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**INVESTIGATION ON RECENT VERTICAL MOVEMENTS IN THE
EARTH'S CRUST IN THE U. S. S. R. AREA**

Among the quantitative methods of studying recent vertical movements in the Earth's crust a particular place is allotted to the Second precise and highly precise levelling, thanks to which it is possible to obtain the relative rate value of recent vertical movements covering considerable areas.

For a preliminary study of recent movements in the USSR area, use was made of the data on Second Levelling of the first- and second-order performed along the lines run during previous years for establishing the country's vertical control.

To investigate the possibility of applying these data both for the purpose of studying recent movements in the Earth's crust and for working out the methodology for a research into them, we chose the western half of the European part of the U. S. S. R. as having the greatest number of Second Levelling lines and as adjacent to the Baltic, the Black and the Azov seas.

In 1953 there were 33412 kms of Second Levelling lines run in this area, of which 21767 kms of lines had been first levelled following modern methods, while the initial levelling of 11645 kms of lines had been accomplished in accordance with the obsolete manual of 1883.

In order to increase the degree of the reliability of final results, the study of recent vertical movements in the Earth's crust was carried on by employing geodetic, oceanographic and geologic-geomorphological methods combined.

The general principle of the geodetic method of study of recent vertical movements is well-known.

It is worthy of note that recent movement research is based on the assumption of movement equability during the time interval between the dates of performing the first and second levellings as accepted for processing.

The oceanographic method of determining the recent movement rate in the Earth's crust consists in deducing the rate of these movements as based on the data for tide gauge observations of many years' standing made at different points along sea coasts. This latter method is founded on the supposition that the effects of eustatic factors on the rate deduction of recent movements is not great, being expressed, as compared to them, by a value of the second order.

It is necessary to be in possession of the data on world-wide tide gauge observations performed during many years to be able to check up on the hypothesis stating that the World Ocean level is permanent during the period of time elapsing between relevellings.

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We had at our disposal solely the data on gauge observations along the coasts of the seas washing the European continent. In 1959 we repeated Gutenberg's deduction of the rate of the eustatic change of the World Ocean level according to the new data obtained from more continuous ranges of gauge observations which were subjected to a more rigorous processing. Besides, we performed a similar investigation having made recourse to the data got along all the coasts of the European seas, including the seaboard that had been glaciated. In this particular case we considered that the processes causing the uplift of some coasts and the depression of others could not be treated as isolated from each other.

We obtained separately the value of the average rate of all the European coasts undergoing depression and of all the shores subject to uplift. The average rate of all the coasts being depressed is equal to 1.1 mm per year, and corresponds to the value of the eustatic change of the World Ocean level as computed by Beno Gutenberg.

Basing on the study performed, one gets the impression of the slope of the European continent from the North to the South. Its northern part is being uplifted at an appreciable rate, while the central and the southern ones are being slightly depressed.

The use of the gauge observation material while studying recent vertical movements in the Earth's crust according to the data on Second Levelling had a double purpose attached to it :

1. Determination, in a single system, of the rate values for recent movements in the whole of the area studied;
2. Check up of the rate values of recent movements, as computed with respect to Second Levelling data.

The problems of geologic-geomorphological investigation on the materials for Second Levelling during the complex study of recent vertical movements were as follows :

1. Studying engineering-geologic conditions for fixing bench-marks on the most important lines of Second Levelling, with the aim of finding out the extent of their stability;
2. Geologic-geomorphological interpretation of the map on the rate of recent movements, drawn by the aid of Second Levelling materials, as well as by those for tide gauge observations.

Processing the materials on Second Levelling in studying recent vertical movements in the Earth's crust in the area of the Western half of the European part of the U.S.S.R. comprised the following phases :

1. Collecting, systematizing and computing the values of the relative rate for individual lines;
2. Analysis and check up of these materials, which permitted the choice of lines to be used further for compiling a map of the rate of recent movements;
3. Choice of major framework of lines for Second Levelling to be adjusted together with gauge observation data;
4. Adjustment of this net;
5. Deducing errors for adjusted values of the rate of the movement at several points situated in the area investigated;
6. Plotting on a topographic map the values for recent movements obtained from the adjustment and from the additional lines of level not included in the general adjustment;

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7. Drawing isolines (lines of equal rate of recent movements) on the map, taking into account the structural peculiarities of the regions under discussion.

The analysis and check up of the available data constituted the most important phase of the work as regards recent vertical movements in the Earth's crust in the Western half of the European part of the U.S.S.R.

Resulting from the analysis made it had been found out that the data on Second Levelling run by means of modern precise and highly precise levelling methods should form the foundation for the study of recent movements in the Earth's crust.

