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Hydrogeochemical earthquake precursor in the southern Baikal region

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Abstract

This paper presents the results of study of seismically induced variations in helium concentration in groundwater in the southern Baikal region. Unlike previous studies, data were obtained not only in Baikal deepwater but also in artesian wells in the southern Baikal region. The correlation coefficients between the data obtained at these observation stations, indicator functions, and an integrated indicator functions were calculated. They provide an objective assessment of time variations in concentrations due to changes in the stress–strain state of the Earth's crust related to earthquake preparation and hence permit one to predict the time of an earthquake.

Keywords: groundwater; concentration of dissolved helium; correlation coefficients; integrated indicator functions; earthquake focus; earthquake precursor; southern Baikal region

Introduction

It is known that major earthquakes are preceded by changes in geophysical fields, including the chemical composition of groundwater in the areas of earthquake preparation due to changes in the stress–strain state of the Earth's crust (Kissin, 1982; Kissin and Grinevsky, 1990; Rikitake, 1975; Sobolev, 1993; Vartanyan, 2000; Wyss and Habermann, 1987). One of the first studies of variations in hydrogeochemical composition due to seismicity was performed in Uzbekistan on the eve of the 1966 Tashkent earthquake (Ulomov, 1971; Ulomov and Mavashev, 1967). Subsequently, hydrogeochemical studies aimed at predicting the time of earthquake occurrence have been conducted in many seismically active regions of the Earth. The Baikal region characterized by high seismic activity was no exception.

In 2004, we began to study the helium concentration and its seismically induced variations in Lake Baikal deepwater in the southern Baikal region. At that time, it was already known that shortly before earthquakes, the chemical composition of near-surface crustal fluids in the Lake Baikal region undergoes variations (Prasolov, 1990). The purpose of our study was to identify hydrogeochemical earthquake precursors in the southern Baikal region. Based on five years of research, it was possible to establish that on the eve of earthquakes, there are noticeable peculiar variations in the content of dissolved helium. Especially informative data on these variations were obtained on the eve of the strong (M = 6.3) Kultuk earthquake of August 27, 2008 in the southern part of Lake Baikal (Semenov, 2010; Semenov and Smekalin, 2011). During three weeks before the earthquake, the following changes in helium concentration were observed. First, it significantly increased with respect to the average value and then gradually decreased until two days before the seismic event, when the helium concentration dropped below two standard deviations from the background values, which is typical of a short-term earthquake precursor (Zubkov, 1983, 1987). Finally, immediately before the shock during and after the earthquake, it reached high values again. A few hours after the main shock, on August 28, 2008, the helium concentration was again established at the background level. This is seen in Fig. 1*a,* which shows the variation of normalized helium concentration in Lake Baikal deepwater in the period from 06.15.2008 to 11.10.2008. The triangles denote the dates of the beginning of the drop in helium concentration (07.03.2008, mark 550) and the occurrence of the 2008 Kultuk earthquake with M = 6.3 (08.27.2008, mark 605). It follows from Fig. 1*a* that 45 days before the earthquake, the helium concentration in Lake Baikal deepwater first increased to 1.20 and then decreased to 0.88; i.e., in the period preceding the earthquake, the normalized

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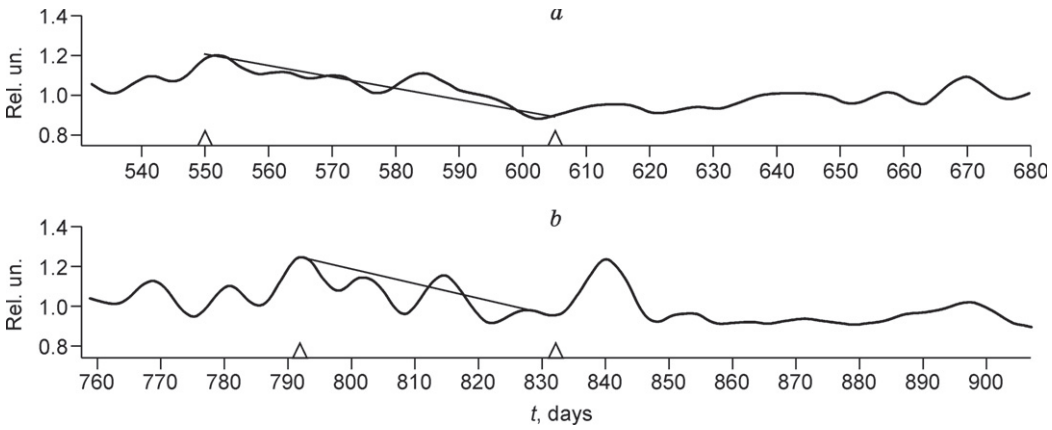

Fig. 1. Variation of normalized helium concentrations in Lake Baikal deepwater: *a,* in the period from 06.15.2008 to 11.10.2008; *b,* in the period from 01.21.2009 to 06.25.2009. The thin line shows the trend of decreasing helium concentration. Here and below, the parameter *t* is the number of days from the beginning of observation (01.01.2007) of the helium concentration. For description, see the text.

helium concentration values changed by 0.32 (32%). Minimum helium concentration in samples was found on the eve of the earthquake.

