WORLD MAP OF ACTIVE FAULTS, THEIR SEISMIC AND ENVIRONMENTAL EFFECTS

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1. Terms and methods

The synonyms "active fault" and "living fault" were introduced in 40's by american and european authors, respectively, to designate the faults with manifestations of tectonic movements, that occur presently or can occur in the nearest future. Tectonic movements are nonuniform in time. Three types of the fault movement regimes have been differentiated. They are creep, impulse and impulse-creep ones [1].

The creep regime is characterized by slow continuous motion, accompanied by frequent weak earthquakes and relatively frequent (tens years) moderate earthquakes. So, the fault activity can be registered by geodetic and seismological techniques. The fault zone between Pamirs and Tien Shan in the Central Asia is typical.

The impulse regime is characterized by displacements up to several meters during strong earthquakes, following to each other with several hundred or thousand year intervals. Magnitudes and recurrence interval of the earthquakes is defined by historical, archeological and special geological-geomorphological methods [1, 2, 3]. The Khangay, Gobi-Altai and Kobdo faults in Mongolia are typical.

The impulse-creep regime is really combination of two previous types. It can be documented by combination of geological, geomorphological, seismological and geodetic techniques. Some segments of the North Anatolian fault as well as fault zones in eastern active margin of Asia are typical.

Regime of fault motion depends on properties of rocks in the fault zone. It can vary even along the single fault (the San Andreas and the Talas-Fergana ones). So, there arose the problem of a characteristic time which is adequuate for specifying the fault activity, direction, mean rate, and character of movements. Allen [4] suggested to consider a fault to be active if it yields evidence for the displacements in the Holocene, i.e. over the last 10,000 years. In our opinion [1, 2], this interval, even in mobile regions, should include the Late Pleistocene, i.e. the last 100,000 years. Outside the mobile

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should be based on motion that occurred not only over the last 100,000 years, but also during the Middle Pleistocene, i.e. over the last 700,000 years.

Active faults are important for studies of recent geodynamics, seismic and other geological hazards.

2. The International Lithospere Program Project II-2 "World Map of Major Active Faults "

The importance of studying active faults led to the establishment of the ILP Project II-2 in 1989 with V.G.Trifonov as a chairman [5]. Now 70 scientists from 50 countries work on the project for the purpose of the compiling the maps of continents (Eurasia, Africa, North and South America, and Australia with New Zealand) on the scale 1:5,000,000 and the World map on the scale 1:20,000,000. Also, maps of active faults in some mobile regions are compiled on more detailed scales. The maps will be accompanied by the Explanatory Notes and the Catalogs of active faults.

The work on Project II-2 is organized as follows. The project is subdivided into three subprojects including, respectively, Eurasia (Moscow center, led by V.G.Trifonov), Africa (Belgium center, led by J.Klerkx) and North and South America (Denver center, led by M.Machette). National and regional representatives submit the information on active faults to these centers, the information being digital data, maps, papers etc. There it is standardized, edited, sometimes complemented with data from other sources, and incorporated in database [6]. The final map of a continent is compiled with the use of the database after consultations with the national and regional representatives.

The database contains digitized fault lines, each of them accompanied with formalized description of all fault parameters available. A list of the parameters is the following.

(A) Obligatory parameters, characterizing every fault and necessary for compiling the map, are: (1) number; (2) name; (3) age of last manifestations of activity (contemporary and historical; Holocene-Late Pleistocene; Middle Pleistocene); (4) intensity of motion ($V>=5$ mm/yr; $5>V>=1$ mm/yr; $V<1$ mm/yr; $V<<1$ mm/yr); (5) sense of motion (trust; reverse; normal; extension; dextral; sinistral; oblique; transform; surface continuation of subduction zone; flexure; unknown); (6) uplifted side (for faults with vertical component of offset); (7) direct or indirect manifestation in the land surface; (8) reliability of the data (A, B or C; A means the best); (9) references.

(B) Additional characteristics are: (10) dip; (11) magnitudes of vertical and lateral offsets with age of the displacements; (12) rates of motion for the defined time interval; (13) layers of the lithosphere, ruptured by the fault; (14) methods and techniques of identification and studies; (15) seismic manifestations; (16) environmental manifestations; (17) any remarks.

Being ASCII codes originally, the database is easily convertable into any GIS format, providing besides drawing customarily charts, excellent opportunity for correlating active faulting features with any natural phenomena, settlements or constructions.

