ISSN 1028-334X, Doklady Earth Sciences, 2006, Vol. 409, No. 5, pp. 697–700. © Pleiades Publishing, Inc., 2006.
Original Russian Text © A.A. Nikonov, S.V. Shvarev, 2006, published in Doklady Akademii Nauk, 2006, Vol. 408, No. 6, pp. 784–787.

GEOLOGY

New Data on Seismotectonics and Seismicity of Gornyi Altai

A. A. Nikonov and S. V. Shvarev

Presented by Academician Yu.G. Leonov October 7, 2005

Received October 28, 2005

DOI: 10.1134/S1028334X06050035

Strong earthquakes in the southern part of Gornyi Altai on September 27 and October 1, 2003 clearly demonstrated the correctness of the previous concepts [1, 2] of the general high seismic potential of the region. On the other hand, the earthquake generated a large surface rupture in a zone that was not previously distinguished as a seismogenerating and hazardous one. Thus, the earthquakes mentioned above clearly revealed the insufficiency of knowledge about active structures in the region, as well as their seismogenerating role and potential seismic hazard. Unlike neotectonic, geomorphological, and paleoseismogeological studies, attempts to relate strong earthquakes to neotectonics [3] and active faults [4, 5] are not effective enough due to the small scale of investigation, use of incomplete catalogues of strong earthquakes, vague understanding and insufficient grounds for the identification of active faults, and, finally, lack of data on the uncertainty of determination of epicenters and orientation of sources.

In order to fill in this gap in our knowledge, we tried to mobilize the available material into three major groups of the problem: manifestation of neotectonics; recent fracture tectonics, including ruptures due to modern, historical, and prehistorical earthquakes; and strong earthquakes in the region approximately within the last 250 yr. Thus, we attempted to refine relationships between tectonic and seismic data.

The study region is a member of the Inner Asian neotectonic orogenic belt located between the Siberian and Indian plates. It is characterized by maximum contrasts of topography and absolute heights (up to 4.2–4.5 km) in the entire belt. Horst-shaped ridges of the region, bounded by fractures dipping to the axial zones of mountains, are manifested as upthrusts and overthrusts.

Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, ul. Bol'shaya Gruzinskaya 10, Moscow, 123995 Russia; e-mail: nikonov@ifz.ru

Active fractures in Altai make up a fan-shaped structure (in the plan view), which extends from the southeast to the northwest as a narrow band along structures of the Mongolian part and widens to the west, northwest, and north in the Russian Altai territory. Our map of active faults is a generalization of materials in [2–4, 6–8, and others]. In order to compile this scheme, we mainly used fractures characterized by definite geological indications and spatial coincidence in maps compiled by different researchers. Cenozoic fractures are dominated by a NW-striking upthrust and strike-slip faults [3, 4, 7, 8], indicating an environment of regional compression [4]. The associated normal and pull-apart faults are subordinate [3, 4, 7, 8]. Dextral strike-slip displacements with a vertical component were recorded in Altai by seismological studies [9, 10]. Within the Altai and adjacent territories, researchers have detected and mapped both seismotectonic (seismic ruptures) and seismogravitational (large rockfalls) deformations [2, 7, 11, 12], which are also reflected on our map. Additional places of rockslides are shown on the map based on information collected in the 19th and early 20th centuries.

In order to refine the location of neotectonic faults and determine their interrelations, we also analyzed remote images. Panchromatic space photos taken in the 1980s with a KFA-1000 camera with optical resolution equal to 5 m were used. Transformation of the images into cartographic projection and preparation of photo maps with different degrees of detail allowed us to analyze the remote data with different degrees of the generalization of images at scales varying from 1 : 50 000 to 1 : 1 000 000. This method also made it possible to reveal both the general trends of the lineament network of the territory and the detailed pattern of some ruptures. Active faults distinguished by different authors are confined within this network, thus confirming the inheritance of ancient weakened zones by neotectonic and recent activity. Within the lineament zone, we could distinguish individual sectors with a fresh geomorphological pattern, which separate steps of differ-

