag.GRD – Grid field ΔT (Map sheet number);
   - Nr. Mag.MAP – Map of ΔT field, scale 1 : 200,000.
3. Information level Regions – magnetometric data sorted by selected regions at scales of 1 : 50,000 to 1 : 200,000:
   - Region Mag.GRD – Grid field ΔT;
   - Region Mag.MAP – Map ΔT at a scale of 1 : 50,000 to 1 : 200,000.
4. Information level JTSK50,000 – magnetometric data sorted by 147 sheets of the basic map SR 1 : 50,000:
   - Map Mag.GRD – Grid field ΔT (Map number);
   - Map Mag.MAP – Map of ΔT field at a scale of 1: 50,000.

3.3.3 Magnetic map of Slovakia at scales 1 : 500,000 and 1 : 200,000

The Magnetic Map of the Slovak Republic ΔT was compiled from the magnetic data database at a scale of 1 : 500,000 (Fig. 3. 1). The map provides a very varied magnetic picture of Slovakia, as the ΔT values range from -1,000 to +1,100 nT.

The most significant changes in ΔT values were found at sites of morphological elevations formed by products of mainly Tertiary and partly Quaternary volcanism.

In the Slovenské stredohorie Mts. there are mainly the volcanic mountain ranges of Pohronský Inovec, Štiavnické vrchy, Vtáčnik, Kremnické vrchy, Poľana, Javorie and Krupinská planina Plateau. In the Eastern Slovakia dominate the Neovolcanic Mountains of Slanské vrchy and Vihorlatské vrchy Mts.

The anomalous effects of Tertiary volcanism products were also found in the central part of the Pannonian Basin, Žiarska kotlina and Zvolenská kotlina basins.

The magnetic effects of neovolcanites in the wider area of Pohronská Polhora and north and NE of Rimavská Sobota are relatively distinct.

In the Východoslovenská nížina Lowland, the manifestations of neovolcanites were found especially in Malčice – Čičarovce – Kráľovský Chlmec – Streda nad Bodrogom – Zemplín – Brehov area.

In the area of the Cerová vrchovina Upland, the anomalous effects of Quaternary volcanism products are shown.

Tab. 3.1 Review of measurement campaigns

Region Nr.	Region name	A	Year	Transporter	Electronic navigation
1.	MALÉ KARPATY MTS. – SW	125	1981	Mi-8	-
2.	MALÉ KARPATY MTS. – NE	125	1980	Mi-8	-
3.	POVAŽSKÝ INOVEC MTS.	135	1979	Mi-8	-
4.	STRÁŽOVSKÁ HORNATINA HIGHLAND	135	1979	Mi-8	-
5.	MARTINSKÉ HOLE	135	1980	Mi-8	-
6.	M. FATRA AND ORAVSKÁ MAGURA MTS.	135	1980	Mi-8	-
7.	NW SLOVAKIA	140	1989	Mi-8, An-2	+
8.	TRIBEČ MTS.	135	1979	Mi-8	-
9.	VTÁČNIK AND POHRON. INOVEC MTS.	90	1976	Mi-8	-
10.	KREMNICKÉ VRCHY MTS.	90	1977	Mi-8	-
11.	ŠTIAVNICKÉ VRCHY MTS.	90	1976	Mi-8	-
12.	KRUPINSKÁ VRCHOVINA UPLAND	135	1979	Mi-8	-
13.	POĽANA AND JAVORIE MTS.	135	1977	Mi-8	-
14.	KRUPINSKÁ VRCHOVINA UPLAND – E	135	1978	Mi-8	-
15.	ĽUBIETOVÁ BELT	135	1978	Mi-8	-
16.	SLOVENSKÉ RUDOHORIE MTS. – W	135	1977	Mi-8	-
17.	LUČENSKÁ KOTLINA DEPRESSION	135	1977	Mi-8	-
18.	CEROVÁ VRCHOVINA UPLAND	100	1983	An-2	+
19.	RIMAVSKÁ KOTLINA DEPRESSION – W	135	1978	Mi-8	-
20.	MURÁNSKA PLANINA PLATEAU	0	1978	Mi-8	-
21.	LEVOČSKÉ VRCHY MTS.	35	1990	An-2	+
22.	SLOVENSKÉ RUDOHORIE MTS. – E	0	1977	Mi-8	-
23.	RIMAVSKÁ KOTLINA DEPRESSION – E	30	1983	An-2	+
24.	BRANISKO – ČIERNA HORA MTS.	35	1980	Mi-8	-
25.	KOŠICKÁ KOTLINA DEPRESSION – S	80	1983	An-2	+
26.	SLANSKÉ AND ZEMPLÍNSKE VRCHY MTS.	85	1980	Mi-8	-
27.	VIHORLATSKÉ VRCHY MTS.	20	1981	Mi-8	-
A	PODUNAJSKÁ NÍŽINA LOWLAND				
B	FLYSCH BELT WEST				
C	VÝCHODOSLOVENSKÁ NÍŽINA LOWLAND				
V	FLYSCH BELT EAST AND POLONINY MTS.		2006		
Z	SKORUŠINSKÉ AND CHOČSKÉ VRCHY, VEĽKÁ FATRA, VYSOKÉ AND NÍZKE TATRY, MTS. PODTATRANSKÁ KOTLINA DEPRESSION AND KOZIE CHRBTY MTS.		2008		

A – azimuth of airborne profiles in [°]

The presence of Tertiary volcanism products has been proven in Podunajská nížina Lowland both by drilling and magnetic measurements. With the exception of the Burda Mountains, neovolcanic rocks are buried at relatively large depths and therefore their magnetic manifestation is relatively little pronounced.

The map also shows the anomalous effects of magnetic rocks in pre-Tertiary formations. The wider anomalies on the NW and W of Slovakia (the areas of Malacky – Skalica and Púchov – Bytča – Čadca – Námestovo) should be considered as manifestations of the profoundly deposited Proterozoic complexes of the North European platform that subduct below the Carpathian orogeny. We assume that the Obidowa-Słopnice unit with black complexes contributes to the overall image of the Earth's geomagnetic field.

The next anomalous territories were discovered in the wider area of Pezinok and the area of Galanta – Sereď – Hlohovec.

Relatively significant presence have magnetic rocks of the pre-Tertiary age in the territory Panické Dravce – Lučenec – Lovinobaňa – Málinec – Kokava nad Rimavicou – Klenovec – Muránska Dlhá Lúka – Rejdová – Dobšiná – Rudňany – Slovinky – Jaklovce – Vyšný Klátov – Seňa till the state border with Hungary.

The most significantly indicated are almost in-line magnetic structures:

a) Lovinobaňa – Málinec – Horná – Kerná;
b) Kokava nad Rimavicou – Klenovec – Hačava – Muránska Dlhá Lúka;
c) Panické Dravce – Lučenec – Breznička – Poltár – Hrachovo;
d) Dobšiná – Rudňany;
e) Košická Belá – Vyšný Klátov – Šaca.

A more extensive anomaly was found in the territory: Moldava nad Bodvou – Paňovce – Veľká Ida – Seňa – Buzica.

The Cerová vrchovina Upland is very distinct in the magnetic map.

Special attention has to be paid to the most extensive magnetic structure of Rimavská Sobota – Hnúšťa – Revúca – Slavošovce – Betliar – Krásnohorské Podhradie – Plešivec – Gemerská Ves – Uzovská Panica. Highest values of ΔT show the territory between Lubeník and Štítnik.

In Eastern Slovakia, anomalies in the vicinity of Zbudza appear to be very noticeable. A more extensive anomaly characterizes the territory on the Sečovce – Trhovište – Stretava axis. The presence of magnetically active rocks in Tertiary subsoil also reveals relatively large anomalies with relatively low amplitude in the Podunajská nížina Lowland.

A more detailed description of the nature of magnetic anomalies is presented in particular in the works of Kubeš (2001), Filo (2003), Bezák (2004) and Kubeš & Kucharič (2005).

In the Nízke Beskydy Mts. and the Poloniny Mts. a deficiency of magnetically active rocks is confirmed, possibly they are in great depths, which reduces (masks) their magnetic manifestation at the surface. Four major geomagnetic anomalies were found in the region. The most widespread negative anomaly is located in the area of the villages Ondavské Matiašovce – Žalobín – Jasenovce – Karná – Lieskovec. It reaches the amplitude -50 nT. Another vastly larger, more significant negative anomaly of the amplitude to -150 nT is located west of Nová Sedlica and north of the village of Zboj. By ground magnetic measurements, two positive anomalies were found in Stakčínska Roztoka and Ulič.

A different picture of the occurrence of magnetic rocks is given by geomagnetic measurements in the following areas: mountain ranges of Veľká Fatra, Starohorské vrchy, Chočské vrchy, Oravská vrchovina, Stredné Beskydy, Vysoké and Nízke Tatry, Spišská Magura, Skorušinské vrchy, Podtatranská kotlina Depression, Horehronské podolie, Kozie chrbty Mts. and Hornádska kotlina Depression. Altogether, more than 70 geomagnetic anomalies have been identified and described, which are caused by various petrographic types of rocks and rock complexes. These are in particular pyrrhotite, amphibolite, melaphyre, more basic granitoid differenciates – tonalites.

3.4 Map of magnetic anomalies sources and their tectonic classification

The source map was progressively compiled region by region as they were gradually measured. Their names are based on the work by Mazúr & Lukniš (1980). This division was selected due to its use in the previous stage of 2001 (Atlas of Geophysical Maps and Profiles). The resource map does not include interpretations of insignificant, non-extensive anomalies that may be due to the morphology of the terrain, or civilization impact.

In terms of age we divided them into:

I: sources of magnetic anomalies in pre-Tertiary basement – Fig. 3.3;

II: sources of magnetic anomalies of Tertiary and Quaternary volcanism – Fig. 3.4.

I: Sources of magnetic anomalies in pre-Tertiary basement

The detected magnetic field anomalies have been interpreted in the past by various authors and various interpretive techniques that have been constantly evolving. Within

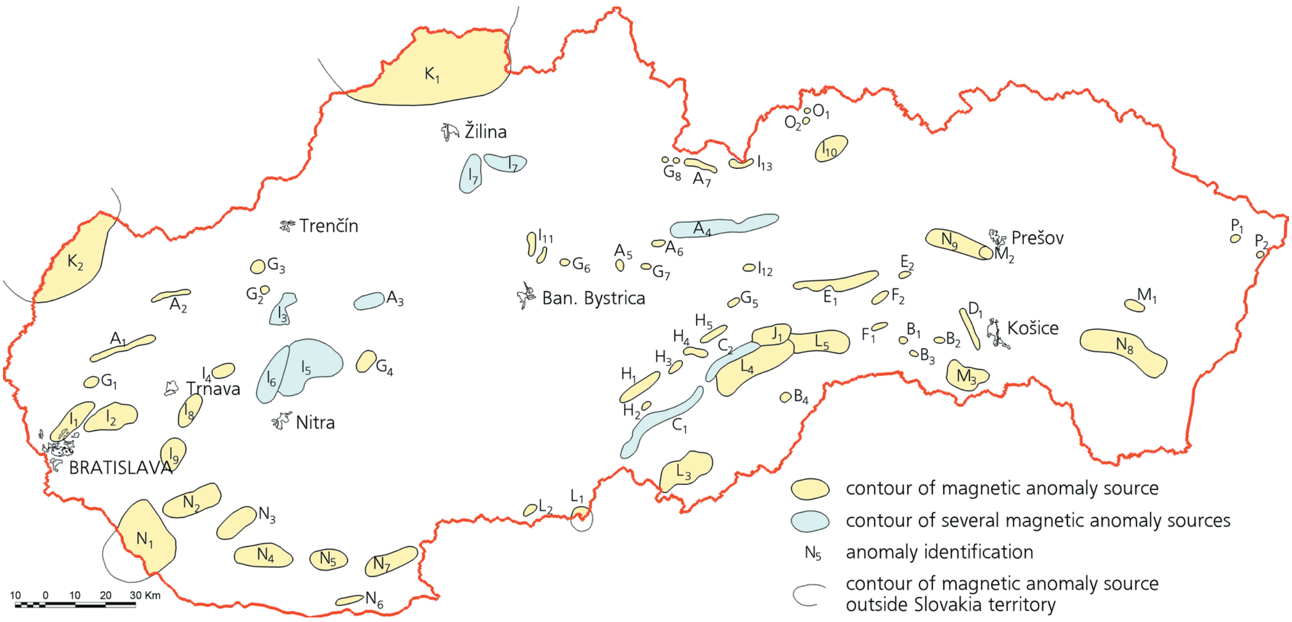

***Fig. 3.3** Sources of magnetic anomalies in pre-Tertiary basement (Kubeš, 2008)*

the framework of the regional geomagnetic division of the SR, created on the basis of a magnetic map and regional geomorphological division by Mazúr & Lukniš (1980), extensive large-scale magnetic regions have been delineated, with contours of large anomalies, groups of anomalies of smaller size, and magnetic anomaly zones (Kubeš, 2001, 2008).

