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Master thesis

Features of formation of gas hydrates in Deryugin Basin-Sea of Okhotsk

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«Cold Region Environmental landscapes Integrated Science»

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Abstract:

After the middle of the 21st century, the oil and gas available for human use will naturally gradually be exhausted. Since the 1970s and 1980s, humans have discovered a new mineral deposit-gas hydrate-on the seabed and land permafrost. The currently discovered global reserves of gas hydrates are huge, roughly estimated to be available for human use for 200 years, and are known as the energy source of the 21st century. In this paper, the features of natural gas mineralization in the Okhotsk Sea Area (Deryugin Basin) will be discussed. Focusing on the features of geological structure as the center, combined with gas source conditions, pressure conditions, temperature conditions and other parameters, analyze the mineralization conditions and features. The results of on-site exploration were used to verify that the area is indeed rich in gas hydrates, and the distribution of some mineral deposits was determined in the sampling of several detection sites. In addition, the current geophysical and chemical methods for gas hydrate exploration and feasible mining methods at this stage will also be discussed in this paper.

Introduction:

According to scientists' predictions, the petroleum natural gas energy of softball will be exhausted in 2050. At a time when petroleum gas energy will be exhausted, scientists have turned their attention to the seabed, which is much larger than the land area. The search for seabed energy has become the urgent task of scientists. After conducting a large number of investigations and studies on the seabed, it was discovered that gas hydrates on the seabed can replace petroleum natural gas and become a new energy source in the second half of the 2l century.

Gas hydrates are widely distributed worldwide, with large-scale mineralization and high energy density. The sedimentary layers under the seabed and permafrost zones are regarded as the best locations for large-scale mineralization of gas hydrates. In nature, the proportion of subsea gas hydrate deposits is 99% of the total. At present, most of the gas hydrates that have been detected are distributed in land and offshore areas (off the North Island of New Zealand, the east coast of North and South America, etc.), inland lakes (Caspian Sea, Black Sea, etc.), high-latitude waters (Arctic Ocean surrounding waters, Bering Sea, Okhotsk Sea), and various troughs. Among them, the regions on both sides of the Pacific have the largest reserves, followed by the Atlantic Ocean.

It is calculated that the combustion of one cubic meter of natural gas can provide 36,000 joules of heat, while the combustion of one kilogram of coal can only release 2,900 joules, and one kilogram of gasoline is 4,700 joules. Due to the high energy density of gas hydrates, one cubic meter of pure gas hydrate can release 164 cubic meters of natural gas. According to this calculation, one cubic meter of gas hydrate can fully meet the natural gas needs of a family of three for half a year.

In this paper, I will try to explore the hydrate exploration method and mining method, as well as the gas hydrate mineralization features of the Deryugin Basin, including the study of sedimentary sources, temperature conditions, pressure conditions and geological structure conditions.

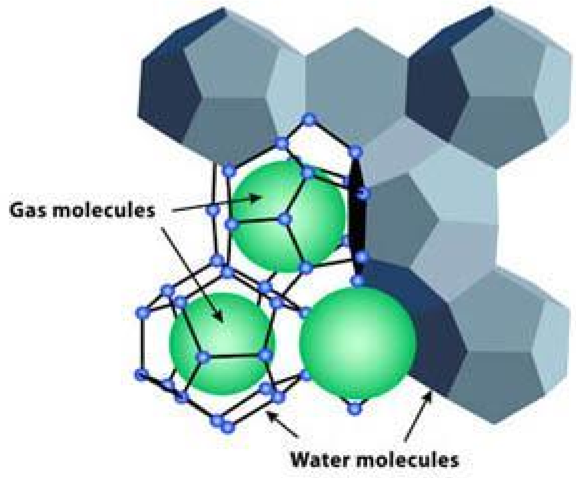

Figure 1. **Molecular structure of hydrates**

Methods:

First of all, the current proven reserves of gas hydrates are much smaller than the predicted reserves. This situation reflects to varying degrees the lack of understanding of the law of gas hydrate survival in the academic community and the lack of methods for gas hydrate exploration. Before discussing the features of gas hydrate accumulation in the Deryugin Basin, we will first discuss the exploration methods that have been demonstrated so far. Including physical, chemical and biological. The area studied in this paper is the Deryugin Basin in the Sea of Okhotsk, located at 200KM northeast of Sakhalin Island. The average water depth is 1000 meters, and the deepest is about 1500 meters.The core area is 144-146 East Longitude and 52.5-54.5 North Latitude.

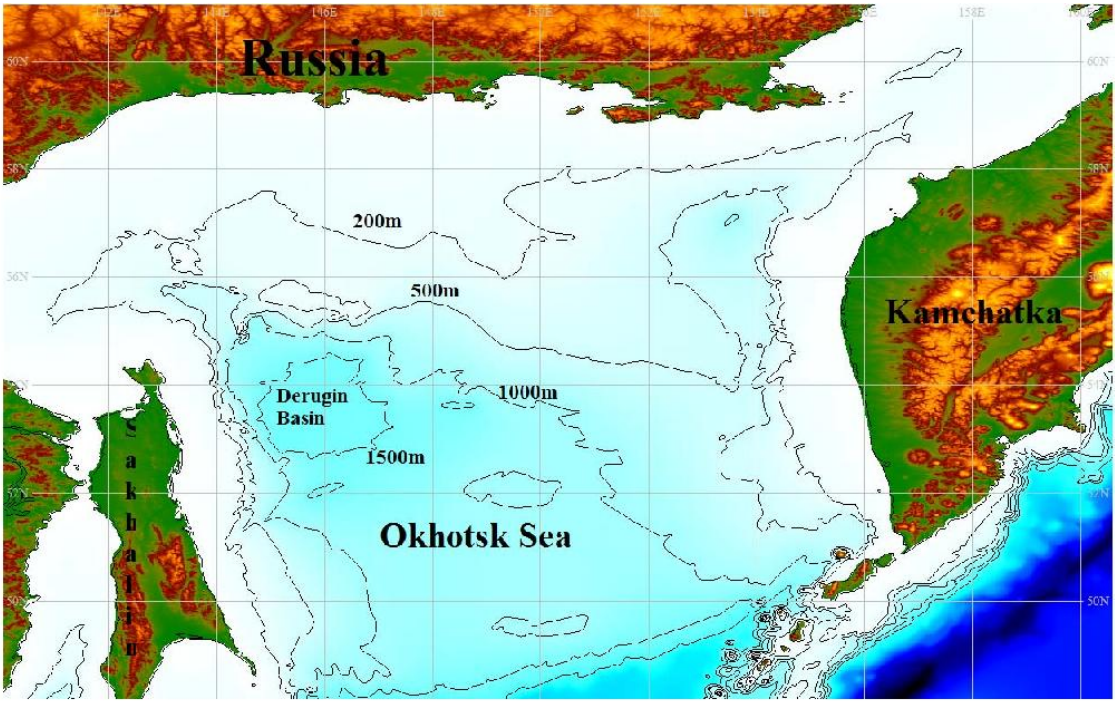

Figure 2. **Location of Deryugin Basin**

Physical methods：

1.1 Seismic*;*

At present, the most commonly used and important physical method for gas hydrate exploration is seismic exploration. The traditional seismic detection method usually uses a scientific research ship as the platform, an air gun as the source of the seismic, and a cable to receive seismic signals. Due to the low frequency, generally 20-120 Hz, it can penetrate deep strata and water depths. Since the gas hydrate storage layer is usually below the average water depth of 500 meters,and most of them are below 1000 meters. Therefore, traditional large-capacity air guns are more conducive *to penetrating thick layers of seawater and revealing the entire gas hydrate stabilization zone. Judging from the existing practical experience and data, the traditional seismic exploration method is still the most effective method, while other methods are often complementary and complementary to the results of traditional methods. The BSR interface it reveals is also the clearest.*

1.2 High-Frequency.

Although the low-frequency seismic method provides a clear BSR interface, its resolution in the longitudinal plane is subject to certain constraints. In order to know the detailed structure of the gas hydrate, people need to use high-frequency seismic to assist. Its working principle is roughly the same as the traditional method, but these two are different equipment. After increasing the frequency up to about 200 Hz, the BSR profile shown after post-processing is clearer.

1.3 ***DTAGS.***

The full name of this system is Deep towed acoustic geophysical system, which is fundamentally different from the seismic detection method. The United States first used this technology to detect hydrates in offshore areas of Canada and the United States. It consists of seismic sources, cables, depth-setting systems and underwater positioning systems. It can provide a frequency of 220-1000 Hz, and the ultimate working water depth is 300 meters. The detailed structure of the gas hydrate can be displayed more clearly in both horizontal and vertical directions than in seismic detection, with a resolution within 10 meters. And it can more clearly show the existence of faults, show the migration and rising channels of gas. But its weakness is that the BSR response is not obvious.

