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JAROMÍR DEMEK

GEOMORPHOLOGICAL MAPPING: PROGRESS AND PROBLEMS

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The author deals in his paper with the present-day state of geomorphological mapping on world-wide scale, mainly on the basis of the activities of the IGU Commission on Geomorphological Survey and Mapping in 1968—1976.

INTRODUCTION

In the last three decades geomorphological mapping achieved an important position in geomorphological research. Geomorphological mapping is nowadays the main research method of geomorphology in many countries. The geomorphological map is no more only a supplement of the text but an independent and indispensable result of geomorphological research. It is thus of great significance for the knowledge of relief of our planet on different levels since it reflects in a telling way the spatial interrelations and associations of various relief elements. The compilation of a geomorphological map requires more detailed investigations of relief than the text, a system approach to the study of relief and the selection of information obtained from the viewpoint of the map purpose.

The heterogeneity of the Earth's relief, the difference in scales and the various demands on geomorphological maps caused a considerable variety of their contents and legends in various countries and even in the individual scientific centres of the different countries. Recently, after 1970, a new development of geomorphological mapping took place in connection with some changes in geomorphology as a science. These changes can be briefly characterized as follows:

a) Better understanding of relief as the result of contradictory interactions of endogenic and exogenic factors owing to better rapprochement and interpenetration of geomorphology with geophysics and tectonics. New results of geophysical studies of the Earth's crust and the Earth's mantle, new geotectonic theories (such as for instance new global tectonics) and the development of methods of investigations of the Earth from the space resulted in the formation of a morphostructural tendency in geomorphology understanding better the relationship of relief to endogenic processes, mainly to those taking place in the upper mantle, and to fault tectonics.

b) Better understanding of relief as one of the basic parts of the landscape sphere of our planet in which life and activities of human society take place; relief affects substantially the activities of man by its properties and the dynamics of various geomorphological processes; man affected on the contrary — accelerated or retarded — the course of most geomorphological processes influencing thus substantially the development of relief. These facts resulted in the origin of a new branch of geomorphology, the so-called ecological geomorphology.

c) New methods of geomorphological research, mainly air and satellite photos, radar images and their processing by computers result in a considerable increase of the amount of information on relief and the possibility of fast cartographical elaboration. These facts support the development of constructive tendencies in geomorphology and the possibilities of geomorphological prognosis increasing simultaneously the practical significance of geomorphology mainly in the solution of one of the main problems of present-day mankind — the questions of complex care of environment.

New trends in geomorphology increased substantially the theoretical and practical significance of geomorphological maps. In this connection the interest in geomorphological mapping increased considerably manifesting itself in the higher number of publications dealing with geomorphological mapping and that of maps published in various countries (cf. D. V. Borisevich-E. A. Lyubimceva 1971, L. R. Serebryany 1973). New handbooks devoted to methods of geomorphological mapping also appeared (A. I. Spiridonov 1970, 1975; I. P. Gerasimov 1970, J. F. Chemekov et al. 1972, N. V. Bashenina et al. 1975).

The IGU Commission on Geomorphological Survey and Mapping published in 1972 an international methodical handbook, the Manual of Detailed Geomorphological Mapping (J. Demek, ed. 1972) and in 1976 the Guide to Medium-Scale Geomorphological Mapping (J. Demek-C. Embleton, eds. 1976).

In spite of this progress in geomorphological mapping there still exists a number of problems to be tackled. In the following text attention will be paid to some problems of geomorphological mapping on international scale as they follow from the activities of the IGU Commission on Geomorphological Survey and Mapping.

PROBLEMS OF THE CONTENT OF GEOMORPHOLOGICAL MAPS

The geomorphological map is a system of information representing a model of geomorphological geosystems existing really in relief.

Owing to the increasing amount of information on relief their recording on a single map becomes still more difficult. Therefore, even with geomorphological maps complexes develop (such as morphostructural, chronological, dynamic maps, etc.) similarly as in geology where lithological, stratigraphical, Quaternary, tectonic, etc. maps exist. But I am nevertheless of the opinion that the conception of a general geomorphological map should be aimed at representing in a suitable selection of information the appearance, genesis and age of the relief. The general geomorphological map with this content is then a basis for partial, special and applied geomorphological maps.

On general geomorphological maps three categories of objects are usually represented in dependence on scale, such as:

a) parts of relief forms, i. e. elementary surfaces (sometimes called genetically homogeneous surfaces) and edges separating them.

b) relief forms i. e. three-dimensional objects of various dimensions and complexity.

c) relief form associations i. e. form complexes forming natural geomorphological complexes (relief types, morphostructures etc.).

Geomorphologists usually represent on detailed geomorphological maps (1:10,000—1:100,00) parts of relief forms, and on geomorphological maps on scales below 1:1 mill. relief form associations. Most problems occur with medium-scale maps on scales between 1:100,000 and 1:1 mill. Some authors are of the opinion that relief forms and their parts can be represented even on medium-scale maps inclusive of maps on 1:1 mill. For instance in the USSR, the Type legend for geomorphological maps on different scales compiled by G. S. Ganeshin-V. V. Soloviev-J. F. Chemekov has been accepted for geomorphological maps on 1:1 mill. prepared within the frame of the State Geological Map of the USSR on 1:1 mill. The base of the legend is the mapping of genetically homogeneous surfaces separated by edges (J. F. Chemekov et al. 1972, p. 245). On the geomorphological map of the GDR on 1:750,000 involved in the new National Atlas of the GDR relief forms will be represented.

But the IGU Commission on Geomorphological Survey and Mapping accepted after a longer discussion the recommendation that maps on scales from 1: 100,000 to 1:500,000 be compiled as maps of relief forms and their parts and maps on scales between 1:500,000 and 1:1 mill. as maps of relief form associations on the basis of morphostructures.

