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Environmental and Ecological Protection Equipment in Deep Sea

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Abstract: The deep sea contains numerous resources that have not been fully recognized and exploited. However, as compared to the land and inshore areas, the deep sea presents more serious problems and challenges regarding environmental and ecological protection. To ensure coordinated development between deep-sea resource exploitation and environmental protection, this study introduces the different types of equipment related to environmental and ecological protection in the deep sea, and summarizes the historical and current situations of and challenges faced by them within the domestic and international context. Additionally, deep-sea equipment related to environmental and ecological protection is introduced from the perspective of *in situ* detection, sampling, experimental simulation on land, and long-period observation. China lags behind in terms of high-precision deep-sea sensor technology. Furthermore, it lacks general matching technology for deep-sea exploration equipment. Thus, there is an urgent need to improve large-scale deep-sea environment simulation equipment in China and enhance the long-term *in situ* experimental ability related to manned submersibles. Finally, this paper proposes development strategies and suggestions with respect to innovation capability, top-level design, talent cultivation, and international cooperation.

Keywords: deep sea; environmental and ecological protection; *in situ* experiment; truth-preserving sampling; *in situ* simulation

1 Introduction

The deep-sea environment is rich in biological, mineral, oil and gas, and space resources; therefore, it can help promote the development of science and technology in various fields. As deep sea is emerging as a new hotspot of human activities, it has raised several challenges in the protection of the deep-sea environment and ecology. In comparison to land and other regions of the sea, the deep-sea region is significantly affected by environmental pollution. Appropriate control of the deep-sea region is difficult because of its unique geographical location and environment. Moreover, its ecosystem is fragile and has poor resilience. Therefore, deep-sea mining and other resource exploitation activities can negatively impact this environmental ecosystem. Given that the pollutants introduced to the deep sea can spread to the adjacent regions of the sea via ocean currents, the ecological impact of deep-sea resource exploitation and development has gained significance, as compared to its impact on the land.

Protection of the deep-sea ecological environment and promotion of the deep-sea environment and ecological protection equipment are crucial approaches to accelerate the process of Anthropocene, and improve living

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conditions on Earth. Globally, since the 1990s, there has been accelerated development in environmental and ecological protection equipment and its related technology. As compared to the coastal and offshore regions, the deep-sea region faces delays in the development of environmental and ecological protection strategies due to its considerably distance from the mainland. At present, technologies and systems related to deep-sea environmental and ecological protection equipment have not been fully established. Therefore, it is imperative to comprehensively determine their related development history, current situation, and future prospects. To this end, this study analyzed the requirements of equipment and technology for deep-sea environmental and ecological protection, defined the connotation and types of deep-sea environmental and ecological protection equipment, and examined the development history along with the current situation of the related equipment. In addition, existing problems related to the development of deep-sea environmental and ecological protection equipment in China were elucidated, and relevant countermeasures were proposed to provide basic scientific support to researchers working on the development of deep-sea environmental and ecological protection equipment in China.

2 High-level environmental and ecological protection by deep-sea equipment

2.1 Strategic requirements

In comparison to land, air, and space, deep sea has been lesser explored and is considered the least understood blind spot for the science community. Human understanding and exploitation of the deep-sea environment is currently in its primary stage. The first country to fully explore the deep sea would seize commanding heights in the Blue Enclosure Movement of the world. China is rich in land and sea resources. Therefore, it is important for China to improve its capabilities in the sustainable development of deep-sea resources as well as control and comprehensively manage the environmental and ecological risks in order to develop a maritime community and an ecological civilization.

Precise tools provide better performance. Therefore, human understanding, exploration, and development of the deep-sea environment and deep-sea resources are being enhanced with growth in marine equipment technology, which is at the frontier of understanding the ecological protection of the ocean, particularly the deep sea.

2.2 Technical requirements

China is gradually progressing in the field of deep-sea exploration, research, and exploitation. Deep sea forms the largest ecological system on earth. However, exploitation of deep-sea resources and energy may disturb and damage this ecosystem. Owing to the unique geographical environment of the deep sea, ocean currents may distribute 99% of the microplastics to the deep sea, where they could get distributed into the sediments of the deep seabed, thereby exerting a severe impact on the deep-sea environment. Numerous studies have detected organic pollutants and endocrine disruptors in the Mariana Trench. Trench sediments cause pollutants to accumulate on the seabed, leading to incalculable damage to the deep-sea ecological environment. The uniqueness of the deep-sea environment limits the application of existing detection methods because extreme conditions in this environment render it difficult to determine the baseline value and estimate the far-reaching impact of resource exploitation and development in the deep-sea environment. Extreme environmental conditions, such as high pressure, low temperature, and darkness, complicate deep-sea exploration and demand extreme requirements from deep-sea ecological protection equipment. Therefore, it is important to systematically study the developmental characteristics of deep-sea environment ecological protection equipment, focus on the future development of sophisticated deep-sea environment ecological equipment, and ensure sustainable development and utilization of deep-sea resources and the development of deep-sea ecological civilization.

3 Development trends of international deep-sea environmental and ecological protection equipment

As depicted in Fig. 1, deep-sea ecological protection equipment mainly includes equipment for *in situ* experimentation, detection/observation, simulation, and ecological sampling and preservation in the deep sea.

