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Prof. Demberel Sodnomsambuu

Dr. Odonbaatar Chimed

Dr. Ulziibat Munkhuu

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ON CONDITIONS OF PREPARATION FOR THE CATASTROPHIC EARTHQUAKES FOCI WITHIN EARTH CRUST OF CENTRAL ASIA

Ruzhich V.V. and Levina Ye.A.

Institute of the Earth's crust SB RAS, Irkutsk, Russia

Contact: Ruzhich@crust.irk.ru

Introduction

According to the known law of recurrence, the quantity of damaging earthquakes with $M \geq 7.5-9.0$ is extremely few but damages caused by them and number of victims force the human community to deal with all responsibility the problem of ensuring of seismic safety. Problems of some specific conditions of preparation for the catastrophic earthquakes foci in the Earth crust of the Central Asian folded belt that includes the Baikal rift zone and collision area of Mongolia are discussed below.

Structure of catastrophic earthquakes foci on the Earth surface

Let us consider the structure regularities of upper segments foci of two dynamically interrelated catastrophic earthquakes: the 1905 (9 and 23 June) Tsetserleg ($M_w = 8.0$) and Bolnai ($M_w = 8.3 - 8.5$) occurred within the Central Mongolia. They were studied in details by members of many international expeditions beginning with A.V. Voznesensky [1]. Zones of seismic dislocations resulted from left-lateral reverse faults with a strike-slip component were extended over 150 and 376km, respectively. In 2001 with the author participation in the composition of Mongolian-Japanese expedition the zone of seismic dislocations was mapped, the total measured extension of which was about 580km (Fig. 1).

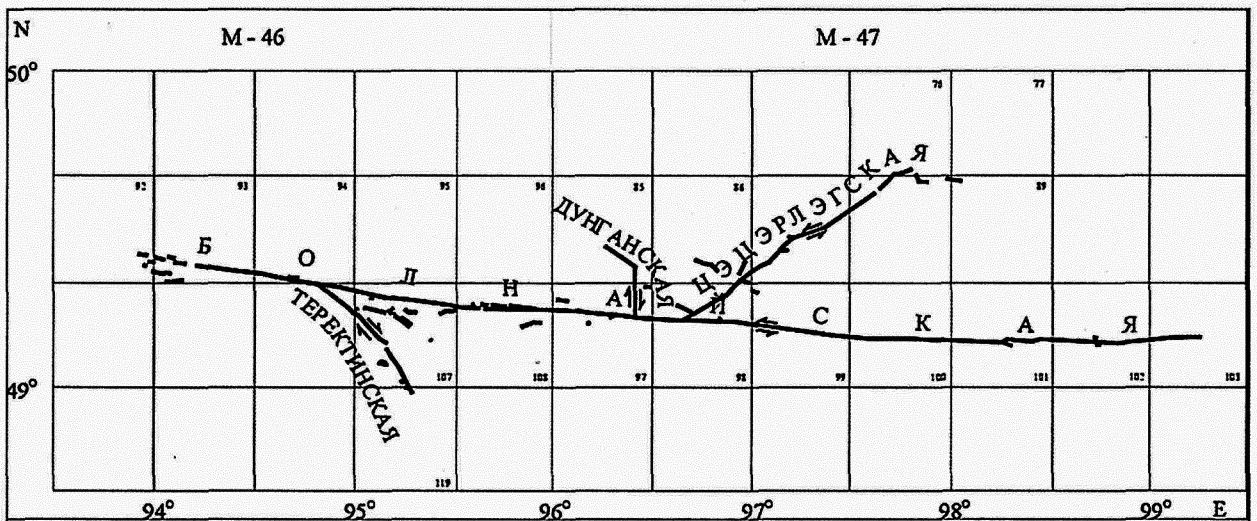


Figure 1: Sketch-map of seismic dislocations of the Tsetserleg and Bolnai earthquakes with the Terekhtin and Dungan bifurcations. Compiled in 2001 from the results of Japanese-Mongolian expedition (head of expedition Ioshihiro Kinugasa).

In addition to enormous extent of the coseismic fracture zones resulted from successive opening of the ancient Northern-Khangai (Bolnai) deep fault it is important to refer to periodic occurrence of similar events based on duration of aseismic periods distinguished during trenches driving within some areas of seismic dislocations covered by neogenic topsoils. According to radiocarbon dating (2) the age of the precedent paleoseismic events are $\approx 2700 - 4000$ years.