Maps of relief forms are indisputably more suitable mainly in practical application than those of form associations. But, on the contrary, they exhibit a number of disadvantages mainly if scales smaller than 1:500,000 are concerned, such as:

a) maps of relief forms on scales smaller than 1:500,000 are not lucid enough and become a mosaic of minute difficultly discernible areas; they represent insufficiently the appearance, mainly the plasticity of relief.

b) in the effort for generalization joining of various forms and, accordingly, formation of form associations take place.

c) maps of relief forms express only difficultly neotectonic relief deformations mainly of megaanticline and megasyncline types.

The application of one legend for geomorphological maps on various scales is certainly attractive but the legends proposed so far do not meet all requirements. In the case of maps on scales smaller than 1:500,000 maps of from associations are to be preferred.

PROBLEMS OF REPRESENTING GEOMORPHOLOGICAL OBJECTS

Geomorphological maps are a type of thematic maps and, therefore, governed by laws of thematic mapping. To represent geomorphological objects on geomorphological maps background colouring, conventional symbols and indices (characters, ciphers) are used. In background the fundamental tone and the tints are distinguished.

In thematic mapping the rule is valid that most efficient representation means are used for most important information involved in the map. In the case of general geomorphological maps most geomorphologists consider relief genesis most important. This is why colour is mostly used on general geomorphological maps to represent the genesis of geomorphological objects. But geomorphological maps are multi-layer maps and the colour tints must therefore express even another information of the content. Mostly two combinations occur, such as:

a) representation of the genesis of geomorphological objects by fundamental tone and their age by a tint of the fundamental tone (e. g. M. Klimaszewski 1968).

b) representation of the genesis of geomorphological objects by fundamental tone and of their inclination by a tint of the fundamental tone (e. g. J. Demek 1969). A. I. Spiridonov (1975, p. 13) mentions that the angle of slope can be estimated on the basis of contours which are an integral part of the topographical base of the geomorphological map. Our experience has shown that the contours are not sufficient to represent the plasticity of the relief and that even in the thematic content of geomorphological maps the slopes are to be distinguished according to their angle the inclinations having to be represented by tints of fundamental colours according to the principle the steeper the slope the darker the tint. The contours together with spot elevations allow to establish the absolute height position of the forms. But the general geomorphological maps must involve necessarily a classification of slope angles perceptible from the map at first sight. The IGU legend uses therefore the following classification of slopes: 0—2°, 2—5°, 5—15°, 15—35°, 35—55° and over 55°. This classification is not only of theoretical but even practical significance (cf. J. Demek, ed. 1972).

Another problem is the use of colours for genetic groups of geomorphological objects. For instance, in geomorphological mapping the forms are divided according to their genesis into glacial, fluvioglacial, cryogenic, marine, lacustrine, anthropogenic, etc. forms. Within these groups erosion-denudational and depositional forms are usually distinguished. The problem is if one fundamental colour is to be used for each genetic form group or if two colours are to be used separately for erosional and separately for depositional relief forms.

The IGU Commission on Geomorphological Survey and Mapping recommended to distinguish by fundamental colours erosion-denudational and depositional forms for the following reasons:

a) erosion-denudational forms and depositional forms express two different tendencies in relief development in dependence on tectonic movements and climatic changes and their distinction reflects simultaneously the trend of geomorphological evolution

b) the distinction increases the legibility of the map and allows to establish easier the chronology of the area represented

c) the distinction improves the plasticity of the map from cartographical point of view.

A. I. Spiridonov (1975, p. 14) objects that this mode of division used in the IGU Unified key to the detailed geomorphological map of the world (N. V. Beshenina — J. F. Gellert — F. Joly — M. Klimaszewski — E. Scholz 1968) results in the division in substance of some relief forms and

elements and in the joining of forms of various genesis. He quotes as an example a talus and an accumulation river terrace which are represented by the same green colour and an accumulation and erosion river terraces represented by various colours (green and brown). In spite of this fact being a certain disadvantage the positive qualities mentioned in the previous paragraph prevail over the disadvantages.

The fact should be taken into consideration that in the construction of the legends to geomorphological maps the use of a high number of colour tints should be limited mainly for two reasons:

a) better legibility of the map

b) lower costs of map print which are rather high mainly in the case of systematic mapping affecting thus unfavourably the possibilities of the publication of maps.

In the legend mentioned 9 fundamental colours and 45 tints have been used. A cartographical analysis has shown that, for instance, in the case of small yellow areas the distinction is rather difficult.

The representation of bedrock and superficial deposits by colours on geomorphological maps used for instance usually on French geomorphological maps is unsuitable. French geomorphological school achieved great success in geomorphological mapping not only of France (cf. e. g. A. Journaux 1969, 1971, 1973, etc.) but even of various other regions of our planet. But certain specific relief properties of France and North Africa affected unsuitably the legend of French geomorphological maps. Lithology should not be neglected in any case on geomorphological maps because mainly erosion-denudational forms depend to various extent on the rocks of the bedrock (their composition, deposition, jointing, etc.). Even forms occur linked immediately to some rock types (e. g. karst forms). The IGU legend expresses therefore — mainly in the case of structural forms — the properties of the rocks of the bedrock and superficial deposits by special symbols.

Experience has shown that the representation of relief age by fundamental colour is less suitable. The establishment of the age of relief is one of most difficult problems in geomorphology. A rather wide space of time of the age of various forms mainly slopes (for instance Paleogene-Holocene) is to be quoted rather often. This fact makes the representation of the age by colour difficult. In addition, a small change of the age of forms established by further research debases the whole map. The IGU Commission on Geomorphological Survey and Mapping recommended therefore to express the age of forms by indices (characters and ciphers).

THE NECESSITY OF STANDARDIZATION OF GEOMORPHOLOGICAL MAPS

In the present-day stage of development of geomorphological mapping on world-wide scale the necessity of standardization of geomorphological maps on various scales comes still more to the fore. The geomorphological maps are nowadays acknowledged components of complexes of thematic maps for science and practice. They are still more applied in the solution of problems of national economy — in mineral prospecting, planning, protection against catastrophic phenomena (floods, landslides, etc.). But a further propagation of the practical application of geomorphological maps is impeded due to the hetero-

geneity of the content and means of representation of geomorphological maps in different countries or even in the individual geomorphological centres.

