

## Postprint: Research and Breakthroughs on Frontier Scientific and Technological Issues of the Hadal Trench

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### Abstract

Hadal trenches, abbreviated as “trenches,” specifically refer to oceanic trench regions with depths greater than 6,000 m. Globally, there are 37 deep-sea trenches, among which the nine deepest trenches (e.g., the Mariana Trench) are located in the western Pacific Ocean. The hadal environment is characterized by high pressure, low temperature, aphotic darkness, tectonic activity, frequent seismicity, and unique life forms, representing an exceptionally distinctive marine extreme environment on Earth. Hadal trenches harbor Earth’s most enigmatic ecosystems, featuring distinctive current dynamics and extensive material and energy exchange with both the overlying ocean and the seafloor. Together with shallow seas (<200 m), bathyal zones (200–3,000 m), and abyssal zones (3,000–6,000 m), hadal trenches constitute a complete marine system and represent a critical component in driving the evolution of the Earth system. Despite their profound significance and fascinating allure, they remain among the most poorly understood and least accessible seafloor regions on Earth.

### Full Text

#### Preamble

Hadal trenches, oceanic regions deeper than 6,000 meters, represent some of the most extreme marine environments on Earth. Globally, 37 deep trenches exist, with nine of the deepest—including the Mariana Trench—located in the western Pacific. Characterized by extreme pressure, low temperature, perpetual darkness, active tectonism, frequent seismicity, and unique life forms, these trenches constitute a critical yet poorly understood component of the ocean system. Together with shallow (<200 m), bathyal (200–3,000 m), and abyssal (3,000–6,000 m) zones, they form a complete oceanic system that drives Earth

system evolution. Despite their profound significance and fascinating properties, hadal regions remain among the least explored and most inaccessible areas of the seafloor.

On April 10, 2014, the Chinese Academy of Sciences (CAS) officially launched the Strategic Priority Research Program (Category B) titled “Frontier Scientific and Technological Issues in Hadal Trench Research and Development,” with renowned deep-sea scientist Professor Ding Kang serving as Chief Scientist. The program plans to conduct scientific investigations and trials in the Mariana Trench using the “Jiaolong” deep-sea submersible and other deep-sea exploration equipment, aiming to establish and develop multiple disciplinary systems including hadal biology, hadal ecology, and hadal geoscience. This initiative will guide further breakthroughs in full-ocean-depth submersible technologies and deep-sea detection equipment, advancing China’s deep-sea science and engineering capabilities into the deepest oceanic regions.

## 1. Background and Significance

### 1.1 Overall Objectives

This program addresses frontier domains in marine science, and its academic and technological achievements will significantly advance China’s marine science enterprise and deep-sea exploration capabilities. The overall objectives are:

- (1) To focus on frontier questions in hadal science, striving for major discoveries in hadal life evolution and adaptation, environmental change and resource effects, and tectonic activity and geological evolution, thereby establishing China’s hadal disciplinary systems in biology, ecology, and geoscience.
- (2) To develop hadal detection equipment suited for exploration and research needs, breaking through bottlenecks in hadal detection technology, simulation experimentation, and full-ocean-depth manned/unmanned submersibles. This will establish a technical system supporting China’s hadal scientific research and technological development, laying a solid foundation for scientific investigations in hadal trenches.
- (3) To establish a Hadal Science and Technology Excellence Center characterized by close integration of deep-sea science and technology, forming a comprehensive alliance with international competitiveness. This center will become an internationally influential “innovation highland” in deep-sea technology, playing a crucial strategic role in national marine development.

### 1.2 Research Content

Hadal science exploration encompasses frontier questions across physical oceanography, geophysics, marine chemistry, geochemistry, marine geology,

marine ecology, marine biology, and marine environmental science. It also involves materials, energy, navigation, control, vehicles, and deep-sea operations. Science and technology are mutually reinforcing in this long-term, complex, and systematic endeavor. Following the principle of “limited objectives with focused breakthroughs,” the program addresses three core scientific questions and three core technical questions through six projects:

- **Project 1:** Basic biological characteristics of hadal trenches and the origin, evolution, and environmental adaptation mechanisms of endemic species
- **Project 2:** Basic environmental characteristics of hadal trenches and exclusive physical oceanographic and geochemical phenomena
- **Project 3:** Plate subduction, tectonic activity, and the formation and evolution of hadal trenches
- **Project 4:** Development, application, and integrated sea trial platforms for hadal detection equipment
- **Project 5:** Key technology breakthroughs for full-ocean-depth submersibles
- **Project 6:** Hadal environment simulation experimental systems

Projects 1-3 constitute the scientific research core, demonstrating the program’s competitiveness in deep-sea science and contributing to establishing China’s hadal disciplinary systems. Projects 4-6 provide technical support through field observations, sample collection, and laboratory simulation. The relationships among the six projects are illustrated in Figure 1 [Figure 1: see original paper].

