OCCUS 2024

The 4th Offshore Carbon Capture, Utilization and Storage Forum

Summary Report

12-15 October 2024

Hangzhou, China

Forum Introduction

Purpose: The Offshore Carbon Capture, Utilization, and Storage Forum (OCCUS) is an annual academic event focused on the interdisciplinary integration of the field of carbon capture, utilization, and storage. Its purpose is to deeply explore the strategic layout of OCCUS and the harmonious development of the blue economy, explore discoveries of basic science and innovative ways of engineering technology practice, promote the quality improvement of industrial technology application, cost reduction, and scale expansion, and promote the synergistic progress of industrial integration and scientific and technological innovation. The Forum aims to build a high-end OCCUS information exchange platform integrating industry, academia, research, finance, service, and application for domestic and foreign research institutions, enterprises, and researchers, share cutting-edge achievements and valuable experience, and jointly cope with the challenges and opportunities in the development of OCCUS. It also actively enhances the potential of marine carbon sinks and assertively promotes the coordinated development of land and sea resources, ecology, industry, and space.

History: Since its inception in Xiamen in 2021, the Forum has been successfully held for four sessions, and the scale is constantly expanding. The first forum (online form) attracted more than 150 people to participate online at the same time, and the cumulative number of participants exceeded 2000; The number of online participants in the second forum (also online) surged to more than 300, and the total number of participants exceeded 10,000. The third forum was presented offline for the first time, showcasing more than 80 exciting academic reports and successfully attracting more than 180 participants to participate in the event. The fourth Forum expanded beyond Xiamen for the first time and was held in Hangzhou on an authorized basis, receiving more than 130 abstracts of reports and more than 200 participants gathered by the West Lake. With the continuous in-depth development of the Forum, the cross-integration of disciplines has been significantly improved in depth and breadth, not only promoting the mutual integration of different

disciplines but also actively advocating the close combination of science, technology, and industry, which has injected a strong impetus for the transformation and development of low-carbon industry. After years of joint efforts from academia, industry, finance, and other colleagues, the OCCUS Forum has developed into an important driving force for developing low-carbon industries in coastal areas.

Novelty: The Offshore Carbon Capture, Utilization and Storage Forum (OCCUS) is an international open platform held annually. Following the trend of the times, the forum is committed to the construction of ecological civilization, promoting the integrated planning and coordinated development of land and sea, and actively responding to the challenges of carbon dioxide emission reduction in coastal and offshore areas. The Forum scientifically plans the industrial layout of OCCUS, aiming to build a new low-carbon development system of Marine space with land and sea coordination and harmonious coexistence between man and nature. The Forum continued to pay attention to the strategic layout of the OCCUS industry's financial development, carbon dioxide physicochemical capture technology in coastal factories and offshore platforms, carbon dioxide absorption and large-scale utilization technology in offshore and far-reaching Marine biological aquaculture, carbon dioxide transportation and safety assurance technology in offshore, sea and seabed, carbon dioxide injection storage, drilling and completion technology in offshore and seabed. Cutting-edge sessions such as subsea carbon sequestration Wells, Formation and Marine environmental risk prevention and monitoring technologies, and the development of OCCUS standards. Through extensive exchanges and in-depth discussions, the forum aims to foster new industries, new models, and new drivers for low-carbon economic development in coastal areas, and effectively support the country in realizing the grand vision of "dual carbon".

Disclaimer

The views, findings, and related publications presented in the summary report of the OCCUS Forum do not represent the personal position of the forum's organizers, organizers, or any participants. None of the opinions,

findings, and publications referred to in the report provide any kind of express or implied warranty, liability, or consequence as to the accuracy, completeness, or validity of the information, technology, instruments, products, etc. covered in the report, nor does it imply that the use of such information will not infringe any individual's private rights, including intellectual property rights. The mention of any commercial product, technology, service, or trade name, trademark, or manufacturer in the report does not constitute or imply an endorsement, recommendation, or preference for those products. The OCCUS Forum expressly disclaims liability for any loss or damage that may result from the use of the information in this report, including, without limitation, the consequences of any business or investment decisions.

Copyright

Acknowledgment

This summary report details the reports and discussions of the 4th Offshore Carbon Capture, Utilization and Storage Forum, which was held at the Bailui Canal Hotel in Hangzhou, Zhejiang Province from October 12 to 15, 2024. The forum was co-sponsored by the State Key Laboratory of Marine Environmental Science (Xiamen University) and the Pacific Society of China and was hosted by the Second Institute of Oceanography, Ministry of Natural Resources. Meanwhile, South China Sea Institute of Oceanology, CAS, Wuhan Institute of Rock and Soil Mechanics, National Key Laboratory of Efficient Offshore Oil and Gas Exploitation, National Key Laboratory of Marine Gas Hydrate, College of Oceanography, Zhejiang University, Qingdao Institute of Marine Geology, Beijing Huairou Laboratory, Beijing Gangzhen Technology Co., LTD., Hangzhou Xihu District Science and Technology Association, Chinese Oceanography Huihai The Sub-Committee of Bottom Science, Seabed Exploration and Development Branch of China Ocean Engineering Consulting Association, Zhejiang Provincial

Society of Oceanography and Key Laboratory of Seabed Science of Ministry of Natural Resources and other institutions are jointly organized. The organizers expressed their sincere gratitude to the members of the Steering Committee, the Academic Committee, the Organizing Committee, and the Secretariat for their strong support and valuable contributions to the Forum. We would also like to express our appreciation to all the conveners, facilitators, and rapporteurs for their efforts and to all the participants for their active participation and communication.

This report was compiled by Lu Xu and Xi-xi Wang of Xiamen University and Jiahui Yu of the Second Institute of Oceanography of the Ministry of Natural Resources based on the speakers of the forum, and revised and edited by Prof. Jianghui Li, Dr. Ziming Wang and Dr. Fengling Yu of Xiamen University.

Citation

If it involves referencing the data and content of this report, please cite it in the following format: “State Key Laboratory of Marine Environmental Science (Xiamen University), “The Fourth Offshore Carbon Capture, Utilization and Storage Forum” Summary Report, Xiamen University, 12-15 October 2024.”

Basic Information

Theme: Coupling synergy between multi-layer carbon cycle and OCCUS

Time: 12-15 October 2024

Address: Hangzhou Bailui Canal Hotel (No.58 Jinhua Road, Gongshu District, Hangzhou, China)

Sponsor, Organizer and Co-organizer

Sponsor: State Key Laboratory of Marine Environmental Science (Xiamen University), China

Pacific Society of China, PSC

Organizer: The Second Institute of Oceanography, Ministry of Natural Resources

Co-organizer: South China Sea Institute of Oceanology, CAS; Wuhan Institute of Rock and Soil Mechanics, CAS; National Key Laboratory for Efficient Development of Marine Oil and Gas; National Key Laboratory for Marine Natural Gas Hydrate; School of Oceanography, Zhejiang University; Qingdao Institute of Marine Geology; Beijing Huairou Laboratory; Beijing Gangzhen Technology Co., Ltd.; Hangzhou Xihu District Science and Technology Association; Subsea Science Branch of Marine Society of China and Undersea Exploration; Development Branch of China Ocean Engineering Consulting Association; Zhejiang provincial Society of oceanography; Key Laboratory of Undersea Science, Ministry of Natural Resources.

Collaborative Journal:

《Fundamental Research》

《Journal of Marine Science and Application》

《Chinese Journal of Engineering Science》

《Advances in Earth Science》

Steering Committee

Director:

Jiabiao Li (Academician of Chinese Academy of Engineering, Second Institute of Oceanography, Natural Resources)

Associate Director:

Minhan Dai (Academician of Chinese Academy of Sciences, Xiamen University)

Shouwei Zhou (Academician of Chinese Academy of Engineering, China National Offshore Oil Corporation Limited)

Yang Li (Academician of Chinese Academy of Engineering, China Petrochemical Corporation Limited)

Committee Members: (sort alphabetically)

Di Zhou (Researcher, South China Sea Institute of Oceanology, CAS)

Jianfang Chen (Researcher, Second Institute of Oceanography, Ministry of Natural Resources)

Jun Cheng (Professor, Zhejiang University)

Lizhong Wang (Professor, Zhejiang University)

Qiang Liu (Professor-level Senior Engineer, CNOOC Research Institute)

Qingping Li (Professor-level Senior Engineer, CNOOC Research Institute)

Xiaochun Li (Researcher, Institute of Rock and Soil Mechanics, CAS)

Yinxia Fang (Researcher, Second Institute of Oceanography, Ministry of Natural Resources)

Yuxing Li (Professor, China University of Petroleum (East China))

Academic Committee

Director:

Jianghui Li (Professor, Xiamen University)

Associate Director:

Qi Li (Professor, Institute of Rock and Soil Mechanics, CAS)

Tao Zhang (Researcher, Second Institute of Oceanography, Ministry of Natural Resources)

Committee Members: (sort alphabetically)

Fengling Yu (Associate Professor, Xiamen University)

Guang Gao (Associate Professor, Xiamen University)

Haiyan Jin (Researcher, Second Institute of Oceanography, Ministry of Natural Resources)

