Marine and Petroleum Geology 89 (2018) 604–614

Contents lists available at ScienceDirect

Marine and Petroleum Geology

journal homepage: www.elsevier.com/locate/marpetgeo

Research paper

Lake Baikal's response to remote earthquakes: Lake-level fluctuations and near-bottom water layer temperature change

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ARTICLE INFO

Keywords:
Lake Baikal
Gas hydrates
Near-bottom water
Teleseismic waves
Lake level oscillations

ABSTRACT

The 2011 M_w9.0 Tohoku earthquake and the 2012 M_w8.6 and 2016 M_w7.8 Sumatra earthquakes caused water level oscillations in Lake Baikal which were recorded by a water pressure tensor transducer with high sampling rate. Periods of water oscillations were about 100 s, and maximum peak-to-peak amplitudes were as large as 0.15 m for the 2011 Tohoku earthquake and 0.24 m for the 2012 Sumatra earthquake, although the Tohoku earthquake was closer and stronger. The difference in the amplitude of the level oscillations for these earthquakes was probably caused by their focal mechanisms, namely thrust and strike-slip, as well as the direction of the wave propagation. CTD (conductivity-temperature-depth) measurements conducted after these earthquakes at the regularly tested stations showed a temperature increase in the near-bottom water layer after the Tohoku earthquake in March 2011, and a decrease in temperature and electrical conductivity after the Sumatra earthquake in March 2016. These observations cannot be explained by the known processes of deep water renewal, so based on the gas hydrate presence in the Baikal sediments we assume that seismic wave passing could change permeability in the sedimentary layer (at least for the 2011 Tohoku case study) and promote methane flux from the base of the hydrate stability zone and formation of gas hydrates with heat release. As to the 2016 Sumatra study case, we suppose to explain it by gas hydrate dissociation in the subsurface sediments. We present rough estimates of the volume of the formed/dissociated gas hydrates.

1. Introduction

Large earthquakes inevitably have an environmental impact, which can include a hydrodynamic response over teleseismic distances. Water-level fluctuations in wells located thousands of kilometers away from the epicenters of large earthquakes are well known, but there are also numerous reports of water level responses in enclosed or partially enclosed water bodies with free water surface like lakes, fiords, bays and harbors, pools, and other reservoirs (e.g. Kvale, 1955; McGarr, 1965; Vorhis, 1967; McGarr and Vorhis, 1968; Barberopoulou et al., 2006; Bondevik et al., 2013; Granin et al., 2014). Many large earthquakes, both historical (e.g. the 1755 Lisbon earthquake) and present-day ones (e.g. the 1964 Alaska earthquake, the 2004 Sumatra-Andaman earthquake, the 2011 Tohoku earthquake) caused water level oscillations in far-distant reservoirs when long-period seismic waves passed through the area. Such oscillations were named as seismic seiches by A. Kvale (1955) after observing oscillation of lake levels in Norway and England resulted from the Assam-Tibet M8.6 earthquake.

The characteristics of such seiches are determined by the depth of the water reservoir as well as by the thickness of the underlying sediments (McGarr, 1965). In this regard, Lake Baikal, the largest and deepest freshwater lake in the World, is an appropriate case study. In this paper, we report the observed water level fluctuations in southern Lake Baikal after several distant earthquakes (Fig. 1), namely the 2011 M_w9.0 off the Pacific coast of Tohoku earthquake, the 2012 M_w8.6 and 2016 M_w7.8 Sumatra earthquakes (abbreviated in the text to the

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http://dx.doi.org/10.1016/j.marpetgeo.2017.10.024
Received 12 July 2017; Received in revised form 21 October 2017; Accepted 25 October 2017
Available online 26 October 2017

