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GEOGRAPHY

Computer-Based Bathymetric Map of Lake Baikal

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The history of deep-water plumbing of the depth in Lake Baikal started in 1789 when Nikita Karelin, Sergei Smetanin, and Egor Kopylov, employees of the Kolyvano–Voskresensk plants, carried out two traverses with 28 measurements between the head of the Angara River and the mouth the Selenga River. One of such measurements yielded a maximum depth of 1238 m. Thus, Lake Baikal was immediately recognized as one of the world's deepest lakes. Later, according to oceanographic historians, the British captain Fips accidentally discovered an even deeper area when thermometers used for the measurement of water temperature in this lake reached a depth of about 1250 m [1].

In 1902–1908, the hydrographic expedition supervised by K.F. Drizhenko published the *Pilot Chart of Lake Baikal* and *Atlas of Lake Baikal* in which depths were shown in detail for the coastal area. A new stage in the study of deep zones of Baikal has been underway since 1925 thanks to the organization of the permanent Baikal Expedition of the USSR Academy of Sciences under the supervision of G.Yu. Vereshchagin (later on, the expedition was renamed the Baikal Limnological Station; at present, it is known as the Institute of Limnology). The underwater Akademicheskii Ridge was discovered in 1932. In 1931, the maximum depth of Lake Baikal was estimated at 1741 m. However, this depth was not confirmed. New bathymetric maps of Lake Baikal (scales 1 : 300 000 and 1 : 500 000) were demonstrated at the International Limnological Congress in Rome in 1934.

In 1962, A.A. Rogozin and B.F. Lut compiled the Bathymetric Map of Lake Baikal (scale 1 : 300 000). Based on this map, the Central Administration for Navigation and Oceanography, Ministry of Defense, USSR (GUNIO MO) published *Lake Baikal* maps in 1973 and 1974. In 1979–1987, the Navy Hydrographic Survey of the USSR carried out detailed echosounding for the entire Baikal (traverses had a spacing of 100 and 250 m in coastal areas and 1.5–2 km in abyssal areas) and published the four-sheet map *Lake Baikal* in 1992 [2]. This map had the following shortcoming: the bottom relief was mainly represented by isobaths (with a step of 100 m in the general case and 500 m for depths exceeding 1 km); i. e., principal information for depths exceeding 1000 m was practically lacking.

According to the INTAS Project 99-1669 *A New Bathymetric Computer Map of Lake Baikal* [3], which was designed to compile a more complete digital database of depths, we processed materials of the Baikal bottom relief survey carried out by the Navy Hydrographic Survey during expeditions in 1979–1987. We also included data from other expeditions treated by the uniform procedure [4]. The new database made it possible to compile various computer-based maps of Lake Baikal, which are discussed in the present paper.

EQUIPMENT AND METHODS

Along with navigation equipment, hydrographic echosounders with net errors of depth measurement less than 0.25% were used. Corrections due to the Baikal water temperature (4.5%) were taken into account [4].

Databases (depth and coordinates) are presented in the WGS 1984 system. Depth values (in meters) are rounded off to the nearest integer. The Mercator 53°00′ N projection (with a true scale for all the maps) and the EarthVision® software (Version 5.1) were used for mapping. The bathymetric map was written on the CD.

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Table 1. Maximum depths, volumes, surface areas, and average depths of Lake Baikal and its separate basins

Basin	Maximum depth, m			Coordinates only for [**3**]		Volume, km^3		Surface area, km^2		Average depth, m	
	[3]	[5]	[6]	northern latitude	eastern longitude	[3]	[5]	[3]	[5]	[3]	[5]
Total	1642	1620	1637	–	–	23615.4	23015	31722	31471	744.4	731
Northern	904	889	903	54°20′43″	108°42′53″	8192.1	7844	13690	13621	598.4	576
Central	1642	1620	1637	53°14′59″	108°05′11″	9080.6	8943	10600	10469	856.7	853
Southern	1461	1423	1446	51°46′32″	105°22′03″	6342.7	6228	7432	7381	853.4	843

