https://doi.org/10.30730/gtrz

ISSN 2541-8912 (Print)
ISSN 2713-2161 (Online)

ГЕОСИСТЕМЫ ПЕРЕХОДНЫХ ЗОН

Том 7 № 3 2023 Июль – Сентябрь

GEOSYSTEMS OF TRANSITION ZONES

Vol. 7 No. 3 2023 July – September

Научный журнал

Учредитель и издатель:

ФГБУН Институт морской геологии и геофизики Дальневосточного отделения Российской академии наук

Издается с января 2017 г.
Периодичность издания 4 раза в год

Scientific journal

Founder and Publisher:

Institute of Marine Geology and Geophysics of the Far Eastern Branch of the Russian Academy of Sciences

Published since January 2017
Periodicity: Quarterly

Основная задача журнала – информирование научной общественности, российской и зарубежной, о результатах изучения геосистем переходных зон Земли и связанных с ними проблем геофизики, геологии, геодинамики, сейсмологии, геоэкологии и других наук.

The main objective of the journal is informing of scientific community, Russian and foreign, about the results of researches in geosystems of the Earth's transition zones and related problems of geophysics, geology, geodynamics, seismology, geoecology and other sciences.

Журнал:

- индексируется в **Российском индексе научного цитирования (РИНЦ);**
- регистрируется в системе **CrossRef**. Научным публикациям присваивается идентификатор – DOI;
- включен в каталог **Ulrich's Periodicals Directory**;
- включен в международную базу научных журналов открытого доступа – **Directory of Open Access Journals (DOAJ);**
- входит в **Перечень ВАК** – Перечень рецензируемых научных изданий, в которых должны быть опубликованы основные научные результаты диссертаций на соискание ученой степени кандидата наук, доктора наук по следующим научным специальностям и соответствующим им отраслям науки: :

1.6.1. Общая и региональная геология. Геотектоника и геодинамика *(геолого-минералогические)*
1.6.3. Петрология, вулканология *(геолого-минералогические)*
1.6.9. Геофизика *(геолого-минералогические; физико-математические)*
1.6.14 Геоморфология и палеогеография *(географические)*
1.6.17. Океанология *(географические; геолого-минералогические; физико-математические)*
1.6.20. Геоинформатика, картография *(физико-математические)*
1.6.21. Геоэкология *(географические; геолого-минералогические)*
1.5.15. Экология *(биологические)*
1.1.8. Механика деформируемого твердого тела *(технические; физико-математические)*

- отнесен в Перечне ВАК к журналам II квартиля (К2).

The Journal is:

- indexed in **Russian Science Citation Index (RISC)**;
- registered in the **CrossRef** system. Scientific publications are assigned an individual identifier DOI;
- included in the **Ulrich's Periodicals Directory** database;
- included in the **Directory of Open Access Journals (DOAJ);**
- included in the **VAK List** – the List of peer reviewed scientific journals, in which main scientific results of dissertations for the Candidate of Sciences and Doctor of Sciences degrees in the following scientific specialties and corresponding branches of science should be published:

1.6.1. General and regional geology. Geotectonics and geodynamics *(Geology and Mineralogy)*
1.6.3. Petrology and volcanology *(Geology and Mineralogy)*
1.6.9. Geophysics *(Geology and Mineralogy; Physics and Mathematics)*
1.6.14 Geomorphology and Paleogeography *(Geography)*
1.6.17. Oceanology *(Geography; Geology and Mineralogy; Physics and Mathematics)*
1.6.20. Geoinformatics and cartography *(Physics and Mathematics)*
1.6.21. Geoecology *(Geography; Geology and Mineralogy)*
1.5.15. Ecology *(Biology)*
1.1.8. Mechanics of deformable solids *(Physics and Mathematics; Engineering)*

- it is assigned to the K2 quartile in the VAK list.

Адрес учредителя и издателя

ИМГиГ ДВО РАН
ул. Науки, 1б, Южно-Сахалинск, 693022
Тел./факс: (4242) 791517
E-mail: **gtrz-journal@mail.ru**
Сайт: **http://journal.imgg.ru**

Postal address

IMGG FEB RAS
1B, Nauki Str., Yuzhno-Sakhalinsk, 693022
Tel. / Fax: (4242) 791517
E-mail: **gtrz-journal@mail.ru**
Website: **http://journal.imgg.ru**

Редакционная коллегия

Editorial Board

Журнал зарегистрирован в Федеральной службе по надзору в сфере связи, информационных технологий и массовых коммуникаций. (Регистрационный номер ПИ № ФС 77-73243 от 13.07.2018 г.). Территория распространения – Российская Федерация, зарубежные страны.

Переводчик **Качесова Галина Сергеевна**

Редактор к.ф.н. **Низяева Галина Филипповна**
Компьютерная верстка **Филимонкина Анна Александровна**
Корректор **Качесова Галина Сергеевна**
Дизайн **Леоненкова Александра Викторовна**

Адрес редакции журнала и типографии:
693022, Россия, г. Южно-Сахалинск, ул. Науки, 1Б.
gtrz-journal@mail.ru

Формат 60 × 84 /8. Усл. печ. л. 13.2.
Тираж 150 экз. Заказ 8023. Свободная цена.
Дата выхода в свет 28.09.2023.

Подписной индекс в Объединенном интернет-каталоге «Пресса России» (www.pressa-rf.ru) – 80882.
По вопросам распространения обращаться также в редакцию.

Translator **Galina S. Kachesova**

Editor **Galina Ph. Nizyaeva,** Cand. Sci. (Phylology)
Desktop publishing **Anna A. Filimonkina**
Proofreader **Galina S. Kachesova**
Design **Alexandra V. Leonenkova**

Postal address of the Editorial Office and printing house:
1B, Nauki Str., Yuzhno-Sakhalinsk, 693022.
gtrz-journal@mail.ru

Sheet size 60 × 84 /8. Conv. print. sheets 13.2.
Number of copies 150. Order no. 8023. Free price.
Date of publishing 28.09.2023.

Subscription index in the United web-catalogue “Press of Russia” (www.pressa-rf.ru) – 80882.
Please also contact the Editorial Office for distribution.