3. Active faults in Eurasia: general regularities

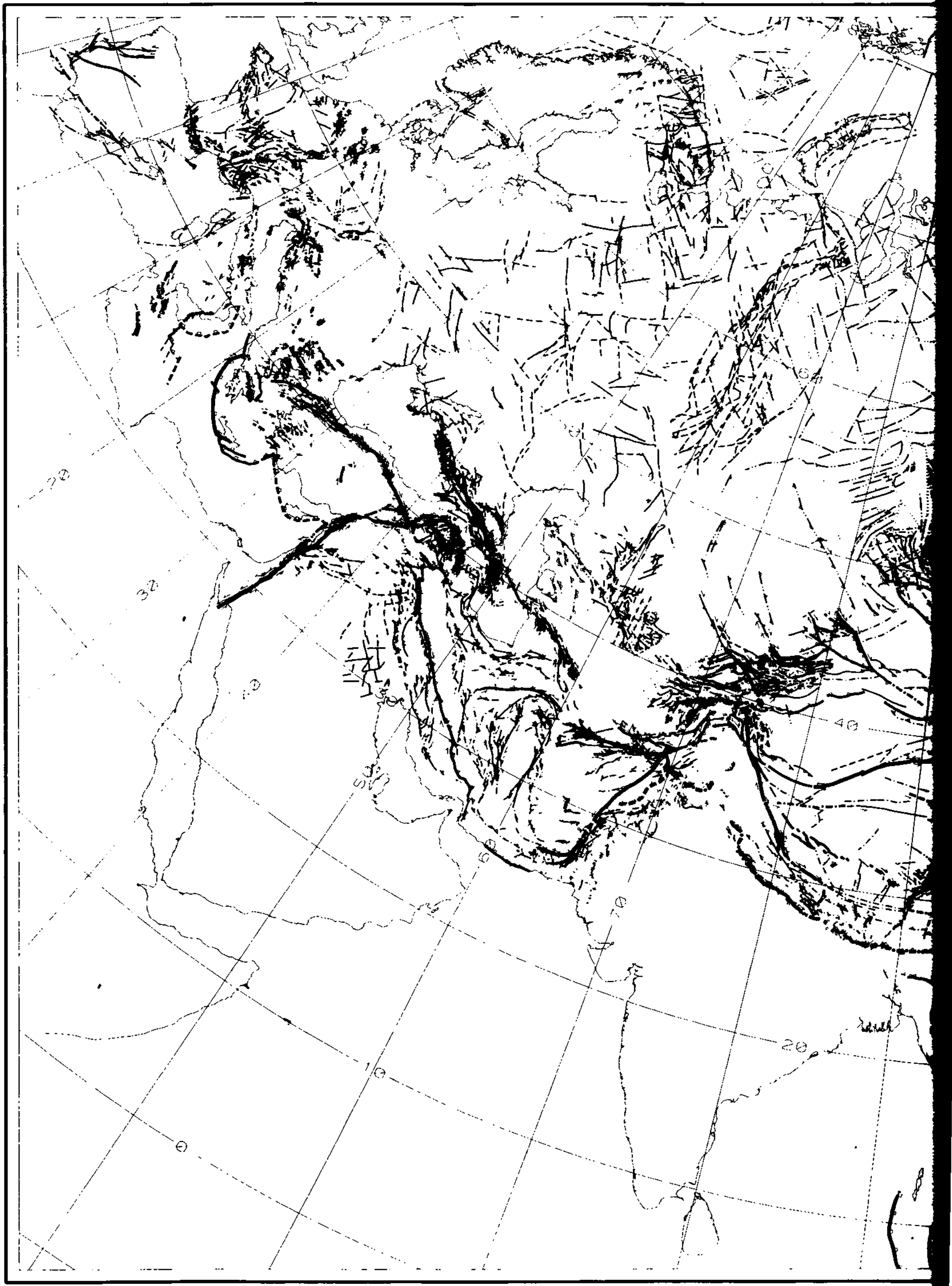
Studies of active faults have been carried out for compiling the preliminary version of the Map of active faults of Eurasia, on the scale 1:5,000,000, by using the database and the ARCINFO system (Figure 1). The studies and an analysis of the Map have revealed the following main regularities of recent faulting.

(1) Exact delineation of the contemporary plates within the continent is impeded by the fact that the active faults group in broad mobile belts including marginal parts of interacting plates and intermediate microplates, slides, and blocks of the lithosphere or only the Earth's crust. The average rates of Late Quaternary motion on certain intraplate faults are not smaller than their values for faults that are considered to be the plate boundaries for structural reasons.