Hongyu Yu (Researcher, Zhejiang University)

Jian Ma (Professor, Xiamen University)

Jianwen Chen (Researcher, Qingdao Institute of Marine Geology)

Jiayi Shen (Associate Professor, Zhejiang University)

Liming Ye (Researcher, Second Institute of Oceanography, Ministry of Natural Resources)

Minghui Zhao (Researcher, South China Sea Institute of Oceanology, CAS)

Pengchun Li (Associate Researcher, South China Sea Institute of Oceanology, CAS)

Tian Zhou (Professor, Harbin Engineering University)

Weiqi Fu (Researcher, Zhejiang University)

Xuwen Feng (Researcher, Second Institute of Oceanography, Ministry of Natural Resources)

Yanzun Li (Associate Researcher, New Energy Research Institute, CNOOC Research Institute)

Zhi Li (Associate Professor, Xiamen University)

Ziming Wang (Associate Professor, Xiamen University)

Organizing Committee

Director:

Weiwei Ding (Researcher, Second Institute of Oceanography, Ministry of Natural Resources)

Associate Director:

Xiongwei Niu (Researcher, Second Institute of Oceanography, Ministry of Natural Resources)
Yuyang Liang (Senior Engineer, Second Oceanography Institute, Ministry of Natural Resources)

Committee Members: (sort alphabetically)

Fansheng Kong, Haitao Wang, Jie Zhang, Lotte Ma, Pingchuan Tan, Qingsheng Guan, Xiaodong Wei, Yan Jia, Yanan Liu, Zhezhe Lu, Zhiteng Yu, and Zhongyan Shen

Secretariat

Secretary-general:

Xiongwei Niu (Researcher, Second Institute of Oceanography, Ministry of Natural Resources)

Members: (sort alphabetically)

Bowen Liu, Liqun Cheng, Lu Xu, Meiqin Hu, Tianrui Wang, Wenfei Gong, Xianli Ren, Xunliang Hu, Yongfa Zhang

12 Sessions

Sessions	Convenors
Session 1: The Earth System Science Theory Behind OCCUS Engineering Technology	Rui Bao, Achim Kopf
Session 2: Synergistic Theory and Technology of Subsea CO_2 Oil Displacement and Storage	Shuyang Liu, Lanlan Jiang, Kai Zhang
Session 3: Site Selection, Monitoring, and Evaluation of Marine Carbon Storage	Jianwen Chen, Lei Xing, Xuexing Song, Jiudi Li, Zongyang Li, Mingying Xie
Session 4: Monitoring and Accounting Methods for Marine Carbon Storage Risks	Qi Li, Jianghui Li, Tao Zhang, Pengchun Li, Qiang Liu
Session 5: OCCUS Rock Physics and Fluid Characterization and Simulation	Xiang Zhou, Yongsheng Tan, Wenyang Wang, Yueyue Liu, Xiaying Li, Xing Li
Session 6: Safety Assurance Technology for Marine CO_2 Pipeline Transportation	Jian Zhang, Yuxing Li, Yong Xiang, Ziming Wang
Session 7: R&D of Equipment related to Marine Carbon Storage	Weiwei Ding, Xinke Zhu, Cantao Zhuang, Ting Yang, Weiwei Wang, Yuan Wang, Xiongwei Niu
Session 8: Development Technology of Carbon Sequestration and Zero Carbon Biochemicals for Marine Organisms	Weiqi Fu, Guang Gao, Dong Wei, Jin Liu, Jianhua Fan, Haiyan Jin
Session 9: Design and Technology Research and Development of Deep Sea CCUS Marine Ranch	Yushun Lian, Jiangao Shi, Shichang Chen
Session 10: Deep-sea Material Energy Cycle and Carbon Sequestration	Pengchun Li, Zhongxian Zhao, Pibo Su, Yanlong Li
Session 11: Polar Multi-level Carbon Cycle	Tao Zhang, Qi Li, Xiaohu Li, Hongyu Yu, Jiayi Shen
Session 12: R&D of OCCUS Standards	Xuwen Feng, Letian Ma, Hongwei Niu

Contents

Introduction 16
Address 18
Overview 19
1 Keynote Presentation 20
1.1 Research on the mechanism and adaptability of CO_2 enhanced oil recovery (EOR) in shale reservoirs . 20
1.2 Integration of process carbon reduction and CCUS innovation in the petrochemical industry 21
1.3 Global plate subduction flux and deep carbon cycle calculation 22
1.4 Progress and Challenges in Offshore CO_2 Storage and Utilization Technologies 23
1.5 Hydrothermal systems of the Arctic mid-ocean ridge and their role in the deep carbon cycle 24
2 Session 1: The Earth System Science Theory Behind OCCUS Engineering Technology 25
2.1 Based on the natural analogues CO_2 Long-term geological storage evaluation method 25
2.2 Efficient Mineralization and Sequestration of CO_2 from Carbon Emission Intensive Industries Using Fly Ash and Seawater 26
2.3 Review of experimental studies on salinization during CO_2 geologic sequestration 27
2.4 Challenges and Responses to the Scale-up of CCUS in a Dual-Carbon Context 29
2.5 Natural gas hydrate systems and their role as carbon sinks 30
2.6 Molecular-Scale Insights into Nanoconfined Water-CO_2 Interactions in Geological CO_2 Storage and Utilization 31
2.7 Research on the potential of carbon emission reduction in the international shipping industry by using accelerated calcium carbonate dissolution 32
2.8 Adaptation of different catalysts for CO_2 capture in flue gas with high temperature water vapor by hydrate method 33
3 Session 2: Synergistic Theory and Technology of Subsea CO_2 Oil Displacement and Storage 35
3.1 Experimental and molecular simulation exploration of the mechanism of CO_2-oil miscibility enhanced by alcohols and surfactants 35
3.2 Research on seabed carbon dioxide sequestration mechanism and regulation methods 36
3.3 Carbon dioxide diffusion and adsorption in clay matrix nanoporous networks 37
4 Session 3: Site Selection, Monitoring and Evaluation of Marine Carbon Storage 38
4.1 Research on key technologies for saline aquifer storage offshore western Guangdong Province 38
4.2 Application of digital core technology in the study of the microscopic mechanism of seabed carbon sequestration 39
4.3 Optimization of leakage monitoring network placement based on microseismic and chemical CO_2 seafloor geologic sequestration 40
4.4 Marine offshore saltwater layer CO_2 Electromagnetic response characteristics of Marine controllable source for migration identification of sealed plume 41
4.5 Evaluation of the suitability of geological storage of carbon dioxide in China's sea area 42
5 Session 4: Monitoring and Accounting Methods for Marine Carbon Storage Risks 44

5.1 Key technologies for environmental monitoring of gas hydrate test mining in the South China Sea and prospects for their application in the field of seabed carbon storage 44
5.2 Several issues in the drafting of technical standards for monitoring geological storage of carbon dioxide46
5.3 Evaluation of Long-Term Reactive Transport and Closure of Carbon Dioxide Saltwater Sequestration 47
5.4 Evaluation of Carbon Dioxide Storage and Injection Capacity in Marine Depleted Gas Reservoirs 48
5.5 Characterization of pore structure evolution pattern and micro-mechanical strength change of cementite reaction layer for cementing in CO_2-rich environment with offshore sequestration 49
5.6 Mechanism and countermeasures of fracture destabilization induced by CO_2 pre-fracturing 50
5.7 Model and application of well-reservoir coupling two-phase flow based on interface tracking theory ... 51
5.8 Geophysical survey and potential evaluation of the Tianyang volcanic fault basin, Leizhou Peninsula, basalt CO_2 mineralization sequestration alternative site 52
5.9 Characterization of the microscopic mechanism and dynamic parameter response of CO_2 hydrate generation 53
6 Session 5: OCCUS Rock Physics and Fluid Characterization and Simulation 54
6.1 Experimental study on the feasibility of high-temperature supercritical CO_2 development and storage in shale reservoirs 54
6.2 Characterization of physical properties and pore structure of fluid sequestered by offshore CO_2 mineralization 55
6.3 Methodology and Software Development for Wellbore Integrity Evaluation of Offshore CO_2 Sequestration 56
7 Session 6: Safety Assurance Technology for Marine CO_2 Pipeline Transportation 57
7.1 Structural Safety and Engineering Countermeasures for Offshore CO_2 Pipelines 57
7.2 Research Progress on Key Technologies for Safe Operation of Marine CO_2 Pipelines 58
7.3 Theoretical modeling of overall buckling of laminated pipes 59
7.4 Quasi-criticality criterion for impurity-containing CO_2 and its application to CCUS pipeline technology60
7.5 Discussion on Guidelines for Determining Water Content Thresholds for CO_2 Fluids Transported via Subsea Pipelines 61
7.6 Research on Corrosion On-line Monitoring and Leakage Early Warning Technology of CCUS System62
7.7 Corrosion protection technology and practice of CO_2 long-distance transportation pipeline 63
7.8 Corrosion and stress-corrosion study of supercritical CO_2 transportation pipeline 64
7.9 Droplet Coalescence and Corrosion Behavior of Pipeline Walls in Supercritical Carbon Dioxide Environments 65
7.10 Selective adsorption and corrosion mechanism of SO_2 and its hydrate on X65 steel welded joints in CO_2 solution 66
8 Session 7: R&D of Equipment related to Marine Carbon Storage 67
8.1 Seabed seismograph and OCCUS field monitoring equipment 67
8.2 Research and development and application of new low-frequency broadband submarine seismometer . 68
8.3 Equipment and technology of submarine seismograph 70
8.4 Research and development progress of submarine seismograph in China 71

