ISSN 0145-8752, Moscow University Geology Bulletin, 2018, Vol. 73, No. 6, pp. 582–587. © Allerton Press, Inc., 2018.
Original Russian Text © G.G. Akhmanov, O.M. Khlystov, M.A. Solovyeva, V.N. Efremov, O.N. Vidishcheva, A. Mazzini, A.A. Kudaev, I.A. Bulanova, A.A. Barymova, E.K. Gordeev, M.T. Delengov, E.D. Egoshina, Ya.V. Sorokoumova, P.O. Ponimaskin, 2018, published in Vestnik Moskovskogo Universiteta, Seriya 4: Geologiya, 2018, No. 5, pp. 111–116.

Newly Discovered Hydrate-Bearing Structure in Lake Baikal[1,2]

G. G. Akhmanov[a, *], O. M. Khlystov[b], M. A. Solovyeva[c], V. N. Efremov[c], O. N. Vidishcheva[a], A. Mazzini[d], A. A. Kudaev[a], I. A. Bulanova[a], A. A. Barymova[e], E. K. Gordeev[a], M. T. Delengov[a], E. D. Egoshina[a], Ya. V. Sorokoumova[a], and P. O. Ponimaskin[f]

[a] *Department of Geology, Lomonosov Moscow State University, Moscow, 119991 Russia*
[b] *Limnological Institute, Russian Academy of Sciences, Irkutsk, 664033 Russia*
[c] *OOO "Seismic Data Analisys Center of Moscow State University", Moscow, 119992 Russia*
[d] *Centre for Earth Evolution and Dynamics (CEED), University of Oslo, Oslo, @ Norway*
[e] *OOO "Marine Research Center of Moscow State University", Moscow, 119992 Russia*
[f] *LLC "SPLIT", Moscow, 121205 Russia*
**e-mail: akhmanov@geol.msu.ru*

Received July 30, 2018

Abstract—A new deep-water hydrate-bearing structure, named after Moscow State University (MSU), has been discovered on July 29, 2018 during the geological-geophysical research of the Class@Baikal project. The structure lies on a fault scarp at the bottom of the central basin of Lake Baikal at a water depth of 1380 m (coordinates N 52°52′/E 107°07′). The "MSU" structure is sub-isometric in planar view, 500 m in diameter, and reveals a multi-summit morphology. Results of initial investigations show an active fluid seepage and gas-hydrate formation within the discovered structure. Laboratory analyses of the sampled gases indicate a significant concentration of thermogenic hydrocarbons.

Keywords: gas hydrates, hydrocarbon gases, seafloor seepages, bottom sampling, seismic profiling, Lake Baikal

DOI: 10.3103/S0145875218060029

INTRODUCTION

On July 29, 2018 during a joint geological and geophysical expedition of the Department of Geology (Lomonosov Moscow State University) and the Limnological Institute of Siberian Branch of Russian Academy of Sciences onboard the R.V *G.Yu. Vereschagin* a hydrate-bearing structure was discovered in the central basin of Lake Baikal. The discovery was conducted in the framework of the Class@Baikal (Floating University) project. During the expedition the morphology and the inner structure of this positive feature were studied, bottom sediment samples were collected, and sediment pore gas was sampled from the cores. The structure was named "MSU" (after the Moscow State University).

Baikal is the largest and oldest fresh-water basin on the planet and the only lake where natural accumulations of gas hydrates have been discovered. Gas hydrates (clathrates) are ice-like crystals consisting of hydrocarbon gases trapped inside cages of frozen water molecules. They are stable at low temperatures and high pressure conditions when constant gas influx occurs.

