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Geophysical prospecting for hydrocarbons in the Intracarpathian Paleogene and in the East Slovak Flysch Belt

Geofyzikální průzkum na uhlovodíky v centrálněkarpatském paleogénu a flyšovém pásmu východního Slovenska

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Abstract: Results are presented of geophysical, namely CDP seismic measurements carried out in the period 1972-84 in the Intracarpathian Paleogene and in the East Slovak Flysch Belt. For interpretation were also used refraction seismic, gravity and magnetic data, results of well-shooting, acoustic and electrologging in deep boreholes, and data on physical properties of rocks obtained by measurements on drill core samples. The well-shooting data were used for velocity studies in the area. Based on reflection seismic data are the time map and the depth structural scheme of the buried Mesozoic relief of the Central Carpathians in the broader environs of Lipany. Seismic measurements indicated numerous tectonic faults, NE-SW striking reverse faults, and normal faults.

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Introduction

In the present article we attempt to summarize the results of geophysical, namely seismic, survey accomplished in 1984 for hydrocarbon prospecting in the Intracarpathian Paleogene, the Klippen Belt, the East Slovak Flysch Belt and their basement. Most valuable data were obtained by CDP measurements on seismic profiles.

The Intracarpathian Paleogene is composed of several lithofacial sequences, from pre-flysch, wild flysch to typical flysch development (Chmelík 1957), often with giant bodies of badly sorted conglomerates of alluvial fan (Marschalko 1965, 1981). After geological mapping, geophysical survey and deep drilling the Intracarpathian Paleogene is at the present prospecting stage relatively most investigated. Results from boreholes (Lipany-1,2,3,4 and 5, PU-Šambron, Plavnica-1) at the southern border of the Klippen Belt confirmed larger tectonic deformation (Nemčok et al. 1977) and presence of irregular breccia series built of Lower Cretaceous and Jurassic rocks in the deeper part of the Intracarpathian Paleogene which Rudinec (1981) regards as olistoliths. Besides the scale-fold structure, the Paleogene strata are affected by the youngest Neogene normal faults.

According to drilling, the basement of the Paleogene in the peri-Klippen zone is Mesozoic. Its entire relief (Cretaceous to Lower Triassic) was verified by borehole Šariš-1 in the interval 1,340–3,836 m. It is the Mesozoic of the Krížna nappes (Koráb et al. 1986) with strongly tectonized crystalline rockc in its basement (3,836–5,000 m).

The Klippen Belt forms a narrow strip between the Flysch Carpathians and the Intracarpathian Paleogene. Mainly in consequence of Neogene folding it takes on the tectonic style of the Carpathian flysch area (Leško-Salaj-Samuel 1963). Within the Klippen Belt in the Hanušovce horst, the borehole Hanušovce-1 penetrated Upper Cretaceous sediments and the Klippen Belt Paleogene to the depth of 4,000 m. Paleogene sediments are represented by the Proč series. To the final depth of 6,000 m were drilled the Eocene sediments (Strihovce, Beloveža and Zlín series) of the Krynica and Rača units of the Magura nappes (Leško et al. 1984).

The flysch belt of the Czechoslovak Carpathians in the eastern part consists of two units, the Magura nappes and the Dukla unit. From S to N the Magura nappes contain the partial Krynica, Bystrica and Rača unit between Smilno and Nižný Mirošov, the tectonic basement crops out to the surface in the form of a window – the Dukla unit. Deep boreholes Smilno-1 and Zboj-1 yielded geological data on the Flysch belt. The borehole Smilno-1 (Leško 1986) struck to the depth of 4,600 m the Rača unit of the Magura nappes formed by the Upper Paleocene to Lower Eocene Beloveža series and the inoceramus series and Upper Senonian to Paleocene breccia. In the depth interval 4,600–5,700 m the Outer Flysch Belt was struck represented by the black flysch series and Eocene breccia, and by Upper Miocene menilite series. The borehole Zboj-1 (Ďurkovič et al. 1982) confirmed down to the depth of 3,800 m the structure of the Dukla unit formed by submenilite Paleocene to Middle Eocene series, by the Cisna Paleocene series and by the Lupkov Upper Cretaceous to Paleocene series. The tectonic basement of the Dukla unit is mainly built of the psammitic Zboj series struck by drilling in the interval 3,800–5,002 m. It is now assumed that the Zboj series is of Upper Eocene to Lower Oligocene age.

Compared to the East Slovak Basin, for example, oscillographic and analog reflection seismic measurements were conducted on a smaller scale in the area of interest because of hard seismological conditions and complicated interpretation. A change came with the arrival of digital recording and processing. In the period 1972–84, 50 seismic CDP profiles at the total length of 477 km were shot for oil and gas prospection in the Intracarpathian Paleogene and in the East Slovak Flysch Belt. Seismic measuremets concentrated in the peri-Klippen area in the broader environs of Lipany (Šambron-Lipany-Kapušany). Large-scale reflection seismic surveys were carried out in the area of Smilno and Zboj. In the area of Adidovce and Zubné three short reconnaissance profiles were situated. Seismic profiles were also stretched near Starina, Tokajík and S of Jakubany.

A relatively dense network of CDP profiles was set in the peri-Klippen area and eight deep boreholes were drilled there (Lipany-1,2,3,4 and 5, Plavnica-1, PU-1 Šambron and Šariš-1). Well- shooting was conducted in six boreholes. A structural scheme of the relief of Triassic dolomites in the basement of the Intracarpathian Paleogene was constructed.

Besides CDP and drilling information, results of refraction seismic, gravity and magnetic measurements, logging in deep boreholes (seismic, sonic, electric) and of measurements of physical properties of rocks on core samples were interpreted.

Application of individual geophysical methods and results

Gravity survey

Leaving aside the gravity measurements of Meinhold-Scheele (1943), Běhounek (1950), Běhounek-Válek (1951) which covered the southern and western margins of the study area only, the first systematic survey in the area was the regional gravity survey conducted by the Research Oil Institute, Brno in the period 1954–57, with one point of measurement per 2–3 km^2. Since 1970 a detailed gravity survey has been carried out in the study area with 3–6 points of measurement per km^2.

The regional gravity measurements were processed and interpreted by Menčík (1957), Čekan-Šutor (1960), Šutor-Čekan (1965) and Tomek in Kadlečík et al. (1977). In the framework of regional gravity survey and of surveys over the entire Czechoslovak territory the Intracarpathian Paleogene and the East Slovakian flysch were investigated by Ibrmajer-Doležal-Mottlová (1959), Ibrmajer-Doležal (1962) and Ibrmajer (1963, 1978).

Fusán et al. (1971) used the maps of Bouguer anomalies and maps of regional and residual anomalies, drilling data and data obtained by other geophysical methods to compile a map of the basement relief of the covered areas in the southern part of the Inner West Carpathians. The map includes only the southernmost margin of our study area.

Results of a deatiled gravity survey in the area between Šambron and Lipany (Váca et al. 1971) were used by Čekan-Mořkovský (1982) to compile maps of residual anomalies. The map of residual anomalies of the gravity field with the radius of averaging ring $r = 2$ km reflects (at the thickness of Paleogene sediments around 2.3 km) the lithological changes in rocks of the Intracarpathian Paleogen. Residual anomalies plotted in the map often correlate with outcrops of rocks exhibiting different densities. On the contrary, the map of residual anomalies of the gravity field with the radius of the averaging ring $r = 2–16$ km mainly characterizes (as documented by reflection seismic measurements) the relief of the basement dolomites (the Krížna unit). It is noteworthy that the positive residual anomaly corresponding to an elevation of dolomites south of Šambron-Krásna Lúka extends without major deformations to the area north of the Klippen Belt.

The gravity field in the broader area of the Humenné Mesozoic subunit was interpreted by Pospíšil-Filo (1982). They concluded that NW of Prešov the Klippen Belt dips to the NE and together with the Magura flysch group is thrust over the Intracarpathian Paleogene, deforming it in the contact zone. The authors assumed that between Prešov and Vranov the Klippen Belt had been strongly deformed by displacement of Mesozoic rocks and that its position is vertical. In the area of Humenné the authors again assumed a dipping of the Klippen Belt to the NE. In their opinion its deformations due to the displacement of Mesozoic blocks were so extensive that they might have caused "disruption" of the Klippen Belt.

Regarding the intricate structure and tectonics of the East Slovakian flysch and its basement, the interpretation is very difficult though numerous problems have been solved. However, the shallow character of the Klippen Belt and of most gravity anomalies in the Flysch Carpathians was confirmed (Tomek in Kadlečík et al. 1977). Only the most important anomalies, e.g. the Snina-Stakčín anomaly and the positive anomaly near Kurimka – perhaps the core zonee of the Smilno window – are probably associated with the flysch relief.

Magnetic survey

The first magnetic measurements in the study area were conducted by Scheele (1944). However, only small parts of the study area were covered (the area between Slovenská Kajňa and Lieskovec and a small area N of Vranov). A systematic magnetic survey was carried out in the period 1955–1957 over the greater part of the study area. It was a regional survey with points of measurement at intervals of 2–3 km. The obtained results were interppreted by Ibrmajer-Doležal-Mottlová (1959), Čekan-Šutor (1960), Šutor-Čekan (1965) and Šutor in Kadlečík et al. (1977).

The geomagnetic field is rather monotonous (± 20 nT). It is most probably due to the low susceptibility of the flysch complexes and their basement, or to their low differential susceptibility. Considering that the mean error of measurement was ± 4 nT, it is obvious that the interpretation of the geomagnetic field is not easy.

Geoelectric survey

A large-scale survey was carried out in the study area for enginering-geoelectric purposes. For investigations of the deep structure which is the subject of the present paper they are not of special importance.

Physical properties of rocks

The studies of rock densities carried out in the period 1953–1964 by the Institute of Applied Geophysics, Brno and by Geological Survey, Prague resulted in compilation of Map of rock densities in Czechoslovakia on the scale of 1:500,000 (Eliáš-Uhmann 1968).

The densities were mainly determined by measurements on samples collected on the surface, but drill cores were also used. According to the map, bulk densities of rocks in the study area range from 2,350 to 2,750 kg/m^3.

Measurements of physical properties of surface rock samples yield data loaded with errors (depending on the degree of weathering, leaching of the calcitic component, etc.). Therefore, measurements on drill cores are more reliable and the changes of physical properties of rocks with depth can be observed.

The measurements of physical properties of rocks currently carried out in Geofyzika Brno include: measurements of density parameters (bulk, mineralogical, natural density, porosity), velocity of propagation of longitudinal elastic waves (vertical and parallel to lamination), magnetic susceptibility, natural gamma activity and U, Th and K contents.

In the study area, physical properties of rocks were determined on drill cores from boreholes PU-1 Šambron, MLS-1 Humenné, Zboj-1, Lipany-1, 2, 3, 4 and 5, Hanušovce-1, Smilno-1, Šariš-1, Prešov-1 (Pl.1). Píchová (1985) summarized the results in tables of physical parameters of individual geologic-tectonic units. Píchová (ibid.) also summarized results of measurements (density and porosity) on surface samples (Mikuška-Chrumová 1983, 1984, Uhmann et al. 1977). The density and magnetic susceptibility of rocks from the western part of the East Slovak Magura flysch were higher than in the eastern part. The porosity of surface samples is considerably higher (due to weathering) and therefore bulk density is lower. Measurements on surface samples were carried out in 1984 and 1985 (Mikuška-Chrumová 1985, 1986). Physical properties of rocks in the area of interest have recently been studied by Ondra-Hanák (1989). They found that samples collected on the surface generally exhibit higher densities in the Klippen Belt including Cretaceous complexes and Paleogene cover – the Proč series – as compared with the Krynica unit and with the adjacent Intracarpathian Paleogene. Thus they contributed to the studies of Menčík (1963).

Stránská et al. (1986) compiled a 1:200,000 map of rock densities for the West Carpathians on the Czechoslovak territory. Besides graphical representation, it contains comprehensive tables of bulk, mineralogical and natural densities and porosities. In the opinion of the authors bulk densities decrease from the Levočské pohorie hills to the E.

The density and radioactivity of the main lithological types and stratigraphic units of the West Carpathians (measurements on 213 drill cores) were described by Husák (1986). He contended that the densities of rocks of the Intracarpathian Paleogene do not depend on the thickness of overlying beds.

Odstrčil (1985) investigated the possibilities of determining densities of near-surface rocks (or the average natural density of the Bouguer slab) from gravity measurements.

Aerial and satellite measurements

An aerial magnetometric and radiometric survey on the scale of 1:200,000 is described in the report of Mašín et al. (1960). The magnetic field in the study area is generally monotonous. A detailed aerial survey on the scale of 1:25,000 covered the southern margin of the area of interest where the magnetic field is monotonous, with the prevailing value of – 10 nT. Striking anomalies can be observed in the broader environs of Radatice over an area of approx. 6 km^2. According to Gnojek (1987) these anomalies are due to a basic body at the depth of approx. 1,900 m (under the surface). Radiometric measurements did not reveal any anomalies.

New information about the geologic structure of the East Slovakian flysch was yielded by remote seensing. A ring structure in the area Svidník-Stropkov, i.e. in the margin of the Zborov anticlinal belt, was detected. Pospíšil-Němčok-Feranec (1982) and Pospíšil (1983, 1985) explained the origin of this structure by the presence of deep tectonic lines, or by a collision zone of different basement blocks.

Refraction seismic survey

Refraction seismic survey was commenced in 1970 with measurements on profile 1(R)/70 between Nová Sedlice and Podhoroď (Hrdlička et al. 1971). In the period 1970–1981 a large-scale survey was carried out in the Intracarpathian Paleogene, in the Klippen Belt and in the Flysch Belt on seven profiles stretched in the direction of the Carpathians and on seven profiles vertical to it, at the total length of 826 km (Pl. 1). The results were – besides evaluation in annual reports – further interpreted by Leško-Mořkovský (1975), Plíva et al. (1976, 1977), Wojas (1977) and Kadlečík et al. (1977).