8.5 Submarine seismic detection in dense ice areas of the Arctic Ocean 73
8.6 Marine gas escape monitoring based on a broadband submarine seismograph 74
9 Session 8: Development Technology of Carbon Sequestration and Zero Carbon Biochemicals for Marine Organisms 76
9.1 Regulation technology and carbon migration mechanism of photosynthetic carbon sequestration coproduction of high protein or high lipid by microalgae driven by CO_2 76
9.2 Metabolically remodeled carbon sequestration Marine microalgae synthesize high-value products 77
9.3 Sedimentation characteristics and mechanism of Mirco class phytoplankton —— lab and field studies 78
9.4 Molecular circadian biological clock regulation of photosynthetic carbon sequestration in phytoplankton80
9.5 Development of aerobic non-oxygen-producing photosynthetic bacteria resources based on genome and single cell Raman spectroscopy 81
9.6 Response of algal fat and polyunsaturated fatty acid production to high CO_2 concentration 82
9.7 Characteristics of response of food microalgae to contaminants in cultured water and migration mechanism in shellfish system 83
9.8 Potential and challenges of CD-driven carbon-setting microalgae as a future food product 84
10 Session 9: Design and Technology Research and Development of Deep Sea CCUS Marine Ranch 85
10.1 Algal carbon sink pasture construction technology to help achieve the national dual-carbon target 85
10.2 Study on dynamic characteristics of netgarment under the combined action of random wave and random boundary deformation 86
11 Session 10: Deep-sea Material Energy Cycle and Carbon Sequestration 87
11.1 Uncertainty analysis of biological gas generation and natural gas hydrate accumulation in Baiyun Sag, South China Sea 87
11.3 Deep-sea sedimentary differences and organic carbon burial in marginal seas: a case study of the South China Sea 89
11.4 Offshore CO_2 Research on capture and transformation and utilization technology 91
11.5 Study on the valve effect of gas hydrate on deep-sea methane cycle 92
11.6 Marine carbon dioxide geological sequestration technology path —— from shallow sea to deep sea .. 93
11.7 The physiological properties of aerobic methane oxidation bacteria in the deep sea and their potential of driven methane "sink" 95
12 Session 11: Polar Multi-layer Carbon Cycle 96
12.1 Research status and challenges of multi-layer carbon cycle in abyss subduction system 96
12.2 Sea ice transport and organic matter composition and source of surface water particles in the Arctic Ocean Basin 98
12.3 Burment and release of organic carbon in the Arctic Ocean since late Pleistocene 100
12.4 Marine soil stabilization and CO_2 solidification by dredging: a new approach to carbon emission reduction and resource recycling 101
13 Session 12: R&D of OCCUS Standards 102
13.1 Preferred survey of target area 102
13.2 Technical guidelines for the determination of the monitoring scope of the carbon dioxide geological

utilization and storage project 103
13.3 Preparation ideas and discussion of Guidelines for Ecological Environment Monitoring and Evaluation of Offshore Carbon Dioxide Reinjection Project 104
13.4 Build a platform to let China's Marine technical standards quickly go to the world 105
14 Student Oral Presentation 107
14.1 Molecular scale insights into nanoconfined water-CO_2 interactions in geological carbon sequestration 107
14.2 Study on the effect of nano-scale surface roughness of silica micropores on the molecular behavior of CO_2 108
14.3 Simulation and leakage risk assessment of impure carbon dioxide brackish water reservoirs 109
14.4 Research on the mechanism and path of Zhanjiang to promote the construction of the CCUS cluster in West Guangdong from the perspective of a coordinated innovation network 110
14.5 Establishment of controlled source electromagnetic forward modeling in the process of CO_2 geological storage monitoring on the seabed 111
14.6 CO_2 mineralization storage potential and site selection 113
14.7 Rapid leak assessment of CO_2 subsea sequestration based on machine learning 114
14.8 Quantitative assessment and transmission mechanism of carbon dioxide geological storage technology risk: a study based on social network analysis 115
14.9 Sealable leakage risk and evaluation method of seafloor carbon sequestration cap 116
14.10 Image guided Marine controllable source electromagnetic method for modeling monitoring and analysis of CO_2 sealed storage layer in the seabed 117
14.11 Feasibility study on time-delay gravity monitoring of carbon dioxide plume migration 118
14.12 Study on the influence of pore heterogeneity on rock transport properties 120
14.13 Study on basalt dissolution and ion synergistic deposition effect under enhanced percolation of CO_2-containing seawater 121
14.14 Experimental study on seepage law and extraction mechanism of supercritical CO_2 injection in heavy oil 122
14.15 Study on microscopic percolation of supercritical CO_2 in compact storage 123
14.16 Experimental study on CO_2 injection and energy recovery in tight conglomerate reservoir 124
14.17 Development and application of "Dolphin" mobile ocean seismograph 125
14.18 Research and development of microalgae carbon sequestration equipment and optimization of culture conditions 126
15 Poster Presentation 128
15.1 Carbon isotope characteristics of authigenic carbonates in ultra-deep oceanic sediments and their implications for deep carbon cycle 128
Yong xin Liu, PhD student, Ocean University of China 128
15.2 Application of laser Raman spectroscopy in the monitoring of carbon sequestration fluid 130
15.3 Geological conditions of carbon dioxide sequestration in Yantai Depression, South Yellow Sea Basin 132
15.4 Acoustic response characteristics during the formation and decomposition of carbon dioxide hydrate: implications from the study of combined acoustic and CT detection 134

15.5 Numerical simulation of carbon dioxide sequestration in brackish water layer in Fushan Depression 136
15.6 The composition and transformation of particulate organic carbon in winter in the north wind abyssal plain of the Western Arctic Ocean were investigated based on fatty acids 138
15.7 Comparative analysis of CO_2 Marine geological sequestration simulation under single - and multi-layer injection conditions 139
15.8 Deep-sea exploration and exploitation of strategic key metals in China in the context of sustainable Marine development: reflections and prospects 140
15.9 Study on solubility difference of CO_2 in different storage environment based on molecular dynamics simulation 142
15.10 Research on standardization of carbon emission reduction accounting for CO_2 capture, oil displacement and storage projects 144
16 Summary and Suggestions for Future Development 146
16.1 Session 1: The Earth System Science Theory Behind OCCUS Engineering Technology 146
16.2 Session 2: Synergistic Theory and Technology of Subsea CO_2 Oil Displacement and Storage 146
16.3 Session 3: Site Selection, Monitoring, and Evaluation of Marine Carbon Storage 146
16.4 Session 4: Monitoring and Accounting Methods for Marine Carbon Storage Risks 148
16.5 Session 5: OCCUS Rock Physics and Fluid Characterization and Simulation 148
16.6 Session 6: Safety Assurance Technology for Marine CO_2 Pipeline Transportation 149
16.7 Session 7: R&D of Equipment related to Marine Carbon Storage 150
16.8 Session 8: Development Technology of Carbon Sequestration and Zero Carbon Biochemicals for Marine Organisms 150
16.9 Session 9: Design and Technology Research and Development of Deep Sea CCUS Marine Ranch 151
16.10 Session 10: Deep-sea Material Energy Cycle and Carbon Sequestration 152
16.11 Session 11: Polar Multi-layer Carbon Cycle 152
16.12 Session 12: R&D of OCCUS Standards 153

Introduction

From October 12 to 15, 2024, the 4th Offshore Carbon Capture, Utilization and Storage (OCCUS) Forum was held in Hangzhou. The forum was co-sponsored by the State Key Laboratory of Marine Environmental Science (Xiamen University) and the Pacific Society of China, and was hosted by the Second Institute of Oceanography, Ministry of Natural Resources. The core purpose of the forum is to clarify the strategic positioning of OCCUS, promote the mutual promotion between basic scientific research and engineering technology practice, and promote the coordinated development of industrial integration and scientific and technological innovation, to enhance Marine sink enhancement capacity, and promote the interactive and coordinated development of land and sea resources, ecology, industry and space, and then promote the coordinated development of China and the global blue economy.

The 4th OCCUS Forum covered 12 main sessions. 5 to 15 oral presentations were scheduled for each session, along with 30 student oral presentations and 20 poster presentations; To ensure that the participating experts can communicate in-depth, 10 to 20 minutes of discussion time is reserved for each session to condense the future development direction of the session.

With the active participation of experts from various fields, the report of this forum shows the diversity of research directions and the characteristics of multi-disciplines. The report not only covers a number of frontier areas and development routes, but also includes terrigenous source-ocean sink matching and multiple scenarios and route planning. At the same time, the report also considers macroeconomic policy recommendations and micro-engineering implementation measures.

