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The Map of Active Faults in Eurasia: Principles, Methods, and Results

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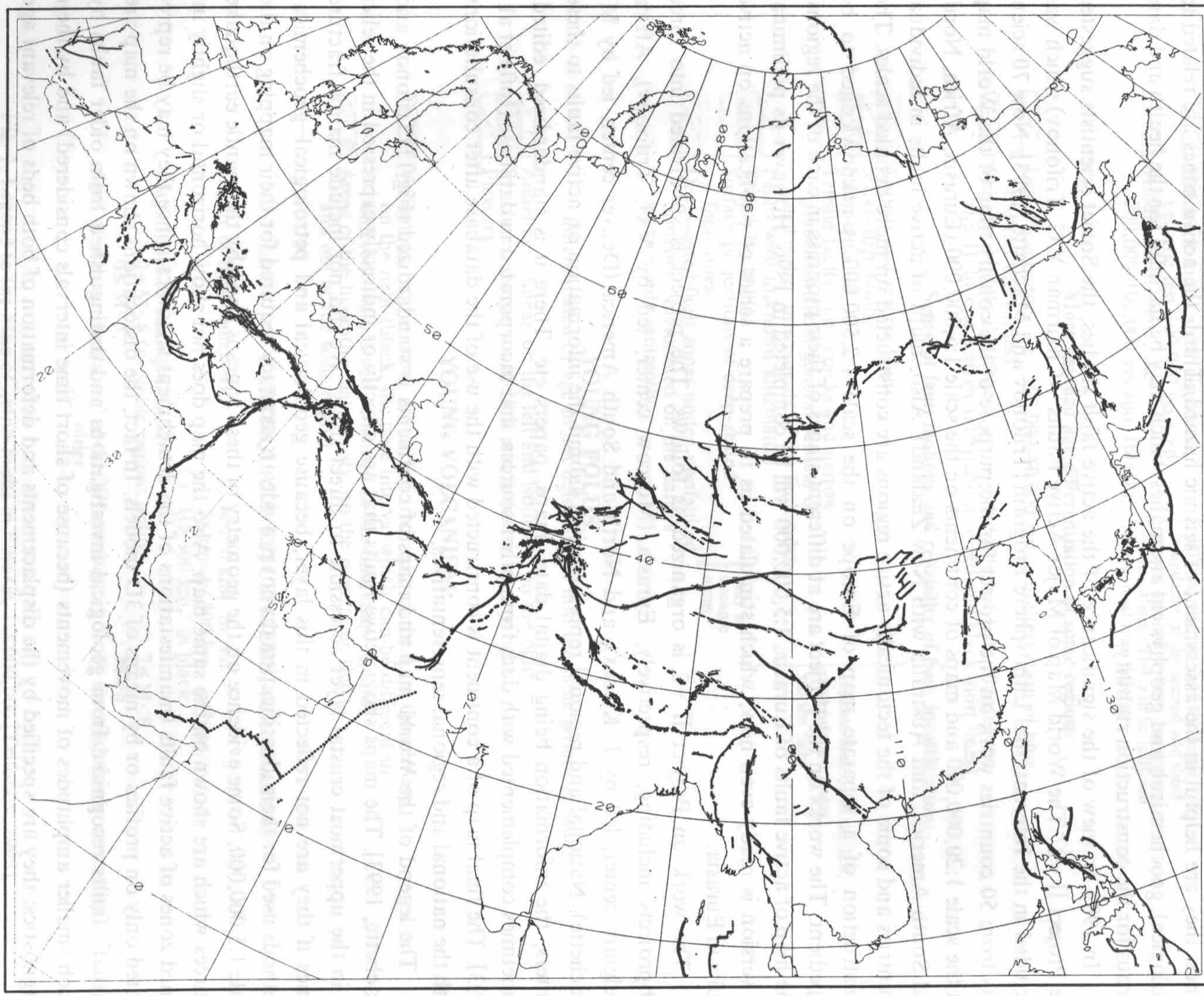
Abstract. The paper describes the principles and methods of the identification, study, and mapping of the active faults, organization of the Project II –2 "World Map of Major Active Faults" of the International Lithosphere Program, the legend of the Map of active faults, general regularities of active faulting in Eurasia, and implications of active faults for the assessment of seismic hazard and for the environment and population.

1. Mapping Principles and Legend

The synonyms " active fault" and " living fault" were introduced in the forties by American and European authors, respectively, to designate the tectonic dislocations associated with movements that occur presently or can occur in the nearest future. Since tectonic movements are nonuniform in time and a fault that was inactive for a long time can experience a large movement, e.g., at a strong earthquake, there arose the problem of a characteristic time which is adequate for specifying the fault activity, direction, mean rate, and character of movements, and associated natural phenomena.

Obviously, the period of instrumental observations which spans tens of years in most countries and regions is insufficient for the determination of these parameters. Historical evidence on earlier movements and related phenomena is also insufficient due to the limitations both of areas documented and of the documents themselves. On the other hand, the information based on all faults that were active over the neotectonic period is redundant and hence incorrect because many faults, active at earlier stages of the period, were passive for a long or entire subsequent period or changed the intensity and, less often, the direction of their movements.

Allen [1975] suggested to consider a fault to be active if it yields evidence for the motions in the Holocene, i.e., over the last 10000 years. In our opinion [Trifonov, 1983, 1985], this interval, even in active areas, should include the Late Pleistocene (i.e., the last 100,000 years) for three reasons. First, the Holocene is too short an interval for some faults to reveal their activity. Second, outside the Late Quaternary glaciations, the stratigraphic differentiation of the Late Pleistocene and Holocene is sometimes unreliable. Third, too small amplitudes of the Holocene motions on some faults and uncertainties of their datings lead to considerable errors in the determination of mean rates and even directions of motion, while less reliably dated but larger,Late Pleistocene displesements on the same faults provide better accuracy of such determinations. The intensity of fault motions in stable platform areas is commonly much lower, and activity pulses related to



Map of major active faults of Eurasia.

Only faults with rates of motion not less, then 1mm/yr, are shown. The faults with rates of motion not less, then 5 mm/yr, are shown by heavier lines

- normal fault
- thrust and reverse fault
- extension fault
- strike-slip fault
- flexure
- unknown
- seismic focal zone
- transform fault
- deep-seated fault zone

Age of the last manifestations of activity

- Middle Pleistocene
- Late Pleistocene and Holocene, including historical and contemporary

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The authors are named in Table 1 (Trifonov's paper, this volume)

strong earthquakes are much fewer. Therefore, determination of the fault activity there should be based on motions that occurred not only over the last 100,000 years but also during the Middle Pleistocene, i.e., over the last 700,000 years. It is these faults that are shown on the Map of active faults, 1:5,000,000. A simplified version of this map, showing the faults with mean rates equal to or higher than 1 mm / yr, is presented in this work.

The studies of active faults are important in three respects. First, they enable the quantification of the recent geological processes and the adequate geodynamic interpretation of the geological past. Second, since the majority of strong earthquakes occur in the active fault zones, they are helpful in the assessment of seismic hazard. Third, the active zones are related to geological, geochemical, and geophysical anomalies which may be harmful for the health and dangerous for the construction stability.

In 1989, in view of the significance of the active fault studies, the Soviet scientists suggested the Project II −2 "The World Map of Major Active Faults" (Chairman V.G. Trifonov) which was included in the International Lithosphere Program [Trifonov and Machette, 1993]. Now 70 scientists from 50 countries work on the project for the purpose of the construction of the World map on the scale 1:20,000,000 and maps of continents on the scale 1:5,000,000 (Eurasia, Africa, North and South America, and Australia with New Zealand). Also, maps of active faults in individual countries and some of the tectonically active regions are constructed on more detailed scales. The construction of a separate map of Europe on the scale 1:2,500,000 is acknowledged to be expedient. The works on the Project are at different stages of their progress in each of the regions. The map of active faults of Eurasia, 1:5,000,000 will be completed in 1996. However its preliminary version is ready even now, which stimulated us to prepare a series of publications on active faults in Eurasia.

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 [Ioffe et al., 1993]. The final map of a continent is constructed with the use of the database after consultations with the national and regional representatives.