Theoretical studies and indirect evidence suggesting the presence of hydrates in the deep Baikal basins have been the topic of discussions since the 80's (Golmshtok et al., 1997; Golubev, 1997; Hutchinson et al., 1991; Efremova et al., 1980). The first evidence of the presence of gas hydrates in Baikal sediments was provided in 1997 during the BDP-97 project when clathrates of biogenic methane were collected at a depth at 121 and 161 mblf (Kuz'min et al., 1998). Then, shallow gas hydrate accumulations, observed as lenses and layers, were discovered in 2000 at the "Malenkiy" structure in the southern basin of the lake (Klerkx et al., 2003). Between 2000 and 2017 national and international projects discovered several hydrate-bearing structures in the southern and central basins of Lake Baikal at depths between 400 and 1500 m in slope and abyssal plane settings (Khlystov et al., 2013, 2017). To date, most of the known structures are located at a shallow depth. MSU is the fifth structure discovered at depth >1300 m. The goal of this article is to provide (1) the first description of the "MSU" morphology and

[1] The article was translated by the authors.

[2] The Class@Baikal-2018 cruise was funded by E.A. Bakay, by the Department of Geology of Lomonosov Moscow State University, by OOO "Seismic Data Analisys Center of Moscow State University", OOO "Marine Research Center of Moscow State University", through the project no. 0345-2016-0007 of LIN SB RAS and the grant of the Russian Foundation for Basic Research (project no. 18-35-00363).