## 2. Progress and Innovations

Since its inception, the Hadal Trench program has achieved significant progress and breakthroughs across multiple directions.

### 2.1 The “Tansuo-1” Research Vessel Platform

The “Tansuo-1” research vessel platform has been completed as a deep-sea engineering operation and test platform that will meet China’s urgent needs for hadal exploration and operations over the next decade. The platform provides sea trial capabilities for full-ocean-depth key technologies and supports sea tests and operations of China’s 10,000-meter manned and unmanned submersibles.

During its inaugural voyage to the Mariana Trench in June–August 2016, “Tansuo-1” successfully completed all mission objectives. The vessel’s DP2 dynamic positioning system demonstrated high-precision positioning performance, and shipboard equipment—including the 10,000-meter depth sounder, CTD water sampler, sediment sampling devices, and seismic experimental systems—operated successfully. This demonstrated that “Tansuo-1” is capable of routine detection operations below 6,500 meters and supporting 10,000-meter submersible operations.

Using the shipboard winch system and sediment sampling equipment, the expedition obtained a box core sediment sample from 9,150 meters, setting a new world record for this type of deep-sea equipment. The expedition also successfully obtained complete depth-series sediment samples from 7,000 m, 8,000 m, 9,000 m, and the maximum depth of 10,822 m. These large-depth sediment samples provide unprecedented opportunities to study global climate change responses in hadal sediments, early diagenetic activity, and the relationship between chemosynthetic life and geological processes.

The expedition also successfully obtained complete depth-series water samples from the Mariana Trench, including samples from 7,000 m, 8,000 m, 9,000 m, and 10,000-meter levels, with a maximum sampling depth of 10,900 m. These large-depth water samples provide valuable resources for studying hadal water column ecological evolution, material cycling, and high-pressure microbiology.

These achievements demonstrate that 10,000-meter deep-sea operations are no longer forbidden territory for China's marine science community, representing another milestone following the successful 7,000-meter sea trials of "Jiaolong."

## 2.2 Ocean Bottom Seismometer

The domestically developed Ocean Bottom Seismometer (OBS) supported by the program exceeded 7,000 meters working depth for the first time. Nine OBS units participated in the Mariana Trench sea trial with 100% recovery rate, reaching a maximum working depth of 7,731 meters and setting a new national record. The seismometers recorded complete data, capturing natural earthquake signals greater than magnitude 7.7 in the Mariana Trench—the third such event recorded since 1900.

The world's first active-source artificial seismic exploration in the western Challenger Deep was conducted, using a shipboard large-volume airgun that fired 960 shots along a 160.9 km profile, successfully recording a complete seismic section.

## 2.3 Hadal Lander

The "Tianya" hadal lander deployed by the program obtained over 100 liters of seafloor water samples—an unprecedented achievement for comparable international equipment. The lander conducted nine dives, eight of which were successful, at depths of 5,530 m, 6,985 m, 7,034 m, 7,526 m, 7,850 m, 7,619 m, 10,822 m, and 5,076 m. It obtained CTD and dissolved oxygen data, batch near-bottom in-situ fixed microbial samples, near-bottom water samples, videos, photos, and some sediment samples. The lander successfully captured batch samples of hadal snailfish and other large organisms.

The "Tianya" lander also carried a self-developed in-situ fixation device that completed microbial collection from nearly 10 stations, with a maximum experimental depth of 7,850 meters and single filtration volume of 150 liters. These

samples maximally preserve in-situ microbial metagenomic information from hadal environments, providing precious resources for revealing microbial community structure, metabolic pathways, and environmental adaptation mechanisms.

#### **2.4 “In-situ Experiment” Lander**

The “In-situ Experiment” lander supported by the program conducted six dives at depths of 6,382 m, 8,079 m, 8,627 m, 9,197 m, 10,225 m, and 10,935 m. It successfully conducted in-situ cultivation experiments on nitrogen cycling and ammonia oxidation at the hadal seafloor, captured amphipods at 10,000-meter depth in the Challenger Deep, and deployed a CAS logo near the deepest point.

#### **2.5 “Haidou” Unmanned Submersible**

The “Haidou” unmanned submersible independently developed by the program successfully conducted one 8,000-meter-level, two 9,000-meter-level, and two 10,000-meter-level dives, reaching a maximum depth of 10,767 meters. “Haidou” became China’s first unmanned submersible to exceed 10,000 meters and conduct scientific operations, setting a national record for unmanned submersible depth and operations. This achievement made China the third country, after Japan and the United States, to possess 10,000-meter unmanned submersible capability.