The legend of the World map and maps of continents is standardized (Fig.1) [Trifonov and Machette, 1993]. The maps show active faults that are directly or indirectly expressed in the relief or in the uppermost crustal layer accessible to direct study. We did not include mantle fracture zones if they are not reflected in this layer, because geophysical and petrological−geochemical methods used for their identification do not provide an accuracy required for their mapping on the scale 1:5,000,000. Some evidence on the geometry of these zones is given by the mantle earthquake sources which are shown on the same map. Also the map does not show horizontal or slightly inclined zones of active faults (manifestations of the detachment tectonics) since they may be represented only on profiles or by means of 3D models. In fact, the dislocations shown on the map are "usual" faults recognized from geological investigations and distinguished from older faults by much smaller amplitudes of movements (because of short time intervals considered) and by their diagnostics: they are specified by the displacements and deformation of both beds of relevant age

ACTIVE FAULTS, differentiated by:

Rates of fault movements V:

- V≥5 mm/yr
- 5 mm/yr>V≥1 mm/yr
- V<1 mm/yr

All faults with unknown rates can be shown only by symbols of either the third or the second group

Age of the last manifestations of activity:

- Historical (blue)
- Holocene and Late Pleistocene, i.e. the last 100,000 yrs (red)
- Middle Pleistocene, i.e., 700,000-100,000 yrs ago (black)

The historical period is different in different regions, and the lower boundaries of the second and third groups may differ from one region to the others. This will be reflected in the final map legend.

More detailed age differentiation in some regions:

- Late Pleistocene, i.e. 100,000-10,000 yrs ago (alternation of blue and red short lines)
- Reliable Middle Pleistocene activity and inferred Late Pleistocene and Holocene activity (alternation of red and black short lines)

Sense of fault motions and reliability of fault identification:

- Thrusts and reverse faults
- Strike-slip faults
- Normal faults
- Tensile faults, i.e. cracks and narrow grabens without general vertical or strike-slip movements of the fault sides
- Faults with unknown kinematics
- Transform faults
- Surface projections of deep-seated foci zones
- Deep-seated fault zones under nonfaulted horizons, manifested on the Earth's surface only indirectly

reliable faults, on the left, and inferred faults, on the right

only in oceanic areas

YOUNG FOLDS,
differentiated by age of last deformation into the same groups as faults:

- Anticlines, linear on the left and isometric on the right
- Synclines, linear on the left and isometric on the right
- Flexures

YOUNG VOLCANISM:

- Volcanoes, active now, on the left (red) and in the Late Quaternary, on the right (black; the time interval which can be different in different regions will be shown in the final map legend)
- Areas of the hydrothermal activity: on the map scale (left), and out of the scale (right)

EARTHQUAKE EPICENTERS, differentiated by:

Depth of hypocenters H: H≤70 km, in red, 70 km<h<300 km, in blue, H≥300 km, in black

Magnitudes of earthquakes M: 4≤M<6 (in stable regions only), 6≤M<7, 7≤M<8, M≥8

Ages of seismic events: of the XX century, older, records of paleoseismicity,

Fig. 1. Legend to the Map of active faults in Eurasia, 1:5,000,000 [Trifonov, 1995].

and younger relief features. In this case, the Earth's surface plays the role of a peculiar, continuously deforming key horizon.

The classification of active faults, reflected in the legend and on the map, corresponds to the principles of their identification. The faults are classified by intensity and direction of their movements, by age of last documented activity events, and by reliability of their identification. The intensity means the average rate of movements over a sufficiently long time interval irrespective of their character: this may be a continuous slow motion or a sequence of single slips related to strong earthquakes and separated by periods of relative quiescence. The classification by sense of motion is quite traditional. Specific attention should be paid to extension faults. First, they are dislocations with pulled–apart walls, motion on which reach considerable amplitudes only if the space between the walls is filled up with magma material and the fault is represented by a chain of volcanoes on the surface. Second, they are the zones of closely spaced low–amplitude tensile fractures, with the net amplitude of their pull–apart movements reaching an appreciable value. Third, they are narrow grabens bounded by normal faults or by normal fault zones (sometimes with an additional pull–apart component) that cannot be resolved individually on the map scale. By age of last activity events, the faults are subdivided into the Middle Pleistocene (0.7–0.1 Ma), Late Pleistocene–Holocene (the last 100,000 years), and historical faults. The latter also include the faults with motions (earthquakes, among others) recorded instrumentally or by other methods during the last decades.

2. Methods

Methods used for the recognition of active faults and determination of their parameters are widely discussed in literature [Allen, 1975; Annales Tectonicae, 1992; Geol. Rndsch., 1955; Nikonov, 1977; Nikonov et al., 1983; Sieh, 1978; Trifonov, 1983, 1985, 1993; Wallace, 1968, 1977, 1978, 1986; and others]. Recently interesting new techniques were reported in regional summaries on active faults in China, Japan, and West United States. Briefly, the methods employed in the studies of active faults can be outlined as follows.

First, on the basis of the neotectonic studies of a region, main tendencies of its development in the Late Cenozoic are defined, and areas, zones, and specific faults are recognized, where the motions may be supposed to continue in the Late Quaternary. Such areas and zones are examined with the use of aerial and satellite photographs to find disturbed relief features in the fault zones. Sometimes the direction and even amplitude of movements can tentatively be estimated [Trifonov, 1993]. Ground–based geological and geomorphological investigations are carried out in the faulted areas revealed from the photographs to determine the character of movements and structural and evolutional features of the faults. Significant are both the direct evidence on the displacements of geological layers or relief elements and their indirect manifestations such as the deformation of the surface trace of the fault, the drainage pattern, the changes in direction, width and longitudinal and lateral profiles of river valleys crossed by the fault, the Quaternary facies variations, and so on. At the final stage of the studies, the aerial and satellite imageries are used for the exact mapping of the fault considered.

Of particular significance are ruptures and motions on faults, associated with contemporary catastrophic earthquakes [Lukianov, 1963]. Being themselves the manifestations of tectonic activity and providing the information about the sense of fault movements, these phenomena serve as reference patterns for the recognition of earlier seismogenic movements. The ancient seismic events remain imprinted in the fault zone structure. Thus, Wallace [1977, 1978] showed that sharp profile bendings of a fault scarp are indicative of the paleoearthquake movements separated by periods of tectonic stability. Differences in the weathering extent of the slickenside at various levels of the fault plane have the same meaning. A nonuniform amplitude distribution of motions on a long segment of the fault provides evidence for discrete seismogenic strike–slip events [Wallace, 1968; Trifonov, 1985, 1995a]. For example, offsets of relief forms by 5–6, 11–12, and 16–17 m are frequent, and virtually absent are offsets by 1–3, 7–9, and 13–14 m. Damming of small valleys due to strike–slip fault motion also is related commonly to a seismogenic event rather than to slow motion at which the river valley, though being bent, has time to adjust its channel to new conditions.

Young motions on faults can sometimes be dated on the basis of historical or archaeological evidence on fault–related damages of ancient constructions or from layers that contain remnants of ancient cultures. Attempts, sometimes successful but always of local significance, were also made to determine the age of young motions from lichenometry, fine–bedded clays of glacier lakes, and annual growth rings. More generally, geologically well–defined young movements are dated by the radiocarbon method. In this case, the sediments are dated that were displaced by a fault or originated after and, sometimes, as a result of displacement (e.g., the onset time of sedimentation in the basins within fault zone). The closer in time are the displaced and post–movement beds, the higher is the accuracy of the movement dating. Recently the radiocarbon dating was complemented by the U–Th method which yields particularly reliable results in the analysis of rising (partially extinct) reef buildings [Sieh et al., 1995].

Dating of strong fault–related paleoearthquakes and associated structural forms is particularly important to constrain both the recent development of a fault and mean rate of movements on it. The methods for such dating were reviewed by Trifonov [1995a]. Archaeological data are occasionally used for this purpose. Thus, using displacements of ancient irrigation galleries, I dated historical earthquakes in the Main Kopet Dagh fault zone. Radiocarbon datings are more often employed for this purpose. In this way, Sieh [1978] dated the displaced beds and beds that overlie seismogenic fractures of various age in the San Andreas fault zone. Deng and Zhang [1990] dated specific collapsed deposits, probably of seismic origin, adjacent to the Haiyuan Fault, China. Paleosoils overlain by seismogenic landslides were dated in the Darvaz–Alay fault zone between the Pamirs and Tien Shan [Nikonov et al., 1983]. The dated paleosoil in the Spitak, North Armenia, 1988 earthquake area is overlain by a seismogenic thrust slice [Rogozhin and Rybakov, 1990]. Trifonov [1985] dated historical earthquakes in Mongolia by the age determination of beds that were deposited in small near–fault basins immediately after their seismogenic subsidence.