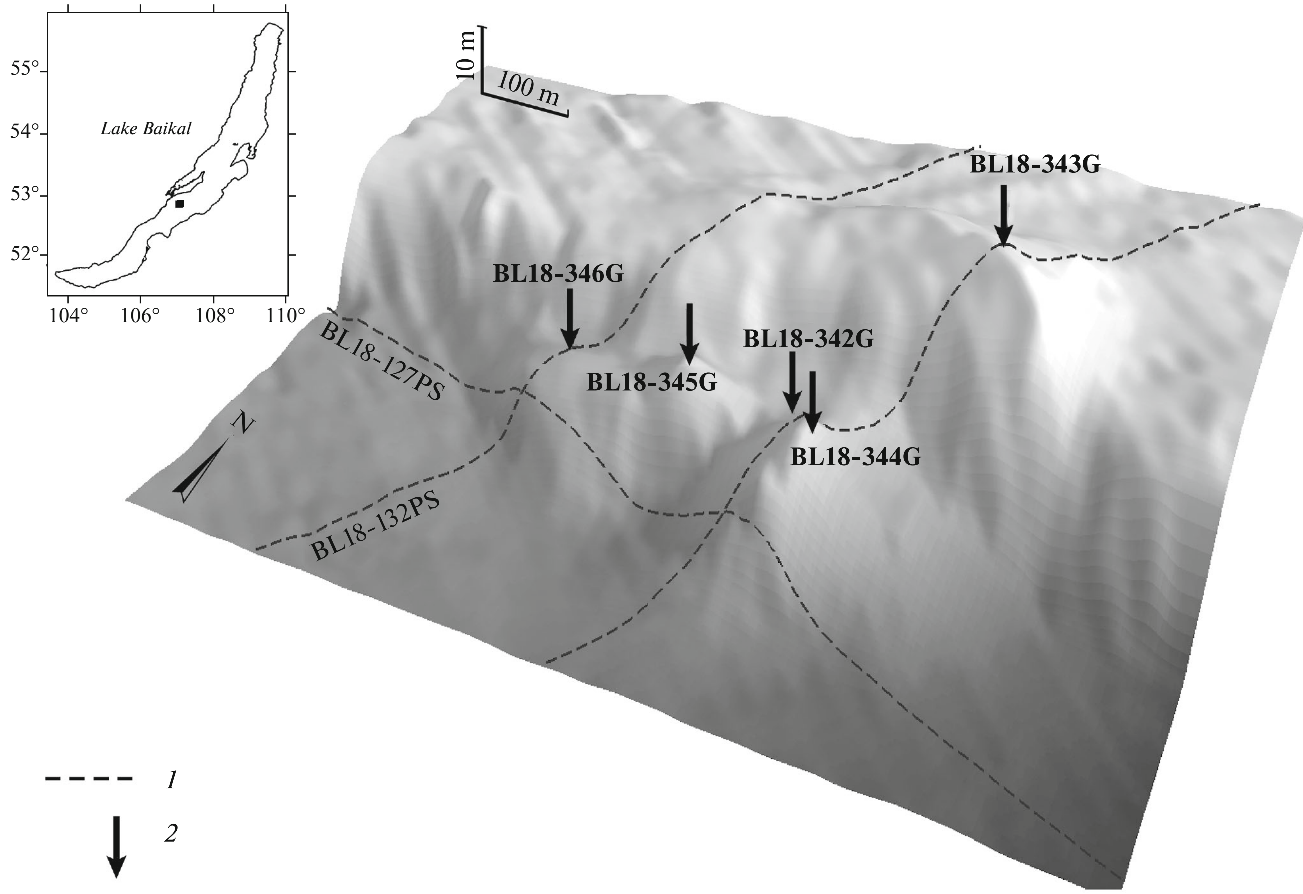

Fig. 1. 3D view of the bottom relief in the area of the "MSU" hydrate-bearing structure with location of seismic profiles (1) and sampling sites (2). Inset map with location of the study area.

its inner structure, (2) the evidences confirming the presence of gas hydrates, (3) the first results of geochemical analyses of the gas extracted from the sediments, and (4) insights about the local tectonic setting and genesis of the structure.

LOCATION AND TECTONIC SETTING

The "MSU" under-water hydrate-bearing structure was found on the middle of the central Lake Baikal basin, at the depth 1380 mblf (at coordinates N52°52′/E107°07′), opposite the Olkhon Gate strait, at a distance of 31 km from the NW coast and 50 km from the SE coast (Fig. 1). The "MSU" is located along a large fault that represents one of the main tectonic features of the central Baikal basin. The fault extents to the SW from the Ukhan cape (Olkhon Island) toward the base of the delta front of Selenga River and crosses the basin diagonally, subdividing it into two almost equal parts. The fault is well expressed in bottom relief as an elongated scarp which is almost straight in planar view reaching its highest elevation near Olkhon Island. The scarp gradually flattens towards the SW. Towards the NE from the "MSU" structure, the fault hosts other hydrocarbon seeping and gas hydrate-bearing sites among those the Novosibirsk mud volcano (20 km from "MSU") and the Saint-Petersburg Seep (4.5 km) (Cuylaerts et al., 2012; Khlystov et al., 2013).

MORPHOLOGY AND INNER STRUCTURE

During the Class@Baikal-2018 expedition three seismic profiles were collected across the "MSU" structure (profile lines BL18-127PS, BL18-132PS and BL18-133PS (Fig. 1)) using a speed vessel of 3.5 knots (7 km/h). The multiple-electrode spark source ("sparker") was used providing a central frequency of the emitted signal of 400 Hz and a 1000 J energy. The recording was carried out with a single-channel streamer (20 m long) equipped with 40 piezoelectric hydrophones. The seismic data were processed onboard using the RadExPro software package developed by the LLC "Deco Geophysical SC". In addition, the "Konengsberg EM710S" multi-beam survey across the structure was carried out by researchers from the Irkutsk National Research Technical University (team leader – Dr. A.G. Chensky) (Fig. 1). The