The more extensive anomalies are attributed to the anomalous effect of bodies of a geological origin. The group of anomalies forms the effects of bodies of smaller size dimensions of the same petrographic type on the limited territory of the given region (e.g. group of anomalies in the Tribeč mountain range). It is more complicated to interpret anomalous zones, where the effects of rocks of different petrographic type, age and tectonic relevance (e.g. anomalous zones in Slovenské rudohorie Mts.) are to be considered. In particular, discontinuity elements are particularly noticeable in the zones as a consequence of younger tectonic processes.

When classifying the anomalies into tectonic units, we make use of the basic tectonic division of the Western Carpathians (Biely, 1996). North of the Klippen zone is the Outer Western Carpathian belt, built mainly by flysch nappes thrust over the North European platform. South of it are the Inner Western Carpathians with the basic crust units of the Tatricum, Veporicum and Gemericum, which are built of a crystalline fundament and the Upper Palaeozoic-Mesozoic envelope.

From the point of view of the distribution of pre-Tertiary magnetic anomalies, they can be divided into three groups:

Magnetic anomalies falling into the area of the Outer Western Carpathians, the sources of which are found in the rocks of the platform below flysch nappes;

The anomalies in the Western Carpathian pre-Tertiary complexes (mainly in Proterozoic? – Palaeozoic, less in Mesozoic complexes), their sources crop out to the surface or are at different depths;

The anomalies in the Tertiary basins subsoil.

The area of the Outer Western Carpathians is characterized by the peaceful course of the magnetic field generated by the magnetic effects of the deep-sea resources of the North European platform. The opposite image provides the magnetic field of the Inner Western Carpathians due to different ferromagnetic minerals in the rocks and smaller depths and source dimensions.

Anomalous magnetic manifestations of varying intensity were recorded in almost all the basic crust units of the Western Carpathians, where they are located mainly in the rocks of the crystalline (in the Malé Karpaty, Považský Inovec, Tribeč, Malá Fatra and Slovenské rudohorie Mts.). Another major sources – albeit of lesser extent – are the basic volcanites of the Upper Palaeozoic and Mesozoic. Significant anomalies also occur in the Tertiary basins subsoil (Podunajská nížina Lowland, Ipeľská kotlina Basin, Lučenská kotlina Basin, Východoslovenská nížina Lowland).

The anomalous manifestations of magnetic rock substrates can be largely suppressed or obscured by the effects of surface and subsurface magnetic rocks induced by Tertiary and Quaternary volcanism products. Based on the results of the interpretation of individual anomalies or anomalous groups and the latest geological data, we have learned that the superposition of the anomalous effects of young volcanism and magnetically active rocks of Tertiary basement must be considered especially in the Podunajská nížina Lowland, the southern part of the Slovenské Rudohorie Mts., Lučenská and Rimavská kotlina basins and the SE part of the Východoslovenská rovina Plain. Also, when interpreting individual anomalies, it should be borne in mind that in many cases it is a superposition of the anomalous effects of rocks with different magnetisation, depth of deposition, geometry and orientation to the action of the current magnetic field of the Earth. The effects of several sources are most evident in the southern part of Slovakia (the area of Gemericum overthrust above Veporicum and the occurrence of the assumed fragments of Cadomian crystalline).

Magnetic properties of pre-Tertiary rocks

One of the pillars supporting the geological interpretation of the sources of magnetic anomalies in the Tertiary subsoil are the results of the study of the magnetic properties of the basic types of rocks. The volume magnetic susceptibility (KAPA) and, to a lesser extent, normal remanent magnetic polarization (NRMP) were determined in the physical laboratories of individual geophysical workplaces of the Czech and Slovak Republics. Measurements of susceptibility values were performed on nearly 10,000 samples taken from the outcrops, mine workings, structural and exploratory wells. To a lesser extent, the results of sounding magnetic measurements are also considered. It is logical that most of the data is available from regions where the Tertiary subsoil rocks crop out or are near the surface and are caught by mining or drilling. Many structural wells were located outside the centres of magnetic anomalies. Many wells often did not have the necessary depth and therefore did not capture the rocks of the subsoil, or terminated in its uppermost parts.

In the Outer Western Carpathians, the results of the study of the magnetic properties of the rocks show that the major source of large-scale anomalies are crystalline rocks in the subsoil of Tertiary complexes. According to the data, the magnitude of the magnetic susceptibility can be assigned to the crystalline rock 300 to 45,000 x 10^{-6} SI units. Increased values of magnetic parameters were found on samples of rocks of intermediate, basic to ultrabasic magmatism (granodiorites, diorites, gabbros, gabbrodiorites, gabbroamphibolites, peridotites and dunites). We note that in this wide range of susceptibility values, the largest proportion have the rocks with susceptibility to 1,000x10^{-6} SI units. Here we have to take into account the fact that only the highest parts of the crystalline structure, which are quite heavily weathered, are caught by the boreholes. Rocks with such magnetic parameters at such depths from the surface can not be the source of magnetic anomalies. Therefore, when interpreting the source, it is necessary to consider effective volume magnetic susceptibility in the range from 1.0 to 1,000 up to 35,000 x 10^{-6} SI units. Rocks in crystalline overburden with a value of up to 400 x 10^{-6} SI units in this case we consider to be practically non-magnetic.

In the Inner Western Carpathians, the Slovenské rudohorie and Slovenský kras Mts. are the most studied in petrophysics point of view. The systematic research of the magnetic properties of the rocks was carried out in the framework of the basic geological and geophysical research carried out within the framework of the research tasks of the former Dionýz Štúr Institute of Geology. The lowest data density on the magnetic properties of rocks in the Tertiary subsoil has the Podunajská nížina Lowland and the Východoslovenská rovina Plain. For example, there is a problem in the Podunajská nížina Lowland to explain the source of the Gabčíkovo anomaly and the Kolárovo gravity and magnetic anomaly. A similar problem also arises in interpreting the source of the Sečovce magnetic anomaly in the central part of the Východoslovenská rovina Plain.

A very interesting group of rocks of the Slovenské rudohorie and Slovenský kras Mts. are serpentinized ultrabasic rocks. They occur in the Young Palaeozoic and in the Mesozoic of Galmus and Slovenský kras Mts. These rocks exhibit magnetic susceptibility values ranging from 12,500 to 63,000 x 10^{-6} SI units; locally even cases with values up to 126,000 x 10^{-6} SI units have been defined. he direct dependence between the degree of serpentinization and the magnetic parameters has been proven. Non-metamorphosed ultra-base rocks (peridotites, dunites, pyroxenites) show significantly lower magnetic properties than the rocks with a relatively higher degree of serpentinization. The carrier of magnetic properties of rocks is a secondary magnetite, which is formed from olivine, pyroxene, amphibole or biotite. Sometimes, the oxidation environment where the serpentinite is formed also manifests itself with the presence of CO_2, which results in the formation of non-magnetic or weak magnetic magnesite. Further metamorphic alterations of serpentinites (steatitization, carbonization, chloritization, amphibolization) lead to a significant reduction of magnetic parameters to such an extent that the original high magnetic rock becomes practically non-magnetic. It has also been found that more serpentinized ultra-basic rocks have higher magnetic properties than less serpentinized ultrabasics.

Another significant source of magnetic anomalies are the products of diabase magmatism (diabases and their volcaniclastics). Their magnetic susceptibility ranges from 300 to 95,000 x 10^{-6} SI units. The sources of anomalies are also the larger bodies of amphibolites and hornblende diorites whose KAPA ranges from 300 to 11,000 x 10^{-6} SI units. We must also not forget the anomalous effects of melaphyres of the Choč unit with susceptibility values to 20,000 x 10^{-6} SI units.

An important information is also about the magnetic properties of metamorphic rocks – mica schists, gneisses, green and talc schists, and dark schists in particular. The susceptibility values observed for this type of rocks range from 350 to 5,700 x 10^{-6} SI units.

It should be noted that only about 25 % of the basic petrographic types of the Slovak part of the Western Carpathians are able to generate real magnetic anomalies of such intensity that they can be geologically interpretable. We also want to draw attention to the fact that the anomalous effect of magnetically active rocks depends not only on their magnetic parameters, but is mainly due to the depth of deposition, dimensions, morphology and the contrast of the environment in which the magnetic object is located.

3.5. Geological and tectonic classification of sources of magnetic anomalies in pre-Tertiary com- plexes

The basic characteristics of magnetic anomalies in the pre-Tertiary formations was elaborated within the framework of the Atlas of Geophysical Maps and Profiles – part Magnetometry (Kubeš, 2001), where the geophysical parameters of the anomalies are presented, as well as the geological characteristics of their sources. Anomalies were grouped according to geomorphological units. The interpretation of the geological source was based on the basic geophysical parameters of the anomaly, its size, depth and knowledge of the magnetic properties of the Western Carpathian rocks.

In this work we classify magnetic anomalies from the point of view of the relevance of their sources to the tectonic units of the Western Carpathians. The classification of the magnetic anomalies in the pre-Tertiary formations is given in Table 3.2.

Sources of anomalies are divided into groups according to tectonic relevance and according to lithology. The complexity of the tectonic structure of the Western Carpathians, as well as the often considerable depth of deposition of the sources of many anomalies, is a reason that the classification of some anomalies is not unambiguous and has a multi-variant solution. There are also cases where a magnetic anomaly is caused by a combination of effects from multiple sources.

According to the tectonic affiliation, the sources of magnetic anomalies in the pre-Tertiary formations of the Western Carpathians can be divided as follows (Fig. 3.3):

Sources of anomalies in the higher nappes of the Inner Western Carpathians:

A. basic volcanites of Hronicum;
B. basic to ultrabasic volcanites of Meliaticum;

Sources of anomalies in Palaeozoic fundament of Gemericum;

C. basic volcanites and phyllites of the Ochtiná tectonic unit
D. amphibolites of the Klátov tectonic unit;
E. basic metavolcanites of the Rakovec tectonic unit;
F. basic metavolcanites of the Gelnica tectonic unit.