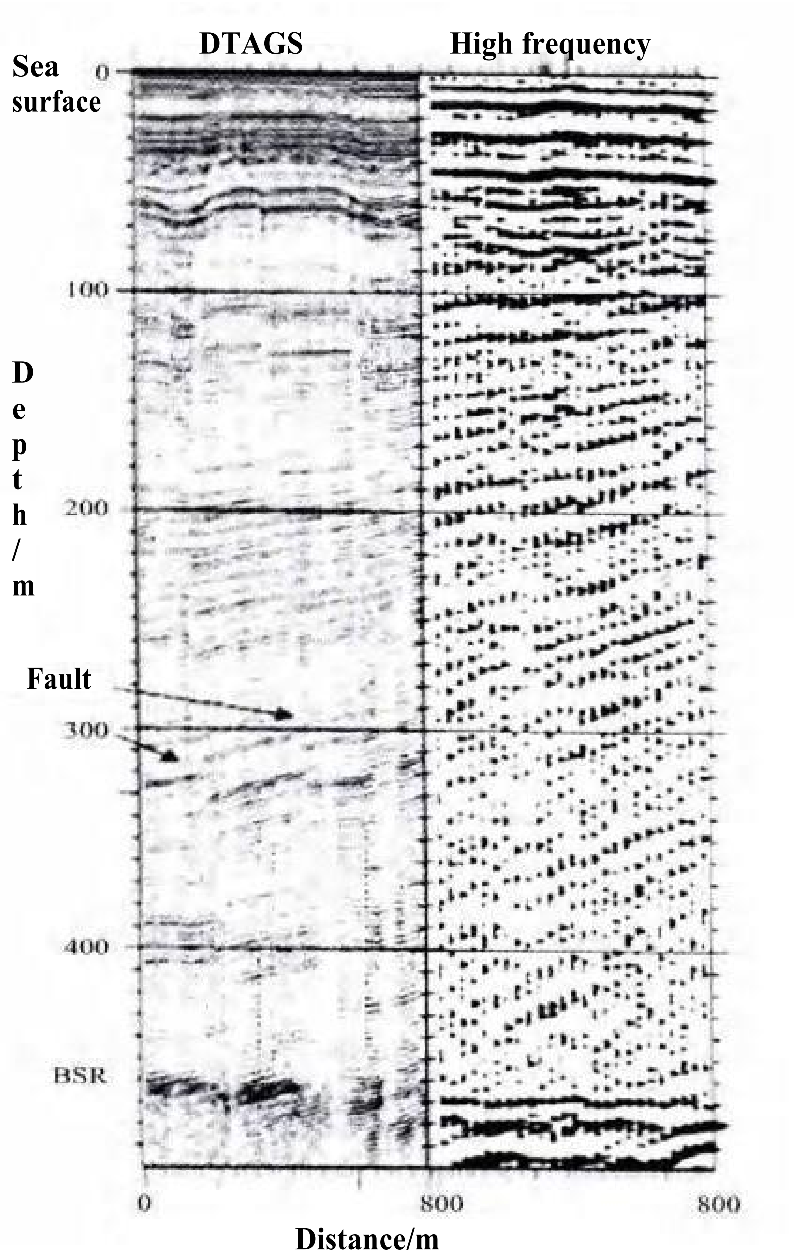

Figure 3. **Comparison of the effects of DTAGS and high-frequency seismic instruments**

1.4 Seabed seismic instrument.

This technology was born in the Cold War era of the United States and the Soviet Union. It is a "black box" placed on the seabed to eavesdrop on each other's nuclear *test data. Its main frequency is only 1.5-2 Hz. Since the 1960s, scientists have applied it to observe the crustal conditions of the ocean, placed devices on the seabed and carried out long-term data collection and monitoring. With the help of the reflected waves of natural earthquakes, the structure of deep strata can be understood.*

1.5 ***Submarine seismic cable*.**

This method refers to laying seismic cables on the seabed for seismic data reception. Initially, it was mainly used for operations in shallows and offshore areas, but practice has proved that this method has particularly unique advantages. Although its use cost is more expensive, researchers still use it gradually for a wider range of exploration operations. Because the cable is laid on the seabed, it is relatively stationary. Therefore, compared with the data loss that is bound to be caused by the towing cable during the movement process, the cable can greatly reduce the noise of water, realize full-wave reception (S-wave, wide-angle data) and 4D repeated observation. In particular, receiving S-waves is a great help to the imaging of gas regions below BSR.

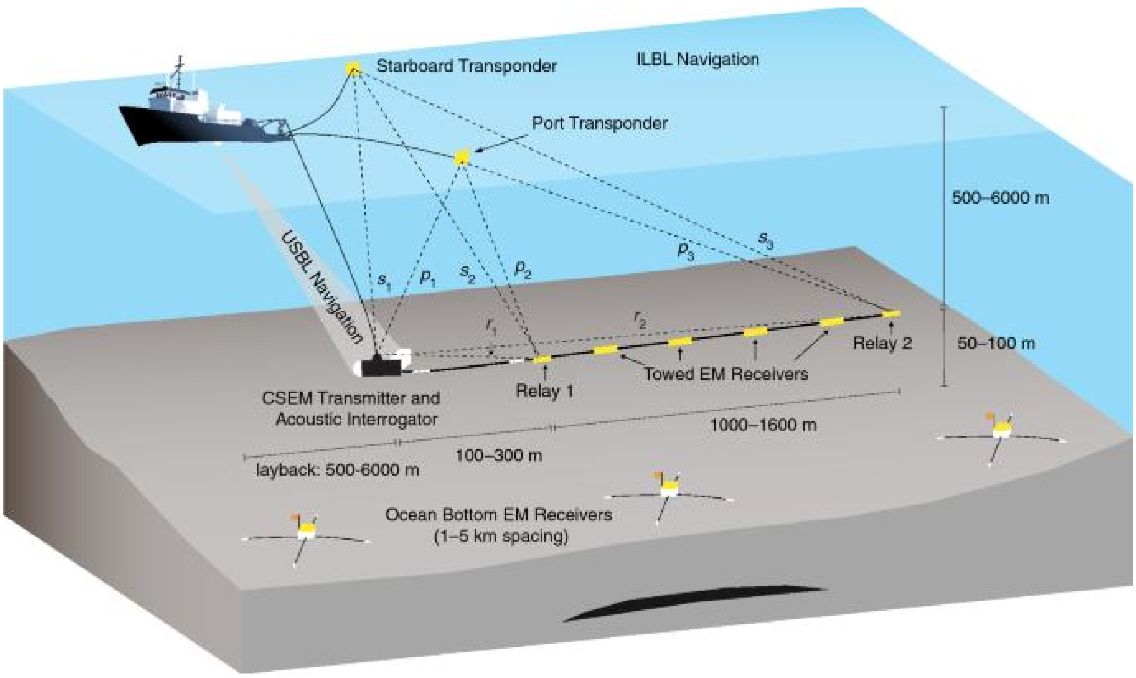

Figure 4. **Schematic diagram of seismic detection method of work ship**

2. ***Micro-geomorphology of the seabed***.

The distribution of gas hydrates is closely related to the landform of the seabed. Special structures such as Pits geomorphology, Carbonate rock crusts, Cold steep, Cold spring biota, Mud volcanoes and Fault structures can be regarded as signs of possible gas hydrate mineralization. For example, due to the presence of gas hydrates, in most cases in this area, diapirs and fluid overflow will create landforms such as pits and mounds on the seabed. After practice, it has been found that the microstructure like acne tumors is often related to gas hydrates.

3. Methane flame detection in water bodies.

In areas where gas hydrates are enriched, due to the presence of faults or diapirs systems, the decomposed methane gas in the sediments directly oozes into the water body on the surface of the seabed through these rising channels, by the form of small bubbles. With the help of a water body echo detector, the presence of these abnormal gases can be detected. In the echo meter, it is imaged as a column of gas shaped like a flame. This technology can easily, quickly and effectively detect methane leakage systems on the seabed.

4. Heat flow on seabed.

This method is also an important means of studying gas hydrates. Since temperature and pressure are necessary conditions for the formation of gas hydrates, the real heat flow and temperature of the seabed are directly obtained by using a heat flow probe, and then the BSR data is used to compare with the estimated heat flow value, and the interval of the gas hydrate stabilization zone can be effectively estimated.

5. Electromagnetic method.

The BSR interface has obvious reactions in the seismic detection profile, but the interface on the gas hydrate is not easy to determine. The gas hydrate is an insulator in terms of physical properties. The thickness and porosity of the gas hydrate can be understood by using the seabed controllable electromagnetic method (CSCM) and the seabed transient electromagnetic method (TEM). Supplemented by seismic detection data to evaluate and calculate the amount of gas hydrate resources.

6. Gravity.

If the uppermost sediments of the seabed are enriched by the gas hydrate, then some of their physical properties are different from sedimentary layers that do not contain the hydrate. By collecting the fluctuation data of ocean fluctuations on the vertical surface of the seabed to calculate the shear modulus of the sedimentary formation, the abnormality of this parameter can estimate the content of hydrates in the formation.

Chemical methods:

1. Abnormal of gas.

About 99% of the gases that make up hydrates found on the seabed are methane gas, in addition to a small amount of ethane, propane, butane and nitrogen. Therefore, it can be inferred that the hydrocarbon gas in the hydrate enrichment area and other non-hydrocarbon gases generated after the reaction will show abnormal content.