Estimated value of average slip velocity of faults sides within zone of coseismic fractures of the Bolnai fault was accordingly about $3.1 \pm 1.7 \text{ mm}$ per year. Another the Gobi-Altai catastrophic earthquake took place 4 December 1957, $M = 8.1$, average focal depth was $17 \div 23 \text{ km}$ (3, 4). Earthquake focus in the form of seismic dislocations was located within the Dolinoozersky fault zone segment in the south-west of Mongolia and was extended over 270 km . Earthquake epicentrum was situated in the Bakhar hole within western part of the Dolinoozersky fault zone near northern piedmont of the Ikhe-Bogdo ridge. The left-lateral reverse and strike-slip faults motions with maxima amplitudes of horizontal displacements up to 4-5 meters and vertical ones – up to 3 – 5m was distinguished by seismogeological studies. Four imbrications extended about 55 – 65km can be distinguished in zone during detailed consideration of its structure. The prospect holes and trenches driving allow gaining insight into the recurrence periods of earlier acts of coseismic opening of the Dolinoozersky fault (4.5) zone segments among loose sedimentary deposits and radiocarbon dating. Additionally to these results and accordingly to author data on radiocarbon dating, the episodes of successive occurrence of paleoearthquakes with $M \approx 6.5 - 7.5$ were aged as follows: 230 ± 50 , 300 ± 70 , 1665 ± 50 , 1945 ± 80 years. Consequently, estimated average velocity of aseismic creep during vertical dislocations in the Dolinoozersky fault was about 1.5 mm/year . The current data resulted from annual (1985-1995s) topographic measurements of the tectonic creep velocity after the earthquake within western (Khutusudzh hole) and central (Tormkhon River mouth) areas of the Gobi-Altai earthquake seismodislocation zone also show that after seismic event the left-lateral shear directivity of horizontal dislocations with average velocity about 1 – 2mm per year was remained during decades.

It is notable, that during surveying of occurred system of seismodislocations a characteristic combination of relatively smooth extended zone segments with saddles between imbrications and bifurcations of seismogenic fractures. Available author data on the Baikal rift zone for earthquakes with $M = 4.6-6.3$ showed that period of their preliminary preparation observed in seismic regime in the form of initiation of epicentral fields of moderate and weak earthquakes and seismic gap is extended from first months to several years with increase in energy of past earthquakes. For example, the 1957 Mogod earthquake with $M = 7.5$ [6] in central region of Mongolia began to reveal the preparation evidences before approximately 10 years and period of moderate calm continued about 3 years. Based on extrapolation for very large intracontinental earthquakes with $M \geq 8.0 - 8.5$ the preliminary stage of calm in the metastable fault segment may be continued over many years and decades creating illusion of an aseismic state of the earth's crust area and thus masking the preparation signs of the seismic catastrophe foci.

Study of deep-seated fragments of paleoseismodislocations

Results of geological study of deep-seated paleoseismodislocations in exhumed geoblocks allowed providing insight into structure and development of deep seismodislocations of the ancient foci of earthquakes initiated at the depths of seismofocal horizon occurrence in the middle part of continental Earth crust [7]. Let us consider the exhumed segments of the Primorsky fault zone extended over than 250 km . It is a part of the Early Paleozoic shear collision zone and one of the most seismically active geostructural elements during the Baikal rift zone formation [8]. After long denudation of the Earth crust the fault segments within the Baikal area situated previously at the depth of 10 – 20km and more became accessible for visual geological study. The study showed that the rocks geochemical transformations with participations of fluids took place in the range of these depths in the fault segments against the background of slow tectonic deformations under the stress-metamorphic conditions. The Fig. 2 shows structures of the deep segments of dislocations being of different scales and ages.

In the upper photography the large arrow indicates the fault of reverse and strike-slip fault dislocation types within Lower Proterozoic granite rock series (b) and more ancient fault marked by small dashes and arrows (a). Details of their structure are given below: a – zone of Neoproterozoic reverse fault with strike-slip component with tightly closed walls, slickensides and signs of viscoelastic flow typical of deep seismogenic fractures; b – zone of Middle Paleozoic brittle fracture with slickensides.



Figure 2: In the upper part of the figure one can see the structure of one segment of the Primorsky fault zone in which two zones of coseismic dislocations of different ages and scales (a and b). At the bottom the segments of zones are shown: a – small arrows indicate the zone of ancient closed fault plane in site of small asperity at the contact of gneisses and granites.

When distinguishing coseismic ruptures within exhumed geological and structural objects the slickensides served as one of the main characteristic for identification of coseismic fracturing [8, 9 et al.]. The blastomylonite rocks, specific composition of mineral hydrothermal filling of fissures on the slickensides planes, pseudotachylites, and the presence of film glassy coat of slickensides are additional indications of deep origin of paleoseismogenic ruptures. Foci of large earthquakes initiating at a depth of seismofocal horizon in the form of coseismic motions in faults are propagated not only into upper but into lower horizons of lithosphere where their characteristics are preserved in the form of plastic slip named as shear-zones. V. B. Savelyeva [10] calculated a value of erosion cut in studied segment of the Primorsky fault segment by traditional minerals “geothermometer” and “geobarometer” which was no less than 10km.

