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Recurrence of strong seismic events in the area of the 2011–2012 Tuva earthquakes according to paleoseismological data

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Abstract

This paper presents the results of paleoseismological studies in the epicentral area of the Tuva earthquake of 2011 ($M = 6.7$) and 2012 ($M = 6.8$). Their seismotectonic position and seismic history over the last millennia has been studied. The results are of great importance because these earthquakes are the strongest in the history of seismological observations in Tuva and are thus the first well-studied strong earthquakes in this region. The data show that relatively weak events similar to the 2011–2012 Tuva earthquakes recurred every 300–500 years in the past millennium, while catastrophic earthquakes with $M = 7.0$–7.2 and higher occur approximately every thousand years.

Keywords: earthquake; active tectonics; paleoseismology; seismic focus; seismic regime; Tuva

Introduction

Detailed studies of seismic hazard are motivated by strong earthquakes of modern times, namely, their seismotectonic position and seismic history over the past millennia. The relevance of such studies in the Republic of Tuva is clearly demonstrated by two strong earthquakes with $M = 6.7$ and 6.8 which occurred in the Kaa-Khem region in winter 2011–2012. (Emanov et al., 2014). The importance of these studies stems from the fact that these events are the strongest in the history of seismological observations in Tuva and are thus the first well-studied strong earthquakes in this region. As a result of the field work, residual seismic deformations caused by the 2011–2012 earthquakes were mapped, and the precise location of the sources of these events, their spatial characteristics and place in the geological structure of the region were established. The earthquakes generated seismotectonic ruptures, landslides, slide-rocks, rockfalls, and settlement cracks on steep slopes, rare slope landslides, and cracks with ejections of liquefied sand in large river floodplains. Collected data on the distribution of secondary effects of the earthquakes were used to delineate the areas of 8 and 9 magnitude quakes (Ovsyuchenko et al, 2014; Rogozhin et al., 2015).

The earthquakes occurred in the axial part of the mountain range called the Academician Obruchev Ridge (Fig. 1). It towers over the surrounding Tuva and Todzha intermontane basins. In the region considered, the axial part of the mountain range strings out along the Kaa-Khem fault zone and consists of a number of narrow ridges with altitudes of up to 2500–2890 m, separated by intramontane basins and deeply incised river valleys. The Kaa-Khem fault is a large shear zone 15–20 km wide, which hosts strongly deformed and altered Paleozoic rocks cut by numerous faults of various orientations and kinematics of displacement. The fault zone has a complex geological history and has played an important structural role throughout the tectonomagmatic activity since the end of the Precambrian (Geology..., 1966; Sugorakova and Butanaev, 2014).

The possibility of strong earthquakes at the Academician Obruchev Ridge has been established relatively recently. Clear evidence of young (Quaternary) tectonic displacements along faults in the western part of the ridge was obtained in a 1:200,0000 scale geological survey in the middle of the 20th century (Chudinov, 1959). Later, in eastern Tuva Chernov (1978) identified a seismogenic structure, named the Kaa-Khem seismogen, which partially coincides with the fault of