ISSN 2541-8912 (Print)
ISSN 2713-2161 (Online)

Геосистемы переходных зон
Том 7 № 3 2023 Июль – Сентябрь
http://journal.imgg.ru
https://doi.org/10.30730/gtrz-2023-7-3

Geosystems of Transition Zones
Vol. 7 No. 3 2023 July – September
https://doi.org/10.30730/gtrz-2023-7-3

СОДЕРЖАНИЕ

CONTENT

REVIEW

UDK 550.84

https://doi.org/10.30730/gtrz.2023.7.3.264-275
http://journal.imgg.ru/web/full/f-e2023-3-3.pdf

Complex geological and geophysical studies on substantiation of the outer limits of the Russian continental shelf in the Sea of Okhotsk and East Siberian Sea (2006–2009): Review[1]

Renat B. Shakirov[@], *Elena V. Maltseva*[@], *Anna L. Venikova*, *Natalia L. Sokolova*, *Alexandr I. Gresov*

@ E-mail: ren@poi.dvo.ru; ekor@poi.dvo.ru

V.I. Il'ichev Pacific Oceanological Institute, FEB RAS, Vladivostok, Russia

Abstract. The paper discusses the results of complex geological and geophysical studies of the deep structure of the seabed along the profiles "Magadan – Southern Kurils" (2-DV-M), "Shantar Islands – Northern Kurils" (1-OM) and "Cape Billings – Outer Continental Shelf Limits" (5-AR), carried out in 2006–2009 within the framework of the State program of expeditionary works on substantiation of national sovereignty over the continental shelf in the Sea of Okhotsk and East Siberian Sea. Federal State Unitary Scientific and Production Company Sevmorgeo was parent organization which managed the expeditionary works; the main executors were the staff of the V.I. Il'ichev Pacific Oceanological Institute of FEB RAS. A special role was assigned to gas-geochemical studies with the purpose to establish regional background and anomalous gas fields to assess prospects for oil, gas and gas hydrates. As a result of complex geological and geophysical expeditions led by A.A. Merezhko (Sevmorgeo) in the Sea of Okhotsk, it was established that the enclave outside the 200-mile zone in the central part of the water area does not differ in geological structure from the adjacent parts and is a natural continuation of the framing geological structures of the basement. The evidence obtained was sufficient to successfully justify the application to the UN. On March 11, 2014, after careful consideration of the application and draft recommendations, the enclave of international waters in the Sea of Okhotsk was legally assigned to the Russian Federation. Studies in the East Siberian Sea have provided a huge amount of data on lithology, geochemistry and gas potential of bottom sediments in this area.

Keywords: Sea of Okhotsk, East Siberian Sea, continental shelf, enclave, geological and geophysical research, methane

Acknowledgements and funding

The authors would like to express their gratitude to their colleagues from the Department of Geology and Geophysics of POI FEB RAS, as well as to the staff of FSUSPC Sevmorgeo for collaborative work.
The research was carried out within the framework of the State project of V.I. Il'ichev Pacific Oceanological Institute of FEB RAS (no. 121021500055-0).

For citation: Shakirov R.B., Maltseva E.V., Venikova A.L., Sokolova N.L., Gresov A.I. Complex geological and geophysical studies on substantiation of the outer limits of the Russian continental shelf in the Sea of Okhotsk and East Siberian Sea (2006–2009): Review. *Geosistemy perehodnykh zon = Geosystems of Transition Zones*, 2023, vol. 7, no. 3, pp. 264–275. http://journal.imgg.ru/web/full/f-e2023-3-3.pdf (Transl. from Russian: Шакиров Р.Б., Мальцева Е.В., Веникова А.Л., Соколова Н.Л., Гресов А.И. Комплексные геолого-геофизические исследования по обоснованию внешней границы континентального шельфа России в Охотском и Восточно-Сибирском морях (2006–2009 гг.): обзор. Геосистемы переходных зон, 2023, т. 7, № 3, с. 264–275). https://doi.org/10.30730/gtrz.2023.7.3.264-275

[1] A translation from Russian: Шакиров Р.Б., Мальцева Е.В., Веникова А.Л., Соколова Н.Л., Гресов А.И. Комплексные геолого-геофизические исследования по обоснованию внешней границы континентального шельфа России в Охотском и Восточно-Сибирском морях (2006–2009 гг.): обзор. *Геосистемы переходных зон*, 2023, т. 7, № 3, с. 264-276. https://doi.org/10.30730/gtrz.2023.7.3.264-275; http://journal.imgg.ru/web/full/f-e2023-3-3.pdf

Introduction

The importance of Pacific and Arctic regional studies within our country is enormous, and interest in these regions continues to grow every year. The Far East, as well as the Arctic segment, has a huge resource base, especially in the exclusive economic zone and on the continental shelf.

The Russian Federation (then still the USSR) signed the 1982 United Nations Convention on the Law of the Sea (hereinafter the Convention) on December 10, 1982, and ratified it on February 26, 1997. The Convention entered into force for the Russian Federation on April 11, 1997.

In 2001, Russia was the first State submitting the Submission to the Commission on the Limits of the Continental Shelf concerning the outer limits of the continental shelf of the Russian Federation in the Arctic and Pacific Oceans pursuant to the item 8 of article 76 of the Convention. It presented geological and geophysical and bathymetric materials showing the belonging of a section of the Sea of Okhotsk waters located outside the 200-mile economic zone of Russia to the continental margin of Eurasia.

There is an enclave of elongated shape and significant area in the center of the Sea of Okhotsk, that is previously known as the Sea of Okhotsk Peanut Hole in foreign literature (Fig. 1). This enclave was considered open for navigation and the extraction of biological resources by any State. The Government of the Russian Federation decided to carry out special expeditionary work in order to submit a corresponding submission to the United Nations Commission on the Limits of the Continental Shelf.

In these works, the State task set special requirements for the regime of navigation, the vessel, the quality and the scope of research. V.I. Il'ichev Pacific Oceanological Institute FEB RAS (POI FEB RAS) had necessary specialists, equipment and experience, and the research vessel Akademik M.A. Lavrentyev fully met all requirements to the ship. In this regard, five complex expeditions were organized in the period of 2006–2009, in which 64 employees of POI FEB RAS and employees of the Federal State Unitary Scientific and Production Company (FSUSPC) Sevmorgeo took part in voyages of different years. All expeditions were carried out on the research vessel Akademik M.A. Lavrentyev. The voyages 41, 42-1, 42-2, 45, and 48 were made in the Sea of Okhotsk (the 2-DV-M and 1-OM profiles). During the 45th voyage (Fig. 2) the works were fulfilled in the East Siberian Sea on the 5-AR profile. These expeditions were headed by R.G. Kulinich, Doctor of geological and mineralogical sciences, B.Ya. Karp, Candidate of geological and mineralogical sciences, and R.B. Shakirov, Candidate of geological and mineralogical sciences, from POI FEB RAS, and by A.A. Merezhko and A.D. Krasnyuk from Sevmorgeo. V.I. Ivanov and V.N. Nikiforov were captains of the expeditions.