Crystallization temperature of hornblende was $850 - 950^{\circ}C$ and pressure was about $5 - 5.5kbar$ in the pseudo-tachylite rock mass. During fast coseismic dislocations, in addition to initial values of rock mass that were increased at this depth, the pressure was instantly increased by $2.0 - 2.5kbar$ and temperature of frictional heating by $500^{\circ}C$ that led to the stage of frictional flash heating and melting with fast shearing strength drop. An approximate absolute age of one episode of seismogenic slip in fissure with slickenside of tourmaline mineralization was determined. A.V. Travin in 2017 by $40Ar/39Ar$ method defined the following values: 719 ± 81 , 737 ± 42 and $673 \pm 5Ma$. Generalization of the many observations results showed that the most optimal conditions for preparation of large and catastrophic foci of earthquakes with $M \geq 7.5 - 8.5$ within continental earth crust occur at pressures

about 2 – 4kbar and temperatures of 350 – 650°C. Therefore, the most optimal parameters within continental earth crust are registered at depths of 10 – 30km under amphibolite and greenstone slate facies conditions of regional metamorphism [7, 10 et al.].

Main factors of preparation for large earthquakes

First group of factors is related to faulted multilevel structure of the earth's crust including large-scaled zones of long-lived deep faults, faulted nodal joints with morphological peculiarities of their asperities and as well as subject to space dynamic interactions between fault systems. *Second group of factors* is related to occurrences of tribochemical processes within internal segments of the fault zones where during frictional sliding of fracture edges under stress-metamorphic reactions conditions in deformed rock massifs occur their the most complicated as well as insufficiently studied stress-metamorphic transformations influencing the friction regimes in faults the seismogeneration depending on depths of the fault occurrence. *The third set of factors* manifests itself as pseudoregular external actions on deformation processes of the earth's crust and upper mantle and then on metastable areas of the deep fault zones. Despite of moderate energy of external factor their modulating trigger mechanism action is manifested itself in the form of various periodicities in the seismic energy dissipation regimes.

The accumulation method allowed confirming the presence of following periodicities within the Baikal rift zone seismic regime including the Lake Hovsgol areas: 1 and 3 months, 0.5 year, 1 year, 4-6, 9-11, 18 and 45 years [8]. Regulating influence of cosmogenic factors on seismic regime is related to variations of the Earth rotation regime, gravitational relationship in the Earth-Moon-Sun system including terrestrial tides. Similar phenomena were reported by authors in the regions of Indo-Eurasian collision and West-Pacific subduction, in Central-Atlantic Ranges [11]. Available positive practice of long-term observations over the Baikal rift zone seismic regime for the purpose of medium-long-term prediction of earthquakes with $M = 4.5-6.3$ is based on stated presentations about the earthquakes foci structure and their medium- and long-term prediction subject to cosmogenic factors [8, 11].

Discussion of results and conclusions

Structure of the seismodislocation zones of considered intraplate earthquakes with the highest magnitudes $M \geq 7.5 - 8.5$ suggests that tectonic conditions of their occurrence are due to spontaneous deformation-wave opening of the fault zones segments extended up to 50 – 100km during their successive stick-slip unification owing to destruction of strength barriers of different morphology. The avalanche-unstable (*AU*) and dilatation-diffusive (*DD*) models describes the preparation of the large earthquakes foci with the greatest approach to real conditions [12]. The energy release of enormous volume of stored elastic energy including seismic one is objectively described according to known kinetic strength concept of S.N. Zhurkov in the course of the rupture stick-slip transfers from one scale level to more higher with the fluid supply in the sliding zone. At the preliminary stage of preparation the tectonic deformations take places at aseismic periods of sliding in the creep regime with average for long aseismic periods velocities about 1 – 3mm per year in order to accumulate the deformations up to critical level. The durations of these periods may be many ten and hundred years including the stages of seismic calms. At present in evaluating seismic hazard the errors of type “miss probability” often arise in many regions due to lack of long series of seismometric observations and proper paleoseismological survey [13].

In the search for signs of preparation for the catastrophic earthquakes foci it is important in the first place to reveal the regions of the large-scale fault zones location and their intersections within which the paleoseismodislocations with established ages are reported. In order to realize the medium- and long-term prediction the creation of seismological and deformation control is necessary in such locations. The important information about prediction can be obtain from observations of time history of various precursors in seismic regime, for example, analysis of changes in the epicentral fields formation from among of moderate earthquakes according to energy, reveal of seismic

gaps, evaluation of duration of seismic calm periods. The further, more successful problem solving of decrease in seismic risks based on improvement of the large earthquakes prediction it is impossible without involvement of data on deep starting mechanisms of high-velocity displacements over extended areas of interacting fault zones examined, for example, in [14-16, 7, 8]. Therefore, it is necessary the comprehensive geologo-geophysical study of deep destructive processes within the fault zone with involvement of experimenters, physicists, geotechnicians and seismologists.

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