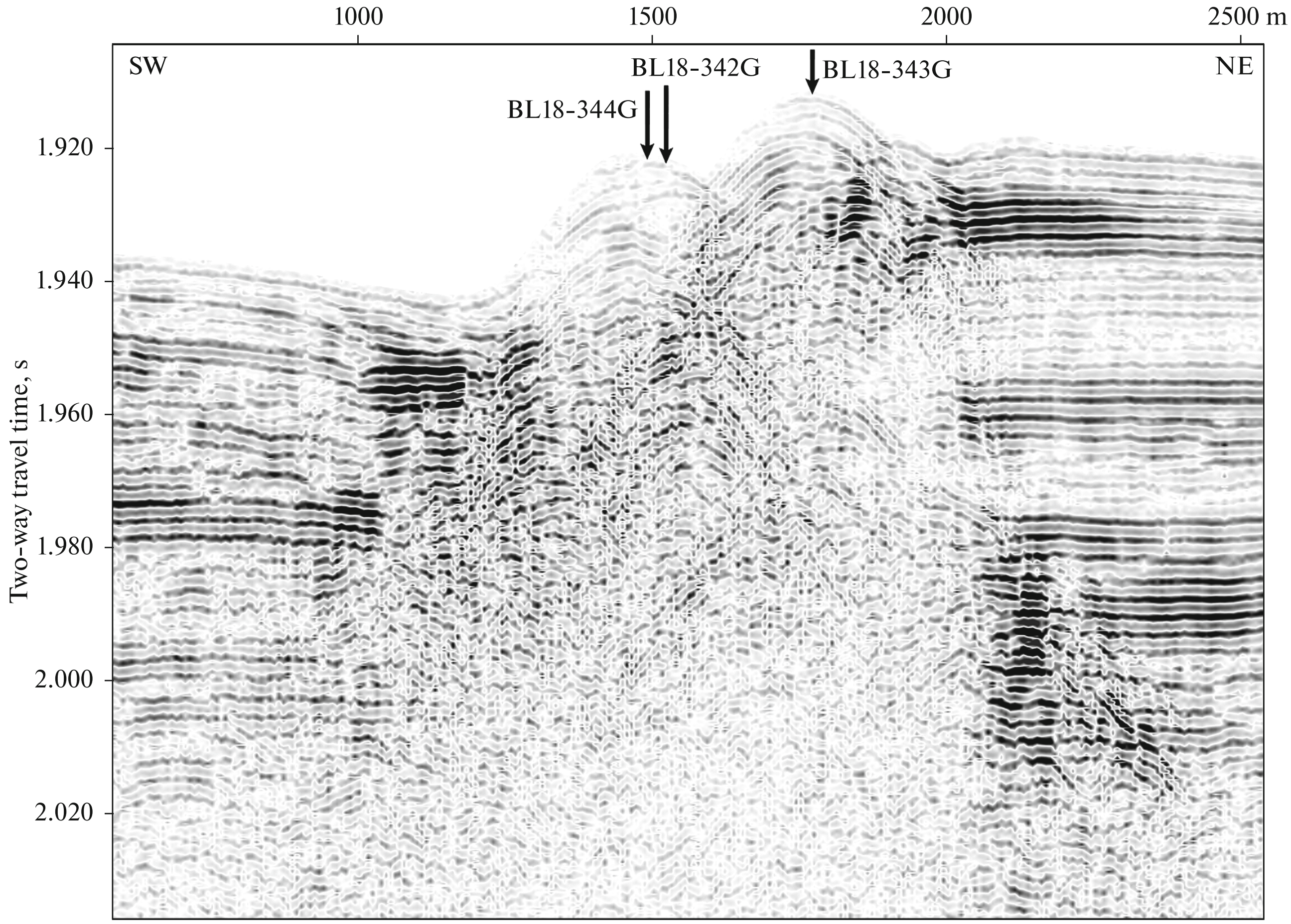

Fig. 2. Fragment of seismic profile BL18-133PS showing "bright spot" acoustic anomalies around the "MSU" structure. Bottom sampling sites arrowed. For location of the profile refer to Fig. 1.

obtained data allowed characterizing the morphology and the inner structure of "MSU" seepage site.

The structure is almost isometric in planar view with a 500 m diameter base. Four distinct pinnacles (5–10 m high) are distributed throughout (Fig. 1). One of them is formed on a upthrown wall of the fault whereas the others three are located on the downthrown wall along the base of the scarp. At the site the total height of the scarp is about 20 m. Seismic profiles through the edifice reveal an inner zone with chaotic seismic wave pattern ("acoustic turbidity"). This chaotic pattern increases in size with depth reaching almost 1000 m in diameter at the base of the seismic record (Figs. 2–4). On the flanks of the structure a few patches with high-amplitude reflectors with reversed polarity are imaged (Fig. 2). These "bright spot" acoustic anomalies are typical features observed near focused seepage sites, implying high gas saturation deposits. Details of the inner structure of "MSU" are masked by the chaotic acoustic wave pattern formed due to gas saturation. However, a vertical transport of solid material (e.g. silty clays from deeper strata) along a feeder channel, as commonly occurring at mud volcanoes, cannot be excluded. The presence of a satellite-structure observed on seismic profiles on the NNE flank of the main structure (Fig. 3) also supports a scenario of vertical sediment migration. This side structure, also characterized by chaotic seismic wave pattern, is not exposed at the lake floor and remains buried by almost 100 m of recent sediments. The horizontal sedimentary layers surrounding the "MSU" are pulled upwards approaching the flanks. We interpret this as further evidence of upward fluid and solid migration along a vertical conduit. About 800 m to the west of "MSU", on the seismic line BL18-127PS, a structure piercing the normal sedimentary section can be clearly observed (Fig. 4), supporting the presence of diapiric or mud volcanic activity. This structure is imaged only with one single profile and requires additional future studies.