The check up of values for the rate of recent movements, computed for different lines of Second Levelling, was based on :

1. Computation of the discrepancies in transferring the values for the relative rate along closed circuits;
2. Multiple determination of rate values for recent movements of the same similar points on the Earth's surface with respect to the different routes of Second Levelling;
3. Comparison of values for the rate of recent movements as computed according to the data on Second Levelling as well as with respect to the gauge observation data obtained between separate points on the seashores of the same sea and on those of different seas.
4. Application of geologic-geomorphological data.

The discrepancies in transferring the relative rate values along the circuits run in the area of the Western half of the European part of the U.S.S.R. ranged from 0 to ± 6 mm per year.

It is illustrated by the data obtained from multiple determinations of recent movement rate values along several routes that the direction and the amount of the rate of recent movements, as observed at the points with considerable uplifts and depressions of the Earth's surface, are manifested convincingly enough. In spots with but insignificant rates of recent movements they are less evident. The latter circumstance ascertains that the errors of the determinations of the computed rate for these points exceed its value.

In the majority of cases, the comparison of the values for the relative rate of recent movements in the Earth's surface, as computed from the data on Second Levelling and gauge observations between individual points on Sea coasts, showed their satisfactory agreement both for the points situated on the seashore of one and the same sea and for the seaboard of different seas. The abovesaid illustrated sufficient reliability of the determination of the computed rate for Sea coasts as well as for the interior area investigated, also evidencing maintenance of a constant relation in altitude (within the limits of measurement precision) of mean sea levels of the Baltic, the Black and the Azov seas during a considerable period of time, i. e. this pointed to a comparatively small effect to be felt in deducing the values for recent movement rates according to the data on the eustatic factor in those seas.

In the area of the Western half of the European part of the U.S.S.R. the distribution of the values for the computed rate evidenced a rather marked regularity: the uplift of the western and south-western part of the territory involved: (Tallin, Baranovitchi, Zlotchev, Znamenka, Kupyansk, Volnovakha, Likhaya) and also the depression of its North-eastern part (Bologoye, Moscow), as well as the state nearing the immo-

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bility in the central portion of this territory (Unetcha, Gomel, Dovsk)

The secured distribution of the values for the computed rate of recent movements was mainly proved by geologic-geomorphological facts, it indicated that the data available from Second Levelling reflected truthfully enough recent movements in the Earth's crust.

By means of Second Levelling lines run in the area of the Western half of the European part of the U.S.S.R. it became possible to establish a net consisting of 27 circuits, connected by 8 gauge posts on the Baltic, the Black and the Azov seas.

The values of recent movement rates computed from the lines of the Second Levelling forming these polygons, were adjusted together with the gauge observation data.

As a weight unit for the adjustment it was decided to give the weight of the value for the computed rate of recent movements along the line 100 kms in length, measured by employing modern methods of precise levelling, 20 years' interval of time elapsing between both measurements. In performing weight computations the actual line lengths were substituted for conventional ones that were calculated from the following formula :

$$L' = \frac{L}{100} \left(\frac{20}{t} \right)^2$$

where L' is the conventional line length of Second Levelling;

L is the actual extent of this line;

t is the time interval between the dates of performance of First and Second Levelling.

As a result of adjustment computations, the most probable values for the rate of recent movements were obtained for the territory of the Western half of the European part of the U.S.S.R., as well as the errors arising from their determination (approximately ± 2 mm per year).

The adjusted rate values made possible the compilation of the map of recent tectonic movements in the area of the Western half of the European part of the U.S.S.R., drawn in isolines. Structural and geomorphological peculiarities of the texture of the area covered by lines of Second Levelling were taken into consideration when drawing isolines.

The above-mentioned map was published in a monograph under the title of "Recent Vertical Movements in the Earth's Crust in the Area of the Western half of the European Parts of the USSR," edited by the Central Research Institute for Geodesy, Aerial Survey and Cartography, (Transactions, volume 123) under the General Supervision of Academician I. P. Gerasimov and Professor J. V. Philippov.

The map was compiled by the following scientists : M. I. Sinyagina and V. A. Matskova, geodesists; A. V. Dzivago, L. G. Kamanin and Yu. A. Mescheriakov, geomorphologists; V. A. Zenin, A. G. Evdokimova and M. V. Remezova, oceanographers.

During the period of time from 1953 to 1959 new lines of Second Levelling were run in the U.S.S.R. area, which helped widen the scope of the preliminary map of the movement rate in the direction to the East and to North-East, up to the Ural Mountains, and also make more accurate this preliminary map for movement rate on the territory of the Western half of the European part of the U.S.S.R.

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At present 62293 kms of lines of Second Levelling have accumulated in the U. S. S. R. area.

While making the map more accurate, 35477 kms of Second Levelling lines were used, 6760 kms of them constituting new lines. The First and Second Levellings were carried on along these lines by following modern methods of the first- and second- order.