Table 2. Areas of 100-m-isobaths in 100 m for the entire Baikal

Isobath, m	Area, km^2	Isobath, m	Area, km^2	Isobath, m	Area, km^2	Isobath, m	Area, km^2
100	27770	500	21530	900	9443	1300	5428
200	26290	600	19630	1000	8478	1400	3562
300	24890	700	17720	1100	7703	1500	1798
400	23260	800	15360	1200	6614	1600	1091

Table 3. Layerwise (step 100 m) water volumes for the entire Baikal

Layer, m	Volume, km^3	Layer, m	Volume, km^3	Layer, m	Volume, km^3
0–100	2894.95	600–700	1868.86	1200–1300	606.627
100–200	2700.16	700–800	1659.94	1300–1400	452.442
200–300	2558.93	800–900	1338.58	1400–1500	243.954
300–400	2411.74	900–1000	887.896	1500–1600	148.175
400–500	2240.23	1000–1100	811.060	1600–1642	18.360
500–600	2058.09	1100–1200	716.666		

All the text materials related to the data set are available directly from the main page. Maps and images of variable scales (.pdf and.jpg formats) are also available from the main page.

The project was accomplished by four teams: (1) University of Gent, Belgium, coordinator (Prof. Marc De Batist, supervisor); (2) University of Barcelona, Spain (Prof. Miquel Canals, supervisor); (3) Institute of Limnology, Siberian Division, Russian Academy of Sciences (Pavel P. Sherstyankin, DSc, supervisor); and (4) State Research Navigation-Hydrographic Institute, Ministry of Defense of the Russian Federation (Prof. Sergei P. Alekseev, DSc, supervisor).

RESULTS AND DISCUSSION

We have obtained the most complete and precise digital bathymetric data comprising 1 312 788 points in the "geographical coordinates–Lake Baikal depth" system.

Based on a new detailed digital bathymetric database, we calculated more precise morphometric characteristics of the lake (tables 1–3). We also compiled bathymetric maps with various supplements: isobaths with 50-m steps for relief representation, color code of depths, shadow relief in black-and-white (gray) and colored versions; bottom slopes in color code; spatial (3D) images of different lake areas; various topographic maps of the Lake Baikal region; and others [3].

All principal morphometric characteristics of Lake Baikal (maximum and average depths, volumes and areas of the surface of the entire lake and its basins, and others) turned out to be higher than values cited previously [5, 6] (Table 1).

The analysis of spatial images of the Baikal bottom and its parts yielded many new interesting details. For instance, one can see in detail the ramified Obruchev fault extending beneath the northwestern shore of the lake. Large flat areas are absent in the deepest parts of basins, but the bottom relief has hilly nature. This is consistent with the recent discovery of mud volcanoes [7].

Computer-based bathymetric maps give detailed and more precise representation of the bottom topography of Lake Baikal, which is especially important for the >1000-m-deep Southern and Central basins (Figs. 1, 2). Several small >1450-m-deep areas are distinguished in the central parts of the Southern Basin with the maximum depth at 1461 m (Fig. 1, Table 1). The steepness of the northern and northwestern underwater slopes reaches as much as 60° in the Kultuk–