Owing to the seismogeological features of the intricate fold-nappe structure of the Flysch Carpathians the interpretation was not easy. The processing and interpretation were also complicated by small differences in densities and velocities of elastic waves between deep flysch complexes and their basement. The velocity boundaries traced by refraction seismic in the flysch can be interpreted as gradient changes of elastic waves velocities, or as different flysch complexes (Kadlečík et al. 1977). The general interpretation of refraction seismic data in regard to drilling and geophysical results obtained on the territories of Poland, the USSR and Czechoslovakia led to the conclusion that the basement of flysch complexes might be a refraction boundary with a velocity of over 6,000 m/s (Kadlečík et al. 1977). However, this opinion was not supported by the results from borehole Smilno-1 which at the depth of the measured boundary (5,000 m) struck basal beds of black flysch. Because of these contradictory results refraction seismic measurements were stopped in the Flysch Carpathians on the territories of Poland, the USSR and Czechoslovakia.

More reliable results were obtained by refraction seismic measurements in the Intracarpathian Paleogene where the data yielded by the borehole Lipany-4 correlated with the depth of the refraction boundary and were in agreement with reflection seismic data.

Refraction measurements in boreholes

The refraction seismic method was employed in boreholes MLS-1 Humenné and Lipany-1 (Pl. 1).

Refraction seismic measurements in the borehole MLS-1 Humenné were carried out to trace the contact of Albian-Cenomanian marl schists and the Lias-Aptian Limestone complex struck by drilling at the depth of 470 m (Filková-Mořkovský-Pernica 1973). The interpreted relief of Aptian limestones of the Humenné Mts. forms a ridge whose axis parallels the line Ptičie-Kamienka.

In the borehole Lipany-1 refracted waves propagated along the velocity boundary between Keuper and Upper Triassic dolomites (Filková-Pernica 1978). The results showed striking anomalies in propagation of refracted waves. Therefore, the refraction method was not applied in other boreholes in the area. The results indicated the presence of a larger number of boundaries that could not be identified until Mořkovský et al. (1987) showed that the boundaries correspond with the relief of dolomites in the Intracarpathian Paleogene basement, and with the tectonic planes (overthrusts) in the Intracarpathian Paleogene or in the Klippen Belt. But their separation from refraction measurements in boreholes is not possible.

Well-shooting and vertical seismic profiling

Well-shooting measurements are of great importance for processing of reflection seismic results and especially for transforming the time data of seismic sections into deep scale. Unlike well-shooting measurements, where only direct waves are registered, in the vertical seismic profiling reflected, or multiple reflected, and transform waves are registered as well. Thus the lithophysical boundaries, from which the waves are reflected, the multiple reflections and the ratio of longitudinal and transverse waves can be considered. These facts are very important for interpretation of profile seismic measurements.

Well-shooting results are presented as a dependence of time on depth (vertical time curves) and as a dependence of velocities (average, layer, interval) on depth or time. The data are computer-processed, as well as vertical seismic data which are presented in the form of time sections.

In the study area, well-shooting was conducted in eleven deep boreholes (Lipany-1, 2 and 3, Šariš-1, PU-1 Šambron, Plavnica-1, Hanušovce-1, Smilno-1, Zboj-1, MLS-1 Humenné, Prešov-1, see Pl. 1) and VSP was carried out in all of them except MLS-1 Humenné.

Reflection seismic survey

The first reflection seismic survey in the East Slovak Flysch (in the environs of Adidovce and S of Stropkov – Pl. 1) was conducted in the period 1959–1960 (Jurga - Cidlinský 1961, Jurga 1962). An oscillographic seismic unit was used and the RNP method ("regulirujemyj napravlennyj prijom", Rjabinkin) was applied. However, the measurements, even with grouping of geophones and shotholes, did not yield satisfactory results.

In 1970, a reflection seismic survey was conducted along a 3 km long parametric profile within the Dukla unit in the area of Ruský Potok (Adamovský et al. 1970). The measurements were carried out in the modification of continuous profiling using the 24-channel analog seismic unit RX 24 S II. The grouping of shotholes (1–3), of different depths of shotholes (10–35 m), masses of explosives (50–100 kg) and geophone intervals in a group (0–5 m) was tested. The obtained material was difficult to interpret and contained only indications of continuous reflections in the range 1.6–2.1 s.

Profile 3/71 was situated between Nová Sedlica and Podhoroď. Measurements were carried out in 1971 (Adamovský et al. 1972a) using the analog seismic unit RX 24 S II. Time sections were constructed using the analog processing system SWZ-1. Field methodology was chosen on the basis of results of parametric measurements near Ruský Potok in 1970. Later on, the original analog records from profiles 1/70 and 3/71 were digitized and digitized time sections were constructed (Lukášová et al. 1974). Thus the seismic material was completed up to times around 3 s.

Since 1972, reflection seismic measurements in the study area were done in the CDP modification. This method of multiple coverage, digital registration and processing yielded much more information.

Besides the profiles measured until 1984, Pl. 1 contains CDP profiles from the period 1985–1986. Until the end of 1986 measurements had been conducted on 64 profiles at the total length of 669 km.

Reflection seismic data obtained in the East Slovak Flysch until 1973 were studied by Kadlečík et al. (1977) and by Leško et al. (1979). They concluded that most events aree of interference character. Some boundaries with strong reflections most probably correspond to tectonic planes. In seismic sections the authors distinguished an upper part with abundant reflections and a lower, relatively monotonous part with less reflection elements. In accordance with interpretation profiles they identified the boundary between the two parts of time section with the flysch basement relief.

Reflection seismic measurements in CDP modification

Parametric measurements

Already the first CDP measurements in the *East Slovak Flysch* in 1972 (profiles 4/72 and 6B/72) showed the absence of continuous reflections and often relatively high noise level. The CDP measurements were therefore followed by parametric measurements carried out on a large scale in 1973, predominantly in the environs of the villages Adidovce and Zubné on short profiles 5B/73, 8B/73 and 9/73 (Pl. 1). Different configurations, explosives, groups of geophones, linear groups of three to seven shallow boreholes, and the effect of filtering on the instrument operation were tested. To determine the signal/noise ratio, wave patterns within the distance of 2,650 m from the shotpoint were measured.

To enhance the suppression of interference waves, weighted groups of geophones at approx. 100 m intervals were tested. This relatively long group did not bring a notable improvement. Nevertheless, the suppression of interference waves was better as compared with the common 50 m intervals. Analogous was the objective of testing linear groups of shallow shotholes. It was found out that the effectivity of such a group equals the effectivity of one deep shothole. Because of unfavourable drilling conditions the testing did not include the expensive grouping of deep boreholes. Experiments with grouping of shallow shotholes showed that this technique might yield favourable results.

Applications of different systems of measurements on profiles – split spread, end-on and reversed end-on spreads – did not stress special advantages of one system over another. Similarly, recording at greater distances from the shotpoint (in the interval 1,325–2,475 m) tested on profile 8B/73 did not yield better results.

Experiments in the environs of Adidovce and Zubné showed that location of 20–30 kg explosives in shotholes on average 25 m deep was most effective.

In 1981 recording to 10 s was tested on profiles situated near the deep boreholes Smilno-1 and Zboj-1 (37/81, 38/81). However, on both profiles a drop in seismic energy to noise level was observed at times over 5 s. Therefore the recording length of 5–6 s was chosen as optimal.

The comparison of results obtained in the environs of Smilno on profiles 34/81 (50 m intervals of points of arrival) and 34A/84 (25 m intervals of points of arrival) favoured the 25 m interval (96-channel recording), namely for measurements to the depth of 3,000–4,000 m. At greater depths the 50 m interval will be predominantly applied. Application of a large coverage which means a greater filtration effect of CDP summation and an improved signal/noise ratio is expected to provide better results.

Parametric measurements were also carried out in the surrounding of Bardejov and Starina (1972), Smilno (1972 and 1981), Matiaška (1975) and Zboj (1973 and 1981) – cf. Pl. 1.

The seismological conditions on the surface are analogous in the *Intracarpathian Paleogene* and in the Flysch Belt. Therefore, analogous experiments were carried out in the two areas. Despite the seismogeological similarity of the surface structure of both areas, recordings from the Intracarpathian Paleogene contained abundant reflections and parametric measurements in the area yielded much better results. The methodology of seismic measurements in the Flysch Belt was modified using results from the Intracarpathian Paleogene. Parametric measurements in the Intracarpathian Paleogene were carried out in the environs of Bajerovce (1974), Hanušovce and Šambron (1975), Šarišské Sokolovce (1976) – cf. Pl. 1.

In the *Klippen Belt* parametric measurements were conducted N of Bystré nad Topľou (1975) – cf. Pl. 1.

Methodology of field works and used instrumentation

Field parameters for CDP seismic measurements were chosen on the basis of results of parametric measurements.

Waves were generated by dynamite technology. In the period 1972–1975 mainly the six-fold coverage was used, later 12-fold coverage. A split spread with 50 m intervals between groups of geophones was used, in 1984 also 25 m intervals.

Arrivals of reflected waves were recorded by digital seismic units SN 338, SN 328 and DFS IV with input filter 16–125 Hz, 12.5–125 Hz or 18–124 Hz respectively, sampling interval 2 ms and record length 5 or 6 s.

Elastic waves were generated by blasting 20–30 kg explosives located in 25–30 m deep holes. Geophones GSC-11D with frequency of 10 Hz were grouped by 24.

Seismic data processing

Until 1978 digitally recorded data had been processed on the EMR 6070 Advance computer with plotter TNR 91. Standard seismic software was used for demultiplexion, amplitude recovery, static corrections, time variable filtration and deconvolution. Seismic waves were migrated through weighted diffraction summation. Kinematic correction were calculated on the basis of velocity tests using 18 chosen velocities. Deconvolution was performed according to the character of the seismic material – before, after or before and after stacking.

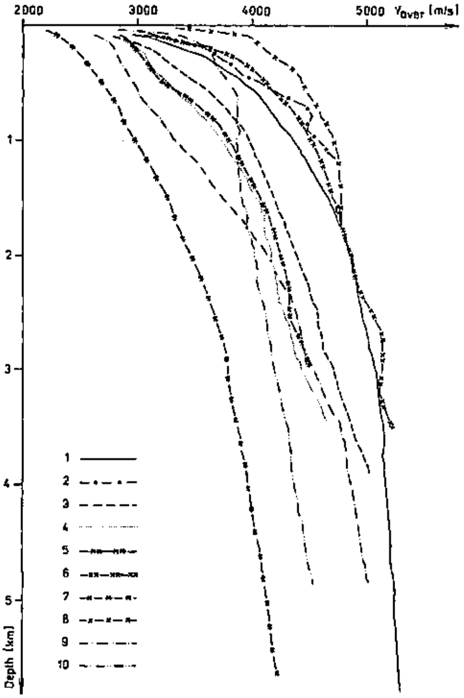
Since 1979 seismic data have been processed on the RDS 500 computer with APOLLO processor, controlled by the program system GEOMAX (registered trade mark CGG). Graphic representation of results is done by plotters VERSATEC and TNR 95. Compared with the EMR system GEOMAX is more versatile. It can be used for automatic calculation of residual static corrections, for processing of SLALOM line seismic data (registered trade mark CGG), for enhancement of the wavefield coherency, for migration of seismic information (program WEMIG). For a correct function of the program WEMIG the inclinations of reflecting horizons must not be larger than 45°. Migration by means of wave equations much better preserves the dynamics and frequency content of the time section. As a rule, deconvolution is performed after summation.

Digital processing of seismic data including its final stage, i.e. graphic representation in the form of migrated time sections is performed in the department of seismic data digital processing, Geofyzika Brno.

Velocities

Well-shooting

For reflection seismic data processing the knowledge of velocities is essential for time/depth conversion. Most reliable information is provided by well-shooting. Fig. 1 shows the dependences of average velocities on depth for individual deep boreholes situated in the study area and chosen for the conversion. It follows from Fig. 1 that average velocities attain the highest values in boreholes PU-1 Šambron, MLS-Humenné, Plavnica-1 and Hanušovce-1. The curve for the borehole Smilno-1 shows the lowest average velocities. Velocities measured in the borehole Šariš-1 and Zboj-1 range between



1. Depth-dependences of average velocities according to well-shooting.
1 – Hanušovce-1, 2 – MLS-1 Humenné, 3 – Lipany-1, 4 – Lipany-2, 5 – Lipany-3, 6 – Plavnica-1, 7 – Smilno-1, 8 – PU-1 Šambron, 9 – Šariš-1, 10 – Zboj-1.

them. The curve of average velocities Lipany-1 demonstrates higher velocities than curves Lipany-3, Lipany-2 and Šariš-1 for the same depths. The curves from boreholes Šariš-1, Lipany-1 and 2 reflect at the depth of 1,350 m, 2,750 m and 2,870 m respectively a striking change of velocity gradients characterizing the influence of the Intracarpathian Mesozoic basement. Similarly the curve of average velocities from boreholes Plavnica-1 demonstrates a larger velocity gradient due to the presence of a block of fractured dolomites at the depth of 2,300 m.

In the Paleogene complex average velocities of elastic waves strikingly decrease from NW to SE, which is due to the lithology of sediments.The Intracarpathian Paleogene in the vicinity of the borehole PU-1 Šambron contains numerous sandstone layers with higher velocities of seismic waves propagation as compared with Paleogene rocks with a higher content of pelitic sediments in the environs of Lipany (Mořkovský-Filková 1985) and in the vicinity of the borehole Šariš-1. At a depth of approx. 1,000 m the curve $V_{aver}(H)$ of the borehole Šariš-1 shows an increased velocity gradient due to calcareous rocks in the basement of the Šambron formation.

Layer velocities in the *Intracarpathian Paleogene complex* range from 2,600 to 5,600 m/s. The exceptionally high values 5,600–5,800 m/s recorded in the borehole Lipany-2 in the depth interval 2,400–2 660 m, and the velocity of 6,300 m/s recorded in the borehole Lipany-5 in the depth intervals 2,560–2,720 m and 2,810–2,900 m are due to the presence of displaced blocks of older rocks (olistoliths?). Layer velocities of individual curves generally increase with increasing depth though the positive character of the increase is locally affected by lithological changes or by tectonic deformation of rocks. For instance, a local decrease in velocities in the depth interval 1,360–1,750 m in the borehole PU-1 Šambron is due to very porous interformational conglomerates in the basement of the Šambron formation. Lower layer velocities can also be observed in intervals 1,620–1,770 m in the borehole Lipany-2 and 2,450–2,560 m in the borehole Lipany-3.

