MAP OF ACTIVE FAULTS OF EURASIA: GENERAL REVIEW

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Summary.

The database and map of active faults of Eurasia, 1:5000000, were compiled according to the ILP Project II-2 «World Map of Major Active Faults». Majority of the large faults forms the Alpine-Himalayan belt, widening to the east, and the East Asian belts. The Alpine-Himalayan belt is asymmetric in transverse and longitudinal directions. The transverse asymmetry is a result of the north-northeastern drift of the Gondwana plates. It produces not only intensive faulting in their borders, but also a wide system of active faults to the northeast of them because of bulldozing. The longitudinal asymmetry is manifested by decrease of compression from the east to the west. This depends on intensity of the collision processes and properties of the lithosphere. Common features in the belt are its segmentation and formation of four syntaxes in the northwestern corners of the segments. The syntaxes are convex to the north and produce redistribution of rocks along the belt what realizes mostly by strike slip. This type of motion predominates in the belt. The East Asian belt is a system of faults along subduction zones in the Asian-Pacific plate boundary. But not all the faults are related to the subduction: some major longitudinal crustal strike-slip zones and associated faults represent a continuation of the continental fault system that does not correspond to direction of the subduction. The intraplate active faults represent the combined effects of plate interaction and local tectonic processes.

Introduction.

The database and map of active faults of Eurasia, 1:5000000, were compiled according to the ILP Project II-2 «World Map of Major Active Faults» with participation of 70 scientists from 37 countries (Figure 1). The final edition was carried out in the Laboratory of Neotectonics and Remote Sensing of the Geological Institute of Russian Academy of Sciences. The reduced copy of the map and some its fragments as well as the map of major faults (with average rates of motion not less than 1 mm/year) were published (Journal 1996; Trifonov 1997, 1999). According to the «active fault» term understanding and the legend, confirmed by the Project participants (Trifonov, Machette 1993), faults manifesting the Late Pleistocene and Holocene (and particularly historic and contemporary) displacements are designed as active in the map, and the faults manifesting the Middle Pleistocene activity are shown as capable.

Description of active faults.

The largest active fault zones of Eurasia are located on the plate and microplate boundaries. The faults are concentrated in the Alpine-Himalayan and East Asian great belts. It is totally shared that the most important features of the Alpine-Himalayan belt are caused by the north-northeastern drift of the Gondwana plates (African, Arabian, Indian, and Australian), bounding the belt from the south. Since the poles of their rotation are located to the west of the belt, the linear rates of the drift increase from 1 cm/year in the western part of the belt up to 6 cm/year in its eastern part. This results in different values of the belt transverse shortening along its different intersections. Our studies showed that average rate of the shortening, calculated as the algebra sum of average rates of motion on active faults is about 2 cm/year in the Caucasus-Arabian intersection and about 3 cm/year in the Pamir-Himalayan intersection (Trifonov *et al.* 1999).

One of the belt peculiarity is the transverse segmentation, isolating its West Mediterranean, Adria-Aegean , Arabia-Iranian, Pamir-Himalayan, and Indonesia-New Guinean segments. A boundary of the two western segments was essentially reorganized in the Late Cenozoic by motion on the Azores-Gibraltar right lateral fault and associated rotation of the Corsica-Sardinia block that resulted by overthrusting of a part of the Adria by the Ligurian nappes. The Indonesia-New Guinean segment is not typical because of the influence of the East Asian belt. So, peculiarities of the segmentation are analyzed in the other segments. All the segments are bordered from the west by weakly bent systems of north-northeast-trending left-lateral faults that continue into the southern plates and join in this or that way with the Middle Indian rift system. The boundary between the Adrian-Aegean and Arabia-Iranian segments is represented by the Levant sinistral fault zone. Average rate of the Late Quaternary slip reaches 7.5 mm/year in the southern (Israel) segment of the zone, but decreases up to 5-6 mm/year in the northern (Syrian) segment, where a part of the motion is passed on the Roum fault along the continental slope. The Levant zone join with the Red Sea rift. The recent boundary between the Arabia-Iranian and Pamir-Himalayan segments is represented by sinistral fault system, where the main features are the Chaman fault and the Darvaz segment of the Darvaz-Alai zone. Average rate of the Late Quaternary slip reaches 1 to 1.5 cm/year. The Chaman fault continues to the south by en echelon row of smaller faults that are prolonged by the Owen fault in the Indian ocean. The eastern boundary of the Pamir-Himalayan segment is represented in the north by the essentially dextral Burma part of the Burma-Andaman arc and continues to the south by faults of the Ninety East Ridge in the Indian ocean.