During 2007–2009, main scope of deep seismic sounding, continuous high-frequency seismic profiling, and lithological test of bottom sediments along with gas-geochemical, geochemical, paleostratigraphic, hydrochemical and other works, was fulfilled on the 2-DV-M, 1-OM and 5-AR profiles.

The most difficult task was to study the deep structure of the Earth's crust. The data of the highest quality for their confident interpretation for the State purposes were obtained here.

The aim of this article is to demonstrate the main expedition results which became the base for substantiating the national sovereign right to the continental shelf in the Sea of Okhotsk and East Siberian Sea.

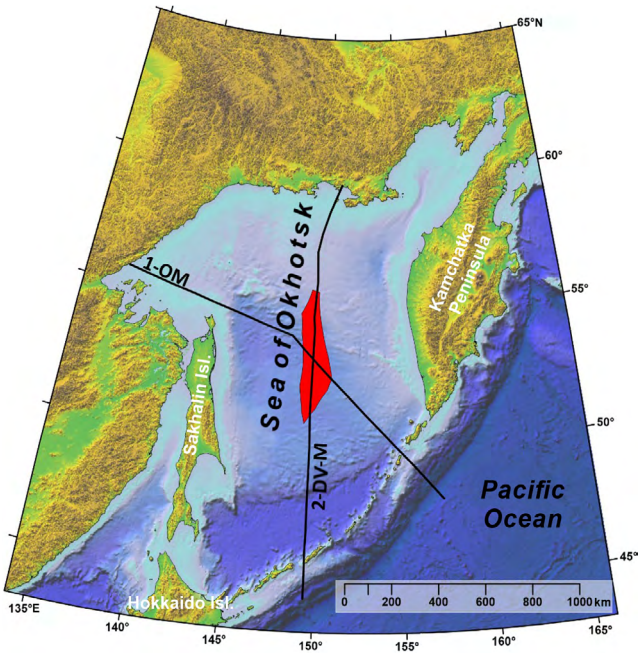

Fig. 1. Enclave in the central part of the Sea of Okhotsk (until 2013) with the 2-DV-M and 1-OM calibration profiles made during the expeditions of 2006–2009.

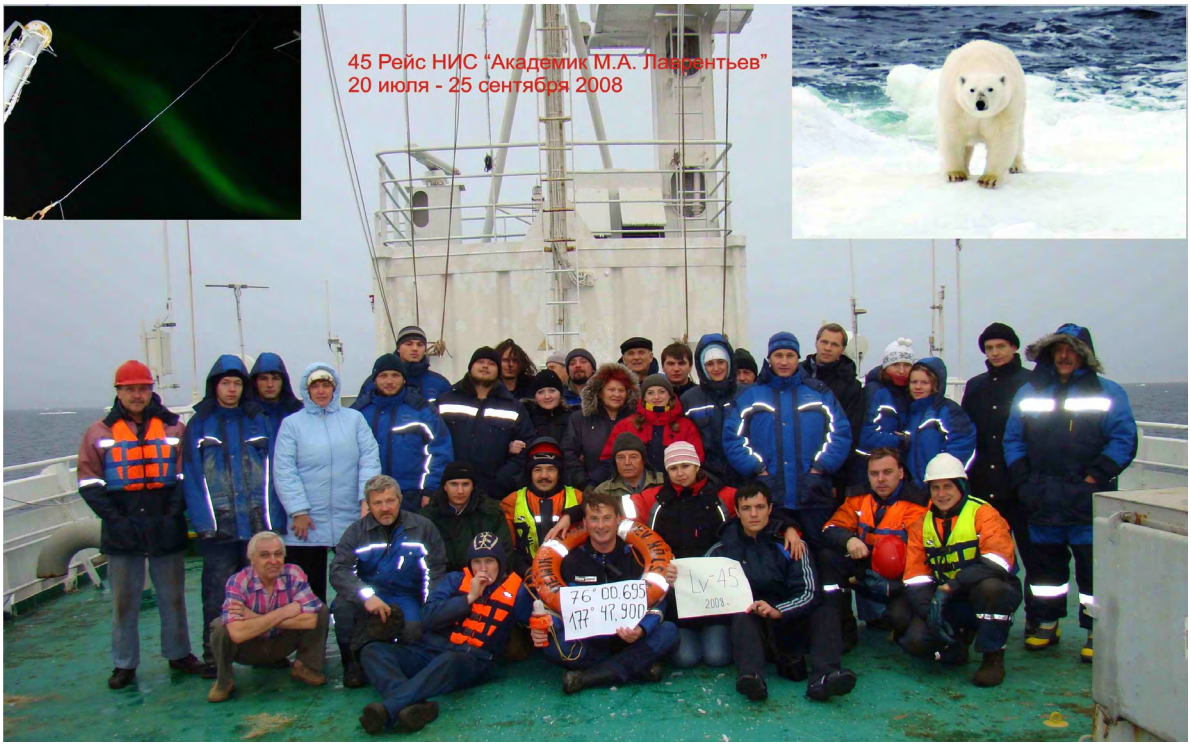

Fig. 2. Scientific membership and crew of the expedition in the 45th voyage of the research vessel Akademik M.A. Lavrentyev, 2008, the East Siberian Sea, the Arctic Ocean. *All photos in the article are from R.B. Shakirov archive.*

Research methods and measurement tools

In total, two regional geotraverses were worked out jointly Sevmorgeo and POI FEB RAS by under the program of the Outer Continental Shelf Limits: the 2-DV-M (2006–2007) and 1-OM (2008–2009) [1] (Fig. 1) profiles in the Sea of Okhotsk, and the 5-AR profile (2008) [2] (Fig. 3) in the East Siberian Sea.