Recently much progress was made by trenching many active fault zones [Prentice et al., 1994; Valensise and Pantosti, 1995]. This technique allows one to identify and date historical earthquakes and hence to estimate their recurrence in a fault zone. However, though a single trench is helpful in exposing the earthquake traces in a section, it is useless for the discrimination between a normal fault and a strike–slip fault with a small vertical component, or between the trace of a strong earthquake at the end of its rupture and the ground motion at the epicenter of a weaker earthquake, i.e., for the estimation of paleomagnitudes. For this purpose, a series of trenches should be dug along a fault, which is labor–consuming and, for that matter, does not solve the problem of the relation between the vertical and horizontal components of seismic source motions. Some ways for estimation of this relation are suggested above.

The radiocarbon datings are reliable only for the last tens of thousand years, i.e., for the Holocene and partly Late Pleistocene. Earlier Pleistocene formations and related fault movements are dated by the less accurate K–Ar, biostratigraphic, and thermoluminescence methods. The geological and geomorphological correlation of displaced and younger deposits and relief forms with formations of known age is widely applied to the age determination of both Holocene and Pleistocene movements. Tephrochronological and paleomagnetic methods are useful in certain regions.

In addition to the geological and geomorphological studies, geodetic, gas–hydrogeochemical, volcanologic, and landscape methods are applied to identify and study the active faults.

Repeated geodetic observations, both ground– and GPS–based, provide information about the direction and rate of contemporary fault movements. However, whenever fairly reliable geological–geomorphological data on the Late Quaternary movements could be compared with the repeated geodetic observations, the latter often yielded consistent directions of motion but considerably higher values of rates. To a greater degree, this is related to the measurements of the vertical rather than strike–slip movements. These discrepancies might be related to the variability of the rates in time and along fault strike, so that the rate is averaged over fairly long time intervals measured by geological–geomorphological methods. For this reason, geodetic data provide evidence for active faults, but one should be cautious in applying them to the estimation of the averaged intensity of movements.

The seismic data are very important. Of course, a single earthquake that occurred in a fault zone and produced no marked surface rupture or deformation of the surface cannot be considered as convincing evidence for the activity of the fault. Nevertheless, chains of epicenters (which may be located at some distance of the surface trace of an inclined fault) are suggestive of the possible activity of the fault, and seismogenic ruptures and other manifestations of strong earthquakes and paleo–earthquakes in the fault zone indicate with certainty such activity. Focal mechanism determinations yield evidence for the sense of motions.

Seismic profiling, gravity, and geothermal data, as compared to other geophysical evidence, are most significant for the estimation of fault activity. Generally, fault–related electromagnetic anomalies do not inficate fault activity. However, as is recently found out, the variability of the electromagnetic fields in active fault zones may be considered, along with the gravity field, as a diagnostic feature, although it can occasionally be related to hydrogeological variations of meteorological origin. The volcanic chains are indicative of faults with a considerable extension component.

3. Study of Active Faults in Eurasia

Until the 1960s no purposeful studies of the active faults in Eurasia were performed. More or less detailed mentions of the young movements can be found in old manuscripts and scientific treatises in connection with the descriptions of effects of strong earthquakes and in publications on regional geology. Significant for the development of such studies were papers on active tectonics published in Geologische Rundschau [1955] and the results on active faults of Asia obtained by Allen [1962], Pavoni [1961, 1964], and Wellman [1966].

Beginning from the 1960s the purposeful investigations of active faults on the USSR territory were initiated by a group of Irkutsk seismotectonists led by V.P. Solonenko and N.A. Florensov [Florensov, 1968; Solonenko et al., 1966, 1968, 1985; Solonenko, 1977; Khromovskikh, 1965; Sherman et al., 1973; Sherman and Levi, 1978; Khilko et al., 1985), and in Moscow these studies were performed by A.A. Nikonov with colleagues [Nikonov, 1970, 1977, 1995; Nikonov et al., 1985) and by V.G. Trifonov with colleagues [Kopp et al., 1964; Trifonov, 1976, 1978, 1983, 1985, 1989, 1991, 1993, 1995a; Trifonov et al., 1988, 1993, 1994b]. These works covered the mountainous areas of Soviet Central Asia, Caucasus, Baikal, and Altai–Sayany regions, Kamchatka, and Mongolia. Later such studies were carried out in Yakutia [Imaev et al., 1990]. These investigations resulted in the construction of the first map of active faults in the USSR and adjacent areas on the scale 1:8,000,000 and in the Explanatory note to the map [Trifonov, 1986–1987]. At the same time the active faults were studied in China [Molnar and Taponnier, 1975; Ding, 1984; Atlas, 1989; Map, 1992], Japan [Maps, 1991–1992], and Iran [Berberian, 1976–1977]. Somewhat later such studies were initiated in Turkey [Barka, 1992, 1995; Saroglu et al., 1992a,b], Greece [Pavlides et al., 1991; and others], Italy [Neotectonic map, 1987; Vittori, 1993; Serva, 1995], France [Sismotectonique, 1993], and other countries.

The 1989 Project II –2 of the International Lithosphere Program encouraged the wider and more intensive investigations of the active faults of Eurasia, which resulted in the collection, analysis, and synthesis of original data and the compilation of a map and catalog of active faults of the whole continent on the basis of a standardized approach and unified map legend. The authors and editors of separate map regions are listed in Table 1. The pertinent papers by national and regional participants of the Project were published where synthetic descriptions of active faults in certain regions of Eurasia are presented. Whenever a map fragment is completely based on a previous publication, we believed it inappropriate to repeat here this description and refer the reader to relevant publications. This is the case with the active faults in France [Sismotectonique, 1992], Japan [Maps, 1991–1992], Portugal [Madeira and Ribeiro, 1990; Ribeiro et al., 1990], and Fennoscandia [Lagerback, 1990; Olesen et al., 1992; 1995].

4. General Regularities of Active Faulting in Eurasia

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, slices, and blocks of the crust. The average rates of Late Quaternary movements on certain intraplate faults are not smaller than their values for faults that are considered to be the plate boundaries for structural reasons. Thus, the rate of motions on the Talas–Fergana strike–slip fault (15 mm / yr) is not smaller as compared with the Darvaz–Alay fault at the northeastern margin of the Indian plate, and the rate on the Pambak–Sevan–Khanarasar strike–slip fault in Armenia (5 mm / yr) is only slightly smaller than the values derived for the Levant and East Anatolian strike–slip faults at the western margin of the Arabian plate.

Table 1. Participants in the construction of the map and database of active faults in Eurasia