Composite catalogue of strong historical earthquakes in the Russian and adjacent Mongolian Altai regions (nos. 1–3, 5, 8, 9, 12, and 14 are adopted from Nikonov's works; nos. 4, 6, 7, 11, 13, and 15 are taken from [15])

No.	Date	Time, h : min : s	Coordinates φ (deg) N; λ (deg) E	Source depth h, km		Magnitude, M	Intensity, I_0
1	December 9, 1761	21:14 ± 1 h	47.5 ± 1.0; 92.0 ± 0.5	(25)	15–40	8.3 ± 0.3	10–11 ± 0.5
1a	December 9, 1761	(21:30) ± 1 h	47.5 ± 1.0; 92.0 ± 1.0	(25)	15–40	(7.5) ± 1.0	(9–10) ± 1.0
1b	December 12, 1761	07:15 ± 1 h	47.5 ± 1.0; 92.0 ± 1.0	(25)	15–40	7.7 ± 0.3	(10) ± 1.0
2	March 1, 1771	02:30 ± 1 h	(50.2 ± 0.5; 87.8 ± 0.5)	(25)	20–30	6.5 ± 0.5	(8–9) ± 0.5
3	October 7, 1786		50.4 ± 0.7; 84.8 ± 0.7	(20)	10–40	(6.0) ± 0.5	(7–8) ± 1.0
4	March 31, 1824	21:00 ± 1 day	50.6 ± 0.5; 83.4 ± 0.5	(20)	7–60	5.2 ± 0.7	(6) ± 1.0
5	October 19, 1894	15:15 ± 15 min	(50.85 ± 0.3; 84.68 ± 0.5)	18	8–45	6.3 ± 0.8	7.5 ± 0.5
	January 16, 1901	Excluded from the catalogue					
6	May 21, 1901	19:00 ± 1 h	50.3 ± 0.5; 83.5 ± 0.5	17	8–34	5.6 ± 0.7	7 ± 1.0
7	April 17, 1904	13:00 ± 1 h	50.5 ± 1.0; 84.5 ± 1.0	(30)	15–60	5.4 ± 0.7	(6) ± 1.0
8	November 17, 1913	09:30 ± 1 h	(51.1 ± 0.5; 84.4 ± 0.5)	30	(10–50)	(5.8) ± 0.7	(6–7) ± 1.0
9	September 22, 1923	20:35 ± 1 h	49.5 ± 1.0; 88.0 ± 1.0	(18)	12–24	6.0 ± 0.5	(8) ± 0.5
10	April 21, 1927	03:21:20	50.2 ± 0.5; 86.9 ± 0.5	28	14–56	6.0 ± 0.7	(7–8) ± 0.5
11	August 10, 1931	21:18:30	47.1 ± 0.5; 89.8 ± 0.5	15	12–20	8.0 ± 0.3	11 ± 0.5
12	August 18, 1931	14:21:00	47.3 ± 0.5; 90.0 ± 0.5	(20)	10–40	7.0 ± 0.3	(8–9) ± 1.0
13	October 19, 1938	04:13:24	49.5 ± 0.5; 90.3 ± 0.5	36	24–54	6.6 ± 0.3	8 ± 1.0
14	March 7, 1939		(49.5 ± 0.5; 87.5 ± 0.5)	(20)	15–40	(6.2) ± 0.5	(7–8) ± 0.5
15	May 15, 1970	17:13:14	50.18 ± 0.1; 91.27 ± 0.1	12	6–24	7.0 ± 0.1	9 ± 1.0
16	July 23, 1988	07:38:11	48.8 ± 0.2; 90.8 ± 0.1	30	15–50	6.4 ± 0.3	8 ± 0.5

Note: Uncertain values are given in parentheses.