Some transverse fault zones under discussion (particularly northeast-trending) have compression component of motion which is manifested by reverse or thrust offsets and parallel folds. At the same time, the transverse zones are characterized by *en echelon* structure with pull-apart basins between some segments. They are most typical for the Levant zone (the Aqaba, Dead Sea, Tiberian, and El-Gaab basins), and are identified in the Darvaz fault zone also (the Kokcha basin). Although the primary position of the western boundary of the Adrian-Aegean segment is changed by the Late Cenozoic motion, its sense is manifested perhaps by active fault pattern in the Apennines. On the contrary to the Late Cenozoic thrust and fold structures, the northwest-trending active faults bound here the *en echelon* system of graben-type basins that are possibly linked by the north-trending sinistral faults (Cello *et al.* 1996).

Active structures inside the segments strike generally from the northwest to the southeast with characteristic bends. The southern margin of the central part of the each segment forms gentle arc, convex to the south-west. The northern corner of the each segment is rounded by the Cenozoic tectonic zones, forming syntaxes that are sharp arcs convex to the north. The main syntaxes are Adriatic, Lesser Caucasus, and Punjab-Pamir. Perhaps, similar syntax is represented by the New Guinea arc. The main syntaxes are areas of local transformation of the general north-northeastern drift of the southern plates to the northern drift. The smaller syntaxes are identified in the eastern parts of each the segments. They are the

