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Formal Morphostructural Zoning of Mountain Territories

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Abstract. Formalization of morphostructural zoning of mountain regions, with special emphasis on determination of lineaments, is considered in this paper. The zoning is based on joint analysis of topography, geology, tectonics and geomorphology, represented on corresponding maps and aerial or space photos. Our goal is to make the zoning objective and reproducible. The importance of this goal follows from the fact that morphostructural zoning, especially the scheme of lineaments, is the starting point of our approach to prediction of strong earthquakes; it is important also to location of some mineral deposits. The definition of large elements of relief is formalized in the first place. On the basis of their characteristics a territory is divided into three types of areas: blocks, lineaments and knots. A precise and objective location of knot and lineament positions is the final aim of our formalized scheme. The application of the suggested algorithm to Eastern Tien Shan is described in the conclusion of the paper, as an illustration.

Key words: Morphostructure – Formal zoning – Mountain – Block – Lineament – Knot – Earthquakes – Relief – Tectonics.

Introduction

The study of many geophysical problems requires a scheme of morphostructural zoning, as a starting point, based on geological and geomorphological evidence. By morphostructures we understand the active tectonic structures expressed in both of the above mentioned kinds of evidence. Among different morphostructures most often the lineaments (zones of intensive relative movements, partly expressed by geological faults) are considered – in connection with estimation of seismic risk, earthquake prediction and with more theoretical problems of geodynamics. The scheme of morphostructures is accepted usually as a part of initial, further unquestioned, base. That is why it is important to make

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morphostructural zoning objective and reproducible; to achieve this it is necessary to formalize the method of such zoning. The suggested formalization is meant to be used by a geomorphologist.

Our approach to the problem was basically the following. Some well known and usually taken for granted terms and notions were accepted without additional specifications, as original elements. On the basis of these notions we made an attempt to define more complicated objects: their quantitative and qualitative characteristics allow to divide a mountain territory into a hierarchical set of areas: mountain countries, megablocks and blocks.

The boundary zones between these areas are called lineaments. They are closely connected with places of strong earthquakes. That is, the epicenters of strong earthquakes are, as a rule, found in the vicinity of the intersection of lineaments (Gel'fand et al., 1973, 1974, 1976).

Moreover, the construction of this formalized scheme of zoning is of interest by itself as a logical problem, since it can be generalized to other problems of this kind.

Basic Ideas

By morphostructure we mean a set of manifestations of tectonic movements of the Earth's crust in the relief (Gerasimov, 1946; Gerasimov and Rantsman, 1973). By morphostructural zoning we mean the division of a territory into a system of hierarchically ordered areas characterized by a definite degree of uniformity of the morphostructure. On the basis of morphostructural zoning we establish three categories of objects: *blocks* – certain areas, *lineaments* – linear zones dividing blocks, and *knots* – places where lineaments intersect. Blocks are assigned ranks from first to third. Blocks of higher ranks are included into blocks of lower ranks as their subareas. Blocks of the first rank – mountain countries – are divided into blocks of the second rank – megablocks. Megablocks are further divided into blocks of the third rank – which we call just blocks. The rank of lineament is equal to the maximum rank of blocks that it divides. Blocks, lineaments and knots are characterized by a consecutive increase of tectonic activity.

The basic objects considered in formal zoning of mountain countries are large elements of relief. These are mountain ridges and mountain massives; the basins between mountain ridges or on their borders; intermountain basins and longitudinal valleys, plateaus, highlands and water basins. The definition of each object in the list of large elements of relief is based on notions, which are simply interpreted in terms of geomorphology. For example: a mountain ridge is a large extensive elevation in which the following elements can be discerned: 1) the highest axis areas; 2) the lowest foot area; 3) inclined planes connecting the axis with the foot – the so called slopes of the ridge. The ridge axis area, in turn, is characterized by some specific features (e.g. the watershed of rivers flowing from the opposite slopes) which are not supposed to be further formalized.

A deeper penetration into the axiomatics of these notions is possible and presents interesting and complicated problems (Voronin and Eganov, 1974).

The limits of formalization of geological notions in this paper follow from our orientation to the geomorphologist engaged in zoning real territories.

Quantitative indices of large elements of relief are the following: altitude or depth, width of basins, thickness of soft sediments, azimuth of elongation (strike), age of rocks. Considerable alterations of quantitative indices are defined on the basis of numerical thresholds which are chosen separately for each territory.

Definitions

It is convenient to begin with the definition of blocks of the third rank, that is just blocks. A block is a territory within which all quantitative indices of large elements of relief of the same kind change insignificantly, whereas across the limits of this territory a considerable alteration of at least one quantitative index takes place.

Megablock is a territory within which all the quantitative indices of large elements of relief of the same kind change regularly, whereas the regularity is broken when crossing the boundaries of this territory.

