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RECENT VERTICAL MOVEMENTS OF THE EARTH'S CRUST IN THE WEST CARPATHIANS

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Les auteurs interprètent dans l'étude la carte des mouvements verticaux récents de l'écorce terrestre dans les Carpates occidentales, qui a été dressée des résultats du nivelage complet de la région carpato-balkanique pour l'époque de 1948—1964. La carie est à lechelle de 1:1 mil. Des analyses des mouvements néotectoniques et de leur comparaison avec les mouvements récents il résulte un degré élevé de la correlation surtout dans les régions montagneuses. Les affaissements prédominent dans les plaines à l'exception de la plaine de la Slovaquie de l'Est. La carte dans ses traits fondamentaux reflète la structure de bloque des Carpates occidentales. Les relèvements les plus grands ont lieu dans le bloque fatro-tatrain. dépassant la valeur de +2,5 mm/année. L'amplitude totale des mouvements verticaux récents dans la région des Carpates occidentales pour la période indiquée atteint environ 6,0 mm/année.

INTRODUCTION

Recently the study of recent movements of the Earth's crust is growing into one of topical tasks of geo-scientific disciplines. The knowledge of recent dynamics of Earth's crust and the knowledge of tendency of its development has a principal significance for geodesy, geophysics, geology, geomorphology as well as for practical application of these scientific disciplines. In the Slovak Socialist Republik the solving of these problems is very topical, as the West Carpathian mountain system belongs to a young orogenetic system. An interdisciplinary approach is applied in the study of these problems.

The Geodetic Service of the ČSSR closely cooperates in the research of recent vertical movements of the Eart's crust of the Carpathian-Balkan area (CBA) within the working group 3.1 of the Commission of multilateral cooperation between the academies of sciences in socialist countries, namely on the complex problem „Planetary Geophysical Investigations" (PGI, or KAPG), with the theme 3.1.5 „Study of vertical movements of the Earth's crust in the territory of the CBA". The common research works in this theme are being realized according to a program approved at international sessions and special workers from Bulgaria, Czechoslovakia, Hungary, GDR, Poland, Roumania, Yugoslavia and USSR take part in them. The theme is coordinated in Hungary. In the ČSSR this is coordinated by the Research Institute of Geodesy and Cartography in Bratislava [16]. Also the Geographical Institute of the Slovak Academy of Sciences is in cooperation within the research of recent vertical movement.

The first main task on this theme lay in compiling a map of recent vertical movements of the Earth's crust in the CBA as orogenetically unified mountain system and its interpretation. As the basis of the map both geodetic and oceanographic materials were used, which is at disposal in the countries of the CBA and this was completed by data (selected lines) from the GDR and Poland. In this way, a network has arosen for the CBA, which is connected with 9 mareographs dislocated on the coast of the Baltic Sea, Black Sea and Adriatic Sea. Its complete equalizing has been realized by the Geodetic Service of the Hungarian People's Republic according to the way of conditional measurements on a computer IBM 360/40 [7]. From the results of the complete equalizing a map of recent vertical movements of the Earth' crust in the Carpathian-Balkan area has been compiled to a scale 1:1 million [5]. The territory of interest within the CBA is situated on 2 map sheets with dimensions 100×65 centimetres. An equidistance conic projection in a normal position has been used for the basic maps. The map of the CBA covers the territory of the ČSSR approximately as far as geographic coordinates $\varphi = 49^\circ 50'$, $\lambda = 16^\circ 10'$ (i. e. all the territory of Slovakia and a part of the Czech Socialist Republic).

The research of the recent vertical movements in the CBA was reported on international interdisciplinary symposia on the occasion of the XVIth General Assembly of the International Union of Geodesy and Geophysics — IUGG in Grenoble [4] and of the XVIIth General Assembly of the IUGG in Canberra [6].

In the submitted contribution we shall deal only with the territory of the West Carpathians in Slovakia.

GEODETIC BASIS OF THE MAP

The geodetic basis of the map is formed by a network of repeated levelling, which consists of 90 polygonal sides forming 26 closed polygons and 9 free polygonal sides. The time intervals Δ_t between repeated levellings range from 5 to 31 years. The estimate of precision of the network was made by the Lallemand formulas (complete mean errors).