In accordance with recommendations of the UN Commission (2002), Sevmorgeo joint POI FEB RAS have started the collaboration works in 2006 (the 41th voyage, the research vessel Akademik M.A. Lavrentyev, headed by R.G. Kulinich, Doctor of geology and mineralogy) at the 2-DV-M meridian profile with a length of about 1000 km, which crosses the Sea of Okhotsk waters on the geotraverse Magadan – South Kurils. Bathymetric observations and geological and geophysical survey, including deep seismic sounding (DSS), high-resolution seismic profiling, geological sampling of the bottom in the profile band, were carried out in the area of the enclave. In addition, common depth point seismic reflection survey (CDP SRS) was performed led by Sevmorgeo.

The works were carried out using equipment of mainly domestic production.

The following equipment was used for deep seismic survey, depth measurement and detail study of the seabed relief at the profiles, search and visual study of gas sources, detection of gas-containing structures, study of material composition of sediments, identification of gas concentration in water and sediments:

- autonomous bottom seismic stations (ABSS);
- ELAC ENIF-LAZ 72 stationary ship deep sea echo sounder;
- sonar system of upgraded ship echo sounders SARGAN-EM and ELAC, two SARGAN-GM sonars;
- Sonic 3M geophysical complex;
- GPS 120 GARMIN navigation receiver for locating the vessel;
- Crystallux-4000M gas chromatograph;
- hydrological SBE-9 CTD sensor and 12-position bathymetric Rosette system (USA);
- wire-line hydrostatic sampling tube for bottom sediments while drifting a vessel and other equipment.

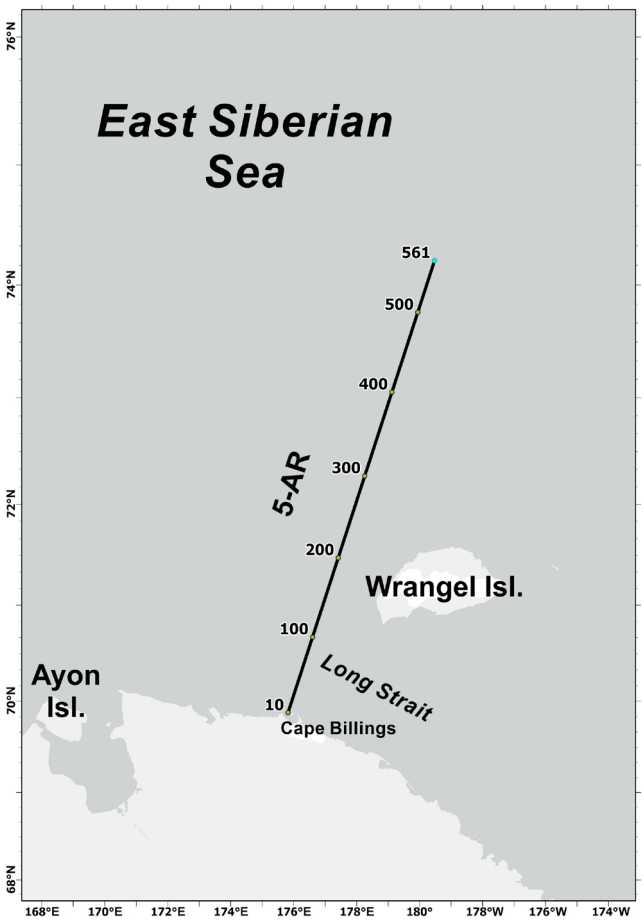

Fig. 3. Layout of the 5-AR profile in the East Siberian Sea (2008).

Fig. 4. General view of the self-floating ABSS prepared to installation.

Seismic survey using the method of deep seismic sounding

Observations were made using autonomous bottom seismic stations ABSS with the SM-26 recorders and on-board control and positioning devices (GPS). Signals were received by means of the GS-20 three-component geophones and hydrophones. The SIN-6M air-gun of domestic production with changeable 80 and 120 liter working chambers [2] were used to excite seismic pulses.

Deep seismic exploration survey with autonomous bottom seismic stations consists of three consequent technological cycles: installation of bottom stations, work out of the exciting line using air-gun source of elastic waves, lifting of bottom stations and rapid assessment of seismic material.

Unfortunately, at present, deep seismic sounding methods in our country are poorly developed. And works using air-gun sources for conducting fundamental studies by scientific organizations is generally prohibited. This situation requires an urgent solution, as expeditionary work on the expansion of the domestic shelf is more significant than ever in the current situation.

The ABSS were arranged along a profile line with an average interval of 10 km between the stations (spacing). For the work, the so-called self-floating ABSS were mainly used. The station case has positive buoyancy and sinks to the bottom under the action of reinforced concrete ballast. Upon completion of the work, the station is released from ballast and floats to the surface in response to a command transmitted via a hydroacoustic channel. The appearance of ABSS as equipped is shown in Fig. 4. Weight of the structure with ballast is about 100 kg (including ballast – 60 kg).

Work out of the excitation line was carried out by the same vessel along the profile line with the «race» from the location of installation of the outer station at a distance of 150 km. The single low-frequency SIN-6M air-gun source with a chamber volume of 80–120 l was used to excite elastic waves (Fig. 5). The air-gun source was

Fig. 5. Pre-operation procedures for the SIN-6M air-gun with a 80 liter chamber.

Fig. 6. Launch of the hydrostatic sampler (the 42th voyage of the research vessel Akademic M.A. Lavrentyev, 2007).

towed aft at a distance of 70–100 m and a depth of 37.5 m. The weight of the air-gun source was 1080 kg. Work out of the excitation line was carried out at low speed of the vessel of the order of 4 knots. "Shooting" was in time, one shot in 2 min. Accordingly, the interval between shots (excitation step) was 250 m.

The air-gun source was continuously supplied with compressed air through a mobile compressor of the laboratory based on a standard 20 foot container.

After work out of the excitation line, ABSS were lifted up, data was read out on-board and the equipment was prepared for further work.

Lithological studies

The samplers of the following types were used for lithological sampling of surface sea floor sediments:

- simple shock direct-flow tube (DT) without inserts with a length of 3 m and an internal diameter of 6 cm;
- shock direct-flow major diameter tube (MDT) with inserts and a length of 4 m, and an internal diameter of 9 cm;
- hydrostatic sampler

(Fig. 6) with inserts (GSP 2) designed by Yu.L. Garan'ko (1978, POI FEB RAS), with a length of 5.5 m and an internal diameter of 12 cm;

- Okean-2 bottom grab.

