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Active faults in Eurasia: general remarks

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Abstract

The database and map of active faults of Eurasia, 1:5,000,000, have been compiled according to the ILP Project II-2 "World Map of Major Active Faults." The map shows the complicated distribution of active faulting. The major faults group in broad mobile belts between relatively weakly faulted parts of the main plates. The faults form the plates, microplates and crustal blocks boundaries there and are accompanied by deformation of the boundary areas. Using active fault data for the seismic hazard assessment (estimation of maximum possible magnitudes of earthquakes in fault zones), it is necessary to take into account the total neotectonic activity of the territory and average rate and sense of motion on the fault. Because trenching gives a possibility to determine only vertical earthquake offset on a fault, it is necessary to make corrections for strike–slip faults to estimate the earthquake magnitude by using this parameter.

Keywords: Active faults; Recent geodynamics; Seismic hazard

1. The ILP project II-2 "World Map of Major Active Faults"

In view of the significance of the active faults studies for understanding of recent geodynamics and seismic hazard assessment, the International Lithosphere Commission initiated in 1989 the Project II-2 "World Map of Major Active Faults," led by the author of this paper. The project was accepted as a contribution of the International Lithosphere Program (ILP) to the United Nations' Decade of Natural Disaster Reduction. The ILP Project II-2 attracted a lot of scientists from different countries and initiated many national projects for active fault studying. Their results enriched the Project II-2 by new detailed results. Later, the Project II-2 was included to the Global Seismic Hazard Assessment Program (GSHAP). It gave a possibility to use the project results directly for seismic hazard assessment and seismic zoning. For example, the new Series of Seismic Zonation Maps of Russia, 1:8,000,000 (Ulomov and Shumilina, 2000) were compiled with using the Project II-2 data.

For better management, the Project II-2 was divided into two subprojects: for the western (led by M.S. Machette, USGS, Denver) and the eastern (led by V.G. Trifonov) hemispheres. The common understanding of the terms and common legend for the maps of countries, regions and continents were discussed and accepted (Trifonov and Machette, 1993).

The "Eastern" subproject studies were concentrated in research and mapping of active faults in Eurasia

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and Africa and included participants from 37 countries. These are: M. Meghraoui (Algeria); A.S. Karakhanian (Armenia); J. Klerkx, D. Delvouix, and M. Hanon (Belgium); R.G. Garetsky, A.M. Boborykin, R.R. Pavlovets and other (Belarus); P. Gochev, M. Matova, and H. Spiridonov (Bulgaria); Ding Guoyu, Gao Weiming, and Deng Qidong (China); S.M. Mahmud, A. Swedan, and M. Abdeen (Egypt); H. Philip (France); S.I. Kuloshvili (Georgia); P. Bankwitz (Germany); R. Muir Wood (Great Britain); S. Pavlides, A. Chatzipetros, and I. Mariolakos (Greece); A. Sinha (India); M. Berberian, Kh. Hessami, and F. Jamali (Iran); A. Gelat and I. Karcz (Israel); E. Vittori, D. Castaldini, M. Panizza, D. Pantosti, L. Serva, and D. Slejko (Italy); Y. Kinugasa and T. Nakata (Japan); Z.H. El-Isa (Jordan); A.V. Timush (Kazakhstan); K.E. Abdrakhmatov (Kyrgizstan); H.H. Silbvee and V.I. Suvezdis (Lithuania); M. Tjia (Malaysia); G.M. Bilinkis (Moldova); P. Khosbayar (Mongolia); O. Olesen (Norway); M. Graniczny and W. Zuchiewicz (Poland); A. Ribeiro (Portugal); M.N. Alekseev, L.B. Aristarkhova, B.A. Assinovskaya, V.I. Babak, D.M. Bachmanov, N.K. Dmitrieva, V.S. Imaev, L.S. Imaeva, A.I. Ioffe, T.P. Ivanova, V.G. Kazmin, M.L. Kopp, A.I. Kozhurin, K.G. Levi, N.V. Lukina, V.I. Makarov, N.A. Malyshev, E.K. Mel'nikov, A.A. Nikonov, V.A. Ogadzhanov, M.V. Rozanov, G.P. Shcherbinina, S.I. Sherman, V.V. Sholokhov, S.S. Shults, Jr., S.F. Skobelev, L.I. Soloviova, M.I. Streltsov, A.L. Strom, V.G. Trifonov, R.V. Trifonov, G.B. Udintsev, G.A. Vostrikov, and D.S. Zykov (Russia); V. Banacki, P. Grecula, and J. Hok (Slovakia); J.M. Diaz and P. Villamor (Spain); N.-A. Morner and R. Lagerback (Sweden); N. Pavoni (Switzerland); A. Barka, F. Saroglu, O. Emre, and I. Kuscu (Turkey); V.P. Palienko, R.P. Kuprash, L.S. Borisenko, and V.I. Somov (Ukraine); R. Yeats, M. Barazangi, and P. Molnar (USA); Sh.H. Abdullaev and A.R. Yarmukhamedov (Uzbekistan); D. Cvijanovich (Yugoslavia).