The lst levelling $m_1 = 0{,}96$ mm per kilometre.

The 2nd levelling $m_2 = 0.53$ mm per kilometre.

The total lenght of the polygonal sides makes 3,961 kilometres (of them 175 kilometres fall to the free polygonal sides) and the total number of levelling points used to compiling the map makes 652. The average distance between neighbouring levelling points makes 6.1 kilometres. For the first levelling the results of the lst Czechoslovak levelling from 1920—1938 as well as those of the 2nd levelling from 1939—1960 were used. For the second levelling the results of the 2nd Czecoslovak levelling (1939—1960) and those of the repeated levelling from 1961—1972 werre used. For the lst levelling the mean of the period is referred to year 1947,6 regarding the length of tractions measured in the individual years, for the 2nd levelling is done to year 1963,9. The mean time interval is 16 (16.3) years.

The part of the network used for the repeated and the 2nd Czechoslovak levellings to be compared makes 79 percent from the total size of the network, namely 3,115 kilometres, while the part used for the 2nd and lst levelings to be compared makes 21 per cent, namely 846 kilometres. Only the levelling lines Horná Štubňa—Brezno—Vernár, Šahy—Lučenec—Lenártovce, Poprad — Vernár—Rožňava—Lenártovce, Poprad—Obišovce, Rožňava—Barca—Čerhov,

Prešov—Obišovce—Barca, Kraľovany—Trstená, Bratislava—Jarovce and Komárno—Komárno represent a geodetic basis of a lower precision. From the mentioned it results that a substantial part of the geodetic basis of the map has been formed from a good and relatively detailed network of the repeated levelling, for which the results of the latest measurings have been used. The density of selected levelling points is not the same in all the network. It is greatest in the Danube Lowland, least in the middle part of Slovakia (Map. 1).

Nine basic levelling points were taken into the network. Further points stabilized on churches, on old and well consolidated public buildings and family houses were selected, in the Danube Lowland also deep stabilizations and subsurface levelling stones were used. The perimeters of the polygons range from 88 to 347 kilometres, in average 227 kilometres. Of the total number of closures 1 exceeds 5 mm per year (5,31), 3 range from 3 to 4 mm per year, 12 do from 1 to 3 mm per year and 10 to 1 mm per year.

MATHEMATICAL TREATMENT OF THE RESULTS OF THE REPEATED LEVELLING AND THE MAP COMPILATION

The absolute rates of movements of all the points (652) of the network have been assigned in a well-known procedure (by dividing the deviations proportionally to the lengths of spans) from the equalized absolute rates of movements of nodal points of the complete equalization of the CBA. The set of data of the absolute annual rates of movements of all the selected levelling points formed the basis to compile a national map of recent vertical movements of the Earth's crust (the maps of the West Carpathians to a scale 1:1 million — Map. 2).

The absolute annual rates of movements being related to the mean levels of the Baltic, Black and Adriatic Seas are represented by isolines with an interval of 0.5 mm per year. The hypothetical isolines are marked in broken lines. Owing to a better orientation more significant towns are plotted in the map.

BASIC FEATURES OF THE RELIEF

The West Carpathians in their present-day shapeness are a young mountain system, which arose in the neotectonic period of the development of the Earth's crust, alternating the previous geosynclinal stage. The neotectonic development in the West Carpathians begins by the Upper Badenian, continuing also in the Quaternary.

The characteristic feature of the surface shapeness of the West Carpathians is their inner dissection, when two contrary forms alternate in short distances, namely the mountain groups and intramontane depressions — the basins — incised between them. The mountain groups form above all arches, arch-horsts and horsts, while the intramontane depressions, or also the near-Carpathian depressions are of a nature of grabens. The relief of the West Carpathians underwent in the neotectonic period some phases of levelling, which were interrupted by intensive vertical movements as it may be seen from the remnants of three denudation surfaces occurring in respective mountain ranges. On the basis of the correlation between the levelled surfaces and the Neogene sediments in the near-Carpathian depressions the total extension of the Neotectonic movements in the West Carpathians was assigned,

attaining above 6,000 metres [19]. In the second half of the Neotectonic stage, i. e. in the period of the Middle Pliocene and the Quaternary, in the West-Carpatian area the following morphostructural units were individualized: the near-Carpathian depressions, middle mountains and high mountains, separated from each other by intramontane basins.