GAS AND GAS-HYDRATE SATURATION

Five bottom sampling station were selected within the "MSU" structure (Fig. 1). The recoveries have demonstrated anomalously high gas saturation of bot-

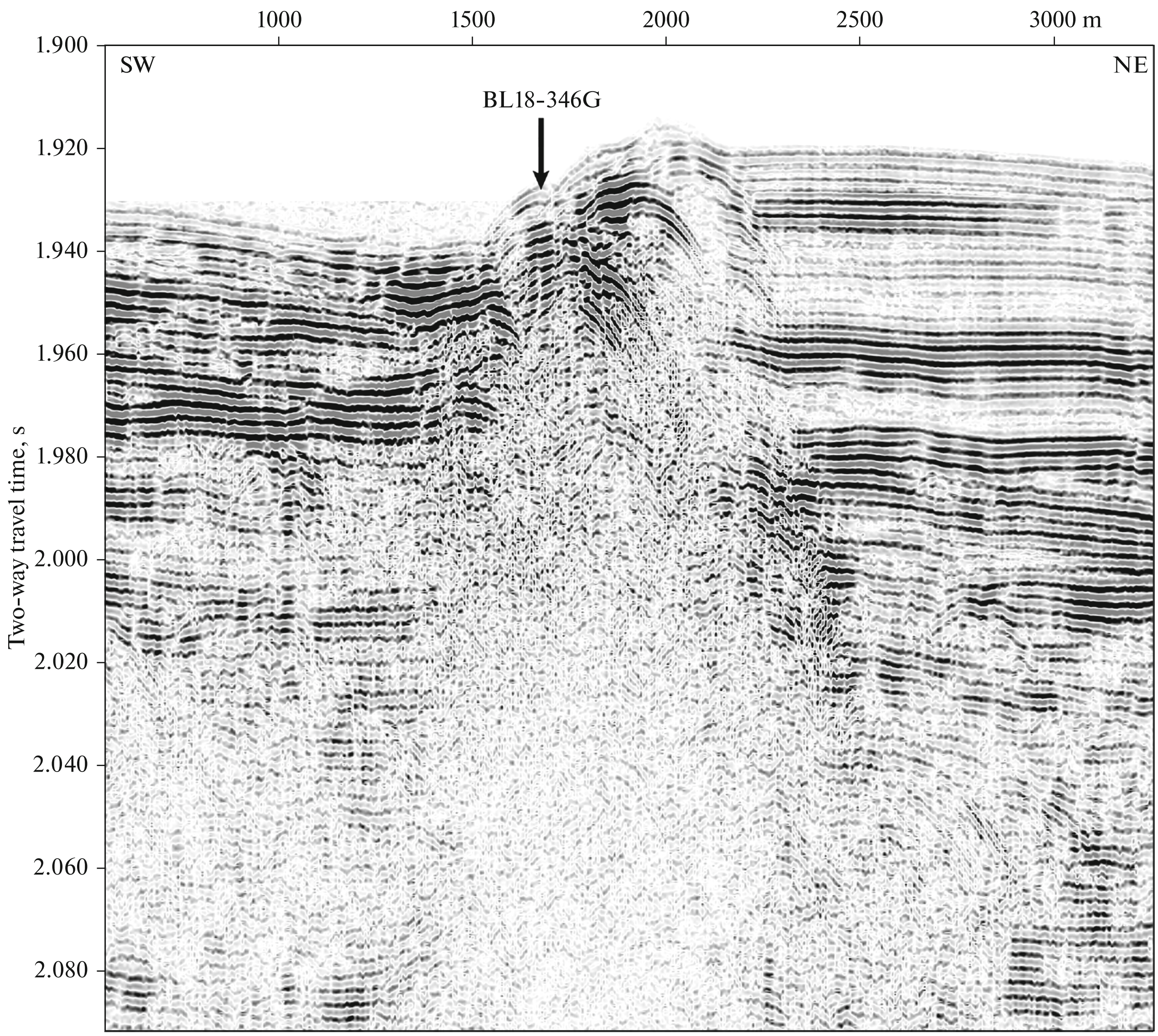

Fig. 3. Fragment of seismic profile BL18-132PS imaging the main "MSU" structure and the adjacent satellite-structure. Bottom sampling site arrowed. For location of the profile refer to Fig. 1.

tom deposits composing the whole structure and especially its western part. The sampling was conducted using a 5 m long, 500 kg gravity core with inner diameter of 100 mm equipped with wide-angle under-water video-camera (48 frames per second; 2.7k resolution) and LED light torch.

Samples of bottom sediments, pore waters, and gases were collected from all the four cored summits of the structure and from a small depression between summits and scarp base. All the sediments recovered showed anomalously high gas saturation in particular for the stations collected in its western part. Typical gas-escape structures were seen in the split core sections together with large fluid migration channels. The oxidized Upper Holocene diatomic ooze layer, typically thick throughout Lake Baikal, was either absent or extremely thin (less than 1 cm) in all the cores recovered at the "MSU". This represent additional evidence for ongoing fluid seepage. The sampled sections consisted of homogenous, structureless, and largely water-saturated very well sorted clays with faint hydrotrolite patches. These deposits are similar to the very fine-grained pelites locally erupted at dormant mud volcanoes.

Core BL18-346G was obtained from the westernmost summit of the structure (Fig. 1) and the recovered section contained gas hydrates. The core consisted mostly of fine clayey sediments with hydrotrolite and with a few very thin silty and fine sandy laminas.

During the corer retrieval, at a depth of about 380 m below lake surface, the ship echosounder imaged a clear gas plume originating from the sampler. This phenomenon typically occurs during the retrieval of