All the obtained data on the active faults were concentrated in Moscow. The active fault database was compiled (Ioffe and Kozhurin, 1996; Ioffe et al., 1993; Trifonov, 2000a). The information presented in the database was divided into two groups. The first group included the most important information obligatory provided for each fault and required for compiling the fault maps. These data were the following: the ordinal number of a fault; the age of the last manifestations of activity (the Middle Pleistocene; the Late Pleistocene–Holocene; the historic and contemporary epochs); the intensity of movements (the rate $V>5$ mm/year; $5>V>1$ mm/year; $V<1$ mm/year; and $V\ll 1$ mm/year; the last group is only identified on the continental platforms); the sense of motion (normal fault; thrust or reverse fault; dextral or sinistral strike–slip fault; extension fault; combination of the mentioned types; flexure; transform fault; continuation of the deep-seated seismofocal zone of subduction onto the Earth's surface; and unidentified faults); the direction of vertical offset (= the position of the uplifted side: +S, +NE, etc.); the direct or indirect manifestation of a fault at the land surface; the reliability of the information presented (A, B or C, and on the maps only two versions are shown: A + B–reliable ones and C–hypothetical); the geometry of a fault line in the land surface represented by series of points with certain geographic coordinates sufficient for accurate reconstruction of the line on the 1:500,000 scale. From these data, the map of active faults in Eurasia and Africa, 1:10,000,000 (its simplified copy is represented in Fig. 1) and in Eurasia, 1:5,000,000 (Trifonov, 1997) were compiled with the use of the ARC-INFO system. The more detailed maps (1:2,500,000 to 1:500,000 scales) were compiled for some countries and important regions.

The second group of the database information was not shown in the maps, but was interesting for understanding the peculiarities of a fault, its seismic and environmental hazard. These data were the following: the name of the fault; information concerning the methods of its identification and determination of the ages of displacements; more precise estimate of the latter; the fault depth; the concrete dip angles, magnitudes of offsets and rates of motion within certain time interval provided, whenever possible, with coordinates of the observation sites; the characteristics of seismic events, volcanic eruptions, and exodynamic manifestations within the fault zone; any other information on the fault; references to the sources of information.

A process of the Project II-2 realization was represented, discussed, and corrected many times in the 29th to 31st IGS, the INQUA Congresses, the IUGG and IASPEI Assemblies, and several special workshops. The results were published in a lot of