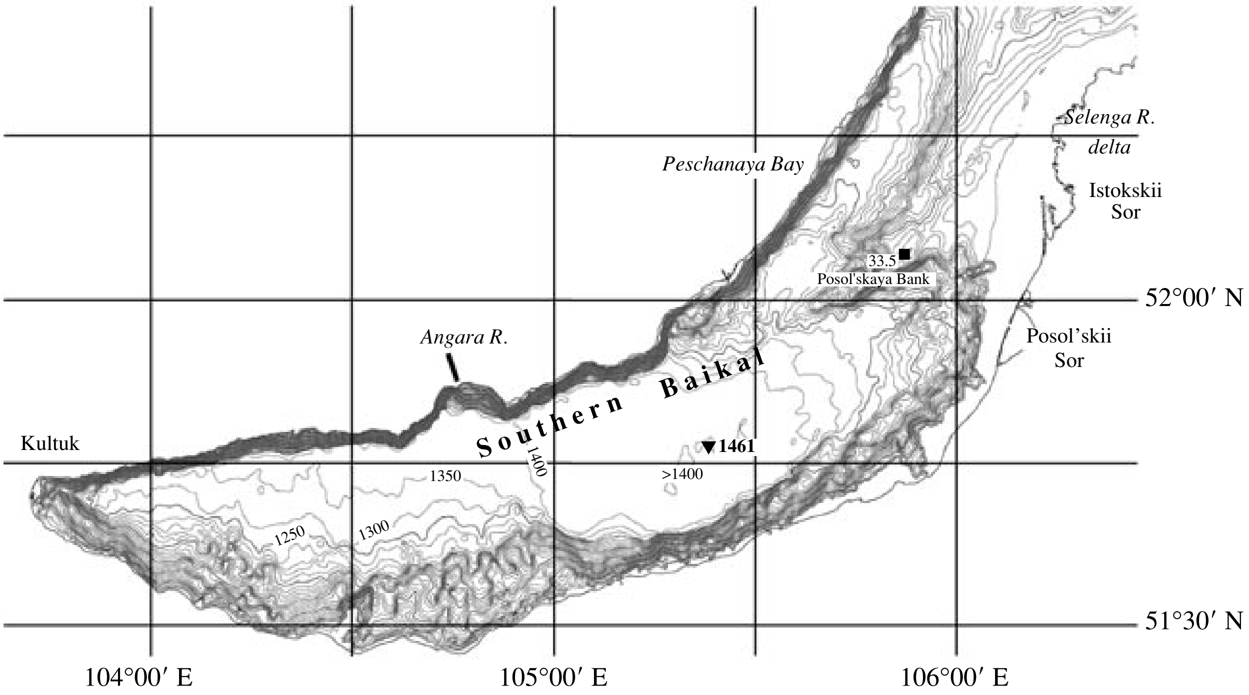

Fig. 1. Bathymetry of the Southern Basin (a fragment of the computer-based map of Lake Baikal). Isobaths are drawn after 50 m; heavy lines, after 250 m. Isobaths for deep-water zones are numerated starting with 1250 m. The black triangle denotes the maximum depth of 1461 m; the black box designates the Posol'skaya Bank (depth 33.5 m).

Peschanaya Bay sector. The Selenga and Selenga Shallow waters are separated from the northern (not deep) part of the Southern Basin by the Posol'skaya Bank located in the middle part of the lake (Fig. 1). Judging from many indications, geological and hydrological processes played the leading role in the formation of the basin. Hydrological processes created conditions favorable for suspension settling, sedimentation, and deposition of bottom sediments.

In the Central Basin, the slope is also steepest beneath the northwestern shore (the Obruchev fault) and is traced up to the northern edge of Olkhon Island behind Izhimei Cape (Fig. 2). The deepest part of the basin (depth >1600 m, width 15 km, area 1090 km^2) extends for approximately 70 km from Ukhan Cape towards Nizhnee Izgolovye Cape on the Svyatoi Nos Peninsula (Fig. 2, Table 2). It is this part of the basin (depth 1600–1642 m) that comprises 18.36 km^3 of unique natural fresh water (Table 3). Thermodynamic and biologic properties of such water can be studied only in Lake Baikal.

At a distance of 30 km from the Selenga delta, the southwestern underwater slope of the basin represents a smooth slope (ramp) with a width of 30 km opposite the Olkhonskie Vorota Strait. The slope decreases from 2° to 1°.