Layer velocities in the *Mesozoic* and *crystalline basement* of the Intracarpathian Paleogene in the boreholes Lipany-1,2, Šariš-1 and Plavnica-1 range from 5,800 to 7,500 m/s. A striking decrease to 5,000 m/s occurs in Lower Lias-Keuper rocks, in variegated Werfenian schists and in Lower Triassic quartzites. For the Humenné Mesozoic formation well-shooting in thee borehole MLS-1 Humenné recorded velocities ranging from 4,000 to 4,140 m/s (pelites, psammites) and 6,100 m/s (limestones, dolomites).

Layer velocities recorded within the *Klippen Belt*, where the borehole Hanušovce-1 reached the depth of 4,000 m, range from 3,400 to 5,700 m/s.A noticeable decrease of velocities within the interval 3,450–3,800 m is obviously due to tectonic deformation.

In the *Magura nappe* reached by the borehole Smilno-1 in the depth interval 0–4,600 m, layer velocities first gradually increase with depth (from 2,700 to 4,950 m), then from 1,750 m downwards the recorded range is 4,950–5,000 m/s, except the depth interval 2,850–3,100 m where the velocities are substantially lower. It may be due to tectonic dissection. Layer velocities within the Rača and Krynica unit of the Magura nappes struck by the borehole Hanušovce-1 in the depth interval 4,000–6,003 m beneath the Klippen Belt range from 5,500 to 5,700 m/s.

For the *Outer Flysch Belt* penetrated by the 5,700 m deep borehole Smilno-1 in the basement of the Magura nappes, layer velocities around 5,000 m/s are characteristic.

Layer velocities recorded in the borehole Zboj-1 in the *Dukla nappe unit* range from 3,800 to 5,000 m/s (in the interval 100–3,800 m). Layer velocities in the *Zboj series* struck by the borehole Zboj-1 range from 5,000 to 5,700 m/s in the depth interval 3,800–5,002 m.

Subsurface velocities

The above presented well-shooting data provided only separate pieces of information about acoustic waves velocities. To gain more comprehensive knowledge about the changes of velocities of elastic waves propagation throughout the area of interest, subsurface velocity values yielded by reflection seismic profiling were considered.

For processing, all the numerous secondary factors affecting the propagation of elastic waves must be taken into account. It is e.g.the tangential tectonics which may directly influence the physical properties of rocks, and by displacing stratigraphic formations significantly influence the velocities (Mořkovský-Filková 1985). At the same time it must be assumed that the relative dependences of velocities, despite the differentiated effect of lithology on the rate and intensity of weathering, are preserved. A diagram was constructed of the distribution of subsurface velocities in the Intracarpathian Paleogene, in the Klippen Belt, and in the adjacent part of the Magura Flysch (Pl. 2). Studies of subsurface velocities and the assumed vertical and horizontal distribution of lithostratigraphic complexes helped to delimit the areas of the industrial model velocity curves. They were, of course, based on well-shooting data.

The highest subsurface velocities (4,200–4,600 m/s) in the *Intracarpathian Paleogene* were measured south of Jakubany and in the strip of outcrops of the Šambron formation (calcareous sandstones prevailing over claystones with beds of conglomerates), stretching from the borehole PU-1 Šambron to the ESE. Towards the north and south the subsurface velocities strikingly decrease to 2,800–3,600 m/s which is connected with the presence of the prevailingly claystone Paleogene facies. The increase in velocities south of Jakubany is due to the top sandstone Paleogene series. In the broader environs of Lipany, subsurface velocities range from 3,300 to 3,900 m/s. East of Lipany, in the broader environs of Sabinov, the velocities range from 3,000 to 3,300 m/s. In the area east of Šarišské Sokolovce and Gregorovce a decrease to 2,500–3,000 m/s was recorded. The same values occur in Lower Miocene complexes in the environs of Kapušany. Farther eastwards, in the area Kapušany-Bystré nad Topľou, the subsurface velocities again increase. In the southernmost parts of the western section of the Intracarpathian Paleogene near Šarišské Michaľany a gradual decrease from NW (via Medzany) to SE can be observed. Also this phenomenon can be related to the lithofacial changes within the Palaeogene, most probably to claystone series which prevail over sandstone beds.

In the *Klippen Belt*, between Kamenica and Šarišské Sokolovce, subsurface velocities range roughly from 3,900 to 4,200 m/s. Near Terňa, Hanušovce and Údol subsurface velocities are lower (3,000–3,600 m/s). Generally, subsurface velocities of elastic waves in the Klippen Belt are higher as compared with the adjacent part of the Intracarpathian Paleogene. An exception is the area of Údol and Plaveč, covered by Upper Eocene graywacke and calcareous, often slightly diagenetically lithificated sandstones and calcareous claystones of the Ujak development – Malcov series – where the velocities are practically the same as in the Intracarpathian Paleogene.

In the *Magura Flysch* the highest subsurface velocities (4,200–4,600 m/s) were observed in the Čergov massif, south-west of Hertník. For this area, coarse-grained calcareous Čergov sandstones are typical. Striking drops of velocities (2,700–3,300 m/s) at the northeastern ends of profiles 46/83 and 74/85, south of Hertník are associated with the contact of sandstone layers with the prevailingly pelitic Malcov series.

Generally, the diagram of subsurface velocities confirms the relations between velocities of elastic waves propagation in the Intracarpathian Paleogene revealed by well-shooting (Mořkovský-Filková 1985), i.e. the gradual decrease in velocities from the Šambron area towards the southeast due to lithofacial changes. However, this may also manifest the differences in compaction which have been described for the Intracarpathian Paleogene by Ondra-Hanák (1989). The change in velocities was also indicated by refraction seismic data (Jarý et al. 1976).

The areas of the individual model velocity curves in the Intracarpathian Paleogene

For application of velocity models (based on well-shooting data) on reflection seismic profiles, the areas of individual velocity curves, or the transition zones between them had to be delimited. For this purpose not only subsurface velocities, but also results of analysis of geophysical information in time sections, and data on stratigraphy and structure (Pl. 2) were used.

The *velocity curve PU-1 Šambron* covers the area where subsurface velocities range from 4,200 to 4,500 m/s. The velocity V_o obtained by well-shooting in the borehole PU-1 Šambron is 4,200 m/s. Although in the environs of Plaveč a drop in subsurface velocities can be observed, we use, with regard to the assumed small thickness of the here outcropping Ujak claystones – the Malcov series – the velocity curve PU-1 Šambron for the whole area east of the borehole PU-1 Šambron towards the Klippen Belt.

The area of the *velocity curve Šariš-1* was delimited on the basis of prevailing occurrences of subsurfaces velocities in the range 2,900–3,000 m/s (well-shooting in the borehole Šariš-1 yielded velocities V_o ranging from 2,000 to 3,000 m/s).

Velocity curves Lipany-1, 2 and *3* apply for an area of velocities ranging from 3,000 to 3,600 m/s. Regarding the evident drop in velocities of elastic waves in the area east of the Lipany boreholes, the velocity data yielded by measurements in the boreholes were corrected. Layer velocities obtained in the borehole Prešov-1 were also taken into account (in the Intracarpathian Paleogene complex the layer velocity was 3,950 m/s). The lowest velocities were observed between Terňa and Šarišská Poruba, i.e. in an area where the Čelovce depression Neogene rocks crop out. Farther to the east an increase in velocities of elastic waves is assumed.In the broader surroundings of Hanušovce the velocity distribution will probably be very similar to that in the environs of Lipany.

Velocity analyses would not be suitable for the areas of interest (the Intracarpathian Paleogene and the Flysch Belt) contrary to less tectonized regions as e.g. the East Slovakian Neogene Basin. The reasons are thee high order of velocities and lack of larger reflections corresponding to layer boundaries. Continuous reflection horizons are usually due to fault tectonics – overthrusts. Because of lack of seismic data such an analysis can hardly be objective. Therefore, velocity analyses were only used to substitute other velocity data.

A short review of results of processing the data on velocities of seismic waves propagation in the Intracarpathian Paleogene, in the Klippen Belt, and in the East Slovak Flysch

Velocities of elastic waves propagation in the *Intracarpathian Paleogene* were documented by well-shooting in boreholes PU-1 Šambron, Šariš-1, Lipany-1, 2 and 3, Plavnica-1, and Prešov-1 (which in the basement of Neogene sediments verified the Intracarpathian strata).

The studies of velocities in the *basement of the Intracarpathian Paleogene* were based on seismic data from boreholes Lipany-1, Lipany-2, Šariš-1 and Plavnica-1 drilled in the Mesozoic basement. There the layer velocities were 6,300 m/s in the borehole Lipany-1, 6,000 m/s and 7,200 m/s in the borehole Lipany-2. In the upper, pelitic layers (Middle Cretaceous) in the borehole Šariš-1 in the depth interval 1,340–1,450 m (not present in the Lipany area) layer velocities attain 4,800 m/s. The deeper Middle Cretaceous to Jurassic strata down to the depth of 2,605 m and Keuper claystones down to the depth around 2, 800 m exhibit average layer velocity of 5,800 m/s. In the Middle Triassic dolomite complex layer velocities range from 6,000 to 7,500 m/s, while in the Werfenian formation they drop to 5,000 m/s. The Mesozoic rocks in the borehole Plavnica-1 exhibit layer velocities of 5,000 m/s, 6,500 m/s and 7,400 m/s. The crystalline complex in the borehole Šariš-1 is characterized by relatively low "layer" velocity of 5,850 m/s, which is due to strong tectonic deformation.

Velocity data from the *Klippen Belt* were produced by well-shooting in the borehole Hanušovce-1 (points A,C).

Velocities in the *Flysch Belt* in the area of the Smilno tectonic window were reliably measured in the borehole Smilno-1. Reliable are also the seismic results from the borehole Zboj-1. They were used for evaluation of velocities on profiles stretched in thee area of Zboj and Starina, Adidovce and Zubné.

For *extrapolation of traveltime curves* (at depths without well-shooting data) for the pelitic-carbonatic complex of the Upper Mesozoic we utilized layer velocities in the range from 4,800 to 5,800 m/s, for extrapolation in the carbonatic complex the velocity of 6,300 m/s was used. This layer velocity value was obtained by averaging the velocity values measured in boreholes Lipany-1, 2, Šariš-1 and Plavnica-1. We also considered the thickness of the drilled interval and its lithological composition. Further, refraction seismic results from the profile 12/R/74,75 where a velocity boundary with boundary velocity of 6,300 m/s was considered. The boundary can be regarded as the surface of Central Carpathian carbonate series covered by Paleogene strata. The given layer velocities were compared with seismic data from boreholes Ďurkov-1 (Filková-Mořkovský-Pernica 1969) and Kecerovské Pekľany-1 (Pernica-Filková 1974a) in the Košická kotlina depression.

Velocity studies in the crystalline complex are not easy because of lack of seismic data. To determine the characteristic "layer" velocities, we consider data typical of the crystalline complex built of granodiorites and gneisses in the study area in the borehole Šariš-1, in the Košická kotlina depression in boreholes Rozhanovce-1 (Filková-Mořkovský-Pernica 1971) and Kecerovské Pekľany-1 (Pernica-Filková 1974a), in the Danube Basin and on the southeastern slopes of the Bohemian Massif, e.g. in boreholes Kolárovo-3 (Jakeš et al. 1978), Osvětimany-1 (Pernica-Filková 1975) and Ždánice-4 (Pernica-Filková 1974b). Taken into account were also the average values from measurements of velocities of longitudinal elastic waves propagation on samples of rocks similar to the rocks in the study area (Uhmann 1974).

It should be noted that because of a limited amount of information and data about velocities of elastic waves in deep-seated complexes we often had to make conclusions on the basis of separate or not quite explicit information.

Using the above given information about velocities of elastic waves and using geological models we constructed graphs $2t_0(H)$ for seismic CDP profiles. They were used for time-depth conversion of data from seismic sections. An example of the simplified dependence $2t_0(H)$ for profile 42/82 is in Pl. 3.

Methodology of interpretation

Geological interpretation of reflection seismic profiles included incorporation of stratigraphic data from deep boreholes in time and depth sections, tying up the horizons corresponding to stratigraphic data, and identification of indications of fault tectonics. Tectonic lines were located according to discontinuities of continuous boundaries, anomalous dipping of reflections, and according to all available geological and geophysical data.

Correlation of reflection horizons and stratigraphic boundaries and identification of faults were done in migrated version with deconvolution and with enhancement of wave field coherency. Also unmigrated materials were used for interpretation. They were utilized namely for verification of geophysical reliability of reflection elements, for study of diffracted and interference waves, etc. In this way obtained geophysical material for time sections was by means of graphs $2t_0(H)$ converted to depth.

In the course of interpretation of seismic data from the broader environs of Lipany it was found that the only boundary for reliable study is the relief of Triassic dolomites in the Intracarpathian Paleogene basement. In the intricate tectonic structure, CDP data alone are not sufficient for a serious evaluation of the fault tectonics and for tracing the tectonic lines in the area. The studied boundary, i.e. the Triassic dolomites relief, was in the broader environs of Lipany interpreted on individual seismic profiles and consequently a structural scheme of the area was compiled.

The used stratigraphic data were provided by Moravské naftové doly, k.p. Hodonín, branch Michalovce and by the Geological Institute of Dionýz Štúr, Bratislava. Other sources are quoted in the text.