Sources of anomalies in crystalline Tatricum and Veporicum:

G. amphibolites and metamorphites with positions of basic rocks;
H. mica schists and amphibolites of the lower Hercynian lithotectonic unit;
I. more basic differenciates of Hercynian granitoids
J. Rochovce granite .

Sources of anomalies in Cadomian fundament:
K. Cadomian fundament in the northern zone of the Western Carpathians (North-European platform, Brunia);
L. Cadomian (?) fundament in the southern zone and its overburden units.
Sources of anomalies of vague affiliation:
M. Ultrabasic rocks of unknown affiliation;
N. sources of anomalies of unknown membership at greater depths (probably mostly crystalline in combination with other sources);
O. Sources in the Inner Carpathian Paleogene;
P. Flysch Belt of the Outer Western Carpathians;

Tectonic affiliation of magnetic anomalies sources

A. Basic volcanites of Hronicum

The products of Permian basic and intermediate volcanism of the Ipoltica Group of Hronicum cause relatively significant magnetic anomalies in the Malé Karpaty Mts., in the southern part of the Strážovské vrchy Mts. and north-eastern part of the Kráľova hoľa part of the Nízke Tatry Mts. (Vozár, in Kubeš et al., 2001).

In the central part of the Malé Karpaty Mts., the anomalous effect on the surface of the cropping-out melaphyres in the Sološnica-Smolenice (A_1) area is clearly displayed. The linear zone of the ENE-WSW direction reaches a length of 20 km and a width of 1.4 to 2.2 km and is signalled by anomalies with an amplitude of up to 250 nT. This part of the zone includes covered bodies of melaphyres in the territory of Smolenice-Trstín.

Less pronounced is the effect of the assumed volcanites in NE parts of the mountain range (Brezovské Karpaty). The anomalous zone (A_2) passing through Brezová pod Bradlom reaches a length of up to 12 km and a width of 0.8 to 1.0 km. Anomaly values do not exceed 75 nT. We assume the upper edge of the rocks at a depth of about 100 to 150 m.

Melaphyre bodies are also associated with isolated magnetic anomalies with amplitude up to 75 nT in the wider neighbourhood of Nitrica (SW of Prievidza, Nitrické vrchy – A_3). Significantly different is the anomalous effect of basic and intermediate rocks in Malužiná – Nižná Boca – Liptovská Teplička – Hranovnica – Spišská Teplička (Malužiná – Vikartovce anomaly – A_4). Here the ground-based profile measurement revealed the presence of narrow magnetic zones of the linear type, which correlate very well with the course of geologically discovered occurrences of melaphyres of the Ipoltica Group. The anomalous zone of the E-W direction reaches a length of 40 km and a width of 3 to 5 km. The results of the measurements point to the fact that the volcanic rocks in this region have a larger area extent than documented in the past geological knowledge. The new measurements recorded the melaphyres in the Vysoké and Nízke Tatry Mts. (A_5, A_6 and A_7).

B. Basic to ultrabasic volcanites of Meliaticum

In the territory of the Slovenský kras Mts. the ground and aeromagnetic mapping has proven the presence of a large number of large-scale anomalies with a different amplitude (from 50 to 300 nT), which belong to the basics of the Meliaticum unit and the Bôrka nappe. An absolute lack of magnetic anomalies is characterized at the Plešivecká and Silická planina plateaus, where the Silicicum carbonates reach considerable thickness.

The Bôrka nappe borders the northern part of the Slovenský kras Mts. in the area between Jasov and Jelšava. Magnetic anomalies are generated by basics of this complex, which are scattered, have a small area extent, and indistinct amplitudes.

The sources of magnetic anomalies are serpentinites, which are found on the basis of tectonic slices, and are often embedded in complexes of Werfenian shales. They are predominantly metabasic rocks (metabasalts, green schists, glaucophanites (Mello, in Kubeš et al., 2001).

The variability in the petrographic composition of the rocks is similarly reflected in the variability of the magnetic properties of these rocks. Nearly all effusive rocks have undergone various alterations (serpentinization, spilitization, metamorphosis in the green and blue schists facies), which also affects their magnetic properties.

The melange-like character of Meliaticum is generally accepted and results in a similar magnitude of magnetic anomalies, such as those found in the Bôrka nappe, which are therefore of the local type, with a small area and reach negligible magnetic field values. According to their 2D modelling it is obvious that their rooting is shallow and rarely exceeds the level of 500 m below the surface.

The rock sources of magnetic anomalies in the Meliaticum are similar to those of the Bôrka nappe (Mello, in Kubeš et al., 2001). They are serpentines of the ophiolite formation of the Bodva valley, which can be found predominantly in the form of slices and protrusions pressed directly into the Werfenian Silicicum Fm., and the Jaklovce palaeobasalts (metabasalts), which are predominantly metamorphosed under anchizone conditions. The petrographic variability of volcanic and volcaniclastic rocks, which affects the magnetic properties, involves a different degree of metamorphosis in addition to the initial material, which is associated with the subduction – accretion process of the Meliaticum ocean closure.

In the magnetic maps, the effects of glaucophanites (B_1) and serpentinites (B_2, B_3, B_4) are most striking. The most significant are the Hačava (B_1), Jasov (B_2), Miglinec (B_3), anomalies in the area between Čoltovo and Bretka (B_4). The Hačava anomaly (B_1) represents the effect of a glaucophanite body oriented in the E-W direction. This is the largest surface occurrence of these rocks in the entire Western Carpathians. The Rudník-Jasov area (B_2) is characterized by two anomalies (Rudník and Jasov). The anomalies with amplitude 120, or 170 nT respond to serpentinite at the surface or they are covered by a thin layer of Tertiary sediments. The Miglinec anomaly (B_3) with amplitude of 125 nT is bound to a serpentine body in the valley of the same name. The anomalous zone reaches a length of up to 4 km and a width of about 1 km. The dimension of the anomaly thus far exceeds the surface dimension of the body. In the western part of the Meliaticum unit, the Bretka anomaly (B_4) is most noticeable. The anomalous zone of the ENE-WSW direction represents two partial anomalies – Čoltovo and Bretka. The anomaly at Čoltovo reaches an amplitude of up to 200 nT. It shows the anomalous effect of serpentinites, covered by Quaternary sediments at places. The Bretka anomaly with amplitude of about 300 nT is one of the most prominent in the region. The source of the anomaly is a large body of serpentinites, locally exposed, below the younger sediments. All basal and ultrabasic bodies, including glaucophanites, have relatively small thicknesses (up to 300 m).

C. Basic volcanites and phyllites of the Ochtiná tectonic unit

In the Ochtiná tectonic unit phyllites and schists dominate, often with a high carbon content, with less metacarbonates. Basic metavolcanites and ultrabasics are also present. In today's tectonic position, this unit crops out between the Veporicum and Gemericum. At the surface, it is exposed only in the narrow lane along the Ľubeník Line, but its occurrence is also assumed to be more southern in the Neogene subsoil and the rocks of the Gelnica Group.

The Ochtiná unit is relatively rich in the magnetic rocks. They are mainly diabase tuffs and tuffites, as well as phyllites probably with the addition of volcaniclastic material with increased magnetic parameters. Locally, the bodies of hornblende gabbros, gabbrodiorites, gabbro-amphibolites, and ultrabasics (serpentinites) are present. The anomalous zones of the southwest-northeast direction extend from Lučenec to the northeast direction – the Lučenec-Poltár (C_1) and Ľubeník (C_2) anomalies.

Magnetic maps show a more pronounced anomalous zone C_1. Here we assume a substantially larger area extent of the magnetic rocks and at the same time a greater complexity compared to the anomalous zone C_2. The anomaly reaches amplitude of 50 to 150 nT. The interpreted depth of the upper edge of magnetically active rocks ranges from 100 to 800 m below the surface with a patterned effective magnetic susceptibility around 12,000 x 10^{-6} SI units.

The Ochtiná tectonic unit may contribute, in combination with other sources, to the generation of other anomalies, e.g. the Gemer one (L_4).

D. Amphibolites of the Klátov tectonic unit

The typical sign of the monotone Klátov unit is the presence of metamorphosed rocks in the P-T conditions of the higher-temperature amphibolite facies. With the epizonally metamorphosed Rakovec Group it has a tectonic contact; the superincumbent of the Klátov Group is made up of discordantly deposited Westphalian and Permian rock complexes.

The Klátov unit is composed predominantly of amphibolites that are associated with gneisses, serpentinized spinel peridotites (metamorphosed to to antigorite serpentinites), and to a small amount with crystalline carbonates (Spišiak et al., 1985).

The zone of magnetic anomalies in the SE-NW direction, the source of which are the metabasics of the Klátov unit, is located W of Košice. It achieves amplitude of up to 250 nT with a length of 20 km and a width of up to 3 km (D_1). The most intense in the magnetic maps are the surroundings of Vyšný Klátov (Klátov anomaly).

Gnojek & Vozár (1992) were involved in interpreting the magnetic anomalies in the Klátov unit. They note that the amphibolite bodies in the north of the anomalous zone fall steeply to the WSW near the surface and at a depth of 1,500 m the slope angle drops to 40-30°. In the southern part of this band, the sources are tilted very steeply towards the WSW, up to the normal; however the reversible dip to ENE can not be excluded.

It is obvious that the major sources of anomalies are, in particular, amphibolites associated with biotite-hornblende gneisses that are characterized by effective magnetic susceptibility to 12,000 x 10^{-6} SI units. The anomalous bodies project to the surface or are located close to the surface and reach a considerable vertical dimension (Ivanička in Kubeš et al. 2001).

E. basic metavolcanites of the Rakovec tectonic unit

The Rakovec tectonical unit is one of the Gemericum Hercynian units. It is a volcanogenic-sedimentary formation characterized by basic volcanism with a tholeiite magmatic trend.

From the qualitative and quantitative interpretation of magnetic anomalies in the Rakovec Group by Filo and Kubeš (in Šefara, 1987) it has emerged that the main source of anomalies are mainly metabasic bodies at different depths. In Dobšiná-Nálepkovo area they are covered by a complex of metabasalt tuffs and tuffites.

Interpretation of Ivanička (in Kubeš et al., 2001) confirmed that the major sources of anomalies are metabasalt tuffs and tuffites with metabasalts positions. It is a very thick complex of basic rocks, whose magnetic properties are affected in particular by their mineral composition (amphibole, basic plagioclases, magnetite, ilmenite, hematite). Their interpreted effective magnetic susceptibility ranges from 12,000 do 20,000 x 10^{-6} SI units. The territory south of Spišská Nová Ves (Dobšiná – Hnilec – Nálepkovo) is accompanied by intensive magnetic anomalies with amplitudes up to 550 nT (E_1 – Rakovec). The anomalous zone reaches a length of 25 km and a width of up to 4 km. The continuous course of the anomalous zone is strongly disturbed in the vicinity of Hnilec, where the occurrences of bodies of Gemeride granites are proven. Another anomaly probably caused by the metabasalts of the Rakovec unit is located in the vicinity of Slovinky (E_2 – Slovinky) with amplitude of up to 50 nT. Their upper edge is interpreted to a depth of approximately 500 m below the surface with average magnetic susceptibility 12,000 x 10^{-6} SI units.

F. Basic metavolcanites of the Gelnica tectonic unit

The Gelnica unit builds a substantial part of the Palaeozoic of the Spišsko-gemerské rudohorie Mts. It is composed mainly of flysch sediments (sandstones and claystones) and synchronous rhyolite-dacite, rare basic volcanites.