MAXIMUM DEPTHS OF LAKE BAIKAL

Maximum depth values recorded in the lake are of great interest. The difference between the values obtained by the GUNIO (1642 m) [2] and the manned submersible *Pieces* (1637 m) [6, 8] is not very high. Nevertheless, this issue requires further special study. The site of the maximum depth (1642 m) revealed during the preparation of the Bathymetric Map of Lake Baikal (four sheets) is located 22 km east of Izhimei Cape in a 1.5 km-wide depression where greater depths are hardly possible. More promising in this respect is the region near Izhimei Cape. A basin, several kilometers in diameter and more than 1630 m deep, is located 3–5 km away from the cape. Here, depths greater than the 1637-m depth discovered by the M/S *Pieces* submersible may be encountered. A.A. Bukharov and V.A. Fialkov, codiscoverers of this depth, wrote: "The new maximum depth of 1637 m has been recorded on the eastern side of Olkhon Island 3.2 km from the shore. However, this depth may not be the *maximum* (italicized by the authors of this work) one in Lake Baikal since the southeastward bottom slope is 5°–7° at the *Pieces* diving site." This is also supported by the depth of 1637 m (Fig. 2) revealed in this region by B.F. Lut and A.A. Rogozin and presented in the GUNIO map in 1974 [2].

Figure 3 shows the major structural features of the transverse and longitudinal sections of Lake Baikal. The transverse sections show asymmetry that is particularly prominent in the Southern (section *1*) and Central (section *3*) basins. Heights in Fig. 3 are given relative to the sea level in the Baltic system; i. e., the aver-