Geophysical and geological information

The Intracarpathian Paleogene and peri-Klippen area in the broader surroundings of Lipany

It should be noted that the *opinions on the tectonic structure of the Intracarpathian Paleogene* changed many times. In the 1950s the first information about tectonics was connected with geological mapping works of J. Ilavský, B. Leško and O. Samuel, which were focused on lithostratigraphy mainly. Then followed the team work on the geological map of Czechoslovakia on the scale of 1:200,000, sheets Vysoké Tatry Mts. and Košice-Zborov, edited by O. Fusán and A. Matějka. The works were continued within the framework of detailed mapping and prospection for hydrocarbons by T. Ďurkovič, P. Gross, F. Chmelík, T. Koráb, B. Leško, R. Marschalko, J. Nemčok, and others.

In 1963, E. Menčík summarized the geophysical data from the flysch belt in eastern Slovakia (incl. the Intracarpathian Paleogene) for the purposes of oil prospection. The author observed the direct relation between gravity anomalies and the surface structure of the Klippen Belt, and pointed out the scope of interpretation. Of basic importance were the works by R. Marschalko, explaining the development of the Intracarpathian sedimentation area from the viewpoint of dynamic sedimentology.

In summary it can be stated that many authors studying the tectonic structure on Polish and Czechoslovak territories assumed a comparatively simple brachysynclinal structure of the Intracarpathian Paleogene. The assumption was mainly supported by small inclinations of layers known from outcrops. Numerous normal faults and the reverse thrust of the Klippen Belt over the Intracarpathian Paleogene were assumed – Fusán et al. (1963), Matějka et al. (1964), Stráník (1965). A larger tectonic deformation of the Intracarpathian Paleogene was assumed near the Klippen Belt and confirmed by Nemčok et al. (1977).

In his works from the period 1952–1959 Golab (fide Chmelík 1963) described nappe dislocations in the Polish part of the area. Other authors, however, do not share his opinion. Chmelík (1963) and Chmelík in Buday et al. (1967) in his study of the Intracarpathian Paleogene between Ružomberok and Prešov mentioned only overthrusts and normal fault sections, not nappes. In agreement with Leško (1958), Chmelík (1963) revealed the tectonic contact of basal and higher Paleogene series along the northern margin of Branisko. But he emphasized overthrusting of younger complexes over older ones, including the Mesozoic. The author paid attention especially to the Hromoš-Šambron anticlinal zone which he considered the most important post-Paleogene structure predisposed by WNW-ESE directions disturbing the anticlinal zone. He assumed steep dipping to the SSW and overthrusting to the NNE. Chmelík (ibid.) further assumed that a similar dislocation is followed by the flow of the Torysa river between Krivany and Sabinov. In the course of Styrian movements the Klippen series and the Magura Flysch were thrust back over the Intracarpathian Paleogene and thus most megasynclines and megaanticlines originated. It should be noted that many of the opinions and problems forwarded by Chmelík (1963) or by Chmelík in Buday et al. (1967) have been further studied and led to drilling the deep borehole Šariš-1 (Leško-Chmelík-Rudinec 1982).

An entirely new aspect in these works is the interpretation of significant Old Styrian movements in the Intracarpathian Paleogene, described as the Lipany overthrusts. Most important for a progressive evaluation of seismic data was the identification of the main elements of the tectonic style of reverse overthrusts. In many cases this interpretation completed the interpretation of the above mentioned field mapping finds of Chmelík.

Interpreting the data from the borehole Lipany-1, Leško-Nemčok (1979) mentioned a generally lower intensity of folding in the Intracarpathian Paleogene as compared with the borehole PU-1 Šambron. The contact proper of the Paleogene base with the Mesozoic has the character of sediment deposited in situ. The upper part of the basal lithofacies incorporates sliding bodies, indicating a general change in sedimentation. Later, Leško et al. (1982) did not study tectonic problems.

Closely related to the discussed problems is the structure of the peri-Klippen zone. At the contact with the Intracarpathian Paleogene and at the contact with the Krynica unit, it was explained by Nemčok by the overthrusting of the Magura Flysch and the Klippen Belt over the Central Carpathians, or by the thrusting of the Central Carpathians under the Klippen Belt and outer flysch (1961, 1978). Thus he also explained the double-vergency of the Magura nappe (1983, 1984). Previous regional geophysical works concerned with these problems were evaluated by Kadlečík et al. (1977) and Leško et al. (1979). Of recent works regarding the peri-Klippen zone, Polish results must be mentioned. Using data from deep boreholes Maruszyna IG-1 and Banska IG-1, and from geological field work, Birkenmajer (1985) constructed a geological section implying the author's conception of only south-vergent overthrusts. He does not assume the existence of north-vergent reverse faults neither at the northern margin of the Klippen Belt, nor in the Magura nappes. It should be noted that data from the Polish boreholes do not exclude that the tectonic style is that of the Lipany area, i.e. submersion of sub-Tatra nappes in the basement of the Intracarpathian Paleogene towards the north. Regarding the lack of data about the character and course of the Paleogene-Mesozoic boundary, namely south of the borehole Banska IG-1, also this interpretation, i.e. rather steep submersion of the Mesozoic under the floor of the borehole Maruszyna IG-1 is possible.

Interpretation of tectonics in reflection seismic profiles

As the general conception of the tectonics of the study area was based on qualitative evaluation of reflection seismic data, we shall outline the reasons that complicated the identification of extensive seismic boundaries as tectonic planes:

– transgressive lithofacies (incl. numulite limestones) 150 and 100 m thick in boreholes Lipany-1, Banska IG-1 and Zakopane IG-1 found on the Paleogene base suggested regional distribution of a physically distinct boundary

– tectonic zones in Neogene basins represent boundaries, in the time section accompanied by a system of diffracted waves.

Diffractions cannot be observed with overthrusts in the Intracarpathian Paleogene. It is obviously due to several factors:

– small physical contrast along dislocations in strongly compacted rocks

– due to strong compaction and therefore high velocities of elastic waves diffracted envelope waves are only slightly curved and cannot be distinguished from other curved layer boundaries. To a certain extent it relates to the relatively small dip of tectonic boundaries

– computer velocity analyses did not show striking changes of velocities of the observed boundaries.

As it has already been said, new views on tectonization of the Intracarpathian Paleogene were forwarded by Nemčok, and namely confirmed the basic conception published by Leško-Chmelík-Rudinec (1982).

Now to the reasons which led us to localization of reverse overthrusts in the Intracarpathian Paleogene to the SW, approximately parallel to the surface structure of the Klippen Belt. First of all it was the discrepancy of dippings of layers found on cores from the surroundings of Lipany, with dips of large seismic reflections, often with large amplitudes. Another reason was the zonal arrangement of reflections, especially noticeable on profiles parallel to the young structure of the Klippen Belt (e.g. profiles 42/82, 19/76) and tested by perpendicular profiles. The overthrusts are well demonstrated by data from the boreholes Lipany-1, 3, 2 in combination with seismic section of profile 42/82 (Pl. 3). There, around the borehole Lipany-3 at 1.0–1.2 s subhorizontal arrangement of reflections can clearly be observed. In the respective depth interval, i.e. 2,100 –2,500 m, dark-grey to black-grey consolidated calcareous claystones with dips of layers 15–43° prevail. In their base at the depth 2,925–2,929 m, calcite-healed fractures form horizontally oriented systems (Rudinec-Řeřicha 1983). Tectonic deformation from the depth 2,100 m upwards is documented by drill cores and by anomalies on average velocities curve. Also the complex of subhorizontal reflections on profile 22/78 (0.78–1.0 s) corresponding to the depth interval 1,550–2,150 m is documented by core from 2,126–2,129 m of the borehole Lipany-2 where very strong tectonization and inclinations up to 62° are described. Then the continuous reflections in the vicinity of the borehole Lipany-5 at 1.16 s on profile 15/75 (the depth of 2,500 m) confirm the existence of an extensive reflection area. The surface of the Mesozoic was struck at the depth of 2,957 m (Rudinec 1986).

It should generally be noted that with this structural style the lithostratigraphic boundaries are mostly conditioned by the tectonics and by different competence of layers.It is possible to determine the character of stratigraphic boundaries either in the close vicinity of deep boreholes or where significant lithostratigraphic complexes can be distinguished by other geophysical methods (see the positive gravity anomaly Krásna Lúka).

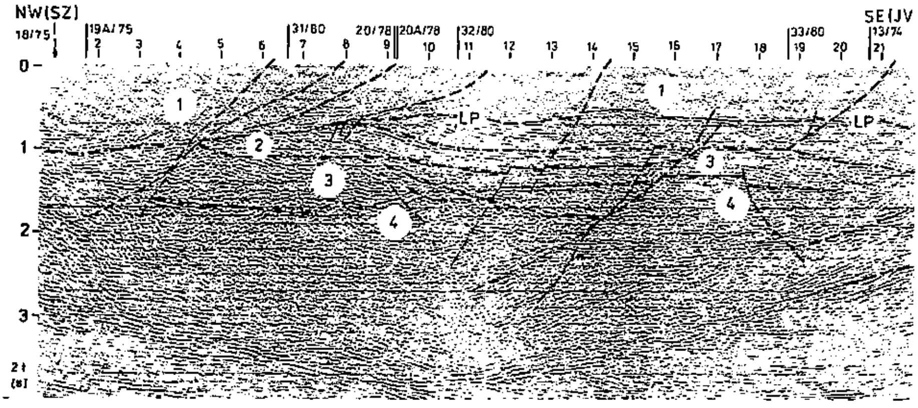
The presented seismic sections (Figs. 2–5, Pl. 3) show that despite the doubtful character of the material available we interpreted numerous faults, prevailingly overthrusts. However, owing to the differences in their seismic manifestations and to the relatively thin network of profiles we often could not tie the indications with one another. For the same reason we did not include in the sections the youngest normal faults, evidently deforming the Klippen Belt as well as the Intracarpathian Paleogene.

In the Intracarpathian Paleogene and in the Mesozoic the seismic manifestations of normal faults are, compared with overthrusts, less distinct. It is obviously due to a strong rock compaction.

Profile 19/76 (Fig. 2)

The NW-SE striking profile runs from the southern margin of the village of Šambron to the area south of Rožkovany, roughly parallel to the Klippen Belt outcrops, at the distance of 7–8 km. Seismic data from the profile enabled comparatively reliable interpretation of the Intracarpathian Paleogene base, of the relief of Triassic dolomites, and of the crystalline basement.

In the area of crossing with profiles 20/78 and 32/80 it can be well observed where the movements of eastern overthrusts ended on the line of displacement of the upper floor of the Intracarpathian Paleogene, i.e. on the Lipany overthrust fault. Owing to the



2. Seismic profile 19/76, time section with geologic interpretation (12-fold coverage, interval between the points of arrival 50 m, time-variable filtration and deconvolution, wave field coherency, wave migration). 1 – Intracarpathian Paleogene, 2 – Upper Mesozoic, pelitic-carbonatic complex (Albian-Keuper); 3 – Middle Triassic dolomites (or varied schists and Lower Triassic quartzites); 4 – crystalline complex; LP – Lipany overthrusts.

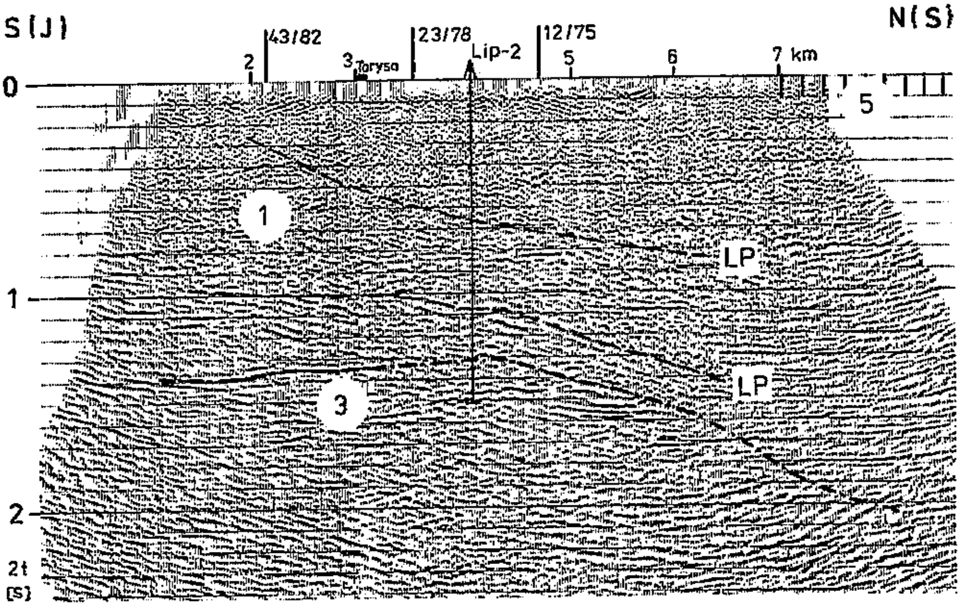
mentioned structural elements the elevation Bajerovce-Krásna Lúka is ranged with a system of N-S striking overthrust faults and thus related to the Branisko elevation (Leško-Chmelík-Fusán 1980). It is confirmed by the course of gravity isoanomalies. The north-western part of the profile near the crossing with the profile 31/80 was affected by fault dislocations called by Leško-Chmelík-Fusán (1980) north-southern western overthrust faults and regarded younger as compared to the eastern overthrusts. Contrary to these authors we suppose that the foundation of N-S overthrusts cannot be identified with the continuation of the Muráň-Divín fault towards the NE. They are rather independent tectonic zones, both in terms of genesis and direction.

As regards the longitudinal structural elements, i.e. approximately parallel to the profile, the Lipany overthrust fault, overlapping the N-S striking eastern overthrust faults, is clearly indicated. The Lipany overthrust fault has been affected by recent normal faults which apparently offset dislocations of the overthrust zone. The contact of the Upper (pelitic-carbonatic) Mesozoic with the Paleogene is most probably tectonic. Directions of reflections and their size within the Upper Mesozoic inner structure are obviously affected by eastern overthrusts. Using data from crossing profiles and from boreholes Šariš-1 and PU-1 Šambron we investigate the extent of the Upper Mesozoic conditioned by tectonics and by denudation.

