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A draft seismotectonic map of Europe

(Principles, contents, methods)

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Earthquakes are, as well known, the most direct and most striking indicators of recent tectonic activity of the earth, and their distribution is determined by the laws governing the entire process of tectogenesis. It was established by incontrovertible evidence, based on geological facts, that tectonic movements were widely spread over the entire Globe in old and in recent geologic epochs. This, however, does not mean that their intensity was everywhere the same. The heterogeneous structure of the earth's crust indicates that individual zones have their own history of development, as well as, different degrees of differentiation and different intensities of manifestations of tectonic movements of old and recent epochs.

Recent tectonic movements, which are often represented by seismic phenomena, also possess a clearly defined differentiation of intensity and space distribution.

That is why for an investigation of the relations between seismicity and tectonics in various areas different methods of geologico-tectonical analysis should be used.

The seismicity of a given territory is characterised by the following elements:

a) location of epicentres,

b) energy of earthquakes,

c) reoccurrence of earthquakes of different energies, or in the absence of proper information, the maximum energy of a single earthquake, recorded in this area.

These elements can only rarely be determined from direct observations, i.e. from statistical data. Only in regions with closely spaced epicentres and frequently occurring earthquakes sufficient statistical data can be accumulated during the limited period of observations.

But in most cases the obtained statistical material is far from sufficient for valuable conclusions to be drawn on the seismicity of a given area, since the number of earthquakes, recorded during the period of qualified observations, is usually too small. However, making use of the laws

governing the tectonic development of the territory, one might be able to interpolate and extrapolate seismostatistical data to regions, in which no or few earthquakes have been recorded, and thus suggest some ideas on the nature of seismicity to be expected in the given region. A study of the relations between seismicity and tectonics results finally in a SEISMOTECTONIC MAP, which can be used for an analysis of the origin conditions of earthquakes, and form a basis for compiling forecasting maps of seismic zoning.

Investigation of numerous regions in the South and South-East of the USSR has shown that the tectonic movements of the old and recent times consist mainly in vertical uplifts and subsidences of separate sections of the earth's crust (oscillatory or epeirogenic movements). And with the development of these vertical movements, or rather with their contrast, shown by the close vicinity of regions with different, and sometimes even rapidly changing, velocities and different direction of the tectonic movements, are most probably connected the tangential stresses, directly responsible for the origin of earthquakes. It is just in zones of such "contrast conjugations" that the tangential stresses arise, and their maximum intensity is to be found in places, in which maximum contrast of vertical movements is observed.

It should be underlined in connection with the above statements that the precent highland relief, due to recent tectonic movements in the axial part of an uplift, cannot be considered as an indicator of high seismicity. Only in areas with significantly contrasting conjugations of zones of recent uplifts and subsidences does high seismicity exist.

The velocity gradient of relative vertical movements of the crust can be used as a valuable tectonic indicator of the intensity of tangential stresses. The gradient implies a change in velocity per unit horizontal distance in the direction, transverse to the boundary dividing the sections, moving vertically to one another. In principle the value of the velocity gradient might be determined by various methods (the degree of accuracy varying considerably from case to case): geodetic — for the recent epoch; geomorphological — on the average, for the quaternary period, or for part of it (for instance, for the time elapsed from the last glaciation, i. e. for the last 10—15 thousand years); geologic (by comparing the thickness of deposits of a definite age in two adjacent sections) — on the average for significantly longer geologic periods (millions and tens of millions of years). For regions, in which the seismicity and geology have been closely studied, a quantitative correlation between seismic activity and the average value of the velocity gradient of vertical tectonic movements can be carried out.

Although such quantitative correlation of tectonics with seismicity is of an undoubtful interest, the value of the velocity gradient of recent tectonic movements cannot, however, be always or everywhere established. Tectonic fractures, with which earthquakes are connected, often do not appear on the surface, and can only be supposed to exist deep down. In such cases indirect tectonic indications have to be used.

In most papers dealing with relations between tectonic elements and seismicity use is made of *qualitative* correlations, showing at the given stage of investigations of good enough correlation.

The geotectonic analysis permits to outline the following general laws governing these relations:

High seismicity is typical for regions of a recent active reorientation of the tectonic pattern, in which the general direction of the tectonic movements has changed repeatedly during the alpine cycle, the last change having taken place in recent time.