Region	Authors	Additions and edition
North Arctic Ocean	B.A.Asinovskaya, M.N.Alekseev	N.V.Lukina
Iceland	V.G.Trifonov	
Fennoscandian shield:		
Norway, Sweden and Finland	R.Lagerback, N.-A.Morner, R.Muir-Wood, O.Olesen, et al.	
Kola Peninsula	T.P.Ivanova and publ.data	I.P.Ivanova, D.I.Garbar
Karelia	D.S.Zykov	A.I.Kozhurin
Belgium, Netherlands Luxemburg	Publ.data	M.Hanon
Germany	Publ.data of L.Abornen, P.Bankwitz, H.Quitzow and O.Vahlensieck et al	P.Bankwitz, S.F.Skobelev
France	Publ. data of B.Grellet, Ph.Combes, Th.Granier, H.Philip	H.Philip, M.V.Rozanov
Spain	J.M.Diaz, P.Villamor	
Portugal	A.Ribeiro	
Italy	D.Castaldini, M.Panizza, D.Pantosti, L.Serva, D.Slejko E.Vittori et al	E.Vittori
Greece	S.Pavlides, I.Mariolakos et al.	S.Pavlides
The former Yugoslavia	Publ. data of D.Cvijanoich et al.; H.Arsovski et al.	S.F.Skobelev
Bulgaria	M.Matova	S.F.Skobelev
Romania	Publ.data	S.F.Skobelev
Poland	Publ.data of M.Bac-Moszaszwili (ed) and W.Zuchiewicz (ed)	S.F.Skobelev
East European Platf.:		A.I.Kozhurin, N.V.Lukina
Baltia	H.H.Silbvee, V.I.Suvezdis	
Belarus	R.G.Garetsky, A.M.Boborykin, R.R.Pavlovets, N.V.Aksamentova V.M.Burak, I.V.Dankevizh, M.A.Nagorny	
Ukraine	V.P.Palienko, R.P.Kuprash, V.I.Somov	
Moldova	G.M.Bilinkis	
Russia	V.I.Babak, N.K.Dmitrieva, O.L.Grachova, N.A.Malyshev, E.K.Melnikov, V.A.Ogadzhianov, L.A.Pustovetova, V.A.Rudnik, G.P.Shcherbinina, L.I.Soloviova,	
Urals	S.F.Skobelev	
Crimea	R.P.Kuprash, N.V.Lukina, D.S.Zykov	
Caucasus		V.G.Trifonov
Foredeep	V.A.Viginsky	
Northwest Caucasus	N.V.Lukina	
North Caucasus	T.P.Ivanova, M.L.Kopp, V.G.Trifonov	
Armenia	A.S.Karakhanian, A.I.Kozhurin,	

Continued Table 1.

Region	Authors	Additions and edition
	V.G.Trifonov	
Azerbajan	V.G.Trifonov, M.L.Kopp	
Georgia	S.I.Kuloshvili	
Turkey	A.Barka, F.Saroglu et al.	V.G.Trifonov, A.Karakhanian
Syria, Lebanon	V.G.Trifonov	
Israel	V.G.Trifonov, A.Gelat, I.Karcz	
Jordan	Z.H.El–Isa	
Red Sea	V.G.Kazmin	
Irag	M.Graniczny	
Iran	M.Berberian	V.G.Trifonov
	K.Hessami	A.Karakhanian
	F.Jamali	G.A.Vostrikov
Copet Dagh	V.G.Trifonov	
Turan platform	L.B.Aristarkhova, A.A.Nikonov,	
(western part)	V.V.Sholokhov	
Uzbekistan	Sh.H.Abdullaev, V.I.Makarov	V.I.Makarov
	S.S.Shults, Jr., A.R.Yarmukhamedov	
Kyrgizstan	K.E.Abdarakhmatov, V.I.Makarov, N.V.Lukina, S.F.Skobelev, A.L.Strom, V.G.Trifonov	
Southern Kazakhstan	A.V.Timush, V.G.Trifonov	
Pamirs	V.G.Trifonov,A.A.Nikonov	
Afganistan	S.F.Skobelev	
Pakistan, India	T.Nakata, A.Sinha,R.Yeats et al.	
China	Ding Guoyu and publ. data	Ding Guoyu, A.I.Kozhurin
Kazakh shield, Altai	N.V.Lukina	
Sayans, West Siberia		
Mongolia	P.Khosbayar, V.I.Makarov	V.G.Trifonov

The vertical component of movements on active faults is often characterized by thrust and reverse motions rather than by normal–fault ones. This is true for the faults both in mobile belts and in areas of moderate and weak mobility. Thus, most part of the continent is under the conditions of compression, which is consistent with estimates of the present–day stress state, obtained by different methods [Kropotkin, 1977].

More than half of active faults in the mobile belts of Eurasia have a strike–slip motion component which is considerably 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 motions on thrusts, reverse faults, and even normal faults [Trifonov, 1991]. Along with strike slips of transition, which displace one fault side as a whole relative to another, the strike–slip faults of rotation and squeezing of rocks away from the area of maximum compression must be discriminated. They produce the lateral shortening of the collision belt and redistribute rock masses along it.

The active faulting pattern observed on the Earth's surface reflects mainly the dislocations and deformations 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 crystalline crust and between the upper crust and the layers near the Moho boundary [Makarov et al., 1982; Kozhurin and Vostrikov, 1988; Pushcharovsky and Trifonov, 1990; Trifonov, 1983, 1989, 1991]. This discrepancy is caused mostly by the different response of rheologically different rocks to essentially identical loadings (Southeastern Caucasus and Central Asia). However, the orientation of stresses and direction of motions in certain regions (Central Japan and Western Tien Shan) are not the same in different crustal layers. In general, the motions and deformations of the lower crust play the same role for the kinematics of the upper crust, as the asthenosphere 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.

Tectonic features of the lateral shortening in the present–day mobile belts are subdivided into three types:

(1) 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 subducting slab beneath the crust of the allochtonous plate [Kozhurin and Vostrikov, 1988]. Arcs of the Crete and Lesser Antilles type represent a particular case, because the subduction here is accompanied by the overriding of the allochtonous plate. In the Aegean region, the latter is caused by the lateral compression of the Anatolian microplate moving westward and by the concurrent extension due to the rise of the anomalous mantle, initiated by the tectonic destruction of the regional lithosphere [Trifonov, 1995a]. Similar overriding is likely to occur in Pacific island arcs [Melekestsev, 1980], but there it is much dominated by the subduction processes.

(2) 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 slices (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 underthrust plate (the Himalayas–Tibet and Main Zagros thrust). However, if the lithosphere of the interacting plates is continental, the amplitude of such underthrusting does not exceed 300 km. In this case the lower crust is a main zone of the tectonic flow and deformation of rock masses, while the mantle part of the lithosphere (mantle lid), with overlying crust detached, sinks into the mantle, undergoing considerable deformations as well.

(3) A "bulldozing" is a main mechanism responsible for the distribution of deformations and movements over vast areas of the Central and East Asia. The mechanism is related to the northward drift of the Indian plate, giving rise to the deformation and movement 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 2 is typical of the lithosphere near the northern front of the Indian plate (the Himalayas and Pamirs). Further to the north and northeast, deformations concentrate in boundary zones between blocks and microplates, forming mountain systems, whereas weakly deformed central parts of large blocks often form the intermontane basins, subsiding isostatically in response to their filling with clastic material. Interblock mobile belts near the Indian plate have the struc-

ture of type 2. Further the intensity of the neotectonic folding diminishes and is replaced by purely fault–type structures dominated by strike–slip movements. Extension structures (the Baikal system and Shansi graben) develop on the curved segments of large shear belts.

In the region of Alpine Europe and Mediterranean, the processes of types 2 and 3 are less pronounced, being of local character and associating with the lithosphere extension features. The latter are represented both by rifted zones and by isometric basins such as the Pannonian and Aegean basins. The wide occurrence 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 interaction zone of the Arabian and Eurasian plates is intermediate between Central Asia and Alpine Europe.

An essential element of the active tectonics in the Alpine–Asian collision belt is represented by the Pamir–Punjab, Arabian–Lesser Caucasus, and Adriatic syntaxes facing north and being asymmetric [Kozhurin, 1995; Trifonov, 1995b]. Their western flanks are fairly narrow and exhibit features of weak compression or extension. Compression structures are more pronounced their northeastern flanks 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 meridional orientation of the syntaxis axes at their northeastern flanks, produces an additional compression.

The present–day pattern of active zones in the mobile belts was, in general, formed in the Pliocene. Earlier the configuration of neotectonic faults differed from the contemporary one in certain areas.

Special attention should be paid to the active faults of platform areas. Within the Russian and West Siberian plates, where the crystalline basement is overlain by a thick sedimentary cover, the presumably active faults are identified by their indirect features only: smoothed steps in the surface, having combined, erosional and tectonic origin; straightened–out segments of the Holocene river valleys; straight boundaries of crustal blocks differing in the pattern of the Late Quaternary vertical movements; and manifestations of the so–called glacial dislocations. The majority of such linear zones are likely to represent Quaternary faults of very low amplitudes or systems of parallel fractures. Many of them exhibit low–amplitude surface displacements of the crystalline basement or are related to basement faults that do not displace appreciably its surface. Dislocations of this type were discovered, for instance, beneath Saint Petersburg at subway building [Mel'nikov et al., 1994]. They displace the pre–Quaternary sedimentary cover and control the paleochannels of the last interglacial and, in certain cases, thickness variations of the last glaciation moraine and Holocene deposits (Fig. 2).