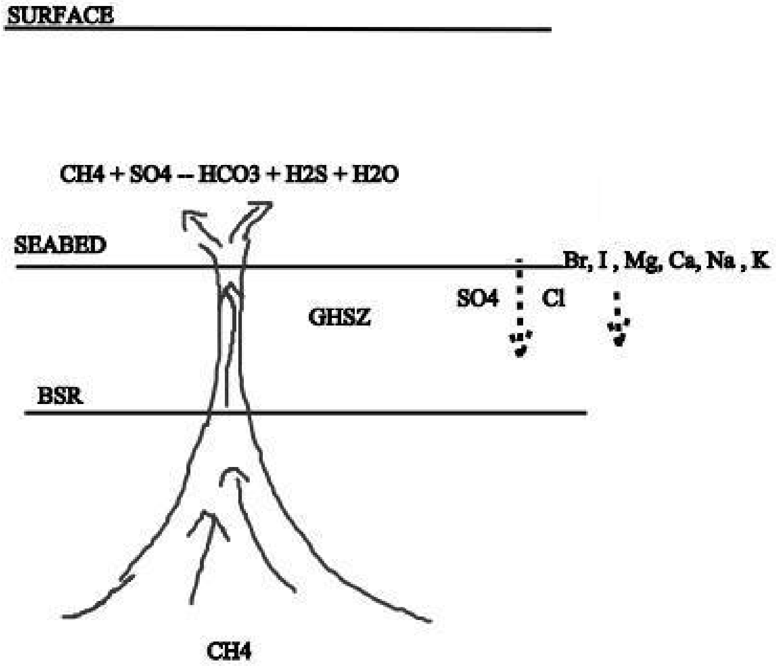

Figure 5. **Schematic diagram of chemical fluid release**

1.1 Abnormality of methane.

Headspace samplar is usually used to collect free methane gas for sampling. In normal seawater, the content of methane gas is between single digits and tens of thousands of ng/L, and methane leakage formed by the decomposition of hydrates can increase this value up to thousands of times. In the water column profile of the seabed, the concentration of methane generally increases with the increase of water depth.

1.2 Abnormality of H_2S.

H_2S has been found in all core samples of hydrate-endowed sediments around the world. This is due to the chemical reaction between the rising methane gas and SO_4, which produces a large amount of H_2S. H_2S gas ejection has been found off the coast of Canada and the United States. From this, it can be inferred that the high H_2S content may be a sign of large-scale storage of hydrates.

2. Fluid chemistry.

This method mainly uses the abnormal concentration of molecules and ions in the liquid at the bottom of the seabed and the fluid in the pores of the sediments to infer the possibility of the existence of gas hydrates. The reason is that due to the special molecular structure of the gas hydrate, free ions cannot enter its interior, so the salinity in seawater increases and the salinity in its pore water decreases.

2.1 Contents of Cl ions and SO_4 ions.

The concentration of Cl in pore water is abnormal; in areas where hydrates are distributed, the salinity in pore water decreases with the increase of sedimentation depth. The formation of hydrates produces salt discharge, which causes the salinity in the pore water to increase abnormally. As the sediment is compacted, the solid and liquid separate. The liquid is squeezed upward, causing the salinity at the top of the sediment to increase, while the salinity near the hydrate decreases.

In addition, in the hydrate storage area, there is always a decrease in the content of SO_4 ions as the depth changes. The reason is that methane gas reduces SO_4 ions in sediments under the action of microorganisms, and the reaction formula is as follows （as figure 5）：

$CH_4+SO_4=HCO_3+HS+H_2O$.

2.2 Isotope.

Stable isotopes are the most effective means to study the source of hydrate mineralization gas. The d13C, dD values in methane (these two values in the methane can be used for determination the origin of methane-in the from of free gas or gas hydrates: microbial or diagenetic, thermogenic or catagenetic, abiogenic e.g.mantle) and the 34S values in hydrogen sulfide are important bases for determining and judging hydrate mineralization. Another theory proposes to use the Sr concentration in pore water and the ratio of 87Sr/86Sr to determine the source of mineralization fluid.

Biological method:

1. Cold steep - Fungal diversity

Cold steep is an important sign of the gas hydrate enrichment area, because usually cold steep is formed because the methane gas in the sediments rises with the cracks and jets out of the seabed, forming a plume and affecting the surrounding environment. The temperature of cold steep is not necessarily lower than that of the seabed water, and sometimes it may be higher, so it has a significant impact on the surrounding biological clusters. For example, for the impact of the surrounding fungi, algae, or plankton species, researchers can usually assist by collecting seabed water samples from the target sea area and analyzing their biological samples to determine whether there may be hydrates or natural gas deposits in the area.

Results:

BSR:

The full name is bottom-simulating reflector. It is a kind of strong reflection on a certain interface in seismic detection. In the detection of gas hydrates, BSR is an important reference condition for the presence or absence of gas hydrates. If a certain area is rich in gas hydrates, the BSR is regarded as the lower interface of the hydrate *stabilization zone, but in the non-hydrate zone, the BSR (Figure 3) may also be the boundary of the conversion of opal-A to opal-CT or the node of the conversion of smectite to illite.*

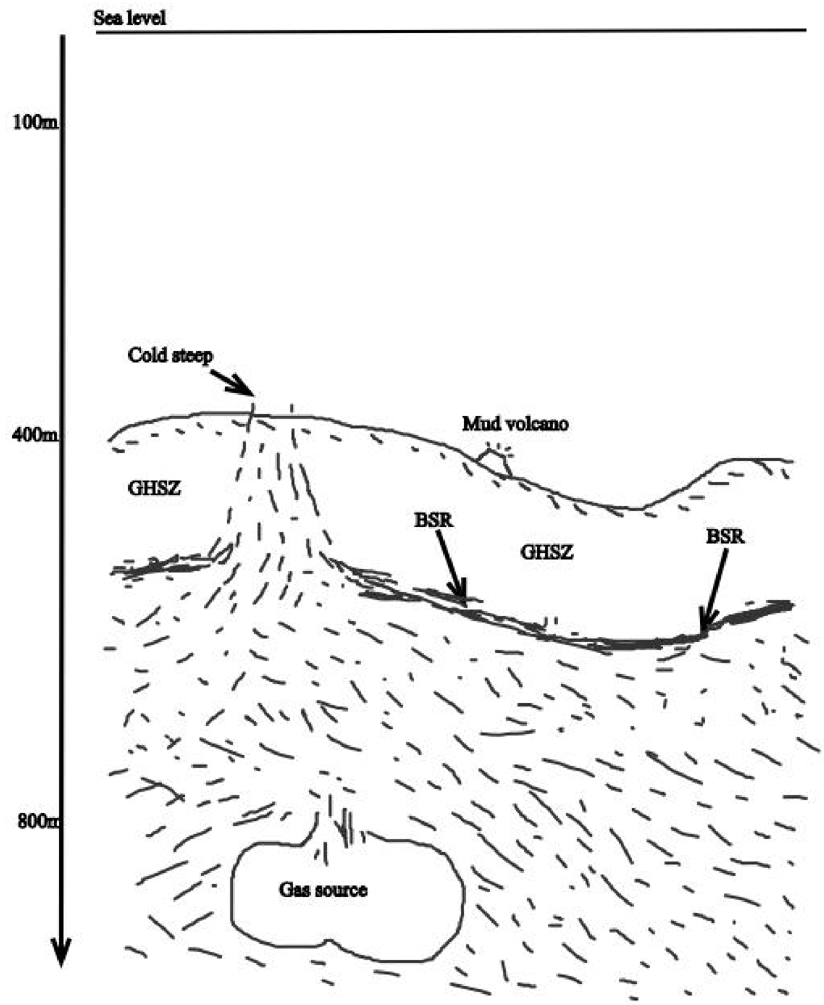

Figure 6. **Schematic diagram of BSR**

GHSZ (Gas hydrates stabilization zone):

Taking the parameters of geothermal gradient (average value 30-36 C), average seabed temperature 1.5C, methane content 100%, and salinity 3.5%. Since the depth of the Deryugin Basin deepens with offshore distance, I calculated and plotted the prediction chart of the hydrate stabilization zone of the Deryugin Basin based on different water depths (as shown in the figure 7 and 8).

