

The role of morphostructures in prospection and exploitation of oil and gas deposits in the Foredeep and the Flyschzone of the West Carpathians

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Значение морфоструктур при разведке месторождений нефти и природных газов в Западных Карпатах

В области южной и центральной Моравии были проведены геоморфологические и геодезические исследования во флишевой зоне Карпат, карпатском передовом прогибе и в венском бассейне. Исследования были направлены на поиски молодых структур, погребенных полигенетических поверхностей выравнивания и зон выветривания. В результате исследований были найдены морфоструктуры, которые являются перспективными на поиски и разведку углеводородов. Некоторые известные месторождения (Долни Дунайовице, Градиско, Жданицкий лес) находятся на этих морфоструктурах. Было обнаружено 5 полигенетических поверхностей выравнивания, из которых наиболее важной является мезозойско-палеогеновая. Это поверхность автохонного основания карпатского передового прогиба, внешнего флиша и вероятно и венского бассейна. Геодезические измерения определили наиболее молодую динамику земной поверхности в области исследований. Ее изучение является одним из методов поисков нефтегазаносных структур. Этот метод решения поисков был в Чехословакии использован впервые.

The role of morphostructures in prospection and exploitation of oil and gas deposits in the Foredeep and the Flysch zone of the West Carpathians

A geomorphological and geodetical research in the Flysch zone of the West Carpathians, Carpathians foredeep and the Vienna Basin was done. The geomorphological investigation was aimed at searching for young elevation structures and to the research of five buried polygenic paleo-reliefs and their weathered rocks. The morphostructures were established, which are perspective for the next the prospection for oil and gas. Some known occurrences of oil and gas (Dolní Dunajovice, Hradisko, Zdanický les) are identical with these young morphostructures. The most important paleo-relief is Cretaceous-Paleogene polygenic paleo-relief entering below the Carpathian foredeep and the Carpathian

nappes and probably the Vienna Basin. The geodetic research established the youngest dynamics of the earth surface of the area in question. The knowledge of the dynamics is an important aid for the prospection for oil-gas structures. This broad application of different methods for the research in traditional areas of potential oil and gas occurrences was used for the first time in the West Carpathians.

The Czechoslovak-Soviet expertises on the research of the deep structure in the Carpathian Foredeep and flysch nappes resulted, in 1971, among others, in a recommendation to develop a geomorphological and geodetical regional research of young tectonic movement of the earth surface. Given the complexity of the Carpathian nappes structure and mountainous surface relief, young elevations may delimit the sites of extensive structural traps for hydrocarbons with in the subhorizontal layers of underthrust platform border. The principal aim the investigations was consequently the search for deposits of mobile natural hydrocarbons in the gently inclined palaeozoic, mesozoic and tertiary sediments of the platform cover under the Carpathian flysch nappes of very complex structure. This investigation proved to be very useful also in the exploitation of gas deposits (Dolní Dunajovice) and in the operation of underground gas reservoirs. An incentive to these considerations was given by the discovery of an oil-gas deposit autochthonan Miocene and the granite elevation near Lubná (Chmelík — Němec, 1968) not far from Kroměříž.

A morphostructural analysis of the areas with deposits of oil and gas is of a long tradition in USSR since the period between the world Wars I and II. In areas little investigated in terms of geology and geophysics, the morphostructural research is oriented to a detailed study aimed at detecting the tendencies of the movements up to the present time.

In the investigation took part besides

the workers of the Central Geological Survey in Prague, T. Czudek and A. Ivan from the Geographical Institute of the Czechoslovak Academy of Sciences in Brno and P. Vyskočil from the Research Institute of Geodesy, Topography and Cartography in Zdíby.

After the first experience had been gained (cf. Zeman, 1973, 1977), a morphostructural analysis, geodetic research of recent surface movements and the investigation of the paleo-reliefs under the sediments of the Carpathian Foredeep, flysch nappes and the Neogene Viena Basin were executed.

The morphostructural analysis detects the young tectonic elevations of the surface of region under study, the geodetic research of recent surface movements supplies data on the current activity of these morphostructures. Along with it we focused our attention to the research of paleoreliefs and the fossil weathered zones of the platform cover, their storing capacity and permeability.

It has been namely established that in the territory under research gas and oil occurs in many places, with in the weathered and jointed rocks of the buried palaeo-reliefs Pre-Miocene relief (Kostelany, Staříč, Ždánice; Ďurica in Shott — Stopell, 1976, Ďurica in Semenovič, 1981).

