SUCCESSFUL PREDICTION OF THE STRONG ZHUPANOVSKOE EARTHQUAKE (MW7.2) BASED ON THE MULTI-INSTRUMENTAL BOREHOLE MEASUREMENTS

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During the long-term studies at the Institute of Volcanology and Seismology (IVS) FEB RAS new methods have been developed for continuous monitoring the stress-strain state of the geological medium. The methods are based on the multi-instrumental borehole measurements. Observations are provided by the automated network of multi-instrumental boreholes measurements. The network consists of five radio telemetric stations based on the boreholes and the data center in the IVS FEB RAS. Continuous geoacoustic measurements at depths up to 1012 m and electromagnetic measurements with underground electric antennas comprise the backbone of the network (Gavrilov et al., 2013). In addition we monitor continuous measurements of specific electrical conductivity, density, temperature and water level in boreholes. Water salinity, water discharge, water level fluctuations and water density measurements in boreholes are also used as additional data. The successful predictions of the earthquakes based on these data have demonstrated promising prospects of this direction of study for medium- and short-term earthquake prediction.

We discuss the methods and approaches that we use for assessing the current seismic hazard in the region of Petropavlovsk-Kamchatskii by the example of successful prediction the strong Zhupanovskoe earthquake (M_w=7.2).

Monitoring methods. We use two main continuous monitoring methods for prediction of earthquakes that are dangerous for Petropavlovsk-Kamchatskii. These methods allow controlling changes in fluid-saturated geological medium of the near-borehole space.

The first monitoring method is based on the effect of modulation of the geoacoustic emission (GAE) intensity by the weak varying electric field (Gavrilov et al., 2008; Gavrilov et al., 2013). In the sufficiently highly fluid-saturated medium, the impact from the harmonic electric field with slowly varying amplitude will cause the corresponding changes in the GAE amplitude in this medium. In this case, for instance, the diurnal variations in the amplitude of the external electric field will induce the corresponding diurnal variations in the root mean square (RMS) GAE intensity (Gavrilov, Naumov, 2017). The final stage of the preparation of relatively strong earthquakes is typically marked by the significant changes in the amplitudes of GAE responses to the weak varying electromagnetic radiations (EMR) in the borehole area. These changes are associated with changes in the fluid-saturation of the geological medium. The effect of changes in amplitudes of GAE responses to the external EMR impact (in sufficiently highly fluid-saturated medium) generally holds for earthquakes, for which the quantity S is more than 5%. S = L / Rh * 100%, where L=100.44M-1.29 is the length (in km) of the earthquake source approximated by ellipse; M is the magnitude of the event calculated from seismic moment; and Rh is the hypocentral distance in km.

The second monitoring method is used for monitoring the changes in the electrical resistivity of rocks in the vicinity of the borehole with underground electric antennas (Gavrilov, 2014). Method uses continuous background electromagnetic radiation in the borehole zone, either natural or artificial. The depth of monitoring of the electrical resistivity of rocks is from 400 to 2300 m, depending on the frequency channel. Before all strong earthquakes with quantity S≥ 20%, the changes in the electrical resistivity $\Delta\rho$ reached values from 350% to 700%. The value of the parameter $\Delta\rho$ has changed by about 700% two days before the Zhupanovskoe earthquake (Fig. 1).