(2) The vertical component of offsets on active faults has been often produced by thrust or reverse motion rather than by normal ones. It is true for the faults both in mobile belts and in areas of moderate and weak activity. Thus, most part of the continent is under the conditions of compression now.

(3) More than half of active faults in the mobile belts have a strike-slip motion component which is greater than or comparable with the vertical component. It is in strike-slip zones that the highest rates of the intracontinental movements are most often observed, which may be explained by the fact that the strike-slip movements are less energy-consuming than the movements on thrust, reverse faults, and even normal faults [7]. Three types of strike-slip faults are differentiated. They are: strike slips of transition, which displace one fault side as a whole relative to another; the strike slips of rotation and strike slips of squeezing of rocks away from the area of maximum compression. Two the latter types produce the lateral shortening of the collision belt and redistribute rock masses along it.

(4) The active faulting pattern observed on the land surface, reflects mainly the rupturing and deformation of the Upper crust. Basing on the geophysical data, we revealed differences in the arrangement of the active fault zones between the sedimentary cover and cristalline crust and between the Upper crust and the layers near the Moho discontinuity. This discrepancy is caused mostly by the different response of rheologically different rocks to essentially identical loadings (Southeastern Caucasus and large part of Central Asia). However, the orientation of stress and direction of motion in certain regions (Central Japan and Western Tien Shan) are not the same in different crustal layers. In general, the motion and deformation of the Lower crust play the same role for the kinematics of the Upper crust, as the asthenoshere does for the lithosphere as a whole. Thus, the crust of mobile belts moves and is deformed, to a large extent, independent of the mantle lithosphere.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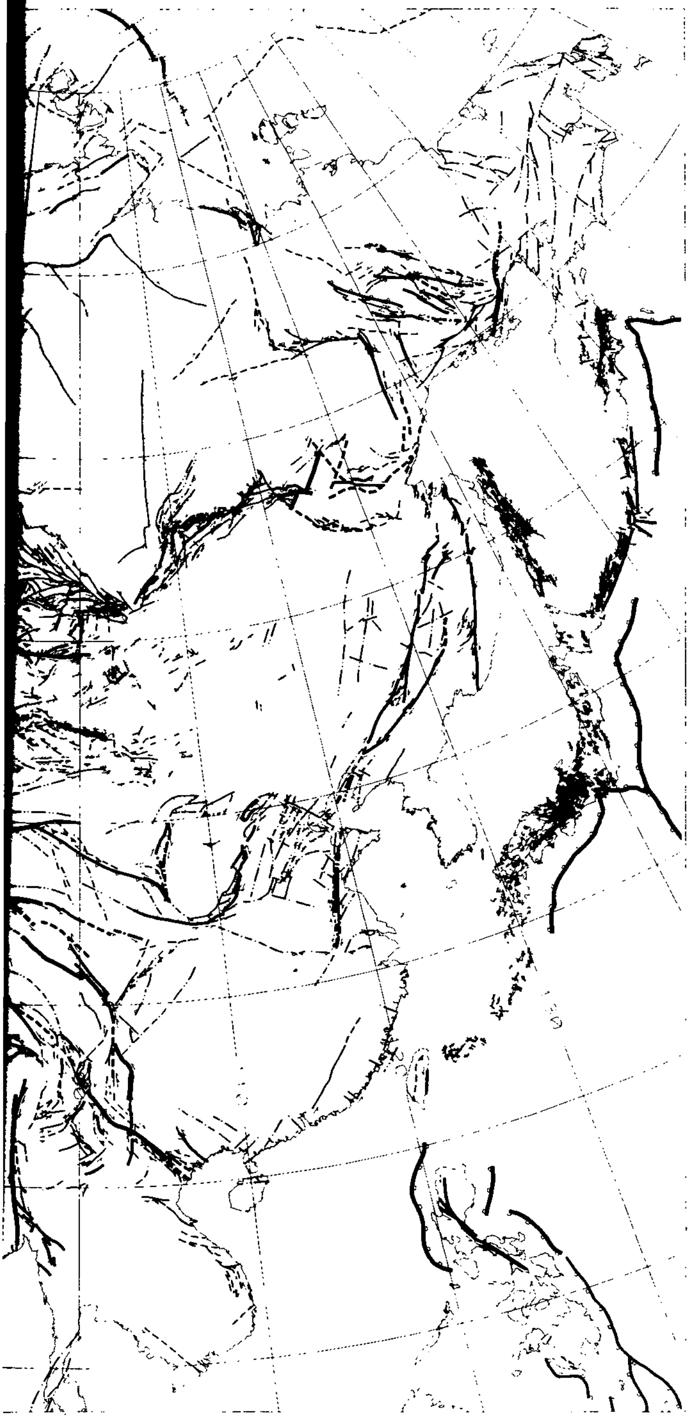
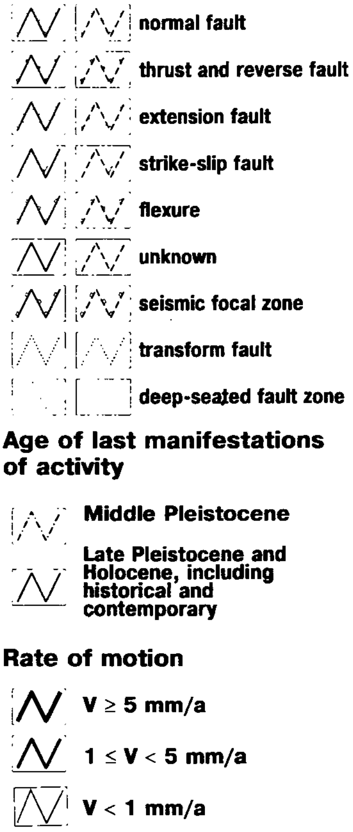