Results of morphostructural analysis in Central and South Moravia

I. P. Gerasimov et al. (1974) and J. A. Meshtcheryakov (in Fairbridge, 1968) de-

fine morphostructure as a large relief element arisen from interaction of endogenous and exogenous geologic factors, the endogenous factor — i. e. tectonic movements — playing the main part.

In Central and South Moravia the following morphostructural areas (in accordance with the classification of Gerasimov et al., 1974) were delimited:

1) the folded platform foreland of the south-eastern part of the Bohemian Massif its relic of the mesozoic-paleogene "global" peneplane,

2) the Carpathian Foredeep with a number of morphostructures, which reflect the neogene to quaternary tectonic activity of the underlying basement at the earth's surface,

3) the junction zone of the Carpathian Foredeep and the north-western margin of the Carpathian nappes. The morphostructures of this area correspond to brachyanticlinal doming of the Upper-Pliocene levelled surface. Their relative elevation reaches up to 200—230 m. This morphostructural area constitutes the most mobile zone in the area under investigation from the geodetical and geomorphological point of view. It bears a gas deposit in, on the Hradisko elevation, and another, more important one near Dolní Dunajovice (fig. 1),

4) region of the Sub—Silesian—Ždánice nappe bearing morphostructure of Ždánice Forest reflects a domal uplift of Upper Pliocene levelled surface. Geological and geophysical cooperations led here to the discovery of the oil deposit Ždánice (Krejčí, 1976) and Uhřice (oil and gas, Thon — Kostelníček, 1980),

5) the region of Rača nappe with the morphostructure of Chřiby characterised by top level of tectonic desintegrated levelled surfaces. Towards North-East, reliefs of this levelled surface descend

stepwise to the fault of the river valley of Morava. By these faults partial elevations delimited. (Kostelany elevation, Chmelík — Němec, 1968; Ďurica, 1974),

6) area of the north-western margin of the Viena Basin is characterised by an extensive Young Pliocene levelled surface. This surface is deformed by young brachyelevations, which extend from Sobůlky village passing Strážovice village to the Zaječí hills. The Osvětimany elevation also belongs here (fig. 1). No hydrocarbon deposits have been found in this area up to now,

7) the Hradiště Graben as the northern outstretch of the Vienna Basin,

8) the Upper Moravian Basin the tectonic predisposition of which falls to the beginning of the Panonian. Due to a negligible thickness cover of the platform no oil and gas deposits are expected in this area,

9) area of the northern part of the Vizovice Hills build of the Magura group of nappes. This area was originally covered with miocene (Badenian) sediments. In its south-western part remnants of Carpathian beds occur. This area underwent an elevation during the Upper Miocene time associated with almost complete denudation of Miocene sedimentary cover. With respect to the Badenian sediments of the Vienna Basin, the Upper Miocene uplift of the Vizovice Hills amounts to as much as 1 km, or even more, and, as related to the Carpathian Foredeep, some hundreds of meters. The prevailing part of the Vizovice Hills underwent another uplift in the Middle Pliocene time. Hydrocarbon deposits in deep structures have not been looked out in this area up to now,

10) area of the White Carpathians (the Magura nappe) represents a morphostructural elevation of Upper Miocene age. Isolated findings of proluvial sediments in the western part of it give evidence that