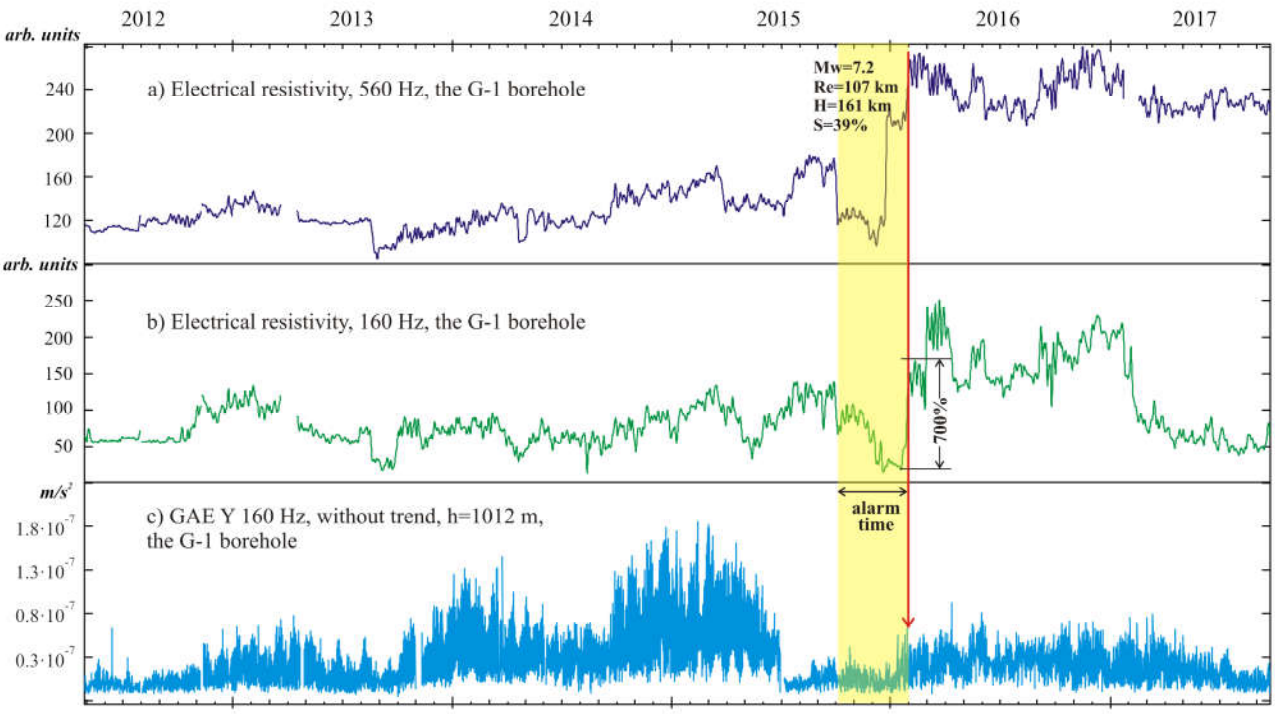

Fig. 1. *The results of geoacoustic measurements and electromagnetic measurements with underground electric antennas in the zone of the G1 borehole in time vicinity of the Zhupanovskoe earthquake:*
a) electrical resistivity variations for the 560-Hz channel (monitoring depth of ~ 500 m); b) electrical resistivity variations for the 160-Hz channel (monitoring depth of ~900 m); c) the changes in the amplitudes of GAE responses to the external electromagnetic impact for the depths of about 1000 m.

Comparison with the earthquakes focal mechanisms. We compared the data of geoacoustic and electromagnetic measurements based on the G-1 borehole with the data on the focal mechanisms earthquakes that occurred in the Avacha Bay zone (eastern Kamchatka) in the interval from March 2011 to August 2017. A comparison showed that changes in the earthquakes focal mechanisms parameters are consistent with the anomalous changes in the main parameters of geoacoustic and electromagnetic measurements at the same interval. This result indicates that the data of GAE and EMR borehole measurements in the Petropavlovsk-Kamchatskii area reflect changes in the stress-strain state of the geological medium at least for the Avacha Bay zone.

On the predict of the Zhupanovskoe earthquake. The Zhupanovskoe earthquake occurred on January 30, 2016 at the epicentral distance Re = 107 km from Petropavlovsk-Kamchatskii, at the depth of 161 km (R_h =193 km). According to the USGS NEIC data, the magnitude of the earthquake was M=7.2 and the S parameter was S = 39%. In terms of the S-parameter, this earthquake was strongest over the entire period of geoacoustic borehole measurements at Petropavlovsk-Kamchatskii geodimanical testing site (since 2000). The earthquake was accompanied by ground shaking which was felt in Petropavlovsk-Kamchatskii with intensity up to 5 (Mercalli scale) (USGS NEIC data).

The Zhupanovskoe earthquake was preceded by simultaneous abrupt changes in the GAE and the resistivity of rocks data in the G-1 borehole vicinity in July 2015 and in October 2015. We assume that these changes were associated with rapid changes in the field of mechanical stresses in the borehole zone. One of the reasons for such conclusions was a significant decrease in the amplitude of GAE responses for depths of 1000 m after pumping 22 l of water from the G1 borehole in July 2015. This indicated a sharp decrease in the water-saturation of the geological medium in the near-borehole zone. This conclusion is confirmed by a comparison of the in-situ experiments results at the G-1 borehole in June 2014 and July 2015, and by the results of measurements in the R-2 borehole located 20 km from the G-1 borehole.

These results served as the basis for the conclusion about the seismic hazard threatening the Kamchatka region where it was stated that the probability of the earthquakes with S ≥ 12% increased. The Report on earthquake warning for the Kamchatka region was submitted in October 2015 to the Kamchatka

Branch of the Russian Exert Council on Earthquake Prediction, Seismic Hazard, and Risk Assessment. The seismic hazard warning was extended up to January 22, 2016 inclusive.

Two days prior to the Zhupanovskoe earthquake, electromagnetic measurements with underground antenna detected the anomalously rapid and significant growth in the electrical resistivity in the depth interval down to 2250 m in the zone of the G-1 borehole (Fig. 1). Therefore, on January 29, 2016, the day before the earthquake, the new Report about the increased probability of earthquakes with a parameter of S≥12% was urgently submitted.

The prediction of the earthquake that occurred on January 30, 2016 has been officially recognized as proven to be completely correct in terms of all the parameters.

In the last five years (2013 - 2017), six strong Kamchatka earthquakes with magnitudes from 5.4 to 6.9 and S values from 12% to 39% that occurred at epicentral distances from 37 km to 526 from Petropavlovsk-Kamchatskii have been successfully predicted. Predictions were not made for two strong earthquakes that occurred during the specified time.

References

Gavrilov V., Bogomolov L., Morozova Yu., Storcheus A. Variations in geoacoustic emissions in a deep borehole and its correlation with seismicity // Annals of Geophysics. - October/December 2008.- Vol. 51. - № 5/6. - P. 737-753.

Gavrilov V.A., Panteleev I.A., Ryabinin G.V., Morozova Yu.V. Modulating impact of electromagnetic radiation on geoacoustic emission of rocks // Russian journal of Earth sciences. - March 2013. - Vol. 13. - № 1. - ES1002, doi: 10.2205/2013ES000527

Gavrilov V. A. Method for Continuous Monitoring of Electrical Rock Resistivity // Seismic Instruments, 2014, Vol. 50, No. 3, pp. 196–205. © Allerton Press, Inc., 2014. Original Russian Text © V.A. Gavrilov, 2013, published in Seismicheskie Pribory, 2013, vol. 49, no. 3, pp. 25–38.

Gavrilov V. A., Naumov A. V. Modulation of geoacoustic emission intensity by time-varying electric field // Russian Journal of Earth Sciences. - 2017. Vol.17. - No. 1. - : 10.2205/2017ES000591.