High enough seismicity is also typical for tectonic scars, whose development has been going on far a long time, or for zones of conjugation of large structural crustal elements, and distinguished in the past and in recent time by sharply varying directions of the vertical tectonic movements. Foci of strong earthquakes are in most cases confined to such scars or to deep faults.

Zones of deep faults can be identified by an analysis of the distribution of facies and thicknesses and also by the use of some indirect indications, such as: 1. differentiation and contrast of vertical tectonic movements in general, and of recent tectonic movements in particular; 2. reconstruction of the relief within narrow strips; 3. young volcanism and 4. significant gravity gradients.

Revealing of zones, distinguished by a contrast of recent-neogene-quaternary-movements, is of the greatest importance, it being also desirable to obtain a numerical expression for the value of the velocity gradient of the recent movements. However, in some cases manifestations of the velocity gradient of recent movements might be absent, since these started not long ago, and so could not have produced any significant geomorphological results. In such cases geodetic methods, sensitive to recent tectonic movements, might be of help.

Geomorphically the neogene-quaternary movements may be manifested by changes in the recent drainage pattern. Main water sheds might be displaced in such a way, that the axes of uplifts and depressions would be drawn together, and regions of young uplifts may be transformed into subsidences.

A study of the history of development has shown in certain regions the existence of large transverse uplifts, whose marginal parts are often com-

plicated by deep faults, to which in some places young volcanic eruption centres are confined.

When analysing the seismic phenomena on platform, one's attention is drawn to regions of recent activisation of tectonic movements, represented by large arched uplifts, sometimes complicated by faults of considerable length.

A correlation of data on tectonics and on seismicity permits to compile several tectonic maps.

The principal among them is the map, in which the *fundamental laws governing the geotectonic development of large regions, as well as of separate narrow zones are reflected.*

The first draft seismotectonic map of Europe is based on all the above statements.

It was compiled at the Institute of Physics of the Earth, Acad. of Sc. of the USSR, and edited by V. V. Belousov and A. A. Soŕskij. The map is of scale 1 : 2,500,000 and it includes geological data obtained from published references and personal studies conducted by M. V. Gzovskij (HPR), A. V. Gorjačev (Spain, Portugal), N. N. Leonov (the European part of the USSR, PPR), I. V. Kirillova (Italy, Turkey, Caucasus, Crimea), N. I. Nikolaev (neotectonic data), I. A. Rezanov (Austria, Switzerland), G. I. Reisner (Algeria, Morocco), E. M. Rudich (England, Iceland, Ireland, Norway, Sweden, Finland), B. A. Petruševskij (GDR, FRG, Denmark, Belgium, Netherlands, Luxemburg, France), A. A. Sorskij (APR, Greece, FPRY, Caucasus, Crimea), V. V. Ez (BPR, CSSR, RPR). The map also includes seismological data collected by V. Kárník (maps, catalogue for all Europe), S. S. Andreev, A. Y. Levickaja, G. D. Panasenko, E. F. Savarenskij, A. D. Tzkchadaja (USSR), E. Ben Osman (Tunis), J. Bonelli (Spain), M. Båth (Sweden), Ch. Charlier, J. Van Gils (Belgium), D. Csomor, A. Rethyl (HPR), A. Galanopoulos (Greece), F. Gassmann (Swiss), E. I. Grigorova, K. T. Kirof (PRB), R. Malaroda, M. de Panfils, C. Raimondi (Italy), M. Ipek, N. Öcal, C. Omote (Turkey), G. Petrescu, C. Radu (RPR), E. Peterschmitt, J. P. Rothé (France), J. G. Scholte (Holland), A. Sellevoll (Norway), W. Sponheuer (GDR, FRG), E. Tillotson (Great Britain), M. Toperczer, B. Trapp (Austria), D. Tradjic (FPRY), E. Tryggvasson (Iceland), V. E. Buné (map of seismic activity of all Europe).

In accordance with the recommendations of the European Seismological Commission (Alicanté, 1959, Helsinki, 1960) the here proposed draft seismotectonic map was compiled by scientists of the Institute for Physics of the Earth of the Ac. Sci., USSR, in contact with European scientists. The tectonic basis was prepared by geologists-tectonists, and the seismic material summarised by seismologists.

