



Gas hydrate of Lake Baikal: Discovery and varieties

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ABSTRACT

This paper summarizes the results of recent gas-hydrate studies in Lake Baikal, the only fresh-water lake in the world containing gas hydrates in its sedimentary infill. We provide a historical overview of the different investigations and discoveries and highlight some recent breakthroughs in our understanding of the Baikal hydrate system. So far, 21 sites of gas hydrate occurrence have been discovered. Gas hydrates are of structures I and II, which are of thermogenic, microbial, and mixed origin. At the 15 sites, gas hydrates were found in mud volcanoes, and the rest six – near gas discharges. Additionally, depending on type of discharge and gas hydrate structure, they were visually different. Investigations using MIR submersibles allowed finding of gas hydrates at the bottom surface of Lake Baikal at the three sites.

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1. Introduction

Lake Baikal is the largest and the oldest fresh-water reservoir on our planet. The lake basin is located in Eastern Siberia on the border between the Siberian Craton and the Central Asian Fold Belt, and it forms the central part of the large, intracontinental Baikal Rift Zone. The lake is more than 600 km long, 80 km wide (in the widest place) and its water depth amounts up to 1637 m at deepest point. With a total basement subsidence of ~10 km, more than 3/4 of this huge depression are filled up with several kilometers of sediments. Their total volume is estimated to be in the order of 75,000 km³ (Logachev, 2003). The age of the oldest sedimentary deposits in the Central and the Southern Basins of the lake surpasses 25 Ma (Oligocene), and there are some data testifying that the sediments in the Central Basin, near the delta of Selenga River, started to accumulate as far back as in Palaeogene (ca. 60 Ma) (Nikolayev, 1998). Geophysical data indeed reveal a maximum thickness of the sedimentary infill (about 9 km) near the Selenga delta (Scholz and Hutchinson, 2000). Elsewhere in the Southern and the Central Basin, the sedimentary thickness does not exceed 7.5 km, while in the north-east of the Northern Basin it amounts to 4.4 km (Hutchinson et al., 1991). Such a long sedimentation history and such large amounts of sediments containing a considerable amount

of organic matter favoured the formation and accumulation of different types of hydrocarbons. These oils and natural gases migrate in free or dissolved state towards the lake floor where high pressures (corresponding with the large water depth) and low temperatures of the near-bottom waters (3.5 °C approximately) are propitious for the formation of gas hydrates.

2. History and results of study on Baikal gas hydrates

The history of gas hydrate investigations in Baikal can be subdivided in four stages with key moments in 1997, 2002, and 2008.

Before 1997, the possible presence of gas hydrates was evoked in a few reports. The very first reference to hydrates in Baikal was made in a VNIIGAZ study, indicating a “site with possible gas hydrate accumulation” in sediments of Lake Baikal (Yefremova et al., 1980). The discovery of the first Bottom-Simulating Reflector (BSR) during a multi-channel seismic survey in 1989 (Hutchinson et al., 1991) was the first real indirect geophysical indication for the presence of hydrates. Later, a predictive map depicting the base of the hydrate stability zone in Lake Baikal was published, which was based on geothermal modeling and heat-flow measurements (Golubev, 1997). A more precise map of the base of gas-hydrate layer corresponding to the mapped BSR recognized on multi-channel seismic data from 1992 was published by Golmshtok et al. (1997). Interestingly, the BSR was only observed in the Southern and Central Basin and was not always parallel to the lake floor. These first estimates of the depth and extent of the gas hydrate

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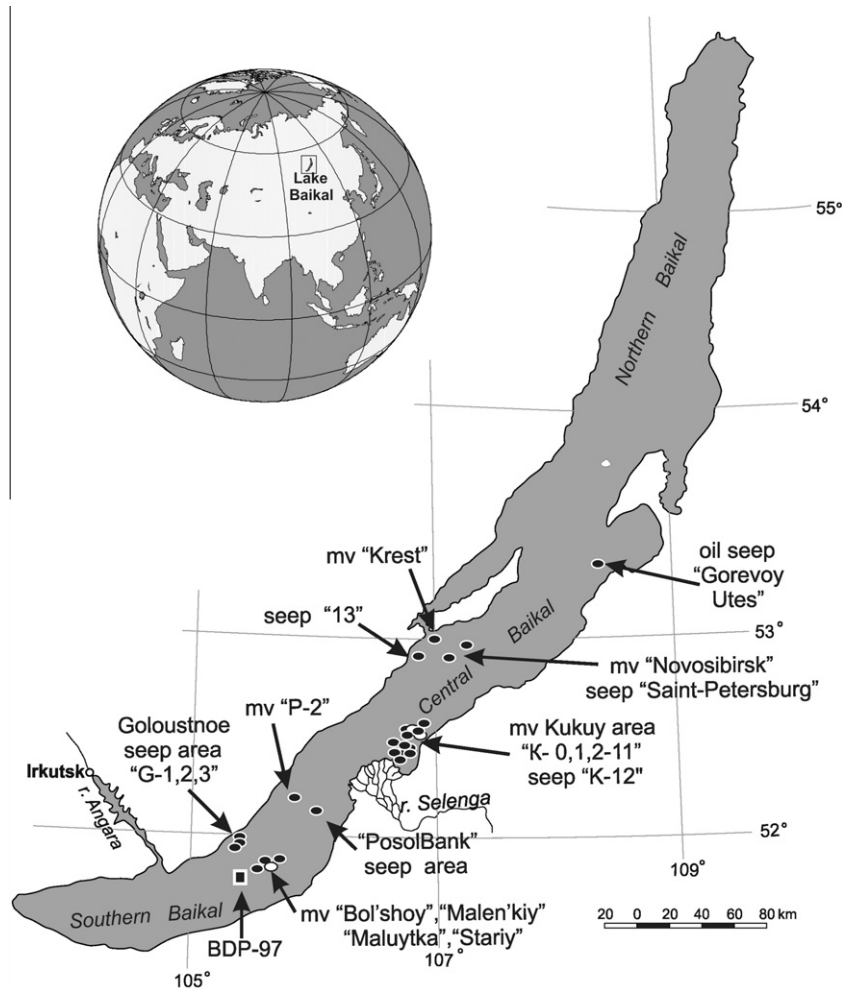