Geomorphologists become still more aware of this fact and, therefore, as early as in 1965 at the meeting of the IGU Commission on Applied Geomorphology held in Czechoslovakia work was started aiming at the standardization of geomorphological maps on worldwide scale. In 1965, the already mentioned projects of the Unified key to the detailed geomorphological map of the world (N. V. Bashenina — J. F. Gellert — F. Joly — M. Klimaszewski — E. Scholz 1968) appeared. This legend became the basis of further activities of the Commission on Geomorphological Survey and Mapping established at the 21st International Geographical Congress in India, 1968. Practical experience has shown that the legend is suitable for the compilation of detailed geomorphological maps on 1:10,000—1:100,000. The legend is to be understood as an outline which can be completed according to need in keeping the basic parameters. It is to serve general geomorphological maps and cannot therefore fully meet the demands of morphostructural or special maps (e. g. structural-geological oil prospecting).

The legend exhibits some insufficiencies. It has been for instance criticized by N. V. Bashenina (1975, p. 68) for not paying attention enough to forms of tropical clima-morphological regions, limiting of the representation of free and bound solifluction only to plains, insufficient expressing of slope processes. Critical comments were also submitted by A. I. Spiridonov (1975a, pp. 13—14, 1975b, pp. 24—26).

In spite of these imperfections the legend is a significant step towards standardization of geomorphological maps and was the basis for the publication of methodical international handbooks of detailed geomorphological mapping in English (1972), Russian (1976) and German (1976).

At the present time, the IGU Commission on Geomorphological Survey and Mapping is concerned with the standardization of medium-scale geomorphological maps. To the 23rd International Geographical Congress in Moscow the methodical handbook Guide to Medium-Scale Geomorphological Mapping will appear (J. Demek - C. Embleton eds. 1976) involving all international experience with medium-scale geomorphological maps. The Guide also comprises sample legends to general medium-scale geomorphological maps and examples of maps. With medium-scale geomorphological maps the question of standardization is more complicated than with detailed geomorphological maps. This is why the recommendation of the IGU Commission on Geomorphological Survey and Mapping is to be understood as an instruction for the compilation of regional legends without which we cannot obviously do so far.

INTERNATIONAL SMALL-SCALE GEOMORPHOLOGICAL MAPS

The progres in geomorphological mapping in recent years has created conditions for another new stage of development of small-scale geomorphological mapping. Most small-scale geomorphological maps (smaller than 1:1 mill.) have been compiled so far within national frames. The IGU Commission on National Atlases played an important part in their unification. But in spite of this fact, the analysis of small-scale geomorphological maps exhibits considerable differences in the content and means of representation of these maps.

The differences make the publication of international small-scale geomorphological maps of groups of countries or continents considerably more difficult.

The compilation of international geomorphological maps is of considerable scientific and practical significance mainly for the following reasons:

a) The compilation of small-scale geomorphological maps of larger territories requires the formation of scientific concept of relief development on a level satisfying the international scientific public; thus the compilation of the map results in a rapprochement of different opinions on international level, and a further evolution of the theory of geomorphology.

b) The compilation of an international geomorphological map requires a uniform approach to the representation of the content which leads to the development of the theory of thematic mapping.

c) The compilation of small-scale maps of larger territories allows to get acquainted with phenomena and laws unknown so far without a map.

d) The compilation of international geomorphological maps requires a closer cooperation of scientists of various countries and often results in vivid discussions allowing to define the program of work with more precision and leading to a more intensive international cooperation and mutual understanding.

Within the frame of broad international cooperation the International Geomorphological Map of Europe on 1:2.5 mill. is being compiled. The idea of the compilation of this map originated in 1965 at the meeting of the IGU Commission on Applied Geomorphology held in Czechoslovakia. The original scale of 1:500 000 has been found unreal. Owing to this fact, the scale of 1:2.5 mill. was adopted after the establishment of the IGU Commission on Geomorphological Survey and Mapping in 1968. This scale is suitable for the following reasons:

a) There exists a new topographical world map 1:2.5 mill. compiled by the cartographical services of socialist countries.

b) The map scale is detailed enough for a map of a continent.

c) The map of Europe on this scale can appear not only in sheets but also as a wall map.

The original topographical base was elaborated by Kartografie Praha in a rectangular grid for the purpose of the compilation of the map of Europe.

After longer discussions a legend was elaborated for this map, whose 5th version is binding for the map of Europe mentioned.

At the present time, authors' originals of a considerable part of Western and Central Europe, the Ural and the northern section of the European part of the USSR are available. Unfortunately, difficulties appeared mainly in Western Europe as to contacting the various morphostructures and forms (e. g. moraines) at the frontiers of individual countries. But simultaneously, the cooperation among European geomorphologists improved and their willingness to a rapprochement of their different viewpoints increased.

The print of the sample sheet was delayed owing to the tardy delivery of the topographical base. But now, the sample sheet of a complicated territory of Central Europe is in the press and will be submitted at the 23rd International Geographical Congress in the USSR in this year.

In the course of the preparation of the International Geomorphological Map of Europe many difficulties will arise because it is necessary to compile geomorphological maps of geomorphologically relatively less investigated territo-

ries of Europe and North Africa where geomorphological maps have been compiled so far only in small measure. On the other side, the work on the map resulted in an unprecedented activity of European geomorphologists and valuable experience was gained as to international coordination of work.

A significant contribution to the realization of this work has been UNESCO's permanent support. Dr. K. O. Lange, UNESCO's representative, takes active part in the meetings of the IGU Commission on Geomorphological Survey and Mapping.

In the next period, the IGU Commission on Geomorphological Survey and Mapping intends to elaborate a regional geomorphology of Europe on the basis of experience with the compilation of the International Geomorphological Map of Europe.

CONCLUSIONS

The unprecedented development of geomorphological mapping after World War II means a new quantitatively and qualitatively superior stage in the development of geomorphology as a science. In the last three decades geomorphologists gained considerable experience and passed successively over to the standardization of geomorphological maps on various scales within international frame. In the work on the International Geomorphological Map of Europe a progress has been achieved. It is the first attempt at the unification of small-scale geomorphological maps on continent scale. The compilation of the map results even in a unification of opinions concerning the origin and development of relief in Europe.