The new lines contributed to diminishing the percentage of gaps in the Second Levelling loops. Discrepancies in the polygons became of smaller value. The lines of Second Levelling on the territory of the western half of the European part of the U. S. S. R. covered the area involved with a net built up of 33 polygons and 40 traverses starting on a fixed mark and terminating anywhere (so called "hanging traverses") tied to 11 gauge stations on the Baltic, the Black, the Azov, and the Barents seas, whose recent movement rates had been determined independently from processing gauge observations.

As a result of processing and of combined adjustment of the Second Levelling net, the most probable rate values were obtained for 3545 points, with an error of $\pm 0.7 - \pm 1.1$ mm per annum, which helped make more accurate and detailed the map that had been previously compiled. The general character of the distribution of the computed rate values in the area of the West of the European part of the U. S. S. R. remained the same as on the preliminary map.

The values for the rate of recent movements in the area in question are within the limits of -4.0 mm per year to $+10.8$ mm per year. (The map of recent tectonic movement rate is enclosed).

26816 kms of Second Levelling lines run in the area of North-East and East of the European part of the U. S. S. R. were processed, the job being done by employing the methodology assumed while preparing the map. It is necessary to point out that there was also made a preliminary map of recent vertical movement rate for this area.

A certain regularity was discovered here, as well as regards the distribution of the movement rate: the depression of the North-Eastern part increasing (with respect to the absolute rate value) northward and the uplift of the Eastern part of the area, growing Southward.

At the present time investigating recent movements is going on in the area of Kazakhstan and in that of Central Asia.

All the maps compiled for the rate of recent movements are regarded by us as those of the first approximation.

A special Second Levelling net has been planned for the purpose of making a map of the second approximation. Second Levelling lines have been planned in such a way as to show the characteristic of the tectonic activity of all the geomorphologic provinces of the U. S. S. R., and also to cross all the main regions of uplifts and depressions in the area of the European part of the U. S. S. R., as evidenced by the preliminary maps for rates.

The net of Second Levelling lines being developed will connect into a single system the gauge stations existing on all the seas washing the U. S. S. R. territory. Resulting from processing Second Levelling data in the area of the European part of the U. S. S. R., some general regularities are known to be made apparent as regards the nature of recent movement distribution.

A continuously increasing number of scientists in all the countries the world over participate in the study of recent crustal vertical movement problem.

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In spite of the fact that somewhat differing premises have been applied as the basis for processing both Second Levelling and gauge observation data in the U.S.S.R. as well as by foreign scientists in their research, the order of rate values for recent movements in the Earth's crust resulting from these studies is approximately similar, being expressed by millimeters per year.

The above-mentioned circumstance gives evidence first to the idea that difference in the methods employed for processing does not affect the final results, and, secondly, proves the reliability of rate values for recent movements as deduced in various countries.

It is to be hoped that the joint action of many scientists will bring about a scientific theory on the nature of distribution as well as on the causes giving rise to recent vertical movements in the Earth's crust on the territory of the whole Globe.

The following conclusions can be made with respect to recent movements in the Earth's crust, resulting from the investigation involving that problem :

1. The only correct method to be applied to the study of recent deformations of the Earth's figure is considered to be the complex method of investigating recent vertical movements as based on geodetic, oceanographic, geologic-geomorphological and geophysical materials. At the present phase of work the main task consists in accumulating these materials and in developing a single methodology to make a map of recent vertical movements in the Earth's crust.

2. The regularity in the movements of different Earth's surface regions in the area of the European part of the U.S.S.R. gives rise to a lot of new problems, on the one hand involving the use and processing of geodetic materials (reducing the observed data to one epoch, etc.), and, on the other hand, to tasks in connection with adjacent sciences, such as geology, geophysics, geomorphology, and so on.

3. The problem of the study of recent vertical movements cannot be separated from the question of investigating the eustatic changes of the World Ocean level. To successfully solve the above stated propositions, it is necessary to have established continuous ranges of gauge observations along the sea coasts of all the continents as well as highly precise nets of Second Levelling and of Gravimetric observations on the whole of the Earth's globe.

4. The results obtained from the research of recent vertical movements in the Earth's crust on the U.S.S.R. terrain are as follows : considerable uplifts of the Earth's crust in the regions that have undergone glaciation (the foothill belt of the Carpathians, the Donets basin area, etc.) as well as the depression of the regions which have been subjected to glaciation for a long time (the coasts of the White and Barents seas). They make one think that the causes bringing about the uplift of Fennoscandia and North America are not wholly confined to the forces of eustatic flattening.

5. At the present time it is not deemed possible to extend the obtained rate values for recent movements in the Earth's crust to a geologically long period of time as the oscillatory nature of movements should be taken into account, since the materials available do not provide for the possibility of establishing the period (length) of oscillations, of their intensity and direction.