In the eastern part of the Slovenské rudohorie (Volovské vrchy Mts.) there are numerous local anomalies with maximum amplitude of up to 75 nT and only exceptionally up to 100 to 150 nT. The previous interpretations were devoted mainly to Švedlár, Mníšek nad Hnilcom, Smolník, Pača and Henclová. Kucharič (1986) attributed the magnetic anomalies to the surface or near-surface variegated volcanic complex, represented mainly by bimodal diabase-keratophyre formation.

More intense anomalies are likely to show a larger accumulation of intermediary and basic volcanism products of the Bystrý Brook Fm. (Ivanička et al., 2001). In the magnetic maps, the effects of the above mentioned rocks in the Úhorná – Smolník – Smolnícka Huta (F_1 – Smolník anomaly) zone are most clearly visible. In a similar way, we characterize the Švedlár anomalous zone (F_2). In both cases, there are sources of magnetic anomalies on the surface, or close to the surface at depth max. up to 200 m.

In magnetic maps, the linear interface NE-SW with the axis Gelnica – Helcmanovce – Mníšek nad Hnilcom – Betliar is significantly displayed. This interface divides the Gelnica unit into two parts – the West and the East ones. The main difference between them rests in the fact that the western part is considerably richer in the occurrence of magnetic rocks at the surface or in the immediate vicinity of the surface.

G. Amphibolites and metamorphites with positions of basic rocks in crystalline of Tatricum and Veporicum units

Anomalous effects of sources of magnetic anomalies of this type were dealt with by Filo & Kubeš (in Šefara et al., 1987) mainly in the Malé Karpaty, Považský Inovec, Malá Fatra and Tribeč Mts.

In the Malé Karpaty Mts. the anomalous effect of the extensive body of amphibolites (Vozár in Kubeš et al., 2001) is manifested in the territory NW of Pezinok (G_1 – Pernek anomaly). The low values of the measured field here range from 25 to 50 nT and correlate very well with the morphology of the terrain. Relatively positive anomalies of morphological elevations and relatively negative anomalies of morphological depression are evidenced by the fact that amphibolite bodies reach only a relatively small thickness (up to 300 m). It cannot be excluded that the source of this anomaly may be somewhat more basic granitoid differenciates just below the surface.

Similarly to the Malé Karpaty Mts., the bodies of amphibolites in the eastern part of the Nízke Tatry Mts. are also displayed, where only terrestrial magnetic field measurements were performed.

In the Považský Inovec Mts. we are attributed to amphibolites the anomalies at Hrádok – G_2 and Kálnica – G_3 (Határ & Ivanička in Kubeš et al., 2001). The anomaly at Kálnica may be partly caused by volcanites of the Upper Palaeozoic. In both cases these are bodies with a greater depth range (over 1,000 m).

Amphibolite bodies with a relatively small thickness (less than 300 m) cause negligible magnetic anomalies in the eastern part of the Tribeč mountain range (G_4 – Skýcov), which represent three local anomalies with an amplitude of 50 to 150 nT. Maximum values are bound to more pronounced morphological depressions, controlled by the river network. The peaks of the magnetically active rocks appear the closest to the surface just in these sharp incised valleys. The source of local anomalies is the complex of mica schists with amphibolite positions.

In the Slovenské rudohorie Mts. there are anomalies in the territory of SW of Muránska Huta (G_5). This is part of a series of Muráň granite-gneisses, in which the amphibolites intercalations also appear. The entire complex of magnetic rocks does not exceed a thickness of 750 m. Amphibolites of this type are found in the Nízke Tatry Mts. near Bukovec (G_6) and Brezno (G_7) and in the Vysoké Tatry Mts. near Žiar (G_8).

H. Mica schists and am*phibolites of the lower Hercynian lithotectonic unit*

In the territory of Lovinobaňa – Málinec – Kokava nad Rimavicou – Klenovec – Rimavská Píla – kóta Tŕstie – altitudinal point Krížna Poľana (Brezina) – Muránska Dlhá Lúka, the existence of a complicated magnetic zone with amplitudes from 50 to 300 nT was verified by aeromagnetic and terrestrial magnetic measurements (Fig. 3.3). The zone is oriented in the NE-SW direction and reaches a length of almost 50 km (anomalies H_1 až H_5 – Málinec, Rovné, Kokava, Klenovec and Píla).

This linear magnetic field, Filo (in Bodnár et al., 1988) attributed to the presence of mica schists complexes with the positions of amphibolites, also pointing to the presence of small bodies of serpentinites (the Uhorské vicinity). These magnetic mica schists are part of the lower Hercynian lithotectonic unit, which came to the surface within palaeoalpine tectonic processes of mainly transpressional character. Therefore, it creates a complicated structure, which is also reflected in the complexity of the magnetic zone. The magnetic properties of the mica schists are so pronounced that they also manifest themselves below the non-magnetic granitoid complexes of the Middle Hercynian lithotectonic unit up to 3 km deep. Conversely, the mica schists rocks, which we interpret as part of the middle lithotectonic unit, are mostly non-magnetic.

Our interpretation confirms that the main source of the anomaly are garnet-bearing mica schists with amphibolites (Bezák in Kubeš et al., 2001). In the southwest part of the zone, the effects of metasediments, metavolcanites and black shales of unknown classification are also shown. The results of the study of the magnetic properties of rocks from the KH-1 borehole show that the rock of this complex is greatly enriched in pyrrhotite, which affects the magnetic parameters, especially the values of natural remanent magnetic polarization.

The minimum proportion has the mica schist complex in the vicinity of Kokava nad Rimavicou (Kokava anomaly – H_3). Interesting is the position of the Klenovec anomaly (H_4). The source of the anomaly are again mica schist rocks with a clear orientation in the E-W direction. The whole complex goes submerges to S to a depth of about 1,000–1,500 m below a non-magnetic or very weak magnetic complex formed by albitized biotite paragneisses. Larger area extent have mica schist rocks in the area of Rimavská Píla – Muránska Dlhá Lúka (H_5). However, the thickness of the complex is considerably smaller than in the case of the Málinec (H_1) or the Klenovec (H_4) anomaly.

I. More basic differenciates of Hercynian granitoids

The results of the study of the magnetic properties of granitoids showed two important facts. The first is that the main carriers of magnetic parameters are mainly magnetite and titanomagnetite. The other is that the magnetic properties of the rocks are directly dependent on the degree of basicity of the rocks. In the case of granitoids, it is an increase in magnetic parameters (mainly magnetic susceptibility) in the order: biotite granodiorite – tonalite – hornblende diorite – gabbrodiorite. An exception is the Rochovce granite with a high content of magnetite, which belongs, however, to another age group.

The results of the geophysical and geological interpretation of the magnetic anomalies that we give to the granitoids bodies in the Tatricum and Veporicum crystallines have brought further insights. We start from the fact that the amplitude of the ΔT anomaly varies from 40 to 100 nT. The highest anomaly amplitudes have been found in regions where the magnetic rocks of granitoids rise directly to the surface or are located at depths of up to 500 m below the surface. Here we list the occurrences of granitoids in the north-eastern part of the Považský Inovec Mts., in the southern part of Strážovské vrchy Mts., in Malá Fatra Mts. and in the central part of the Tribeč mountain range. They are predominantly smaller-dimensional bodies of relatively small thickness.

The amplitude of the anomalies changes very little with regard to the depths of the sources and their thickness. This would indicate that the deeper the source is, the higher magnetic parameters and the higher basicity it has. It is possible to document the results of the geological and geophysical interpretation of magnetic anomalies from the southwest part of the Malé Karpaty Mts., the southern part of Považský Inovec Mts., the Embayment of Topoľčany (the Višňovce Depression), but mainly from the central part of the Podunajská nížina Lowland.

In the Malé Karpaty Mts. dominates Svätý Jur magnetic anomaly (I_1), which accompanies almost the entire NE part of the Bratislava Massif. Kohút (in Kubeš et al., 2001) considers granitoid complex (granodiorite-diorite) with a top edge at a depth of up to 2.0 km, found in the base of the practically non-magnetic Bratislava granitoid. We also consider the presence of basic granitoids in case of Grob anomaly (I_2). They are located at a depth of 2.5 to 3.0 km. The mutual spatial position of the sources of the anomalies I_1 and I_2 is influenced by the Malé Karpaty fault system of NE-SW direction, along which not only the source of the Grob anomaly has submerged towards SE, but also its shift towards NE. We cannot exclude the other interpretation of these anomalies, which is based on the views of the overthrust tectonic structure of the Malé Karpaty Mts., which admits magnetic complexes of metamorphites in the basement of non-magnetic granitoids of the Bratislava Massif.

Mountain range of Považský Inovec is rich in the occurrences of more basic differenciates of Tatricum granitoids (Határ in Kubeš et al., 2001). The discussed rocks form a complicated but apparent anomalous zone of the NE-SW direction with a length of about 70 km and a width of 5 to 7 km. It includes not only magnetic Inovec (I_3) and Hlohovec (I_4) anomalies, but also Sereď (I_8) and Galanta (I_9) anomalies in the Podunajská nížina Lowland. The top edge of magnetically active rocks in the northern part of the mountain range is located at the surface or near the surface, but in the SW direction their depths reach a level of about 3.0 km below the surface (e.g. anomaly I_9).

In the magnetic map, the effects of more basic granitoid differenciates are quite evident especially in the SW parts of the Tribeč mountain range, the Embayment of Topoľčany and Rišňovce depression. Surface and near-surface sources represent a group of anomalies in the wider area of Veľký Tribeč Hill (Tribeč – I_5; Ivanička in Kubeš et al., 2001).

Deeper deposited rocks are located in the territory of Topoľčany – Chrabrany – Ludanice (I_6 – Preseľany). The upper edge of the bodies is interpreted by Ivanička (in Kubeš et al., 2001) in a depth range of 1.0 to 1.5 km. The most extensive anomaly with amplitude of 75 nT was found in the area of Šurianka – Preseľany – Lefantovce – Čajkovce. The anomaly centre is located in the immediate vicinity of Preseľany, where the top edge of the source should be 1.7 to 2.0 km deep. In the southwest, the upper edge of the rocks submerges to a depth of more than 2.5 km.

In the area of Malá Fatra Mts. we define two anomalous areas where the effects of granitoids are shown. At places, they are accompanied by small positions of the amphibolite bodies at the near-surface level. The anomalous area is located in Kriváň as well as in Lúka parts of Malá Fatra Mts. (Malá Fatra anomalies – I_7; Kohút in Kubeš et al., 2001).

Kežmarok magnetic anomaly (I_{10}) forms a large-scale structure in the space Levoča – Torysky – Podolínec – Lendak – Kežmarok – Levoča, which almost coincides with the central part of the Levočské vrchy Mountains. Its amplitude with a maximum in the area of Bušovce does not exceed 20 nT, but is very readable. The first interpretation was performed by Gnojek et al. (1992), which set the upper magnetic edge at a depth of 4 km with effective magnetic susceptibility 10,000 x 10^{-6} SI units. After quantitative interpretation and modelling along the seismic profile no. 750/92 and correction with the data from reflex seismics (Hrušecký in Kubeš et al., 2001), a body model with a ceiling at a depth of about 2,500 m below the surface, with an average thickness of about 1,000 m, was accepted. It is assumed that such a large-scale magnetic anomaly is generated by more basic differenciates of Tatricum crystalline granitoids. However, based on the results of the interpretation and modelling of the magnetic anomaly after the seismic profile, it turns out that the magnetic mass continues further north through the Klippen Belt, suggesting that it is a combination of multiple sources with the influence of the platform. The magnetic effect of tonalites can be observed in the Nízke Tatry Mts. near Slovenská Ľupča (I_{11}), and Vernár (I_{12}) and Tatranská Štrba (I_{13}).