However, repeated geodetic observations in some of such platform zones provided evidence for the relative vertical movements of the flanks. The movement rates estimated from the relative displacement of geodetic bench marks at different sides of the zones are many times higher than the average rate derived from the displacements of the basement surface or horizons of the sedimentary cover. To explain such a divergence, essential is the experiment carried out by Churikov [1995] in the zone of a minor fault in Kamchatka, 20 km northeast of the town of Petropavlovsk. During 800 days the author made weekly measurements of the relative displacement of the 2.8–km baseline ends. Smooth seasonal variations and, against their background, short–lived fluctuations of an amplitude to 15 mm were revealed. Eventually they did not change the relative position of the baseline ends. Similar fluctuations might occur at the flanks of the hypothetical faults in platform areas. Because the trend of such movements, if does exist, is negligibly small, they are shown on the map of active faults by a special symbol.

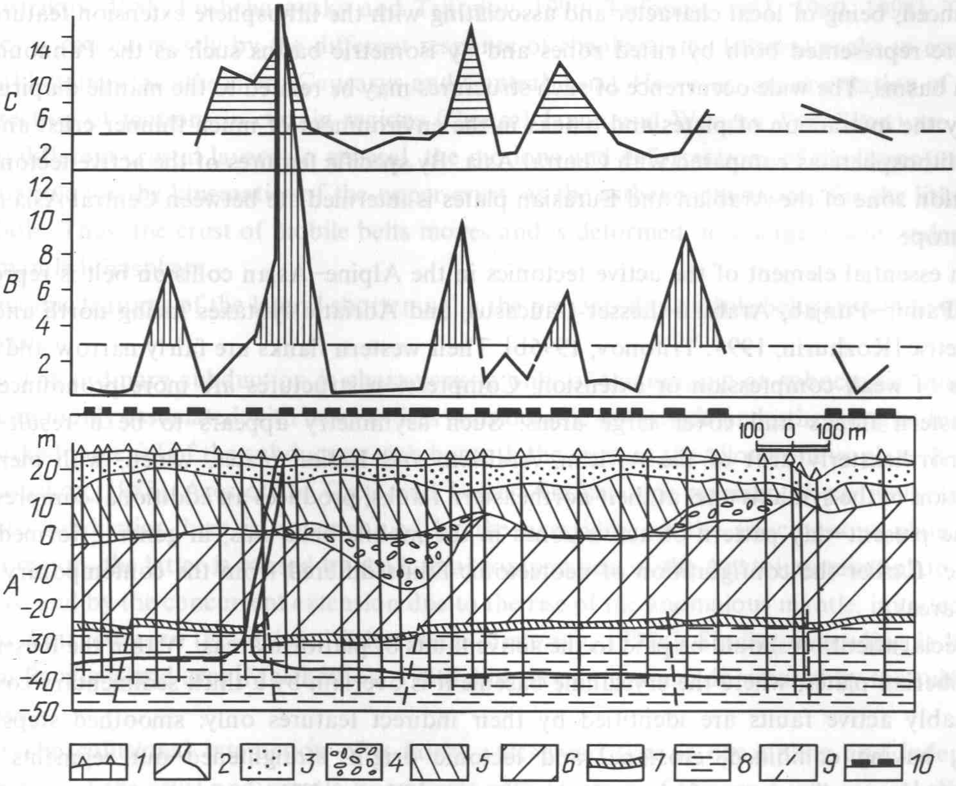

Fig. 2. Results of comparing the geological structure of the sedimentary cover in the Kalininskii District, Saint–Petersburg (A) with the yearly number of oncological patients per 1000 men (B) and with the soil radon concentration in kBq / m (C) [Mel'nikov et al., 1994]. (1) holes; (2) gallery and roof of the subway tunnel; (3) postglacial sand and sandy loam; (4) gravel–sand deposits of interglacial paleochannels; (5) loam ad sandy loam of the last glaciation moraine; (6) Cambrian clay; (7) weathering crust of Vendian deposits; (8) Vendian sand–clay deposits; (9) faults; (10) location of residences on the surface.

Furthermore, the supposed zones of active platform dislocations exhibit certain regularity [Trifonov et al., 1993]. Two zones, probably, of the reverse fault type bound the Baltic shield on the southeast. Normal to them is the zone of extended fractures of NW strike with, probably, normal strike–slip motions. Several tentative reverse faults are recognized around the Carpathian arc, while normal faults are supposed to bound subsiding neotectonic structures (e.g., the Pripyat Basin). Transverse fractures also are found there. Supposed active faults run along the Crimea and Caucasus and along the western slope of the Urals. Arc–like systems bound the western, northern, and eastern flanks of the Near–Caspian Basin. They are crossed by transverse fracture zones. Those of the northwestern strike join with linear zones extending from the Baltic shield. There are known local platform areas with a specific pattern of such dislocations. Thus, the sediment–covered part of the East European platform exhibits features of the dynamic response both to the adjacent mountain–fold structures (the Carpathians, Caucasus, and Urals) and to the Baltic shield and proper platform structures such as Near–Caspian Basin.

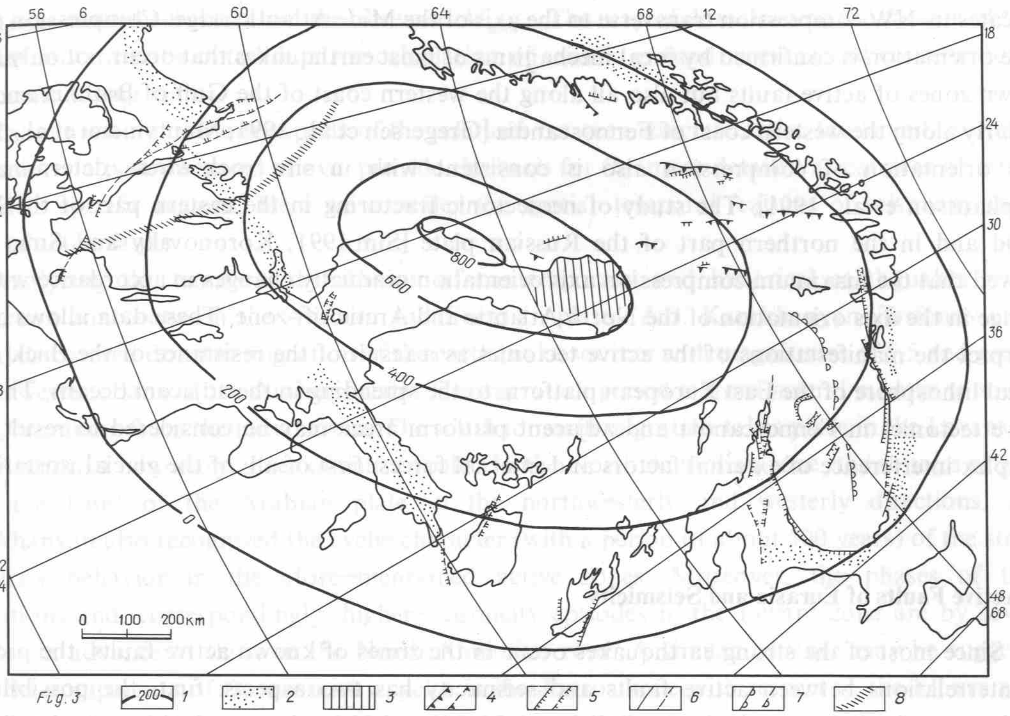

Fig. 3. Map of active tectonics in Fennoscandia, compiled by T.P. Ivanova and V.G. Trifonov.

(1) Theoretical isolines of the postglacial uplift of Fennoscandia during the last 13,000 years [Morner, 1979]; (2) Late Quaternary tectonic depressions bounding the Fennoscandia shield; (3) area of the most intensive (10 mm / yr and higher) recent uplift from geodetic data [Morner, 1979]; (4)–(6) active faults, reliable to the left and tentative to the right: (4) reverse faults and thrusts, (5) normal faults, (6) faults with the uncertain direction of motions; (7) flexure–fracture zones, reliable to the left and tentative to the right; (8) deep active zone expressed only indirectly on the Earth's surface.