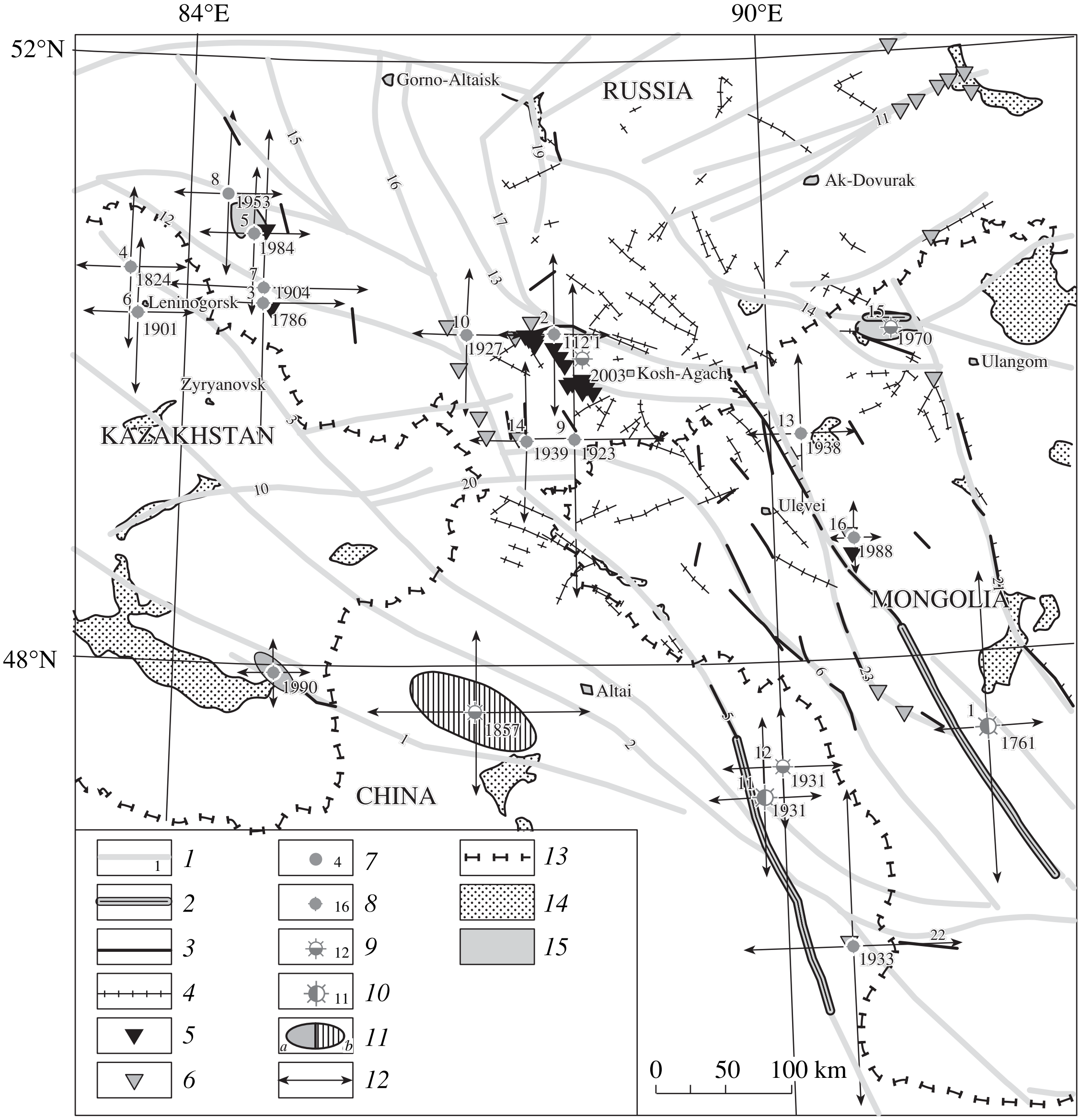
ent levels (rectilinear benches, watershed terraces, and slope trenches) that can be interpreted as young seismogenic ruptures. In the majority of cases, such sectors conjugate with the active faults, which are known from land based investigations, in the form of both immediate coincidence (e.g., the Tsagan–Shibeta and Kobda faults) and auxiliary ruptures. Rejuvenated ruptures also occupy a significant place on our map. They extend beyond the known structures both at their continuations and in the oblique (transversal) direction.