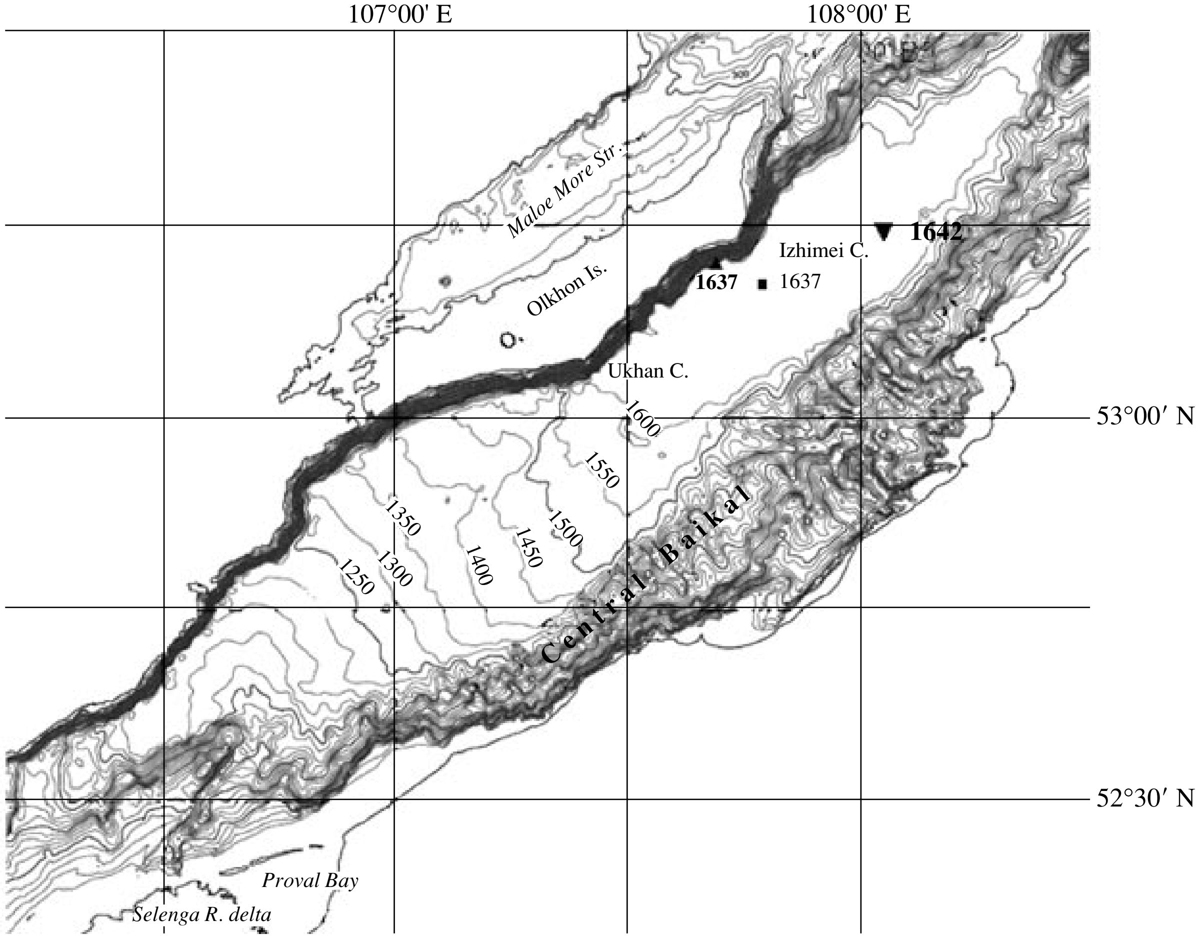

Fig. 2. Bathymetry of the Central Basin (a fragment of the computer-based map of Lake Baikal). Isobaths are drawn after 50 m; heavy lines, after 250 m. Isobaths for deep-water zones are numerated starting with 1250 m. Maximum depths of Lake Baikal are designated by black symbols: 1642 m (inverted triangle), based on the computer-based map [3] and GUNIO 1992 map [2]); 1637 m (normal triangle), based on [8]; and 1637 m (box), based on GUNIO 1974 maps [2].

age level of the water surface in Lake Baikal is 455.5 m higher than the datum level of the Kronshtadt gauge.

Along with the familiar features of basins (Fig. 3), several new structural and genetic features were revealed in the course of analysis of the <gridBaikal3> and <gridbathy_blank_final2> databases with the help of Global Mapper, Fledermouse, and other software packages.

The familiar features are related to asymmetry of slopes: northwestern slopes are steeper than eastern ones; depth gradient is 900 m in the Northern Basin, 1450 m in the Southern Basin, and 1600 m in the Central Basin. Deviations from asymmetry are mainly observed in the Northern Basin.

The lake is 672 km long along the thalweg from Kultuk to Nizhneangarsk (Fig. 3). In the Central Basin, the maximum width is ~73 km (between the Kochernikov River on the western bank to the Krestovyi Cape on the eastern bank). The minimum width is ~29 km near the Selenga Shallow waters.

Among less familiar or recently revealed features distinguished in computer-based maps of the lake is the fact that the northwestern slope in the steepest areas extends for several kilometers (or less than 1 km) and terminates with a troughlike depression. This is related to geological dynamics of the tectonic origin of slopes (the Obruchev fault), i.e., to constantly subsiding places. Near the southern slope of Mt. Izhimei (Olkhon Island, Central Basin) and in many other places in Lake Baikal, the steep underwater slope ends with a distinct depression (Fig. 3, cross section *3*). Such deep troughlike depressions are also known in Lake Baikal as "underwater flexure-shaped trenches" [8]. The asymmetry of northwestern and eastern slopes of the Northern Basin is less prominent (Fig. 3; sections *4, 5*), as was mentioned in [8].