More definite features of the active faulting are recognized in Fennoscandia (Fig. 3). A system of young depressions and coastal benches, bounding the shield, is complicated by transverse grabens such as the Kandalaksha graben, White Sea and Oslo graben, Kattegat Sound. Strong earthquakes are related to them. Two extended systems of Holocene reverse faults trending northeast are revealed north of the Gulf of Bothnia [Lagerback, 1990; Olesen et al., 1992, 1995]. The average rates of Holocene motions on them reach occasionally a few millimeters per year, i.e., higher than the rates in orogenic zones. The eastern of these systems continues to the east as a postglacial flexure–fracture zone along the Kola Peninsula axis [Nikonov, 1977]. A system of Holocene tectonic scarps of an amplitude to 20 m and greater extends along its northern coast [Tanner, 1930; Nikonov, 1977].

General analysis of active faults in Fennoscandia reveals their spatial relation to the postglacial uplift, which is corroborated by the following evidence: arcuate troughs bounding the arch; grabens that are transverse to them; alignment of major faults along the uplift axis and the highest rates of motions on them immediately after the glacier melting, when the rates of uplift were maximal [Morner, 1979; Nikonov, 1977]; and at last the density contrasts of rocks exposed at sides of the Holocene ruptures, which yield evidence for the possible isostatic adjustment of the preceding nonuniform glacial erosion. Also, the reverse motions on active faults in Fennoscandia indicates its NW compression transverse to the axis of the Mid–Atlantic ridge. Compression of the same orientation is confirmed by focal mechanisms of most earthquakes that occur not only in the known zones of active faults but also all along the western coast of the Gulf of Bothnia and particularly along the western coast of Fennoscandia [Gregersen et al., 1991; Mantyniemi et al., 1993]. This orientation of compression also is consistent with in situ rock stress determinations [Stephansson et al., 1991]. The study of neotectonic fracturing in the eastern part of the Baltic shield and in the northern part of the Russian plate [Sim,1991; Koronovsky and Sim, 1992] showed that the maximum compression axis orientation gradually changes in accordance with the change in the axis orientation of the North Atlantic and Arctic rift zone. These data allows one to interpret the manifestations of the active tectonics as a result of the resistance of the thick continental lithosphere of the East European platform to the spreading in the adjacent oceans. Thus the active tectonics in Fennoscandia and adjacent platform areas may be considered to result from complex interference of external factors and internal forces, first of all, of the glacial isostatic origin.

5. Active Faults of Eurasia and Seismicity

Since most of the strong earthquakes occur in the zones of known active faults, the problem of interrelations between active faults and seismicity has two aspects: first, the possibility of seismotectonic zoning on the basis of their combined analysis and, second, the more detailed assessment of seismic hazard on the basis of spatial–temporal regularities in the occurrence of strong seismic events in active fault zones.

In their combined analysis Shebalin et al. [1995] subdivided the North 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 differences in the state of knowledge about different regions on the other hand, such division was based on the minimal number of parameters that are easy to determine and apply.

The parameters of active faults were taken from the database of active faults of North Eurasia, created within the framework of the Project II – 2 of the International Lithosphere Program [Ioffe et al., 1993].

Seismological data were taken from the new Unified catalog of earthquakes in North Eurasia (1994, N.V. Kondorskaya and V.I. Ulomov, Eds.) which includes all documented events with magnitudes 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.

In all, about 450 domains were specified on the territory of North Eurasia [Shebalin et al,1996], which may be subdivided into two types: (1) axial domains for which M_{max} is highest on the axis and gradually decrease 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 plane domains with quasi–constant M_{max} all over the area of a domain. In the areas of mantle seismicity, the domains are subdivided also into (overlapping) crustal and mantle domains.

An essential characteristic of each domain is the maximum expected magnitude M_{max} (e) which is commonly greater than the observed M_{max} . The map of domains and the catalog of their characteristics are the initial data for calculation of seismic ground motions and construction of the seismic zoning map.

Examination of various aspects of the relations between concrete active faults and seismicity, which were in part discussed above, provide the basis for the more detailed assessment of seismic hazard in specific regions. 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 zone between the Arabian and Eurasian plates, A.S. Karakhanyan [Trifonov et al., 1994a] 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. A.S. Karakhanyan 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. A similar advance may be suggested from the comparison of the seismicity cycles in the Zagros zone with respect to the Elburz 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 motion 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 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 motions along the intersecting zone [Trifonov et al., 1994a,b]. A different type of the areas considered is represented by "virtual" intersections (in plane view) of fault zones that are active in different crustal layers. The Shemakha area, Southeast Caucasus may be cited as an example [Makarov et al., 1982]. Stresses concentrate on the boundaries of such layers and can generate earthquakes.

The epicenters of strong earthquakes concentrate between neighboring terminations of en echelon segments of a strike–slip fault (the North Anatolian zone in the 20th century [Ambraseys, 1970]). Near–fault basins are often formed in such areas. Depending on the relative position of the segments and the direction of motions, the basins can experience the extension of pull–apart type or compression of push–inside type. The studies performed by A.S. Karakhanyan and the author in Armenia showed that the 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 [Ivanova and Trifonov, 1993]. 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. One of the processes that are accelerated under such conditions is the alteration of peridotite to serpentinite. Tha associated changes in the rock volume may change the stress field and enhance the seismicity.

6. Environment Implications of the Active Faults of Eurasia

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 permafrost phenomena. The aerial and satellite–assisted experiment "Tien–Shan–Intercosmos–1988" carried out by the author and subsequent investigations in the active fault zones of the same region revealed alternating magnetic anomalies and electrical conductivity anomalies of rocks. Higher concentrations were found of carbon dioxide, methane and other hydrocarbons, helium and occasionally hydrogen, radioactive elements, mercury, and some other heavy metals. Radioactive elements and heavy metals commonly occur as gases and solutions. In active zones, they are recorded in mineral springs, soil, and vegetation (Table 2) [Lukina et al., 1991]. All these features are harmful for health and for stability of constructions.

Table 2. Heavy element concentrations in lucerne from fields located in and outside the active fault zone, southern boundary of Tien Shan [Lukina et al., 1991]

Test site	Content of elements (ppm)			
	Mn	As	Zr	Nb
Fayzabad fault (active)	880	32	10	18
Knodja–Obigram fault (weakly active)	340	16	8	5
Outside active faults	250	13	0	0

The detailed investigation and mapping of active faults in the city of Saint Petersburg and suburbs and correlation of these faults with the environmental parameters revealed the oppression of biota (Table 3) and increase in the cancer diseases (Fig. 2) [Mel′nikov et al., 1994]. These are more intensive than those related to the industrial pollution.

Table 3. Content of ill trees in forests located in and outside the active fault zones (f.z.), Saint Petersburg [Melnikov et al., 1994]

Number of trees and % of ill tress	Linden		Birch		Pine	
	in f.z.	outside	in f.z.	outside	in f.z.	outside
Total number of trees	742	428	1133	1281	619	1977
% of trees with dichotomy of tops	9.16	3.74	21.89	5.31	5.01	1.06

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 civilization originated in the active zones bounding the Arabian plate. Thus, the fault influence on the health and activities of people can be both negative and positive and requires further multidiscipline studies. However, as is 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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References

Allen, C.R., 1962, Circum−Pacific faulting in the Philippines−Taiwan region, J. Geophys. Res., 67, no. 12, 4795−4812.

Allen, C.R., 1975, Geological criteria for evaluating seismicity, Bull. Geol. Soc. Amer., 86, no. 8, 1041−1057.

Annales Tcetonicae, 1992, Supplement to V. 6 (Special Issue: Major Active Faults of the World), 284 pp.

Atlas of Active Faults in China, 1989, Chinese working group of the UNESCO−IGCP Project 206, Seismol. Press, 11th Cartographic Publ. House, Beijing, 118 pp.

Barka, A.A., 1992, The North Anatolian fault zone, Annalae Tectonicae, Suppl. to V. 6 (Special Issue), 164−195.

Barka, A.A., 1995, Active faulting in Central and Western Anatolia. In: G. Valensise and D. Pantosti (Eds.), Active Faulting Studies for Seismic Hazard Assessment, National Inst. Geophys., Rome, 27−31.

Berberian, 1976−1977, Contribution to the Seismotectonics of Iran, Geol. Survey of Iran, Tehran, Pt. 1 (1976),516 pp.; Pt. 2(1977), 278 pp.