But this positive development is not without problems. Several questions were discussed in this paper. But it should be realized that no further progress in geomorphological mapping and, accordingly, in geomorphology as a science is possible at the present time without the standardization of the content and modes of representation of geomorphological maps on various scales on international level.

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ЯРОМИР ДЕМЕК

ГЕОМОРФОЛОГИЧЕСКОЕ КАРТИРОВАНИЕ: ДОСТИЖЕНИЯ И ПРОБЛЕМЫ

За последние тридцать лет геоморфологическое картирование заняло прочное место в геоморфологических исследованиях. С 1970 г. можем наблюдать новый подъем геоморфологического картирования, связанный с некоторыми изменениями в геоморфологии как науке, т. е. более глубоким пониманием связи рельефа с эндогенными процессами, а также более глубоким пониманием рельефа как одной из составляющих ландшафтной сферы (возникновение так наз. экологической геоморфологии).

Несмотря на достижения в геоморфологическом картировании все еще существует ряд проблем, которые необходимо решать. При рассмотрении этих проблем автор исходит, гл. обр., из материалов Комиссии МГС по геоморфологическому исследованию и картированию.

Первой проблемой является принятие общей точки зрения по вопросу содержания геоморфологических карт различных масштабов в международном масштабе. Геоморфологическая карта является информационной системой, представляющей собой модель геоморфологических геосистем, реально существующих в природе. Автор подробно приводит рекомендации по вопросу содержания геоморфологических карт различных масштабов, которые приняла Комиссия МГС по геоморфологическому исследованию и картированию.

Вторая проблема заключается в необходимости стандартизации выразительных средств геоморфологических карт различных масштабов. Автор рассматривает достижения и недостатки различных международных условных обозначений, рекомендованных Комиссией МГС по геоморфологическому исследованию и картированию. В качестве своего вклада в дело международной стандартизации геоморфологических карт Комиссия МГС по геоморфологическому исследованию и картированию издала в 1972 г. Руководство по подробному геоморфологическому картированию на английском языке, и в 1976 г. — на немецком и русском языках. К 23-му международному географическому конгресу в СССР выйдет в 1976 г. на английском языке Пособие по геоморфологическому картированию в среднем масштабе.

Третья проблема состоит в издании международных геоморфологический карт, которые представляют собой новый этап в развитии обзорного геоморфологического картирования. С 1968 г. Комиссия МГС по геоморфологическому исследованию и картированию составляет Международную геоморфологическую карту Европы 1:2,5000 000, первый лист который должен выйти по случаю 23-го международного географического конгресса в СССР. Карта издается в сотрудничестве ЮНЕСКО, МГС и Чехословацкой академии наук.

Автор считает, что исключительное развитие геоморфологического картирования после Второй мировой войны означает новый, качественно более высокий этап в развитии геоморфологии как науки. За последние 30 лет геоморфологи приобрели значительный опыт и начали постепенно переходить к стандартизации геоморфологических карт различных масштабов в международных рамках. Успешно протекают работы над Международной геоморфологической картой Европы, которая является первой попыткой в создании обзорных геоморфологических карт в масштабе континента по общему принципу. Это положительное развитие не обходится, однако, без проблем, на которые указал автор в этой статье. По мнению автора нельзя забывать о том, что без стандартизации содержания и изобразительных средств геоморфологических карт различных масштабов на международном уровне невозможен дальнейший прогресс в геоморфологическом картировании, а тем самым и в дальнейшем развитии геоморфологии как науки.

GEOGRAFICKÝ ČASOPIS

ROČNÍK 28 1976 ČÍSLO 2

JOZEF KVITKOVIČ, JOZEF PLANČÁR, VINCENT VYSKOČIL

THE ISOSTATIC CONDITIONS IN RELATION TO THE RECENT VERTICAL MOVEMENTS OF THE EARTH'S IN THE WEST CARPATHIANS

Jozef Kvitkovič, Jozef Plančár, Vincent Vyskočil: The Isostatic Conditions in Relation to the Recent Vertical Movements of the Earth's Crust in the West Carpathians. Geogr. Čas., *28*, 2, 1976; 1 map, 10 refs.

In the submitted paper, the authors deal with an analysis of the isostatic conditions and the recent vertical movement tendencies in relation to the subsurface geological structure and the morphostructures in the West Carpathians. A good correlation has been found between the compensation conditions, the depths of Moho-discontinuity, the Neotectonic blocks on the one hand, and the respective types of morphostructures on the other. The recent movement tendencies of the Earth's crust have generally a direction of compensating isostatic movements between the individual blocks, respectively the morphostructures.

In the study of isostasy in the West Carpathians, L. Tanni (6), J. Popelář (5) have been engaged. In the papers mentioned the correlation dependences of gravity anomalies upon altitudes above sea-level of the field were investigated, and V. Vyskočil (9, 10) included into the correlation analysis also the depths of Moho-discontinuity ascertained by subsurface seismic sounding. The outcomes show that in the West Carpathians an isostatic compensation of macroforms of the Earth's crust occurs, namely mostly in the sense of Airy's hypothesis. The least dependence upon field altitudes above sea-level is shown by isostatic anomalies having been calculated for Airy's-Heiskanen's isostatic system with compensation depths T=20 km and T=30 km.

From the map of isostatic corrections for the territory of the ČSSR (8) it is obvious that the values of isostatic corrections in the area of the West Carpathians range for T=30 km from 20 mGal in the Podunajská Nížina Lowland to 70 mGal in the Vysoké Tatry Mountains. In this way, in isostatic anomalies, there is a shift of positive values in general as well as the contrast between the original negative Bouguer's anomaly in the Tatry Mts and the positive anomaly in southern Slovakia is markedly lowered.

In general, isostatic anomalies represent the gravity effect of anomalies from a perfect equality of masses in the individual vertical columns of lithosphere. Airy's-Heiskanen's system used, however, is not perfectly relevant for the virtual distribution of compensation masses and hence the calculated values of isostatic anomalies are to a certain measure, in this way, unfavourably influenced.