V. KÁRNÍK compiled a catalogue of European earthquakes and 5 maps of epicentres, representing earthquakes of intensities VI, VII, VIII, IX, X and also deep earthquakes, classified according to magnitude. At the present stage of investigations direct use of V. KÁRNÍK's maps is made difficult by the large number of maps and lack of a classification of epicentres according to the degree of accuracy of their location. In connection with these difficulties, as a contemporary measure, the seismologists of the Institute of Physics of the Earth compiled from KÁRNÍK's data a map in isolines of the reoccurrence of earthquakes of intensity VII over an area of 1000 km². On this map epicentres of earthquakes of intensities IX—XI and of deep earthquakes were also plotted. In the compilation of this map use was made of maps, containing earthquakes of intensities VI, VII and VIII. The map was compiled in accordance with the principles, proposed by Y. V. RIZNIČENKO for maps of seismic activity. But the seismic data, plotted on this map, are preliminary and only of an illustrative kind. They will be improved after KÁRNÍK will have finished his investigations.

In accordance with the principles of tectonic regioning based on geologic development, the entire territory of Europe and the adjacent parts of North Africa and Asia were divided into two large areas:

I. Areas having a continental crust,

II. Areas with an oceanic crust.

In areas, in which the crust is of a continental type, two large zones stand out: zone of the alpine geosyncline, including the Mediterranean region and the basins of the Black and Caspian seas; and zone of the alpine platform, whose separate parts are of different ages (precambrian, caledonian and hercynian).

According to the nature of the predominant vertical movements, the geosyncline and the platform are divided into regions of predominant uplifts and regions of predominant subsidences.

Regions of predominant uplifts within the alpine geosyncline are in their turn divided into: regions of stable uplifts, inherited from the preceding geotectonic cycle; and regions of newly formed uplifts, arising from true geosynclinal and parageosynclinal troughs. The newly formed uplifts are also divided according to age into mezosoic and cenosoic.

In regions of predominant subsidences, represented by fore-deeps, intermontagne and superimposed troughs, sections are distinguished by the age of submersion (miocene, pliocene-quaternary and recent).

Within the alpine platform a division is made according to the predominant directivity of vertical movements. There is also a subdivision according to the age of the folded basement and in some cases a further, more detailed, differentiation is indicated.

Within regions, having an oceanic crust, the following features are shown in the map: emerged ocean ridges, rising above the ocean level and their under water sections; shelves, continental slopes of uncertain structure; and zones, which had undergone sharply defined differentiated movements in the neogene-quaternary period. Within oceans and inland seas deep water depressions are indicated.

In addition to the above enumerated zones, the seismotectonic map of Europe shows also large structural elements, bearing a direct relation to seismicity. These are: deep faults and large fractures, which had been active during the neogene-quaternary period; low angle overthrusts and nappes; zones of young volcanism; main mezocenosoic grabens, and also zones of contrast conjugations of uplifts and subsidences of the neogene-quaternary period. A correlation of the above enumerated tectonic elements with seismicity puts into relief the following general picture.

Seismicity is generally confined to regions of the alpine geosyncline, whereas within platform zones rather few seismic foci are recorded. Such distribution seems quite natural, since active development of zones of the alpine geosyncline is still going on, and in a number of places the tectonic movements show a sharply defined differentiation. It should be noted, however, that the manifestations of seismicity within the geosyncline are also irregular. Neither in the Alps, nor on the Balcans, in Turkey, or in the Caucasus, is seismicity connected with folded structures of the alpine type, but is due to block movements of the earth's crust.

Although various countries show different seismotectonic data, it is still possible, due to the here proposed design, to outline some general laws governing the relations between tectonics and seismicity.

Here they are in the most general form:

The highest seismicity is confined to zones, in which during the neogene-quaternary period a general reorientation of the tectonic pattern has been occurring, and stable uplifts of the beginning of alpine cycle have been drawn into differentiated subsidences along zones of intersecting faults. Simultaneously rejuvenation of old deep faults has been taking place, and volcanic eruptions have been occurring. Separate parts of the uplifts have been collapsing. Hereto belong the region of the Aegean sea and the adjacent parts of Greece and Turkey, where throughout the entire history of mankind disastrous earthquakes were being recorded. No less significant collapse has been occurring in the basins of the Tyrrhenean sea and of the Western Mediterranean, where they have been resulting in strong earthquakes of the Iberian peninsula and Sicily. In the eastern part of the alpine geosycline a similar process has been taking place in the southern region of the Crimea. High seismicity and volcanic activity of Italy are connected with the deep-water depressions of the

Tyrrhenean sea. The same process, although connected with the destruction of old structures, is evidently taking place within the Atlantic ocean, where strong earthquakes are known in Iceland, South Norway and Scottland.