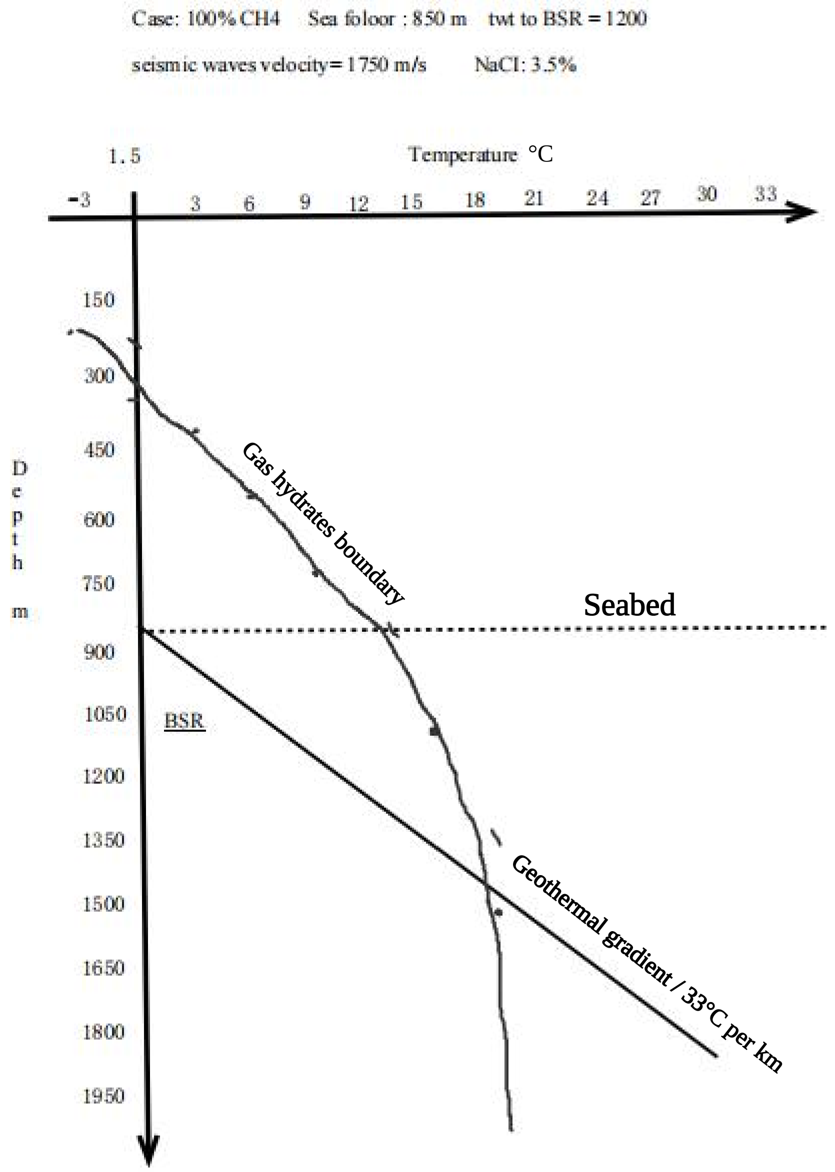

Figure 7. **Hydrate phase boundary table in Deryugin basin (within the above specific parameters)**

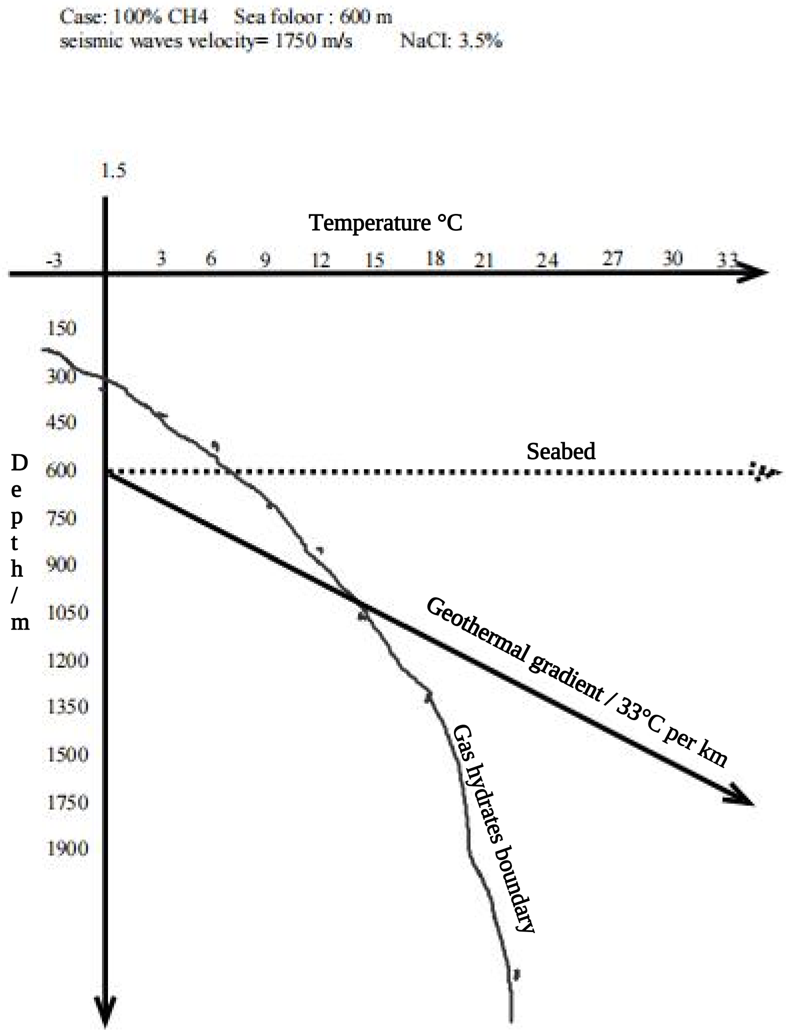

Figure 8. **Hydrate phase boundary table in Deryugin basin (within the above specific parameters)**

In Figure 8, on the seabed at a depth of 600 meters, under the above conditions, the hydrate stabilization zone should be within 400 meters down from the seabed as the base point. In Figure 7, I tried to locate the seabed at 800 meters depths. Under the parameters of same conditions, it shows that the range of 500 meters below the seabed is a hydrate stabilization zone.

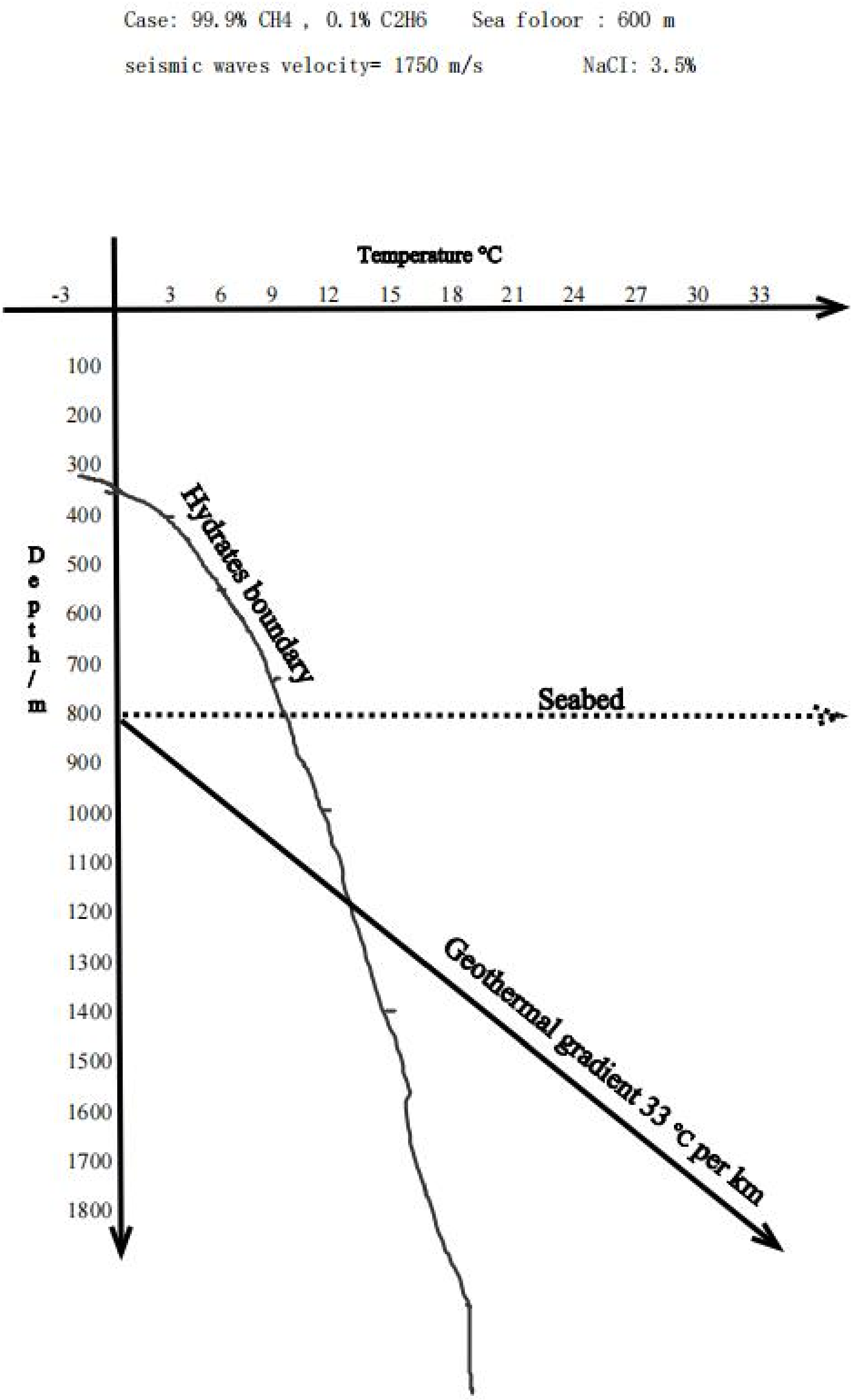

Figure 8.1 **Hydrate phase boundary table in Deryugin basin (within the above specific parameters)**

According to the actual data collected by the China-Russia-South Korea-Japan joint expedition in a series of surveys on seabed geology and hydrates conducted in the northeast of Sakhalin Island from 2003 to 2015, one of the BSR reaction diagrams (Figure 9) also confirmed the accuracy of the predicted reservoir formation in Figure 7.