Basic regular changes of quantitative indices of large elements of relief are defined in the following list: 1) Monotonous increase of the altitude of ridge axes across and along their extension; 2) Monotonous decrease of the basin width in a system of near-parallel basins or along a set of basins forming a chain; 3) Successive change of strike of ridge axes resulting in specific configurations of axes defined by means of recalculation for the mountain territory under consideration; 4) Uniform changes of the ridge axis altitude in a system of approximately parallel ridges.

It should be emphasized here, that changes introduced by us as considerable and regular are typical for the territories, on which the scheme of zoning has been worked out. It is quite probable that in zoning new territories it would be necessary to regard some other types of changes of quantitative indices of large elements of relief which would prove considerable or regular.

By mountain country we mean a territory with a common type of orogenesis and a uniform appearance of relief. Usually, we distinguish four basic types of orogenic processes: volcanic, epiplatformal, epigeosynclinal, continental-rift formation. Besides, territories with different types of relief can be found among the uniform orogeneses.

Characterizing the appearance of a relief we take into account the following features: general level of altitudes (4 types: below 1500 m, below 3500 m, below 5500 m, and above 5500 m), character of large elements of relief combinations, character of their contours and their predominant directions (4 types: latitudinal, longitudinal, North-East, North-West).

Lineaments and Knots

A morphostructural lineament is a linear zone 10–40 kilometers wide and 100–1000 kilometers long which separates two blocks. A lineament, thus, is analogous to a fault. But not all lineaments are marked by faults, and vice versa it is not through every fault that a lineament can be drawn. A lineament can be characterized in two ways. On the one hand it can be defined as a zone where relative displacements of adjacent blocks take place. At the same time lineaments are characterized by a number of specific features, which make it possible to consider them as independent morphostructures and distinguish them from blocks.

We distinguish three types of lineaments.

Longitudinal lineaments are approximately parallel to the predominant strike of large elements of relief. They stretch along the boundaries of these elements, separating the relatively elevated areas from relatively low ones. A longitudinal lineament is characterized by contrasting types of relief and to considerable extent is expressed also by large faults, which are seen at the surface or may be detected by usual tectonic methods.

Transverse lineaments are oriented slantwise or across the predominant strike of large elements of relief, and their manifestations at the surface are not continuous. These lineaments are, as a rule, traced by sharp specific changes of longitudinal morphostructures. Here is the list of these changes: 1) A turn of the strike of the axis of the ridge or of its foot, or of the axis of the longitudinal valley. 2) A change of the dominant altitude. 3) Termination of large elements of relief. 4) A change in the thickness of soft sediments. Also, the change in the regular pattern of other indices, as listed above, may be an additional indication of transverse lineaments.

To trace a transverse lineament is much more difficult than to trace a longitudinal one. For example, the transverse lineaments in California were found only after the basic ideas of the present formalization had been applied (Gel'fand et al., 1976). The existence of these lineaments was confirmed by photos from space.

Lineaments of the third type are major strike-slip faults with large-scale horizontal movements. First rank is assigned to lineaments of this type. An example is the San Andreas fault.

It should be emphasized, that the features of lineaments as independent morphostructural units, which were enumerated before, are not sufficient for them to be fully defined and just contribute to specifying their positions as block boundaries more precisely.

By a morphostructural knot we mean a zone formed by the intersection of two or more lineaments. Some specific features of relief typical of knots, which were produced by tectonic movements along lineaments of different strikes, give us the opportunity to separate the knot from lineament zones and to consider it as an independent morphostructural object. As compared to lineament zones, knots reveal an increasing number of types of relief, mosaic pattern of rocks, and a variety of combinations of linear relief forms of different strikes. The knot boundary is drawn by means of following each of the crossing lineaments and marking the place where the mosaic relief and the particular quality of rocks disappear, the number of linear forms of relief is reduced and one can see only forms of the predominant strike.

Morphostructural zoning based on our scheme is drawn on a map 1:2,500,000 by means of joint analysis of tectonic, geological and topographic maps of the scale 1:2,500,000 and maps of larger scales, as well as literature material and photos from space. In the first stage of zoning we divide the territory into mountain countries and draw lineaments of the first rank. In the second stage we divide the mountain countries into megablocks and draw lineaments of the second rank. In the third stage we construct just blocks and lineaments of the third rank, and in the fourth stage we mark the knots. The knot boundaries can be established precisely only by means of field observations. In places where the respective exploration has not been undertaken, one has to consider some formally defined area of lineament intersection instead of a knot.