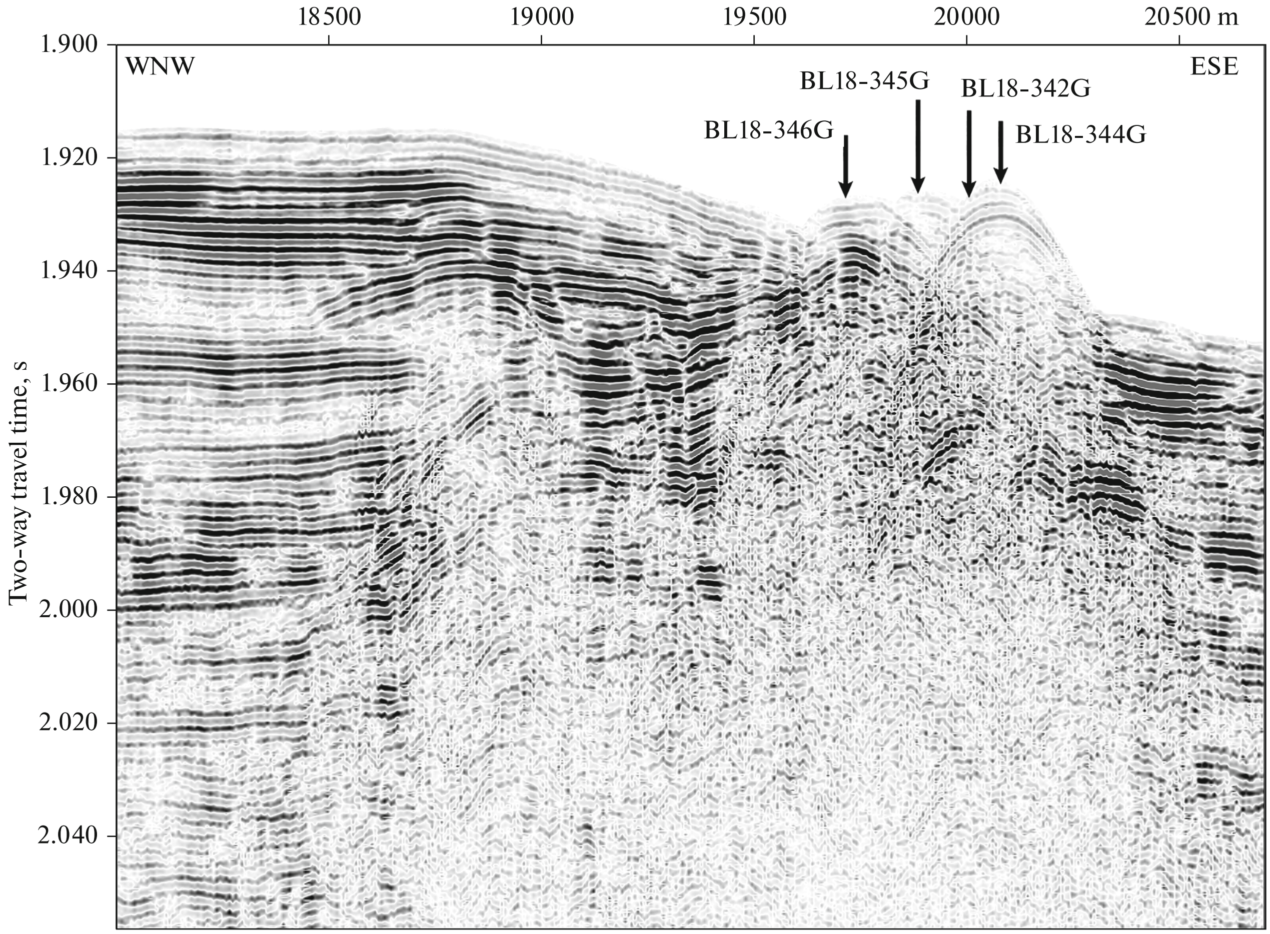

Fig. 4. Fragment of the seismic profile BL18-127PS showing vertical piercing in the WNW of the "MSU". Bottom sampling sites arrowed. For location of the profile refer to Fig. 1.

corers containing gas hydrates. Once the gas hydrates reach a water depth lower that 380 m (i.e. above the upper boundary of gas hydrate stability zone on Baikal) they start vigorously dissociating in the water column, producing large bubbles. Intensive gas bubbling was registered also by the video-camera installed outside the corer. Once the core was taken onboard and the recovered sections were split, visible crystals of gas hydrates were not observed. However, for several minutes after the core splitting, the lowermost sections produced the hissing noise that is very typical for ongoing dissociation of micro-crystals of gas hydrates. The sediments appeared very "dry" and with typical "roquefort"-structure and became water-saturated and mousse-like within a few minutes. All the above evidences indicate that the sediments recovered at BL18-346G station were gas hydrate bearing with clathrates present as micro-crystals. However, the presence of prior larger hydrate deposits (in the form of lenses, veins, lamina, etc.) in the sampled section cannot be excluded.

Gases sampled from the recovered sediments were analyzed by G.A. Batalin and B.I. Gareev in the Laboratory of Isotope and Element Analysis, Institute of Geology and Petroleum Technologies of Kazan Federal University, using the ThermoFisher Scientific Delta V Plus isotope mass-spectrometer with the ISQ-TRACE 1310 gas chromatography add-on. The measured methane concertation in the deposits of the "MSU" structure is as high as 126 104 μL/L, exceeding of 9.5 times the typical background values (up to 13 350 μL/L (Vidishcheva et al., 2017)). Ethane (up to 250 μL/L), propane (up to 2.22 μL/L), butane (up to 0.57 μL/L), pentane and iso-pentane were also detected in the samples. Carbon isotopic analyses ($\delta^{13}C(CH_4)$ ranging from –63.6 to –66.8‰; $\delta^{13}C(C_2H_6)$ from –28.7 to –31.1‰; $\delta^{13}C(C_3H_8)$ from –21.9 to –24.5‰; $\delta^{13}C(C_4H_{10})$ from –23.9 to –35.0‰) suggest that a significant portion of the discharged gases has a thermogenic origin.