According to data on the thickness of the Middle to Lower Triassic complex from borehole Šariš-1, the complex is ranged with typical seismofacies. As on profiles 20/78, 20A/78, etc., it is a series of mostly 100–200 m long events with large amplitudes. Along the profile 19/76 they often subhorizontally dip to the SE, i.e. dip parallel with the eastern overthrusts. The Lower Mesozoic boundary is well indicated as in the crystalline complex reflections of the described character disappear (see profiles 20/78 and 20A/78 in Fig. 5). The contact proper between the Mesozoic and crystalline complex may be tectonic. Towards the NW of station 4.0 km, i.e. of the indication of the Muráň fault and western overthrust faults, the indications become less and less evident. In sense of Čekan-Mořkovský (1982) we regard these parts as the culmination of the Krížna dolomite relief in the zone Bajerovce-Krásna Lúka. Also the increased thickness of dolomite westwards of the crossing with profile 32/80 interpreted from seismic data are in accordance with gravity data.

Profile 22/78 (Fig. 3)

The profile is stretched perpendicular to the principal structural elements of the area. It runs from the outcrops of the sandstone series S of Červenica towards the NE through the deep borehole Lipany-2 crossing the southern margin of the Klippen Belt. The number and quality of reflection seismic elements from the Intracarpathian Paleogene are in accordance with near profiles of the same trend. The zone of joint reflections at the time 1.0–1.1 s in the south-western part of the profile indicates the Lipany overthrust fault. NW of the profile 22/78, the Lipany fault is even better indicated in the seismic material, while towards the SE the indications fade out. Generally, it can be said that the indications of the Lipany fault become clearer with distance from the Klippen Belt, i.e.



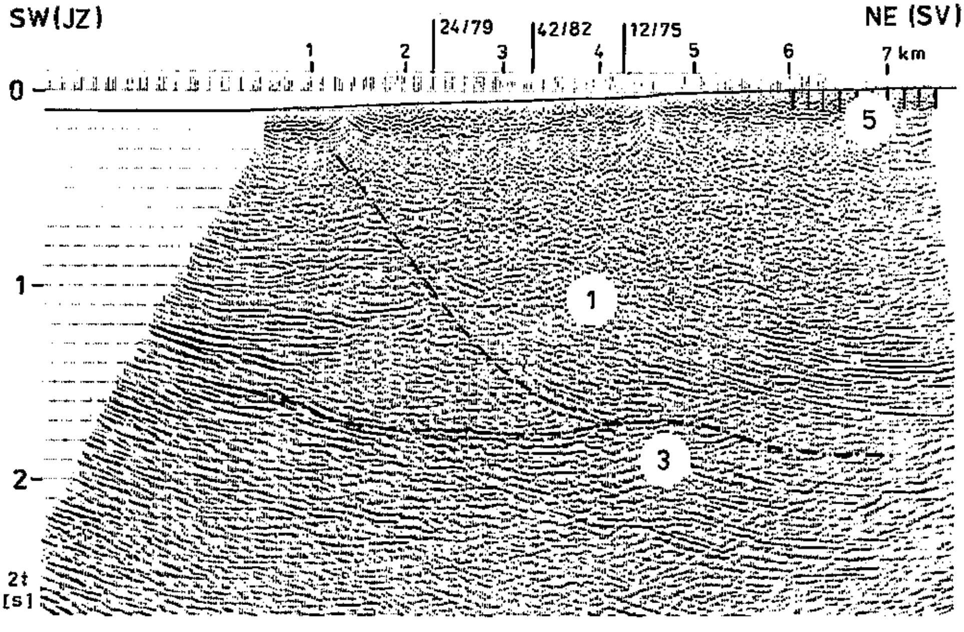
3. Seismic profile 22/78, time section with geologic interpretation (12-fold coverage, 50 m interval between the points of arrival, time-variable filtration and deconvolution, wave field coherency, wave migration).
1 – Intracarpathian Paleogene; 3 – Middle Triassic dolomites; 5 – Klippen Belt outcrops; LP – Lipany overthrusts.

towards the SW (profiles 21/78, 33/80). In the borehole Lipany-2 at the depth of 2,365 m (i.e. at the time approx. 1.09 s) a great loss of mud occurred. Considering the negligible primary porosity of rocks, it testifies to the existence of a crushed zone along a significant tectonic zone. We are of the opinion that related to this significant zone – the Lipany overthrust fault – are most occurrences of Mesozoic rocks, so far regarded as elements transferred by sedimentation – olistoliths. From results obtained on the profile 22/78 and on other seismic profiles in the area it follows that the Lipany fault represents only part of a whole system of reverse movements that affected e.g. the northern margin of the sandstone series at the southern termination of the profile 22/78, predisposed the Torysa river valley and displayed other effects.

The Mesozoic relief in the Intracarpathian Paleogene basement reached by the borehole Lipany-2 can be comparatively well traced to the Klippen Belt outcrops. The dipping of the relief towards the N was also confirmed by the boreholes Lipany-4 and Lipany-5. The stretch of the Klippen Belt at depth cannot be drawn in seismic section.

Profile 26/79 (Fig. 4)

The profile runs from Šarišské Michaľany roughly towards the NNE closely behind the northern margin of the Klippen Belt outcrops. The dolomite relief in the Intracarpathian Paleogene basement is indicated by the presence of reflections with large ampli-



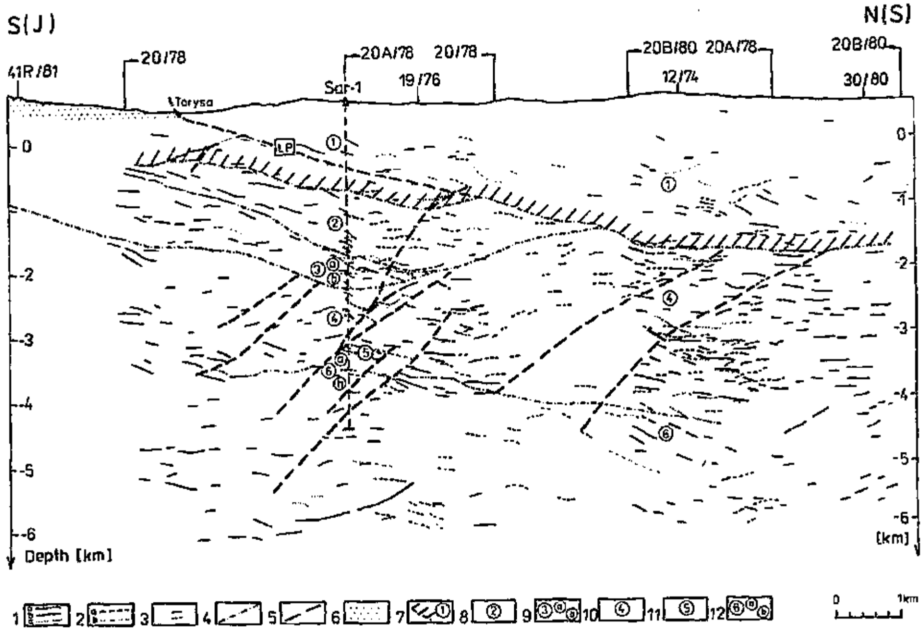
4. Seismic profile 26/79, time section with geologic interpretation (12-fold coverage, 50 m interval between the points of arrival, time-variable filtration and deconvolution, wave field coherency, wave migration).
1 – Intracarpathian Paleogene; 3 – Middle Triassic dolomites; 5 – Klippen Belt outcrops.

tudes. In the central part of the profile a local arching of the relief can be observed. It is probably the front part of the high block of the Inner Carpathians, along which overthrusting from NE to SW took place.

Some elements observed on the profile 42(82 at the crossing with profile 26/79 (e.g. the subhorizontal reflection zone at the time interval 0.9–1.0 s which might indicate overthrust tectonics) do not appear on the described profile. A striking phenomenon on the profile 26/79 in the time interval 1.2–1.6 s beneath the Klippen Belt outcrops is a group of subparallel reflections with large amplitudes. They are interpreted as manifesting intensive imbrications of deep sequences of the Intracarpathian Paleogene. The dips of reflections in the marginal parts of profile 26/79, similarly as with the profile 22/78, are not reliable. Distortion due to migration played a role there.

Profile 20/78 - 20A/78 - 20B/80 (Fig. 5)

When interpreting the reflection seismic profiles we made some changes in the interpretation of stratigraphy of the borehole Šariš-1 done by Koráb et al. (1986).



5. Seismic profile 20/78-20A/78-20B/80, depth section with geologic interpretation.
1 – events on profiles 20/78 and 20B/80: a – very strong reflections, b – strong reflections, c – weak reflections; 2 – events on profile 20A/78: a – strong reflections, b – weak reflections; 3 – dippings of beds revealed by borehole Šariš-1; 4 – stratigraphic boundaries; 5 – faults; 6 – sandstone series of the Intracarpathian Paleogene (its base is indicated by inclined hatching); 7 – Intracarpathian Paleogene (its base is indicated by inclined hatching; 8 – Albian–Lias; 9 – Lower Lias–Keuper (Upper Mesozoic pelitic-carbonatic complex): a – Lower Lias, b – Keuper; 10 – Middle Triassic (dolomite with anhydrite layers); 11 – Lower Triassic (coloured Werfenian schists, quartzites); 12 – crystalline complex: a – granodiorites, b – gneisses; LP – Lipany overthrusts.

Because of lack of drill cores (first in the depth interval 1,735–1,740 m) and of small reliability of drill cuttings for stratification of the drilled series we emphasized the geophysical boundaries traced in the borehole and on reflection seismic profiles 20/78 and 20A/78 as well as in other well log data. Further we considered the tectonic structure in general. The depth data obtained by seismic interpretation of stratigraphic and tectonic boundaries must be regarded with tolerance considering especially the anisotropy of velocities of elastic waves propagation and the complex development of the Intracarpathian Paleogene in general. Anisotropy of velocities in folded areas expresses the ratio of structural difference of rocks in longitudinal direction and in direction perpendicular to the youngest tangential tectonics, which is the limiting factor affecting also the velocities of elastic waves. In the further description of the seismic profile 20/78-20A/78-20B/80 the depth data are taken from the collar of the borehole Šariš-1.

0–1,340 m the Intracarpathian Paleogene

On the profile 20/78 in the Intracarpathian Paleogene single fragmented reflections prevail. The only continuous system is the zone of reflections in the borehole Šariš-1 at the depth of 995 m, dipping towards the NNE. In our opinion these reflections correspond to the Lipany overthrusts, i.e. to the fault zone which we regard as one of the most important overthrust dislocations in the Intracarpathian Paleogene. In the area of the Lipany boreholes we encounter older rocks (often tectonic shreds), containing Mesozoic microfauna. In agreement with Ďurkovič in Koráb et al. (1986) we consider the interval 0–950 m or 0–955 m as corresponding to a complex with prevailing claystones. The ratio of sandstones and claystones is 1:8 to 1:10. In the interval 1,075–1,080 m, Ďurkovič (ibid.) also identifies nummulites determined by E. Koehler in drill cuttings. Results of resistivity and radioactivity well logging also prove a lithological boundary at the depth of 995 m.

In regard to increasing velocities and to the character of electric logs it may be expected that sandy calcareous claystones to calcareous sandstones prevail in the interval 995–1,150 m, i.e. under the overthrust surface. It also correlates with an increased content of $CaCO_3$ in fragments of rocks in the mud.

The Paleogene-Mesozoic boundary can be identified only with difficulty because of lack of cores. At the depth of 1,080 m, however, Gašparíková (ibid.) identifies ?Middle Cretaceous foraminifers s which Kullmanová (ibid.) ranges to the depth of 1,280 m. These finds, however, should be explained similarly as the finds of Mesozoic faunas in the Intracarpathian Paleogene near Lipany, or by redeposition. The Paleogene boundary-Mesozoic can presumably be traced in the borehole Šariš-1 at the depth of 1,340 m where electric logs show a horizon with increased apparent resistivity. It cannot be excluded, however, that it is an indication of fault tectonics. Nevertheless, contrary to overlying series the complexes at depth are manifested as different seismofacies.

1,340–3,836 m Mesozoic

Regarding the interpretation of the time section of profile 20/78 and other available data, we distinguish three complexes of typical seismofacies in the Mesozoic in the borehole Šariš-1.

In the *upper complex*, corresponding to the Albian–Lias (1,340–2,350 m), strong conspicuous events prevail. Of a similar character are the seismic reflections on profile 19/76. The increased content of $CaCO_3$ in the drill cuttings corresponds to strikingly increased velocities of elastic waves ant to increased apparent resistivity in the interval 1,340–1,710 m. At the depth of 1,435 m Kullmanová in Koráb et al. (1986) identifies calcareous siltstones, at the depths of 1,640 and 1,720 m organodetrital limestones – calcarenites. In the rock complex from 1,370 to 1,710 m the high layer velocities (over 6,000 m/s) should indicate overwhelming prevalence of limestones. In the interval 1,710–2,300 m oscillations of layer velocities correspond to alternation and predominance of marly limestones over calcarous claystones.

In contrast to the upper complex, no strong events can be observed in the *middle complex* representing Lower Lias to Keuper (2,350–2,860 m), namely around the borehole Šariš-1, maybe with the exception of the upper tectonized boundary. Towards the NE of the borehole Šariš-1 the complex is entirely tectonically reduced at the crossing of profiles 20A/78 and 19/76. Towards the SW, on the contrary, the thickness of the complex greatly increases, this being valid mainly for the upper part of the complex. Lithologically, the upper part contains prevailingly a series of calcareous claystones with inclusions of limestones where layer velocities, obviously in dependence on the content of carbonates, range from 5,000 to 5,800 m/s. According to sonic logs, velocities of elastic waves strikingly increase at the depth of 2,605 m as compared with the upper part of the complex. As the sonic curve from 2,605 m downwards, i.e. in Keuper intervals confirmed by drill cores, is of a similar character, the boundary Lias-Keuper can be safely set in the depth. It should also be noted that the curve of layer velocities at the depth of 2,600 m shows an increase to 6,000 m/s. The boundary Keuper-Middle Triassic in the basement is evident from sonic log and well-shooting.