In general, positive isostatic anomalies indicate an excess and negative anomalies do a shortage of masses in respective blocks of lithosphere. As in the West Carpathians, virtually, positive isostatic anomalies only occur (except the Záhorská Nížina Lowland), the distinguishing between the „light" lithosphere on the outer side of the Carpathian arc and the „heavy" lifhosphere on their inner side may be understood only relatively.

In the study of the recent vertical movement tendencies in relation to the morphostructures on subsurface geological structure of the West Carpathians J. Kvitkovič and J. Plančár (2) have been engaged. The authors point out a good correlation of vertical movement tendencies in relation to the morphostructures, the subsurface geological structure as well as to the regional gravity anomalies.

In the paper submitted, we shall be engaged in detail with isostatic conditions in relation to the recent vertical movements of the Earth's crust in the West Carpathians. This analysis shall be made on the basis of a map of isostatic anomalies within Airy's-Heiskanen's system for T=30 km and the map of recent movement tendencies in the West Carpathians (2).

From a comparison of the map of isostatic anomalies with the subsurface geological structure of the West Carpathians (Map 1) it results that the delimited Neotectonic blocks — the Danube, south-Slovakian, east-Slovakian, Beskydo-Bukovian, Fatro—Tatrian, Kremnica—B. Štiavnica, Moravia—Slovakian as well as the subsurface faults bounding these blocks manifest themselves relatively well on the map of isostatic anomalies. After introducing corrections upon the lighter filling of the sedimentary basins in the Inner Carpathians, we can get still a more striking correlation between the regional distribution of both isostatic anomalies and subsurface tectonic elements of the Earth's crust. These corrections upon the sedimentary filling in the Podunajská Nížina Lowland make up to +60 mGal, in the Východoslovenská Nížina Lowland up to +50 mGal, and in southern Slovakia about +20 mGal. Then, all the area of southern Slovakia implying the Danube, south-Slovakian, and east-Slovakian blocks will be characterized by a continuous zone of high positive isostatic anomalies. According to the map submitted, we can divide relatively unambiguously the West Carpathians into two regions, namely the region rising north of the line Trenčín—Zvolen—Prešov—Humenné with relatively low values of isostatic anomalies on the one hand, and the subsiding region south of this connecting line with high positive values of isostatic anomalies. From the analysis of isostatic conditions, of recent movement tendencies of the mountain system mentioned, and of the course of Moho-discontinuity depths it results that the causes of endogenic processes as well as the compensation phenomena connected with them are to be quested approximately on the border of the upper mantle and the Earth's crust.

The above mentioned movement division of the West Carpathians into two major parts can be confirmed also by the fact that in the rising region, besides the intermountain basins, the morphostructures of middle-mountain to high-mountain type exceed, while in the subsiding region, the morphostructures of the type of lowlands, basins and middle-mountains are found. Thence a relatively good correlation of morphostructures arises, not only to the vertical movement tendencies, but to the isostatic conditions, too.

The isostatic compensation betwen the individual blocks occurs above all

along the subsurface faults. On the map of isostatic anomalies, the blocks in the subsiding region manifest themselves strikingly, namely the Danube, south-Slovakian, and east-Slovakian ones, which are, in general, characterized by positive anomalies. The south-Slovakian block has a special character, because it is noted for its striking positive isostatic anomalies, the intensity of its subsiding, however, attains in a prevailing part 0,0 to —0,5 mm per year; on the other hand, the Danube block shows differentiated subsidences from 0,0 to —3,0 mm per year and the east-Slovakian block from 0,0 to —2,0 mm per year. These differences of recent movement tendencies of the individual blocks connect probably with their different geological structure and Neotectonic development.

A disharmony in regional isostatic conditions is shown by the Záhorská Nížina Lowland and southern part of the frontal Carpathian foredeep, which both after introducing corrections upon sedimentary filling shall attain lower positive anomalies than the subsiding region of southern Slovakia. We suppose that the lower values of isostatic anomalies are caused by a shortage of masses in greater depths, which, in turn, may be caused by a system of subsurface faults on the contact of the Bohemian Massif with the West Carpathians.

DIFFERENTIATED RECENT MOVEMENT TENDENCIES AND THE LOCAL COMPENSATION CONDITIONS OF MORPHOSTRUCTURES OF THE INDIVIDUAL BLOCKS

With respect to a regional character of the field of isostatic corrections, the local gravity disturbances caused by differences in the density of rocks in small depths under the Earth's surface are transferred to the map of isostatic anomalies virtually without alternation. Local disturbances are most frequent in southwestern, southern and southeastern Slovakia and they are provoked by considerable contrasts between the densities of rocks of the Neogene sediments and of the crystalline-Mesozoic formations. In general, we can say that locally positive isostatic anomalies indicate an excess and negative anomalies a shortage of masses in a near-surface part of the Earth's crust.

In the Danube block, a whole series of local isostatic anomalies appears with various amplitudes. The positive anomalies coincide with the morphostructures of core mountains — the Malé Karpaty, Považský Inovec, and Tríbeč Mts and they illustrate also the continuation of them to depth to the Neogene sediments of the Podunajská Nížina Lowland. For instance, the horst morphostructure of the Tríbeč goes on approximately SW up to the region of Šaľa, where it ends in a depth approximately of 2500 m [1]. The greater horizontal gradients of isostatic anomalies on the edges of core mountains indicate their tectonic delimitation, which is in a good correspondence with up-to-date attainments in geomorphology, geology, and geophysics.