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J. Rochovce granite

In the middle part of the Slovenské rudohorie Mts., a significant anomaly (J_1 – Rochovce) of 350 nT, induced by the Cretaceous Rochovce granite with a high concentration of magnetite was found by magnetic measurements.

One of the first interpretations of the Rochovce magnetic anomaly was carried out by Filo already in 1977. He assumed that the anomaly produce ultrabasic rocks at a depth of 1,200 m. KV-3 structure borehole in the depth range 0 to 550 m captured phyllites belonging to the Southern Veporicum, the 50 m thick position of the more acidic granitoids (aplites) and the 100 m thick position of the metabasites. In the interval of 700 to 1,600 m the presence of granites was found. Because of its magnetic properties, this granite has an exceptional position in the area of the Western Carpathians.

The results of the geochemical survey also proved the presence of W-Mo mineralization in the southern part of the abnormal anomaly (Václav et al., 1990). For this reason, a large number of RO-1 to RO-22 drilling wells was implemented here. It was proved by the drills that the relief of the upper edge of the Rochovce granite ranges from 500 to 725 m below the current surface.

In the Southern Veporicum there are also rare magnetic anomalies, which may be leucocrate granitoids of Permian or Alpine age, probably also with increased concentrations of magnetite.

K. Cadomian fundament in the northern zone of the Western Carpathians (North-European Platform, Brunia)

The territory of the Západné Beskydy Mountains, the Stredné Beskydy Mountains and the Záhorská nížina Lowland are accompanied by significant regional magnetic anomalies (K_1 – Beskydy, K_2 – Skalica) whose centre is located outside the Slovak Republic. Their amplitude in our territory reaches up to 120 nT. In the Západné and Stredné Beskydy Mts., the anomaly is oriented in the E-W direction, about 50 km in length. In the Záhorská nížina Lowland it reaches up to 40 km in the direction of NE-SW.

The issue of geological interpretation of sources of anomalies in the flysch rock basement have recently been given considerable attention by a wide range of geologists and geophysicists. The origin of magnetic anomalies of this regional type is not yet clearly explained. One group of authors is based on a classical interpretation in the sense that the anomaly is caused by one or several genetically related sources found in the crystalline of the platform. The second group is based on data on the magnetic susceptibility of rocks that suggest that crystalline surface forms a significant interface that can explain its relief based on the interpretation of magnetic field anomalies. Based on our results of interpretation of the Beskydy and Skalica anomalies, we find that when determining the depth of the sources of magnetic anomalies one should consider both alternatives. In general, the complexes of the intermediate, basic, exceptionally also ultrabasic rocks as well as the metamorphites of the basic rocks are considered to be the decisive source of magnetic anomalies. Crystalline is represented in this territory by Cadomian units of Brunia and it contains just such types of rocks, which are also exposed at the surface.

According to the results of the Jablunkov 1 structural borehole located at the peak of the Beskydy anomaly, the Palaeozoic envelope of the platform and the upper part of the crystalline have low magnetic parameters and their influence on the overall character of the Beskydy anomaly is negligible. Interpreted anomaly (K_1) is caused by rocks inside the crystalline. The decisive influence on the anomalous field of the region have rocks with an upper margin in the depth range of about 6.0 km in the border area of the Czech Republic, Poland and Slovakia, which are submerging down to the depths of 10 to 12 km southwards (Bytča surroundings). It is possible that this rock complex continues to the south, as interpreted by Filo on the 2T profile.

A similar geophysical-geological interpretation was obtained also in the analysis of the source of the rock anomaly (K_2). Here we want to note that the Skalica anomaly continues on the territory of the Czech Republic, where the magnetic rocks of crystalline form its relief. Proof of this is the difference in the maximum values of the anomaly. We have already mentioned that in the case of the Beskydy anomaly, magnetic field values were measured to 120 nT, in the vicinity of Břeclav amplitudes reach 260 to 400 nT. Such differences in the anomaly amplitude are not related to the depth of source, but mainly to the lithological composition and the magnetic properties. We believe that magnetic rocks in the south-eastern part of Moravia are predominantly gabbro – gabbrodiorite – gabbronorite and gabbroamphibolite rocks.

L. Cadomian (?) fundament in the southern zone and its superincumbent units

In the southern part of the Inner Western Carpathians, there are several magnetic anomalies in the Tertiary basement, which we cannot be explained by the effects of well-known units (mainly the mica schists of the Southern Veporicum and the Ochtiná unit). Based on the interpretation of the tectonic structure of the Tertiary basement in the southern part of Slovakia, in addition the crystalline rocks exposed in the Western Carpathians, the occurrence of fragments of the Cadomian fundament is likely (Bezák et al., 1997). This interpretation is also supported by the xenoliths of the unknown crystalline of the basalt magma in the Fiľakovo region and the presence of heavier substances in the Tertiary basement in this region with similar densities as the Cadomian crystalline in the North European platform.

In the Ipeľská kotlina Basin, the dominant position has the Kováčovce magnetic anomaly (L_1) with amplitude of up to 300 nT. It is part of the magnetic zone of the ENE-WSW direction, which continues from the territory of Hungary. At the centre of the anomaly was the structural well MV-12 with a final depth of 1,102 m. In the depth range 0–558 m, non-magnetic Tertiary sediments are present. In the range of 558–900 m, the position of garnet-bearing mica schists, which exhibit relatively high magnetic susceptibility (6,300 x 10^{-6} SI units) and NRMP (around 1000 nT), was verified. The lower part of the borehole (interval 900–1,102 m) consists of amphibolite gneisses and amphibolites with an average susceptibility of 4,100 x 10^{-6} SI units and NRMP 7500 nT. Filo (in Vass et al., 1979), interpreted the Kováčovce magnetic anomaly as the effect of the amphibolite body, enriched in the magnetite at places. Based on the findings from the MV-12 drill, we assume that the magnetic anomaly is probably caused by the combined effect of the magnetic mica schists of the Southern Veporicum and the underlying probably Cadomian fundament with the content of the metabasic rocks.

In the territory of Trebušovce – Lesenice (L_2 – Lesenice anomaly, Fig. 3.3) magnetic anomaly ΔZ with amplitude up to 50 nT and ΔT with amplitude up to 25 nT was detected. The top edge of the magnetic body is interpreted at a depth of about 500 m below the current surface. The geological source of the anomaly is vague. It is probably part of the relics of the Ochtiná unit rocks similarly to the territory NW of Lučenec. Magnetic parameters and orientation of an anomaly in the NE-SW direction would indicate this. However, the anomalous effect of the mica schists of the Southern Veporicum and the Cadomian fundament cannot be excluded.

There are two positive, extensive large-scale magnetic anomalies of regional character in the Cerová vrchovina Upland, with amplitudes up to 300 nT, which have been merged due to the proximity of their sources to one anomaly (L_3 – Blhovce-Fiľakovo). The Blhovce-Fiľakovo magnetic anomaly was the subject of an interpretation in the construction of a structural-tectonic map of the Inner Western Carpathians. Filo & Kubeš (in Šefara 1987), both anomalies were considered to be part of a significant magnetic zone, which continues from the Blhovce area to the WSW up to the Börszönyi mountain range. The interpreted depth of the upper edge of the magnetic bodies was set within the range of 1.0-1.4 km. The lower boundary of the magnetic complex was estimated at 5.0-6.0 km. Based on the petrographic characteristics of the FV-1 borehole, which was located at the centre of the anomaly, it was assumed that the source of the anomaly are the Palaeozoic metabasics and the metasediments of Gemericum or Veporicum. The latest interpretation (Vozár in Kubeš et al., 2001) confirmed earlier interpretations. According to this, the magnetic effects originate from the Palaeozoic rocks, which are located in the Tertiary basement at a depth of more than 1,000 m below the surface. In our opinion, the metamorphic rocks in the borehole are affiliated to the Ochtiná unit and the mica schists of the Southern Veporicum, which probably overlie the assumed Cadomian fundament.

Another regional anomaly (Gemer L_4) is situated SE of Rožňava, in the territory of Gemerské Teplice – Licince – Gemerská Ves – Veľký Blh – Hrušovo – Ratková – Rákoš – Turčok. It occupies an area of about 300 km^2 and is oriented in the SW-NE direction. The upper edge of the magnetic rocks complex is interpreted at 4–4.5 km below the surface. Given the dimensions of the anomaly and magnetic and gravity parameters, it is likely that, similarly to the L_3 anomaly, it is induced, in addition to the magnetic rocks of the Ochtiná unit, by the presence of mica schists of the lower Hercynian unit and the fragments of the southern Cadomian fundament.

The Rožňava anomaly (L_5) is located in the wider area of Rožňava, in the area of Revúcka Lehota – Slavošovce – Roštár – Betliar – Drnava – Silica – Slanec – Gemerský Sad – Gemerské Teplice – Ľubeník and occupies an area of about 500 km^2. It is oriented in the E-W direction. The larger masses of basic metavolcanites and metavolcaniclastics belonging to the Rakovec Group (Vozár in Kubeš et al., 2001) were considered to be the source of the anomaly. Parts of the complex are smaller magma bodies of gabbrodiorites (Vozárová & Vozár in Rakús and Vozár, 1993). The upper edge of the magnetic complex is interpreted at a depth of about 3 km (west of the Štítnik fault) up to 4 km (east of the Štítnik fault). Given these and other physical parameters of the anomaly, it is very likely that the influence of the crystalline of the predicted underlying Cadomian fundament contributes to the source of the anomaly.

Ultrabasic rocks of vague affiliation

The Zbudza magnetic anomaly (M_1) is located in the northern part of the Východoslovenská nížina Lowland. It has northwest – southeast direction and max. amplitude of 80 nT. By quantitative interpretation and modelling, the basic parameters of the magnetic body, the upper edge of which lies at a depth of about 2.6 km with a thickness of 800 to 1,000 m, were determined. The upper edge of the body falls to the NNW (below the village of Zbudza) up to a depth of 3.6 km below the surface and at the SSE below Humenné to the same depth. Based on the results of the Zbudza-1 borehole, we assume, like Gnojek (1987a), that the sources of this anomaly are the serpentinized pyroxenites of unknown affiliation with a thickness of 1 km with an interpreted magnetic susceptibility 60,000 x 10^{-6} SI units.

The Bzenov anomaly (M_2) with amplitude up to 60 nT is oriented in the E-W direction. The main source of the Bzenov anomaly are most likely ultrabasic rocks below Branisko with a top edge at a depth of about 800 m below the surface. A body with a thickness of about 600 m is dippimg to the north.

Gnojek (1987b) gives an interpretation of the Bzenov magnetic anomaly in two variants. The first assumed in the Inner Carpathian Palaeogene basement the existence of rocks that correspond to the rocks in the crystalline regions, the second one magnetic rocks with a magnetic susceptibility of 20,000 x 10^{-6} SI units, which often occurs in gabbro and peridotite.