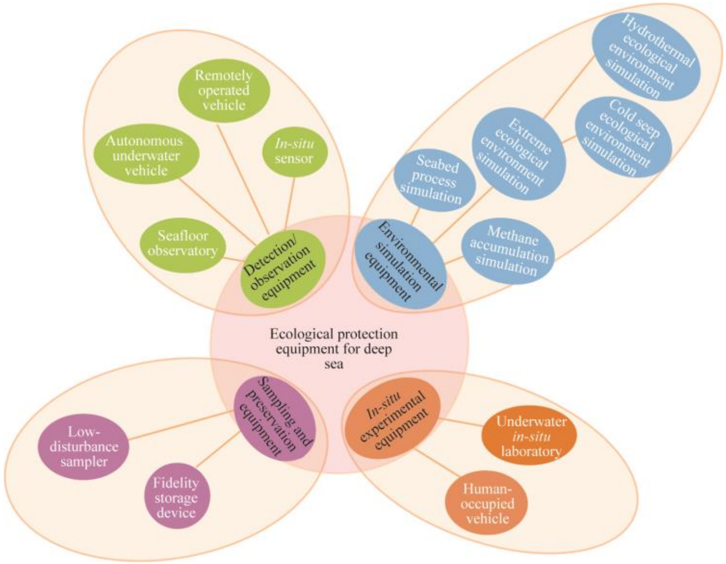

Fig. 1. Classification of the ecological protection equipment for deep sea.

3.1 *In-situ* experimentation equipment

Since the last century, various underwater *in-situ* laboratory systems have been built by different maritime powers to investigate and study the characteristics of the deep sea. For instance, underwater laboratories, including Sea Man, Aquarius, SEALAB series, and Tektite series of the United States; Bentos-300 of the former Soviet Union, the Conshelf series of France, Helgoland of Germany, and Progetto Abissi of Italy are manned experimental platforms designed for long-term stay and operation on the seabed for the purpose of scientific research. These laboratories support scientists in the investigation and study of the marine ecological environment (Figs. 2–4). In the 1970s, the United States developed the NR-1 deep-sea mobile working platform at a depth of 914.4 m and a displacement of 372 t. This platform can perform several underwater tasks, such as installation and maintenance of the submarine infrastructure, seabed mapping, tracking the sampling process, and environmental monitoring.

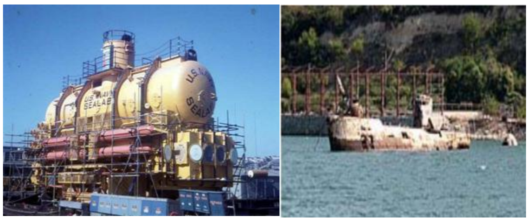

Fig. 2. SEALAB 3 of the United States (left) and Bentos-300 submarine laboratory of the former Soviet Union (right).

Fig. 3. Aquarius Underwater Laboratory of the United States (left) and Helgoland Underwater Laboratory of Germany (right).

Fig. 4. Arumina manned workstation of the United States (left) and NR-1 deep-sea operation platform (right).

3.2 Detection and observation equipment

In the 1970s, the British HMS Challenger pioneered the investigation of the physical characteristics of the deep sea, and determined the relationship between ocean circulation and ocean temperature distribution [1], which marked the beginning of physical oceanography. Since then, there has been continuous development in deep-sea detection technologies. An important aspect of this technology is the detection instrument, which can be loaded on to a submersible or placed in the deep sea for *in-situ* detection and for providing *in-situ* data that could prove useful for research and development related to deep-sea ecosystems and environmental protection. The main detection instruments for deep-sea include conductivity-temperature-depth profilers, conductivity meters, acoustic Doppler current profilers, Raman spectrometers, and various sensors [2]. In 2007, the University of New Jersey in the United States developed the Slocum glider. This glider integrates a variety of physical and optical sensors and has the ability to measure temperature, salinity, average depth current, surface current, fluorescence, and apparent and inherent optical characteristics [3]. In 2010, the Japanese Oceanic Administration used the autonomous underwater vehicle (AUV) Urashima to collect data on a large number of environmental parameters above the active hydrothermal field near Okinawa in order to generate a habitat map of the hydrothermal vent community on seabed topography [4]. In the same year, the French National Marine Research Institute deployed marine monitoring instruments via scientific research vessels. These instruments provide real-time monitoring of the natural dynamics of the hydrothermal vent ecosystem, study the changes in the flow, composition, and temperature of the hydrothermal fluid discharged from an unstable environment in the mid-Atlantic ridge, and identity the influence of the hydrothermal system on the animal community [5].

The observation equipment for the deep sea include submarine observation stations, submarine observation chains, and submarine observation networks. The submarine observation station realizes the long-term continuous observation of a fixed position on the seabed based on self-contained electric energy storage. Given its simplicity and feasibility, it has widespread applications in submarine observation. However, owing to the limitation of self-contained electric energy and the required real-time communication, submarine observation stations rely on deep-sea vehicles, such as underwater vehicles, to supplement their exhausting energy and collect information. The submarine observation chain resolves communication issues related to the observation data, thereby expanding the functions of the submarine observation stations. The observation chain may link several submarine observation stations, send the observation data to the sea surface via underwater acoustic communication, and ultimately send the signal back to the shore-based laboratory through satellites and other systems so that scientists may conduct real-time research. However, the traditional submarine observation chain is incapable of resolving the energy supply problem of the submarine *in-situ* observation station. Even the adopted underwater acoustic communication mode encounters problems of low data bandwidth and poor real-time performance. The seabed observation network includes a fully functional observation platform on the seabed, networking observation equipment on the seabed and in boreholes on the seabed, and an optical fiber electric energy network for the transmission of electric energy and collected information to various observation points for the purpose of long-term automatic observation. Undoubtedly, many countries are focusing on constructing seabed observation networks. Since 1989, the PAP-SO, constructed by the ocean center of the UK, has been performing time-series studies on deep-sea biogeochemistry and ecology [6]. The LEO-15, which was established in the United States in 1996 as well as the OOI-RSN, which was established by the University of Washington in 2010, focused on observing the environmental and ecological effects of natural gas hydrate and its influence on earthquakes. Furthermore, the University of Victoria, Canada, established Ocean Networks Canada (ONC). The world’s first wired ocean observation station VENUS was established in 2006 [7]; whereas, the world’s first regional cabled ocean observation network NEPTUNE was established in 2009 (Fig. 5) [8]. Since 2008, several European institutions have begun constructing a long-term multidisciplinary seafloor observatory network (EMSO) (Fig. 6). In addition, real-time monitoring of different parameters, such as temperature, pH, salinity, water cycle, and seabed movement, has been performed in key European sea regions (from the Arctic Ocean to the Black Sea) for long-term observation and research in geophysics, chemistry, biology, and oceanography [9].