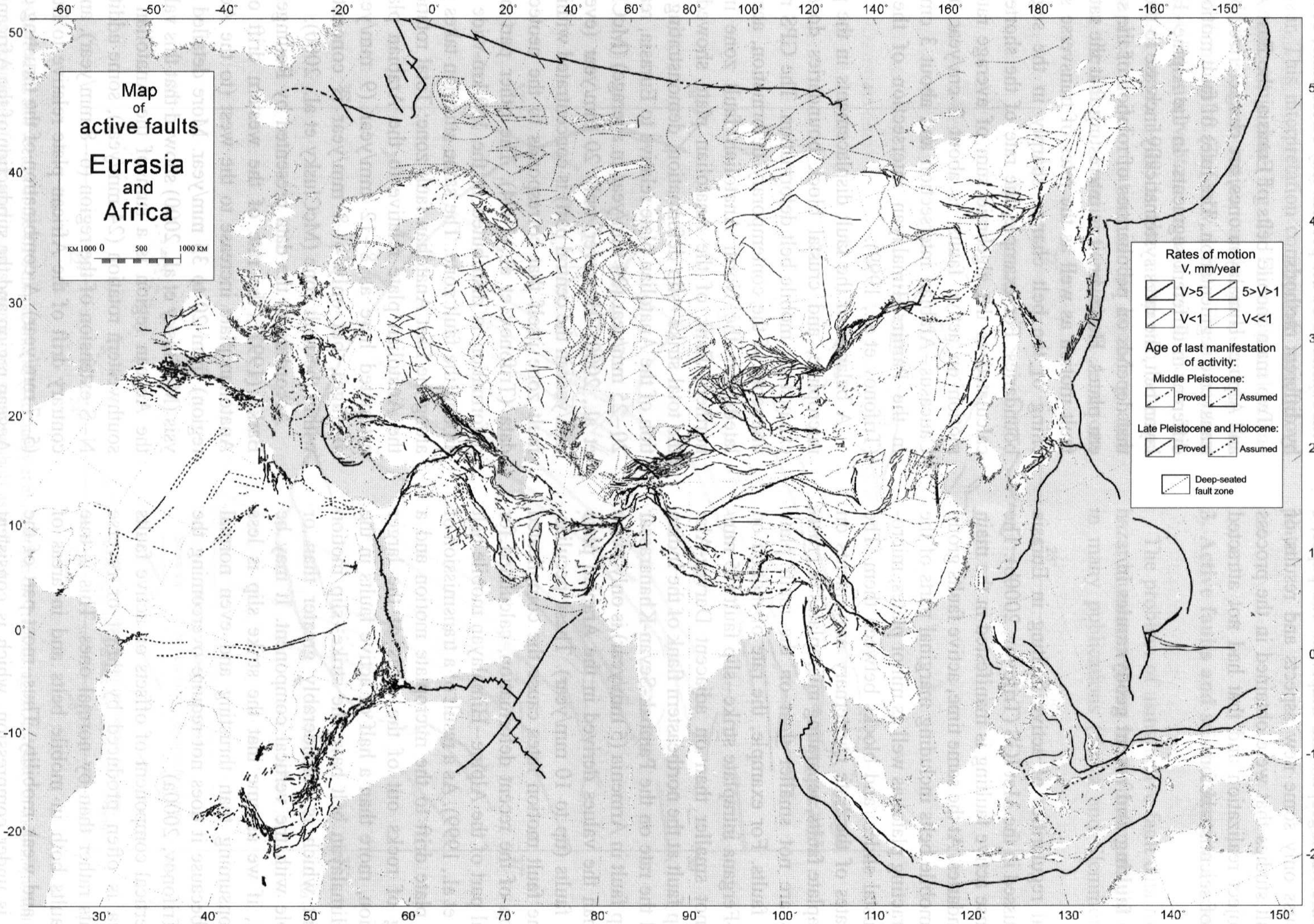

Fig. 1. Simplified map of active faults in Eurasia and Africa.

papers, some monographs and maps. In this paper, I shall discuss only some new aspects and results of active fault studies that were obtained in the process of the project realization and that had not attracted attention of scientists before.

2. Active faulting and recent geodynamics in Eurasia

General regularities of active faulting in Eurasia were discussed in the 31st IGS (Trifonov, 2000b). The most intense active faulting is manifested in the main plate boundaries. At the same time, active faults group in broad mobile belts including marginal parts of the main interacting plates as well as minor plates, microplates, crustal slides, and blocks between them. The average rates of the Late Quaternary movements on some intraplate faults, separating microplates or crustal blocks are not smaller than on the main plate boundary faults. For example, the rate of motion on the Talas-Fergana intraplate strike–slip fault (15 mm/year) is not smaller than on adjacent Darvaz-Alai strike–slip fault at the northeastern flank of the Indian plate, and the rate on the Pambak-Sevan-Khanarassar strike–slip fault in Armenia (5 mm/year) is only twice smaller than the values derived in the Arabian plate boundary faults (up to 10 mm/year). These peculiarities of the fault motion rates cause the complicated distribution of the recent deformation, calculated for the central part of the Alpine–Himalayan mobile belt (Trifonov et al., 1999). As a result of a transmission of the main plate drift to the microplate motion and a squeezing of rocks out of the areas of the larger compression, more than a half of active faults in the Alpine–Himalayan belt have the strike–slip motion component which is considerably greater than or comparable with the vertical component. It may be explained, if we assume that the strike slip is less energy consuming than thrusting and even normal faulting, because it does not require overcoming the gravity (Trifonov, 2000a).

