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Mercury hazard of earthquakes in the Baikal seismic zone

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ABSTRACT. On the west coast of Lake Baikal, we defined long-term and short-term variations in Hg concentrations of groundwater in 2017 to 2019 and from 2019 to the present, respectively; the latter variations were associated with the 2020–2021 Baikal-Khubsugul seismic reactivation of active faults. We inferred that increasing Hg concentration in groundwater was due to crustal extension with the highest Hg enrichment related to aftershocks. We argue that a Hg flux depends on the nature of fault activities and elevated Hg concentrations in sedimentary layers may designate the release of Hg_{gas} and Hg_{gw} from seismically active faults in the past 14.4 Ka.

Keywords: mercury, groundwater, earthquake, Lake Baikal, monitoring

1. Introduction

It is widely accepted that half of the mercury emissions into the atmosphere are due to volcanic activities; another half are due to the human industrial revolution. An increase in both contributions was inferred from the content of about 4 ng of mercury in 1 cubic decimeter of ice before 1850 with the later increase in mercury concentration. Concerining the volcanic contribution, it is reasonable to connect Hg concentration with the intensity of eruptions of the Earth's volcanoes. In fact, volcanic activities intensified before 1850. The strongest historical eruption of the Tambora volcano occurred in 1815. Volcanic ejects were estimated throughout the global aerosol optical depth (AOD). This parameter is characteristic of the transparency of the stratosphere for solar radiation expressed in terms of the rate of sulfate accumulation (10.5 kg/km^3). There is a good agreement between 16 eruptions and cooling events in the time interval of 1630–1850 years. Thereafter, a relative decrease in AOD indicated a decreasing intensity of volcanic activities (Crowley et al., 2008). Consequently, these data did not support the current opinion about the increase in mercury influx due to increased volcanic activity since 1850.

In addition to volcanism, there is another sufficient natural source that contributes mercury to the atmosphere. Mercury is extracted from rocks during earthquakes. For example, 1.2 days before the main shock of the Dushanbe earthquake on 29 September 1981, the concentration of gaseous mercury (Hg_{gas}) increased by 400 % at a distance of 20 km from the epicenter (Varshal et al., 1984). Therefore, a release of Hg_{gas} was considered an earthquake precursor (Cicerone et al., 2009). The recorded mercury emission showed anomalous behavior of this metal in seismogenic faults. Elevated mercury concentrations related to earthquakes were also detected in groundwater (Koval et al., 2003; 2006).

The aim of this paper is to show anomalously high Hg concentrations in groundwater, which were recorded in the Kultuk area on the west coast of Lake Baikal before and during the Baikal-Khubsugul seismic reactivation in 2020 and 2021.

2. Materials and methods

The Kultuk polygon was arranged for hydrogeochemical monitoring in 2012 within the frame of the Irkutsk State University project funded by the Federal Target Program "Scientific and scientific and pedagogical personnel of innovative Russia" for 2009–2013 to substantiate the forecast of strong earthquakes in the southern Baikal basin. Six groundwater stations were selected from 45 ones for regular measurements of concentrations for 72 chemical elements (including Hg), as well as uranium isotope ratios, by ICP-MS technique using an Agilent 7500ce mass spectrometer. The water was sampled on average every two weeks.

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During the Baikal-Khubsugul seismic reactivation in 2020 and 2021, samples were taken more frequently (every three or four days). A 2 ml water sample was passed through a 0.45 μm filter, fixed with a drop of nitric acid and used for element measurement. The activity ratio of the uranium isotopes ($^{234}U/^{238}U$) (*AR4/8*) and the activity of ^{234}U (*A4*) were measured after uranium separation on an ion exchange column. The method used for water analysis and the stations of the Kultuk area were described elsewhere (Chebykin et al., 2015; Rasskazov et al., 2015).

3. Results

Preparation of strong earthquakes was traced through variations of *AR4/8* and *A4*. Both parameters increased when active faults were affected by extension and decreased when those experienced compression (Rasskazov et al., 2020). In addition to uranium isotopes, mercury showed variations that can be used for the prediction of strong earthquakes (Chebykin et al., 2022) (Fig.). Other chemical elements and hydrochemical parameters (Eh and pH) varied in different ways. Their predictive value was uneven because causes of their temporal variations remained unclear, even if they changed before and during an earthquake. Such parameters could change during one earthquake but remained unchangeable during another one.

From a series of observations of uranium isotopes, we recorded a complete seismogeodynamic cycle from crustal compression to extension in the southern Baikal basin, suggesting the pulsating development of seismogenic deformations in the Baikal seismic zone as a time-ordered process. Due to gravitational forces, the upper crust experiences all-round compression, against which additional compressional and extensional impulses occur.

In groundwater from the Kultuk area, a range of mercury concentrations was measured from values below the detection limit (about 0.01 μg/dm³) to 0.12 μg/dm³. In a comparative analysis of the time series of Hg and ^{234}U, the behavior of gaseous and dissolved mercury in water was presented in terms of compression and extension in the crust.