Using “Haidou,” China obtained its first batch of 10,000-meter-level temperature-salinity-depth profiles—two profiles exceeding 9,000 meters (9,827 m and 9,740 m) and two exceeding 10,000 meters (10,310 m and 10,767 m). These data provide valuable baseline information for studying spatial variation patterns of hadal water mass characteristics, deep-ocean current structures, and designing 10,000-meter manned submersibles.

#### **2.6 Underwater Glider**

The independently developed underwater glider reached a maximum depth of 5,751 meters, completing eight effective dive cycles and transmitting data via satellite in real time. This set a national depth record for underwater gliders, approaching the current world record of 6,000 meters.

#### **2.7 Biological Samples**

Through 13 large-organism trapping experiments using program-developed landers and gliders, over 2,000 large biological specimens were obtained at depths of 5,000 m, 6,000 m, 7,000 m, 8,000 m, 9,000 m, and 10,000 m levels, including amphipods, endemic hadal snailfish, and unknown species. This marks the first time China has obtained hadal snailfish with trench-specific characteristics and large organisms from 10,000-meter depths, providing precious samples

for exploring species origin and evolution, population genetics, and symbiotic microbial adaptation to extreme high-pressure environments.

## 2.8 Full-Ocean-Depth Manned Sphere

Core technologies including the 10,000-meter manned sphere (Figure 2 [Figure 2: see original paper]) and 10,000-meter buoyancy materials have achieved major breakthroughs, providing critical initial conditions for the national key R&D program “Key Technologies and Equipment for Deep Sea.” China has manufactured its first titanium alloy scaled sphere for full-ocean-depth pressure validation, which passed a 190 MPa hydrostatic pressure test, representing a crucial step toward domesticating materials, manufacturing processes, and structural design for 10,000-meter manned submersible cabins. The developed modular buoyancy material demonstrates excellent pressure resistance, with water absorption rates of 0.25%–0.48% under 120 MPa pressure for 24 hours. Full-ocean-depth solid buoyancy material development has achieved breakthrough progress and staged results.

## 2.9 Ultra-High Pressure Simulation Facility

Ultra-high pressure simulation chambers and hadal extreme environment simulation platforms—major deep-sea research infrastructure—have been constructed and commissioned. A service platform has been established near the strategically important South China Sea, providing necessary conditions for sea trials and operation maintenance of China’ s independently developed 4,500-meter manned submersible, 10,000-meter manned submersible, and deep-sea space station.

# 3. Industrial Significance

## 3.1 Program Culture

Since its launch, the program has consistently adhered to the philosophy of integrating CAS’ s distinctive yet dispersed deep-sea science and technology forces (particularly those not previously involved in marine research) under program leadership, maximizing the effectiveness of CAS’ s talent aggregation to support leapfrog development in China’ s hadal science and technology. This open, collaborative management approach leverages CAS’ s comprehensive disciplinary strengths, assembling existing and potential deep-sea science and engineering capabilities.

Within just over two years since its April 2014 launch, besides marine-oriented institutes such as the Institute of Oceanology, South China Sea Institute of Oceanology, Institute of Acoustics, and Shenyang Institute of Automation, teams from the Institute of Metal Research, Dalian Institute of Chemical Physics, Shanghai Institute of Ceramics, Institute of Geodesy and Geophysics, Institute of Geology and Geophysics, and Institute of Hydrobiology—previously

uninvolved in marine technology—have played important roles. Currently, 12 CAS teams (Figure 3 [Figure 3: see original paper]) and 10 external universities, enterprises, and institutional partners (Figure 4 [Figure 4: see original paper]) participate in the program.

Through two years of implementation, the program has gradually established a “culture of collaboration, culture of action, and culture of academic equality,” forming a hadal research team. Through the “Tansuo-1” equipment sea trial and scientific expedition (TS01-01), applications of multiple deep-diving vehicles, and intensive hadal operations, the program has trained a group of frontline maritime operation commanders and forged a team capable of conducting 10,000-meter-depth scientific operations.

Through two years of joint efforts, the program has preliminarily established a talent highland for China’s hadal frontier research, achieving breakthroughs in core key technologies and gaining domestic and international academic reputation and influence. These accomplishments have laid the foundation for launching full-ocean-depth technology and equipment development during China’s 13th Five-Year Plan period. In the prioritized national key R&D program, the “Deep Sea Technology and Equipment” key special project reflects the pioneering and leading role of CAS in major national strategic science and technology frontiers, representing the results of advanced management concepts and efficient work by program leadership.

#### 4. Future Deployment

The program will adopt effective measures in an open model to attract multidisciplinary forces from CAS and nationwide to conduct extensive and in-depth scientific research on the 10,000-meter hadal samples and data obtained during the “Tansuo-1” TS01-01 expedition, yielding major scientific achievements.