The vertical component of offsets on active faults in Eurasia is often produced by thrust or reverse movements rather than by normal 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 compression, which is consistent with estimates of the present-day stress state, obtained by different methods.

Two main mobile belts of Eurasia, the East Asian and Alpine–Himalayan ones, are characterized by the transverse segmentation. The rates of fault motion are different in different segments. In the Alpine–Himalayan belt, the rates systematically increase to the east that depends on peculiarities of rotation of the southern plates. However, it is interesting that the rates of fault motion as well as the rates of transverse shortening of the belt change sharply in the segment boundaries. For example, the rate of the shortening, calculated as the algebraic 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 of the belt (Trifonov et al., 1999).

A balance of the fault displacements in the plate, microplate, and crustal block boundaries does not exhaust the mobile belt deformation. The GPS measurements of the contemporary deformation, accumulated near the North Anatolian fault zone in the northern flank of the Anatolian plate showed that the total strike–slip deformation, demonstrating rotation of the Anatolian plate relative to Eurasia, reaches 20–25 mm/year (24 mm/year in average) (McClusky et al., 2000). However, only 20 mm/year (even 15 mm/year in the central part) is concentrated within the fault zone itself that corresponds to the neotectonic data (Trifonov et al., 1994). The other part of the deformation is distributed in the 100-km-wide bend around the fault zone. The same situation takes place along the East Anatolian fault zone: Total rotation of the Anatolian plate relative to the Arabian plate is estimated here as 8–12 mm/year (9 mm/year in average), but only 4–8 mm/year is concentrated within the fault zone (McClusky et al., 2000).

According to the data presented by Reilinger and Barka (1997), the rate of the western drift of the Anatolian plate increase to the west (to the Aegean region) from 20 to 35 mm/year. More detailed analysis (McClusky et al., 2000) showed that this value in the Aegean region is a sum of the Anatolian plate southwestern rotation (24 mm/year), some additional N–S extension of the region (6–8 mm/year), and the contrary drift of the African plate relative to Eurasia (5–7 mm/year). A combination of the thrusting of the Aegean region and the subduction of the African plate produces total shortening in the Hellenic arc up to 40 mm/year. This interpretation corresponds satisfactory to the neotectonic data (Fig. 2). The additional extension of the Aegean region can be produced by the mantle diapir uplift (Trifonov, 1999). The distribution of the GPS rate vectors around the Okhotsk Sea (Takahashi et al., 1999) is also interpreted better as a complicated deformation in the boundary area between the Pacific, Eurasian, and North American plates than a rotation of the separate Okhotsk Sea plate.

3. Active faults and seismic hazard assessment

The problem of using active fault data for seismic hazard assessment has been fundamentally described in many publications (Serva and Slemmons, 1995;