Churikov, V.A., 1995, Study of vertical deformation during seismic gaps on Kamchatka, IUGG, 21st General Assembly, Abstracts, Boulder, A42.

Deng Quidong and Zhang Weiqi, 1990, The Haiyuan Active fault zone, State Seismol. Bureau, Beijing, 286 pp. (in Chinese).

Ding Guoyu, 1984, Active faults in China. Prediction of earthquakes and continental seismicity, State Seismol. Bureau, Bijing, 225−242.

Florensov, N.A., 1968, Baikal rift zone and some problems of its atudying. In: Baikal Rift, Nauka, Moscow, 40−56 (in Russian).

Geol. Rndsch., 1955, Vol. 43, 216 pp.

Gregersen, S., Korhonen, H., and Husebye, E.S., 1991, Fennoscandian dynamics: Present−day earthquake activity, Tcetonophysics, 189, 333−344.

Imaev, V.S., Imaeva, L.P., and Kozmin, B.M., 1990, Active Faults and Seismicity in Northeastern Yakutia, Yakutian Division, Acad. Sci. USSR, 138 pp. (in Russian).

Ioffe, A., Govorova, N., Volchkova, G., and Trifonov, R., 1993, Data base of active faults for the USSR area, Geoinformatics, 4, no. 3, 289−290.

Ivanova, T.P. and Trifonov, V.G., 1993, New aspects of the relationship between tectonics and seismicity, DAN, 331, no. 5, 587−589 (in Russian).

Khilko, S.D., Kurushin, R.A., Kochetkov, V.M. et al., 1985, Earthquakes and Principles of Seismic Zoning of Mongolia, Nauka, Moscow, 225 pp. (in Russian).

Khromovskikh, V.S., 1965, Seismogeology of the Southern Baikal Region, Nauka, Moscow, 121 pp. (in Russian).

Kopp, M.L., Rastsvetaev, L.M., and Trifonov, V.G., 1964, Tectonic rupturesproduced by strong Holocene earthquakes in central Kopet Dagh Range and piedmonts, Izv. Akad. Nauk SSSR, ser. geol., no. 7, 59–69 (in Russian).

Koronovsky, N.V. and Sim, L.A., 1992, Neotectonic activity and mechanism of the northern East European platform formation, Intern. Conf. on the Oil and Gas Prosperity of the Barents and Kara Seas and Adjacent Land Areas, NIIMorGeofizika–IKU Petroleum Res., Murmansk, N A11.

Kozhurin, A.I., 1995, Repetitive structural combinations in the Himalayan–Mediterranean mobile belt, 2nd Intern. Symp. on the Geology of the Eastern Mediterranean Region, KENES, Jerusalem, 12.

Kozhurin, A.I. and Vostrikov, G.A., 1988, Kurile–Kamchatka island arc system, In: P.N. Kropotkin (Ed.), Neotectonics and the Recent Geodynamics of Mobile Belts, Nauka, Moscow, 67–135 (in Russian).

Kropotkin, P.N., 1977, Stresses in the Earth's crust and faulting, In: Faults in the Earth's Crust, Nauka, Moscow, 20–29 (in Russian).

Lagerback, R., 1990, Late Quaternary faulting and paleoseismicity in northern Fennoscandia, with perticular reference to the Lansjarv area, northern Sweden, Geologiska Foreningens i Stockholm Forhandlingar, 112, Pt. 4, 333–354.

Lukianov, A.V., 1963, Horizontal movements on faults during recent catastrophic earthquakes, In: A.V. Peive (Ed.), Faults and Horizontal movements in the Earth's crust, Akad. Nauk SSSR, Moscow, 34–112 (in Russian).

Lukina, N.V., Lyalko, V.I., Makarov, V.I. et al., 1991, Preliminary results of spectrometry in fault zones of the Fayzabad and Frunze research sites (Intern. Air–Satellite Experiment "Tien Shan Intercosmos–88"), In: Studying the Earth from Space, 6, no. 1, 82–92 (in Russian).

Madeira, J. and Ribeiro, A., 1990, Geodynamic models for the Azores triple junction: A contribution from tectonics, Tectonophysics, 184, no. 3 / 4, 405–415.

Makarov, V.I., Trifonov, V.G., Shchukin, Yu.G., Kuchay, V.K., and Kulagin, V.K., 1982, Tectonic Layering of the Lithosphere in Neotectonic Active Belts, Nauka, Moscow, 116 pp. (in Russian).

Mantyniemi, P., Wahlstrom, R., Lindholm, C., and Kijko, A., 1993, Seismic Hazard in Fennoscandia: A Rgionalized Study (manuscript), 21 pp.

Map of Active Faults of China, 1:6,000,000, 1992, Ding Guoyu (Ed.), State Seismol. Bureau, Beijing (manuscript).

Maps of Active Faults in Japan with Explanatory Notes, 1991–1992, 1:3,000,000 (1991) and 1:1,000,000 (1992), The research group for active faults in Japan, Univ. of Tokyo, Tokyo.

Melekestsev, I.V., 1980, Volcanism and Formation of the Relief, Nauka, Moscow, 212 pp. (in Russian).

Mel'nikov, E.K., Rudnik, V.A., Musiychuk, Yu.I., and Rymnikov, V.I., 1994, Pathogenic influence of active fault zones in the Saint Petersburg area, Geoecology, no. 4, 50–69 (in Russian).

Molnar, P., and Taponnier P., 1975, Cenozoic tectonics of Asia: Effectsof a continental collision, Science, 189, no. 4201, 419–426.

Morner, N.–A., 1979.

Muir Wood, R., 1989, Eztraordinary deglaciation reverse faulting in northern Fennoscandia, In: S. Gregersen and P.W. Basham (Eds.) Neotectonics and Postglacial Rebound, Kluwer, Dordrecht, 143–174.

Neotectonic map of Italy, 1:500,000, 1987, F. Barberi (Dir.), Litografia Artistica Cartografica, Florence.

Nikonov, A.A., 1970, Young folding in the central part of the Afghanistan–Tajikistan basin, In: Studies of Recent Movements in the Earth's Crust at Stationary Geophysical Research Sites, Turkmen. Akad.

Nauk, Ashkhabad, 241–248 (in Russian).

Nikonov, A.A., 1977, Holocene and Cotemporary Crustal Movements, Nauka, Moscow, 240 pp. (in Russian).

Nikonov, A.A., 1995, Active faults: Definition and identification problems, Research on Active Faults, no. 4, Seismol. Press, Beijing, 140–152.

Nikonov, A.A., Vakoa, A.V., and Veselov, I.A., 1983, Seismotectonics and Earthquakes of the Collision Zone between the Pamirs and Tien Shan, Nauka, Moscow, 240 pp. (in Russian).

Olesen, O., Gjelle, S., Henkel, H. et al., 1995, Neotectonics in the Ranafjorden area, northern Norway, NGU (Geol. Survey of Norway), Bull. 427, 5–8.

Olesen, O., Henkel, H., Lile, O.B. et al., 1992, Neotectonics in the Precambrian of Finnmark, northern Norway, Norsk Geol. Tidsskrift 72, 301–306.

Pavlides, S., Rondoyanni–Tsiambau, Th., and Chatzipetros, A., 1992, Preliminary Report on Characteristics of Active Fault Zones of Greece (World Map of Major Active Faults), Aristotle Univ., Thessaloniki, 10 pp.

Pavoni, N., 1961, Die nordanatolische Horisontalverschiebung, Geol. Rndsch., Bd. 51, H. 1, 122–139.

Pavoni, N., 1964, Aktive Horisontalverschiebungszonen der Erdkruste, Bull. Ver. schweiz. Petrol.–Geol. and Ing., 31, no. 80, 54–78.

Prentice, C.S., Schwartz, D.P., and Yeats, R.S. (Eds.), 1994, Proc. of the Workshop on Paleoseismology, US Geol. Survey Open–File Rep. 94–568, Menlo Park, 210 pp.

Pushcharovsky, Yu.M. and Trifonov, V.G. (Eds.), 1990, Tcetonic Layering of the Lithosphere and Regional Geological Studies, Nauka, Moscow, 293 pp. (in Russian).