Leveraging current advantages in hadal equipment development technology and expedition experience, the program will return to the Challenger Deep as soon as possible for a second 10,000-meter scientific expedition. This will intensify environmental detection and sample collection at 9,000-10,000 meter depths and conduct maritime scientific trials of independently developed hadal equipment.

The program will coordinate with the national key R&D program “Deep Sea Detection Technology and Equipment,” advancing its scientific research achievements and technical equipment to the national strategic level through further support and enhancement. This will position China’s deep-sea technology R&D at the international forefront and establish strategic foundations for full-ocean-depth scientific and engineering capabilities, enabling China to explore not only deep space and the moon but also the deepest oceans on Earth. The program also plans to transfer and transform some achievements to improve China’s hadal detection capabilities and promote progress in materials, energy, navigation, control, vehicle, and deep-sea operation technologies, meeting national

marine high-tech development needs and securing a commanding position in the new round of international deep-sea technology development.

In terms of research content and key technology priorities, the national key special project has drawn upon the Hadal Trench program's concepts, focusing on breakthroughs in core common key technologies that constrain China's deep-sea development capabilities, including deep-sea vehicles, detection systems, and strategic resource development. The plan includes developing 10,000-meter manned and unmanned submersibles for full-ocean-depth diving, and completing sea trials and experimental applications of 4,500-meter manned submersibles. Among the projects approved for funding in 2016, 13 directly originated from preliminary work and incubation under the Hadal Trench program, with another project led by the CAS Institute of Semiconductors ("New Magnetotelluric Sensors for Deep-Sea Geophysical Research (2016YFC0301800)") also organized and planned by Chief Scientist Ding Kang. Preliminary statistics indicate that projects incubated and guided by the Hadal Trench program account for one-third of the national key special project, with total funding approaching 900 million yuan.

(Institution: CAS Institute of Deep-Sea Science and Engineering)

The "Frontier Scientific and Technological Issues in Hadal Trench Research and Development" Strategic Priority Research Program launched by the Chinese Academy of Sciences has pioneered China's research in hadal science, technology, and equipment. The program's mid-term results are remarkable, achieving major progress in disciplinary development, infrastructure construction, talent team building, and key technology breakthroughs. The program's implementation has also guided the development direction of China's deep-sea detection technology and equipment, receiving strong support from national key R&D programs. With further implementation, the program is expected to achieve major technological advances and scientific discoveries in the global hadal research field, driving the development of China's deep-sea technology and equipment and making significant contributions to achieving China's 13th Five-Year marine strategic goals.

### Author Biographies

**Ren Ping** holds a Master of Engineering from Shanghai Jiao Tong University School of Naval Architecture, Ocean and Civil Engineering, and is a senior visiting scholar at the Norwegian Institute of Technology. He has served as Director of Research Offices, Laboratory Director, and Chief Engineer at the Underwater Engineering Science Research Institute of the Ministry of Communications and Shanghai Jiao Tong University. He is a member of the Technical Committee of Shanghai Hadal Science and Engineering Technology Research Center, Chairman of the Technical Committee of the National "863" Program's Marine Technology Field during the 12th Five-Year Plan, and a first-level candidate in the Ministry of Communications "Ten, Hundred, Thousand Talent Project," enjoying special government allowances from the State Council. Multiple research

achievements under his leadership have won national and provincial/ministerial science and technology progress awards.

Since the launch of the “Frontier Scientific and Technological Issues in Hadal Trench Research and Development” Strategic Priority Research Program, the project has organized a research team spanning multiple disciplines in science and engineering, including institutes, universities, and industries, led by senior experts but with a very young average age. Within a short time after launch, the team has achieved a series of breakthroughs in frontier science, technology, and engineering related to hadal trenches, producing outstanding results and laying a solid foundation for subsequent work. Most importantly, the team has established an excellent multidisciplinary collaborative and innovative research ecosystem, training a young team with outstanding innovation capabilities.

**Ma Hui** holds a Ph.D. in Physics from Imperial College London and is a professor and doctoral supervisor at Tsinghua University. He currently serves as Director of the Shenzhen Key Laboratory of Non-Destructive Testing and Minimally Invasive Medical Technology. His research focuses on fundamental studies of polarized light scattering in complex media, as well as polarized light scattering measurement techniques, methods, instruments, and related applications. He is President of the Modern Biophysical Technology and Methods Professional Committee of the Chinese Biophysical Society, Executive Member of the Laser Medicine Professional Committee of the Chinese Optical Society, Executive Editor of the *Journal of Laser Biology*, and Editorial Board Member of *Acta Biophysica Sinica*.

*Note: Figure translations are in progress. See original paper for figures.*

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