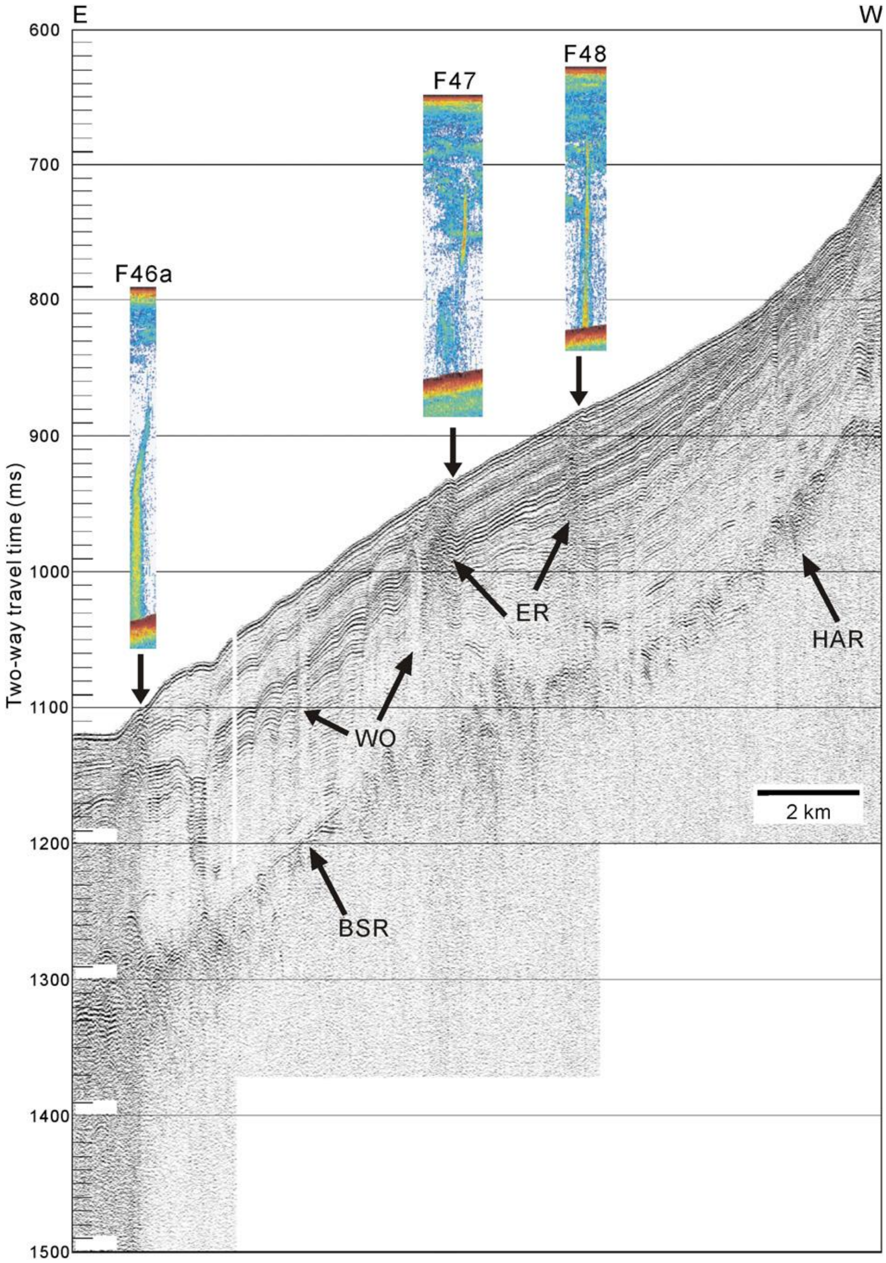

Figure 9. **Hydrate-related geological phenomena such as BSR reflection and methane flame found at an average depth of 1,000 meters in the Deryugin Basin in 2011.**

The figure shows that there is a strong reflection of BSR within 200 meters below the average seabed depth (850 meters) and it is a hydrate stabilization zone.

Acne tumor landscape:

In the chapter on the physical detection method of hydrates, it is mentioned about the role of seabed micro-landforms in hydrate exploration-such as the seabed "acne tumor" landform. In a scientific expedition by a Russian (Joint scientific expedition of Russia, China, Japan and South Korea) scientific research team, R/V Sonne technology was used in the area of 144.00-144.24 East Longitude and 54.32-54.20 North Latitude to obtain the geomorphological performance of "acne tumors" covering the entire area (Figure 10).

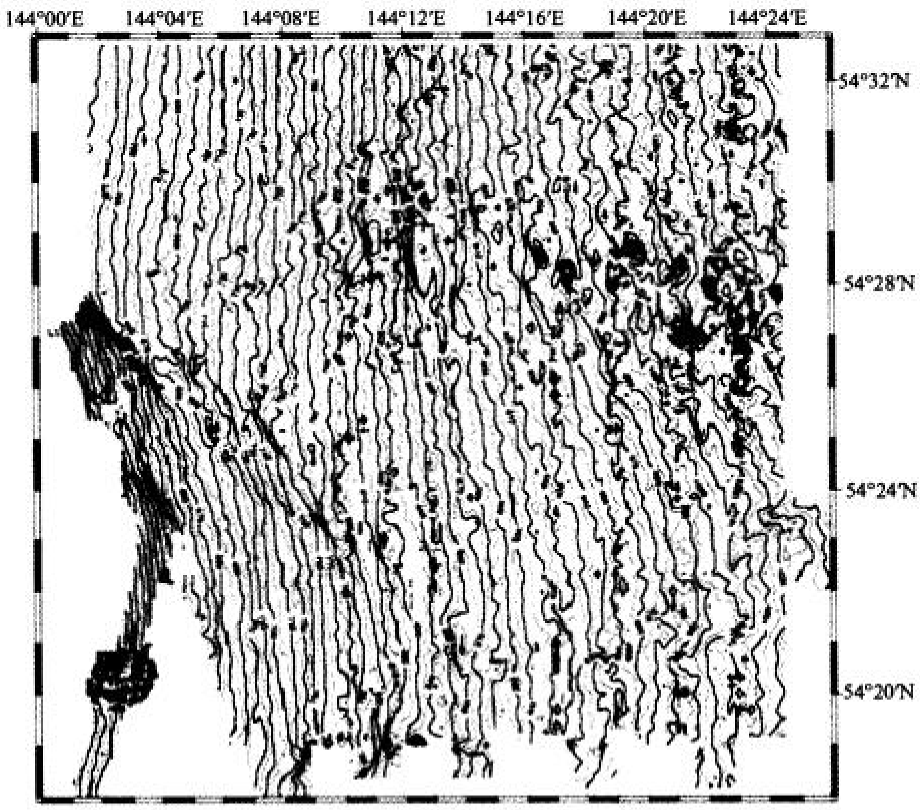

Figure 10. **Using R/V Sonne, the seabed geomorphology of the area obtained after technical treatment.**

Methane flame:

Gas anomalies are mentioned in the chemical detection method. Also in many studies on the northeast sea area of Sakhalin Island from 2003 to 2017, a large number of abnormal ejections and presence of methane gas were found (as shown in Figure 9, 11). Since there are two main ways of hydrate accumulation-diffusion and leakage, methane will leak to the seabed along the ascending channel or Diapirs system in areas where the gas is sufficient, causing methane abnormalities in the seabed waters. Also in Figure 11, a large number of methane flame jets were found at different sites by using the echo system.

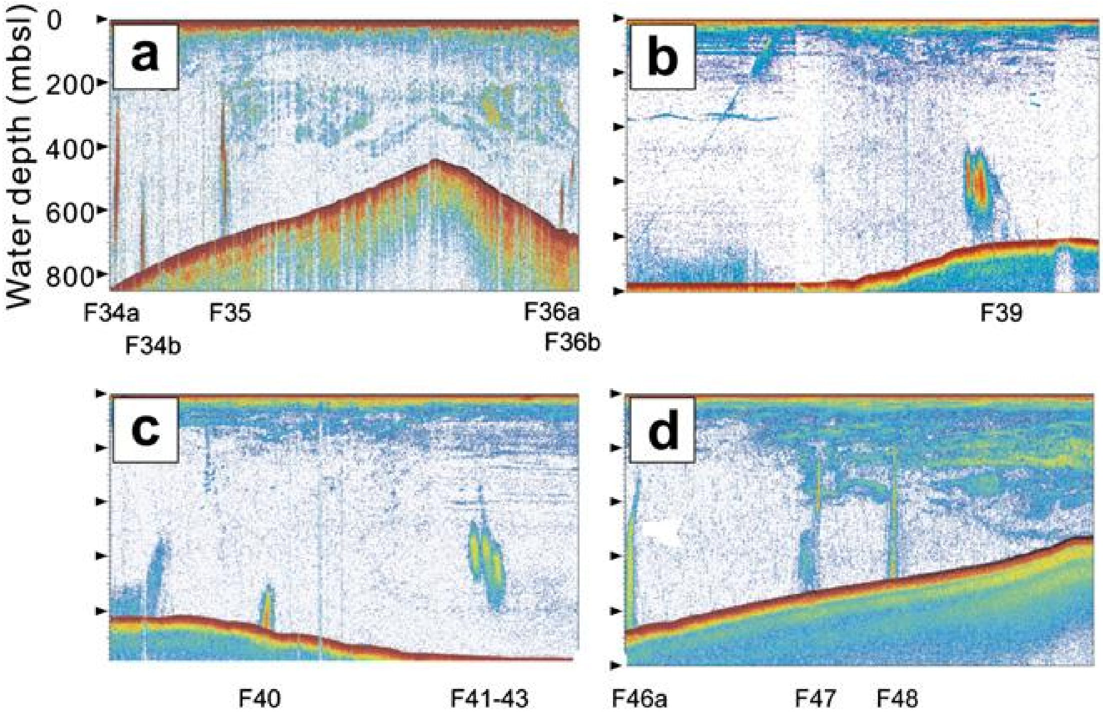

Figure 11. **Methane flames found at different depths and points in the Deryugin Basin**