CONCLUSIONS

The discovery of the "MSU" hydrate-bearing structure in Lake Baikal represents a further step to investigate the modern geological processes characterizing this unique locality. Preliminary results indicate the presence of active fluid discharge and accumulation of hydrates within the structure. The sampled hydrocarbon gases indicate that a portion of the seeping gases has a thermogenic origin and therefore originating from the deeper sited sedimentary series of Baikal basin. The data provide converging evidence to suggest that the "MSU" structure could represent an under-water mud volcano. The formation of the "MSU" structure, its modern activity and hydrate saturation, represent subaqueous manifestation of petroleum system of young, syn-rift sedimentary basin with active neo-tectonics.

REFERENCES

Cuylaerts, M., Naudts, L., Casier, R., et al., Distribution and morphology of mud volcanoes and other fluid flow-related lake-bed structures in Lake Baikal, Russia, *Geo-Marine Lett.*, 2012, vol. 32, no. 5, pp. 383–394.

Efremova, A.G., Andreeva, M.V., and Levshenko, T.V., et al., On gases in the Baikal sediments, *Gaz. Prom. Cep. Geol. Razved. Gaz. Gazokondens. Mectopozhd.*, 1980, no. 2, pp. 15–27.

Golmshtok, A.Ya., Duchkov, A.D., and Hutchincon, D.P., et al., Heat flow estimates in Lake Baikal according to seismic data on the lower boundary of the gas hydrate layer, *Geol. Geofiz.*, 1997, vol. 38, no. 10, pp. 1677–1691.

Golubev, V.A., Geothermal forecast of the depth of lower boundary of gas hydrate layer in Baikal sediments, *Dokl. Ross. Akad. Nauk*, 1997, vol. 352, no. 5, pp. 652–665.

Hutchinson, D.R., Golmshtok, A.J., Scholz, C.A., et al., Bottom simulating reflector in Lake Baikal, *EOS*, 1991, vol. 72, pp. 307–308.

Khlystov, O., De Batist, M., Hachikubo, A., et al., Gas hydrate of Lake Baikal: discovery and varieties, *J. Asian Earth Sci.*, 2013, vol. 62, no. 1, pp. 162–166.

Khlystov, O.M., Minami, H., Hachikubo, A., et al., Distribution of hydrate bearing structures in the Lake Baikal. Map no.185, in *Ekologicheskii atlas Baikalskogo regiona* (Ecological Atlas of the Baikal Region), 2017. http://atlas.isc.irk.ru. Cited June 29, 2018.

Klerkx, J., Zemskaya, T. I., Matveeva, T. V., et al., Methane hydrates in Deep Bottom Sediments of Lake Baikal, *Dokl. Earth Sci.*, 2003, vol. 393, no. 9, pp. 1342–1346.

Kuz'min, M.I., Kalmychkov, G.V., and Geletiy, V.A., et al., The first find of gas-hydrates in the sedimentary rocks of Lake Baikal, *Dokl. Earth Sci.*, 1998, vol. 362, no. 7, pp. 1029–1031.

Vidishcheva, O.N., Kislitsyna, E.V., Akhmanov, G.G., et al., Mud volcanoes, seeps, and gas hydrates in Lake Baikal: Geochemical characteristics of hydrocarbon gases, *Tr. VI Mezhd. nauch.-prakt. konf. "Morskie issledovaniya i obrazovanie (MARESEDU-2017)"* (Proc. VI Int. Sci.–Pract. Conf. "Marine Researches and Education (MARESEDU-2017)"), Tver: OOO PoliPRESS, 2017, pp. 211–215.