This forum has comprehensively demonstrated China's industrial development and research status in the emerging low-carbon field of "Offshore Carbon Capture, Utilization and Storage", as well as the achievements made in scientific and technological progress and engineering practice. The forum provides a platform for knowledge sharing and in-depth communication among experts in related fields, aiming to explore a development path for emerging low-carbon industries to achieve the Carbon Neutrality target.

Participants of the 4th Offshore Carbon Capture, Utilization and Storage Forum

Address

Dr. Yan Bai, researcher of the Second Institute of Oceanography, the Ministry of Natural Resources, extended a warm welcome to the leaders, experts, scholars, technical elites, and young students attending the forum.

Prof. Minhan Dai, Academician of the CAS and honorary director of the State Key Laboratory of Marine Environmental Science (Xiamen University), delivered an enthusiastic speech. Prof. Dai emphasized the key role of OCCUS in addressing climate change, and hoped that elite scholars from different fields would take advantage of this academic event to discuss the future development path together.

Prof. Jiabiao Li, academician of the Chinese Academy of Engineering and director of the Steering Committee of the Forum, stressed China's responsibility as a major country in achieving the goal of carbon peaking and carbon neutrality. He suggested that in the future, original basic research in the field of CCUS should be strengthened to increase the normative citation impact of the discipline. At the same time, we should vigorously promote the standardization work, promote the scale and commercial development of CCUS, and promote the internationalization of its standards, to strive for the right to speak in the international arena. In addition, Prof. Li also proposed to develop marine geological carbon storage technology and make use of a number of advantages of marine geological carbon storage.

Prof. Yinxia Fang, director of the Second Institute of Oceanography of the Ministry of Natural Resources, introduced in detail the innovative research results of the institute in the fields of Marine Geology, Marine Physics, Marine Remote Sensing, and Marine Biochemistry, and shared the preparation process of the Forum. She said that this forum will focus on the core issue of Offshore Carbon Capture, Utilization and Storage, and in-depth discussion of the new mechanism of the multi-layer carbon cycle in the Earth system, new strategies for the coordinated development of the OCCUS blue economy, new methods of science and technology, and new measures for industrial technology upgrading and expansion, aiming to provide solid scientific and technological support for the realization of the "dual carbon" goal.

Overview

The OCCUS Forum has been successfully held for four consecutive years, attracting more than 200 representatives of scientific research institutions, business representatives, and researchers nationally and internationally to discuss the development path of OCCUS. The Forum is committed to contributing wisdom and strength to promoting Marine carbon sink potential as well as the comprehensive and coordinated development of land and sea resources, ecology, industry, and space.

The 4th OCCUS Forum involves 12 sessions, and successfully attracted the participation of more than 200 professionals, who through the sharing of reports and in-depth discussions, put forward valuable suggestions for the development prospects of various thematic areas. In addition, the venue also set up a special poster exhibition area to show the innovation achievements in related fields, and inject new vitality into the future development of Marine science and technology.

In addition, the Forum set up a special "Outstanding Student Report Award" to encourage students who have excelled in the field of "offshore carbon capture, utilization and storage" to actively engage in research in this field and commit to its future development.

The student winners are:

The 1st prize:

Fei Hou, China University of Geosciences (Wuhan)

The 2nd prize:

Xi-xi Wang, Xiamen University

Fu-tao Mo, Zhejiang University

The 3rd prize:

Bin Liu, South China Sea Institute of Oceanography, CAS

Jian-jie Niu, Peking University

Bo-wen Chen, Wuhan Institute of Rock and Soil Mechanics, CAS

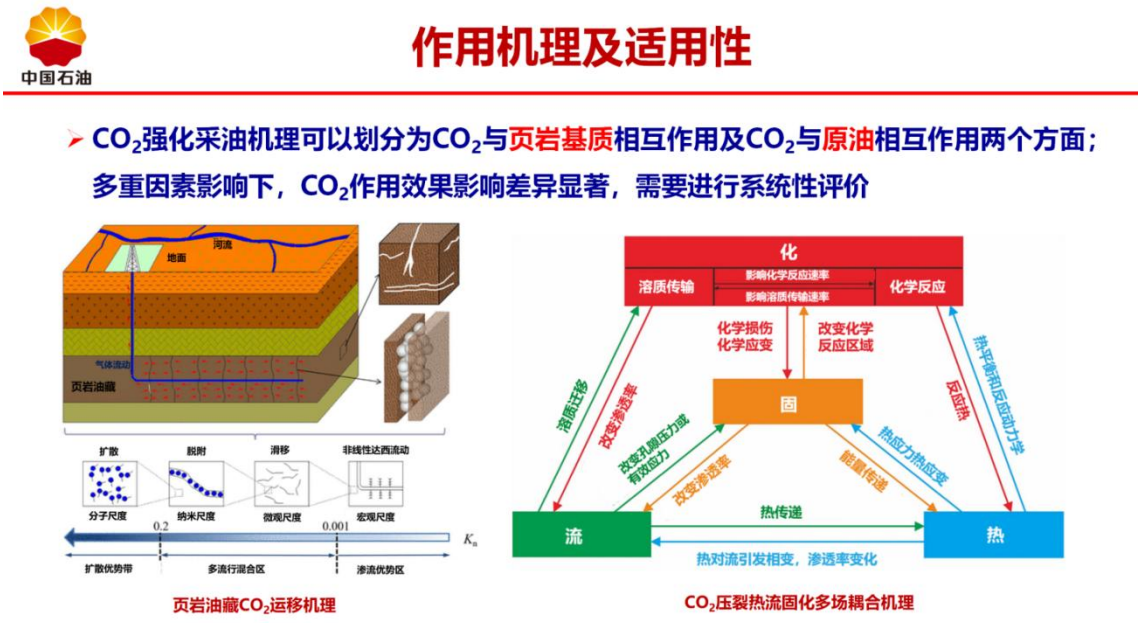
Prof. Yinxia Fang, director of the Second Marine Institute, and Prof. Hongwei Zhao, director of Qingdao Institute of Marine Geology of China Geological Survey, presented the award to the winning students.

1 Keynote Presentation

1.1 Research on the mechanism and adaptability of CO_2 enhanced oil recovery (EOR) in shale reservoirs

He Liu, Academician of CAE, Research Institute of Petroleum Exploration & Development

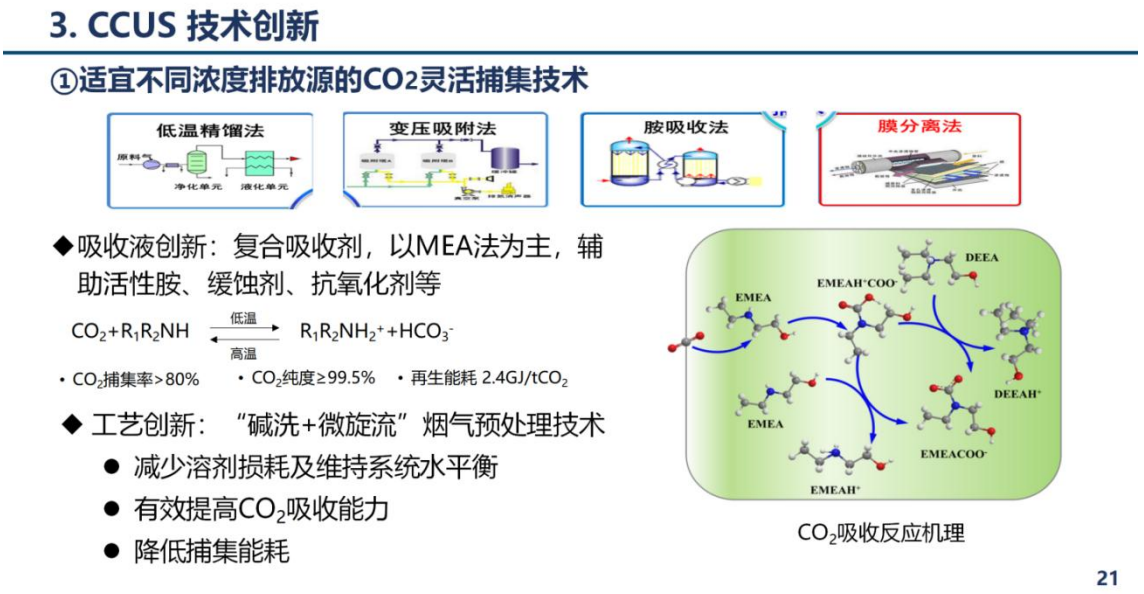
The lecture discusses in detail the prospects of CO_2 enhanced oil recovery (EOR) application in Chinese shale reservoirs, emphasizing the dual advantages of the technology in terms of enhanced recovery and reduced carbon emissions. Through diffusion, adsorption, and dissolution, CO_2 can effectively change the physicochemical properties of shale reservoirs, enhance oil mobility, and increase recovery. Experiments in shale oilfields such as Jimushar and Gulong have shown that there are significant differences in the effectiveness of CO_2 enhanced oil recovery (EOR) under different geological conditions. The lecture also analyzes the challenges faced by the technology in practice, including the complex CO_2 fracturing process, the high cost of CO_2 transportation and storage, and the infrastructure that needs to be further developed. To overcome these difficulties, the lecture recommends strengthening technology research and development and policy support to further promote the commercial application of CO_2 enhanced oil recovery (EOR) and help China achieve its carbon neutrality goal.