H2S content exceeds the standard:

In a sampling of hydrates conducted in Russia and China around the Deryugin Basin, when the sampling device was opened, the physical gas hydrate smelled strong *hydrogen sulfide gas. Thus, the theory that hydrogen sulfide gas exceeds the standard in the chemical survey method is also confirmed.*

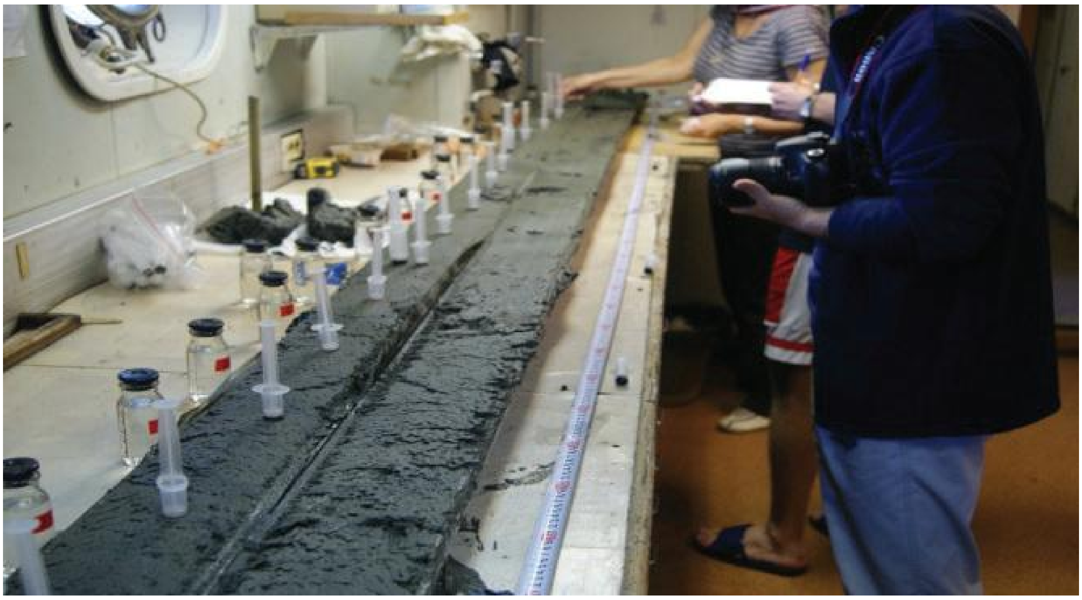

Figure 12. **Sediment samples directly sampled from the sea basin have a strong pungent smell**

Cold Steep - Eukaryotes:

Submarine cold steep often occur in areas with rich gas hydrate reserves. The temperature of a cold steep is not necessarily lower than the water temperature of the seabed, and it can form a plume-like jet to radiate the surrounding ecosystem. During a joint expedition(Russia,China,Japan,Korea Okhotsk Sea Compound Joint Investigation Voyage in May 2006), researchers collected biological samples around a cold steep in an area rich in gas hydrates. After researching the samples and statistics, the diversity of eukaryotes has been discovered. Such as algae diversity, fungal diversity and plankton diversity. And the diversity of fungi is the highest, and the diversity of plankton is the lowest. The average coincident diversity of the three types of organisms can reach 90%.

Discussion:

Features about the formations of gas hydrates in Deryugin basin:

According to a large number of practices, it has been proved that there are a large number of gas hydrates in the Deryugin Basin. The formation of gas hydrates in this area can be discussed from the following four aspects.

1.1 Sources of gases

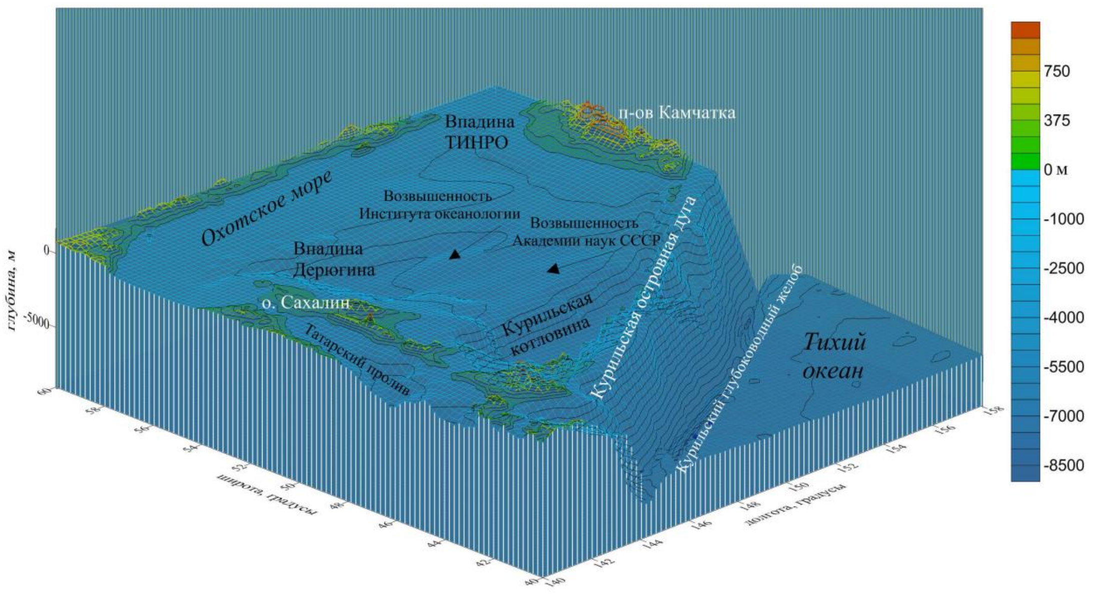

Figure 13. **3D topographic map of the seabed of the Okhotsk Sea.**

1.1.1 ***Sediment source.***

The Okhotsk Sea is located on the northwestern edge of the Pacific Ocean and is the second largest land edge sea in the Northwestern Pacific Ocean. The north-south span is about 2,000 kilometers, and the east-west span is about 1,700 kilometers. It is surrounded by continental plates on the east, west, and north sides, and is mostly dominated by alpine landforms. For example, the Chersky Mountains in the north and *the Dzhugdzhur Mountains in Khabarovsk Krai have an altitude of more than 3,000 meters, and the average altitude is more than 2,000 meters. Sakhalin Island is the western boundary of the sea area, and Sakhalin Island is about 1,000 kilometers north-south. Its mountain range is north-south, with a maximum elevation of 1,600 meters, high mountains in the south and impact plains in the north. The Deryugin Basin extends to the east 200 kilometers from the northern part of the island. In the south, the Kamchatka Arc separates the Okhotsk Plate from the Pacific Plate.*

These tall mountain systems that surround the Okhotsk Sea continue to provide a rich source of sediments every year. These sediments are transported to the sea by rivers, glaciers, or landslides, especially structures like the depth of the Okhotsk Sea that deepen from the surrounding area to the central area, forming a wide and deep shelf sedimentary system in the sea area, especially in the basin.

1.1.2 Thickness of sedimentary strata.

Due to the rich sources of sediments, sedimentary strata in a wide area except for the Kuril Basin have been adequately developed. After researching, it was found that the thickness of the sedimentary strata in this area generally exceeds 10 kilometers, and depressions of more than 10 kilometers have appeared in the thickness of the sedimentary cover generated in the Cenozoic. As shown in Figure 14.