The use of modern high-precision maps of Lake Baikal seems to be promising for the substantiation of new investment projects on natural resources and nature preservation. However, a thorough substantiation of conclusions on ecological safety or hazard

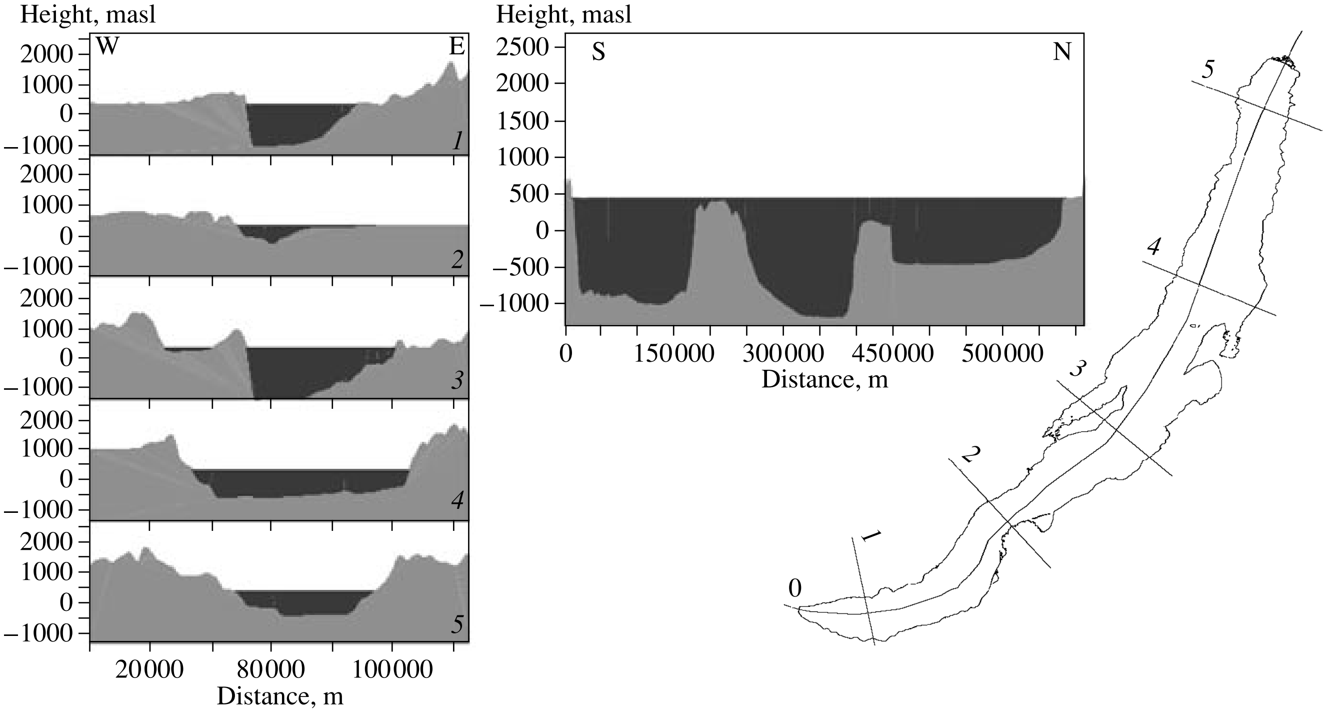

Fig. 3. Longitudinal and transverse profiles of Lake Baikal: (0) longitudinal profile from the southern to northern edge of the lake; transverse profiles: (*1*) across the Southern Basin, (*2*) at the boundary between the Southern and Central basins (Buguldeika River–Srednyaya Channel), (*3*) across the Central Basin (Maloe More Strait–Olkhon Island), (*4*) across the Northern Basin (the Zavorotnyi Cape area), (*5*) across the Slyudyanskii Cape.

related to such projects requires a full-scale simulation with the use of digital cartography data [9, 10].

It should be pointed out that according to requirements of normative documents accepted in Russia and the existing marine-engineering practice of implementation of underwater pipeline projects [11, 12], a comprehensive engineering survey is carried out at the stage of investment substantiation prior to designing. These works include hydrographic engineering, geophysical engineering, hydrometeorological engineering, and so on, as well as the obligatory environmental studies. For instance, such studies during the designation of the "Blue Flow" gas pipeline on the Black Sea bottom [11–13] revealed that this pipeline will have an insignificant impact on the Black Sea ecosystem. This conclusion was confirmed later by the results of the pipeline's operation.