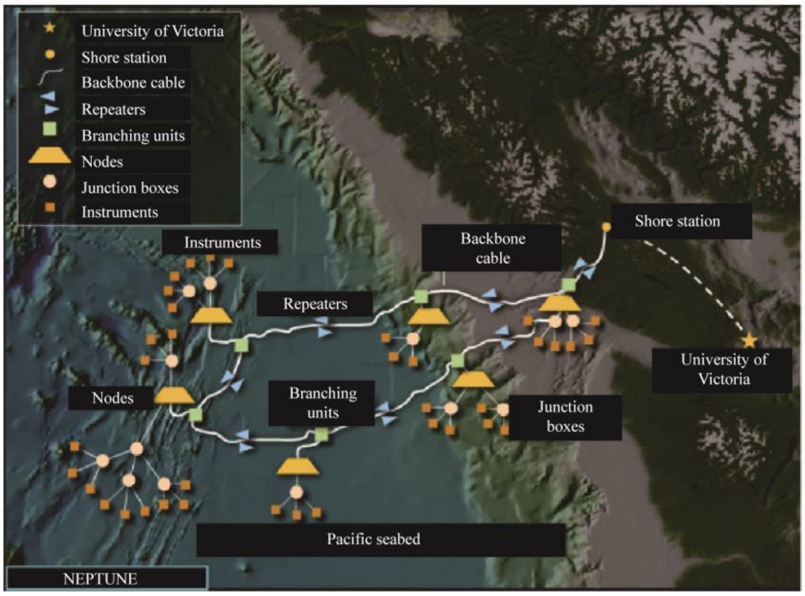

Fig. 5. Distribution of the ocean networks in Canada.

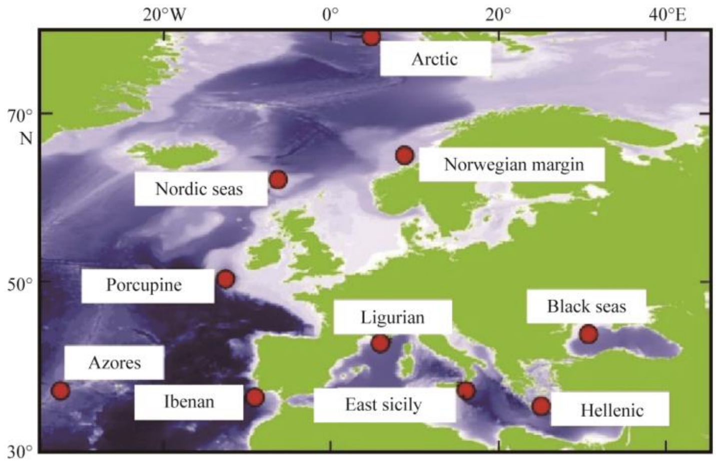

Fig. 6. Location map of the European multidisciplinary seafloor observatory.

3.3 Environmental simulation equipment

Given the limitations of extreme environmental conditions and safety considerations, it is impossible to conduct actual sea experiments for all environmental tests. It is usually difficult for scientists to perform a detailed deep-sea environmental ecological research. Therefore, it is of great significance to precisely retrieve the deep-sea environment and simulate its ecological evolution process on land for conducting relevant scientific research for the ecological protection of the deep-sea environment.

In 2004, W. J. Winters, who was part of the U.S. Geological Survey (USGS), developed a set of submarine sediment experimental equipment (GHASTLI, Fig. 7). The equipment combines *in situ* research with theoretical research. Furthermore, it applies remote sensing technology to improve the understanding and evaluation of seabed sediments. Until 2005, the National Energy Technology Laboratory (NETL) of the United States had constructed six deep-sea high-pressure reaction vessels with a maximum pressure of 137 MPa to simulate the seabed environment. In 2011, Germany's Helmholtz Potsdam Center constructed a large-scale submarine reservoir simulator (LARS) with an internal effective volume of 425 L and a design pressure resistance of 25 MPa. It is primarily used for the study of the geological storage of CO_2 and combustible ice decomposition.

Fig. 7. GHASTLI system of the United States Geological Survey.

The deep-sea biological environment simulation equipment is an important part of deep-sea environment simulations. The University of Minnesota has developed a series of high-pressure and high-temperature simulation devices that are capable of continuously cultivating deep-sea hydrothermal microorganisms and are used to study the metabolic processes of these hydrothermal microorganisms and their related geochemical processes mediated by them [10]. Scientists at the Microbial Ecological Technology Laboratory of Ghent University, Belgium, have developed a high-pressure environment simulation system that is capable of continuously cultivating deep-sea microorganisms in the long term (Fig. 8). Additionally, Japanese researchers have developed a series of equipment for microbial sequencing and batch culture in the high-pressure extreme environment of the deep sea. Scientists from France and Japan have jointly developed a mobile high-pressure and high-temperature reactor for the *in situ* study of the law of chemical energy synthesis reaction in deep-sea hydrothermal environments and evaluated the possibility of synthesizing oligopeptides from monomeric amino acids under extreme conditions [11].