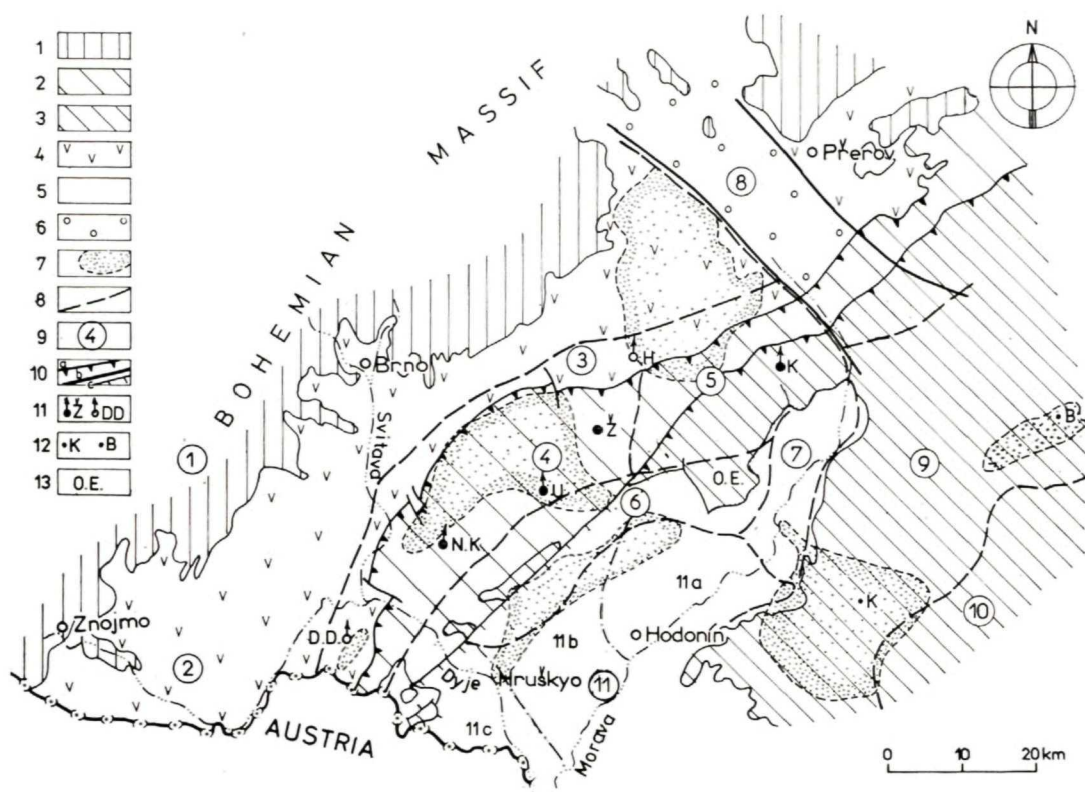


Fig. 1. Map of Morphostructures of the SE Moravia. 1 — SE margin of the Bohemian Massif (crystallina rocks, Paleozoic and Jurassic sediments), 2 — sub-Silesian-Zdánice nappe (sediments of Jurassic, Paleogene and Upper Cretaceous sediments), 3 — Rača-nappe (sediment of Cretaceous and Paleogene), 4 — Carpathian Foredeep (sediments of Miocene), 5 — Vienna Basin (sediments of Miocene and Pliocene), 6 — the Upper Moravia Basin (Pliocene and Quaternary sediments), 7 — region of annual velocities of Recent Tectonic rising Movements ranging from 0.0 to +1.5 mm/year (Vyskočil, 1978), 8 — boundaries of morphostructural areas, 9 — No of morphostructural areas, 10 — nappe overthrusts (a), Quaternary active faults (b), Bulhary-fault (c), 11 — oil and gas deposits (Dolní Dunajovice, Nikolčice—Kurdějov, Uhřice, Ždánice, Kostelany—Lubná), 12 — remnants of Carpathian and Badenian beds, 13 — Osvětimany elevation

of local uplifts continuing even during the Quaternary,

11) area of the Vienna Basin may be divided according to the thickness and the age of its Quaternary filling as well as to the deformation of its Late Pliocene levelled surface into three parts. The boundaries between them form the river valleys of Morava, Dyje and Stupava. These parts

are as follows: a) the area of wind blown sands and of fluviolacustrine sediments situated between the towns of Písek, Svatobořice and Hodonín; b) the area of loess and wind blown sands between the locality Hodonín, Svatobořice, Rakvice and Lanžhot; c) the area of fluvial terraces between Bulhary, Sedlec and Poštorná.

Hydrocarbon deposits in deep structures,

on basis of sedimentar filling of Czech part of Vienna Basin have not been looked out in this area up to now. The areas 1—10 are described in great detail in the study of A. Zeman (1977). The area 11 is dealt with in the work A. Zeman et al. (1981).

Results of the research of recent tectonic movements using geodetic methods

The investigation by means of repeated geodetic measurement carried out during the last decade yielded a dynamic characteristic of explored area (Fig. 1), (Vyskočil — Zeman, 1980). It contributed considerably to the knowledge of mobility of the respective morphostructural areas. The geodetical measurement in charge of the Central Geological Survey in Prague were executed by the Research Institute of Geodesy, Topography and Cartography in Zdíby.