The practice of map coverage for marine survey and investigations shows [14] that computer-based maps cannot be applied properly without solving some principal problems. In particular, it is necessary to provide the exact coordination of topographic and marine bathymetric data. This is important, for instance, for analyzing the distribution of natural and technogenic pollutants in water. These problems have also been solved by compiling computer-based maps of Lake Baikal.

Thus, computer-based bathymetric maps of Lake Baikal provide new insights into familiar structural elements of the lake bottom. Moreover, they can reveal new details. The significance of such maps for educational purposes, professional workers, and admirers of Lake Baikal is difficult to overestimate.

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REFERENCES

1. V. A. Snezhinskii, *Practical Oceanography (Works in Open Sea)* (Gidrometeoizdat, Leningrad, 1954) [in Russian].
2. *Map of Lake Baikal*, 2-Sheet Version (GUNIO MO SSSR, Leningrad, 1974), 4-Sheet Version (GUNIO MO RF, St. Petersburg, 1992) [in Russian].
3. *A New Bathymetric Map of Lake Baikal*. INTAS Project 99-1669 Team, October 2002. http:/allserv.ugent.be/~mdbatist/intas/intas.htm, http:/www.lin.irk.ru/intas/index.htm.
4. L. G. Kolotilo and P. P. Sherstyankin, *Tables of Sound Velocity in Lake Baikal Water and Tables of Depths Mea-*

sured with Echosounder (GS TOF, Vladivostok, 1985) [TsVMB, D221/K614-T] [in Russian].

5. E. M. Kolokol'tseva, *Morphometric Characteristics of Lake Baikal: Mesozoic and Cenozoic Lakes of Siberia* (Nauka, Moscow, 1968), pp. 183–188 [in Russian].
6. A. A. Bukharov and V. A. Fialkov, *Lake Baikal in Figures: Abridged Handbook* (Radian, Irkutsk, 2001) [in Russian].
7. P. Van Rensbergen, M. De Batist, J. Klerkx, et al., Geology **30**, 631 (2002).
8. A. A. Bukharov and V. A. Fialkov, *Geological Structure of the Lake Baikal Bottom: A View from Pieces* (Nauka, Novosibirsk, 1996) [in Russian].
9. G. N. Golubev, N. S. Kasimov, and V. S. Tikunov, Ecology, No. 5, 339 (1995).
10. I. A. Garagash and L. I. Lobkovskii, in *Proceedings of VI International Scientific–Technical Conference "Modern Methods and Instrumentation for Oceanographic Investigations"* (IO RAS, Moscow, 2000), Part 1, pp. 9–19 [in Russian].
11. S. P. Alekseev, A. N. Dobrotvorskii, and S. A. Druzhevskii, in *Proceedings of V International Conference RAO-01 "The Development of Shelf in Russian Arctic Seas," St. Petersburg, Russia, September, 11–14, 2001* (St. Petersburg, 2001), pp. 268–274 [in Russian].
12. V. I. Osipov, in *Cooperation Between Countries of the Black Sea Region as an Important Factor of Ecologically Acceptable Power Supply: Proceedings of the International Scientific–Practical Conference, Sochi, Lazarevskoe, Russia, April 21–24, 1999* (Moscow, 1999), pp. 109–111 [in Russian].
13. N. A. Aibulatov, in *Proceedings of VI International Scientific–Technical Conference "Modern Methods and Instrumentation for Oceanographic Investigations"* (IO RAS, Moscow, 1999), Part 1, pp. 26–35 [in Russian].
14. A. M. Abramov, S. P. Alekseev, K. G. Stavrov, et al., in *Proceedings of the Concluding Conference on Results of the First Stage of Implementation of the Federal Special Program "World Ocean," Moscow, Russia, September 26–27, 2002* (RAS, Moscow, 2002), pp. 280–283 [in Russian].