1.2 Integration of process carbon reduction and CCUS innovation in the petrochemical industry

Li-li Sun, Academician of CAE, Sinopec Engineering Incorporation (SEI)

The report focuses on the integrated application of process decarbonization and CCUS technologies in China's petrochemical industry, demonstrating their potential to reduce emissions and improve energy efficiency. The report notes that the petrochemical industry is one of the major sources of carbon emissions, and that in recent years China has significantly reduced the industry's carbon footprint through a number of technological innovations. Among other things, the report highlights million-ton CCUS projects in Qilu Petrochemical and Shengli Oilfield, demonstrating the successful application of CCUS in the industrial sector. Through absorption, membrane separation and other technologies, CO_2 is efficiently captured and utilized in the production of oil drive and chemical raw materials. The report also emphasizes the possibility of combining CCUS with carbon market mechanisms, and that policy support and industry cooperation are crucial for large-scale applications. In the future, the petrochemical industry will continue to promote technological innovation to achieve deep decarbonization goals.

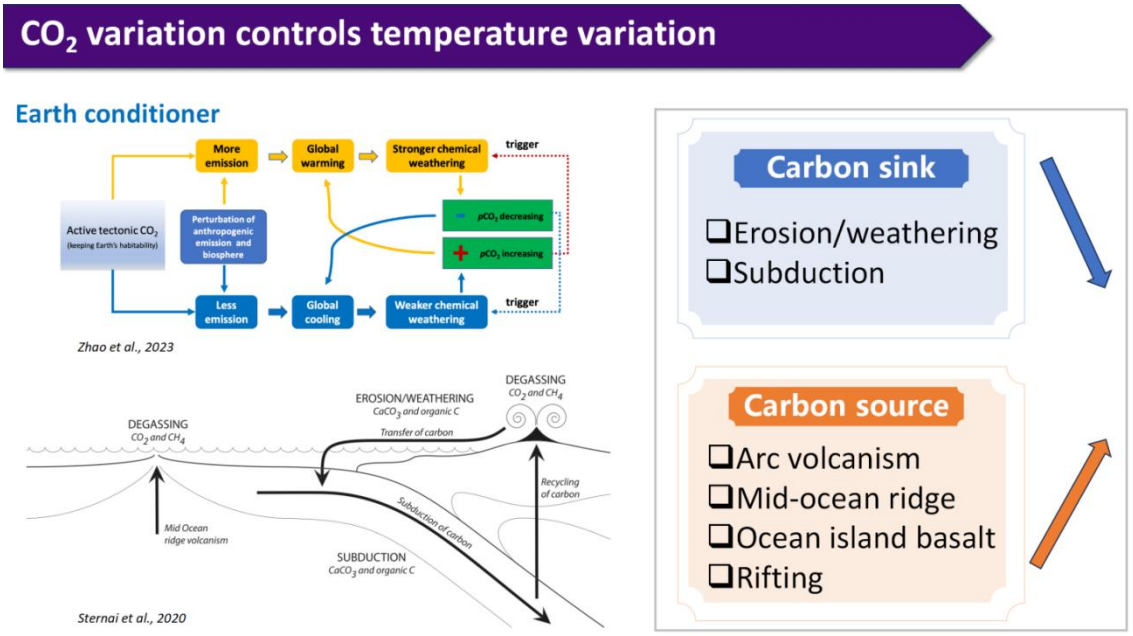


CO_2吸收反应机理

1.3 Global plate subduction flux and deep carbon cycle calculation

Liang Zhao, Research Professor, Institute of Geology and Geophysics, CAS

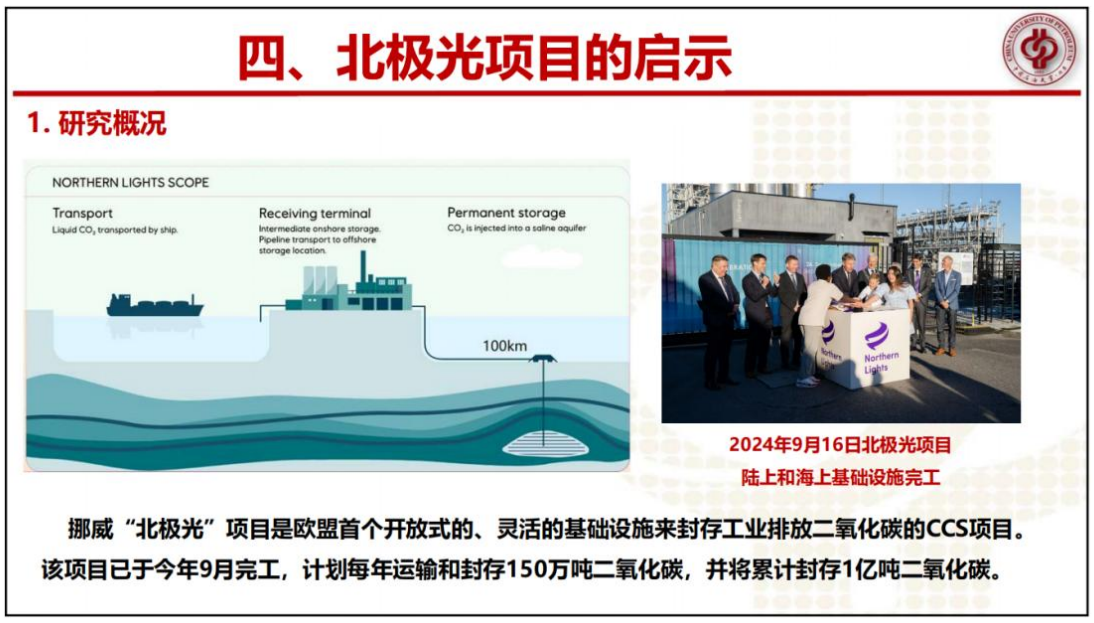
The report explores the link between global plate subduction fluxes and the carbon cycle in the deep Earth. By analyzing data from the Indo-Eurasian plate collision and other subduction zones around the globe, carbon inputs and outputs from different subduction zones are calculated. The report reconstructs the history of plate subduction from the Cenozoic to the present through seismic and geologic data, showing how subduction plays a central role in the deep carbon cycle. In particular, there is a strong link between the convergence of the Indo-Eurasian plate and changes in global atmospheric CO_2 concentrations. The report also points out that the contribution of volcanic arcs and submarine spreading ridges in global carbon export should not be overlooked. Future studies will incorporate 3D modeling for a more detailed analysis of carbon cycle processes, aiming to improve the understanding of the global carbon cycle, especially the impact of deep carbon reservoirs and release mechanisms.



1.4 Progress and Challenges in Offshore CO_2 Storage and Utilization Technologies

Bo Peng, Professor, China University of Petroleum (Beijing)

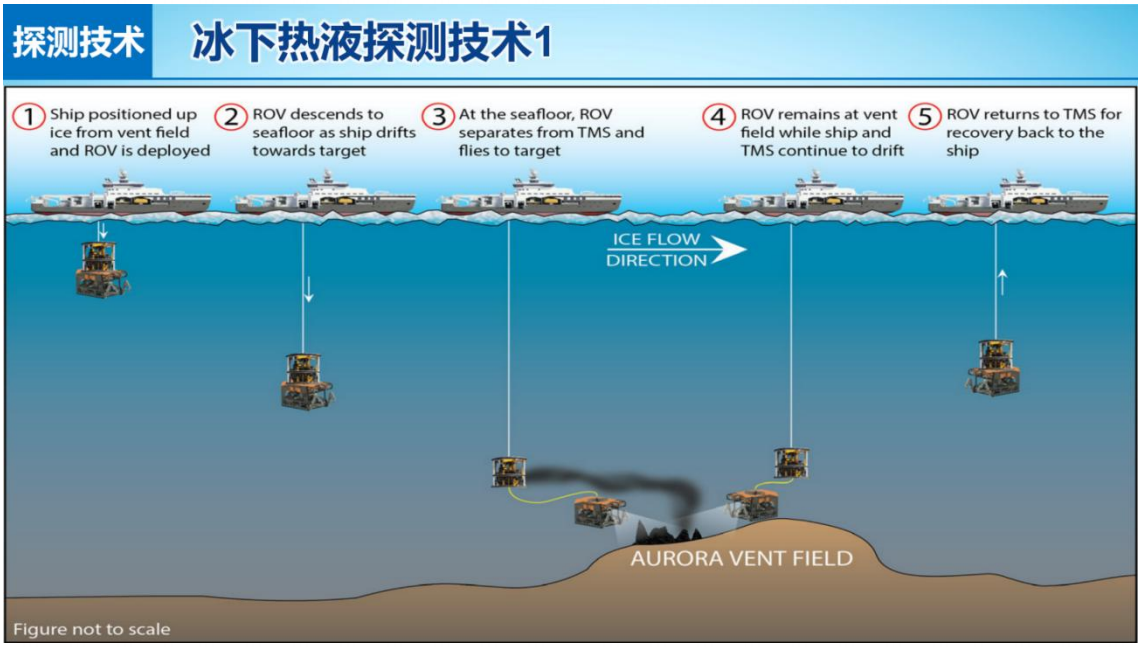
The report provides a comprehensive overview of the latest developments in CCUS technology in offshore applications, especially its key role in the context of global carbon neutrality. Globally, the CCUS project operating in 2022 captures a total of 43 million tons of carbon dioxide, and future new projects are expected to capture 200 million tons per year. The report focuses on several typical projects, such as Sleipner in the North Sea, Gorgon projects in Australia, and Chinese applications in oil fields in the Bohai Sea region. Special emphasis is placed on the major technical challenges facing the offshore CCUS, including reservoir stability, CO_2 Migration mechanism, the precision of the storage geological model, etc. Combined with the successful cases of the Northern Lights project, the report explores the possibility of improving the efficiency of CCUS through intelligent technology and digital twin technology in the future. In addition, the potential of CCUS combined with CO_2 enhanced oil recovery (EOR) and its key role in achieving peak carbon dioxide emissions and carbon neutrality targets in China are also mentioned.