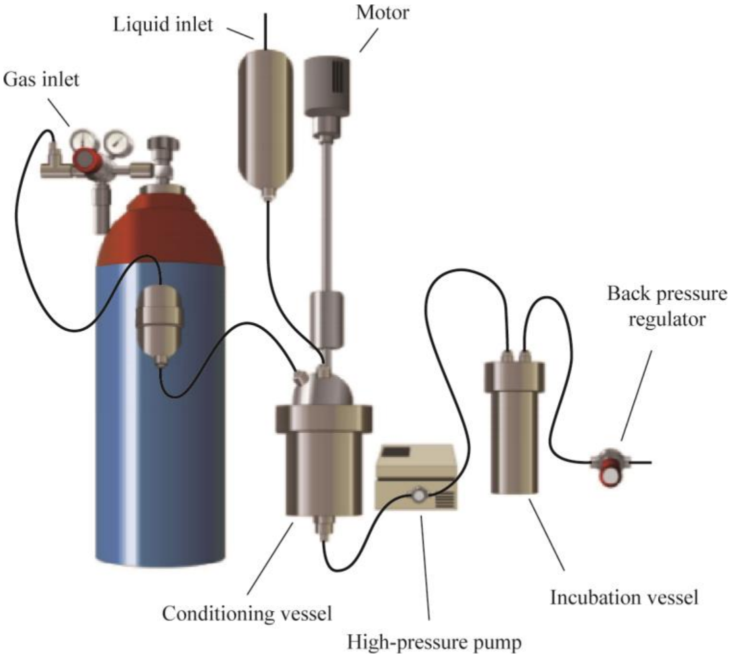

Fig. 8. Belgian simulation system for high-pressure deep-sea microbial environment.

3.4 Sampling and preserving equipment

Deep-sea sampling equipment is necessary for marine environmental and ecological scientific research. Since the realization of seabed sampling in 1872, there has been great progress in this technology because several countries have focused on deep-sea exploration and development. Sampling equipment may be divided into shallow holes (<5 m), medium holes (5–50 m), and deep holes (>50 m), based on the depth of sampling. In 1986, the University of Washington commissioned the Williamson Company to develop the world's first seabed core sampling rig. In 1996, the Japan Metal Mining Corporation funded the development of the first medium-hole and deep-hole drilling and sampling equipment with a core diameter of over 30 mm and the capability to drill to a depth of 20 m. In 2005, the British Geological Survey independently developed a core sampling rig, RockDrill 2 [12], for middle and deep holes in the seabed, which performed well in terms of drilling and application frequency. Both Australia and Germany have developed ultra-deep sampling rigs with drilling depths of over 50 m [13]. The deep-sea drilling and sampling technology of a country is representative of its comprehensive strength, which gradually develops in terms of depth, multifunction, intelligence, specialization, and fidelity.

Deep-sea fluid sampling equipment is a key device in sampling equipment technology. In 2017, the Japan Institute of Marine Geoscience and Technology developed a WHATS-3 sampler with the capability of sampling pure hydrothermal fluid of high quality; using this sampler, it successfully conducted sea trials in five hydrothermal fields at a maximum depth of 3300 m [14].

4 Development status of deep-sea environmental and ecological protection equipment in China

After years of intense exploration, in 2003, China developed deep-sea environment detection devices. Since then, numerous independently developed devices have emerged every year (Fig. 9).

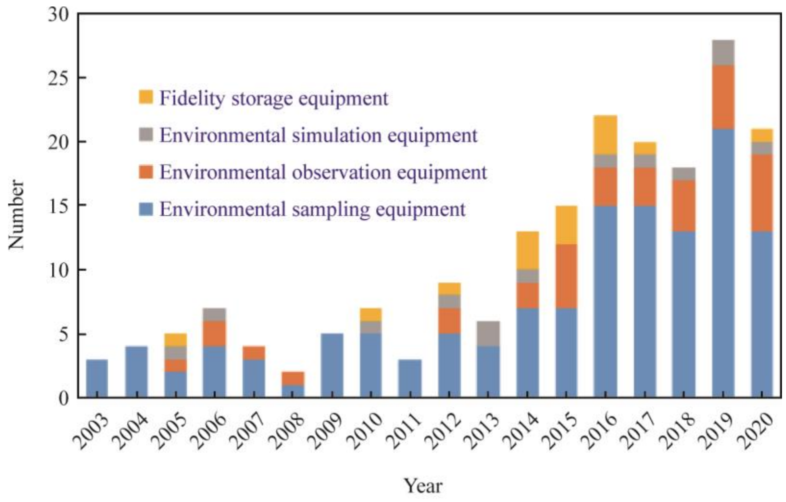

Fig. 9. Development trend of the patents for deep-sea environmental and ecological protection devices in China.

China's deep-sea environmental and ecological protection equipment technology (Fig. 10) focuses on the simulation of the deep-sea hydrothermal environment; other ecological environments, such as cold seeps, seamounts, and oceanic crust, are rarely simulated. Deep-sea environment detection equipment is also emphasized by the technical field of deep-sea environmental and ecological protection equipment in China. However, China lacks long-term underwater technology for in *situ* environmental and ecological protection experiments.

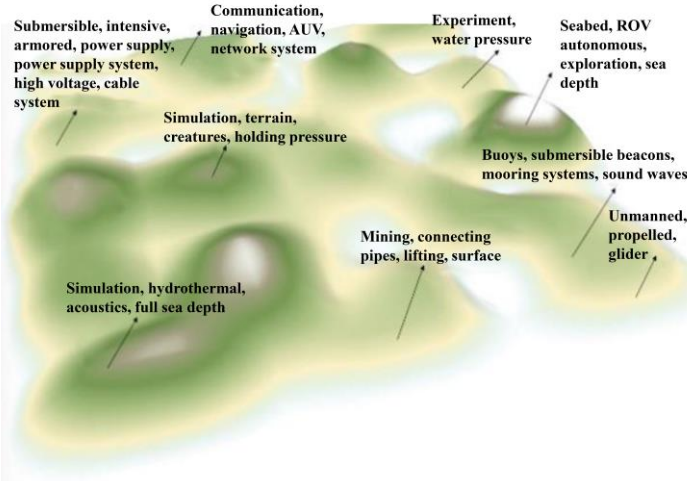

Fig. 10. Hotspot map of the patented technology of deep-sea environmental and ecological protection devices in China.

4.1 *In-situ* detection and experiment devices

Deep-sea submersibles, including human-occupied vehicles (HOVs), remotely operated vehicles (ROVs), and AUVs are important for *in-situ* detection in deep-sea environments.