SW of Košice, on a relatively large area, magnetic anomalies of different amplitude and orientation have been verified. The entire anomalous region is known as the Komárovce magnetic anomaly (M_3). The Komárovce magnetic anomaly with amplitude of up to 300 nT is most visible in the areas of Paňovce – Čečejovce and Šaca – Veľká Ida – Komárovce. Less pronounced and less extensive anomalies were found in the area between Jasovo and Nováčany and east of Paňovce. The negative anomalies accompany the band of positive anomalies in their northern and north-eastern parts. It is an anomalous effect of the lower edge of magnetic rocks, inclined to the south, or to SW. The main sources of magnetic anomalies are probably serpentinized ultrabasic rocks captured by the KO-1 (Komárovce) borehole at a depth of 943.0 m, which according to some interpretations could belong to the Meliaticum. Their bottom edge was not verified with a 1,534 m final depth of the borehole. Elevated values of magnetic rocks have been found in rocks samples mainly in the depth range above 1,000 m. Magnetic susceptibility values move within the range 1,500–21,000 x 10^{-6} SI units.

The question of the interpretation of the source of magnetic anomalies in the wider area of Komárovce was also dealt with by other authors (Gnojek, Hovorka & Pospíšil, 1991, Gnojek & Vozár, 1992). In their interpretation of the source of the anomalies there are quite significant differences. In particular, there are differences in the data about the magnetic parameters of the object and especially the thickness of the source. In the first work, the authors assume a source thickness of up to 3,000 m and an effective volume magnetic susceptibility of 15,000 x 10^{-6} SI units, in the second work the lower edge of magnetically active rocks is laid down to a depth of 7 km, considering effective volume susceptibility up to 35,000 x 10^{-6} SI units. Based on our findings, we believe that the interpretation of the first authors (Gnojek et al., 1991) is much more realistic.

N. Magnetic anomalies sources of vague affiliation at greater depths

(probably mostly crystalline in combination with other sources)

The most comprehensible are the sources of magnetic anomalies buried at greater depths. These are sources in the Neogene basement of the Podunajská nížina Lowland ($N_1 – N_7$) and the Východoslovenská nížina Lowland (N_8). A special case is the N_9 anomaly in the Inner Carpathian Palaeogene. The sources of deep anomalies in the area of southern Slovakia can be of three kinds: they can be induced by the Tatricum and Veporicum crystalline rocks (basics, more granitoid differenciates, mica schists), whereas the influence of the fragments of the southern Cadomian fundament can also contribute, and the third source are the ultrabasic rocks, which intruded the crust in particular in the Tertiary and were associated with local asthenoliths ascent.

Several anomalies, the sources of which are probably metabasites in crystalline, are found in the Neogene basement in the Podunajská nížina Lowland. The most notable is the Gabčíkovo anomaly (N_1) with amplitude up to 200 nT. It also continues to the territory of Hungary. At the centre of the anomaly we interpret the presence of andesites with a top edge at a depth of about 3.2 km. In the western part and southeast of Gabčíkovo Hrušecký & Konečný (in Kubeš et al., 2001) suggest the presence of magnetic rocks of Tatricum crystalline with the top edge at a depth of about 5.0 km to 6.0 km. In the vicinity of the Gabčíkovo anomaly, drillings FGC-1, DS-1, DS-2, FGGA-1, FGHP-1, VTP-11, GPB-1 and CR-1 were realized with a maximum depth of up to 3,000 m. Neither of these drills has provided evidence of the presence of magnetic rocks in the Tertiary fill and no borehole reached the Tertiary basement. Based on the tectonic situation and the depth of the anomaly we assume its sources in the Tatricum crystalline or Cadomian fundamentals. Metabasic rocks are most likely to occur, as heavier masses are also indicated in this area.

Two significant magnetic anomalies – the Kráľov Brod (N_2) and Vlčany (N_3) – have been found in the Podunajská nížina Lowland, which are probably caused by more basic granitoid differenciates with amplitudes of 100 to 140 nT. The source of the Vlčany anomaly was interpreted to a depth of 5.0 to 6.0 km and to the Kráľov Brod 4.5 to 5.0 km below the current surface.

From the point of view of the deep burial of the source of the magnetic anomaly of Búč (N_6), there is an exception in the area of the Podunajská nížina Lowland. It is the only one that is shallowly deposited and is probably caused by basal to ultrabasic rocks in the underlying Mesozoic complex, which probably no longer belongs to the Western Carpathian units, but it is a Pelsonia block. We interpret its source at a depth of 0.6 km below the surface. In all three cases, the influence of the underlying Cadomian fundament can also be assumed.

The Bíňa anomaly (N_7) with a maximum amplitude of up to 75 nT in the eastern part of the Podunajská nížina Lowland is probably induced by the rocks of the mica schist complex (Hrušecký in Kubeš et al., 2001). It is located at a depth of 3.0 to 3.5 km. These rocks underlie the non-magnetic sediments without a volcanic fraction. The magnetic anomaly is oriented in the NE-SW direction. The interpreted source length is about 17 km and a width of about 7 km. Even in this case, we cannot exclude the influence of the underlying Cadomian fundament.

In the vicinity of Kolárovo in the Podunajská nížina Lowland there is a faint but extensive magnetic anomaly, coinciding with an intense positive gravity anomaly known from the geological literature as the Kolárovo anomaly (N_4). For the first time, this magnetic anomaly was observed in the "Structure-Tectonic Map of the Inner Western Carpathians" (Filo in Šefara et al., 1987). For the source of this anomaly the authors suggested basic rocks (gabbros and metabasics, gabbroamphibolites, gabbrodiorites) with effective magnetic susceptibility of 12,000 x 10^{-6} SI units, which should be located at a depth of 5 km with a thickness of about 7 km. At present, we give the Kolárovo anomaly in connection with the massive body of gabbroamphibolites (gabbrodiorites) with a top edge at a depth of 5.5–6.0 km. According to the interpretation, Bezák et al (1997) refers to crystalline rocks or the residue of the basics of the Meliaticum unit in the suture zone, which was also used for the output of partial asthenolith bodies in the Tertiary extension processes.

Rather ambiguous is the interpretation of the sources of a less pronounced, but extensive Strekov anomaly (N_5) with a depth of about 3.5–4.0 km. We assume that the sources of the anomaly are the same rock complexes, as in the case of the Kolárovo anomaly.

In the Východoslovenská nížina Lowland, the dominating position has the Sečovce anomaly (N_8) with amplitude to 100 nT. Man (1961), Pospíšil & Filo (1977), Mořkovský & Cverčko (1987) and Gnojek (1987a) were involved in the interpretation. They put the source depth in the range from 5.5 to 6.5 km with various effective magnetic susceptibilities (5,000–100,000 x 10^{-6} SI units). For its source, Janočko (in Kubeš et al., 2001) considers the complex of magnetic rocks at the southwest edge of the Pozdišovce-Iňačovce unit. They are bound to tectonic contact with the practically non-magnetic rocks of the Zemplín unit.

According to the present geological knowledge, the Pozdišovce-Iňačovce unit consists of phyllites of different compositions. We believe that this rock complex cannot be the source of an interpreted regional Sečovce anomaly. Structural boreholes made so far did not reach the Tertiary basement. According to our interpretations, the sources of the Sečovce anomaly are probably metamorphites of basic rocks with a roof at a depth of about 6.0 to 8.0 km. According to the interpretation of Bezák et al. (1997) the proximity of ascended asthenolith in the bedrock also contributes to the magnetic effect. Similarly, these types of anomalies are interpreted by Vass et al. (1988).

In the southern part of Šarišská vrchovina Upland, a relatively large area anomaly with amplitude of up to 40 nT (Šariš – N_9) was recorded by aeromagnetic mapping. It is oriented in the ESE-WNW direction, reaching a length of nearly 20 km and a width of about 6 km. Its eastern boundary is questionable due to lack of magnetic information for technical reasons. The top edge of this source is interpreted to a depth of 1.8–2.5 km. The Šariš anomaly is divided into two parts – the northern and the southern ones, based on the magnetic field. The northern part of the anomaly is caused by magnetic rocks whose upper edge lies at a depth of about 2,500 m. The southern part forms an anomalous effect of rocks at a depth of about 1,800 m. The anomalies in both parts of the Šariš anomaly were considered to be either more basic differenciates of the granitoids of the Western Carpathian crystalline, but neither the influence of the basic rocks of the crystalline of the North European platform is excluded, as we predict also in the case of the Kežmarok anomaly (I_{10}).

O. Sources in the Inner Carpathian Palaeogene

New anomalies have been detected in new terrestrial magnetic mapping in the Spišská Magura Mts. region, most likely due to Menilite Mb. (O_1 and O_2), which are located at or near the surface at Lendak and Hanušovce.

P. Flysch Zone of the Outer Western Carpathians

These little significant magnetic anomalies are again caused by the Menilite Mb. found at the surface at Roztoka and Ulič in Bukovské vrchy Mts. (P_1 and P_2).

3.6. Geomagnetic research in neovolcanites of Slovakia

The most significant magnetic anomalies in Slovakia were recorded in the areas of neovolcanic mountain ranges. They are characterized in particular by the rapid alternation of positive and negative anomalies in the range from -1,100 to +1,000 nT.

In the Slovenské stredohorie Mts. there are mainly Pohronský Inovec and Štiavnické vrchy (1), Vtáčnik (2), Kremnické vrchy (3), Poľana (4), Javorie (5) and Krupinská planina Plateau (6). In the Eastern Slovakia dominate the neovolcanic mountains Slanské vrchy (7) and Vihorlatské vrchy (8). The anomalous effects of Tertiary volcanism products were also found in Žiarska kotlina Basin (13) (Fig. 3.4).

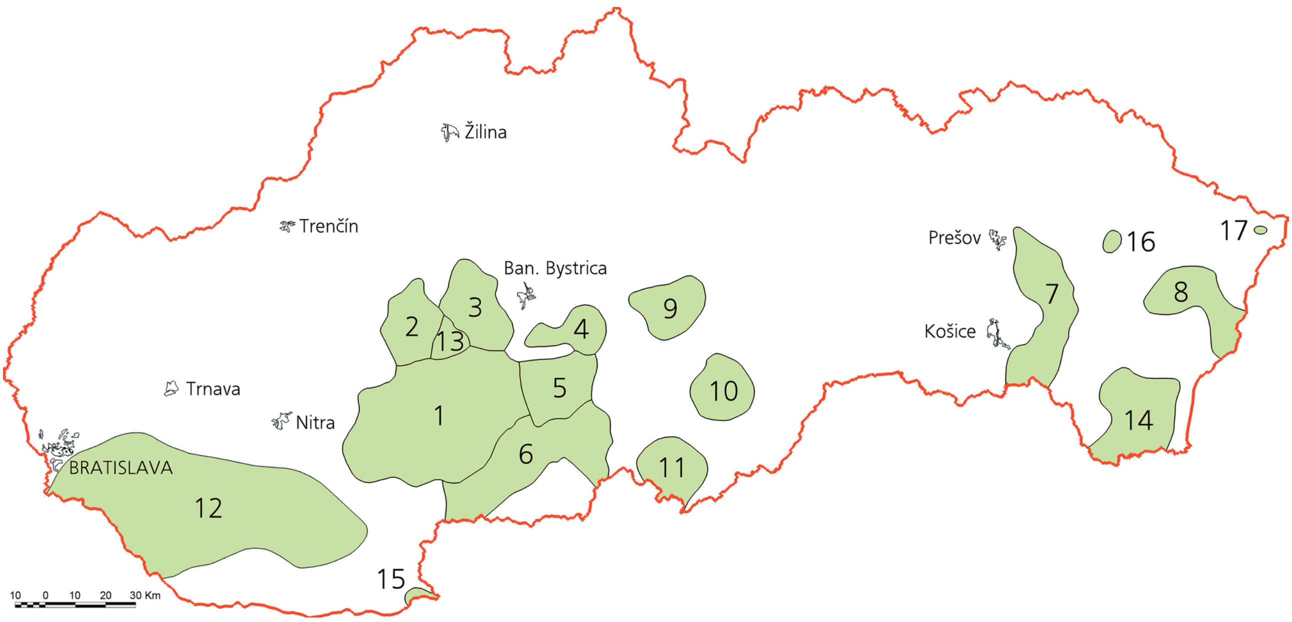

Fig. 3.4 *Distribution of neovolcanites – sources of the geomagnetic anomalies – in the territory of the Slovak Republic (Kubeš, 2008)* **1:** *Pohronský Inovec and Štiavnické vrchy Mts.;* **2:** *Vtáčnik Mts.;* **3:** *Kremnické vrchy Mts.;* **4:** *Poľana Mts.;* **5:** *Javorie Mts.;* **6:** *Krupinská planina Plateau;* **7:** *Slanské vrchy Mts.;* **8:** *Vihorlatské vrchy Mts.;* **9:** *wider vicinity of Pohronská Polhora;* **10:** *Pokoradzská tabuľa Plateau;* **11:** *Quaternary volcanism of Cerová vrchovina Upland;* **12:** *Podunajská nížina Lowland;* **13:** *Žiarska kotlina Basin;* **14:** *Východoslovenská nížina Lowland;* **15:** *Burda Mts.;* **16:** *buried volcanites at Humenné;* **17:** *buried volcanites at Zboj Village.*