1.5 Hydrothermal systems of the Arctic mid-ocean ridge and their role in the deep carbon cycle

Tao Zhang, Research Professor, Second Institute of Oceanography, Ministry of Natural Resources

The report is organized around the hydrothermal systems of the Arctic mid-ocean ridges and provides an in-depth analysis of the unique role of these systems in the global carbon cycle. The report points out that hydrothermal systems are important carbon sources and sinks, and in particular, hydrothermal plumes active under ice caps provide new ways of understanding carbon emissions. Through new discoveries such as the AURORA hydrothermal field, the researchers reveal how high-precision hydrothermal plume detection can be performed in extreme environments. The report also discusses how hydrothermal systems are involved in deep carbon cycling processes through seafloor carbon fixation and release mechanisms. Future research will focus on the development of new autonomous detection systems to overcome technological limitations in the Arctic environment. The report emphasizes the scientific and environmental importance of gaining a deeper understanding of the contribution of Arctic hydrothermal systems to the carbon cycle in the context of global climate change.

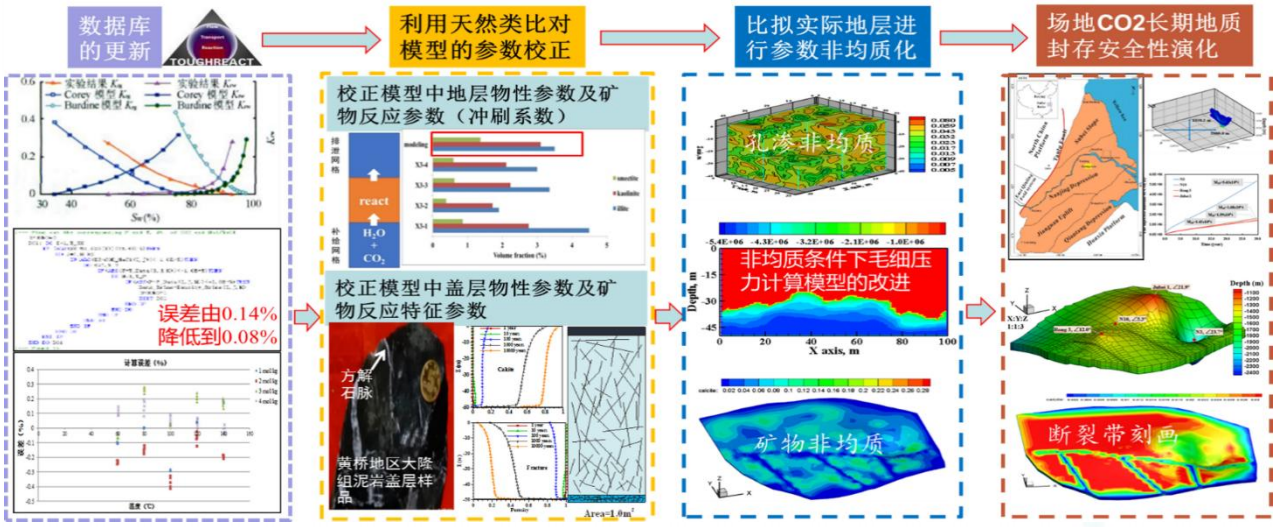


2 Session 1: The Earth System Science Theory Behind OCCUS Engineering Technology

2.1 Based on the natural analogues CO_2 Long-term geological storage evaluation method

Bing Zhou, Associate Researcher, Petroleum Exploration and Development Research Institute of Sinopec

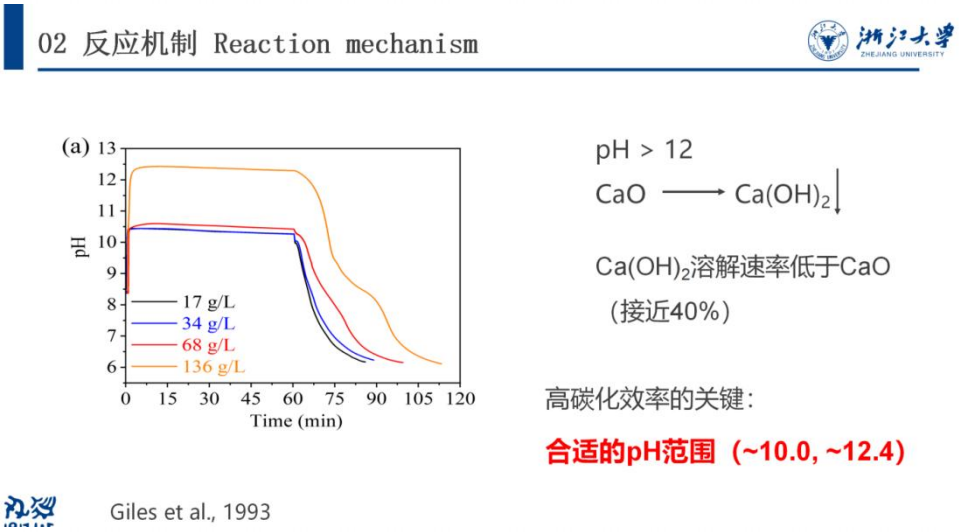
In the basic research of CO_2 geological storage, facing the difficulty of verifying the reliability of numerical simulation in large spatial and temporal scales, it is proposed to introduce the natural analog of CO_2 geological storage, i.e. natural CO_2 gas reservoir, and to modify the simulation method by fitting the history of the natural CO_2 gas reservoir to realize the reliable evaluation of numerical simulation of CO_2 storage in large spatial and temporal scales. In this study, the Huangqiao gas reservoir, a natural CO_2 gas reservoir in the North Jiangsu Basin, is selected as a natural analog of CO_2 geological storage, and the neighboring Jurong oil and gas reservoir is selected as a target area for long-term geological storage of CO_2, and through the geologic dissection and numerical simulation inversion of the Huangqiao natural CO_2 gas reservoir, we establish the Through the geological dissection and numerical simulation inversion of Huangqiao natural CO_2 gas reservoir, we established the correction model of “flushing coefficient”, and applied the correction model to the numerical simulation of CO_2 geological storage in Jurong oil and gas reservoir, and then simulated and evaluated the process of its long-term storage. This modified validation method based on natural analogs can effectively solve the problem of the reliability of numerical simulation in large spatial and temporal scales, and provide a basis for the study of long-term geological storage of CO_2.



2.2 Efficient Mineralization and Sequestration of CO_2 from Carbon Emission Intensive Industries Using Fly Ash and Seawater