Of the West-Carpathian mountain ranges the Vysoké Tatry Mts (the Gerlachovský Štít 2655 metres above sea level), the Západné Tatry Mts, the Nízke Tatry Mts and other mountain ranges with glacial, or almen relief were most uplifted. Next to the glaciation, or next to the intervention of mountain ranges above the upper timber line, further morphological phenomena as evidence for the Quaternary movements can be quoted, like the unbalanced gradient curves of the brooks, the convergence of terraces along the streams, the occurence of facetted slopes, the phenomena of antecedence, shiftings of river streams and the like. Analogical evidence can be quoted also for the area of middle mountains.

Of the lowlands the Danube Lowland was subsiding most intensively, where the thickness of Quaternary sediments in its central parts attains above 300 metres. The present-day surface of lowlands is situated within an extension from 94 to 190 metres above sea level. Differentiated subsidences mainly of the Danube and the East Slovakian Lowlands, next to a considerable thickness of the Quaternary sediments, is inferred by us further from the missing of river terraces, from the changes of river network, from sand dunes, peat bogs and fossile soil horizons buried under the present-day surface of the lowland. To the recent vertical movements in these areas attention is called also by a frequent occurrence of earthquakes.

Further evidence of the occurrence of the Pleistocene movements, which are, as a rule, closely, connected with the present-day movements is afforded by the results of the study of periglacial alluvial cones in the intramontane basins and piedmont areas. The slope streams with their erosive activity, or by accumulation react on movements of the individual blocks. On the uplifting blocks the periglacial alluvial cones are terraced, while on the subsiding blocks the elder cones are deposited under the younger ones and also morphologically they manifest themselves very slightly. Such examples of a differentiated movement of blocks in relatively short distances occur on the foots of the Vihorlat, Slánske Vrchy, Vtáčnik, Malé Karpaty Mts and in other places. The extinction of volcanic activity in the Cerová Vrchovina Mts and in the valley of the Hron, further frequent occurrences of travertines, mineral springs and earthquakes sufficiently call attention to a young to present-day tectonics being alive in the West Carpathian area.

INTERPRETATION OF THE MAP OF RECENT VERTICAL MOVEMENTS IN THE WEST CARPATHIANS

The map submitted, in basic features, reflects recent vertical movements in the West Carpathians. Going out from the course of levelling network we can state that it runs mostly along the valleys and basins and only in a few cases it transits across the ridges of mountain ranges, in other words, it does not express sufficiently movement intensity in considerably large areas. They are namely the mountain ranges, where on the basis of the knowledge of geomorphology, neotectonics and Quaternary geology we could expect a grea-

ter differentiation of vertical movements. The map submitted reflects larger morphostructural units — the neotectonic blocks laid out by O. Fusán et al. [1], J. Kvitkovič, J. Plančár [11], O. Fusán, J. Imbrmajer, J. Plančár [2].

On the map the subsidence area of southwestern Slovakia confined by a subsurface fault on the line Trenčín—Banská Štiavnica stands out markedly. The subsurface fault mentioned southeast of Banská Štiavnica is crossed by another subsurface fault running from Poprad to Nové Zámky and Komárno. The area of southwestern Slovakia confined in this way belongs to the Danubian block. Only the marginal NW part belongs already to the Moravian-Slovakian blocks. The Danubian block and also the Moravian-Slovakian blocks have in general a subsidence tendency, with maximum subsidences —3.1 millimetres per year. Only near Trnava a marked region is situated with uplifts attaining values of +1.6 millimetres per year. To the subsidence area also morphostructures of a horst character are included, mainly the Malé Karpaty, Považský Inovec and Tríbeč Mts, which are built of Paleozoic and Mesozoic rock complexes predominately. The morphostructures mentioned stand out in the relief very markedly and by the Považský Inovec they attain as much as 1.042 metres above sea level. On the foot of the Malé Karpaty Mts seismoactive fault disturbances run [12]. The central parts of the Danubian block manifest themselves in the Quaternary period as accumulation, i. e. subsidence areas. The subsidence area of the Danubian block is marked for expressive positive gravity anomalies and lesser thicknesses of the crust, namely 24 to 30 kilometres [11]. The other part of Slovakia belongs according to the map, excluding some local exceptions (in the Slovakian-Polish borderland north of Poprad and in the East-Slovakian Lowland north of Michalovce), to the uplifting area. By these facts this submitted map differentiates from the survey maps of recent vertical movements of the Earth's crust published up-to-day and covering the territory of Slovakia [9, 21, 22, 17].