Negative local anomalies manifest themselves virtually in all the region of the Podunajská Nížina Lowland and the greatest anomalies are found in its northern spurs along the Váh, Nitra, and Žitava rivers. Striking is the positive anomaly near the mouth of the Malý Dunaj to the Váh within a broader region of Kolárovo. The positive anomalies are provoked prevailingly by crystalline-Mesozoic rocks and the anomalies in the region of Kolárovo by presence of

basic rocks in a depth of about 4 km [1]. The negative anomalies are caused by lighter Neogene sediments. From the viewpoint of local isostatic conditions we suppose that the shortage of masses in the partial sedimentary depressions is not compensated locally in deeper parts of the Earth's crust. This is suggested also by a relatively constant depth of Moho-discontinuity in the Danube block (28—30 km, Fig. 1). The geographical distribution of isostatic anomalies corresponds relatively well with the map of recent movement tendencies [2]. The positive local anomalies correspond to subsidences from 0,0 to —0,5 mm per year and the negative local anomalies to subsidences from 0,0 to —3,0 mm per year, the greatest negative local anomalies in northern spurs of the lowland being in correspondence with the most intensive subsidences from —1,5 to 3,0 mm per year.

The highest positive anomalies within the whole area of the West Carpathians appear in the south-Slovakian block and they are provoked especially by crystalline-Mesozoic rocks. The lower positive anomalies in southern part of the Krupinská Planina are influenced by relatively larger thickness of volcanic-sedimentary complexes and in southeastern part of the Slovenské Rudohorie (the Slovak Ore Mountains) above all by granitoid rocks in the depth. In the south-Slovakian block, the individual morphostructures do not manifest themselves virtually on the map of isostatic anomalies. It is caused by the fact that the distribution of masses in the near-surface part of crust is approximately equal almost in the whole region, evidence of which is also a relative small dissection of the Tertiary relief underlying [1].

From the general judgement it results that the contemporaneous movement tendencies of the individual morphostructures within this block (from +0,5 to —0,5 mm per year and on western edge of the block accentuated by subsidences to —3,0 mm per year) are in a good correspondence with local isostatic conditions. Evidence of this lies also in a relatively homogeneous field of isostatic corrections, which expresses small differences in excess and shortage of masses.

In the east-Slovakian block, the morphostructures on northeastern edge manifest themselves by striking positive anomalies, namely the Humenské Vrchy Mts, the volcanic arch Vihorlat-Popričný and the horst morphostructure of the Zemplínske Vrchy Mts in SW part of the block. The central part of the block is occupied by the Východoslovenská Nížina Lowland, which is noted for lower positive values of isostatic anomalies. Still lower values are characteristic for the morphostructures of the Slanské Vrchy Mts and the Košická Kotlina Basin. The lower values are influenced especially by Neogene sedimentary-volcanic complexes.

The contemporary movement tendencies are relatively striking and range within 0,0 to —2,0 mm per year, the Východoslovenská Nížina Lowland subsiding most intensively. The differentiated movement tendencies of the individual morphostructures have analogous conditions as in the region of the Danube block, i. e. that relatively lower values of local anomalies show the greatest subsidences.

Out of the comparison of isohypses of Moho-discontinuity with the map of isostatic anomalies we suppose that the morphostructures of the Humenské Vrchy Mts, Vihorlat with the Popričný, further the Slánské Vrchy Mts and the Košická Kotlina Basin have a local compensation not only in the upper parts

of the Earth's crust, but also in its lower part, as they are found in the zones of subsurface faults on the edge of block.

The Beskydo-Bukovian block. The morphostructures in this block, from the viewpoint of isostatic anomalies, manifest themselves slightly, similarly as in the south-Slovakian block. It is caused by small difference densities of Flysch rocks building the individual morphostructures. A marked difference in values of isostatic corrections is found in NW part of the block. The low anomalies are caused probably by regional compensation of the lower part of the Earth's crust along the Klippen Zone. They extend from the Pieniny — along the sub-Tatrian furrow in a moderate arc southwestwards to the region of the Záhorská Nížina Lowland. The relation of the contemporary movement tendencies to the isostatic conditions is analogical, too, as in the south-Slovakian block, i. e. that relatively small movement tendencies from +0,5 mm per year to —0,5 mm per year are accentuated above all by locally compensation conditions in the near-surface part of the Earth's crust.

The Fatro-Tatrian block. Above all, the high mountain ranges of the West Carpathians exceed in it. They have a character of arches, arch-horsts and horsts — the Vysoké Tatry, Západné Tatry, Belanské Tatry, Nízke Tatry, Malá Fatra, Veľká Fatra, and Chočské Vrchy Mts. The regional anomaly field connects here very well with the course of Moho-discontinuity, out of which we judge that the compensation conditions of the morphostructures mentioned have causes mainly on the border between the Earth's crust and the mantle and that the whole block, from the viewpoint of recent movement tendencies, is marked prevailingly for uplifts from —0,5 to more than +2,0 mm per year. The arch-horst morphostructures of the Západné, Vysoké, and Belanské Tatry Mts manifest themselves by a slight positive local isostatic anomaly, in contrast to their surroundings, at the same time, they are marked, however, also by the most intensive uplifts within the whole area of the West Carpathians, namely more than +2,0 mm per year.

Southwestern part of the Fatro—Tatrian block, from the viewpoint of regional course of isostatic anomalies after introducing corrections upon the Neogene filling of intravolcanic depressions as well as out of the character of regional gravity field at various radii of sorting out represents a self-contained block, respectively a partial block within the Fatro—Tatrian block. This partial block can be denoted as the Kremnica—Štiavnica block. The anomaly field in this block is reflected by a granitoid body in the depth [1] and on the surface it manifests itself by horst morphostructures of the neovolcanic mountain ranges of the Kremnické Vrchy, Vtáčnik, Pohronský Inovec, Štiavnické Vrchy, Javorie, Poľana, and western fringes of the Slovenské Rudohorie Mts. Further, the Zvolenská, Žiarska, and Pliešovská Kotlina Basins belong here. After introducing corrections upon the Neogene volcanic-sedimentary filling of basins, the delimitated partial block would manifest itself by relatively positive values. The locally isostatic anomalies correspond relatively well with the morphostructures of basins of the character of grabens. The differentiated movements of morphostructures range approximately from —0,5 to +1,0 mm per year and in rough features they correspond to the local compensation conditions.