Yi-wen Pan, Professor, Zhejiang University

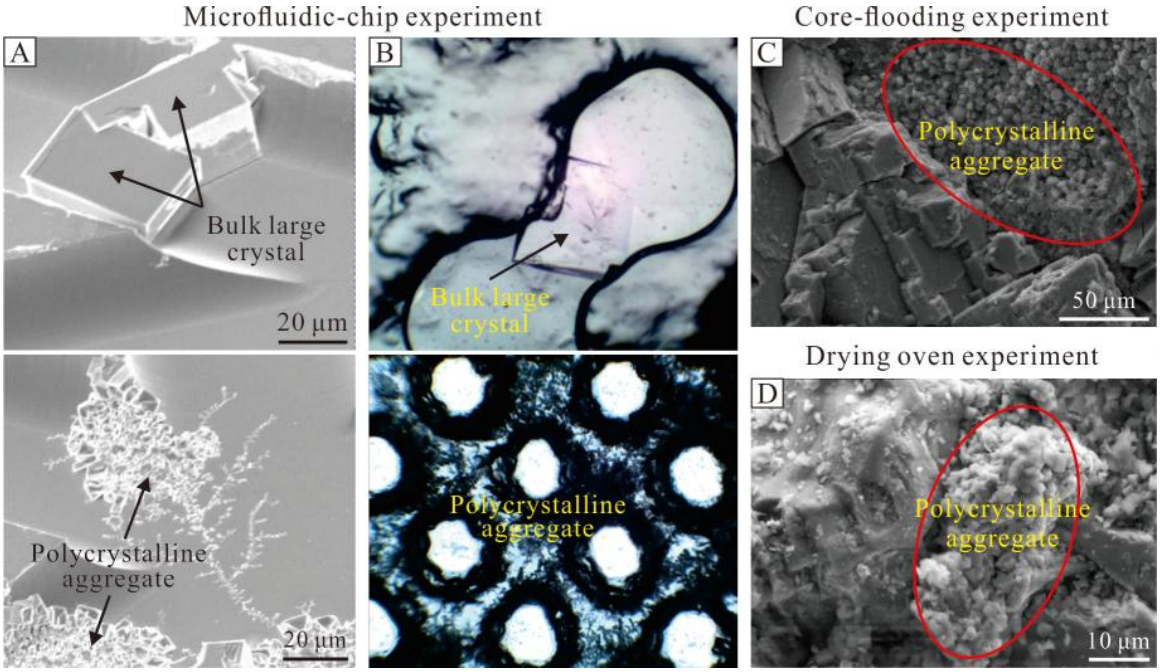
CO_2 emitted from coal combustion accounts for nearly 70% of the total national carbon emissions, with a large amount of coal combustion coming from coal-fired power plants, and the rest coming mainly from energy-intensive traditional industries such as chemicals, iron and steel, and cement. Some of these carbon-intensive industries are located in coastal areas, so we propose the use of seawater media to achieve CO_2 sequestration by fly ash mineralization as a potential means of source emission reduction. In this study, high carbonation efficiency was obtained by using seawater to mineralize and sequester CO_2 with fly ash at ambient temperature and pressure, and the real-time CO_2 uptake capacity was more than 50%. Mechanistic investigation showed that similar to brine with high NaCl concentration, the high salinity of seawater facilitates the leaching of CaO from fly ash, and also has the advantages of being rich in calcium and magnesium ions, inexpensive, abundant, and conveniently accessible, which can be used as an alternative to brine with fly ash for CO_2 sequestration. Meanwhile, the key to realizing high carbon sink efficiency is to control the low pH range (8.2~10.4). In this pH range, the leaching rate of CaO is faster than that of $Ca(OH)_2$, and the faster CaO leaching rate increases the amount of Ca leached, thus improving the carbonization efficiency. The precipitation and dissolution of $Mg(OH)_2$ in this pH range also affected the rate of $CaCO_3$ production and crystallinity. The concentration of heavy metal ions in the solution after mineralization is far below the requirements of national standards and can be discharged directly, which is environmentally friendly. The lower pH of the mineralized solution effectively improves the solubility of the alkali source, so that the alkali source can be directly dissolved at a faster rate without fine crushing, and the alkalinity of the solution can be increased to reduce the pCO_2 of the solution to be discharged, to realize the effect of adding alkali to increase sinks at low cost and high efficiency. Therefore, the efficient, environmentally friendly, and low-cost mineralization method of CO_2 sequestration using fly ash and seawater at ambient temperature and pressure can be effectively combined with seawater alkali-enhancement technology, and has great potential for popularization and application.



2.3 Review of experimental studies on salinization during CO_2 geologic sequestration

Xiao-long Sun, Lecturer, China University of Petroleum (East China)

Salt precipitation accompanied by formation drying in the process of CO_2 geological storage is an important secondary change leading to the damage of reservoir accessibility, and this paper systematically summarizes the progress of experimental research on salt precipitation. Salt precipitation research mainly relies on four types of experimental systems, including core repulsion experiments, microfluidic chip experiments, static water-rock reaction experiments, and surface drying experiments, and the nature of salt precipitation during CO_2 injection is the coupling of two-phase repulsion, brine evaporation, capillary reflux of brine, diffusion of salt solutes, and growth of salt nucleation. The macroscopic distribution pattern of salt precipitation includes homogeneous distribution, non-homogeneous distribution, and semi-homogeneous distribution, which are evaporation-controlled, capillary reflux-controlled, and diffusion-controlled, respectively; and the salt crystals mainly include single crystals and microcrystalline aggregates. This paper focuses on the systematic analysis of the influencing factors of salt precipitation, formation water salinity, CO_2 injection rate, and initial reservoir characteristics are the main controlling factors that determine the amount and distribution of salt precipitation and its damage to the injectability of the reservoir, and it is generally believed that low salinity, high injection rate, and high reservoir pore permeability are conducive to slowing down the salt precipitation effect and its negative impact on the injectability of the reservoir. The relatively homogeneous pore and reservoir structure and hydrophobic wettability characteristics are favorable to reduce the possibility of localized strong salinization development, and the coupling mechanism of pore and reservoir structure and wettability on salinization is to be investigated by specially designed experimental samples. Monovalent salt-dominated formation aqueous solutions and supercritical replacement fluids have relatively weak salinization effects, but there are relatively few studies focusing on the composition and phase state of brines and replacement fluids. In addition, although a large number of experimental studies have been carried out on the salinization mechanism, distribution law, and influencing factors in the context of CO_2 geological sequestration, the sample sizes used in the commonly used core replacement and microfluidic chip experiments are much smaller than the actual reservoir sizes, which may lead to the underestimation of ectopic brine recharge in the process of salinization, and thus lead to the misperception of the salinization content and its process, which is to be reduced by improving the design of the samples and the experimental system. The experimental sample design and experimental system should be improved to reduce the experimental error.


Microfluidic-chip experiment
Core-flooding experiment
A
Bulk large crystal
20 μm
B
Bulk large crystal
C
Polycrystalline aggregate
50 μm
Drying oven experiment
Polycrystalline aggregate
20 μm
Polycrystalline aggregate
D
Polycrystalline aggregate
10 μm

2.4 Challenges and Responses to the Scale-up of CCUS in a Dual-Carbon Context

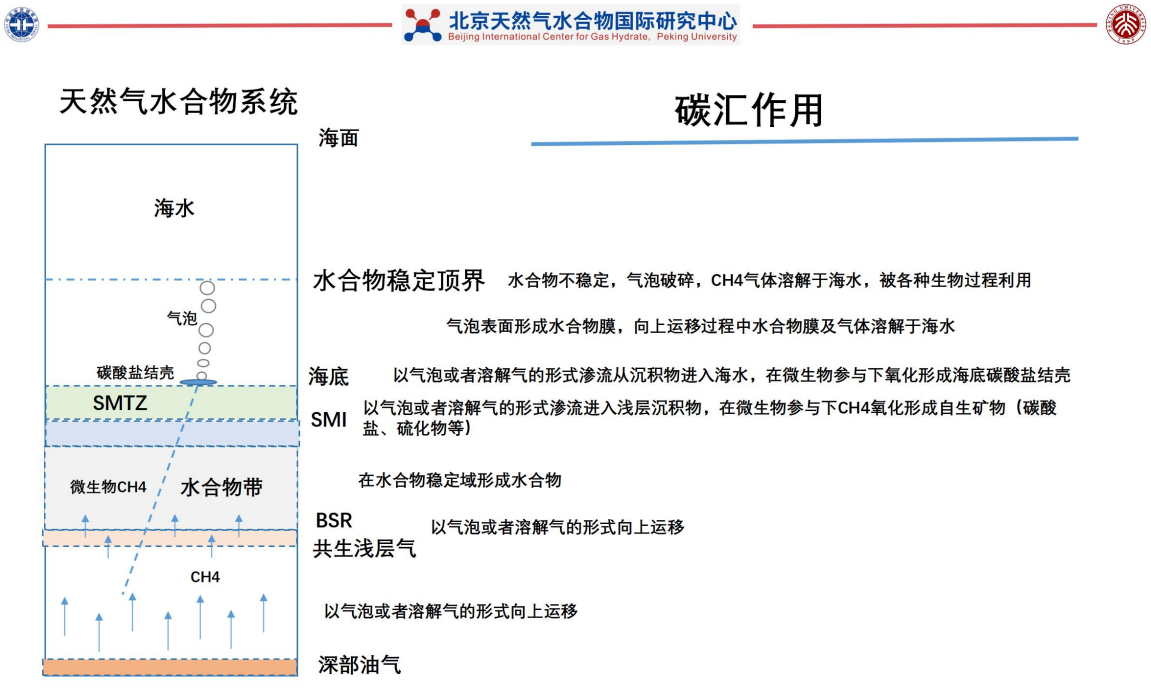
Xue-hai Yu and Yang Yang, Professor-level Senior Engineer, National Energy Group New Energy Technology Research Institute Co., LTD

CCUS is an important part of the target technology combination of carbon neutrality. Nearly 100 CCUS demonstration projects have been put into operation and planned in China, of which more than half of the projects have been put into operation, with CO_2. The capture capacity is about 4 Mt/year, and the injection capacity is about 2 Mt/year. The capture sources cover power, oil and gas, the chemical industry, cement, steel, and other industries. At present, China's CCUS industry has gradually entered the stage of large-scale capture demonstration and application on a small scale, and is accelerating the development of the whole process, integration, scale and regional industrial cluster direction, especially in the 10-million-ton CCUS project in the Pearl River Delta and Yangtze River Delta region. The national energy group actively responds to the national strategy, speeds up the transformation and upgrading of enterprises, around low energy capture, efficient utilization, and safe storage, carries out a series of CCUS technology research and development and engineering demonstrations, focuses on new carbon capture absorber system research and development, formed from tons, tons to every scale of carbon capture process package, applicable to 5% to 20% low concentration and 80% and high concentration of high concentration carbon source scene, can serve the thermal power generation, coal chemical industry, cement plant, steel plant and other industries. CCUS technology has progressed in China, but each link technology development is not balanced, and the large-scale business applications still exist in different degrees of gap, large-scale carbon capture still faces large energy consumption, high cost, technology and equipment amplification, strong coupling, poor flexibility and long cycle safe and stable operation of the key problems, promote CCUS technology and industrialization, should be from Government, capital, scientific research, enterprises four aspects.