Figure 1. Preliminary map of active faults of Eurasia, compiled by R.V.Trifonov by using the database of the ILP Project II-2 "World map of major active faults".



(5) Tectonic features of the lateral shortening in the present-day mobile belts are subdivided into three types:

(a) The ordinary subduction is characteristic only of the oceanic or suboceanic lithosphere and is commonly associated with more or less considerable low-angle underthrusting of fragments or reworked material of the subducted slab beneath the crust of the allochtonous plate.

(b) The collisional interaction of a fairly widespread type is decoupling and independent deformation of the crust and mantle, sometimes with layering of the crust into several slides (the Pamirs and adjacent frontal zones of the Indian plate). Nappe-fold structures develop in the Upper crust which in certain cases can entirely overlap the underthrusted plate (the Himalayas-Tibet and Main Zagros thrust). However, if the lithosphere of the interacting plates is continental, the magnitude of such underthrusting does not exceed 300 km. The Lower crust (with the Middle crust in some regions) is a main zone of the tectonic flow and deformation of rocks, while the mantle part of the lithosphere, with overlying crust detached, sink into the mantle, undergoing considerable deformation as well (the Pamirs and Hindu Kush).

(c) A "bulldozing" is a main mechanism responsible for the distribution of deformation and motion over vast areas of the Central and Eastern Asia. The mechanism is related to the northward drift of the Indian plate, giving rise to the deformation and motion of adjacent microplates and crustal blocks, which in their turn cause the tectonic zones adjacent to them to move and so on. This mechanism is associated with characteristic structural transformations. The deformation of type "b" is typical of the lithosphere near the northern front of the Indian plate (the Himalayas and Pamirs). Further to the north and northeast, deformation concentrates in boundary zones between blocks and microplates, forming mountain systems, whereas weakly deformed central parts of microplates and large blocks often form the intermountain basins, subsiding isostatically in response to their filling with clastic material (the Tien Shan and Western China). Interblock mountain zones near the Indian plate have the structure of type "b" (the Southern Tien Shan). Further the intensity of the neotectonic folding diminished and is replaced by purely fault-type structures dominished by strike-slip movements (Western Mongolia). Extension structures (the Baikal rift system and Shanxi graben) develop on the curved segments of large shear zones.

In the Alpine Europe and Mediterranian, the processes of types "b" and "c" are less pronounced, being of local character and associating with the lithosphere extension features. The latter are represented both by rift zones and by isometric basins such as the Pannonian and Aegean basins. The wide occurence of such structures may be related to the mantle diapirism initiated by the interaction of plates and blocks in the environment of much thinner crust and more heated lithosphere as compared with Central Asia. By specific features of the active tectonics, the region of the collision of the Arabian and Eurasian plates is intermediate between Central Asia and Alpine Europe.