Preliminary, seismic data were used to determine the nature of sedimentary deposits. Then, the stations laying was identified and sediments were sampled based on echo sounding and seismic profiling data. A polyethylene insert cut lengthwise into two sections was used to quickly remove the sediments from the tube. The sampled core was moved to the on-board laboratory, where it was lithologically described and submitted for subsequent gas-geochemical analysis. Lithological study of bottom sediments was carried out mainly by the Sedimentology and Stratigraphy Laboratory, POI FEB RAS.

Gas-geochemical studies

The gas-geochemical study technique is enshrined in the Passport of the Gas Geochemistry Laboratory, POI FEB RAS (PS 1.051-21) and approved by Conclusion 58 issued by Federal Budgetary Institution Primorsky CSM, as well as in patents and publications [3–5].

The sampling discreteness for the core was 0.15–0.30 m, with the concentration of gas-geochemical samples in the zones of maximum lithological and structural variability up to 0.05–0.10 m.

The sediment was sampled with a 10 ml syringe with a cut-off spout into the 70 ml bottles filled with a salt solution of approximately 2/3 (not more than 50 ml). At least 10 ml of sediment was taken. A bottle was then filled with salt solution to the top, and covered with a rubber cork. The remaining air was removed using a needle. 12 ml of salt solution was extracted from the closed bottle with a syringe, and air was injected through the second needle at that. The bottles were placed in an ultrasonic bath for 5 minutes at maximum power, then were periodically shaken intensively during 2–3 hours. The interval between the sampling of the sediment and gas chromatographic analysis was 2.5–3.5 h.

The gas components (nitrogen, oxygen, carbon dioxide, methane and other hydrocarbon gases) in the sediment samples were determined on-board by means of the Crystallux-4000M chromatograph (Russia) (Fig. 7). The chromatograph module has three detectors: two thermal conductivity detectors (TCD) and one flame ionization detector (FID). Certified control gas mixtures were used to calibrate the device. The measurement error is 5 % [6].

Fig. 7. Crystallux-4000M chromatograph (the 42th voyage of the research vessel Akademic M.A. Lavrentyev, 2007).

Study results

The Sea of Okhotsk holds a most unique position among the marginal seas of the continental margin of the Asian continent in terms of its geological structure and resource potential. It extends deep into the continent and is characterized by an extension overdeepened shelf.

Earlier, as a result of POI FEB RAS studies headed by E.P. Lelikov [7], the various types of granitoids was found to be widely spread in the foundation of the Sea of Okhotsk. That is a main evidence of the continental nature of the origin of the basin. Granitoids are dredged on all submarine uplifts of the Sea of Okhotsk [7]. The rocks of the foundation on the water area of the Sea of Okhotsk are raised at numerous stations, on uplifts and banks, including those within the Central Okhotsk Arch [8]. Its geological structure was identified to include metamorphic, magmatic and sedimentary rocks of Paleozoic-Mesozoic age, which are related to alkali-lime potassium-sodium series of Pacific type in terms of geochemical specialization.

X-ray diffraction analysis of clay fractions showed that the main source of their input into the bottom sediments can be only continental crusts of weathering, which, according to the findings of the experts of the Federal State Budgetary Institution VNIIOkeangeologia, indicate the existence of a number of islands or an entire archipelago in the area of the Central Okhotsk Arch. From a geomorphological point of view, the northern and central parts of the area of the Sea of Okhotsk are interpreted as an overdeepened shelf, and, according to the results of complex works, it is shown that the enclave is located within the Sea of Okhotsk continental margin.

In the course of data processing of the VNIIOkeangeologia in Sevmorgeo with the participation of POI FEB RAS (V.G. Prokudin), in particular, it was revealed that the structure of the Earth's crust in the Kuril (South Okhotsk) basin and within the Central Okhotsk Arch varies greatly, and the main characteristics of this difference were identified.

Directly on the 2-DV-M profile (works of 2006–2007), 201 cores of bottom sediments (gravity corer) were raised and 9 stations of bedrock dredging were made at the places of their outputs on the bottom surface under the guidance and mainly by POI FEB RAS together with Sevmorgeo. Petrographic studies have identified three types of rocks – metamorphic, eruptive (volcanic and intrusive) and sedimentary. In 2008–2009, these works was supplemented by a similar set of studies at the 1-OM profile (Shantar Islands – Northern Kurils): more than 150 trips of geological tubes. During lithological sampling, works were carried out around the clock (three tours of 8 hours each), and up to 20 sediment sampling stations were worked out per day. 417 sampling stakes were worked out at the 2-DV-M, 1-OM and 5-AR regional profiles based on the results of preliminary interpretation of seismoacoustic profiling [9]. A representative catalog of lithological descriptions of the bottom sediments of the samples has been compiled.

The following areas were allocated based on the characteristics of the lithological composition an the section Magadan – Kurils – Pacific Ocean: 1 – North Okhotsk with depths of 60–250 m; 2 – Central Okhotsk with depths of 250–1700 m; 3 – an area confined to the north side of the Kuril Basin and its bed with depths of 1700–3360 m; 4 – an area occupying the south side of the Kuril Basin with depths of 3360–1600 m; 5 – oceanic one with depths of 400–800 m.

The North Okhotsk and Central Okhotsk areas are represented, in general, by a uniform set of sedimentary layers consisting of a fine aleurite-pelitic base (dominant in composition) and a large aleurite-psammitic (sandy) admixture.

The Kuril Basin is represented by thin siliceous pelite sediments.

Only the uppermost surface layer has been sampled at the oceanic area. It is represented by sand (from coarse- to fine-grained with a mixture of fine gruss and gravel), consisting of black volcanic scoria, black basaltoid weathered rocks, yellow-gray tuffaceous sandstone and white crystals of feldspar.

As a result of gas-geochemical survey on the 2-DV-M profile (2007), a regional background concentration of methane (regional background) in the sediment along the profile was identified, it was 3 ppm (3 cm^3/m^3), and five new zones with anomalous methane concentrations (up to 1230 μl/l) were detected [9]. Background fields of methane concentration are mainly formed in

sediments in the central deep sea area of the Sea of Okhotsk. Against this background, methane anomalies are detected in the areas of structural noses, where relatively powerful sediment matter lenses can be formed, including due to landslides. Large-scale processes of generating gaseous hydrocarbons may take place in these bodies similar to other gas-bearing areas of the highly productive Sea of Okhotsk (Fig. 8).