HOVs can carry scientists into the deep sea, enable maneuvering cruise, hover, or sit-bottom detection on seamounts, ocean ridges, cold seeps areas, and hydrothermal vents. Additionally, they effectively perform *in-situ* detection and experimental tasks related to marine geology, marine physical chemistry, and marine earth environments and ecosystems. Currently, China's independently developed HOVs include the 7000 m class Jiaolong and the 4500 m class Shenhaiyongshi, while its 10 000 m class Fendouzhe HOV has cleared the sea trial. With these developments, China is ready to embark on a new journey in the development of manned deep-sea equipment.

In recent years, China has developed various ROV devices, including the 6000 m Hailong III, 4500 m Haima, 4500 m Faxian, and 6000 m Haixing. These devices can conduct fine sampling using a manipulator, which can work underwater for a long time, thereby achieving a real-time and accurate return of deep-sea data.

An AUV is another device capable of performing underwater tasks based on pre-programming with strong autonomy and high flexibility. In addition, AUVs can carry various sensors and sonars to conduct fine detection in deep-sea environments, sediment identification, and deep-sea sample collection. China has also developed several AUVs, such as 4500 m class Qianlong III and 10 000 m class Haidou. Moreover, China's deep-sea lander systems, including Tianya, Haijiao, and *In-situ* Experiment, can conduct *in-situ* experiments at a depth of 10 000 m.

Furthermore, China has developed special detection devices suitable for the extreme environments of the deep sea. The Raman spectrum detection system based on ROV was developed independently by China, and is widely applied in deep-sea hydrothermal vents, cold seeps areas, and gas hydrate exploration research processes for the *in situ* detection and analysis of the material composition and concentration of fluids, sediments, and pores [15]. The LIBS developed by the Ocean University of China [16] and loaded on to the Faxian ROV effectively detects the concentration of metal ions, such as K, Ca, Na, Fe, Cu, and Mn in deep-sea water and sediments. The seawater turbidity meter developed by Zhejiang University, China [17] can rapidly measure and analyze sulfide concentrations in hydrothermal vents. The Chinese Academy of Geological Sciences [18] developed a Zr/ZrO_2 electrochemical sensor with high temperature and pressure resistance for the *in situ* detection of the concentration of dissolved H_2S and other compounds in the hydrothermal solution within the range of 2–200 °C to effectively reflect the true chemical state of the submarine hydrothermal solution. This sensor also exhibited good corrosion resistance and mechanical stability. The deep-sea *in-situ* methane sensor developed by the China University of Geosciences can be used for continuous real-time observation in a designated area, enabling long-term dynamic observation of the methane concentration flux and diffusion in deep-sea gas hydrate decomposition that may occur in the future.

The extreme environment of the deep sea requires *in situ* detection devices to be tolerant of high temperature and pressure, flexible, simplified in operation, and with a high degree of accuracy. The development of detection sensors should focus on long-term and stable observation, diversified parameter monitoring, and dynamic and

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continuous observation.

4.2 Sampling and preservation devices for deep-sea environment

Owing to the limitations on the number, type, and precision of the detection devices carried to the deep sea, it is usually necessary to collect and bring the samples to the onshore laboratory for a precise and comprehensive analysis. This creates an urgent demand for accurate, flexible, automatic, and corrosion-resistant sampling devices that can be used in extreme environments under high pressure. In addition, heat preservation and pressure preservation devices are required to ensure high-fidelity storage of the collected samples during their transportation to the laboratory.

With regard to deep-sea drilling and coring equipment, owing to the technical blockade issues by developed countries, China's seabed core sampling equipment development began late. However, since the successful development of China's first deep-sea shallow-layer core sampling rig in 2000, the nation's deep-sea coring technology has progressed continuously, with great improvements in the core holding capacity and sampling diameter [19].

With regard to deep-sea surface sediment sampling, China has developed a deep-sea TV grab, which plays an important role in the investigation of massive sulfide and polymetallic nodules [20]. Deep seabed sediments are sampled using gravity sampling devices, which are simple to operate; however, their sampling ability for hard sediments is limited because they are prone to blockages. Zhejiang University in China [21] developed a sediment sampler driven by hydrostatic pressure combined with its own gravity. This device is effective for the sampling of hard sediments. Furthermore, there has been sufficient progress in the development of an undisturbed pressure-keeping sampler, pressure-keeping transfer device, and airtight water collection system for deep-sea sediments [22]. Pan [23] designed a deep-sea hydrothermal multi-cavity sampling device that could collect six hydrothermal samples in a high-temperature and high-pressure environment, thereby exhibiting high sampling efficiency. The air-cushion gas hydrate fidelity cylinder developed by Alley [24] exhibited good performance in pressure holding, which could achieve deep sampling of deep-sea gas hydrate.

In summary, higher performance, better adaptability, and simpler operation are the future directions of research and development of sampling equipment for deep-sea environments. On the other hand, the preservation device should ensure fidelity in sample acquisition, transportation, and experimentation. In addition, there is a need for fidelity devices, in terms of quantity and capacity.

4.3 Deep-sea environment simulation device

A deep-sea environment simulation device simulates the extreme environment of the deep sea and can be used for related experimental research, thereby reducing the huge manpower and material cost required for *in situ* detection, minimizing the risk to the life of underwater experimenters, and decreasing underwater equipment damage. Moreover, such a simulation equipment has the advantage of time rather than space to simulate the environmental conditions of the different sea regions and then conduct systematic research. In addition, the deep-sea environment simulation device can be used to test resistance to high pressure, high temperature, and corrosion of other deep-sea devices. In recent years, China has progressed greatly in the development of special deep-sea simulation equipment for seabed process simulation, formation and decomposition of deep-sea combustible ice, extreme biological environment of the deep sea, and deep-sea equipment performance testing.

