ESTIMATION OF THE RATES OF RECENT MOVEMENTS OF THE EARTH’ S CRUST FROM GEOLOGICAL-GEOMORPHOLOGICAL INDICATORS BY METHODS OF MATHEMATICAL STATISTICS

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Abstract

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ESTIMATION OF THE RATES OF RECENT MOVEMENTS OF THE EARTH' S CRUST FROM GEOLOGICAL-GEOMORPHOLOGICAL INDICATORS BY METHODS OF MATHEMATICAL STATISTICS

(Presented by Academician I. P. Gerasimov, March 6, 1967)

The present article is devoted to an example of the application of correlation and regression analyses to the solution of a specific geomorphological problem. The essence of the problem is to determine, from a complex of geological-geomorphological indicators, the values of the rates of recent tectonic movements at points where there are no repeated-leveling lines. This problem was first posed and solved by Yu. A. Meshcheryakov for the Donbass (^{1}). In doing so, a method was used for evaluating geological-geomorphological indicators in points. At each observation point the sum of points was calculated—the indicator E. Between E and the rate of recent movements, a relation equation was established, making it possible to estimate the rate of recent movements at points within polygons of repeated leveling. A shortcoming of this method is a certain subjectivity in evaluating geomorphological indicators in points and, in addition, the establishment of a relation with the rates of movement not of each indicator separately, but of their sum. In order to eliminate these shortcomings, it was decided to apply methods of mathematical statistics*.

The study was carried out on the example of the territory of the geodetic polygon Orel—Kursk—Voronezh—Gryazi—Orel, situated within the central part of the Central Russian Upland and the western margin of the Oka-Don Lowland. In this territory, as a result of field work, 60 observation points were selected, for which instrumentally measured values of the rates of recent movements V were available. At each of them the values of five geomorphological indicators were determined: the gradient of the longitudinal profile of the river i, the relative height above the high-floodplain interfluve h, the composition of the alluvium of the high floodplain A, the degree of inundation of the high floodplain during flood time m, and the width of the high floodplain S. As a result of the field work carried out in 1964-1966, the existence of a definite relation between these indicators and the rates of recent tectonic movements was revealed. For the purpose of an exact assessment of this relation, we investigated the correlation relation between each of these indicators and V.

Of the five geomorphological indicators, two (m and A) were determined qualitatively. For the numerical expression of these indicators, the method described in the literature of assigning rank numbers to them was used; following A. B. Vistelius, we associated the distribution of these rank numbers with types of sedimentation environments (^{2}). Table 1 shows the gradations into which the indicators A and m were subdivided, and the rank numbers corresponding to them.

The other three indicators (h, i, S) had numerical expression; however, the set of values for each indicator separately is nonuniform

* This work was carried out on the initiative and under the scientific supervision of Yu. A. Meshcheryakov.

Table 1

Scale of rank numbers

	Composition of the alluvium of the high floodplain	Rank number
Above the river cut only the floodplain facies is exposed	Clays and heavy loams with distinct signs of stagnant conditions of sediment accumulation	1
Above the river cut only the floodplain facies is exposed	Sands with interbeds of sandy loams and loams with distinct signs of stagnant conditions of sediment accumulation	2
Above the river cut only the floodplain facies is exposed	Heavy sandy loams with weak signs of stagnant conditions of sediment accumulation	3
Above the river cut only the floodplain facies is exposed	Medium loams with interbeds of sand	4

	Composition of the alluvium of the high floodplain	Rank number
Above the cut the floodplain and channel facies are exposed	Sands with subordinate interbeds of sandy loams and loams, or a sandy-loam composition of the floodplain facies and exposures above the cut of the channel facies, represented by coarse- and medium-grained sands	5
Above the cut the socle is exposed	Sands and loams; in the channel facies—pebbles, or a socle floodplain	6
Degree of inundation of the high floodplain during flood	Degree of inundation of the high floodplain during flood	
Flat floodplain with a distinct rear seam; flooded annually; in low-water periods strongly waterlogged	Flat floodplain with a distinct rear seam; flooded annually; in low-water periods strongly waterlogged	1
Flat floodplain with a distinct rear seam; flooded annually; in low-water periods weakly waterlogged	Flat floodplain with a distinct rear seam; flooded annually; in low-water periods weakly waterlogged	2
Flat floodplain with a distinct rear seam; flooded at mean and high water; in low-water periods dry	Flat floodplain with a distinct rear seam; flooded at mean and high water; in low-water periods dry	3
Flat floodplain with an indistinct rear seam; flooded only at high water; in low-water periods dry	Flat floodplain with an indistinct rear seam; flooded only at high water; in low-water periods dry	4

	Composition of the alluvium of the high floodplain	Rank number
Convex floodplain with an unexpressed rear seam; practically not flooded	Convex floodplain with an unexpressed rear seam; practically not flooded	5