In the southern part of the Russian Altai territory, the Kurai deep fault is the best studied and, thus, representative zone. It is an intricate deep fracture in the form of a combined upthrust–strike-slip fault structure (12–15 km wide) with a complicated internal structure and total amplitude of the displacement of limbs equal to a few kilometers along the vertical direction and tens of kilometers along the horizontal direction. The >80-km-long northern branch (Kubadarinsk fault) is characterized by a steep dip of the displacement plane. However, subordinate NNW- and N-striking crush zones are developed. The neotectonic motions occurred here both along the old and new tectonic contacts up to the Quaternary period, the major type of displacements being represented by overthrusts directed from north to south.

The large NW-striking Fuyun fault in China can be considered the second reference sector. As is known, this area was marked by the earthquake in 1931 with $M = 8$. Along this well-traced fault, a system of surface ruptures developed over a distance of 176 km during the earthquake. In addition, traces of earlier seismic ruptures and several strong earthquakes with a mean recurrence interval of 230–250 yr were found here [13, 14].

The efficiency of comparison of parameters of the strongest earthquakes with manifestations of active tectonics and paleoseismicity depends on the completeness and reliability of the initial data, primarily related to the recorded strong earthquakes, i.e., on the quality of the regional catalogue and duration of monitoring. First, it was necessary to check, verify, and supplement the catalogue of strong ($M \geq 5.5$) earthquakes in the regions, first of all, by analyzing the missed and forgotten primary sources [14]. In the present work, we use a more advanced and complete version of the catalogue, compiled by one of the authors, of strong historical earthquakes in Gornyi Altai during the last 250 yr (Table 1).

Figure 1 shows that not only the Mongolian Altai region [9, 11] but also the Russian Altai territory were characterized by the location of epicenter areas of a number of earthquakes within confidence limits or their confinement to the distinguished (without using seismic data) active fracture zones (their influence zones) and revealed sectors of large paleoseismic deforma-



Schematic map of ruptures, seismic deformations, and strong earthquakes. (*1*) Fractures: neotectonic faults with partial signs of young activation, faults: Zaisan (1), Irtysh (2), Markakol (3), Kara–Irtysh (4), Fuyun (5), Sagsai (6), Kobda (7), Khangai (8), Dzebkhan (9), Chingis–Narym (10), Sayan (11), Uimon (12), Kurai–Chuya (13), Shapshal (14), Peschanyi (15), Katun (16), Sumulta (17), South Chuya (18), Telets (19) South Altai (20), Tsagan–Shibeta (Tankhil) (21), Bulgan (22), Tolbonur (23); (*2–6*) seismic deformations: (*2*) seismic ruptures at the surface related to known earthquakes; (*3*) paleoseismic ruptures based on geological data; (*4*) the same, but based on deciphering data; (*5*) large rockfalls and landslides related to known earthquakes; (*6*) the same, but related to paleoearthquakes; (*7–12*) strong earthquakes: (*7*) epicenters of historical earthquakes with $M = 5.0–5.9$; (*8*) the same, but with $M = 6.0–6.9$; (*9*) the same, but with $M = 7.0–7.9$; (*10*) the same, but with $M \geq 8.0$; (*11*) projections of earthquake sources (at the map scale): (*a*) proved, (*b*) inferred; (*12*) limits of uncertainty in epicenter localization; (*13*) state borders; (*14*) large reservoirs; (*15*) settlements.