South-Eastern Moravia territory was covered by the levelling network, remeasured in 1971—1975 in the prevailing part of the territory under study. Selected parts of the territory were remeasured in the period 1976—1980. In the 1976—1979 another remeasurement of the main line of the state network was effectuated.

A map of vertical displacement based on the results of the 1971—1975 remeasurement has been constructed for south-eastern and partly for central Moravia (Vyskočil, 1978).

As far as the horizontal movements are concerned, spreading was found in Vyškov Gate depression as well as in the southern part of the Moravian Gate, in the Upper-Moravian Basin and in the Hradiště Graben.

All principal morphostructural units of the South and Central Moravia manifest themselves as mobile. From the geological analysis of the recent movements and their tendencies it can be inferred that they cor-

respond to the prolongation of the Lower Sarmatian geological processes of the territory under investigation. A correspondence was found between the motions of the earth surface and the distribution of accumulation and denudation areas in the course of the Quaternary. Insofar as the geodetic search for mobile structural elevations with occurrence of oils and gas is concerned, the deposits ascertained are in the area are joined, in most cases, with uplifting morphostructures (Fig. 1).

An geodetical investigation started in 1978 of recent earth's surface movements relative to the alternative filling and letting out of the underground gas reservoirs (Lobodice, Hrušky — Tvrdonice) and to the exploitation of the gas deposit of Dolní Dunajovice in the territory under consideration. Remeasurements were effectuated every three months e. g. on the gas reservoir Hrušky — Tvrdonice in 1978—1981.

It is evident from these remeasurements that the height differences at the earth's surface are of periodic character corresponding to the filling (April—October) and emptying (November—March) of the reservoir. The change of the gas pressure at the depth of about 1,100 m by about 6.5 MPa corresponds to an uplift (depression) on the earth's surface above the reservoir by about 8 mm (Fig. 2).

The deposit of natural gas of Dolní Dunajovice is intersected, in its central part, by a transverse remeasurement profile at the length of 7 km. In the profile three deep-founded bench marks and five pole bench marks are located. The results of measurements (1978—1980) confirm the fact established in other gas deposits (e. g. in Gröningen in the Netherlands) that all the points of the profile sink systematically during exploitation of the deposit. During the first year a sinking of as much as 6 mm occurred, during the following 7 months, the sinking being about 10 mm in one and

a half year, which corresponds with the average sinking of the ground surface during the exploitation of the deposit of about 0.5 mm per one month.

Of the two instances of experimental measurements, which continue at present, it becomes evident that the changes in tension under the earth surface in natural and artificial gas accumulation cause recordable changes in the heights on the earth's surface. It has been proved objectively that the gas migration in filling and emptying the underground reservoir can be followed by means of geodetic methods as a doming or a subsidence of the earth surface. A comparison of these results of investigation with the total earth surface dynamics implies an idea that some of motional tendencies outside the known gas deposits indicate perhaps the presence of natural oil and gas migration as well as the hydrocarbon deposits not detected as yet.

Research of paleo-reliefs

It follows from the results of the drilling prospection for oil and gas in our territory that, as significant reservoirs function weathered and jointed sediments, granitoids and metamorphosed rocks. The reservoir role of the fossil weathered rocks for oil and gas was pointed out in this territory already by V. Homola (1959), M. Dlabáč — E. Menčík (1964), F. Chmelík et al. (1969), D. Ďurica (in Schott — Stoppel, 1976).

We assume that weathered zones could promote also lateral migration of oil and gas especially from deeper parts of the platform westwards and north-westwards to the front of the superimposed Carpathian nappes. Only part of the migrating oil and gas could be trapped. In Central and South Moravia, 5 polygene paleoreliefs were examined (Fig. 3):