In 2011, China commenced a 90 MPa deep-sea ultra-high pressure environment simulation system project [25]. The submarine hydrocarbon leakage simulation and experimentation equipment developed independently by Li et al. [26] can be used to study the variation in the characteristics of hydrocarbon gas concentration and molecular composition during submarine leakage and understand the main factors behind the leakage. The leakage-type gas hydrate formation simulation device developed by Wang et al. [27] can rapidly generate gas hydrate. It has the formation characteristics and morphology of the finished product, which is similar to those of the seabed samples. The Ocean University of China [28] constructed a Raman spectroscopy system and a high-temperature and high-pressure simulation experiment platform, using the Raman spectra of CO_2, CH_4, and other gas aqueous solutions in deep-sea hydrothermal regions. It provided a technical reference for the application of a Raman spectroscopy system for the detection of material composition and environmental information in the deep-sea environment. Zhejiang University developed [29] an extreme environment simulation system to simulate the supercritical high temperature and high pressure of the deep sea. This system included a multi-stage microbial-culture platform and a monitoring system that exhibited the characteristics of biological non-toxicity and portability on board, thereby establishing a basis for research on deep-sea microbial growth and biogeochemical processes. In recent years, the Guangzhou Natural Gas Hydrate Research Center in the Chinese Academy of Sciences has set up one-dimensional, two-dimensional, and three-dimensional simulation experimental units to study the natural gas hydrate exploitation process in complex sediments (including artificial and natural sediments). The experimental system adopts advanced visualization technology along with acoustic, optical, and electrical detection technologies, thereby reaching the international level of advances in terms of technology and scale. In particular, in 2009, the Comprehensive Simulation Experimental System for Natural Gas Hydrate Exploitation was built with the support of the major scientific research equipment research project of the Chinese Academy of Sciences. This system is the first unit device in the world to be used specifically for 3D hydrate exploitation simulation, having the capabilities of gas hydrate accumulation environment simulation, basic physical property measurement, and exploitation simulation. The effective internal volume of the high-pressure reaction kettle reaches 117.75 L, while the maximum working pressure is 25 MPa, which covers the storage conditions of hydrate reservoirs in the sea regions and frozen soil areas of China. The visualization function enables the detection of basic physical properties, such as acoustics, optics, electricity, mechanics, geochemistry, and geophysics, of combustible ice storage. The device can simulate the formation environment of natural gas hydrate reservoirs in different geological structures and conduct physical simulation research, including depressurization method, thermal shock method, and chemical injection method on the exploitation of natural gas hydrate in the sediments.

In recent years, to provide a stable pressure for underwater equipment, Shanghai Jiaotong University, Zhejiang University, and CSIC have individually developed various pressure environment simulation test platforms of 40 MPa, 60 MPa, and 90 MPa, which can ensure the safety and pressure resistance of deep-sea operation equipment [30].

Generally, the development of simulation equipment for extreme environments is focused mainly on the *in-situ* simulation of extreme environments in the deep sea, such as high temperature, high pressure, low temperature, and high pressure. It is noteworthy that rapid and accurate pressure control technology, biological non-toxic environment simulation, and large-capacity biological culture technology remain the core challenges in deep-sea equipment research and development. Thus, it is important to develop multi-functional, multi-objective, and multi-parameter simulation equipment with automation, large volume capacity, high pressure, visualization, integration, and rapid response to changes in environmental parameters.

4.4 Submarine observation network

While China’s ocean observation technology has had significant achievements, it is still not as systematic as that of developed countries. In terms of data acquisition, China has achieved real-time and local data acquisition without time series and distribution rules via shore-based station monitoring and ship-based marine surveys, which render it difficult to study the entire ecosystem. Therefore, the construction of a submarine observation network is of great significance to China, both strategically and practically. In 2008, the Xisha Ocean Observation and Research Station, which was the first deep-sea observation station in China, was constructed at Yongxing Island Experimental Base. This station provides real-time observation data for the entire year for this region. The observation system comprises a base automatic weather station, an off-island wave tide meter, a submarine boundary layer observation subsystem, an ocean optical monitoring subsystem, an anchored comprehensive observation buoy, and a trap anchor system structure [31]. The system can realize real-time observation of meteorological conditions of air temperature and pressure, as well as the ocean parameters of water temperature, wave, and tidal level. The submarine boundary layer observation subsystem comprises an acoustic doppler current profiler, a water level gauge, an ocean current meter, a temperature and salt meter, a depth meter, and other sensors. The subsystem can obtain long-term hydrological data of ocean currents and temperatures at the seabed for over 1000 m. The marine optical monitoring subsystem, based on hyperspectral technology, automation technology, and buoy and remote communication technology, realizes continuous real-time observation of optical radiation in the upper ocean, including the sea surface. The anchored comprehensive observation buoy has a marine hydrological multi-parameter measuring instrument installed under the buoy to observe the marine environment of Xisha’s upper layer. Moreover, its on-site storage can store data for over a year. The collected samples can be used to study the deposition flux, deposition rate, sediment source, and migration characteristics of deep-sea particulate matter. In addition, the station can carry a variety of marine environment observation instruments for

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multi-parameter synchronous observation.

The Xisha Ocean Observation and Research Station integrates the multidisciplinary technologies of deep-sea environment exploration in China, which provides a scientific basis for deep-sea environment protection, resource development, climate change, disaster prevention, mitigation, and marine military affairs. In particular, the station can obtain important information for a detailed study of the ecological processes of tropical marine environments. In the future, it will be necessary to not only observe offshore waters but also construct a network in the deep-sea environment. The complexity of the deep-sea environment obviously increases with increasing seawater depth. To ensure a comprehensive, long-term, continuous, and real-time observation of the deep-sea environment, it is necessary to develop scientific equipment and submersible standards that can withstand high voltage, corrosion, and biological adhesion for a long time as well as prevent short circuit and communication interference.

With support from the National Development and Reform Commission, China has established several submarine observation systems in the East China Sea and the South China Sea to realize all-weather, real-time, high-resolution, and multi-interface comprehensive observations. From the seabed to the sea surface, the systems provide long-term continuous data and an *in-situ* scientific experiment platform for a deep understanding of the marine environment in these two seas.