4. Discussion

Based on observations during the preparation and implementation of the 1999 earthquake in the southern Baikal basin, we inferred that mercury concentration bursts in the area of the Listvyanka settlement, which 20–30 or more times exceeded background values, were associated with seismicity and that the maximum emission of mercury from faults was produced before seismic events (Koval et al., 2003; 2006). Subsequent observations in this area showed discrete mercury emissions that continued after the earthquake in the southern Baikal basin until 2004. The latest growth of Hg concentration was detected in 2006. Until 2013, mercury concentrations remained at the level of the

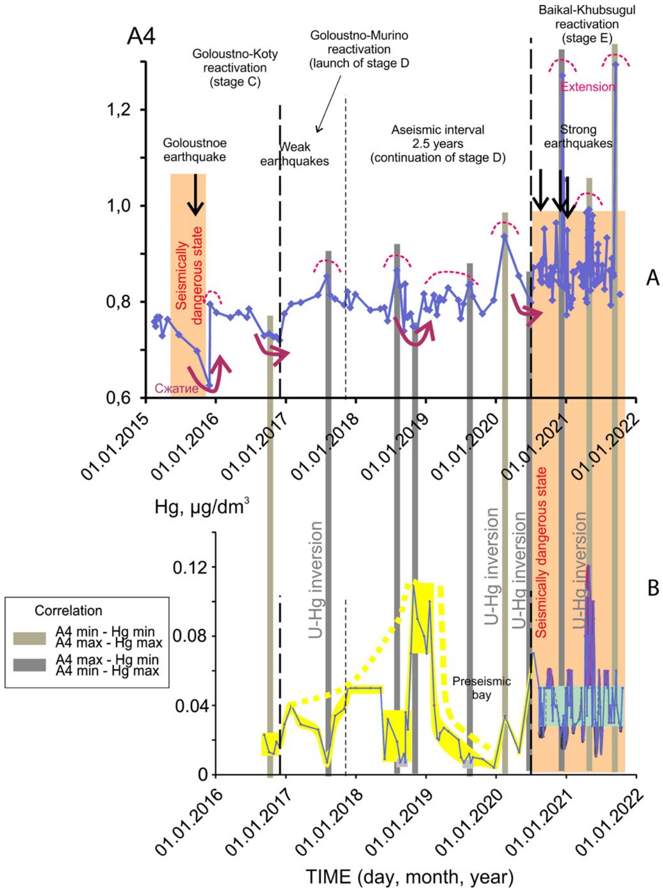

Fig. Transition from crustal compression of 2015 to extension of 2020–2021 in terms of maxima and minima of *A4* (A) and maxima and minima of Hg_{gw} (B) in the groundwater time series of station 27 (Kultuk area).

background value. During the 2008 Kultuk earthquake and later, no mercury anomalies were recorded in the Listvyanka area (Grebenshchikova et al., 2020).

Listvyanka observation series from 1997 to 2013 indicated an increase in the Hg concentrations caused by the 1999 strong earthquake, but there was no increase related to the 2008 strong earthquake in the southern Baikal basin. This selectivity was due to specific reactions to seismogenic deformations in the Angara fault of the Listvyanka area. The fault was reactivated during the 1999 seismic event in the southern Baikal basin but did not show any reactivation during the 2008 Kultuk earthquake. A series of the Hg_{gw} observations in the Kultuk area, which were obtained during the preparation and implementation of the Baikal-Khubsugul reactivation, exhibited data on the most sensitive site for recording reactivated faults in the southern Baikal basin.

Mercury concentrations were also studied in the bottom sediments from a shallow Lake Okunevoe in the Selenga delta where an increase in mercury concentrations from 20 ng/g to 40 ng/g and more was determined around 1870 and in the second half of the 20th century (Roberts et al., 2020). To match the title of the journal “Environmental Pollution”, the authors interpreted the increase in mercury concentrations as a consequence of the industrial development in Siberia and Mongolia: water pollution associated with gold mining. However, the authors did not provide specific information about gold mining activities in this area, so the proposed explanation for the increase in mercury concentrations has no grounds. Mercury, indeed, concentrates in bedrock, soils, bottom sediments, and surface waters in the industrial zone of the Irkutsk Region (on the left bank of the Angara River from the Baikal to Zima railway station) and along the northwest coast of Lake Baikal (Kitaev et al., 2008).

The Selenga delta is an area of high seismic activity. A series of strong seismic shocks occurred here in 1769 to 1779 (three events in 10 years) and in 1839 to 1885 (5 events in 46 years). A new (currently ongoing) seismic series in the area was marked by the earthquake in the central Baikal basin on 29 August 1959, although strong earthquakes (Mondy and Gobi) occurred somewhat earlier, in 1950 and 1957, respectively (Melnikova et al., 2012). Consequently, the recorded increase in the mercury concentrations in the sedimentary layers of Lake Okunevoe around 1870 and in the second half of the 20th century was likely not related to human activities but reflected the natural process of mercury entering the sediment due to the flux of Hg_{gas} and Hg_{gw} during earthquakes.

Paleoearthquakes accompanied by volcanism in the Baikal seismic zone date back to the past 14.4 Ka with shortening quasi-periods from 5600 to 3100 years or less (Rasskazov and Makarov, 1997). Similar to mercury-elevated sedimentation marking seismicity in the 19th to 21st centuries, mercury marking earlier seismic episodes can be expected.

5. Conclusions

Based on groundwater monitoring in the Kultuk area, we determined long-term increase and decrease in the Hg concentrations in 2017 to 2019 and short-term ones in 2019 to the present, which were definitely related to seismicity of active faults. We recorded increasing Hg concentration in groundwater resulted from an increase in the extension and detected the highest values during aftershocks. We indicated that a Hg flux depended on character of fault activities, and elevated Hg concentrations in sedimentary layers might designate release of Hg_{gas} and Hg_{gw} from seismically active faults in the past 14.4 Ka. Therefore, the elevated Hg concentrations in sedimentary layers of the second half of the 18th century to the present in the Selenga delta may originate from fault activities.

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Conflict of interest

Authors declare no conflict of interest.

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