The results suggested that the long-term decrease in the helium concentrations exceeding two standard deviations from its background values, and, most important, its subsequent sudden increase on the eve of the earthquake could be considered as a short-term earthquake precursor.

However, further observations showed that a 20–30% change in helium concentration in Lake Baikal deepwater is not always an earthquake precursor. As an example, Fig. 1*b* presents the change in helium concentration in Lake Baikal deepwater in the period from 01.21.2009 to 06.25.2009. The triangles in the figure denote the dates of 03.02.2009 (mark 794) and 04.11.2009 (mark 834). During this time interval, the helium concentration readings changed from 1.25 to 0.95, i.e., by 0.3 (30%). However, any seismic activity in this and subsequent periods was not observed.

In addition, difficulties arise in detecting the minimum point of helium concentrations that would precede the seismic event. For this, we plotted the variation of helium concentration in the period preceding the Kultuk earthquake. Figure 2 shows the spectral characteristic $S(\omega)$ of the helium concentration variation in Lake Baikal deepwater obtained during an observation period of 1960 days.

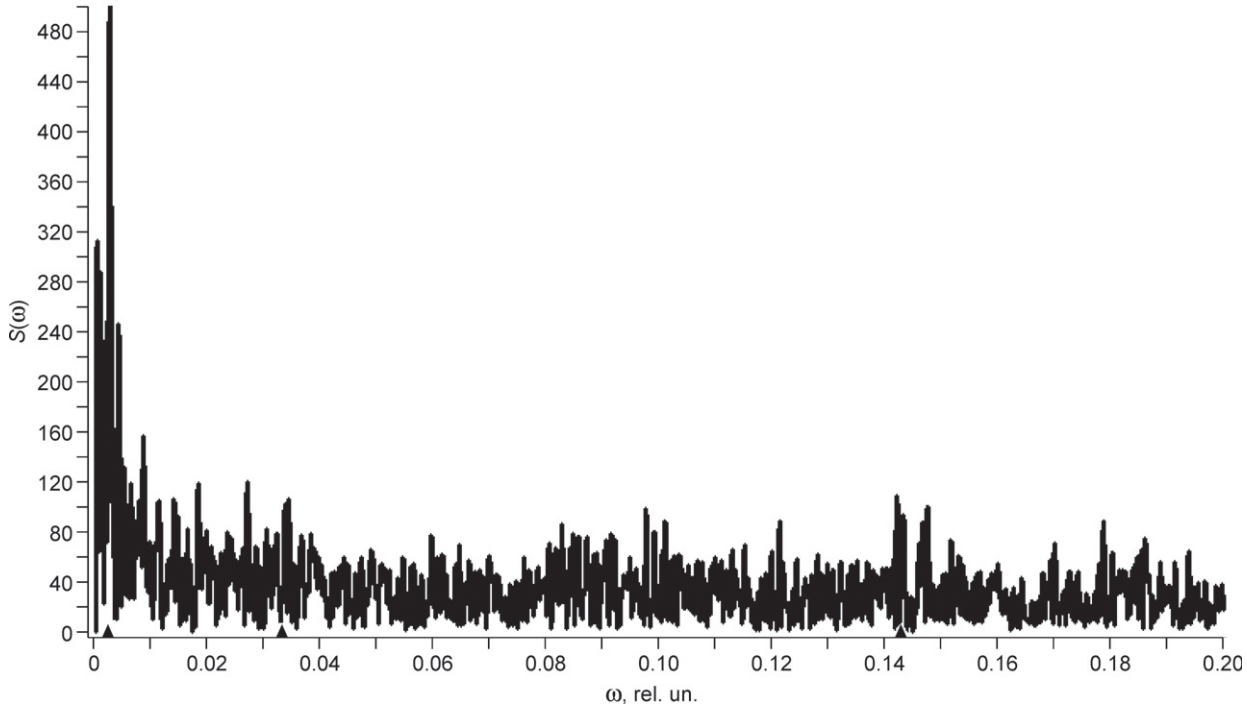

Fig. 2. Variation of helium concentrations for a period of 1960 days. The triangles from right to left mark the squares of the amplitudes of weekly, monthly, and annual cycles of change in helium concentration in Lake Baikal deepwater.