ESC2016-622-4, 2016
35th General Assembly of the European Seismological Commission

Analysis of the State of Stress before and after the Deep Okhotsk Earthquake

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On May 24th 2013, the largest ever recorded deep earthquake occurred beneath the Sea of Okhotsk, west of the Kamchatka peninsula, Russia. The hypocenter of the earthquake was located in the transition zone between the upper and lower mantle at a depth of 609 km. There was no damage from the earthquake, but the effects were felt in Petropavlovsk-Kamchatsky, the main city on the Kamchatka peninsula and all over Asia, as far away as Moscow, and across the Pacific along the western seaboard of the United States. A prior deep earthquake occurred in Bolivia in 1994 at a depth of 647.1 km. The moment magnitude of the deep Bolivian earthquake was 8.2.
In the Kuril-Okhotsk region there were only 6 deep earthquakes with Mw $\geq$ 7.0 in the 300–650 km depth range from 1976 to 2016, according to the Global CMT Project: 12 May 1990 (Mw 7.2, h=612.5 km), 17 November 2002 (Mw 7.3, h=479.8), 5 July 2008 (Mw 7.7, h=635.6 km), 24 November 2008 (Mw 7.3, h = 491.6 km), 14 August 2012 (Mw 7.7, h=598.2), 24 May 2013 (Mw 8.3, h=609 km). The 2013 event was preceded by nearby large earthquakes in 2008, the epicenter of the first 2008 earthquake was located 115 km to the southwest, the epicenter of the second one – 95 km to the southeast.
The goal of the present study is to reconstruct the state of stress before and after the 2013 Okhotsk earthquake. Reconstruction of the tectonic stress was performed using the method of cataclastic analysis (MCA) of discontinuous displacements. This method integrates some of the main principles of the theory of plastic deformation and a generalization of the results of rock failure experiments. The reconstruction of the state of stress is based on earthquake foci data. Stress reconstruction is performed for the data set (4.6 $\leq$ Mw $\leq$ 5.5) on a $0.25^0 \times 0.25^0$ grid, at six depths: 1) 0-30 km, 2) 30-60 km, 3) 60- 90 km, 4) 90-120 km, 5) 120-220 km, and 6) 480-660 km.
Analysis of the reconstruction has shown that the principal stress axis $\sigma 1$ and $\sigma 3$ are oriented almost orthogonal to the axis of the Kuril-Kamchatka Trench at the depths 0-30, 30-60, 60-90 km. The principal stress axis of maximum compression $\sigma 3$ dips under the oceanic plate at an angle of 15-30^0. Principal stress axis $\sigma 1$ dips gently beneath the continental plate at an angle 55-75^0. The intermediate principal stress axis, $\sigma 2$, is subhorizontal and parallel to the Kuril-Kamchatka Trench almost everywhere. But at the depths 90-120, 120-220, 480-660 km the principal stress axis $\sigma 1$ and $\sigma 3$ have opposite orientation.
The area of horizontal compression and the area of horizontal extension are obtained for the depth range 480-660 km according to the results of reconstructions. The 2002 deep earthquake (thrust fault) and the 2012 deep earthquake (reverse fault) are located on the boundary with the area of horizontal compression. The 2013 deep earthquake (normal faulting) and its largest aftershock (normal faulting) are located within the area of horizontal extension. It should be also noted that the reconstruction of the state of stress was performed for the data set 4.6 $\leq$ Mw $\leq$ 5.5, because the larger an earthquake's magnitude is, the larger its influence on the local variation of the natural stress field is. Thus, the mechanisms of 2002, 2012, 2013 earthquakes correspond to the reconstructed geodynamic regimes. This is especially important for the 2013 Okhotsk earthquake and its largest aftershock because it shows that the area of horizontal extension existed here before these deep earthquakes happened.

The reported study was partially supported by the Grant of the President of the Russian Federation, research project MK-6640.2015.5 and by RFBR, research project No. 15-05-08903 a.