The maximum methane content up to 35 752 µl/l was established in the sediments of the East Sakhalin slope (station LV-45-465A) at the 1-OM profile (2008) (Fig. 8). This zone is entirely located within the Deryugin Trough (or Deryugin Basin). Gas-hydrates (south of the 1-OM profile) were repeatedly found in the sediments of this area with the participation of the Gas Geochemistry Laboratory of TOI FEB RAS. In 2008–2009, no methane hydrates were detected at the 1-OM profile. This may indicate the northern boundary of their distribution in the trough. However, the measured methane concentrations simultaneously indicate the presence of local zones of free flow of natural gas, where gas-hydrates can be formed under favorable P–T conditions. The minimum methane content in the bottom sediments is about 0.2 µl/l in the Shantar graben sediments. In 2009, increased methane concentrations up to 87 µl/l were found in the northeastern part of the Deryugin Depression and on the slope of the Kuril Basin with a length of about 30 km (Fig. 8).

A common pattern of increasing methane concentrations with a sampling depth was approved in the course of gas-geochemical work in the bottom sediments. Found anomalous concentrations of methane are usually confined to the horizons of 90 cm and below along the sediment core. According to isotope study, hydrocarbon gases of all types of genesis have been found, from microbial to magmatogenic.

The main result of complex geological and geophysical expeditions in the Sea of Okhotsk

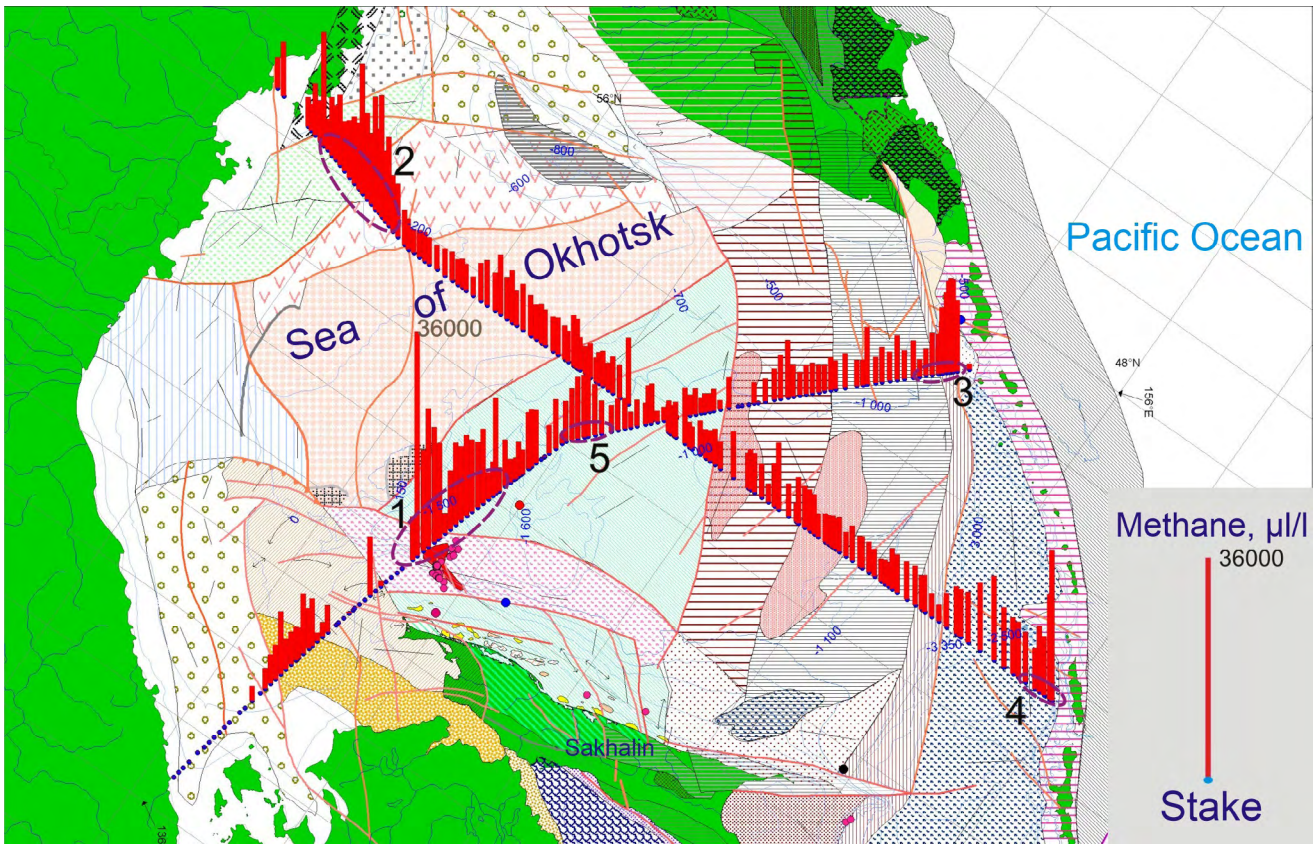

Fig. 8. CH_4 distribution (bar graphs) in the bottom sediments, sampled at the 2-DV-M and 1-OM profiles (2007–2009) in the Sea of Okhotsk region. The map is based on the tectonic map by V.V. Kharakhinov [10]. Red circles are the places where has-hydrate deposits are found; blue circles are gas flames; pink circles are gas flames which were found in places, where has-hydrate deposits are detected; yellow spots along the coast of Sakhalin Island are oil and gas fields. Zones of anomalous methane concentrations in the bottom sediments are marked by a dotted line.

is the establishment of the fact, that the enclave outside the 200-mile zone in the central part of the water area does not differ in geological structure from the parts adjacent to it, and it is a natural continuation of the rim geological structures of the foundation. The presence of the considered complexes and granitoids within the area was approved by the results of geological sampling immediately the 2-DV-M profile.

The evidence obtained from these expeditions data was sufficient to support the application to UN successfully.

On March 11, 2014, after careful consideration of the application and draft recommendations, the enclave of international waters in the Sea of Okhotsk was legally allocated to the Russian Federation. Under the item 8 of article 76 of the 1982 UN Convention on the Law of the Sea, the limits of the Russian continental shelf in the Sea of Okhotsk are final and binding for all States. The Decree of the Government of the Russian Federation of August 15, 2015, No. 845 "On the continental shelf of the Russian Federation in the Sea of Okhotsk" established, that the seabed and subsoil of the submarine area (enclave) located in the central part of the Sea of Okhotsk, are the continental shelf of the Russian Federation. As a result, the Russian continental shelf in the Sea of Okhotsk has increased by 56 400 km^2, and the Sea of Okhotsk Peanut Hole, the desirable area for the foreigners, which, in their opinion, was in the form of peanut, ceased to be.