The Moravia-Slovakian block. The morphostructures of the outer Flysch belt belong here. They start by the Myjavská Pahorkatina, Biele Karpaty and end

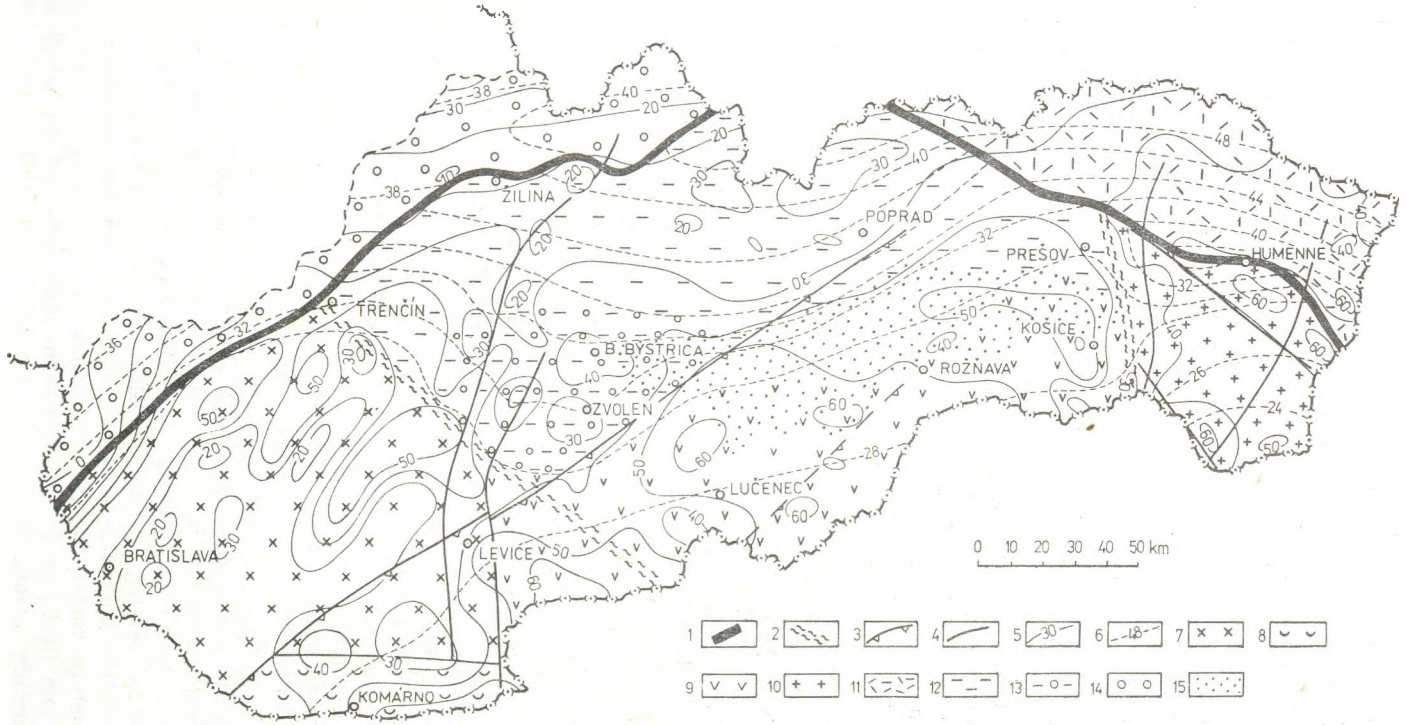
by the Slovenské Beskydy and Oravská Magura Mts in western foredeep of the Tatry Mts. Out of the depression morphostructures, the Záhorská Nížina Lowland, Oravská Kotlina Basin as well as a part of the frontal Carpathian foredeep belong here. The individual morphostructures are not illustrated virtually in the anomaly field. All the morphostructures fit into the zone of slightly differentiated, relatively negative anomalies caused partly by a shortage of masses in the near-surface part of the Earth's crust in contrast to relative heavy rocks of the Bohemian Massif on NW side as well as to those of the Západné Karpaty Mts on SE side.

The recent movement tendencies in this block range from —0,5 to +1,0 mm per year. The most intensive subsidences manifest themselves in the Záhorská Nížina Lowland filled by the Neogene sediments, the highest uplifts +1,0 mm per year being in the morphostructures of erosion-tectonic massifs of the outer Flysch belt. The relatively negative zone of isostatic anomalies on the outer side o fthe Carpathian arc connects with the subsurface structure, too. When we give the intensity of movement tendencies into a connection with local isostatic conditions, it is to state that the deepened morphostructures have the most intensive manifestations.

CONCLUSION

From the general judgement of manifestations of contemporary movement tendencies it results that the area of the West Carpathians north of the line Trenčín—Zvolen—Prešov—Humenné has an increasing tendency roughly and southern area from the connecting line mentioned is marked for subsidences. The mentioned geographical distribution of recent vertical movements in the West Carpathians corresponds well with the regional distribution of isostatic anomalies, mainly after introducing corrections upon the lighter Neogene sediments. The uplift area, in general, manifests itself by low values and the subsiding area by marked positive values of isostatic anomalies. From the geomorphological point of view it is to accentuate that in the uplift area, besides the structures of middle-mountain nature, also the morphostructures of high mountain ranges rise with extremely dissected relief attaining relative height differences of 641 m and more, most of which were glaciated in the Pleistocene. On the other hand, in the subsiding area, the morphostructures of a lowland and basin nature are found predominantly. The regional distribution of contemporary movements correlates well also with the course of Moho-discontinuity, the most intensive manifestations being bound upon subsurface faults bounding the blocks of the Earth's crust.

From the analysis of up-to-date attainments about recent movement tendencies gained by geomorphological and geodetical as well as geological methods in correlation with the distribution of isostatic positive and negative local anomalies, it becomes apparent that some negative local anomalies manifest themselves by relative greater subsidences than the positive anomalies. The locally isostatic anomalies connect with an irregular distribution of masses in small depths under the Earth's surface and no general conclusions can be deduced from them, as to the movement tendencies of the whole blocks and their subsurface causes.