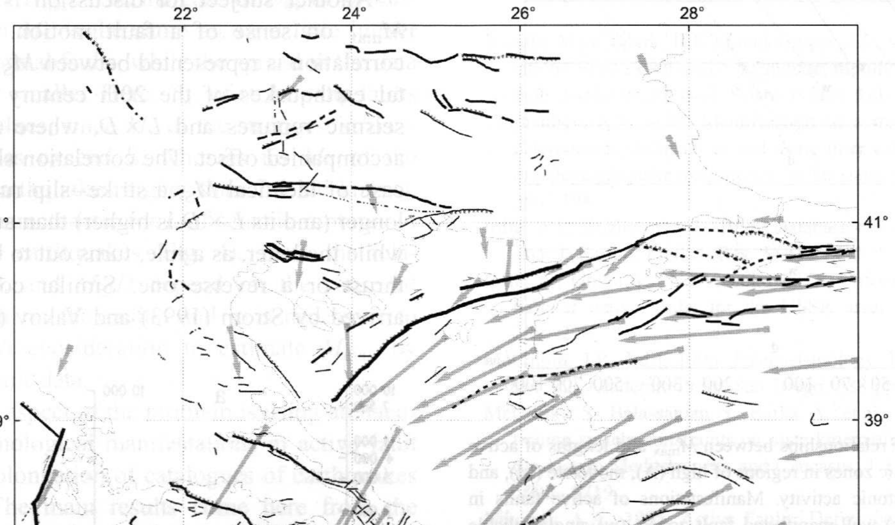

Fig. 2. Active faults and vectors of the GPS displacements (McClusky et al., 2000) in the Aegean region. Intensity of motion on faults and age of the last manifestations of their activity are shown by the same symbols as in Fig. 1.

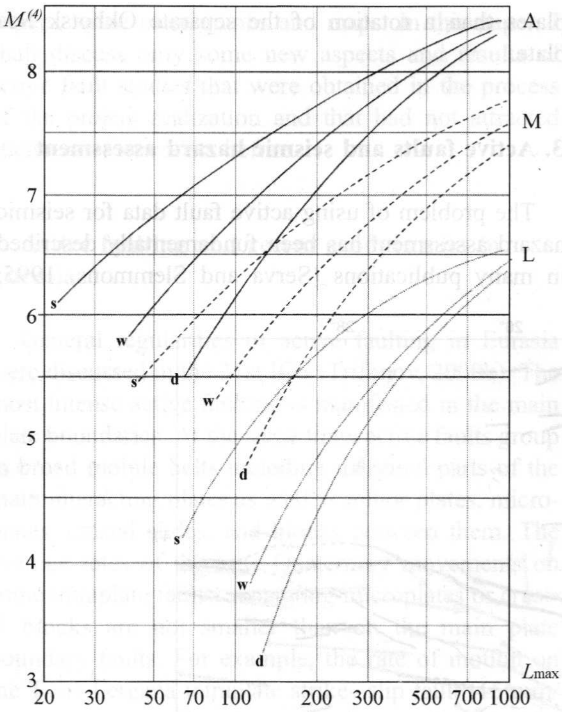

Fig. 3. Graphs of relationships between M_{max} and lengths of active faults L for seismic zones in regions of high (A), moderate (M), and weak (L) neotectonic activity. Manifestations of active faults in seismic zones: (s) well-manifested fault zones; (w) single reliable faults; (d) weakly manifested faults (Shebalin et al., 2000).

Nikonov, 1995; Stiros and Jones, 1996; McCalpin, 1996; Yeats et al., 1997; and others). Thus, here I shall add not so much. There are two aspects of the problem. The first one is using active fault parameters for identification and estimation of a potential (M_{max}) of seismic zones. The M_{max} estimation is based on the statistics of relationships between magnitudes M of occurred earthquakes and lengths L of accompanied seismic ruptures or seismic offsets D (Bonilla et al., 1984; Slemmons et al., 1989; Wells and Coppersmith, 1994; Chipizubov, 1998). Results of the correlation are represented usually by regression equations such as $M_S = a + b\text{Lg}L$ and $M_S = c + d\text{Lg}D$. It is assumed that these equations give a possibility to estimate M_{max} by using L of active fault zone or its separate segment and D of maximum individual quick displacement, identified in the fault zone. However, coefficients a, b, c, and d vary considerably in different regions as well as for the Earth as a whole, according to the data presented by different authors. Obviously, it depends on different activity of the regions. Shebalin et al. (2000) proposed to take these variations into account by using different graphs of the M_{max}/L correlation for regions of different neotectonic activity (Fig. 3). He proposed also to take into consideration the intensity of the fault manifestation in the land surface on the assumption that it corresponds to the rate of motion and reliability of a fault.