The East-Slovakian block covers the SE of Slovakia. In the west side it is confined by the Hornád fault system on the line Prešov—Košice and in the northeast by a subsurface disturbance on southern margin of the klippen zone running in the area of Humenné. On western and northern margins of the block-volcanic structures of a horst nature appear markedly, namely the Slanské Vrchy and Vihorlat with Popričný Mt. These were uplifted above their surroundings as much as 900 to 1200 metres by young movements in the Pliocene and Quaternary [19]. Less exposed are the morphostructures built by Paleozoic and Mesozoic rocks, namely the Zemplínske Vrchy and Humenské Vrchy. In these morphostructures the uplifts attain in the Neotectonic stage 400—600 metres. On the map submitted the mentioned mountain ranges manifest themselves by unambiguous uplifts from 0.0 to +2.0 mm per year analogically as also the Košice Basin and the East Slovakian Lowland. From the geomorphological and Quaternary-geological view point the latter two morphostructures should belong to subsidence areas. This fact is reflected also in the formerly compiled map of recent movements of the Earth's crust, mainly by J. Kvitkovič, J. Vanko [9], Y. A. Meshcheryakov et al. [21], P. Marčák et al. [17]. The subsidence of this area can be inferred by us also from conspicuous positive gravity anomalies and lesser thicknesses of the crust (24—32 kilometres), which are very near to those in the Danube Lowland [11]. The Pleistocene and Holocene subsidence in the East Slovakian Lowland is documented

by a basis of loess sheets spreading under the level of contemporaneous streams, further by the occurrence of buried horizons of fossile soils in a structural plain, by the aggradation ramparts to be enlarged and by the thickness of the Holocene sediments, which range from 2 to 8 metres. The incorporation of the East Slovakian Lowland to the area of uplifts results probably from an unhomogeneous starting material taken as the basis to compile the map of the Carpathian-Balkan area, a part of which is also the analyzed map.

The extensive area of southern Slovakia between the Danube block and the East Slovakian block is covered by the South Slovakian block, which is broken to partial blocks. From the morphological viewpoint the matter is predominantly in a middle mountain area with occurrence of intramontane basins. Significant is the elongated Lučenec-Kočice lowering, which is marked for a hilly relief river terraces and periglacial alluvial cones. All the area of the South Slovakian block was uplifting differentiately in the Neotectonic period. The uplifts range here from 900 to 1200 metres [19]. At present a predominant part of the block displays uplifts ranging from +1.0 to +1.5 mm per year. Only the southwestern part of the block in the Danube Lowland, between Šahy and Komárno, subsides with intensity from —0.5 to —2.0 mm per year.

Northern Slovakia is marked for uplifts ranging from 0.0 to +3.0 mm per year. It consists of three blocks. In the middle part it is the Fatra block, in western part between Dolný Kubín—Žilina and Trenčín the Slovakian-Silesian block spreads, and the northeastern part of the territory, in a wider area of Bardejov and Humenné, is covered by the Beskydy-Bukovian block.

The Fatra-Tatra block is confined from the northern side by a subsurface fault running along the edge of the klippen zone. At the same time, it is a marked seismo-active zone [12]. In SE in a considerable span it is in contact with the South Slovakian block, along the Vepor subsurface fault and in SW it is confined by a subsurface fault on the line Banská Štiavnica—Trenčín. The block is broken to partial blocks. All the area of the Fatra-Tatra block is marked for intensive negative gravity anomalies of ca 400 μ m.s^{-2} and the Moho depth attains here 30—42 kilometres. Above all morphostructures with a high mountain relief belong to this area, which in the course of the Neotectonic period was uplifting by 1500—2000 metres, even also more. The Vysoké Tatry Mts, the Nízke Tatry Mts, Veľká Fatra Mts belong here. Further middle mountains of a type of berglands and gebirgslands occur here, namely the Strážovské Vrchy Mts, Žiar Mts, Kremnické Vrchy Mts, Skorušina Mts, Spišská Magura Mts and others. This block is marked for largest intramontane basins, namely the Poprad, Hornád, Liptov, Turiec, Žilina, Upper Nitra and Zvolen Basins.