5 Challenges encountered by China in the development of deep-sea environmental and ecological protection equipment

The deep-sea environment is a large complex ecosystem, which can be explored only by developing high-performance detection, experiments, and simulation equipment and a richer equipment pedigree. Overall, China’s deep-sea environmental and ecological protection equipment development has progressed rapidly, with great breakthroughs in deep-sea exploration and development. However, China continues to rely on developed nations for core technologies related to deep-sea equipment. In the current international scenario of the COVID-19 outbreak, a breakthrough in core R&D capability based on system integration is imperative.

5.1 Limitations of high-precision deep-sea sensor technology

In general, China lacks high-precision instruments, including deep-sea sensors. Although certain deep-sea exploration instruments have been developed through independent research, challenges related to detection accuracy, innovation, equipment type, performance level, and long-term stability of the instruments persist. Most deep-sea exploration technologies are in the introductory and re-development phases. Moreover, their high-precision instruments rely on commercial instruments imported from other countries.

5.2 Lack of general supporting technology

With respect to research and development related to unique materials, communication, positioning, load, and power equipment for the deep sea, China lags behind developed countries. Owing to the limitations of the deep-sea exploration platform, the sampling size of the developed devices is small, and the sampling efficiency is low. The deep-sea exploration equipment lacks uniform technical standards, with uneven technical levels and incompatible transmission interfaces.

5.3 Lack of large-scale environmental simulation equipment

Compared to developed countries, China needs to catch up in the field of deep-sea extreme environment simulation. Most of the land simulation can only be performed at a fixed depth and under static pressure. Additionally, the related equipment cannot be operated under changing pressure gradients, geothermal gradients, or simulating ecological environment systems. In particular, there is a lack of large-scale equipment for simulating the environment of deep-sea cold seep ecosystems and ecosystem conservation. Thus, there needs to be a breakthrough in core technologies, such as large volume capacity and operation under variable temperatures and pressures.

5.4 Inadequate capability of long-term manned in-situ experiments

The development of various deep-sea exploration equipment, including Jiaolong, Shenhaiyongshi, and Haidou have greatly promoted China's capabilities in deep-sea exploration and experimentation. However, there are certain defects in the observation, such as point area and short time. Moreover, there is a lack of equipment for conducting long-term manned *in-situ* experiments. In these aspects, China remains behind developed nations.

6 Suggestions for better development of deep-sea environmental and ecological protection equipment in China

6.1 Promoting independent innovation and establishing a comprehensive demonstration platform

China's capability of independent research and development in the field of deep-sea environmental and ecological protection equipment needs urgent improvement through the development of world-class independent equipment, which could facilitate the country's marine scientific research and development along with other marine activities. It is imperative to establish a comprehensive R&D system for deep-sea environmental and ecological protection equipment, along with a leading and innovative comprehensive application demonstration platform. Moreover, major scientific and technological infrastructure for deep-sea environmental and ecological protection and resource development should be established, along with the establishment of a large-scale deep-sea *in-situ* simulation experiment center and long-term *in situ* underwater laboratories. This can realize the synchronization of the extensive development of marine resources with ecological protection, thereby cultivating new marine industries, which could promote the adjustment of China's industrial structure. This approach would endorse China's marine economy and contribute toward the maintenance of medium- and high-speed economic growth of the nation.

6.2 Top-level design, overall coordination, and key construction

It is reasonable to formulate an overall strategic plan for the development of deep-sea environmental protection equipment, strengthening the top-level design, performing overall planning and coordination, and increasing the support in key directions. Moreover, the key focus areas of scientific research institutes, universities, and business centers, which are the main bodies of marine innovation, should be clearly defined, and their respective advantages should be taken care of. In addition, redundant construction should be avoided, and the rapid development of marine equipment engineering technology should be promoted.

6.3 Focusing on personnel training and realizing innovative achievements

It is necessary to focus on cultivating innovative talent and encouraging innovation in all forms. A reasonable and effective medium- and long-term incentive and restraint system should be established to provide a comprehensive technology platform and talent reserve for the research and sustainable development of deep-sea environmental and ecological protection equipment. Scientific and technical personnel should be encouraged to realize high-tech achievements, application of cutting-edge innovations in deep-sea equipment technology should be promoted, and forward-looking layout and the integrated development of the relevant industrial chains should be supported.

6.4 Strengthening international cooperation and promoting industrial cooperation under a global governance system

With unprecedented changes taking place in the world in the past century, international cooperation is undergoing profound adjustments. In this scenario, China should actively participate toward global governance of mutual cooperation, joint construction, and sharing among nations, thereby making full use of the favorable conditions for opening-up to the rest of the world and expanding international as well as regional scientific and technological cooperation in various forms. Moreover, China should actively introduce international-level advanced marine environmental and ecological equipment technology, encourage the introduction as well as re-innovation of technologies, and achieve accelerated progress in the field of deep-sea exploration. It is imperative to support Chinese scientists and research institutions to participate in or lead large-scale international and regional scientific engineering projects. Furthermore, China should implement a strategy for constructing the 21st century Maritime Silk Road, strengthen cooperation with the countries bordering this road, take the belt and road initiative in key marine environmental and ecological equipment technologies and industries, and establish a marine community in deep-sea ecology, thereby laying a solid foundation for its deep-sea environmental and ecological protection equipment industry.

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References

[1] Dekov V M, Cuadros J, Kamenov G D, et al. Metalliferous sediments from the H.M.S. Challenger voyage (1872—1876) [J]. Geochimica et Cosmochimica Acta, 2010, 74(17): 5019–5038.

[2] Kirkham N R, Gjerde K M, Wilson A M W. DEEP-SEA mining: Policy options to preserve the last frontier—Lessons from Antarctica's mineral resource convention [J]. Marine Policy, 2020, 115: 103859.

[3] Schofield O, Kohut J, Aragon D, et al. Slocum gliders: Robust and ready [J]. Journal of Field Robotics, 2007, 24(6): 473–485.