Fig. 1. Geographical distribution of the sites where gas hydrates have been studied in Lake Baikal. The square indicates the location of the BDP-97 borehole; circles show mud volcanoes (mv) or the sites of underwater discharge of gas or gas-saturated fluids (seep).

stability zone were used to make the first assessments of the resource potential of the Baikal hydrate reservoir yielding estimates varying from 8.8×10^{11} to $9 \times 10^{12} \text{ m}^3$ (of gas at STP conditions) (Golubev, 2000; Vanneste et al., 2001). A key discovery was made in 1997 when the first and only samples of deep gas hydrates were obtained during the International Baikal Drilling Project (BDP). While drilling the borehole BDP-97 from the ice, core samples taken from sub-bottom depths of 121 and 161 m contained frozen sand-silt material that released abundant amounts of gas while heated. Laboratory analyses of the sediment samples showed that the cement was, in fact, gas hydrate of cubic structure I (CS-I), composed mainly of methane of biogenic origin ($\text{CH}_4 \times 6\text{H}_2\text{O}$; $\delta^{13}\text{C}$ between -58 and -68‰) (Kuz'min et al., 1998).

From 1997 onwards, gas-hydrate research on Lake Baikal began to focus on hydrate occurrences at or near the lake bottom. Between 1997 and 2002, different geophysical studies were carried out in various regions of the Southern and the Central Basins (De Batist et al., 2002), aimed at mapping and characterizing a series of lake-floor structures related to the discharge of gas and/or gas-saturated water. Earlier, Ginsburg and Solovyev (1994) had established that the main deposits of near-bottom submarine gas hydrates in oceans and seas occur in association with such seep structures. The new seismic, side-scan sonar and bathymetric data revealed four such seep structures along one of the main faults within the Southern Basin. On the side-scan sonar mosaics, these structures ranged from 200 to 2000 m in diameter and up to

60 m in height, had practically isometric contours in the center of which one or more culminations could be seen; the echograms outlined positive topographic structures. The seismic data showed below these structures "muted" (transparent) acoustic signals and an irregular BSR behavior. Owing to their size and morphological characteristics they were named "Bol'shoy" (Big), "Malen'kiy" (Small), "Malyutka" (Baby) and "Stariy" (Old) (Van Rensbergen et al., 2002; De Batist et al., 2002). One year later, in 2000, coring of "Malen'kiy" structure allowed for the first time the recovery of surface (near-bottom) gas hydrates in the form of lenses, strata, and massive formations within clayey sediments (Klerkx et al., 2003; Matveeva et al., 2003). Hydrate and gas analyses demonstrated that these were CS-I methane hydrates of biogenic origin.

From 2002 to 2008, geological and geophysical studies focused further on the search for new sites of hydrocarbon discharge with gas hydrate occurrences. Geophysical data, acquired in 2002 in the Central Basin, revealed four new structures in Kukuy Canyon, which were named "K-1", "K-2", "K-3" and "K-4", and two – in the vicinity of Olkhon Island, which were named "Saint-Petersburg" and "Novosibirsk" (Klerkx et al., 2006) (Fig. 1). In 2003 and 2004, hydrates were taken from the "Bol'shoy" and "K-2" structures. Similar to the observations at the "Malen'kiy" structure, the hydrate-bearing sediment in the "Bol'shoy" and "K-2" structures consisted of a mud breccia, which was clearly different from the typical alternating diatomaceous and clayey layers normally found in the surface sediments of Lake Baikal. Such type of breccia

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