Ribeiro, A., Kullberg, M.C., Kullberg, J.C., Manuppella, G., and Phipps, S., 1990, A review of Alpine tectonics in Portugal: Foreland detachment in basement and cover rocks, Tectonophysics, 184, no. 3 / 4, 357–366.

Rogozhin, Ye.A. and Rybakov, L.N., 1990, Tectonic position and geological consequences of the Spitak earthquake, 7 December 1988, Geotectonics, 24, no. 6, 496–504.

Saroglu, F., Emre, O., and Kuscu, I., 1992a, The East Anatolian fault zone of Turkey, Annales Tectonicae, Supplement to V. 6 (Special Issue), 99–125.

Saroglu, F., Emre, O., and Kuscu, I., 1992b, Active Fault Map of Turkey, 1:1,000,000, Dir. of Mineral Resources and Explor., Ankara.

Serva, L. (Ed.), 1995, Perspectives of Paleoseismology, Assoc. of Engineering Geologists Special Publ. No. 6, 140 pp.

Shebalin, N.V., Ulomov, V.I., Tatevossian, R.E., Trifonov, V.G., Kozhurin, A.I., and Ioffe, A.I., 1995, Unified seismological taxonomy of the Northern Eurasia, IUGG, 21st General Assembly, Abstracts, Boulder, p. B346.

Shebalin N.V., Trifonov V.G., Kozhurin A.I., Ioffe A.I., Tatevossian R.E., Ulomov V.I., 1996. Unified 36 seismotectonic zoning of the Northern Eurasia, 29th Tectonic Conference "Neotectonics and Contemporary Geodynamics of Continents and Oceans". Abstracts. Moscow, pp. 152–154 (in Russian).

Sherman, S.I. and Levi, K.G., 1978, Transform faults in the Baikal rift zone and seismicity of its flanks, In: Tectonics and Seismicity of the Continental Rift Zones, Nauka, Moscow, 7–18 (in Russian).

Sherman, S.I., Medvedev, M.E., and Ruzgich, V.V., 1973, Tectonics and Volcanism in the Southwestern Part of the Baikal Rift Zone, Nauka, Novosibirsk, 136 pp. (in Russian).

Sieh, K.E., 1978, Prehistoric large earthquakes by slip on the San Andreas fault at Pallett Creek, California, J. Geophys. Res., 83, no. B8, 3907–3939.

Sieh, K., Zachariasen, J., Taylor, F.W., Edward, R.L., and Hantoro, W.S., 1995, Paleoseismology of the Sumatran subduction zone: Unusual opportunities for understanding the complexities of earthquake cycles, In: Active Faulting Studies for Seismic Hazard Assessment, National Inst. Geophys., Rome, 227–234.

Sim, L.A., 1991, Studies of tectonic stresses from geological indicators: Techniques, results, and recommendations, Izv, vuzov: Geol. i Razvedka, no. 10, 3–27 (in Russian).

Sismotectonique de la France Metropolitaine, 1993, Mem. Soc. Geol. France, no. 164: V. 1, 76 pp.; V. 2, 24 pp.

Solonenko, V.P. (Ed.), 1977, Seismic Zoning of the Eastern Siberia and its Geological–Geophysical Basis, Nauka, Moscow, 304 pp. (in Russian).

Solonenko, V.P., Treskov, A.L., Kurushin, R.A. et al., 1966, Live Tectonics, Volcanism, and Seismicity of the Stanovoy Highland, Nauka, Moscow, 232 pp. (in Russian).

Solonenko, V.P., Treskov, A.L., and Zhilkin, V.M., 1968, Seismotectonics and Seismicity of the Baikal Rift System, Nauka, Moscow, 220 pp. (in Russian).

Solonenko, V.P., Nikolaev, V.V., Semeonov, R.M. et al., 1985, Geology and Seismicity of the BAM Zone: Seismogeology and Seismic Zoning, Nauka, Novosibirsk, 191 pp. (in Russian).

Stephansson, O., Ljunggren, C., and Jing, L., 1991, Stress measurements and tectonic implications for Fennoscandia, Tectonophysics, 189, 317–322.

Tanner, V., 1930, Studier over kvartarsystemet i Fennoscandias nordliga delar IY, Bull. de la Commission Geologique de Finlande, V. 88, 594 pp.

Trifonov, V.G., 1976, Aerial, satellite, and land–based techniques for studying young faults, Kopet Dagh, In: Environmental Studies by Space Techniques: Geology and Geomorphology, VINITY, Moscow, 103–113 (in Russian).

Trifonov, V.G., 1978, Late Qauternary tectonic movements of western and central Asia, Bull. Geol. Soc. Am., 89, no. 7, 1059–1072.

Trifonov, V.G., 1983, Late Quaternary Tectonics, Nauka, Moscow, 224 pp. (in Russian).

Trifonov, V.G., 1985, Development of active faults, Geotectonics, 19, no. 2, 95–103.

Trifonov, V.G. (Ed.), 1986–1987, Map of Active Faults of the USSR and surrounding territories, 1:8,000,000, GUGK, Moscow–Irkutsk (1986); Explanatory Notes, Geol. Inst. AN SSSR, Moscow (1987), 50 pp.

Trifonov, V.G., 1989, An overview of neotectonic studies, Intern. Geol. Rev., 31, 111–161.

Trifonov, V.G., 1991, General features and peculiarities of the recent dynamics of continents, In: R.G. Goretsky (Ed.), Geodynamics and Tectonic Evolution of the Tectonosphere, Nauka, Moscow, 144–160 (in Russian).

Trifonov, V.G., 1993, Seismotectonics and remote sensing, Berliner Geowiss. Abh., Reihe D, Bd. 5, 73–88.

Trifonov, V.G., 1995a, World map of active faults (Preliminary results of studies), Quat. Intern., 25, no. 1, 3–12.

Trifonov, V.G., 1995b, Active faults and their seismic and environmental effects, Seminar on Active Faults, European Centre on Prevention and Forecasting of Earthquakes, Athens, 6 pp.

Trifonov, V.G., Makarov, V.I., Skobelev, S.F., Kozhurin, A.I., and Shults, S.S., Jr., 1988, Aerial and Satellite Studies in Seismically Dangerous Regions, Nauka, Moscow, 134 pp. (in Russian).

Trifonov, V.G. and Machette, M.N., 1993, The World map of major active faults Project, Ann. Geofis., 36, no. 3–4, 225–236.

Trifonov, V.G., 1993, Study and mapping of active faults, In: Seismicity and Seismic Zoning of North Eurasia, V. 1, "Global Changes of Environment and Climate" Program Publ., Moscow, 196–206 (in Russian).

Trifonov, V.G., Karakhanian, A.S., Assaturian, A.O., and Ivanova, T.P., 1994a, Relationship of earthquakes and active faults in Anatolia, the Lesser Caucasus, and the Middle East, In: Continental Collision Zone

Erathquakes and Seismic Hazard Reduction, IASPEI / INDNR, Yerevan, 41–55.

Trifonov, V.G., Karakhanian, A.S., and Kozhurin, A.I., 1994b, Major active faults of the collision area between the Arabian and Eurasian plates, ibid., 56–76.

Valensise, G. and Pantosti, D. (Eds.), 1995, Active Faulting Studies for Seismic Hazard Assessment, 11th Course of Intern. School of Solid Earth Geophys., Erice, National Inst. Geophys., Rome, 294 pp.

Vittori, E, 1993, Project of map and database of active faults in Italy: Methodological approach, In: Proc. of Sci. Meeting on Seismic Protection, Venice, 119–130.

Wallace, R.E., 1968, Notes on stream channels offset by the San Andreas fault system, Stanford Univ. Publ., Geol. Sci., 11, pp. 6–20.

Wallace, R.E., 1977, Profiles and ages of Joung Scarps, north–central Nevada, Bull. Geol. Soc. Am., 88, no. 9, 1267–1281.

Wallace, R.E., 1978, Geometry and rates of change of fault–generated range fronts, north–central Nevada, J. Res. US Geol. Survey, 6, no. 5, 637–650.

Wallace, R.E. (Ed.), 1986, Active Tectonics, National Acad. Press, Washington, D.C., 266 pp.

Wellman, N.W., 1966, Active wrench faults of Iran, Afghanistan and Pakistan, Geol. Rndsch., Bd. 55, no. 3, 716–735.

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