(6) An essential element of neotectonics in the Alpine-Asian collision belt is represented by the Pamir-Punjab, Arabian-Lesser Caucasus, and Adrian syntaxes facing north and being asymmetric [8]. Their western flanks are fairly narrow and exhibit features of sinistral motion with weak compression or extension. Compression structures, combined with dextral slip along the plate boundaries are more pronounced northeastern flanks of the syntaxes and cover large areas. Such asymmetry appears to be a result of the north-northeasterly drift of the African, Arabian, and Indian plates, which, with northern orientation of the syntaxis axes, produces an additional compression at their northeastern flanks.

(7) The present-day pattern of active zones was, in general, formed in the Pliocene. Earlier the configuration of neotectonic faults differed from the contemporary one in certian areas (the Levant and Zagros zones, for example).

4. Seismotectonic zoning of the Northern Eurasia by using active fault data

In the combined analysis of active faults and seismicity, Shebalin et al. [9] subdivided the Northern Eurasia territory (the former USSR and neighboring countries) into domains that are internally uniform in the seismotectonic sense. Because of the diversity of geological structure and present-day geodynamic processes on the one hand and difference in the state of knowledge about different regions on the other hand, such division was based on the minimum number of parameters that are easy to determine and apply.

The parameters of active faults were taken from the database of active faults of Eurasia, created within the framework of the ILP Project II-2. The following parameters of the faults were taken into account: (1) location, represented by a system of points with determined geographic coordinates; (2) total length; (3) the last manifestations of activity; (4) intensity (average rate) of motion; (5) structural position; (5) reliability of the data.

Seismological data were taken from the New (1994) Unified Catalog of Earthquakes of the Northern Eurasia (N.V.Kondorskaya and V.I.Ulomov, Eds.) which includes all documented events with magnitudes of 4.5 and higher for the period from ancient times to 1994 and with magnitudes of 3.5 and higher for the period from 1960 to 1994. The following parameters of earthquakes were taken into account: (1) location in geographic coordinates; (2) magnitude; (3) depth of hypocentre; (4) reliability of the data.

In all, about 450 domains were specified on the territory. They may be subdivided into two types: (1) axial domains (a) for which Mmax is highest on the axis and gradually decreases away from it, assuming the values of the adjacent domains at the boundaries; the majority of the axial domains have one axis, but some of them have two and, exceptionally, even three axes; and (2) uniform, or flat domains (f) with quasi-constant Mmax all over the area of a domain. In the areas of mantle seismicity, the domains were subdivided also into crustal and mantle domains.

The following characteristics of each domain were collected in the database: (1) number with index "a" or "f"; (2) name; (3) boundaries, represented by a system of points with determined geographic coordinates; (4) total square; (5) length (for axial domains); (6) excerption of earthquake parameters from the catalog of earthquakes; (7) excerption of active fault parameters from the database of active faults; (8) the longest active fault; (9) tectonic position of the domain and thickness of the Earth's crust and the lithophere. Graphs of recurrence of earthquakes as well as graphs of depth distribution of the hypocentres were compiled for domains by using the data of (6) and (7). In the stable platform territories earthquakes and active faults are much rarer, than in recent mobile belts. So, several domains with similar characteristics were joined together there for compiling the graphs.

An essential characteristic of each domain is the maximum expected magnitude Mmax(e) which is commonly greater than the observed Mmax. Mmax(e) was estimated by interpretation of graph of earthquake recurrence with taking into account a form of the graph, duration of period of observation and reliability of the historical data, a length of the longest active fault as well as general pattern of active faults and structural position of the domain. The recurrence of earthquakes with Mmax(e) and Mmax(e)-0.5 was derived from the same graph. The map of domains and the catalog of their characteristics are the initial data for calculation of seismic ground motions and construction of seismic zoning map.

5. Relationship of active faults and strong earthquakes in Eastern Mediterranian, Middle East and Lesser Caucasus

Examination of various aspects of the relations between concrete active faults and seismicity, provides the basis for the more detailed assessment of seismic hazard in specific regions. Eastern Mediterranean, Middle East and Lesser Caucasus [10] is one of them. Here we consider the spatial-temporal features of seismicity in the zones of active faults.