The *lower complex*, Middle to Lower Triassic (2,860–3,836 m), is in the upper part built of Middle Triassic dolomite strata with anhydrite layers, in the seismic section indicated as a set of short, dynamically striking seismic boundaries. They are based at the depth of 3,739 m, i.e. in a zone of a notable decrease of elastic waves velocities indicated both by well shooting and by sonic log. An increased content of claystone-anhydrite admixture in dolomites is indicated by sonic measurements in the intervals 3,465–3,533 m, 3,600–3,620 m and presumably also in the interval 3,690–3,739 m, which is in accordance with the lithological content of drill cuttings. According to Rudinec-Řeřicha in Koráb et al. (1986), not only gypsum, but also variegated claystones appear at the depth of 3,735 m. According to seismic data, we regard dolomite strata in the borehole Šariš-1 as tectonically reduced. It is indicated by high, nevertheless "oscillating" acoustic values suggested in the interval 3,675–3,690 m. Towards the NE and the SW of the interpreted dislocation the thickness of the dolomite complex increases.

In the basement of dolomites, down to the depth of 3,836 m, Koráb et al. (1986) identified a series of coloured Werfenian schists and stratigraphically unclassified quartzites. According to acoustic log, the top of the Werfenian series occurs at the depth of 3,739 m. The lower boundary is not, similarly as at Branisko, sharp. Obviously, it is a gradual transition and the quartzites can also be ranged to the Werfenian as it is indicated by lower velocities from the depth of 3,774 m. This transition to depth is manifested as an increase in numbers of quartzite layers 0.5–1.0 m thick. The sharp decrease in elastic waves velocities in the Werfenian was recorded also by well-shooting and is evident in ultrasonic checking of quartzite samples from the depth of 3,794.5 m. The sonic log shows a continuous layer of quartzites in the interval 3,800–3,825 m, with only scarce intercalations of claystones. In dependence on the content of the clayey admixture layer velocities in dolomites range between 6,000 and 7,500 m/s, in the Werfenian they drop to 5,000 m/s.

3,836–5,000 m crystalline complex

According to Koráb et al. (1986) in granodiorites the interval 3,836–4,125 m occurs in the final section of the borehole, in muscovite-biotite gneisses in the depth interval 4,125–5,000 m. In physical terms these rocks do not differ substantially, with the exception of a higher anisotropy in gneisses. Gneisses of predominantly migmatite type exhibit slightly increased densities and substantially increased magnetic susceptibility values. Granodiorites from the depth interval 4,126–4,129 m exhibit anomalously increased gamma activity and increased U-content (Píchová-Plička-Mitevová 1986). This fact as well as the lower velocities of elastic waves measured on samples can be best explained as indications of deep tectonics. In the interval 3,836–3,885 m sonic log recorded oscillating velocities, which may correspond to a zone of intensive weathering.

Profile 42/82 (Pl. 3)

Profile 42/82 stretches from the northern environs of the village of Krivany towards the SE, north of Lipany and Sabinov to the area south of Terňa. It is situated roughly 3–4 km from the Klippen Belt outcrops. The profile passes near boreholes Lipany-1 and Lipany-3, and the borehole Lipany-2 was located on it. Reflections in the Intracarpathian Paleogene are weak, with small amplitudes. Stronger events occur at the base of the complex. In the Mesozoic relief reflections are in places dynamically intensive and sometimes, in larger segments, continuous. The seismic contrast between the sporadic events in the Paleogene and the abundant, strong and continuous reflections from the Mesozoic relief can be with advantage used to trace the relief. Similarly, the inner structures of the Mesozoic basement or the deeper complexes produce more or less strong events.

In the seismic section, the Paleogene-Mesozoic boundary is studied on data from the boreholes Lipany-1, 2 and 3, and also (using data from the transverse profile 15/75) from the borehole Lipany-5. Towards the SE the boundary rises to the area of the Lipany boreholes from where it gradually falls.

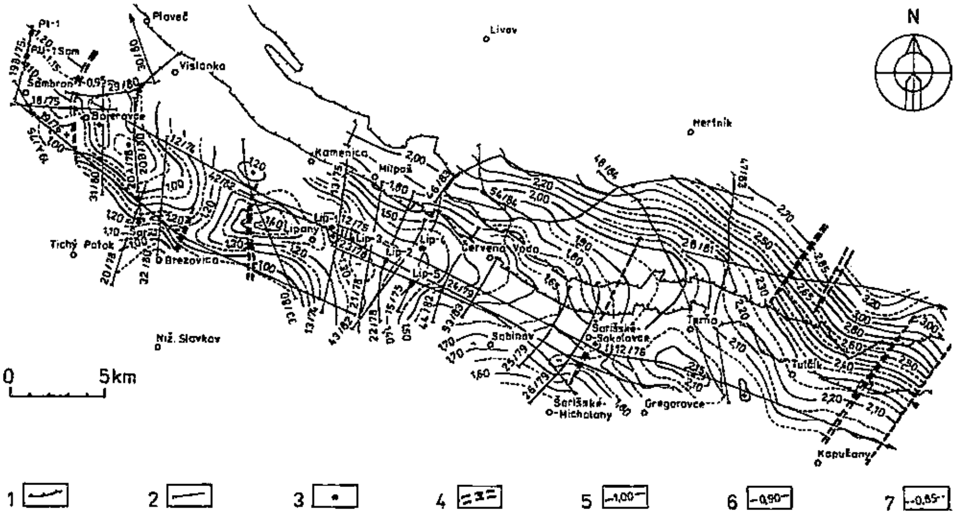
In the time interval 1.1–1.15 s, i.e. the start of the profile – station – 19.3, subhorizontal events indicate the Lipany overthrust fault. It is considered to be one of the youngest faults. Approximately to the E from the crossing with the profile 53/83 subhorizontal events, like on the profile 12/75, become weaker. It might indicate a change in the intensity or in the time plan of the Lipany overthrust faults. Overthrusting is evidenced by the tectonic deformation of the Intracarpathian Paleogene noticeable on drill cores (slickensides of cores from the borehole Lipany-1, 2, 550 m, etc.).

In the time interval 0.5–0.7 s and also in other intervals the reflections are subhorizontal and traces of correlation of reflection elements can be observed. It indicates partial, less intensive reverse movements (from NW to SE) within the upper parts of the Intracarpathian Paleogene. At the station around 25.0 km a fault is interpreted. It may be the Fričovce fault (Matějka et al. 1964).

Time map of the relief of Triassic dolomites (Fig. 6)

The map is based on time sections, more exactly on the course of the relief of Triassic dolomites in them.

The map illustrates the morphology of Triassic dolomites at an approximation only. The interval of isolines is large (the interval of isochrones 0.05 s corresponds to nearly 150 m at the depths of interest). It must be taken into account that the map does not document the variability of velocities in the area.



6. Time map of the relief of Triassic dolomites. 1 – Klippen Belt, 2 – CDP seismic profiles; 3 – deep boreholes; 4 – faults; 5 – isochrones of two-way time at 1.0 s intervals; 6 – as above, at 0.1 s intervals; 7 – as above, at 0.05 s intervals.

Relief of Triassic dolomites (Pl. 4)

Depth sections were used to construct a structural scheme in isonormals. Later it was transformed into a map of isohypses, using the system of auxiliary orthogonal profiles

(Gurvič 1964). The structural scheme in isohypses illustrates the vertical depths of the studied boundary.

In the southernmost part of the area, between Brezovica and Gregorovce, the isolines demonstrate a dipping of the relief towards the N and NE into a striking depression zone, stretching from the borehole Šariš-1 towards the E to Lipany. There, WNW of Lipany, the interpreted boundary reaches the maximum depth −2,850 m. The depression zone continues farther to the ESE. It can be further followed from the southern environs of the borehole Lipany-5 to the surroundings of Sabinov. In the area S of Sabinov the depression is rather shallow and wide. It is bounded by the isonormal −3,100 m. Farther to the E the depression deepens and S of Terňa attains the maximum depth of 3,950 m. Presumably, it continues to the SE, into the area of the sunken block of the Prešov fault in the northern part of the Prešovská kotlina depression.

The course of the described depression coincides quite well with the distinct Sabinov gravity low in the map of residual anomalies for r = 2 km and r = 2–16 km (Čekan-Mořkovský 1982).

In the western part of the area, SE of Šambron, dominates the arching of the complex of Triassic dolomites. Its top part stretches from WNW to ESE and is well demonstrated on profiles 31/80 and 20A/78. The elevation character of the relief corresponds to a striking, W-E trending gravity anomaly in the map of residual gravity anomalies with the radius of averaging ring r = 2–16 km (Čekan-Mořkovský 1982) and in the map of residual anomalies for $r = 8\sqrt{5}$ km (Váca et al. 1971). A continuation of the ridge can be observed in the area SW and SSE of Kamenica. There the structure has two highs. SW of Kamenica it is delimited by isoline −2,450 m, in the environs of borehole Lipany-1 its highest value is −2,300 m (borehole Lipany-1 struck Triassic dolomites at the depth −2,299 m). Farther to the E, in the vicinity of borehole Lipany-2, isonormals form an enclosed local elevation with a minimum depth of 2,450 m. On the inconspicuous ridge, extending from the elevation area towards the SE, the borehole Lipany-5 is situated. Similarly, on an extension stretching from the borehole Lipany-2 towards the ENE, the borehole Lipany-4 is located. Towards the E, an extensive elevation structure can be observed. It is elongated, trending from WNW to ESE and delimited by the highest isoline −2,850 m. The ridge extending to the SE can be followed to the area SE of Šarišské Sokolovce.

The tectonic structure of the study area has been discussed above. In Pl. 4 some tectonic lines are drawn as interpreted on reflection seismic profiles. They are Neogene normal faults which can either be observed on several seismic profiles or are illustrated in schemes.

The tectonic structure of the area W of Lipany is characterized by normal faults, N-S to NE-SW trending, dipping to the W, with amplitudes up to 500 m. It is likely that the local N-S isohypses of the relief of Triassic dolomites correspond to these tectonic features or at least were predisposed by them. In the area of Šarišské Sokolovce a dip to the SE with a step of approx. 300 m has been interpreted. On seismic profiles 42/82 and 12/75 the fault is well indicated, while on the profile 24/79 thee indications are rare. It cannot be excluded that it is the Fričovce fault, or one of the parallel faults located more to the W (Matějka et al. 1964). The fault may continue to the NNE. Because of absence of seismic profiles this continuation is only indicated. On the profile 12/76 in the environs of Hanušovce, two faults dipping to the W are assumed. The easternmore of them was interpreted (Adamovská et al. 1977) as the Pavlovce fault (cf. Matějka et al. 1964). A comparison with the tectonic line is presumably the Lipnice fault. On the profile 28/81 the faults are not indicated. It can therefore be assumed that they fade out to the S. On the profile 28/81 two faults with a considerable step, dipping to the SE, are interpreted. They probably fade out N of the Klippen Belt. The indicated continuation of the faults towards the S and N coincides with orientations of faults revealed by geological mapping (Matějka et al. 1964).

The isohypses in the structural scheme indicate a general dipping of the relief of Intracarpathian dolomites to the N and NE, and its dipping beneath the outcrops of the Klippen Belt. This trend is interrupted by a striking ridge with the axis southern Šambron–Bajerovce–Krásna Lúka–northern Krivany–Lipany–Červená Voda–Šarišské Sokolovce. Boreholes Plavnica-1 and Plavnica-2 (personal communication R. Rudinec) revealed that in the southwestern part of the area, between Šambron and Vislanka, the tectonic structure is rather complicated. As compared with the structural scheme (Pl. 4) the dipping of the relief of dolomites to the N may be even steeper.

The area of Smilno

In the surroundings of the Smilno tectonic window where the Dukla series emerge from the basement of the Magura Flysch, reflection seismic surveys were conducted in 1972, 1981 and 1984 (Adamovský et al. 1972b, Mořkovský et al. 1982, Novák et al. 1985).

In seismic sections only short, weak and dipping reflections can be observed. There are ample interferences and low-frequency disturbances and numerous diffracted waves.

We shall discuss in more detail the section of profile 34A/84 in close vicinity of the borehole Smilno-1. The profile 34A/84 (interval between the points of arrival 25 m) was measured on a line very near the profile 34/81 (interval 50 m).

The upper part of the seismic section (the top of Beloveža series in the Dukla unit) is characterized by absence of reflections. The reflections appear at approx. 1.0 s.

A comparison with drilling data showed that inclinations of recorded events do not agree with inclinations of layers. At times 2.0–2.2 s strong events with large amplitudes occur. In the segment S of the borehole they dip steeply to the N. In close vicinity of the borehole they are subhorizontal. North of the borehole they slightly rise to the N and their amplitudes are less distinct. This range of reflections may coincide with the deeper part of submarine slide, i.e. with the boundary between the Magura and Outer Flysch (Leško 1986). Let us note, however, that in well-shooting and VSP data (Filková 1983) the boundarry is not manifested as a velocity boundary and does not reflect elastic waves. In this time interval (2.0–2.2 s), corresponding to the depth interval 3,840–4,330 m, 15–80° dipping of beds was documented on drill cores (Leško 1986).

At the time around 3.4 s a range of strong events, subhorizontal or slightly dipping to the N, can be observed near the borehole. According to extrapolated well-shooting results from the borehole Smilno-1 (Filková 1983) they are at the depth of approx.

7,400 m. Leško (1986) regarded this group of reflections (on profile 34/81) as an indication of basis for menilite flysch strata separated from the basement sediments by a tectonic overthrust surface. The crushed zone described by Leško (1986) at a depth of around 3,000 m demonstrated in seismic logs (Filková 1983) by a decrease in layer velocities from 5,000 m/s to 3,700 m/s in the interval 2,850–3,100 m is in the seismic logs indicated only sporadically (e.g. in the northern margin of the section, obviously at the time around 0.9 s, at the stem of the borehole at the time 1.64).