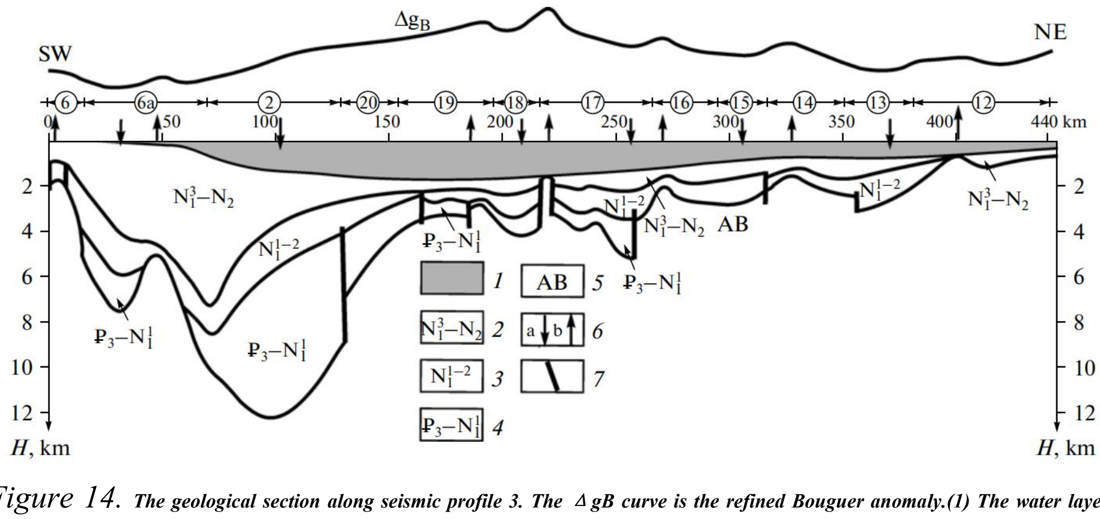

Figure 14. ***The geological section along seismic profile 3. The ΔgB curve is the refined Bouguer anomaly.(1) The water layer; (2 – 4)the RSSCs: (2) the Upper Miocene – Pliocene (RSSC IV), (3) the Lower – Middle Miocene (RSSC III), (4) the Oligocene – Lower Miocene (RSSC II); (5) the AB; (6) the axes of (a) the troughs and (b) rises; (7) faults. The circled numbers denote the structural elements (corresponding to those in Fig. 4), from the SW to NE: (6) the Schmidt – Odoptu Rise; (6a) the East Schmidt subzone; (2) the Deryugin Trough; (20) the Institute – Deryugin Trough; (19) the Atlasov Rise; (18) the Central Okhotsk Trough;(17) the rises and troughs in the Central zone; (16) the Lebed' Rise; (15) the Lebed' Trough; (14) the Kashevarov Rise; (13) the East Kashevarov Trough; (12) the rises and troughs in the Central Okhotsk zone.***

(According to P. F. Volgin, V. P. Semakin, and A. V. Kochergin, 2007, Structural Elements of the Sedimentary Cover in the Deryugin Basin of the Sea of Okhotsk）

The sedimentary cover can be divided into three seismic units.

The lower unit is a paleogene formation that has developed from the bottom of the basin, with a maximum thickness of 6,000 meters. However, the continuity of this unit is poor and it is not in integrated contact with the lower strata. It also exhibits different sedimentary facies features, mainly coarse debris, sand and mud in the offshore shelf area, as well as turbid current deposition in the semi-deep sea area.

The central unit is widely present, with a maximum thickness of 4500 meters, and the sedimentary age is Oligocene to Miocene.

The upper unit is the clearest and continuous in seismic reflection. The maximum thickness in the basin area is 6000 meters.

1.1.2 ***Organic carbon content.***

*The content of organic matter plays a decisive role in the formation of hydrates. If it is assumed that there is a stable hydrate storage zone 5 meters below the seabed, the porosity of the sediment is 40%, the hydrate occupies 5% of the pores, and the aggregation rate of free gas into hydrate reaches 1%, then the pressure intensity of the gas source rock below should be 16*10^8 m3/km2(According to 2002, Lu H, Prelim inary experimental results of the stable P —T condition of methane hydrate in a non fossil clay). The intensity is basically comparable to that of medium and large natural gas fields, and such a high intensity requires a higher organic carbon content. However, if the carbon content in the formation is less than 0.5%, it is impossible to generate hydrates. The carbon content in all currently known hydrate storage areas is higher than 0.5%. Due to the special geographical location of the Okhotsk Sea, its sources of sediments and organic matter are quite extensive and rich. According to long-term data collection and observations, the dissolved organic carbon (DOC) and particles organic carbon (POC) in the coast from the northwest coast were 13.6 and 0.9 TaG/a, respectively (According to 2004, Nakatsuka T， Toda M ， Kawamura K ， etat． Dissolved and particulate organic carbon in the Sea of Okhotsk：their transport* *from continental shelf to ocean interior). The Amur River imports about 300km3 of fresh water into the Okhotsk Sea every year, of which DOC has 2.5Tag/A. This amount can be compared with the input of the world's largest river.*

A large number of clay, diatoms, hydrochloric acid rocks, shells and other samples collected by the gravity sampler in the marginal area of Deryugin basin, due to the large amount of hydrogen sulfide, emit a strong and pungent smell. After the gas composition was tested, it was found that the methane content was also very high. These evidences all indicate to varying degrees the high content of organic carbon in the sedimentary strata in this area, and the content is above 1.5%.

Total organic concentration of bottom sample of Okhotsk Sea

Samples	Latitude(N)	Longitude (E)	Depth/m	TOC/%	Documents
XP99-MC50	55°35. 28′	140°50. 76′	184	2. 20	Seki,etc,2006
XP99-MC63	54°59. 35′	141°00. 14′	134	1. 07	Seki,etc,2006
XP99-MC5	51°27. 87′	145°03. 09′	787	2. 18	Seki,etc.2006
XP99-MC85	52°21. 10′	146°17. 59′	1 440	1. 82	Seki,etc,2006
XP99-MC22	49°31. 38′	145°40. 39′	490	2. 41	Seki,,etc,2006
XP99-MC19	48°35. 77′	149°41. 68′	1 613	0. 63	Seki,etc,2006
GGC-15	48°10. 1′	151°20. 2′	1 980	1. 05	Ternois,etc,2001
936	51°00. 9′	148°18. 8′	1 305	1. 7	Gorbarenkoetc,2004
kit	54°30′	144°12. 4′	860	1. 8	Mazurenko,ect,2005

Figure 15. **TOC ratio of samples collected at different sites in the eastern Sakhalin Sea area**

1.1.3 Deposition rate.

The deposition rate is also an important control condition for the generation of hydrates. A higher deposition rate is more conducive to promoting the formation and development of hydrates. Generally speaking, formations with higher sedimentation rates have larger porosity, leaving more space for hydrate diffusion generation and storage; at the same time, rapid sedimentation is also conducive to a large number of *organic debris being quickly buried without being oxidized, which provides more material sources for the late biological conversion of methane. In the known hydrate proven areas(According to 2001, TernolsY， KawamnraK， Keigwin L， et a1． A biomarker approach for assessing marine and terrigenous inputs to the sediments of Sea of Okhotsk for the last 27000 years), the carbon deposition rate in the formation exceeds 3cm/kca, and in the Central American Trough it is as high as 105cm/kca. Among the sedimentary samples collected at different sites in the Okhotsk Sea area, the lowest sedimentary rate was measured by carbon 14 method at 5.5cm/kca, and the highest was 16.5cm/kca. The average rate of most formations is around 10cm/kca.*

2. ***Temperature conditions.***

The stable formation of hydrates is strictly limited by pressure and temperature. Low temperature and high pressure are conducive to stable hydrate generation and storage. The Okhotsk Sea is located at high latitudes and is affected by the Siberian monsoon in winter, and most of the sea surface is covered by sea ice. At the beginning of March every year, about one-third of the sea surface is covered by sea ice, and in May, there is still some drift ice in the northwest continental shelf area. In summer, the sea temperature is higher, and it can reach about 10 ℃. According to scientific research data, there is a low temperature layer in the area of 50-120 meters below the sea surface, and the water temperature is stable around freezing all year round. The temperature of the water body begins to increase at this depth, and the water temperature is about 2 ℃ at a depth of about 800 meters. The water temperature near the seabed is 1.5 ℃. It can be seen that in the Okhotsk Sea, the overall temperature from the shelf to the basin is low, and such a temperature is definitely beneficial for the generation and storage of hydrates.

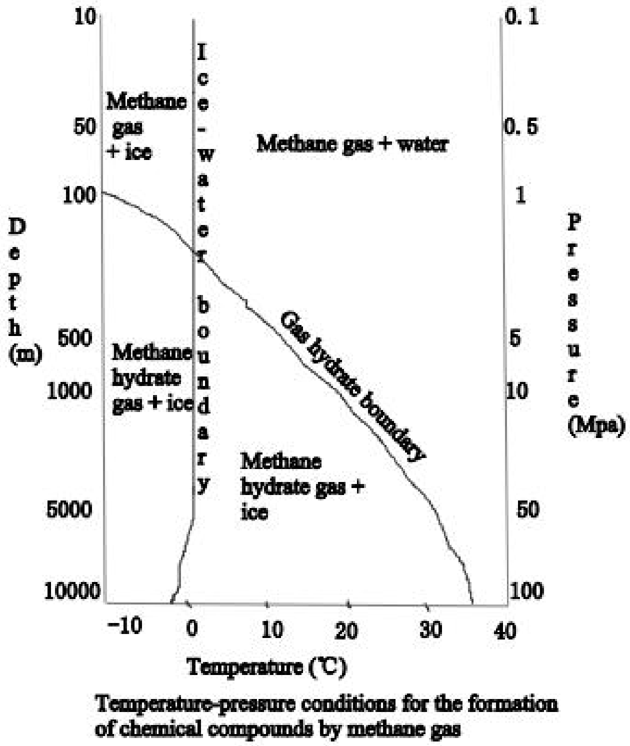

Figure 16. **Hydrate phase boundary.**
(According to 2014, COLLETT'S. The gas hydrate petroleum system[C] / / Proceedings of the 8th International Conference on Gas Hydrates)

3. ***Pressure conditions.***

The pressure changes caused by formation extrusion, high-pressure trapping gas and temperature differences are generally difficult to estimate. Therefore, in most cases, only two factors, water pressure and rock pressure, are considered. After observation, it is known that the water temperature of the Okhotsk seabed is stable at about 1.5 degrees all year round, so the relationship between the water depth of the gas hydrates formation and the depth of the subsurface strata can be calculated only considering the pressure conditions. For example, under the conditions of meeting 100% methane to generate hydrates, a depth of 350 meters can provide the pressure necessary to generate hydrates. Therefore, in theory, areas with a depth of more than 350 meters in the Okhotsk Sea can become gas hydrate mining areas. If the average geothermal gradient is around 33 degrees per km, if the water depth is 350 meters, and the hydrate can be deposited in the area of 450 below the seabed, if the water depth is 3000 meters, and the hydrate can be deposited within the range of 800 meters below the seabed.