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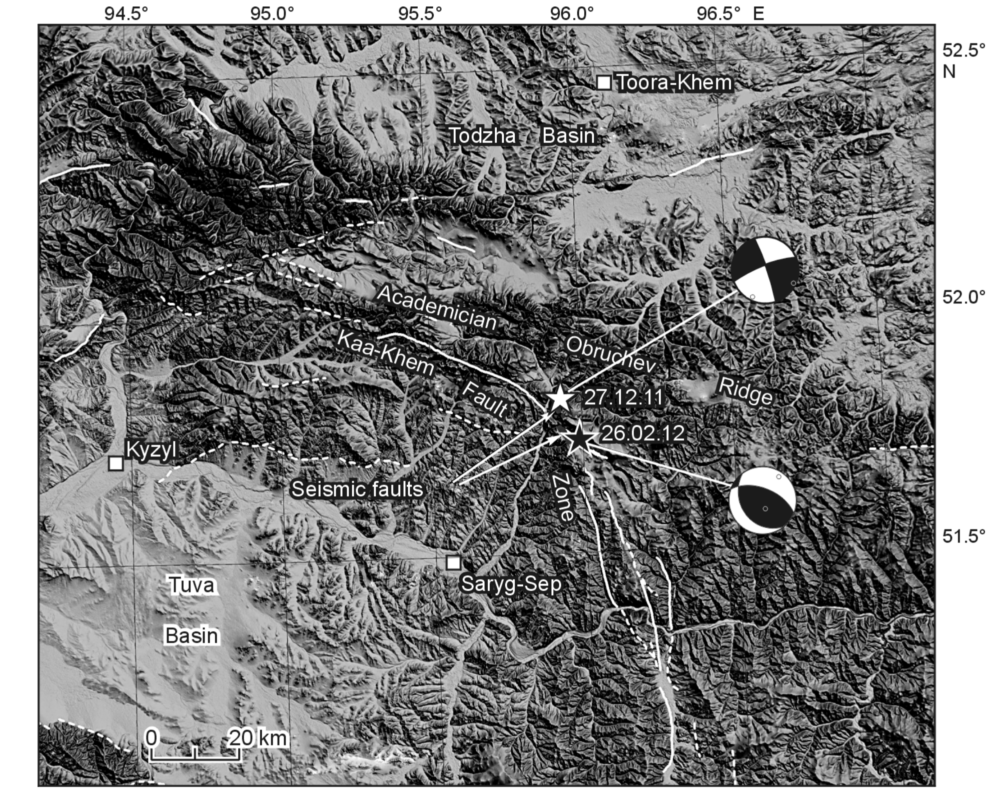

Fig. 1. Position of the seismic faults of the 2011–2012 earthquakes in the Kaa-Khem active fault system. White dashed lines indicate inferred active faults, and solid lines indicate the faults studied using data (Arzhannikov, 2000; Arzhannikov and Zelenkov, 1995). The earthquake focal mechanisms are shown according to GS RAS (http://www.ceme.gsras.ru).

the same name. According to the results of paleoseismogeological studies conducted in the region of the Academician Obruchev Ridge (Arzhannikov and Zelenkov, 1995), the seismic potential of the Kaa-Khem zone was evaluated as M = 6.6–7.0 (Arzhannikov, 1998; Khromovskikh et al., 1996). Thus, the long-term prediction made from paleoseismogeological data was valid in the event of the Tuva 2011–2012 earthquakes.

The Academician Obruchev Ridge exhibited moderate seismic activity over half a century of instrumental seismic observations. In the 1960–1980s, earthquakes with moderate magnitudes (M = 4.0–5.5) recurred here, but the epicentral area of the 2011–2012 earthquakes was almost aseismic over more than 50 years (Emanov et al., 2014). The seismic calm was interrupted in 2011. The question of how long it lasted can be solved only using a paleoseismological approach.

Methods

For regions with a short period of instrumental seismic observations, such as the Altai–Sayan Highlands, paleoseismogeological data are and will remain the only source of information about the strongest earthquakes and their recurrence intervals (Florensov, 1960; Solonenko, 1962, 1973). This is of fundamental importance in the long-term prediction of seismic disasters because traces of ancient earthquakes make it possible to identify the sources of future strong earthquakes. The paleoseismogeological approach is based on the fact that strong earthquakes of the past, often the prehistoric past, leave geological traces on the surface—paleoseismodislocations. The main objective of such studies is to identify and examine all possible traces of seismogenic activation in young sediments and landforms—primary seismotectonic dislocations, soil liquefaction, landslides, avalanches, etc. (McCalpin, 2009; Rogozhin, 2012). In the source zones of the Tuva earthquakes, ancient seismic dislocations were studied in detail. The radiocarbon method was used to determine the age of traces of paleoearthquakes. Buried paleosoils were dated in the laboratories of the Institute of Geography of RAS and the St. Petersburg State University.

Surface manifestations of the Tuva earthquake sources

The 2011–2012 earthquakes sources are expressed on the surface as seismic faults cutting the roots and trunks of trees, stones, the shrub-and-moss layer, and all landforms on their path (Ovsyuchenko et al., 2014). According to focal-mechanism solutions (Ovsyuchenko et al., 2016), the movement in the first earthquake was dominated by strike-slip kinematics, and that in the second earthquake by reverse-fault kinematics with a strike-slip component (Fig. 1). For the NW strike of the nodal plane, the horizontal slip was right-lateral; for the NE strike, it was left-lateral. The types of fault displacements correlate well with the focal-mechanism solutions, and their