ŽILINA
POPRAD
PREŠOV
HUMENNÉ
TRENČÍN
B. BYSTRICA
KOŠICE
ROŽŇAVA
ZVOLEN
LUČENEC
BRATISLAVA
LEVICE
KOMÁRNO
0 10 20 30 40 50 km

Although in the West Carpathians and in adjacent Danube basins, the recent movements observed have, in general, the direction of isostatic compensation movements, no conclusion can made of it that the blocks of the Earth's crust will stabilize themselves gradually to a state of ideal isostatic equilibrium. From the up-to-date experience it results that in the litosphere, no tendencies to reaching a permanent and total isostatic equilibrium manifest themselves. According to V. V y s k o č i l (9), isostasy manifests itself as a statistical regularity only, in which the existence of anomalies from a perfect equality of masses in the individual vertical columns of lithosphere is to be considerad as a quite current and normal phenomen. At the same time, however, isostasy acts as a regulator maintaining these anomalies within certain terms. The pressures, which are a motive power of vertical tectonic movements, may have various causes, affecting isostatic equilibrium being only one of them. In many cases, the resulting pressure and the tectonic movement of blocks of the Earth's crust corresponding to it acts against the direction of isostatic compensation.

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Map. 1. Map of isostatic anomalies and of subsurface geological structure of the West Carpathians (according to O. F u s á n et al. (1) complemented by J. K v i t k o v i č - J. P l a n č á r - V. V y s k o č i l).

1 — crustal discontinuity of northern fringe of the Inner West Carpathians, 2 — choss subsurface faults, 3 — marked Alpine dislocations, 4 — cross faults of the Neogene weakening of crust, 5 — isostatic anomalies, 6 — depth of Moho-discontinuity in km, 7 — Danube block, 8 — Pannonian block, 9 — south-Slovakian block, 10 — east-Slovakian block, 11 — Beskydo-Bukovian block, 12 — Fatro-Tatrian block, 13 — Kremnica-Štiavnica block, 14 — Moravia-Slovakian block, 15 — region of the Slovenské Rudohorie Mts.

ЙОЗЕФ КВИТКОВИЧ, ЙОЗЕФ ПЛАНЧАР, ВИНЦЕНТ ВЫСКОЧИЛ

ИЗОСТАТИЧЕСКИЕ УСЛОВИЯ В ОТНОШЕНИИ К РЕЦЕНТНЫМ ВЕРТИКАЛЬНЫМ ДВИЖЕНИЯМ ЗЕМНОЙ КОРЫ ЗАПАДНЫХ КАРПАТ

Из общих рассмотрений проявлений современных тенденций движений земной коры вытекает, что область Западных Карпат к северу от линии Тренчин—Зволен—Прешов—Гуменне в общем имеет поднимающуюся тенденцию и область в направлении к югу от упомянутой линии отличается неравномерным опусканием [2]. Это географическое распространение рецентных вертикальных движений в Западных Карпатах хорошо соответствует распространению изостатических аномалий, именно после коррекций на менее плотные неогеновые отложения. Область поднятий в общем проявляется низкими данными и область опусканий выразительными положительными данными изостатических аномалий. С точки зрения геоморфологии нужно подчеркнуть, что в области поднятий мимо морфоструктур среднегорного характера выступают также морфоструктуры высоких гор с крайне расчлененным рельефом, достигающим относительных высотных различий 641 м и выше, большинство которых в плейстоцене было покрыто ледниками. Наоборот, в области опусканий находится преимущественно морфоструктуры среднегорного, низменного и котловинного характера. Региональное распространение современных тенденций движений хорошо коррелирует также с ходом Мохо несоответствия, причем самые интенсивные проявления связаны с глубинными разломами, ограничающими блоки земной коры.

После анализа существующих результатов рецентных тенденций движений, полученных при помощи геоморфологических, геодезических и геологических методов в корреляции с расположением изостатических положительных и отрицательных местных аномалий видно, что некоторые отрицательные местные аномалии проявляются относительно большим опусканием, в сравнении с положительными аномалиями. Местные изостатические аномалии связаны с неправильным расположением масс на небольших глубинах под земной поверхностью. Из этих фактов не возможно сделать общие заключения, касающиеся тенденций движений целых блоков и их глубинных причин.

Хотя в Западных Карпатах и в прилегающих подунайских котловинах имеют преверяемые рецентные движения в общем направление изостатических уровновешивающих движений, не может сделать заключения, что блоки земной коры будут постепенно стабилизироваться в идеальное изостатическое равновесие. Изостазия по В. Выскочилу [9] проявляется только как статистическая закономерность, по которой наличие отклонений от современного равновесия масс в отдельных вертикальных столбах литосферы надо считать совсем обычным и нормальным явлением. Но одновременно изостазия служит как регулятор сохраняющий эти отклонения в определенных пределах. Давления, которые являются движущей силой вертикальных тектонических движений, имеют различные причины, причем нарушение изостатического равновесия является одной из этих причин. Во многих случаях общее давление и ему соответствующее тектоническое движение блоков земной коры воздействует в обратном направлений против направления изостатического выравнивания.

Главное внимание уделяется отношению изостатических аномалий к тенденциям движения отдельных блоков и морфоструктур. Было бы интересно обсудить также общее развитие изостатических отношений Западных Карпат и прилегающих областей в неотектоническом периоде, значит с точки зрения палеогеографии.

Карта 1. Карта изостатических аномалий и глубинного геологического строения Западных Карпат (по О. Фусану и колл. [1] — дополнили: Й. Квиткович, Й. Планчар В. Выскочил).

1 — крустальное несоответствие северной окраины внутренних Западных Карпат, 2 — поперечные глубинные разломы, 3 — выразительные альпийские дислокации, 4 — поперечные

разломы неогенового ослабления коры, 5 — изостатические аномалии, 6 — глубина Мохо-несоответствия в км, 7 — подунайский блок, 8 — паннонский блок, 9 — южнословацкий блок, 10 — восточнословацкий блок, 11 — бескидско-буковский блок, 12 — фатро-татранский блок, 13 — кремницко-штьявницкий блок, 14 — моравско-словацкий блок, 15 — область Словацкого рудогорья.