It can be said that the results obtained on profiles 34A/84 and 34/81 are not identical. This can be demonstrated on the above described event at around 3.4 s. On the profile 34A/84 it is subhorizontal and slightly dips to the N, while on the profile 34/81 the event is subhorizontal and rises towards the N. It is so because the profiles run through different terrains. This fact, however, makes a reliable interpretation of individual events on different seismic profiles impossible. It was proved that compared with the profile 34/81 the group of events at 3.4 s on the profile 34A/84 can be correlated in a much longer segment. On the profile 34/81 more events can be observed in the interval 1.6–3.0 s.

Seismic data document a tectonic diversity due to several phases of fold-overthrust and Neogene normal fault tectonics. It results in a very complicated pattern of interfering waves from sources in seismic profile which is further complicated by intesive side reflecting. Larger seismic interfaces may be due to tectonic faults which, however, cannot be observed at greater distances. It must be noted that inclinations of events larger than 45° cannot be recorded after migration. Direct correlation of drilling and seismic data is therefore difficult.

The surroundings of Zboj

In the surroundings of the deep borehole Zboj-1 reconnaissance profiles 6D/73, 3/75 and 38/81 (Adamovská et al. 1974, Adamovská et al. 1977, Mořkovský et al. 1982) were situated.

In the seismic time section of profile 38/81 only short reflections with small amplitudes can be observed. Numerous diffracted waves often overlap regular events. In close vicinity of Zboj-1 to the N a tectonic line dipping to the NE can be interpreted. The flat character of the line together with other phenomena indicates overthrust style of displacement. Further, a dull boundary dipping from 1.8 s at the start of the profile towards the NE to 2.16 s is interpreted. The boundary may coincide with the contact of the Dukla unit and the Zboj series struck by the borehole Zboj-1 at the depth of 3,800 m (Ďurkovič et al. 1982). Reflections on the profile 38/81 are either subhorizontal, or slightly dipping, which contrasts with the large inclinations of the series as they were revealed by Zboj-1 (up to 90°). It is likely that the seismic elements coincide with partial tectonic elements whose inclinations differ from the layer structure itself.

Conclusions

The present paper summarizes the results of geophysical, mainly CDP seismic measurements conducted in the Intracarpathian Paleogene and in the East Slovak Flysch in the period 1972–84. The survey focussed on the environs of Lipany. In the area of Zboj and Smilno only a small-scale surveys were carried out.

In intensively folded areas the CDP method does not yield satisfactory results as it was shown by the evaluation of reflection seismic data (Kadlečík et al. 1977) and by investigations in the area of the Smilno window in 1981 and 1984. More detailed measurements outlined some younger slightly inclined overthrust planes, which are practically the only continuous reflection elements. Besides intensive folding and younger fault deformation, another factor influencing the origin of useful reflected waves is the great thickness of flysch complexes. The origin of interference waves is accompanied by great loss of energy. Therefore a majority of reflections generated by the surface of substratum are not recorded. In this rspect a negative role is played by the very probable intensive imbrication of the flysch basement.

From this point of view more favourable appears the outer part of the peri-Klippen zone N of Sabinov where the relief of Middle Triassic dolomites can be traced from the Intracarpathian Paleogene to the NE beyond the Klippen Belt to the Čergov mountain top parts.

In the broader area of the Intracarpathian Paleogene CDP measurements yield information, though not very reliable, about the relief of Mesozoic carbonates and about the overthrust structure of both the Mesozoic and Paleogene. However, it is hardly possible to distinguish Paleogene sediments and Keuper pelites. The gravity anomaly Bajerovce-Krásna Lúka is regarded as the culminating zone of the relief of dolomites.

CDP seismic data from the broader area of Lipany were used to construct a time scheme and a depth structural scheme of the buried Mesozoic relief of the Inner Carpathians. Interpretation of CDP data indicated, namely in the Intracarpathian Paleogene, numerous faults, in vast majority reaching the recent relief. They are mostly post-Eocene, presumably Old Styrian NE-SW striking overthrust faults which significantly influenced the structure of the Intracarpathian Paleogene, of the Klippen Belt and of the Krynica unit. Leško-Chmelík-Fusán (1980) called these tectonic lines along the inner margin of the Klippen Belt the Lipany overthrust faults. To verify them and to solve the problems connected with young overthrust tectonics will require close cooperation with specialists in mapping the area of interest. Seismic indications of normal faults are in the Intracarpathian Paleogene and in the Mesozoic less noticeable as compared with overthrusts. Obviously, it can be explained by strong compaction of rocks and by shortage of reflections from fault planes due to their large steep inclination.

An important point of the presented concept is the interpretation of the Intracarpathian Paleogene basement continuation to the NE beyond the Klippen Belt. It can be more or less reliably traced up to the top parts of Čergov. In regard to the basement dipping to the N, the southern and top parts of Čergov become an elevation zone divided by young overthrust faults. The northernmost of them can function as barriers for accumulation of hydrocarbons.

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Přeložila D. Malíková

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Geofyzikální průzkum na uhlovodíky v centrálněkarpatském paleogénu a flyšovém pásmu východního Slovenska

(Resumé anglického textu)

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Již první výsledky reflexně seizmických měření provedené metodou RNP v oblasti východoslovenského flyše signalizovaly mimořádně obtížné seizmogeologické podmínky (Jurga-Cidlinský 1961). Jak se ukázalo později, jsou podmíněny zejména složitou vrásovo-příkrovovou stavbou území a značnou mocností flyšových komplexů. Vznikají velmi intenzívní poruchové vlny a současně dochází k silnému útlumu užitečných odražených vln. Proto nejsou registrovány reflexy od reliéfu flyšového podkladu. Následná reflexně seizmická měření s analogovou registrací a zejména pozdější seizmická měření SRB potvrdila výše uvedené poznatky o nepříznivých seizmogeologických podmínkách východoslovenského flyše.

Seizmická měření SRB provedená v centrálněkarpatském paleogénu ukázala, že v této oblasti jsou podmínky pro seizmický průzkum – oproti flyšovým Karpatům – příznivější. Na základě interpretace seizmického materiálu je možno, i když místy ne zcela jednoznačně, sledovat reliéf karbonátů v podloží sedimentů paleogénu a také přesmykovou stavbu jak mezozoika, tak zejména paleogénu. Možnost odlišení sedimentů centrálněkarpatského paleogénu od pelitů keuperu na základě časových řezů SRB je ovšem malá. Na základě těchto relativně příznivých výsledků a také v souvislosti s příznivým hodnocením perspektiv naftoplynonosnosti přibradlové oblasti byla v širším okolí Lipan proměřena poměrně hustá síť seizmických profilů SRB, která v této oblasti umožnila konstrukci strukturního schématu zakrytého reliéfu dolomitů Centrálních Karpat v podloží paleogénu.

Ve flyšovém pásmu byly větší objemy reflexně seizmických prací v modifikaci SRB realizovány zejména v oblasti Smilna a v okolí Zboje.

V tomto článku předkládáme nejzávažnější výsledky zpracování a interpretace seizmických materiálů SRB, získané ve studované oblasti. Největší pozornost byla věnována širšímu okolí Lipan. Kromě reflexní seizmiky bylo využito i výsledků tíhových a magnetických měření, měření fyzikálních vlastností hornin, refrakční seizmiky, vrtní refrakce, seizmokarotážních měření a výsledků akustické i elektrické karotáže i výsledků dalších geofyzikálních metod.

Gravimetrie

Za první prakticky využitelná tíhová měření lze považovat až gravimetrické práce počínaje rokem 1954. Jednalo se o regionální tíhová měření s hustotou jednoho měřicího bodu na 2–3 km^2. Detailní tíhový průzkum s hustotou 3–6 měřicích bodů na km^2 je v zájmovém území prováděn od roku 1970. Jeho dílčích výsledků v území mezi Šambronem–Lipany využili Čekan-Mořkovský (1982) k sestavení map reziduálních anomálií tíhového pole. Ukázalo se, že mapa reziduálních anomálií tíhového pole s poloměrem vystředění 2 km zobrazuje litologické změny hornin centrálněkarpatského paleogénu. Mapa reziduálních anomálií s poloměrem vystředění 2–16 km naopak zřejmě charakterizuje (jak ukazují výsledky reflexní seizmiky) reliéf karbonátů Centrálních Karpat. Výsledky tíhových měření byly souborně zpracovány zejména Menčíkem (1957), Čekanem-Šutorem (1960), Ibrmajerem-Doležalem-Mottlovou (1959), Ibrmajerem-Doležalem (1962) a Ibrmajerem (1963, 1978). Vzhledem ke komplikovaným strukturně tektonickým poměrům východoslovenského flyše a jeho podkladu, i přes řadu řešených problémů, je interpretace tíhových dat stále velmi složitou.

Magnetometrie

Jak ukázalo regionální magnetické měření s hustotou jednoho měřicího bodu na 2 až 3 km^2 provedené v letech 1955–1957, je charakter geomagnetického pole monotónní (± 20 nT). To nepochybně souvisí s malou susceptibilitou flyšových komplexů i jejich podloží, resp. s jejich malou diferenční susceptibilitou. Uvážíme-li, že měření bylo konáno se střední chybou ± 4 nT, je zřejmé, že interpretace geomagnetického pole je problematická. Naměřený materiál souborně zpracovali Ibrmajer-Doležal-Mottlová (1959), Šutor-Čekan (1965), resp. Šutor in Kadlečík et al. (1977).

Fyzikální vlastnosti hornin

Fyzikální vlastnosti hornin byly měřeny na hlubinných vrtech PU-1 Šambron, MLS-1 Humenné, Zboj-1, Lipany-1,2,3,4,5, Hanušovce-1, Smilno-1, Šariš-1, resp. Prešov-1 (příl. 1). Komplexně zpracovala fyzikální vlastnosti hornin v zájmové oblasti Píchová (1985).

Údaje o fyzikálních vlastnostech hornin jsou významné ze dvou hledisek. První hledisko souvisí s využitím těchto dat při hodnocení výsledků geofyzikálních metod. Zvláštní význam mají údaje o hustotách hornin při interpretaci tíhových měření v oblastech postižených tangenciální tektonikou. Ondra-Hanák (1989) zjistili celkově vyšší hustoty hornin bradlového pásma včetně křídových komplexů a paleogenních obalů – pročských vrstev – zejména oproti krynické jednotce a i oproti přilehlému centrálněkarpatskému paleogénu. Z výsledků detailních tíhových měření vyplývá, že zejména svrchnokřídové a rovněž i paleogenní obaly bradlového pásma v úseku Plavče–Lubotína až po příčný pavlovský zlom vyvolávají souvislou kladnou anomálii. Zvýraznění této tíhové anomálie zřetelně souvisí s výchozy púchovských slínů a můžeme je sledovat z okolí Mošurova podél jižního okraje bradlového pásma až po pavlovský zlom. Východně od tohoto zlomu, spolu s vyzníváním púchovských slínů a nástupem flyšového vývoje svrchní křídy, tíhový projev bradlového pásma zaniká. Je pravděpodobné, že se tam i snižuje hustota pročských vrstev.

Druhé hledisko se týká obecného posuzování problémů ropoplynonadějnosti území. Analýza fyzikálních vlastností hornin, zejména hustoty a porózity, prokázala vysoký stupeň kompakce hornin zejména centrálněkarpatského paleogénu, a to jak podle výsledků měření na povrchově odebraných vzorcích, tak i na jádrech hlubinných vrtů. Husák et al. (1986) ze stupně kompakce vyvozují původní mocnost šambronských vrstev 5–6 km. Oproti autorům se domníváme, že kromě diageneze hrálo významnou roli i tektonické zhutnění. Výsledkem komplikovaného vývoje jsou velmi nízké primární porózity hornin. V centrálněkarpatském paleogénu, bradlovém pásmu i flyšových Karpatech převažují hodnoty porózity do 1 % (Píchová 1985). Je tedy zřejmé, že s výjimkou karbonátových hornin je nutno z hlediska kolektorských vlastností uvažovat pouze se sekundární porózitou.

Letecké a družicové metody

Letecký magnetometrický a radiometrický průzkum v měřítku 1:200 000 je popsán ve zprávě Mašína et al. (1960). Naměřené magnetické pole je v zájmovém území vcelku monotónní. Detailním leteckým měřením v měřítku 1:25 000, kterým byl zastižen zejména jižní okraj zájmového území, byla zjištěna významnější anomálie pouze v širším okolí Radatic. Gnojek (1987) ji považuje za projev bazického tělesa. Při radiometrickém průzkumu bylo naměřeno pole bez výraznějších anomálií.

Metodami dálkového průzkumu země byla zjištěna kruhová struktura v prostoru Svidník-Stropkov. Její vznik vysvětlují Pospíšil-Nemčok-Feranec (1982), resp. Pospíšil (1983, 1985) buď její přítomností na systému hlubinných tektonických linií, nebo jako oblast kolizní zóny odlišných podložních bloků.

Refrakční seizmika

Celková délka refrakčně seizmických profilů proměřených v zájmové oblasti činí 826 km (příl. 1). Výsledky měření jsou zveřejněny v příslušných zprávách a jsou také obsahem komplexních hodnocení zejména Plívy et al. (1976, 1977) a Kadlečíka et al. (1977).

Všechna zpracování refrakčních měření ve flyši narážela na potíže podmíněné seizmogeologickými podmínkami složité vrásovo-příkrovové stavby flyšových Karpat.

Z celkového hodnocení podkladů refrakční seizmiky vzhledem k dosaženým vrtným a geofyzikálním výsledkům jak na našem, tak i polském a sovětském území vyplynul názor, že za podklad flyšových komplexů by bylo možno považovat refrakční rozhraní o hraniční rychlosti vyšší než 6000 m/s (Kadlečík et al. 1977). Tento názor však nepotvrdil vrt Smilno-1, který v hloubce udávaného rozhraní (5000 m) zastihl bazální polohy černého flyše. Uvedená rozporná zjištění vedla k zastavení refrakčně seizmických prací jak na našem, tak i na polském a sovětském území flyšových Karpat.

Věrohodnějších výsledků se dosáhlo refrakční seizmikou v centrálněkarpatském paleogénu, kde údaje vrtu Lipany-4 nejsou v rozporu s udávanou hloubkou refrakčního rozhraní a kde je i obecný souhlas s výsledky reflexní seizmiky.