South of Dolný Kubín, in the area of the Fatra-Tatra block, a region with the most intensive uplifts within the West Carpathians at all is situated, with more than +2.5 mm per year. The region mentioned is situated in the western part of the Liptov Basin incised between the Chočské Vrchy, Veľká Fatra, and Nízke Tatry Mts. Its appearance in the morphostructure mentioned is unexpected and calls for a more detailed investigation. The most intensive uplifts in the West Carpathian area are supposed in the Vysoké Tatry and Nízke Tatry Mts, which belong to the highest mountain ranges in the West Carpathians. Alas, across the quoted morphostructures, except small exceptions, no levelling network runs. The hypotheses of geomorphologists of the occurrence

of more intensive recent uplifts in the morphostructures mentioned have been confirmed by L. Hradilek [3], who by means of three-dimensional triangulation ascertained uplifts with +8.4 mm per year on the Baranec Mt in the Západné Tatry Mts.

The Slovakian-Silesian block covers NW Slovakia. It belongs already to the Outer Zone of Flysch Carpathians, which is confined from southeast by a subsurface fault along the klippen zone. The block proper is marked for differentiated movements ranging from 0.0 — +1.5 mm per year. It becomes apparent that the most intensive uplifts with +1.5 mm per year belong morphologically to the most exposed erosive-tectonic massifs of the Babia Hora and Pilsko Mts in the Slovakian-Polish borderland. The Moho depths attain here ca 38 kilometres and the negative gravity anomalies do 300 to 400 μ m.s^{-2} [11]. The recent vertical movements with and intensity of +0.5 — +1.0 mm per year manifest themselves in erosive-tectonic massifs of a type of berglands to gebirgslands, namely in the Javorníky, Slovenské Beskydy, Oravská Magura Mts and others.

The Beskydy-Bukovian block is built of the Outer Flysch zone and covers NE part of eastern Slovakia. In the south it is confined by a subsurface fault along the klippen zone. In the territory erosive-tectonic morphostructures of a type of berglands and gebirgslands are situated. In the Neotectonic period this area was uplifting with values of to 1,200 metres [19]. The recent vertical movements attain values of +1.0 to +2.0 mm per year mainly in the area of the Slovakian-Polish borderland. The sandstone massif of the Bukovské Vrchy Mts stands out conspicuously with values of +1.5 mm per year. The intensity of gravity anomalies in the Beskydy-Bukovian blocks is ca 100 μ m.s^{-2} and the Moho depth reaches to 40—48 kilometres.

It results from the characteristics and intensity of recent vertical movements in northern Slovakia that the Fatra-Tatra block has been uplifting more intensively regarding the neighbouring blocks on its western and eastern edges. We judge that probably the matter is in inherited movements from the Neotectonic period.

CONCLUSION

The submitted map of recent vertical movements in the West Carpahians has been compiled of the results of complete equalization of the Carpathian-Balkan area for a period 1948—1964. It reflects the general tendency of recent vertical movements of this young mountain range in the territory of the Slovak Socialist Republic. From the map conspicuously stands out an extensive subsidence area of SW Slovakia, which, in general, corresponds to the Danube block [1, 2, 11] and the marginal parts of the neighbouring blocks. The subsidences locally attain also more than —3,0 mm per year. Next to the Danube Lowland and the Záhorie Lowland, to this recently subsiding area belong also the marked horst morphostructures of the Malé Karpaty Mts, Biele Karpaty Mts, Považský Inovec Mts, Tríbeč Mts, Pohronský Inovec Mts and Vtáčnik Mts. Except two lesser regions in eastern Slovakia, the other part of the territory of Slovakia belongs to the uplifting area. The Fatra-Tatra block with values of +0.5 to more than +2.5 mm per year has been uplifting most intensively. An analogical tendency is also in the Beskydy-Bukovian block in NE area of Slovakia. In the mountain area of the West Carpathians, a relati-

vely high correlation degree manifests itself between the tendencies of the movements of the Neotectonic period and the recent movements. The study of recent vertical movements of the Earth's crust becomes one of topical tasks of geoscientific disciplines in the last time, namely both from the theoretical viewpoint and from that of practice. The practice needs the knowledge of recent dynamics of the Earth's crust, mainly in projecting new settlement, plants and extensive investment wholes. The gained attainments of recent vertical movements of the Earth's crust are a contribution for the aims mentioned.