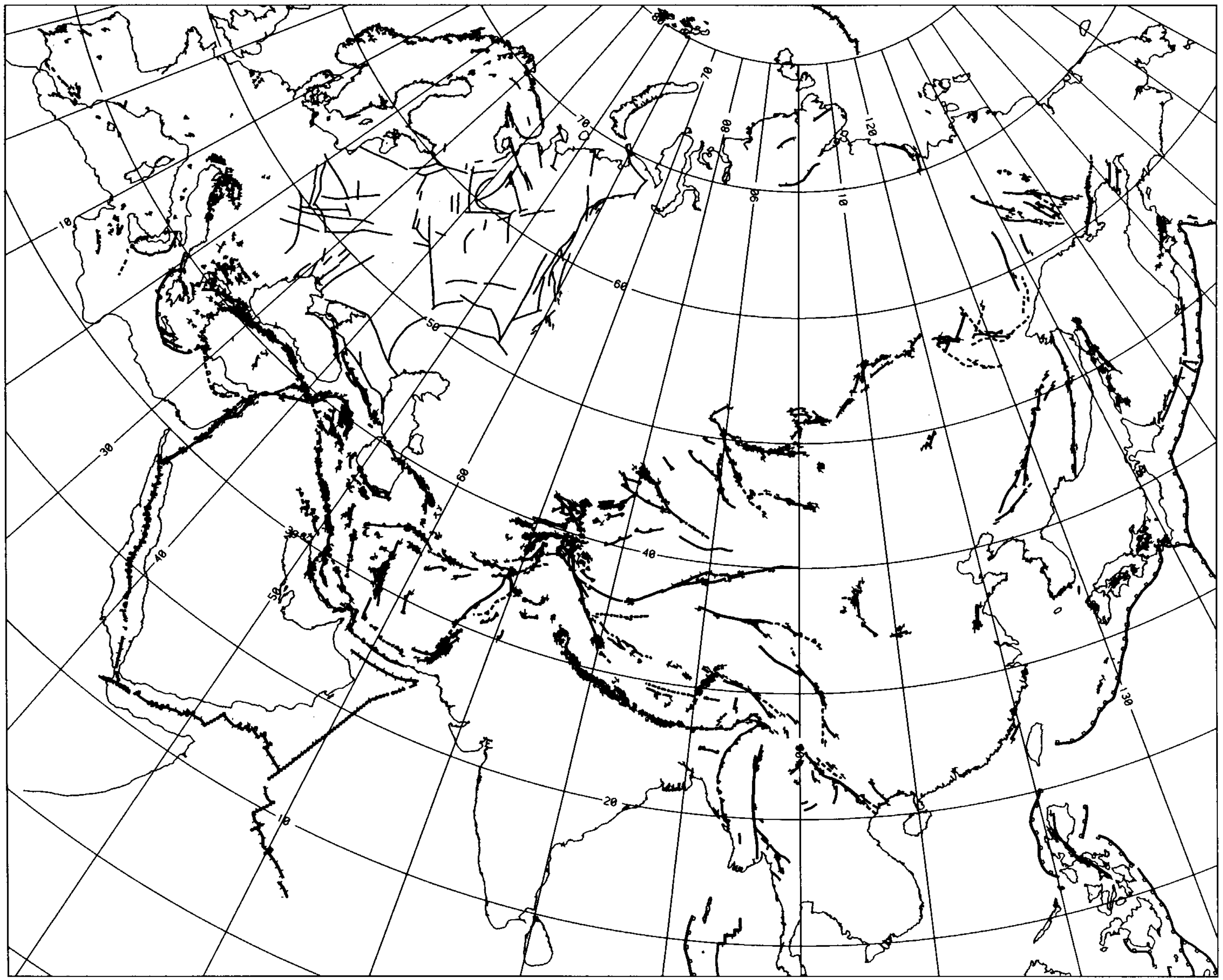

Figure 1. Map of major active faults in Eurasia, compiled by R.V.Trifonov with using the database of the ILP Project II-2 "World map of major active faults".

Rhodes syntaxis between the Crete-Hellen and Cyprus arcs, the Oman syntaxis between the Zagros and Makran (the Aladagh-Benalud arc to the north of the Lut block is formed by its drift), and the Assam syntaxis to the east of the Himalayas.

The main syntaxes have common structural features. Their western flanks are formed by the sinistral fault zones of the segment boundaries. Dextral active faults strike along the northeastern sides of the syntaxes. The dextral faults go out to the southeast, being replaced by the thrust-and-fold active zones convex to the southwest. Such is, for example, the relationship between the Pamir-Karakorum dextral fault and the Boundary and Frontal active zones of the Himalayas. The same relationships are characteristic for the northeastern side of the Lesser Caucasus syntaxes and northeastern flank of the Arabian plate. Two systems of active faults are found here.

One of them is formed by the Pambak-Sevan-Khanarassar fault zone in Armenia. The dextral component of motion is several times more, than reverse, and reaches 4-5 mm/year. The southeastern termination of the Khanarassar fault continues by the Tebriz fault. It strikes to the east-southeast and the reverse component increases because of this turn. Fragments of the system under discussion are identified southeastward behind the Zagros. The found regularity is manifested there too: the reverse or thrust component of motion increase where a fault is bent to the east relative to the general southeastern trend.

The second system follows just along the Arabian plate boundary. It is represented in the northern part by the southeastern segment of the North Anatolian dextral fault zone with average rate of motion of about 9 mm/year. The Main Recent fault of Zagros branches out it to the southeast. It is also mostly right lateral fault with rates of the Late Quaternary motion 5 to 10 mm/year. Its main southeastern continuation is represented by the arched Dena fault. It strikes to the south and is characterized mostly by dextral displacements, but southward it turns to the southeast and thrusting and associated folding predominate on its branches. The Kazerun-Borazjan and Kareh Bas dextral zones branch to the south off the Dena fault. The Kazerun-Borazjan zone goes out in the southern direction in proportion with thrusted and folded active zones branch out it to the southeast. The Kareh Bas zone strikes to the south with predomination of the dextral component of motion. Southerly the zone forms several step-like bends to the southeast, and these southeastern segments are characterized by thrusting. It turns finally to the southeast forming the flexure-thrust zone with uplifted northeastern side. The described faults demonstrate dependence of sense of motion on the fault strike. At the same time, the system of right lateral faults is not straight as a whole: it is south-southeast-trending in the northern part (the North Anatolian zone), then turns to the southeast (the Main Recent fault) and finally to the south (the Dena, Kazerun-Borazjan and Kareh Bas faults).