[4] Kumagai H, Tsukioka S, Yamamoto H, et al. Hydrothermal plumes imaged by high-resolution side-scan sonar on a cruising AUV, Urashima [J]. Geochemistry, Geophysics, Geosystems, 2010, 11(12): 12013.

[5] Blandin J, Colaço A, Legrand J, et al. The MoMAR D project: A challenge to monitor in real time the Lucky Strike hydrothermal vent field [J]. ICES Journal of Marine Science, 2010, 68: 416–424.

[6] Smith K, Ruhl H, Bett B, et al. Climate, carbon cycling, and deepocean ecosystems [J]. Proceedings of the National Academy of Sciences, 2009, 106(46): 19211–19218.

[7] Tunnicliffe V, Barnes C R, Dewey R. Major advances in cabled ocean observatories (VENUS and NEPTUNE Canada) in coastal and deep sea settings [C]. Tallinn: Baltic International Symposium, 2008: 1–7.

[8] Best M, Barnes C, Bornhold B, et al. Integrating continuous observatory data from the coast to the abyss: a multidisciplinary view of theocean in four dimensions [C]. Favali P, Santis A D, Beranzoli L (eds.). Sea floor observatories: A New Vision of the Earth from the Abyss. Berlin: Springer, 2013: 500.

[9] Favali P, Beranzoli L. EMSO: European multidisciplinary seafloor observatory [J]. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2009, 602(1): 21–27.

[10] Houghton J L, Seyfried W E, Banta A B, et al. Continuous enrichment culturing of thermophiles under sulfate and nitratereducing conditions and at deep-sea hydrostatic pressures [J]. Extremophiles, 2007, 11: 371–382.

[11] Zhang Y, Arends J B A, Wiele T V, et al. Bioreactor technology in marine microbiology: From design to future application [J]. Biotechnology Advances, 2011, 29(3): 312–321.

[12] Sven P, Peter M H , Thomas K, et al. Shallow drilling of seafloor hydrothermal systems using the BGS rockdrill: Conical Seamount (New Ireland Fore-Arc) and PACMANUS (Eastern Manus Basin), Papua New Guinea [J]. Marine Georesources and Geotechnology, 2005, 23:175–193.

[13] Freudenthal T, Wefer G. Scientific drilling with the sea floor drill rig mebo [J]. Scientific Drilling, 2007 (5):63–66.

[14] Miyazaki J, Makabe A, Matsui Y, et al. WHATS-3: An improved flow-through multi-bottle fluid sampler for deep-sea geofluid research [J]. Frontiers in Earth Science, 2017, 5: 45.

[15] Zhang X. Quantitative applications of raman technique for deepsea environment and sediment detection [D]. Qingdao: Ocean University of China (Doctoral dissertation), 2009. Chinese.

[16] Liu G F. The software design and realization for deep-sea situ laser induced breakdown spectrometer [D]. Qingdao: Ocean University of China (Master`s thesis), 2015. Chinese.

[17] Liu Z M. The research of technology on turbidity sensor used in deep sea and signal processing [D]. Hangzhou: Zhejiang University (Master's thesis), 2005. Chinese.

[18] Zhang X, Zhang R, Hu S, et al. Development of Zr/ZrO_2 high temperature and high pressure sensors for in-situ measuring chemical parameters of deep-sea water [J]. Science in China Series E: Technological Sciences, 2009, 52(8): 2466–2473.

[19] Wan B Y, Huang X J. Development of core sampling drilling for deep seabed Shallow Strata [J]. Mining Research and Development, 2006(S1):49–51. Chinese.

[20] Cheng Z B, Wu Y H, Shi F D, et al. New type of sampler for deepsea deposit: Grab with TV and its usage [J]. Coastal Engineering, 2011, 30(1): 51–54. Chinese.

[21] Qin H W, Chen J Q, Wang J J, et al. Design and sea trial research of new hydrostatic corer [J]. China Mechanical Engineering, 2013, 942–945. Chinese.

[22] Liu G H, Chen D H, Yang C J, et al. Design and application of stratified gastight system for acquiring water sample in deep-sea [J]. Meteorological Hydrological and Marine Instrument, 2009, 26(2): 9–12. Chinese.

[23] Pan J W. The design of deep-sea hydrothermal sampler with multicavity [D]. Qingdao: Qingdao University of Science & Technology (Master's thesis), 2015. Chinese.

[24] An L. Research on pressure-holding characteristics of a new deep-water fidelity canister[D]. Hangzhou: Zhejiang University (Master's thesis), 2014. Chinese.

[25] Li C. Reliability analysis of deep sea ultra-high pressure environment simulation system [D]. Qingdao: First Institute of Oceanography, MNR (Master's thesis), 2013. Chinese.

[26] Li S L, Dong H P, Zhao Q F, et al. Experimental simulation of seabed hydrocarbon gas seepage: Variation of content and molecular composition of the hydrocarbon variation of content and molecular composition of the hydrocarbon [J]. Marine Geology Frontiers, 2020, 36(5): 1–13. Chinese.

[27] Wang Y B, Fan S S, Guan J A, et al. Experimental simulation of oceanic leakage hydrate formation [J]. Natural Gas Geoscience, 2007 (4): 596–600. Chinese.

[28] Wang Y Y. Raman spectrometry measurement of hydrothermal gases under simulated deep-sea environment [D]. Qingdao: Ocean University of China (Master's thesis), 2009. Chinese.

[29] Dong X X, Jiang K, Chen H, et al. A design of deep-sea extreme environment simulator [J]. Journal of Tropical

Oceanography, 2014, 33: 101–108. Chinese.
[30] Liu Y, Cheng Q, Wu D F, et al. Development of an experiment device for simulating full depth ocean environment [J]. Chinese Hydraulics ＆ Pneumatics, 2020 (8):7–11. Chinese.
[31] Li J, Chen R Y, Wang S A, et al. Development of international marine observation system and construction of deep-sea station in China [J]. Journal of Tropical Oceanography, 2012, 31(2): 123–133. Chinese.