State works for substantiating the sovereignty of the Russian outer continental shelf in the Arctic region are continued and have achieved some success in a number of the water areas.

In 2008, at the research vessel Akademik M.A. Lavrentyev (voyage 45) Sevmorgeo and POI FEB RAS carried out the part of such works in the East Siberian Sea on the 5-AR profile (Billings Cape – Mendeleev Ridge) (Fig. 9).

In the same way as in the Sea of Okhotsk, the deep seismic sounding was performed under the guidance of Sevmorgeo, and the employees of POI FEB RAS (headed by V.G. Prokudin, Candidate of geological and mineralogical sciences) carried out the continuous seismic profiling and made 56

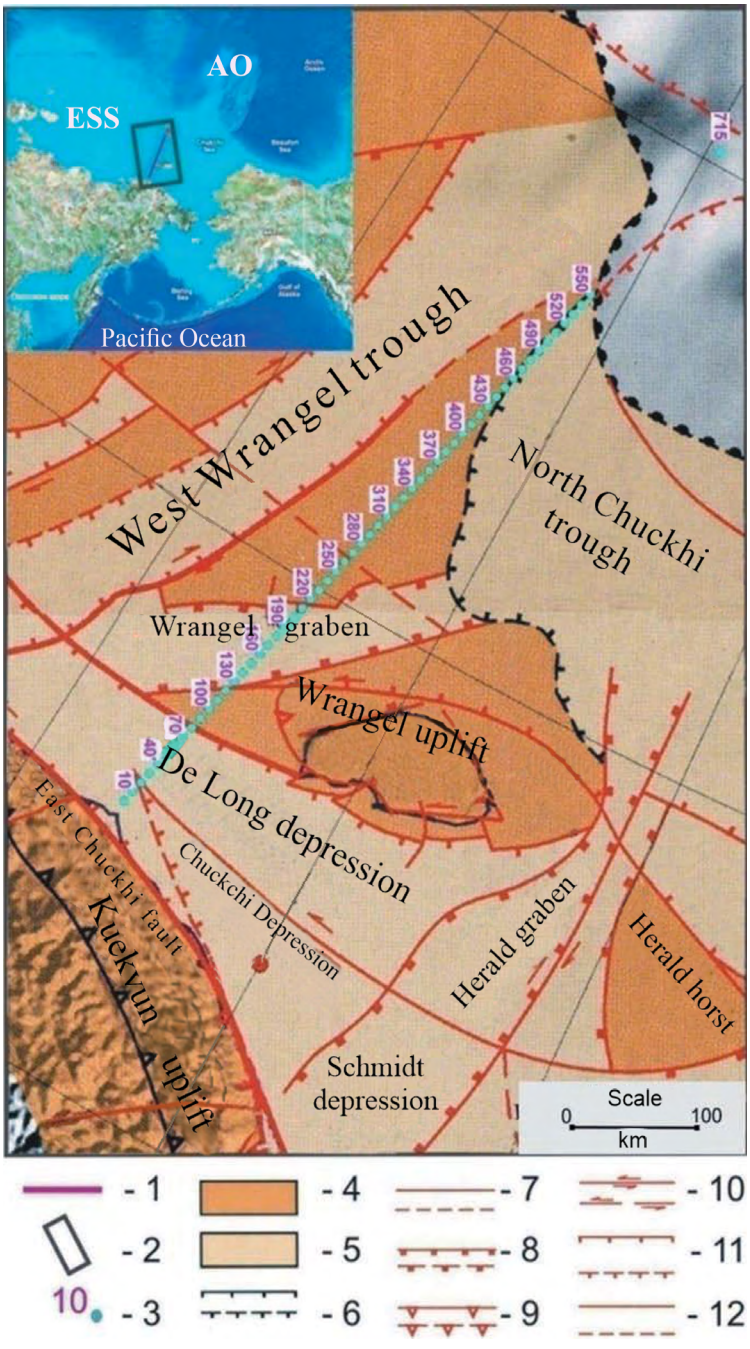

Fig. 9. Position of stakes of the bottom sediments sampling in the East Siberian Sea on the map of neotectonic structures expressed in the relief of the Arctic shelf [11]. 1 – profile of the works of 2008; 2 – site of the works; 3 – sampling stakes; 4 – uplifts and horsts, depressions; 5 – graben, ramps; 6 – reliable/presumptive boundaries (dashes are directed towards depressions). Recent faults (main faults are shown by thickened lines): 7 – reliable/presumptive; 8 – normal faults; 9 – reverse faults; 10 – strike-slip faults; 11 – unknown type; 12 – without identified displacement. AO – Arctic Ocean.

stations of lithological and gas-geochemical sampling. Geological samplers (gravity tubes) raised up the cores with a length of up to 3 m.

The following features of hydrocarbon gas distribution have been characterized using the gas-geochemical survey of the bottom sediments along the profile. Methane was detected in all bottom sediment gas samples at concentrations ranging from 2.0 ppm to 2.4 vol.%. Background methane concentrations in the bottom sediments were 13 ppm (8 μl/dm^3). This value is 4 times higher than this in the Sea of Okhotsk. Thus, there is enough high regional hydrocarbon background in the East Siberian Sea, which indicates a long diffusion seepage of natural gas through the low-permeability formations [9].

In general, the anomalous methane fields of low and medium intensity are observed throughout the profile (Fig. 9). Studies have found these fields to be formed within uplifts characterized by low sediment thickness and complicated by the intensive development of faults and tectonic disturbance, which are inherently the areas of gas discharge. In the central part of the profile (at a distance of 270 km), there is a site of methane discharge (2.4 vol.%), which is controlled by a fault. High concentrations of methane and hydrocarbon gases (to pentane), as well as the predominance of the heavy carbon isotope methane in the sediments throughout the profile (560 km) allow to consider the continental shelf of the East Siberian Sea to be highly promising in terms of hydrocarbon potential [12, 13].

The similarity of the main characteristics of the gas-geochemical field throughout the shelf and slope of the East Siberian Sea is another proof of the extension of the sovereign Russian shelf from the coastline to the deep sea basin of the Arctic Ocean.