The Pre-Devonian polygenic paleo-relief

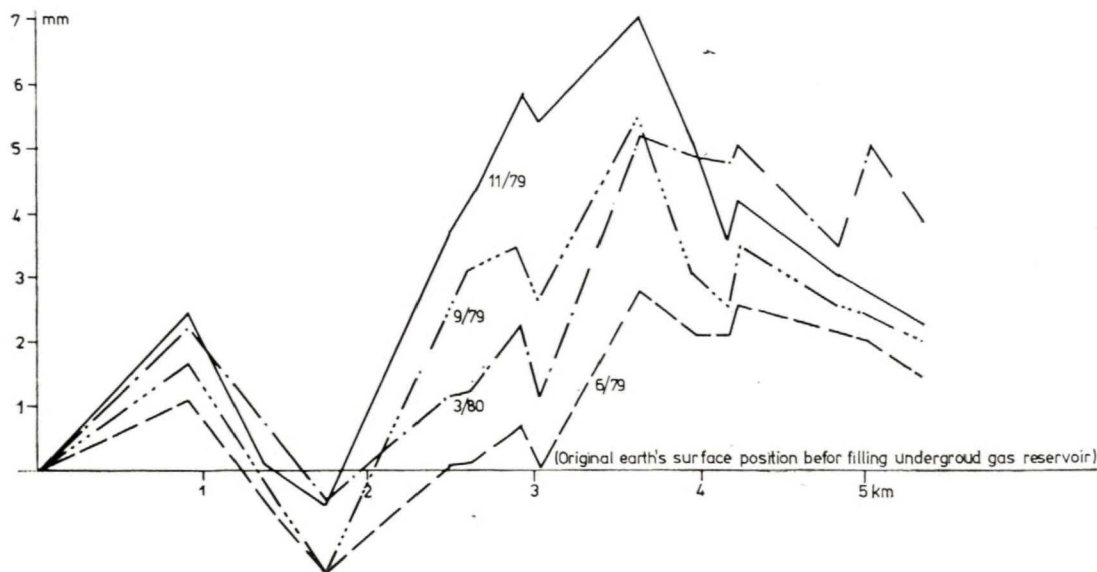


Fig. 2. Scheme of Earth's surface deformations above the operating underground gas reservoir Hrušky — Tvrdonice. The height differences are evidently of periodic character corresponding to the filling (April—October) and emptying (November—March 3/80 — data repeated levelling), (Vyskočil et al., 1980)

was examined in natural outcrops and in the borings. In the bed of the Svratka river in Brno — Pisárky and in the bores in the Moravian Karst region. The basement of the transgressive Devonian sediments is there constituted by the crystalline rocks of which displaying a caolinic weathering. The maximum thickness in the localities examined attained 10 m. The upper part of the weathered rock in the bed of the Svratka in Brno-Pisárky displays 28 % porosity and $240 \times 10^{-15} \text{ m}^2$ permeability. The weakly weathered basal part at the same site was 28 % porosity, but its permeability was $5.2 \times 10^{-15} \text{ m}^2$ only.

Middle-Devonian polygenic paleo-relief. The hiatus between Eifelian and Givetian sequence is evidenced by karstification of the limestone (Bezvodová, Zeman — in print). From the point of oil-gas prospection, attention should be drawn to this horizon inside the Devonian carbonates.

Upper-Paleozoic polygenic paleo-relief has been examined on the surface of Devonian limestones at Čebínka u Brna and on the crystalline rocks, West of Ostrovačice village, under the Permo-Carboniferous. In limestones it is represented by cracked and karstified clastics. The weathered crystalline zone attained a maximum thickness of 10–15 m.

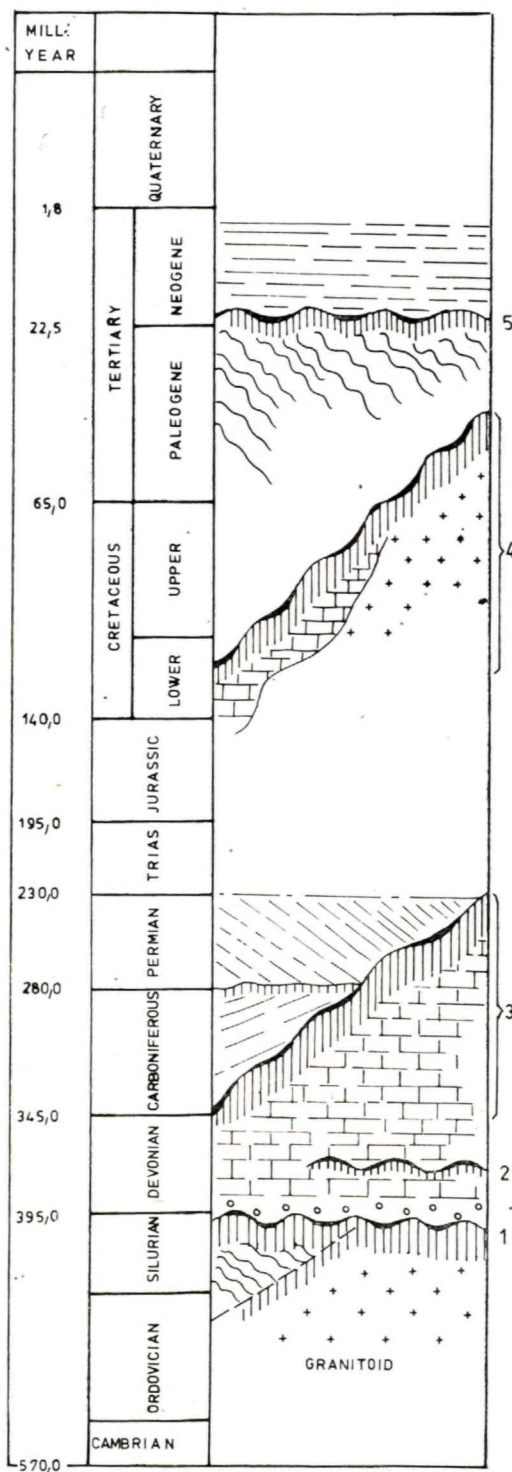
Cretaceous-Paleogene polygenic paleo-relief may be compared with the "global" peneplane, as conceived by I. P. Gerasimov et al. (1974).