The boundary strike-slip zones converge in the northern flanks of the syntaxes. Of course, compression component increases here, but more interesting is behavior of strike-slip component of motion. The north-trending Levant zone continues by the northeast-trending East Anatolian zone. The latter bends to the east and joins with the Pambak-Sevan-Khanarassar fault zone (that bends to the west) at the angle of only 17°, and both zones keep strike-slip sense of motion up to the junction. The same small angle between sinistral and dextral faults has been described by A.S.Karakhanian (personal communication) in the bent Doruneh fault zone to the north of the Lut block in Iran.

The convex to the southwest boundaries between the belt segments and the southern plates have different structure depending on a type of the Earth's crust. If it is oceanic or sub-oceanic (the Crete-Hellenic and Indonesian arcs), recent subduction takes place. In the both arcs it is combined with contrary overthrusting of the northern side. Such overthrusting is explained in the Aegean region by extension of the basin to the south-southwest. The extension is partly a result of lateral compression of the basin that is produced by the western drift of the Anatolian plate along the North Anatolian fault with rate of about 20 mm/year. This deformation has initiated an uplift of the mantle diaper that has produced the additional extension. The extension is manifested by active grabens and normal faults in the Aegean Sea and its western and eastern coasts and has been registered by GPS data. Similar overthrusting of the Indonesian arc is perhaps a result of processes in the East Asian active fault belt, and emanates from higher rate of subduction of the Pacific plate in respect to that of the Australian plate.

If the Earth's crust of the southern plate is continental (foothills of the Himalayas and Zagros), it plunges under the crustal structures of the belt gently because of relatively small average density of rocks. The sedimentary cover of foredeep participates only partly, or does not participate at all in the underthrusting, but it is detached and is deformed independently relative to the basement forming topographically pronounced active thrusts and folds. In the Zagros this process is promoted by the presence of the Late Precambrian evaporate formation in the cover bottom. The age of thrusting and folding has been determined in the Zagros by paleomagnetic dating of the coarse molassa. The data show that folding and following local thrusting and detachment occupied some area in the foredeep in front of the Main Zagros underthrust where tectonic movements could either continue or stop to that moment. When all the area was folded, local detachments joined into a single detachment zone and the area was uplifted. The folding and associated processes propagated into the next area further to the southwest from the Main underthrust. Finally, several zones with successive rejuvenation of folding, detachment and uplift (from Late Miocene up to Recent) formed. Active tectonics of the zones of different age is different. Active reverse and strike-slip faults are discordant relative to the folded structure in the older zone (the High Zagros). Active tectonics of the intermediate zone (the Lesser Zagros) demonstrate recent continuation of folding, thrusting and formation of marginal flexure marking boundary of propagation of the detachment. In the Coastal zone, the most distant from the Main underthrust, we see only local active folds which represent the initial stage of the process. The analogous rejuvenation of the course molassa to the south from the underthrust was described in the Himalayan Foredeep (Yeats 1986).

Deformation and displacements in the southern flanks of the Alpine-Himalayan belt are far from compensation of drift of the southern plates. Their motion is transmitted to an essential degree into the northern parts of the belt by mechanism of bulldozing (Trifonov 1999). It is manifested by active offsets and deformation that concentrate mostly on boundaries of microplates and crustal blocks, but are realized partly in intrablock deformation. Intensity of the latter decreases from the south to the north and northeast, and accordingly a style of active tectonics transforms from combination of faults and folds to only faults. According to general increase of the belt deformation from the west to the east, the bulldozing occupies the large territories in the Central and

Eastern Asia, but is limited only by Iran in the Arabian-Iranian segment and covers still more narrow zones to the west of it, where the extension active structures of different types play the essential role. The bulldozing is combined with squeezing of rocks out of the syntaxes as areas of maximum compression. Because of it strike slip predominates over thrusting and reverse displacement on active faults in the bulldozing areas. The major east-trending sinistral strike-slip zones are known in China (Ding Guoyu 1984) and Mongolia (Trifonov 1999). They are found in the northern Iran (the Dast-e Bayaz, Doruneh, Mosha, and Ipak faults and the rupture zone of the Rutbar, 1990, earthquake in Alborz), while the associated major north-trending dextral faults (the Jabbar, Nalband, Ravar, and Kuh Banan) predominate in the more southern areas of Iran.