Another subject for discussion is dependence of M_{max} on sense of a fault motion. In Fig. 4, the correlation is represented between M_S of 55 continental earthquakes of the 20th century and L of their seismic ruptures and $L \times D$, where D is maximum accompanied offset. The correlation shows that in the case of identical M_S, a strike–slip rupture is usually longer (and its $L \times D$ is higher) than a normal rupture, while the latter, as a rule, turns out to be longer than a thrust or a reverse one. Similar conclusions were arrived by Strom (1993) and Vakov (1992) by using

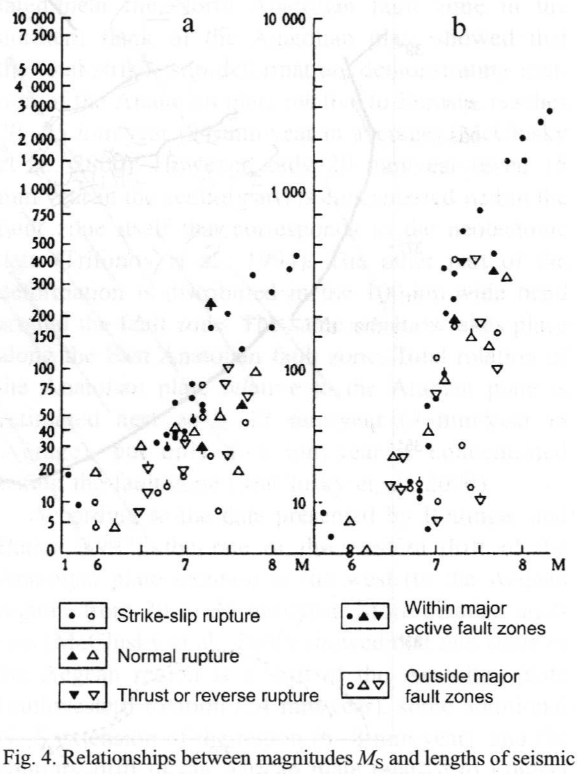

Fig. 4. Relationships between magnitudes M_S and lengths of seismic ruptures L (a) and between M_S and L multiplied by maximum seismic offset $L \times D$ (b) for some strong continental earthquakes of the 20th century graduated by sense of motion.

both seismic ruptures in the land surface and focal zone dimensions, identified by aftershock distribution. The relationships between M_S and values of the maximum and weighted average seismic offsets, D_{max} and D_{av}, were investigated also (Strom, 1993; Strom and Nikonov, 1997). Although the obtained values exhibited a large spread, the tendency was revealed for normal offsets to increase with M_S more sharply than thrust-reverse offsets, and this is more noticeable for D_{av} than for D_{max}. The increase of D_{av} of strike–slip faults with M_S is the same as, or a little higher than, that of normal faults, while the spread in the data is considerably smaller. Here, D_{av} of strike–slip faults reach larger values, since M_S of the strongest strike–slip earthquakes exceed 8, whereas no M_S of the normal fault earthquakes higher than 7.8 are known. The same is characteristic for L of seismic ruptures of the strike–slip earthquakes (Fig. 4). Thus, the relationships M_S/L and M_S/D depend on the sense of seismic motion on the faults, and it is necessary to take them into consideration to estimate M_{max} by using active fault data.

The second aspect of the problem is using archaeo- and paleoseismological manifestations in active fault zones for a prolongation of catalogues of earthquakes to the past. The main results come here from the trenching of the fault zones. However, trenching allows to estimate only a vertical component of fault movements. In order to conclude on the magnitudes of paleoearthquakes, one should rely on strike–slip/dip–slip ratios found independently. At the same time, it should be noted that the latter is not always a reliable measure. Thus, seismotectonic studies in the North Anatolian and some other active zones show that this ratio is often smaller for the individual earthquake than its average value found for the Late Pleistocene–Holocene time span. It seems in the cases just mentioned that the special empirical graphs compiled by Strom (1993) for vertical components of mostly strike–slip seismic offsets can be applied.

4. Conclusion

The database and map of active faults of Eurasia, 1:5,000,000, were compiled according to the ILP Project II-2 "World Map of Major Active Faults." It gave a lot of new data to understand geodynamics of the tectonic processes. Active faults are sources of strong earthquakes and some disasters like the ground deformation, landslides, and volcanism that often accompanied the earthquakes, but can be also by results of slow motion on the faults and be caused by their structural peculiarities.

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