Analyzing the temporal distribution of contemporary and historical earthquakes in the interaction region between the Arabian and Eurasian plates, Karakhanian [11] discovered directed migration of the earthquake sources with magnitudes of 5.5 and greater on the western flank of the Arabian plate. The migration period is from several months to several years, beginning from the initial event. The south to north migration takes place in the Levant and East Anatolian boundary zones of active faults. In the North Anatolian zone, the sources migrate from the front of the Arabian plate in the northwesterly and westerly directions. Karakhanian [11] also recognized the cyclic character (with a period of about 500 years) of the strong seismicity behavior in the afore-mentioned active zones. Moreover, the phases of these oscillations and, correspondingly, higher-seismicity episodes in the Levant zone are by several decades in advance of those in the North Anatolian zone. So, in the 20th centure the Levant zone has been characterized by seismic silence, but the North Anatolian zone is in maximum of seismic activity. A similar advance may be suggested from the comparison of the seismic cycles in the Zagros zone with respect to the Albourz zone. Both the earthquake migration and phase shift of the cycles have characteristically the same direction, namely, from south to north, along the flanks of the Arabian plate or away from it. Obviously, this is related to the redistribution of stresses due to the drift of the plate.

Specific areas of the active zones are found, which are characterized by higher seismicity as compared with the adjacent segments. These are first of all the intersection areas of active strike-slip faults, e.g., the North Anatolian and the East Anatolian faults. The higher seismicity of the latter is related to the development of new branches of the fault zone, which connect its segments separated by motion along the intersecting zone [10, 11]. A different type of the areas considered is represented by "virtual" intersections (in plane view) of fault zones that are active in different layers of the Earth's crust. The Shemakha area, Southeastern Caucasus may be cited as an example. Stress concentrates on the boundaries of such layers and can generate earthquakes

The epicentres of strong earthquakes concentrate between neighboring terminations of en echelon segments of a strike-slip fault (the North Anatolian zone in the 20th century). Near-fault basins are often formed in such areas. Depending on the relative position of the segments and the direction of slip, the basins can experience the extention of pull-apart type or compression of push-inside type. The studies performed by Karakhanian and the author in the Armenian strike-slip active zones showed that push-inside basins are more active seismically than the pull-apart basins.

At last, the majority of strong earthquakes of the Armenian Upland and adjacent areas were shown to be confined to the ophiolitic zones with ultrabasic bodies or to basins underlain by ophiolites [11]. Such association may be related to other specific feature of many strong earthquakes in the collision zones, namely, they occur in the periods of smaller compression, i.e., in the periods of relative extension of the zone and associated intensification of the groundwater circulation [11]. One of the processes that are accelerated under such conditions is the alteration of peridotite to serpentinite. Another accelerated process is metamorphism of basalts [12]. The associated changes in the rock volume may change the stress field and enhance the seismicity.

1/3 of strong earthquakes, occured in the very seismic North Anatolian fault zone, are concentrated in relatively small fault segment, occupying the Erzincan basin and its continuation up to the recent intersection with the East Anatolian fault. The higher seismicity of the area can be explained by combination of three its peculiarities. At first, it is the area of intersection of two active strike-slip fault zones. At second, the Erzincan basin is the push-inside basin between two en echelon fault segments. At last, the basin is underlain by ophiolites with the largest (for the North Anatolian zone) ultrabasic body.

6. Active faulting and environment

The active fault zones are characterized by enhanced erosion and by concentration of landslides, areas of enhanced fracturing and surface deformation, hydrodynamic anomalies, and karst and anomalous permofrost phenomena. The aerial and satellite-assisted experiment "Tien Shan-Intercosmos-1988" and subsequent investigations in the active fault zones of the Tien Shan and Pamirs revealed alternating magnetic anomalies and electrical conductivity anomalies of rocks. Higher concentrations were found of carbon dioxide, methane and other hydrocarbons, radon, helium and occasionally hydrogen, mercury, manganese, arsenic, zircon, niobium, and some other heavy metals. The latter commonly occur as gases and solutions. In active zones, they are recorded in mineral springs, soil, and vegetation [13]. All these features are harmful for health and for stability of constructions.

The detailed investigation and mapping of active faults and related radioactivity in the city of Saint Petersburg and suburbs and correlation of the fault zones with the environmental parameters revealed the oppression of biota and increase in the cancer diseases [14]. These are more intensive than those related to the industrial pollution.

However, the comparative analysis shows that the East European towns founded before 1300 on the supposed active faults and particularly at their intersections and junctions developed essentially faster than the similar towns did outside such faults. First cultivation cultures and oldest urban civilizations originated in the active zones bounding the Arabian plate. Thus, the fault influence on the health and activities of peorle can be both negative and positive and requires further multidiscipline studies. However, as it obvious even now, this influence should be taken into account in the planning of construction, land use, prophylactic medical measures, and population activities on particular territories.

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