It generally inclines in our territory to the South-East entering in this direction below Foredeep filling down to the depths of 1.5–2.5 km. During the Paleogene and at the Miocene times in the East and South-East, this surface was gradually covered by younger sediments and Carpathian nappes. The weathered rocks of the Cretaceous-Paleogene polygenic paleo-relief constitute, under convenient structural conditions, one of the main hydro-

carbon bearing horizons of the platform entering below the Carpathian foredeep and the Carpathian nappes. The age of individual weathering processes leading to peneplanization and deepweathering can be stated, due to the degree of investigation done and to the complexity of geological processes, only generally.

The weathering was intensive. A weathered rock zone developed on silicate rocks, and reaches down to the depth of several metres. Along the tectonic faults it reaches to the depth of some 100 m. It is exemplified by the locality of Blansko quarry (near the railway station). There is a 8–10 m thick layer of the weathered rock of the Brno plutonic body entering below the Upper — Cretaceous clastic sediments. The weathered granitoid rock passes gradually to the depth into the fresh rock. The porosity increases from fresh rock to weathered rock, from 3.6 % to 35.4 %, and the permeability changes from $0 \times 10^{-15} \text{ m}^2$ in fresh rock to $301.9 \times 10^{-15} \text{ m}^2$ in the upper part of the weathered rock. The extent of the Brno plutonic body suggests a large occurrence of this weathered rock horizon on the depressed margin of the platform beneath the Carpathian Foredeep and the Carpathian nappes. Different manifestation was displayed by the Cretaceous — Paleogene weathering on the Upper-Paleozoic conglomerate near town of Miroslav. In this locality carbonate matrix and limestone boulders of the conglomerate have been leached thus creating a rock of extreme permeability $1309 \times 10^{-15} \text{ m}^2$ and porosity 19.2 %.

Simultaneously with the caolinization of silicate rocks karstification of paleozoic and mesozoic limestones was going on at the margin of the Bohemian Massif. This is evidenced by an extensive Karst area in the Devonian limestones North and North-North-West of Brno, partially filled



with sediments of the Badenian. South-East of Brno, under the Carpathian Foredeep, a mogot Karst was moulded in the limestone of Jurassic and Devonian age (Švédské Šance by Brno, Měřín). These forms of Karstification continue possibly further to South-East below the Carpathian Foredeep and the flysch Carpathian. Austrian part of the foredeep the so-called "buried mountains" formed of limestones were described on the surface of the platform basement (Schott — Stoppel, 1976). By analogy with our territory a mogot Karst may also be involved. This is evidenced by the fact that karstification of Jurassic carbonates occurred also on our territory, namely in the Turol quarry, near Mikulov. In this quarry, which is founded in sub-silesian Ždánice unit, an unconformity between the sediments of the Upper Turonian and the underlying Jurassic limestone is visible. The surface of the limestone is rather uneven, covered with limonitic crusts. The limestone body is penetrated by a system of Karst hollows. Near Štramberk in North Moravia the Lower Cretaceous (Hauterivian) reposes transgressively on karsted limestones of the Kotouč hill. From these observations the conclusion can be drawn that under the Cretaceous-Paleogene paleo-reliefs there probably exist, in the places of occurrence of Devonian, Carboniferous and Jurassic limestones, well-developed Karst forms deeply buried below the foredeep filling and the nappes of the Outer Carpathians. These are very good prospective oil bearers, to which increased attention should be devoted.