We explain the predomination of strike slip on active faults in the Alpine-Himalayan belt by the fact that the strike-slip movements are less energy-consuming, than the movements on thrusts, reverse and even normal faults in rheological conditions of the continental crust (Trifonov 1999).

Strike-slip faulting in the East Asian belt is interesting in the aspect under discussion. It is known that the main active features of that belt are related to the Pacific plate subduction. At the same time, major longitudinal strike-slip faults have been described in the belt. They are mostly dextral (the Eastern Face of the Central Kamchatka basin, Eastern Sakhalin fault, Median Line of Japan, Tanlu fault in the Eastern China, and Alpine strike-slip fault in New Zealand), but some zones are characterized by sinistral motion (Taiwan and Philippines). This faulting (particularly dextral movements) can not be explained by oblique subduction. Structural pattern and kinematics of the strike-slip faults are linked with manifestations of motion of microplates and lithosphere blocks in the northeastern flank of the Alpine-Himalayan belt. It is characteristic that these strike-slip faults are distributed in the continental segments of the East Asian belt. It has been proved in some areas (Kamchatka, Japan) that the strike-slip faults are limited by the continental crust and are replaced by other fault and deformation zones both in deeper layers and aside of the continental segments.

The most part of Eurasia belongs to the Eurasian plate and is situated outside the described mobile belts. Most of the identified active faults here are hypothetical and show very small Quaternary offsets. Because of slack motion the faults have not been identified only by the Late Quaternary offsets, and we have used offsets and deformation of the Middle Pleistocene deposits and topographic features. So, the identified faults are qualified as capable. At the same time, small manifestations of the plate interaction give a possibility to find other (intraplate) sources of faulting usually masked in the mobile belts. Three groups of capable (potentially active) faults are recognized in the East European platform by analysis of their structural pattern and position. They are: faults associated with influence of the adjacent parts of the Alpine-Himalayan belt (the Carpathians and Caucasus), faults associated with the Paleozoic Urals renewed in Quaternary, and faults related to the platform structures themselves such as the Near-Caspian basin or the Fennoscandian shield. The first group may be interpreted as the distant result of the plate interaction, the second group is related to interaction of the East European and West Siberian segments of the Eurasian plate, and the third group seems to result from local tectonic processes. Interaction of different tectogenerating factors is manifested most clearly in the Fennoscandia. The northeast-trending active (in Holocene) zones of thrusts and reverse faults inherit the Precambrian fault and deformation zones of the same sense of motion. The kinematic sense of active faulting as well as mechanisms of earthquakes and determination of rock stress *in situ* show the southeastern compression that may be interpreted as a result of the resistance of the thick continental lithosphere to the spreading in the adjacent segments of the Atlantic. At the same time, location of the active faults and the Earlier Holocene age of the most intensive displacements (as well as the strongest paleoearthquakes) demonstrate the important role of the glaciation and postglacial isostatic uplift in the faulting.

Capable faults in the Urals are mostly longitudinal and inherit manifestations of the Late Paleozoic orogenesis. The faults demonstrate structural and geological-geomorphologic evidence of strike-slip Quaternary movements, such as slickensides, lateral offsets of recent valleys and Late Pleistocene moraines, and concentration of lakes in the extension sectors. The faults are sinistral in the Middle and Northern Urals and dextral in the Southern Urals. Their systems are joined to the east of the Bashkir Amphitheater of the East European platform that looks like the indenter. The predomination of strike slip explains weak manifestation of the Quaternary motion in topography.

Conclusion.

The discussed database and map of active faults in Eurasia as a whole have been compiled first. They have been used for seismic hazard assessment of the continent and in particular for seismic zoning of the Northern Eurasia. The data are used also for estimating of other geological hazards and landscape changes (landslides, changes of the coastal lines, swamping and salting or, on the contrary, erosion of some areas, etc.). Active faulting causes hydrogeological changes, fluid activity and geochemical processes that are able to influence to the biota and human being. So, the disasters and environmental effects of active faulting participate in a system of processes that have caused the human society evolution and contemporary life.

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