Tab. 3.2 Tectonic classification of sources of magnetic anomalies in the pre-Tertiary formations of Slovakia

Sources of magnetic anomalies		Geographic region	Name of magnetic anomaly	Label in map	Source depth (km) below surface
A	Basic volcanites of Hronicum	Malé Karpaty Mts.	Sološnica-Smolenice	A_1	0–0.2
		Brezovské Karpaty Mts.	Brezová	A_2	0.1
		Strážovské vrchy Mts. – South	Nitrica	A_3	0–0.3
		Kráľova hoľa Nízke Tatry Mts. – North	Malužiná-Vikartovce	A_4	0
		Nízke Tatry Mts. – South	Malužiná-Vikartovce	A_5	0
		Nízke Tatry Mts. – South	Malužiná-Vikartovce	A_6	0
		Vysoké Tatry Mts.	Malužiná-Vikartovce	A_7	0
B	Basic to ultrabasic volcanites of Meliaticum	Slovenský Kras Mts. – East	Hačava	B_1	0–0.1
		Slovenský Kras Mts. – East	Jasov	B_2	0–0.1
		Slovenský Kras Mts. – East	Miglinec	B_3	0–0.3
		Slovenský Kras Mts. – West	Bretka	B_4	0–0.1
C	Basic volcanites and phyllites of the Ochtiná tectonic unit	Slovenské rudohorie Mts.	Lučenec-Poltár	C_1	0.1–0.8
		Slovenské rudohorie Mts. – centre	Ľubeník	C_2	0.1–0.5
D	Amphibolites of the Klátov tectonic unit	Slovenské rudohorie Mts. – East	Klátov	D_1	0–0.2
E	Basic metavolcanites the Rakovec tectonic unit	Slovenské rudohorie Mts. – East	Rakovec	E_1	0
		Slovenské rudohorie Mts. – East	Slovinky	E_2	0.5–0.7
F	Basic metavolcanites of the Gelnica tectonic unit	Slovenské rudohorie Mts. – East	Smolník	F_1	0–0.2
		Slovenské rudohorie Mts. – East	Švedlár	F_2	0–0.2
G	Amphibolites and metamorphites with positions of basic rocks in crystalline of Tatricum and Veporicum	Malé Karpaty Mts.	Pernek	G_1	0
		Považský Inovec Mts.	Hrádok	G_2	0.1–0.2
		Považský Inovec Mts.	Kálnica	G_3	0.1–0.2
		Tribeč Mts.	Skýcov	G_4	0–0.5
		Slovenské rudohorie Mts. –centre	Muráň	G_5	0.0–0.2
		Nízke Tatry Mts.	Bukovec	G_6	0
		Nízke Tatry Mts.	Brezno	G_7	0
		Vysoké Tatry Mts.	Žiar	G_8	0
H	Mica schists and amphibolites of Lower Hercynian lithotectonic unit	Slovenské rudohorie Mts.– West	Málinec	H_1	0.6–1.0
		Slovenské rudohorie Mts. – West	Rovné	H_2	0.1–0.5
		Slovenské rudohorie Mts. – West	Kokava	H_3	0.1–0.3
		Slovenské rudohorie Mts. – West	Klenovec	H_4	0.0–0.5
		Slovenské rudohorie Mts. – West	Píla	H_5	0.1–0.5
I	More basic differenciates of Hercynian granitoids	Malé Karpaty Mts.	Svätý Jur	I_1	2.0
		Podunajská nížina Lowland	Grob	I_2	2.0–2.5
		Považský Inovec Mts.	Inovec	I_3	0.5–0.7
		Považský Inovec Mts.	Hlohovec	I_4	0.1–1.5
		Tribeč Mts.	Tribeč	I_5	0–0.5
		Tribeč Mts.	Preseľany	I_6	1.0–2.0
		Malá Fatra Mts.	Malá Fatra	I_7	0–0.6
		Podunajská nížina Lowland	Sereď	I_8	3.0–3.5
		Podunajská nížina Lowland	Galanta	I_9	3.5
		Levočské vrchy Mts.	Kežmarok	I_{10}	2.5–3.0
		Nízke Tatry Mts.	Ľupča	I_{11}	0
		Nízke Tatry Mts.	Vernár	I_{12}	0
		Vysoké Tatry Mts.	Štrba	I_{13}	0
J	Rochovce granite	Slovenské rudohorie Mts. – centre	Rochovce	J_1	0.5–0.8

Tab. 3.2 – continuing

Sources of magnetic anomalies		**Geographic region**	**Name of magnetic anomaly**	**Label in map**	**Source depth (km) below surface**
K	Cadomian fundament in the northern zone	Západné and Stredné Beskydy Mts.	Beskydy	K_1	> 6.0
		Borská nížina Lowland	Skalica	K_2	> 6.0
L	Cadomian fundament in the southern zone and its overlying units	Ipeľská kotlina Basin	Kováčovce	L_1	1.0
		Ipeľská kotlina Basin	Lesenice	L_2	0.5
		Lučenecká kotlina Basin	Blhovce- Fiľakovo	L_3	1.0–1.5
		Slovenské rudohorie – East	Gemer	L_4	4.0–4.5
		Slovenské rudohorie – East	Rožňava	L_5	3.0–4.0
M	Ultrabasic rocks of vague affiliation	Východoslovenská rovina Flat	Zbudza	M_1	2.7
		Šarišská vrchovina Upland	Bzenov	M_2	0.8
		Košická kotlina – West	Komárovce	M_3	0.3–1.0
N	Sources of magnetic anomalies of vague affiliation	Podunajská nížina Lowland	Gabčíkovo	N_1	5.0–6.0
		Podunajská nížina Lowland	Kráľov Brod	N_2	4.5–5.0
		Podunajská nížina Lowland	Vlčany	N_3	5.0–6.0
		Podunajská nížina Lowland	Kolárovo	N_4	5.5–6.0
		Podunajská nížina Lowland	Strekov	N_5	3.5–4.0
		Podunajská nížina Lowland	Búč	N_6	0.6
		Podunajská nížina Lowland	Bíňa	N_7	3.5–4.0
		Východoslovenská rovina Flat	Sečovce	N_8	6.0–8.0
		Šarišská vrchovina Upland	Šariš	N_9	1.8–2.5
O	Sources in ICP	Spišská Magura Mts.	Hanušovce	O_1	0
		Spišská Magura Mts.	Lendak	O_2	0
P	Flysch Belt of the Outer Western Carpathians	Bukovské vrchy Mts.	Roztoka	P_1	
		Bukovské vrchy Mts.	Ulič	P_2	

Relatively significant are the magnetic effects of neovolcanites in the wider area of Pohronská Polhora (9), Pokoradzská tabuľa Plateau (10) and Východoslovenská nížina Lowland (14).

In the area of Cerová vrchovina Upland, the anomalous effects of Quaternary volcanism products (11) are clearly manifested (Fig. 3.4).

The presence of Tertiary volcanism products has been proven both by drillings and magnetic measurements in the Podunajská nížina Lowland (12). Neovolcanic rocks are located at relatively large depths and therefore their magnetic manifestation is less pronounced. The exception is Burda (15). The presence of buried volcanoes was also found at Humenné (16) and Zboj (17) (Fig. 3.4).

These anomalies were interpreted in separate papers by Kubeš et al., in Suk, 2002, and by Filo et al., (2003).

The manifestations of Tertiary volcanism products in magnetic maps depend on several factors: magnetic properties, intensity and character of hydrothermal changes, area and vertical dimensions, composition of volcanic complex, morphological conditions and geomagnetic mapping methodology used within individual neovolcanic mountains.

3.6.1 Magnetic properties of neovolcanic rocks

Within the framework of regional geophysical research of neovolcanites in Slovakia, the study of magnetic properties of rocks on samples taken from natural outcrops and selected boreholes was carried out. Laboratory values of volume magnetic susceptibility (KAPA) and remanent magnetic polarization (Ir) were determined. The greatest interest was focused on the detection of magnetic parameters from Kremnické and Štiavnické vrchy Mts.

From the Geofyzika a.s. data obtained, the magnetic properties of the basic types of volcanic rocks show a wide range of KAPA and Ir values (Table 3.3).

The KAPA values ranged from 0 to 94,137 x 10^{-6} (SI), Ir values range from 0 to 61,896 nT. This great variance of values was also found within individual petrographic types. The variability of the values is conditioned by the basic factors that determine the magnetic properties. They are:

a) the quantity and type of ferromagnetic minerals;
b) the magnetic properties of the individual minerals;
c) the type of minerals distribution in the rock;
d) the type and intensity of hydrothermal processes in the rock.

Tab. 3.3 Magnetic properties of neovolcanic rocks

Rocks	Number of samples	KAPA x 10^{-6} [SI]			RMP [nT]		
		min.	max.	x	min.	max	x
Rhyolites	271	18.84	19,230.62	2,996.82	6.28	9,663.66	1,127.76
Rhyolite pyroclastics	144	310.23	13,175.44	3,999.10	14.44	2,346.21	299.56
Rhyodacites	25	1,760.91	15,398.56	7,067.51	18.84	1,283.63	241.15
Dacites	10	7,283.54	16,973.58	12,743.38	296.67	3,594.80	1,372.93
Pyroxenic andesites	1,595	89.18	74,480.80	23,789.90	18.84	61,898.19	2,460.13
Hornblende-pyrox. andesites	25	7,443.06	28,437.10	16,844.22	1,458.84	2,559.60	2,200.76
Hornblende-biotit. andesites	215	639.30	47,787.03	16,748.76	10.05	5,319.91	1,307.87
Propylitized andesites	230	0	628.0	100.48	0	251.20	11.30
Pyroclastics of pyrox. andesites	1,802	339.12	44,834.18	10,304.22	18.59	24,586.20	865.76
Basaltic andesites	22	1,369.04	26,398.61	13,367.61	405.94	5,966.88	2,385.27
Alkali basalts, basanites	76	2,135.20	94,137.20	30,990.54	18.97	19,123.86	5,393.64
Pyroclastics of basalt. basanites	31	18.84	8,626.21	4,270.40	2.14	1,501.05	565.58
Quartzose diorite (propylit.)	435	0	43,960.00	12,220.88	0	728.48	242.41

x – mean value

Despite the great variability of the values of the monitored parameters, we can pronounce the basic knowledge of the direct dependence of the magnetic parameters on the basicity of the rocks. From the mean values calculated for the basic types of neovolcanic rocks (rhyolite – andesite – basalt), the KAPA and Ir parameters are increased with the basicity. It has also been found that secondary alterations, which affect the volcanic rocks in particular in the central volcanic zones, significantly impact the values of the magnetic parameters. In many cases, they lead to significant reductions in the values, and from the originally high-magnetic rocks the rocks can become very low-magnetic or practically non-magnetic.