Map. 1. Selected levelling points in the West Carpathians with values of recent vertical movements from the complete equalization of the Carpathian-Balkan area (in enclosure).

Map. 2. Recent vertical movements in the West Carpathians from the results of the complete equalization in the Carpathian-Balkan area.

1 — Isolines of the rate of vertical movements (mm per year). 2 — hypotethical isolines of the rate of vertical movements (mm per year) (in enclosure).

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RECENTNÉ VERTIKÁLNE POHYBY ZEMSKEJ KÔRY V ZÁPADNÝCH KARPATOCH

Predložená mapa recentných vertikálnych pohybov Západných Karpát bola zostavená z výsledkov súborného vyrovnania karpatsko-balkánskej oblasti pre epochu 1948—1964. Odzrkadľuje všeobecnú tendenciu recentných vertikálnych pohybov tohto mladého horstva na území Slovenskej socialistickej republiky. Z mapy nápadne vystupuje rozsiahla poklesová oblasť juhozápadného Slovenska, ktorá v zásade zodpovedá podunajskému bloku [1, 2, 11] a okrajovým častiam susedných blokov. Poklesy lokálne dosahujú viac ako —3,0 mm/rok. Do tejto recentne subsidenčnej oblasti popri Podunajskej nížine a Záhorskej nížine patria aj výrazné hrasťové morfoštruktúry Malých Karpát, Bielych Karpát, Považského Inovca, Tríbeča, Pohronského Inovca a Vtáčnika. Ostatná časť územia Slovenska, s výnimkou dvoch menších regiónov na východnom Slovensku, patrí do zdvihovej oblasti. V tomto zmysle predložená mapa sa odlišuje od viacerých doteraz publikovaných máp [9, 11, 17, 21, 22], v ktorých širšia oblasť Východoslovenskej nížiny patrila podobne ako Podunajská nížina do regiónov s poklesovou tendenciou. Začlenením Východoslovenskej nížiny do oblasti zdvihov pravdepodobne vyplynulo z nerovnorodého východiskového materiálu, ktorý bol vzatý za základ pre zostavenie mapy karpatskobalkánskej oblasti, súčasťou ktorej je aj analyzovaná mapa. Najintenzívnejšie sa zdvíha fatransko-tatranský blok s hodnotami +0,5 až viac ako +2,5 mm/rok. Podobnú tendenciu má aj beskydsko-bukovský blok v severozápadnej oblasti Slovenska. V horskej oblasti Západných Karpát sa prejavuje dosť vysoký stupeň korelácie medzi tendenciami pohybov neotektonického obdobia a súčasnými pohybmi. Štúdium súčasných vertikálnych pohybov zemskej kôry sa stáva v poslednom období jednou z aktuálnych úloh geovedných disciplín, a to tak z hľadiska teórie, ako aj praxe. Prax potrebuje poznatky o súčasnej dynamike zemskej kôry, a to najmä pri projektovaní sídlisk, závodov a rozsiahlych investičných celkov. Získané výsledky o recentných vertikálnych pohyboch zemskej kôry sú prínosom.

Mapa 1. Vybrané nivelačné body Západných Karpát s hodnotami recentných vertikálnych pohybov zo súborného vyrovnania karpatsko-balkánskej oblasti (v prílohe).

Mapa 2. Recentné vertikálne pohyby Západných Karpát z výsledkov súborného vyrovnania karpatsko-balkánskej oblasti. 1 — izočiary rýchlosti zvislých pohybov (mm/rok), 2 — predpokladané izočiary rýchlosti zvislých pohybov (mm/rok) (v prílohe).