tions. In those cases, when it was possible to estimate the strike of epicenter and source zones, the latter turned out to be extending similarly to the tectonic zones with indications of recent activity. In some cases, when epicenter areas and sources could be delineated, historical earthquakes made up chains that coincided with the independently distinguished lineaments and young fractures in space and direction. Such a pattern agrees with the concept of the domination of subhorizontal submeridional stress in the study region. This fact can serve a sufficient argument for admitting the genetic relation between the neotectonic and young fractures zones, on the one hand, and sources of strong earthquakes in the region, on the other hand. In other words, it is precisely the displacements in the large neotectonic fractures zones, which continue to develop now, that regulate the appearance of at least strong earthquakes in the region. The performed analysis gives grounds to admit that not only the major fractures in the Mongolian Altai region are tectonically and seismically active but also their continuations and branches within the Russian Altai territory. In the southern part of the Russian Altai territory, these fractures are as follows (figure): Kurai–Chuya and Northern Chuya faults (no. 13, earthquakes in 1771 and 2003), Katun fault (no. 16, earthquakes in 1927, 1939, and, possibly, in 1923). Faults in the southwest are follows: Markakol fault (no. 3, earthquakes in 1824 and 1901), Uimon fault (no. 12, earthquakes in 1786 and 1904), and a fault located farther to the north (without number, earthquakes in 1894 and 1913). The new information compels us to pay no less attention to the seismogenerating structures mentioned above than to the Kurai and North Chuya zones. There are sufficient grounds to consider the maximum possible earthquakes with $M \geq 7$ and $M < 7$ for the structures distinguished in the southern and southwestern parts, respectively, of the Russian Altai region. Thus, the seismotectonic approach opens new perspectives for refining and supplementing our knowledge related to the specific seismic hazard in the region.

REFERENCES

1. G. I. Reisner and L. I. Ioganson, *Federal System of Seismological Observations and Earthquake Prediction,* (OIFZ RAN, Moscow, 1996) [in Russian].
2. E. A. Rogozhin and S. G. Platonova, *Source Zones of Strong Earthquakes in Gornyi Altai in the Holocene* (OIFZ RAN, Moscow, 2002) [in Russian].
3. I. S. Novikov, *Morphotectonics of Altai*, Proceedings of the United Institute of Geology, Geophysics, and Mineralogy (Novosibirsk, 2004), Issue 852 [in Russian].
4. N. V. Lukina, Geol. Geofiz. **37** (11), 71 (1996).
5. A. F. Emanov, A. A. Emanov, A. G. Filina, et al., in *Proceedings of the International Conference on the Problems of Seismology in the Third Millenium, Novosibirsk, September 15–19, 2003* (SD RAS, Novosibirsk, 2003) [in Russian].
6. N. L. Dobretsov, N. A. Berzin, M. M. Muslov, and V. D. Ermikov, Geol. Geofiz., No. 6, 35 (1995).
7. E. A. Rogozhin, A. N. Ovsyuchenko, A. V. Marakhanov, et al., *Strong Earthquake in Altai on September 27, 2003: Materials of Preliminary Investigation* (OIFZ RAN, Moscow, 2004) [in Russian].
8. E. V. Devyatkin, in *Neotectonics, Geodynamics, and Seismicity of Northern Eurasia* (Moscow, 2000), pp. 92–120; 425–429 [in Russian].
9. *Earthquakes and Principles of Seismic Zoning of Mongolia* (Nauka, Moscow, 1958) [in Russian].
10. P. Molnar, R. A. Kurushin, V. M. Kochetkov, et al., *Deep Structure and Geodynamics of the Mongolian–Siberian Region* (Nauka, Novosibirsk, 1955) [in Russian].
11. A. L. Strom, Issled. Zemli Kosmosa, No. 2, 81 (1987).
12. G. A. Chernov *Seismogeology of the Eastern Altai–Sayany Mountain Region* (Nauka, Novosibirsk, 1978) [in Russian].
13. Shi Jianbang, Fend Xianyue, Ge Shumo, et al., *A Collection of Papers of International Symposium on Continental Seismicity and Earthquake Prediction (ISCSEP)* (Seismological Press, Beijing, 1984), pp. 325–346.
14. A. A. Nikonov, Izv. Ross. Akad. Nauk, Ser. Fizika Zemli, No. 1, 36 (2005) [Izv. Phys. Solid Earth, No. 1, 34 (2005)].
15. *A New Catalogue of Strong Earthquakes in the USSR Territory* (Nauka, Moscow, 1977) [in Russian].