We also consider for practically non-magnetic rocks the Neogene sediments without a volcanic fraction. We include fine-grained volcaniclastics in the low-magnetic rocks. The group of moderately magnetic rocks represent predominantly medium-grained volcaniclastics.

Coarse-grained volcaniclastics, breccias and solid (unbroken and non-metamorphosed) products of andesite volcanism are assigned to a group of magnetic, strongly magnetic or high-magnetic rocks. These include basalt volcanism products.

The results of palaeomagnetic studies in some of the neovolcanic mountains (Kremnické vrchy, Slanské vrchy, Vihorlatské vrchy) proved the existence of volcanic rocks with normal and reverse magnetic polarization. Palaeomagnetic studies use the ability of some rocks to retain their magnetic parameters obtained at the time of their origination, at the time of their conversion to the final (so far last) state. The study results give the possibility to decode the polarization of the Earth's magnetic field in its geological history along with information on the time course of the alternation of the Earth's magnetic field's normal and reverse polarity.

The results of palaeomagnetic and isotopic studies in East Slovakian neovolcanites and the analysis of polarities of volcanic complexes by aeromagnetic maps (Gnojek & Kaličiak, 1990) provide good information for confrontation with the latest magnetostratigraphic scale.

This magneto-stratigraphical scale allows to specify the age of volcanic rocks (in order of 10^{-2} Ma).

From the magnetostratigraphic scale it follows that a series of inversions emerged during the Miocene. The normal polarities prevailed in the Late Badenian and in the Pannonian, in the Early and Middle Badenian and in the Late Sarmatian (till the beginning of the Pannonian) reverse polarity prevailed. The Early and Middle Sarmatian is a period with an equal representation of both polarities. The longest duration (almost 1 million years) had a reversed polarity period in the Middle Badenian (16.20 to 15.23 Ma). All other periods were clearly shorter than 1 Ma.

The basic and background material for the incorpration of the Neogene volcanic rocks into a magneto-stratigraphical scale are the latest geological knowledge, radiometric age and polarization of objects according to the results of geomagnetic mapping.

3.6.2 Interpretation of magnetic anomalies generated by the products of Tertiary and Quaternary volcanisms and interpretation of volcanic complex thicknesses

We have already mentioned two important factors that greatly influence the overall character of the magnetic field in the neovolcanic mountains. These are the magnetic properties of rocks (rock complexes) and the presence of products with normal and reversed magnetization.

Reverse magnetization rocks are represented by negative magnetic anomalies. The largest presentation they have in Pohronský Inovec, Kremnické vrchy, Štiavnické vrchy, Javorie, Slanské vrchy and Vihorlatské vrchy Mts.

The value of the anomalies largely depends on the area and vertical dimensions of magnetically active rocks. Small volumes (less than 200 x 200 m) and small thickness (less than 30 m) of volcanic rocks may not display a real anomaly in airborne measurements even though their presence has been proven by geological mapping. On the contrary, in several cases we have found anomalies that we interpret as the effect of volcanic rocks of larger dimensions, covered by non-magnetic younger sediments of different thicknesses (e.g. anomalies in Žiarska kotlina Basin, southern and SE part of the Štiavnické vrchy Mts., in the western part of the Slanské vrchy Mts.).

Magnetically active volcanic rocks, in the vast majority of cases, build morphological elevations with different orientation and with different positions in the direction of aeromagnetic profiles. The mutual position of morphostructures and measured profiles has a great effect on the overall character of the magnetic field anomalies. The most optimal image of the anomalous effect of surface and near-surface sources provide measurements along profiles oriented perpendicular to the direction of the mapped morphostructure. The distortion of the anomalous effect of the morphostructure occurs in cases where the profiles are oriented to the structure at oblique angles. The most complicated are the anomalous effects of volcanic complexes oriented in parallel with the orientation of the profiles. With such a case, we meet, for example, in the southern and SE part of the Javorie Mountains.

For the above reasons, the magnetic anomalies were interpreted not only based on the results of geological mapping, but also on the topographic documents at scale 1 : 50,000. The purpose of confronting magnetic and topographic maps was to eliminate as much as possible the impact of the relief on the orientation, amplitude and polarity of the interpreted anomaly or groups of less extensive anomalies.

Particularly pronounced is the deformed character of the anomalies in the highly dissected terrain, i.e., where there is a rapid change of relief. Typical features of this type of relief are narrow backs, steep slopes and deeply incised river valleys.

Based on the mutual relationship of real positive and negative anomalies of ΔT to terrain relief, we have defined sites where volcanic rocks with normal (positive anomalies) or reversed (negative anomalies) magnetic polarization predominate. Separated locations by polarization type are indicated in the magnetic anomaly sources map at a scale of 1 : 50,000 (Kubeš et al. 2001).

Virtually in all the above-mentioned neovolcanic mountain ranges have been implemented terrestrial profile magnetic measurements, mainly aimed at solving metallogenic problems in the central volcanic zones and in their immediate vicinity.

The territory of Central Slovakian Neovolcanites Field was covered by aeromagnetic measurements with an average flight height of 80 m above the terrain (Gnojek & Janák, 1986), 500 m above the terrain and 2,000 m above sea level (Šalanský, 1970). The results of the measured data were displayed on the ΔT anomaly maps (scale 1 : 50,000). The measured values at different altitude levels provide information about the magnetic field changes in the vertical direction.

The nature of the change in ΔT with observation level was analysed at locations where magnetically active volcanic rocks are well defined by geological mapping and drilling results. It has been shown that the relatively smallest decrease in ΔT values with altitude occurs in places where the magnetic volcanic complex has larger area dimensions and reaches relatively larger thicknesses. Above the volcanic complex of smaller area dimensions and smaller thickness, there is a significantly more pronounced decrease in ΔT values with increasing the altitude of the observation level.

Small-dimensional bodies with relatively large depth ranges (necks, dykes, stockworks, etc.) are displayed in intrusive anomalies in terrestrial measurements, but their appearance is not observable in aeromagnetic maps.

In the interpretation of the thicknesses of the volcanic complex, we proceeded from the geological knowledge of the horizontal to sub-horizontal placement of the lower edge of magnetically active rocks over practically non-magnetic sediments without volcanic fraction or only with low content of magnetic minerals (fine-grained volcaniclastics – tuffs and tuffites).

From the analysis of the relationship between geological objects, terrain relief and changes in ΔT values at three height levels (1 m, 500 m and 2,000 m), we found that a magnetically active volcanic complex with a thickness of 100 m produces an anomalous effect in height of 500 m average amplitude 40 nT. This means that, for example, to a magnetic anomaly that reaches a value of 100 nT at 500 m above the terrain, we can attribute volcanic complex with a thickness up to 200 m, to the value up to 200 nT the thickness of up to 500 m, the value up to 400 nT the thickness of up to 1,000 m.

Similarly, the thicknesses of the volcanic complex of Slanské and Vihorlatské vrchy Mts. were interpreted. This was based on the results of aeromagnetic measurements with a flight height of 300 m above the relief (Beneš, 1971). It has been found that a 100 m volcanic complex produces a 300 m anomalous effect of about 70 nT, with a thickness of 500 m around 350 nT and 1,000 m about 700 nT.

The data obtained from the analysis of the magnetic field values at a height of 300 m and 80 m above the terrain were supplemented by information obtained from measurements with a flight height of 500 m and 80 m. From the statistical processing of the values of anomalies at sites measuring 300 m and 80 m above ground relief (East Slovakian neovolcanites), or at a height of 500 m and 80 m above the relief (Central Slovakian neovolcanites), it is known that a 100 m thick volcanic complex is displayed at a height of 100 m above the relief with a magnetic anomaly with an amplitude of about 125 nT. To solve the amplitude relation of the ΔT anomaly to the thickness of the complex, we considered several facts that affect the overall character of the anomaly, but especially its average value. It must be borne in mind that in such morphologically complicated

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conditions the flight height was 80 m strictly maintained and ranged from 60 to 140 m above the ground. In this case, it is necessary to consider the significant influence of surface local magnetic inhomogeneities on the shape and amplitude of the magnetic anomaly, especially in the morphologically dissected environment. The third important criterion for the interpretation of thicknesses is the step of the ΔT in the aeromagnetic maps used, which is not always constant.

In the area of Central Slovakian neovolcanites, the maps of ΔT were constructed with an interval: 0, ±20, ±50, ±100, ±200, ±300, ±400, ±500, ±750 and ±1,000 nT.

In the area of East Slovakian neovolcanites, the interval was chosen: 0, ±10, ±30, ±50, ±70, ±100, ±150, ±200, ±250, ±300, ±350, ±400 and ±500 nT.

In order to solve the relation of the anomaly amplitude to the thickness of the volcanic complex, we used the intervals of ΔT values from both regions (Table 3.4). At the same time, we added data on min. or max. thickness of the volcanic complex. With regard to all problems associated with the quantitative interpretation of magnetic anomalies in such complex geological and morphological conditions, the interpreted data should be considered as more or less indicative. Their refinement requires the use of data from other geophysical methods, e.g. gravimetry and vertical electrical sounding results (VES).

Tab. 3.4

Anomalies ΔT [±nT]			**Interpreted thicknesses of volcanic complex [m]**		
min	**max**	**x**	**min**	**max**	**x**
10	50	30	30	50	40
50	100	75	50	70	60
100	200	150	70	130	100
200	300	250	130	200	160
300	500	400	200	400	300
500	750	625	400	600	500
750	1,000	875	600	800	700

x – mean value ΔT [nT] x – mean thickness [m]

3.7. Conclusions

The Department of Geophysics at SGIDŠ succeeded in supplementary measurement of the geomagnetic field of Slovakia in recent years and to create a unified database of geomagnetic measurements. The created database has allowed for the interpretation of significant magnetic anomalies and their geological significance. We also used the database for the uniform interpretation of geomagnetic anomalies, which contributed mainly to the clarification of the geological structure in all regions of Slovakia and to the creation of geological maps at a scale of 1 : 50,000. The MGII maps are inseparable part of this work. New geomagnetic measurements have also revealed the presence of buried neovolcanites of Pokoradzská tabuľa Plateau, Cerová vrchovina Upland, Lučenská-Rimavská kotlina Depression, Podunajská nížina Lowland, etc. In the north-eastern Slovakia, buried neovolcanites with reversed magnetism at the Zboj Village were found. Different types of granitoid rocks in the vicinity of the Vysoké Tatry, Malé Karpaty, Tribeč, and Veľká Fatra Mts. have been distinguished, since these more basic granitoid differenciates (tonalites) are manifested in the magnetic field by slightly increased values of the total induction of the geomagnetic field. The results of geomagnetic measurements have also contributed to determining the area extent of Vepor Stratovolcano. Geomagnetic measurements can be used especially in neovolcanic mountains, where the lava flows of andesites with their tuffs and tuffites positions (tuffs and tuffites appear in the magnetic field as weak magnetic) are alternating frequently.

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