Fig. 3. Stratigraphic position of the polygenic paleo-reliefs in the studied area. 1 — polygenic paleo-reliefs of pre-Devonian age, 2 — polygenic paleorelief of Middle Devonian age, 3 — polygenic paleo-relief of Upper-Paleozoic age, 4 — polygenic paleo-relief of Cretaceous, Paleogene age, 5 — polygenic paleorelief of Middle to Lower Miocene age

Middle-Lower Miocene polygenic paleo-relief is buried under the sediments of the foredeep and the Vienna Basin. The folded flysch complexes of the Carpathians in the below of the Viena Basin filling were affected by caolinic weathering. These occur also on the denuded margin of the Bohemian Massif. The Lower-Miocene weathered rocks accompany this paleo-relief on the surface of the flysch formations. The significance of the buried flysch relief as an oil bearing reservoir was summed up by K. Bílek (1977). Faults of predominantly South-Eastern and North-Western directions created elevations and depressions on the flysch relief. Under favourable conditions economically important output of oil as archived from this reservoir rock (Vacenovice, Týnec).

The results of the investigation of the buried paleoreliefs and their fossil weathered rocks in the context of geomorphological research indicate that this is one of the potential ways giving the prerequisites for classification of stratigraphic deposits of oil and gas in the contact zone of the Platform and the West Carpathians. The buried paleo-reliefs and their tectonically deformed levelled surfaces are being studied in USSR (cf. Gerasimov — Sidorenko, 1974). It follows from the world statistics that in productive areas, in which non-structural deposits were consistently searched for, the total number of deposits increased appreciably.

Conclusion

A geomorphological and geodetical research was going on in South Moravia in the last decade contributing to the prospection for oil and earth gas deposits. The geomorphological investigation was aimed at a morphostructural analysis searching for young elevation structures and to the

research of buried polygenic paleo-reliefs and their weathered rocks. The geodetic research established the youngest dynamics of the earth surface of the area in question. The knowledge of the dynamics is an important aid for the prospection for oil-gas structures. This broad approach to the solution of the given problems was used for the first time in our country. It has brought a good amount of positive knowledge both for the prospection for hydrocarbons and for related scientific fields. Application of these methods of research will undoubtedly contribute to the solution of the research problem in non — traditional areas of potential occurrences of oil and gas.

Review by Z. Roth

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Význam morfostruktur při vyhledávání ložisek ropy a zemního plynu v Západních Karpatech

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Československo-sovětskou expertizou o úkolu Výzkum hlubinné stavby v předhlubni a flyšovém pásmu Karpat bylo v r. 1971 mimo jiné doporučeno plně rozvinout geomorfologický a geodetický výzkum mladých pohybů zemské kůry. Při složité geologické stavbě a hornatém reliéfu mohou rozrušované mladé elevace vymezovat pasti uhlovodíků v subhorizontálních vrstvách. Cílem výzkumu byla především pomoc při vyhledávání elevačních pastí přirozených uhlovodíků v permském, paleogenním i neogenním platformním obalu pod příkrov flyšového pásma. Geomorfologické výzkumy byly zaměřeny na morfostrukturní analýzu vyhledávající mladé struktury a na výzkum pohřbených polygenetických paleoreliéfů a jejich zvětralin. Geo-

detickými pracemi byla zjištěna nejmladší dynamika zemského povrchu této oblasti, jejíž poznání je důležitou pomůckou pro vyhledávání struktur nadějných na naftu a plyn. Tento interdisciplinární přístup k řešení dané problematiky byl u nás použit poprvé. Přinesl řadu pozitivních poznatků jak pro vlastní úkol, tak pro příbuzné obory. Ve složitých geologických a orografických podmínkách moravských Karpat se ukázala užitečnost těchto prací i při těžbě plynových ložisek (Dolní Dunajovice) a provozu plynových zásobníků (Hrušky). Aplikace těchto metod výzkumu nepochybně přispěje k řešení problému výzkumu v netradičních oblastech možných výskytů přirozených uhlovodíků.