Example

In conclusion, we shall give an example of morphostructural zoning of a part of Tien Shan (Fig. 1). We are considering there a part of one mountain country, which is separated from adjoining regions by lineaments of the first rank: by I_1 and I_2 in the North from Kazah folded region, by I_3 in the South from Tarim stable massive, and by the Talasso-Fergan fault ($T-\Phi$) in the West. The eastern boundary is outside the scheme. Within this territory two megablocks, North Tien Shan (A) and Central Tien Shan (B) are distinguished.

In the North Tien Shan megablock there are the Kirgiz (1) Trans-Ili Alatau (2) and Kungey Alatau (3) ranges and the basin of Issik-Kul. Quantitative indices of the ranges in this megablock change in a common way—the altitude of each range decreases strongly along the axis from the central part. Altitudes of the peaks are approximately the same. The axis of each range in horizontal plane is a broken concave line with the concave side turned in the direction of the basin. These common features support our decision to include these ranges in one megablock.

There is no considerable change of altitude of the axis within each range of Central Tien Shan megablock; however, the altitude increases from range to range in eastern direction. The width of the basins decreases as we proceed to the East, and the chain of basins terminates by longitudinal valleys. The distance between the axes of ranges declines, and as a whole they have a fan-like configuration. These megablocks are divided by a lineament of the second rank (II).

There are two longitudinal lineaments of third rank within the North Tien Shan megablock. These are Kemino-Chiliksky (III_1) and North Issikkulsky (III_2) faults. Let us show, for example, that Kemino-Chiliksky fault divides the territory into blocks of third rank. In fact, this fault divides Trans-Ili and Kungey Alatau. The axes of these ranges have broken configuration, and the difference in strike of their flank parts is more than 20°; that is why these ranges must be attributed to different blocks.

There are two longitudinal lineaments of the third rank within the Central Tien Shan megablock:main Tien Shan (III_3) and Atbashinsky (III_4) faults.

Now we come to transverse lineaments. They all are of third tank. To establish their position it is necessary to specify places where a sharp alteration of quantative indices of large elements of relief takes place.

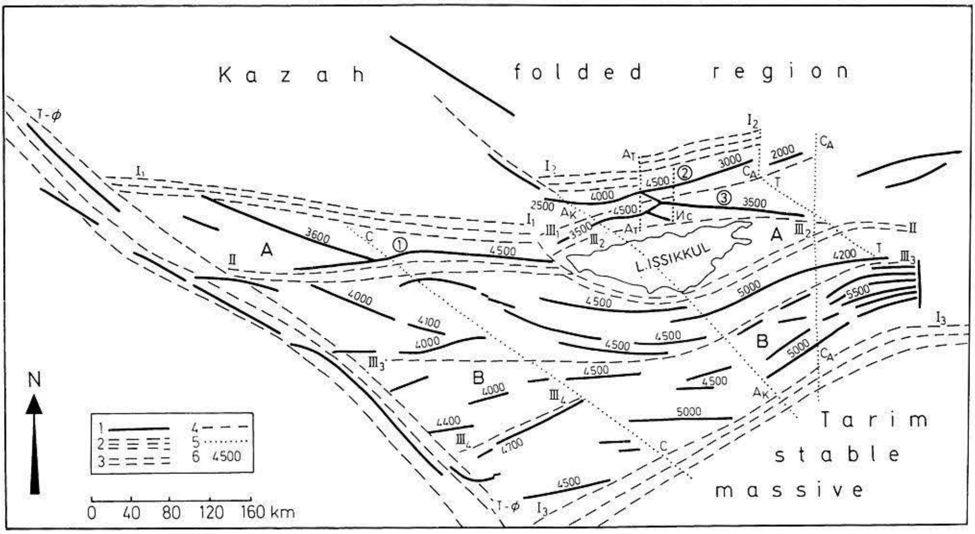

Fig. 1. *1* range axes; *2–4* longitudinal lineaments of the: *2* first rank, *3* second rank, *4* third rank; *5* transverse lineaments of the third rank; *6* the average altitude of range axes. *T–Φ* Talasso-Fergan fault (major strike-slip). Ranges: ① Kirgizsky, ② Trans-Ili Alatau ③ Kungey Alatau. A-North Tien-Shan megablock, B-Central Tien-Shan megablock. (The indices of particular lineaments are explained in the text)

On our territory there are transverse lineaments of the third rank, which are characterized by two different types of strikes. Two lineaments are of North-West strike-Sonkulsky (c) and Akshieraksky (Ak) and three lineaments of meridional strike-Almaatinsky (At), Issiksky (Ис) and Saridjazsky (C_A).

The North West striking lineaments cross both megablocks and separate territories with considerably different levels of range altitude in the Central Tien Shan megablock.

Basins become considerably narrower to the East of Sonkoolsky lineament while they are changed by longitudinal valleys to the East of Akshieraksky lineament.

The transverse lineament zones established by us can be seen on photos from space and some of them look like continuous lines, going far beyond the limits of the territory under investigation.

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