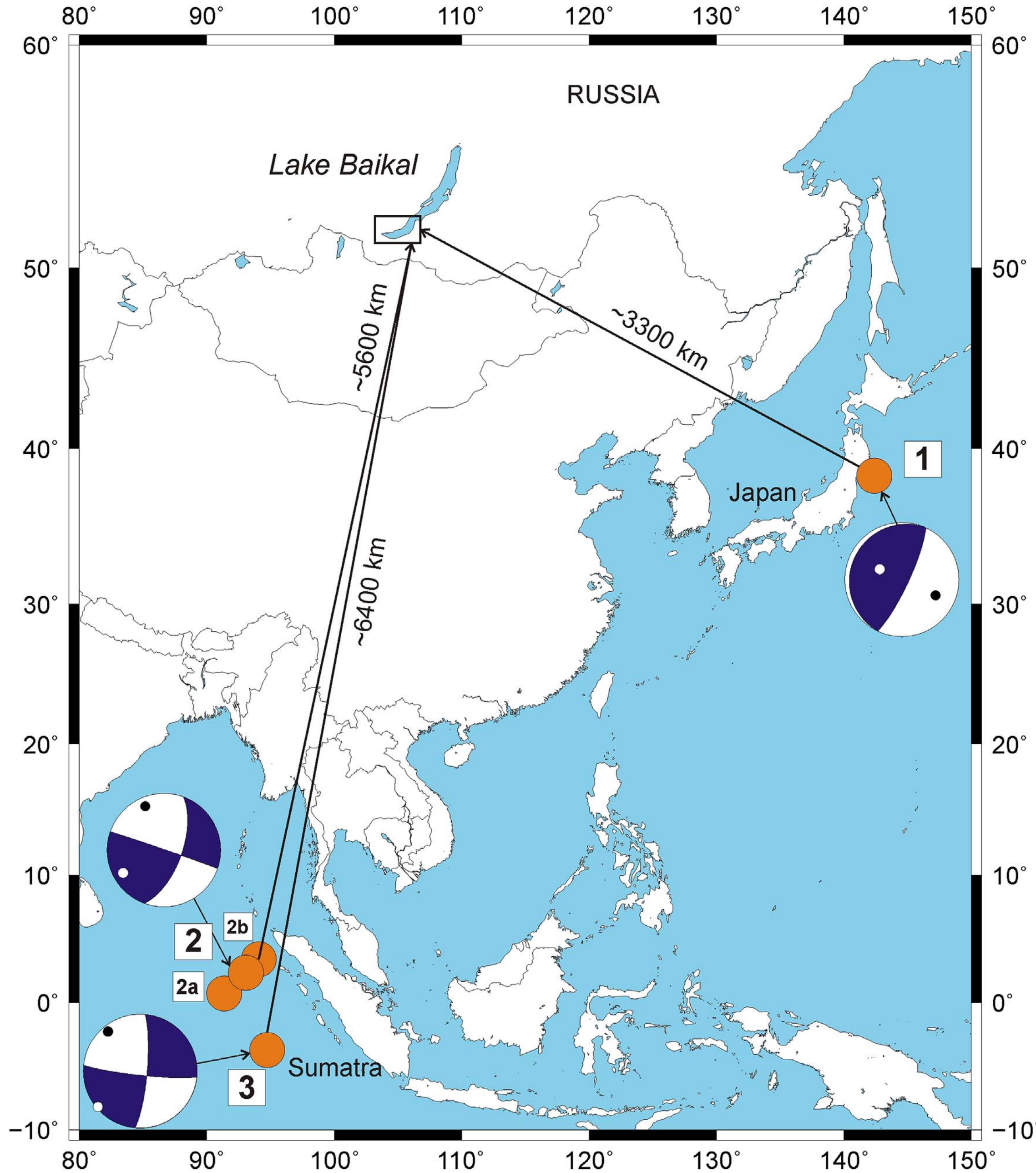

Fig. 1. Location of the region under study (shown by rectangle) and epicenters of the considered earthquakes. Numbers of earthquakes correspond to the Table. Fault-plane solutions taken from the Global CMT Project (www.globalcmt.org) are shown in the lower hemisphere. For the Sumatra 2012 earthquakes (2, 2a, and 2b), the focal mechanism is plotted only for the mainshock, being nearly identical with others.

Tohoku earthquake, Sumatra 2012 and Sumatra 2016 earthquakes, correspondingly). The Tohoku earthquake is one of the largest earthquakes which was caused by thrust faulting along the convergent plate boundary, where the Pacific plate subducts underneath the North American plate. The earthquake was remarkable by the extremely large slip (greater than 50 m) on a small shallow portion of the thrust fault that contributed significantly to the tsunami generation (e.g., Iinuma et al., 2012; Tajima et al., 2013).

The 2012 M_w8.6 Sumatra earthquake is unique because it is the strongest strike-slip type earthquake ever recorded; moreover, it is an intraplate event rather than interplate one, with the epicenter located within the Indo-Australian plate. Another peculiarity of this earthquake was its complex character of the rupture at the source: movements occurred over 160 s on four faults with a maximum slip of 20–30 m (Yue et al., 2012). The earthquake was preceded by foreshocks and followed by aftershocks, the largest of which (M_w7.2 and M_w8.2) also made the water level of Lake Baikal to oscillate. The focal solutions of the mainshock and other large events of the sequence showed dextral strike-slip motions on W-E oriented planes and sinistral motions on S-N planes (U.S. Geological Survey). The 2016 M_w7.8 Sumatra earthquake occurred to the south of the 2012 earthquakes. This shock, like the previous ones, was a result of strike-slip faulting under SE-NW compression (U.S. Geological Survey). A fault of an E-W orientation was ruptured with right-lateral displacement. None of these Sumatra earthquakes resulted in a tsunami because of the mainly horizontal displacement in the foci.

These earthquakes occurred thousands of kilometers away from Lake Baikal, but they were too large to be recorded clearly at all stations of the regional seismic network. One of these stations, Listvyanka (LSTR), is situated at the western side of the South Baikal Basin at the