Conclusion

The State task for the program of determining the limits of the Russian outer shelf spreading has been fully completed. Domestic equipment and devices were mainly used.

Expedition works, with the active participation of POI FEB RAS together with FSUSPC Sevmorgeo, on the State program “Outer Continental Shelf Limits (the Sea of Okhotsk and the East Siberian Sea, 2006–2009)” gave us a lot of evidence for fundamental research. Associated studies have revealed new features of the deep structure of the lithosphere of the Far East water areas, peculiarities of stratigraphy, paleogeography, new zones of oil and gas formation, prospective sites for the search of solid mineral resources, gas hydrates, etc.

The fundamental research carried out and the results obtained in the expeditions became one of the bases for the development of modern programs for the study of mineral resources, the expansion of research activities, the development and use of the World Ocean for sustainable development and national security.

The results obtained within the frameworks of the State program implementation were extremely important for ensuring the effective realization of the national interests of the Russian Federation in the World Ocean. In the East Siberian Sea, which is unique in all respects, but also the least studied sea of the Russian East Arctic, the work on the substantiation of the outer limit of the shelf needs to be continued, of course. In addition, in order to implement the Maritime Doctrine of the Russian Federation and the President’s instructions for the development of the mineral base, it is necessary to carry out comprehensive work on the outer limit of the continental shelf in the Bering and Japan seas.

Currently, the staff of POI FEB RAS retains its research potential at a high level, which allows to further perform complex geological and geophysical studies of the deep structure of the seabed. The staff possesses methods and means that make it possible to expand the knowledge about the deep structure of the lithosphere of the water area and to identify prospective areas for the search of solid minerals, gas hydrates and other resources.

References

1 Sakulina T.S., Kalenich A.P., Atakov A.I., Tihonova I.M., Krupnova N.A., Pyzhjanova T.M. **2011.** Geological model of the Okhotsk Sea region according to basic profiles 1-OM and 2-DW-M. *Razvedka i okhrana nedr = Prospect and protection of mineral resources*, 10: 11–17. (In Russ.). EDN: OHAGYN

2 Sakulina T.S., Verba M.L., Kashubina T.V., Krupnova N.A., Tabyrtsa S.N., Ivanov G.I. **2011.** Complex

geological-geophysical researches on the 5-AP profile in the East-Siberian Sea. *Razvedka i okhrana nedr = Prospect and protection of mineral resources*, 10: 17–23. (In Russ.). EDN: OHAGYX

3 Obzhirov A.I. **1993.** [*Gas-geochemical fields of the bottom layer of the seas and oceans*]. Moscow: Nauka, 139 p. (In Russ.).

4 Obzhirov A.I., Astakhova N.V., Lipkina M.I., Vereshchagina O.F., Mishukova G.I., Sorochinskaya A.V., Yugai I.G. **1999.** *Gas-geochemical zoning and mineral associations of the floor of the Sea of Okhotsk.* Vladivostok: Dal'nauka, 184 p. (In Russ.).

5 Vereshchagina O.F., Korovitskaya E.V., Mishukova G.I. **2013.** Methane in water columns and sediment of north western Sea of Japan. *Deep Sea Research. P. II: Topical studies in Oceanography*, 86-87: 25–33. https://doi.org/10.1016/j.dsr2.2012.08.017

6 Mishukova G.I., Shakirov R.B. **2017.** Spatial variations of methane distribution in marine environment and its fluxes at the water–atmosphere interface in the western Sea of Okhotsk. *Water Resources*, 44: 662–672. https://doi.org/10.1134/S0097807817040133

7 Lelikov E.P., Malyarenko A.N. **1994.** [*Granitoid magmatism of marginal seas of the Pacific Ocean*]. Vladivostok: Dal'nauka, 268 p. (In Russ.).

8 Vasiliev B.I., Sigova K.I., Obzhirov A.I., Yugov I.V. **2001.** *Geology and oil-gas resources of the marginal seas of the northwestern Pacific.* Vladivostok: Dal'nauka, 303 p. (In Russ.).

9 Shakirov R.B. **2018.** *Gas-geochemical fields of the Eastern Asia marginal seas.* Moscow: GEOS, 341 p. (In Russ.).

10 Kharakhinov V.V. **1998.** [*Tectonics of the Sea of Okhotsk oil-gas province*]: [Doctor of Sciences (Geology and Mineralogy) dissertation]. Okha-na-Sakhaline: Sakhalin-NIPImorneft'. (In Russ.).

11 Geology and mineral resources of the Russian shelf areas: Atlas. **2004.** Moscow: Publ. House Scientific world, 108 p.

12 Shakirov R.B., Sorochinskaya A.V., Obzhirov A.I. **2013.** Gasgeochemical anomalies in the sediments of East-Siberian Sea. *Vestnik KRAUNTs. Nauki o Zemle = Bull. of KRAESC. Earth Sciences*, 1(21): 231–243. (In Russ.). EDN: RCCSOL

13 Gresov A.I., Obzhirov A.I., Yatsuk A.V., Mazurov A.K., Ruban A.S. **2017.** Gas content of bottom sediments and geochemical indicators of oil and gas on the shelf of the East Siberian Sea. *Russian Journal of Pacific Geology*, 11: 308–314. https://doi.org/10.1134/S1819714017040030

About the Authors

Employees of the Gas Geochemistry Laboratory, V.I. Il'ichev Pacific Oceanological Institute, FEB RAS, Vladivostok:

Shakirov, Renat B. (https://orcid.org/0000-0003-1202-0351), Doctor of Geology and Mineralogy, Deputy Director, Head of the Laboratory, ren@poi.dvo.ru

Maltseva, Elena V. (https://orcid.org/0000-0003-3230-7042), Cand. of Sci. (Geology and Mineralogy), Senior Researcher, ekor@poi.dvo.ru

Venikova, Anna L. (https://orcid.org/0000-0002-1445-8579), Researcher, anett29@mail.ru

Sokolova, Natalia L. (https://orcid.org/0000-0002-2248-6924), Cand. of Sci. (Geology and Mineralogy), Senior Researcher, natap81@mail.ru

Gresov, Alexandr I. (https://orcid.org/0000-0002-2133-411X), Doctor of Geology and Mineralogy, Principal Researcher, gresov@poi.dvo.ru

Поступила 30.08.2023
Принята к публикации 09.09.2023

Received 30 August 2023
Accepted 9 September 2023