Large scale structure transformation within the geosyncline lead to the formation of a series of superimposed throughs and to fracturing. Such are the superimposed depressions of the Appenine peninsula, of Albania, Greece, Hungary and the Caucasus. Processes of this kind give rise to zones, in which contrast conjugations of uplifts and depressions take place. To these zones seismic foci are confined.

Zones of contrast conjugations are of a various nature. The largest, forming boundaries between the geosyncline and platforms, are often characterised by strong deep foci earthquakes. Such are, for instance the conjugations of the external margin of the Carpathians with the Russian and Wallachian platforms, where deep foci earthquakes are known to occur. The boundaries between platforms and the geosyncline in the Pyrenean zone and on the Iberian meseta are also distinguished by high seismic activity and deep seismic foci.

Within the geosyncline the contrast conjugations correspond to deep faults with numerous seismic foci along them. Many earthquakes of the Caucasus, of the North Anatolian zone of Turkey, of the Dalmatian Coast of Yugoslavia and Albania, of Algeria and of many other countries originate under such tectonic conditions. The regional faults often intersect transverse uplifts, which apparently have deep roots. It was established that in places of such intersection seismogenetic "knots" arise, notable for high seismicity. (The Caucasus, Turkey, Albania, Hungary, etc.)

Young block movements within platforms lead to splitting of the basement and to the formation of large regional grabens. Here are some examples of such structures: the Oslo graben, the Kola-Bothnian zone, both having a precambrian basement and also the Upper-Rhein and Rhone grabens on the hercynian basement. To these structures seismic foci are confined, whose chain arrangement corresponds to the graben strike.

Thus, even a short analysis of the distribution of seismic activity over Europe shows that the principal seismic zones lie within the alpine geosyncline. Inside the geosyncline they are confined to zones of significant differentiation of tectonic movements, represented by deep faults of various directions, and by other above-mentioned geotectonic and geomorphological elements. It is interesting to note that zones of the highest seismicity show a number of geologic indicators, pointing to an activisation of the tectonic processes. In revealing them not only geological

but also geophysical data are used. Isostatic anomalies, as established for Europe, correspond to more mobile regions. A closer spacing of epicentres, is, as a rule, confined to strips with higher gradients of these anomalies.

In regions of lower seismicity the number of geologic indicators of seismicity is usually smaller. Regions of weak seismicity generally show no differentiation or contrast of tectonic movements.

When compiling the first model of the draft seismotectonic map of Europe, the scientists were confronted with difficulties, both of a subjective and of an objective kind. A solution of definite problems, concerning the relations between tectonics and seismicity, may depend on the specific features of the given areas. Correlation of data on seismicity and on tectonics requires a location of epicentres with an error, not exceeding 0.1—0.3°, and also reliable data on the depth of foci, on the energy and mechanism of the earthquakes. Due to the enormous work done by V. KÁRNÍK, we have at present the first summary of data on seismicity. It is, however, necessary for all countries of Europe to bring their knowledge of seismicity to a common level, satisfying the above stated requirements.

Diskussion

A. ZÁTOPEK:

Ich schätze diese Karte sehr hoch. Sie wird auch die Zeitfolge der künftigen Forschungsarbeiten beeinflussen. Es wird möglich sein, auf Grund dieser Karte diese Arbeiten viel besser zu planen als auf der Grundlage von nur geologischen oder manchmal lückenhaften seismischen Karten. Auch für das Studium des Mechanismus der Bebenherde wird die Karte als eine wichtige Unterlage dienen. Wenn dann noch energetische Angaben zur Verfügung stehen werden, wird die Karte in dieser Hinsicht vervollkommnet werden können. Es ist ein schönes Beispiel der modernen komplexen Arbeitsmethode.

V. KÁRNÍK:

I have no question, only two remarks.

1. The seismological informations forwarded to the working group of Prof. BELOUSOV were in the state as they were received from individual countries, i.e. without control, without uniform classification, without completion of some parameters etc. The data therefore are suitable only for preliminary conclusions of general character.

2. The European area according to the definition of the E. S. C. includes all countries north of the 30th parallel, i.e. also Libya, Egypt and the Levantian countries.