4. Geological structure conditions.

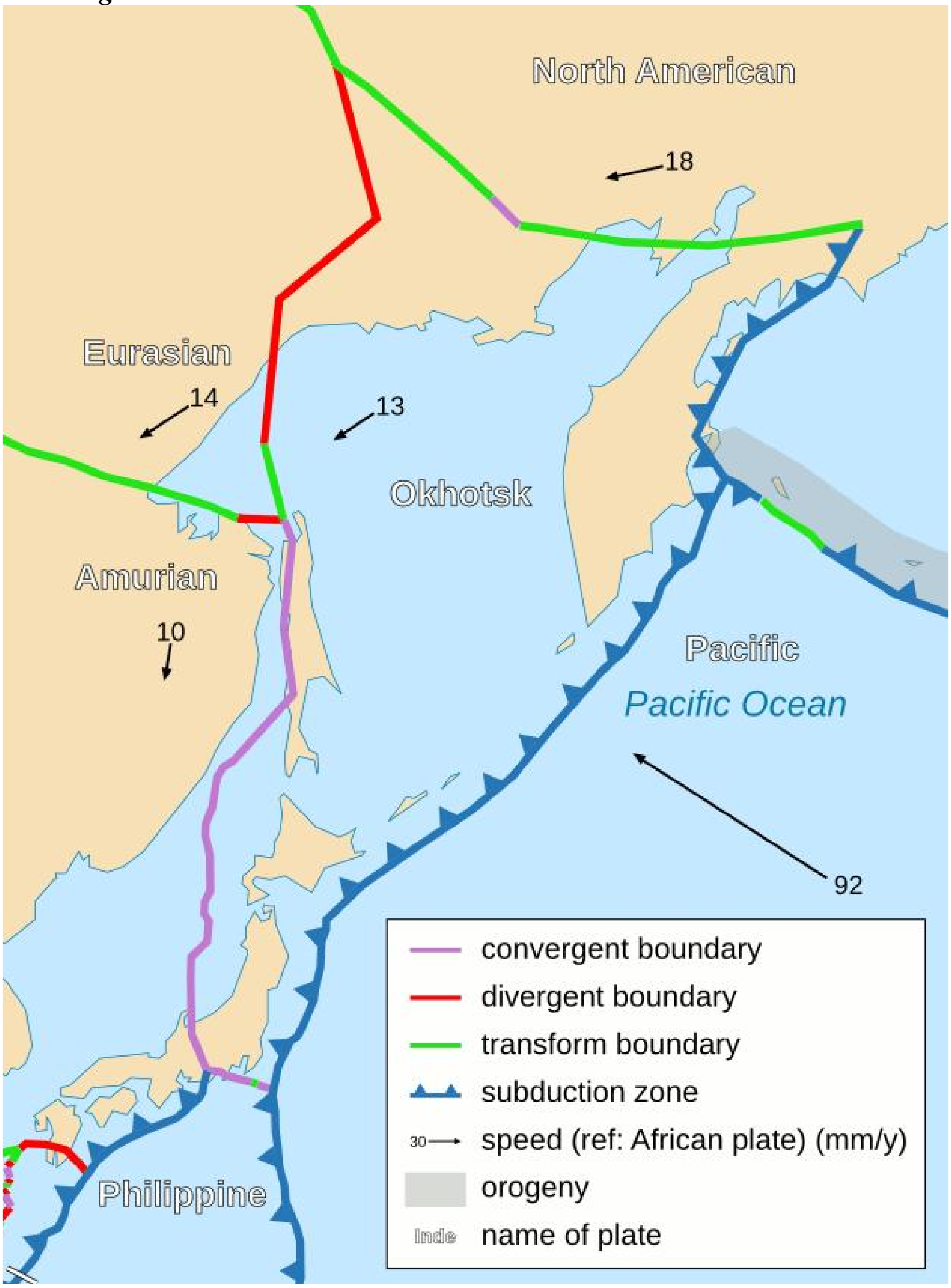

Figure 17. **Map of the location of the Okhotsk Plate and other plates**

Source from WIKI PICTURES

The Okhotsk Sea is an independent plate, surrounded by four major plates (Eurasian Plate, American Plate, Pacific Plate, Amur Plate). The southern boundary is affected by the subduction of the Pacific Plate, and the Kamchatka Arc is formed along the boundary, which is full of volcanoes and very active geological activities. The western boundary is a fault zone from Hokkaido in the south to the northern part of Sakhalin Island in the north, which is more than 2,000 kilometers long and separates the Amur Plate from the Okhotsk Plate. The area is also an ancient subduction zone, and the Deryugin Basin is a new landform formed on the ancient subduction zone. Due to tension and extrusion on this fault zone, the sediments in the basin are wrinkled to varying degrees, and the lower sediments are undering greater pressure, so that more diapirs are more obvious. Through surveys, there are many mud volcanoes around the Deryugin Basin, and it is generally believed that mud volcanoes are an effective channel for the upward transportation of gases.

Mining:

In the future, research on the methods of hydrate mining will be one of the key points in this field. Reasonable and efficient methods can help people make the highest use of this clean energy source. At this stage, there are three main methods that have been used in large-scale mining activities and one method which has been verified in the laboratory.

1. ***Heat injection method*****.**

The method includes hot water injection, steam injection, electromagnetic heating, microwave heating, hot brine heating and solar heating. The heating by injection method is direct, the effect is rapid, the heating position can be controlled, and the impact on the environment is small. It is suitable for reservoirs in many different situations. Compared with other heat injection methods, brine heating technology is more mature. Because it has the characteristics of high thermal efficiency, low heat loss, and high gas production.

2. Decompression method.

This method mainly uses technical means to reduce the pressure of the hydrate layer so that its pressure is lower than the equilibrium boundary point of the hydrate pressure phase at a specific temperature, so as to realize the automatic decomposition of the hydrate. Generally, the free gas below the hydrate is extracted to reduce the pressure drop of the reservoir, which causes the hydrate structure to become unstable and even decompose.

In addition, there is currently a method that has been demonstrated in the laboratory, that is, to significantly reduce the pressure of the reservoir until the temperature drops below 0 degrees Celsius (freezing point), and the hydrate decomposes to produce ice instead of liquid water. In this case, the hydrate can continue to decompose into gas without external heat input. However, the temperature needs to be maintained at 272 Kelvin for the decomposition efficiency to be high. If it is reduced to 268 Kelvin, the decomposition rate will slow down.

3. Chemical inhibitors.

The method is to inject chemical reagents into the reservoir to break the phase balance of the hydrate and change the temperature and pressure conditions, thereby promoting the decomposition of the hydrate. This method is relatively simple to operate, but the disadvantages are high cost, slow effectiveness and the risk of pollution to the surrounding environment.

4. Carbon dioxide replacement.

Since carbon dioxide hydrates are more stable than methane hydrates, Ebinuma proposed for the first time to replace methane in methane hydrates with carbon dioxide, and Ohgaki et al. confirmed the feasibility of this method in the laboratory for the first time. The advantage of this method is that the hydrate reservoir can be completely protected from geological disasters, and carbon dioxide can be sequestered on the seabed to achieve the effect of reducing greenhouse gases. However, the cost of using this method is still unknown.

Conclusion:

In summary, the Okhotsk Sea area constitutes a stable hydrate development and storage area due to its year-round stable low temperature (close to freezing point), sufficient pressure (average depth of 800 meters), rich sediment sources (Amur River, Sakhalin Island) and special geological formations (Ancient subduction zone). And with the rapid development of geophysical methods and chemical methods, people's methods of discovering and understanding hydrates have gradually become more accurate and diverse. In addition, judging from the characteristics of hydrate formation in the Okhotsk Sea area, we can comprehensively judge that there must be a large amount of hydrate deposits in the waters of the Arctic region. In the Arctic, there are a number of rivers that run through the Russian land and eventually flow into the Arctic Ocean, such as the Lerner River, the Kolema River, and the Ob River, which provide a steady stream of large amounts of organic matter and sediments. The Arctic Ocean with an average depth of 1200 meters is sufficient to provide the pressure conditions required for hydrate generation. Finally, in terms of mining, more practice is still needed to verify the best relationship between mining efficiency and cost. More demonstrations and experiments of new methods are also needed in the laboratory.

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