···owing to different values of stream discharge at different observation points. The closeness of the relationship between these features and the rate of recent movements can be established only by excluding the influence of discharge. The mean discharge of a river is equal to the product of the catchment area by the mean runoff module. Since the mean runoff module remains approximately the same throughout the entire territory, 3.5, the catchment area F, which is easy to calculate from a map for any point, may be taken as the discharge value. The investigation has shown that the gradients of the longitudinal profile of a river, the relative height and the width of river floodplains are connected with the catchment area by a curvilinear dependence, which can be expressed by an equation of the form

$$h_1(i_1; S_1)F_1^x = h_2(i_2; S_2)F_2^x.$$

The exponent x was determined empirically, and we obtained formulas for calculating the floodplain height h_{pr}, floodplain width S_{pr}, and slope i_{pr}, reduced to the same catchment area:

$$h_{\text{pr}} = hF^{-0.26}; \qquad S_{\text{pr}} = SF^{-0.2}; \qquad i_{\text{pr}} = iF^{0.5}.$$

Having thus eliminated the influence of the hydrological factor, we were able to proceed to correlation analysis. Pairwise correlation coefficients r were calculated between the rate of present-day movements and each of the indicators separately:

Fig. 1. Map of the rates of present-day tectonic movements. Scale 1:2,500,000. Legend: **1** –repeated leveling lines and values of the rates of present-day movements in millimeters per year, determined by the instrumental method; **2** – values of the rates of present-day movements determined from geomorphological indicators by the regression-analysis method; **3** –isolines of the rates of present-day tectonic movements.

$$r(V, m) = 0.79; \qquad r(V, h_{\text{pr}}) = 0.61; \qquad r(V, i_{\text{pr}}) = 0.60; \qquad r(V, A) = 0.57;$$

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Figure 1: Fig. 1. Map of the rates of present-day tectonic movements. Scale 1:2,500,000. Legend: 1 —repeated leveling lines and values of the rates of present-day movements in millimeters per year, determined by the instrumental method; 2 —values of the rates of present-day movements determined from geomorphological indicators by the regression-analysis method; 3 —isolines of the rates of present-day tectonic movements.

$$r(V, S_{\mathrm{pr}}) = -0.40.$$

The reliability of the obtained correlation coefficients was determined from the ratio r/σ_r, where σ_r is the error of the correlation coefficient, determined by the formula $\sigma_r = (1 - r^2)/\sqrt{n}$ (n is the number of observations). For the indicators m, h_{pr}, i_{pr}, and A, the reality of the connection with V proved sufficiently convincing (σ_r, respectively, equals 0.05; 0.08; 0.08; 0.09). For the indicator S_{pr}, the error of the correlation coefficient is $\sigma_r = 0.108$ and $r/\sigma_r = 3.7$; from this it may be concluded that a connection between S and V exists, but its strength is insignificant.

To solve the problem of estimating the rates of present-day movements from geomorphological indicators, it is necessary to find a multiple-regression equation relating V to m, h, i, A, S:

$$\overline{V}_{m,h,i,A,S} = a_0 + a_1 m + a_2 h + a_3 i + a_4 A + a_5 S.$$

The parameters $a_0, a_1, \ldots, a_5$ are found by solving the system of normal equations obtained by the least-squares method. The system of equations was solved according to the Doolittle scheme, after which the relation equation took the form

$$\overline{V}_{m,h_{\mathrm{pr}},i_{\mathrm{pr}},A,S_{\mathrm{pr}}} = -3.03 + 1.56m + 2.68h_{\mathrm{pr}} + 43i_{\mathrm{pr}} + 0.31A - 4.12S_{\mathrm{pr}}.$$

Substituting into the equation the values $m, h_{\mathrm{pr}}, i_{\mathrm{pr}}, A, S_{\mathrm{pr}}$, we compute the mean, most probable value of V from the observed values of the five geomorphological indicators.

To estimate the accuracy of determining V from the regression equation, 18 control points were used, in which the rate of modern movements was determined both instrumentally and from the equation. Comparison of the instrumentally determined values of V with those computed from the equation made it possible to calculate the root-mean-square error, ± 1.02 mm/year. In this calculation, the instrumentally determined values of V were taken as error-free.

For the territory studied, values of V were also calculated from the relation equation at 43 additional points where there are no repeated leveling data. This made it possible to refine and add detail to the map of the rates of modern tectonic movements compiled by a group of authors under the editorship of Acad. I. P. Gerasimov in 1958 (Fig. 1).

The close agreement between the data obtained by the mathematical method and the results of field investigations substantiates the fundamental possibility of quantitatively determining the rates of modern tectonic movements from geological-geomorphological indicators by means of methods of mathematical statistics.

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