Vrtně refrakční měření

Metoda vrtní refrakce byla aplikována na hlubinných vrtech MLS-1 Humenné a Lipany-1 (příl. 1).

Výsledky získané na vrtu Lipany-1 prokázaly značné anomality v šíření lomených vln, ze kterých i při tehdejším jen omezeném stavu poznatků o hluboké stavbě vyplývalo, že se nejedná o projevy téhož rychlostního rozhraní. Z těchto důvodů byly další práce zastaveny. Získané údaje nasvědčovaly přítomnosti většího množství rozhraní, jež nebylo možno blíže identifikovat. Až z výsledků současného zpracování vyplynulo, že tato rozhraní odpovídají jednak reliéfu dolomitů v podloží centrálněkarpatského paleogénu, jednak tektonickým plochám – přesmykům – v centrálněkarpatském paleogénu, event. v bradlovém pásmu. Jejich vzájemné oddělení z materiálů vrtní refrakce není možné.

Seizmokarotážní měření

Seizmokarotáž byla v zájmovém území realizována na 11 hlubinných vrtech (Lipany-1, 2 a 3, Šariš-1, PU-1 Šambron, Plavnica-1, Hanušovce-1, Smilno-1, Zboj-1, MLS-1 Humenné, resp. Prešov-1, viz příl. 1). Získané údaje daly konkrétní představu o rychlostech elastických vln v pracovní oblasti a umožnily, zejména v centrálněkarpatském paleogénu, věrohodný převod časových údajů do hloubkového měřítka.

Reflexní seizmický průzkum do roku 1971

První reflexně seizmická měření ve východoslovenském flyši oscilografickou seizmickou aparaturou byla uskutečněna v letech 1959-1960 v okolí Adidovců a Stropkova. V letech 1970-1971 bylo provedeno ve v. části flyše měření analogovou seizmickou aparaturou RX 24 S II. Seizmické údaje získané v analogové formě byly později převedeny do digitální formy pomocí počítače EMR ADVANCE 6070. Reflexní seizmická metoda přinesla v uvedeném období obtížně interpretovatelný materiál. Situace profilů je znázorněna v příl. 1.

Reflexní seizmika v modifikaci SRB

Od roku 1972 byl reflexně seizmický průzkum zájmové oblasti realizován v modifikaci společného reflexního bodu (SRB). Do roku 1984 včetně bylo touto metodou proměřeno 50 profilů o celkové délce 477 km; kromě profilů zahrnutých do předloženého zpracování, tj. do roku 1984 včetně, jsou v příl. 1 a 2 zakresleny i profily SRB z let 1985–1986, tedy 64 profilů o celkové délce 669 km.

Terénní seizmické práce byly realizovány odpalovou technologií, nejčastěji středovým roztažením, zpočátku 6násobným, od roku 1976 12násobným překrytím. Vzdálenost středů seskupení geofonů byla 50 m . Registrace odražených elastických vln byla zajištěna digitální seizmickou aparaturou SN 328,SN 338A nebo DFS IV. Do roku 1975 se jednalo o 24kanálové, později o 48kanálové seizmické aparatury. Vzorkovcí interval byl 2 ms.Zdrojem elastických vln byly nálože průmyslových trhavin o hmotnosti 20–30 kg, odpalované z vrtaných sond hlubokých převážně 25–30 m. Metodika terénních prací byla určena zejména na základě parametrických měření.

Do roku 1978 byla naměřená seizmická data zpracovávána na digitální seizmické centrále EMR 6070 řady ADVANCE, vybavené zapisovací jednotkou TNR 91. Seizmické programy umožňovaly standardní zpracování. Migrace seizmických vln byla prováděna pomocí vážené difrakční sumace. Od roku 1979 je v n.p. Geofyzika, Brno, v provozu počítač RDS 500, doplněný procesorem APOLLO a řízený programovým systémem GEOMAX (registrovaná ochranná značka firmy CGG). Oproti systému EMR má GEOMAX podstatně širší programové možnosti. Má např. automatický způsob výpočtu reziduálních statických korekcí. Významná je i možnost měření a zpracování seizmických dat na křivočarých profilech technikou Slalom line (registrovaná ochranná značka firmy CGG). Migrace seizmických vln je realizována pomocí vlnových rovnic (program WEMIG).

Jak ukázalo zhodnocení Kadlečíka et al. (1977) i další práce zejména v okolí Smilna v letech 1981 a 1984, nepřináší metoda SRB v intenzívně zvrásněném flyši významnější výsledky. Při pracích detailnějšího charakteru je možno v seizmických řezech vyčlenit některé mladší přesmykové linie s plošším úklonem. Ty bývají prakticky jedinými souvislejšími odraznými elementy. Nejsou registrovány reflexy, jež by bylo možno s větší mírou pravděpodobnosti spojovat s reliéfem flyšového podkladu.

V centrálněkarpatském paleogénu je možno reflexní seizmikou sledovat reliéf dolomitů mezozoika a přesmykovou stavbu jak mezozoika, tak zejména paleogénu. Jedná se převážně o poeocenní, pravděpodobně staroštýrské zpětné přesmyky od SV k JZ, které vtiskly stavbě centrálněkarpatského paleogénu, bradlového pásma i krynické jednotky významné rysy. Leško-Chmelík-Fusán (1980) tyto tektonické linie podél vnitřního okraje bradlového pásma nazývají lipanskými přesmyky. Jejich ověření v terénu a řešení dalších problémů spojených s mladou přesmykovou tektonikou vyžaduje úzkou spolupráci s mapérskými specialisty studovaného území.

Převod seizmických dat z časového oboru do hloubkového měřítka byl realizován pomocí grafů závislosti $2t_0(H)$. Byly zkonstruovány pro každý seizmický profil na základě geologických modelů a údajů seizmokarotážních měření. Příklad zjednodušené závislosti $2t_0(H)$ pro profil 42/82 je zakreslen v příl. 3. Rychlostní poměry mohly být nejdetailněji vysledovány v širším okolí Lipan, kde byla provedena seizmokarotážní měření na vrtech PU-1 Šambron, Plavnica-1, Šariš-1 a Lipany-1, 2 a 3. Při určení rozsahu působnosti těchto rychlostních závislostí bylo využito zejména údajů podpovrchových rychlostí (příl. 2). Závislosti středních rychlostí na hloubce podle seizmokarotážních údajů vrtů situovaných v zájmovém území jsou uvedeny na obr. 1.

Výsledkem zpracování a interpretace seizmických dat jsou časové a hloubkové seizmické řezy s geologickou interpretací. Jejich ukázky jsou uvedeny na příl. 3 a obr. 2, 3, 4 a 5.

Hlavním grafickým výstupem interpretace časových a hloubkových seizmických řezů SRB je časová mapa a strukturní schéma zakrytého reliéfu dolomitů triasu v podloží centrálněkarpatského paleogénu (obr. 6, příl. 4). V zájmovém území povrch dolomitů triasu vesměs generelně klesá k S až SV. Tento trend je přerušen výrazným hřbetem s osou j. Šambron–Bajerovce–Krásna Lúka–s.Krivany–Lipany–Červená Voda–Šarišské Sokolovce. Závažným momentem předložené koncepce je interpretace plynulého pokračování podkladu centrálněkarpatského paleogénu k SV za bradlové pásmo (ve smyslu názorů Nemčoka 1961, 1978), které lze s různou mírou věrohodnosti sledovat až pod vrcholové části Čergova. Lze se domnívat, že tíhová anomálie Bajerovce-Krásna Lúka je kulminující zónou reliéfu dolomitů.

Vysvětlivky k obrázkům a přílohám

1. Závislost středních rychlostí na hloubce podle výsledků seizmokarotážních měření. 1 - Hanušovce-1; 2 - MLS-1 Humenné; 3 - Lipany-1; 4 - Lipany-2; 5 - Lipany-3; 6 - Plavnica-1; 7 - Smilno-1; 8 - PU-1 Šambron; 9 - Šariš-1; 10 - Zboj-1.
2. Seizmický profil 19/76, časový řez s geologickou interpretací (12násobné překrytí,vzdálenost bodů příjmu 50 m; časově proměnná filtrace a dekonvoluce, zvýraznění koherence vlnového pole, vlnová migrace). 1 - centrálněkarpatský paleogén; 2 - peliticko-karbonátový vývoj vyššího mezozoika (alb-keuper); 3 - dolomity středního triasu (event. pestré břidlice a křemence spodního triasu); 4 - krystalinikum; LP - lipanské přesmyky.
3. Seizmický profil 22/78, časový řez s geologickou interpretací (12násobné překrytí, vzdálenost bodů příjmu 50 m; časově proměnná filtrace a dekonvoluce, zvýraznění koherence vlnového pole, vlnová migrace). 1 - centrálněkarpatský paleogén; 3 - dolomity středního triasu; 5 - povrchový výchoz bradlového pásma; LP - lipanské přesmyky.
4. Seizmický profil 26/79, časový řez s geologickou interpretací (12 - násobné překrytí, vzdálenost bodů příjmu 50 m; časově proměnná filtrace a dekonvoluce, zvýraznění koherence vlnového pole, vlnová migrace).1 - centrálněkarpatský paleogén; 3 - dolomity středního triasu; 5 - povrchový výchoz bradlového pásma.
5. Seizmický profil 20/78-20A/78-20B/80, hloubkový řez s geologickou interpretací. 1 - odrazové elementy na profilech 20/78 a 20B/78 odpovídající reflexům : a - velmi výrazným , b - výrazným, c - nevýrazným; 2 - odrazové elementy na profilu 20A/78 odpovídající reflexům: a - výrazným, b - nevýrazným; 3 - úklony vrstev zjištěné na vrtu Šariš - 1;4 - stratigrafické hranice; 5 - zlomy; 6 - pískovcové souvrství centrálněkarpatského paleogénu; 7 - centrálněkarpatský paleogén (průběh jeho báze je zvýrazněn šikmým šrafováním); 8 - alb-lias; 9 - spodní lias-keuper (peliticko karbonátový vývoj vyššího mezozoika): a - spodní lias, b - keuper; 10 - střední trias (dolomity s anhydritovými polohami); 11 - spodní trias (pestré břidlice werfenu, křemence); 12 - krystalinikum: a - granodiority, b - ruly, LP - lipanské přesmyky.
6. Časová mapa reliéfu dolomitů triasu. 1 - bradlové pásmo; 2 - reflexně seizmické profily SRB; 3 - hlubinné vrty; 4 - zlomy; 5 - izochrony dvojnásobného času po 1,0 s; 6 - dtto, po 0,1 s; 7 - dtto, po 0,05 s.

Příl. 1. Geofyzikální prozkoumanost centrálněkarpatského paleogénu a flyšového pásma východního Slovenska (do roku 1986). 1 - bradlové pásmo; 2 - předterciérní komplexy; 3 - centrálněkarpatský paleogén a flyš; 4 - neogenní sedimenty; 5 - neogenní vulkanity; 6 - reflexně seizmické profily SRB (silně jsou zakresleny profily 19/76, 22/78, 26/79, 20/78-20A/78-20B/80 a 42/82, ilustrované na obr. 2, 3, 4, 5 a příl. 3); 7 - seizmická parametrická měření (od roku 1972); 8 - reflexně seizmické profily (jednoduché překrytí - oscilografická registrace, regulovaný směrový příjem - RNP, hlubinné seizmické sondování - HSS); 9 - refrakčně seizmické profily; 10 - vrtně refrakční profily; 11 - vrty, na jejichž jádrech byly měřeny fyzikální vlastnosti; 12 - vrty, na nichž bylo provedeno seizmokarotážní měření, resp. vertikální seizmické profilování;13 - vrty s provedeným vrtně refrakčním měřením. Vrty: Han - Hanušovce, MLS-1 Hu - Humenné, Lip - Lipany, Pl - Plavnica, Smi - Smilno, PU-1 Sam - Šambron, Sar - Šariš, Zj - Zboj.

Příl. 2. Schéma podpovrchových rychlostí a oblastí působnosti rychlostních křivek zjištěných seizmokarotážním měřením na vrtech PU-1 Šambron, Šariš-1 a Lipany-1, 2 a 3. 1 - bradlové pásmo; 2 - předterciérní komplexy; 3 - centrálněkarpatský paleogén a flyš; 4 - neogenní sedimenty; 5 - neogenní vulkanity; 6 - vrty, na nichž bylo provedeno seizmokarotážní měření; 7 - reflexně seizmické profily SRB. Podpovrchové rychlosti v rozmezí: 8 - 2500-3000 m/s, 9 - 3000-3300 m/s, 10 - 3300-3600 m/s, 11 - 3600-3900 m/s, 12 - 3900-4200 m/s, 13 - 4200-4600 m/s. Oblast použití rychlostní křivky podle seizmokarotážního měření na vrtu: 14 - PU-1 Šambron, 15 - Šariš-1, 16 - Lipany-1, 2 a 3.

Příl. 3. Seizmický profil 42/82 (část). Nahoře: časový řez s geologickou interpretací (12násobné překrytí, vzdálenost bodů příjmu 50 m; časově proměnná filtrace a dekonvoluce, zvýraznění koherence vlnového pole,vlnová migrace). Dole: hloubkový řez s geologickou interpretací a schematickým znázorněním závislosti dvojnásobku času na hloubce. Tato závislost vychází zejména z výsledků seizmokarotážních měření na vrtech Lipany-1, 2 a 3. 1 - centrálněkarpatský paleogén; 2 - dolomity středního triasu; LP - lipanské přesmyky.

Příl. 4. Strukturní schéma reliéfu dolomitů triasu. 1 - reflexně seizmické profily SRB; 2 - bradlové pásmo; 3 - hlubinné vrty, které ověřily reliéf dolomitů triasu; 4 - hlubinné vrty, které skončily v centrálněkarpatském paleogénu; 5 - zlomy; 6 - izolinie vertikálových hloubek reliéfu dolomitů triasu po 500 m, vztažené k nulové hladině; 7 - dtto, po 100 m.