2.5 Natural gas hydrate systems and their role as carbon sinks

Hai-long Lu, Professor, Peking University

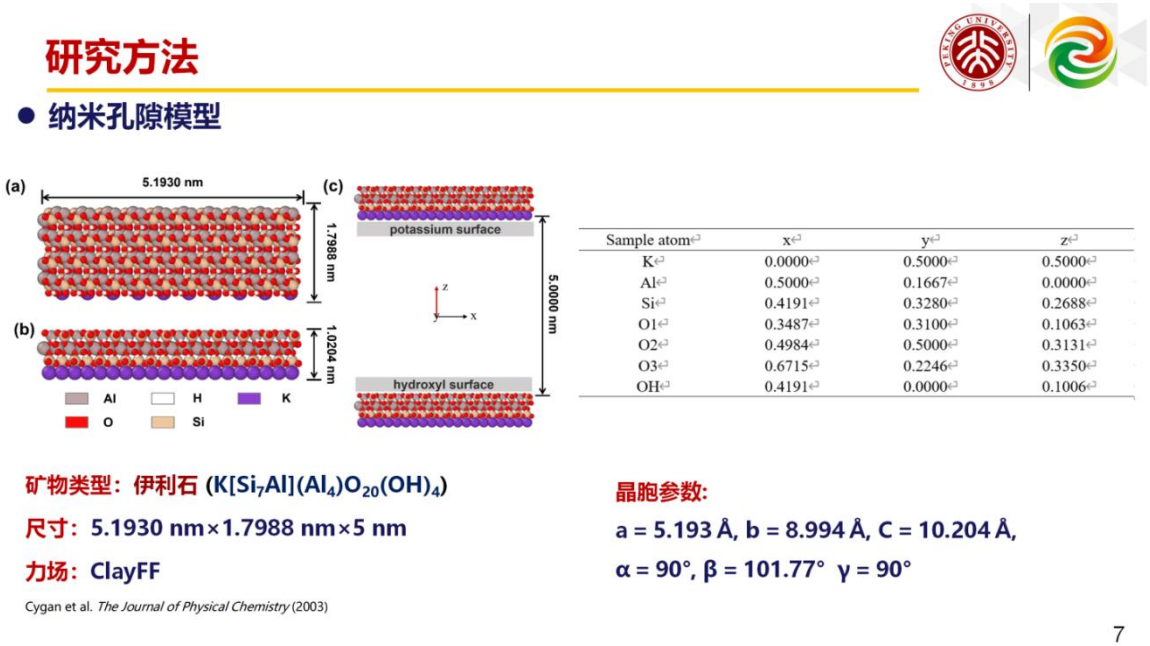
Natural gas hydrates are widely distributed in continental slope sediments and permafrost and are dominated by marine gas hydrates, which are estimated to have a carbon equivalent greater than that of the oil and gas already discovered. The natural gas hydrate system consists of a gas source, a hydrate reservoir and its overlying strata, and seawater. In addition to in-situ microbial genesis, the gas source of natural gas hydrate also includes a large amount of thermogenic gas transported from deep oil and gas reservoirs, as well as methane generated from heavy hydrocarbons migrating from the depths of hydrate reservoirs modified by microbes. Hydrate reservoirs are the largest carbon sinks, given the huge reserves of natural gas hydrates. Some of the methane, etc., transported from strata into seawater along gas chimneys, etc., is oxidized by sulfate in near-seafloor sediments with microbial participation and further form authigenic carbonate minerals that sequester the carbon; others are utilized by microorganisms in seawater; and there is little opportunity for atmospheric access.



2.6 Molecular-Scale Insights into Nanoconfined Water-CO_2 Interactions in Geological CO_2 Storage and Utilization

Kai-qiang Zhang and Jian-jie Niu, Professor, Peking University

Within shale nanopores, nanoconfined water could aggregate in the form of "water film" and "water bridge", which has significant impacts on hydrocarbon recovery and CO_2 storage, and is controlled by the nanopores substrate factors, including nanopore types, nanopore sizes, water molecule concentrations. However, a large amount of CO_2 fluid will be injected during the geological CO_2 storage, but its impact on the nanoconfined water aggregation morphology has not been deeply revealed. Here, typical water film (10 vol%) and water bridge (30 vol.%) scenarios in nanopores are determined. The water/n-octane/CO_2 systems are constructed in water film and water bridge scenarios respectively, and the CO_2 molecules are gradually increased (meaning that n-octane is gradually decreased) to investigate nanoconfined water-CO_2 interactions as well as the hydrocarbon recovery and geological CO_2 storage in nanopores. Our results confirm the competitive adsorptions of nanoconfined water and CO_2 reduce the adsorbed water amount and derive the new water bridge withCO_2additions, either in water film (75.50 mol.% CO_2) or water bridge (5.85 mol.% CO_2) scenarios. Such a phenomenon indicates the substrate surface shifts from water-wet to partially CO_2-wet, with lower fluid molecule diffusions and illite-water-CO_2 sandwich-structured adsorption layer. The above changes will affect hydrocarbon recovery and CO_2 storage from different perspectives. Overall, our work investigates the mechanism of CO_2 effects on distributions and aggregations of nanoconfined water molecules in nanopores, which also provides molecular-scale insights into the nanoconfined water-CO_2 interactions in the processes of geological CO_2 storage and utilization.

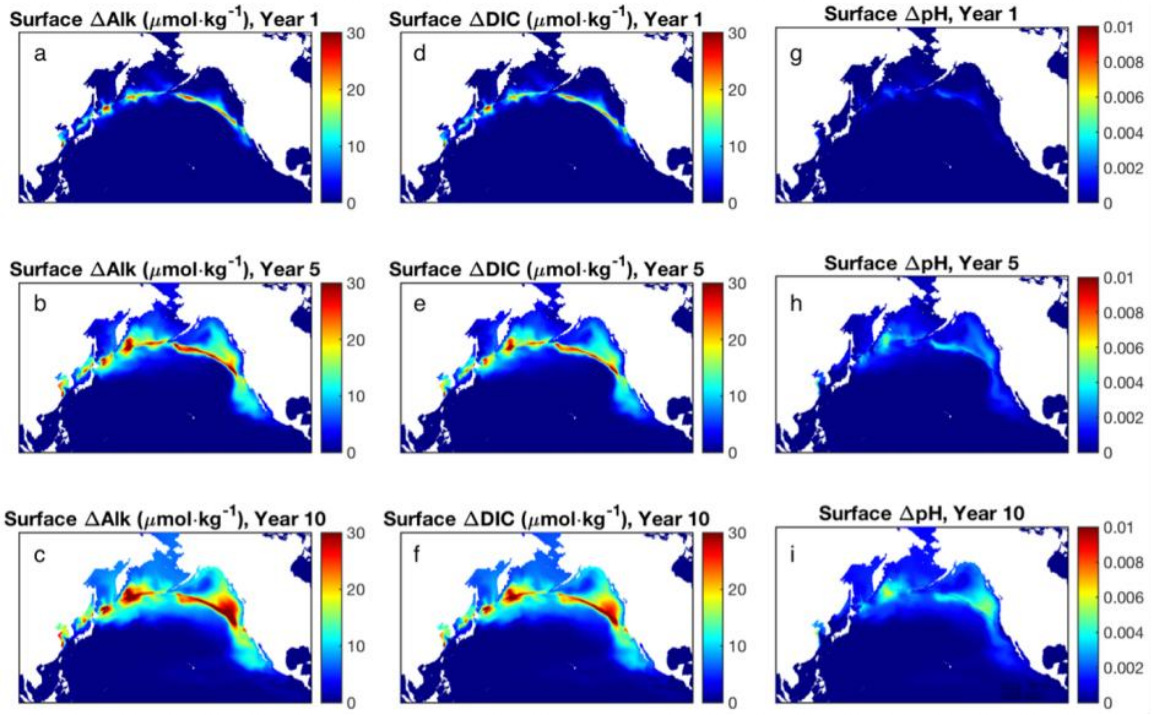


Sample atom	x	y	z
K	0.0000	0.5000	0.5000
Al	0.5000	0.1667	0.0000
Si	0.4191	0.3280	0.2688
O1	0.3487	0.3100	0.1063
O2	0.4984	0.5000	0.3131
O3	0.6715	0.2246	0.3350
OH	0.4191	0.0000	0.1006

2.7 Research on the potential of carbon emission reduction in the international shipping industry by using accelerated calcium carbonate dissolution

Si-jia Dong, Assistant professor, Nanjin university

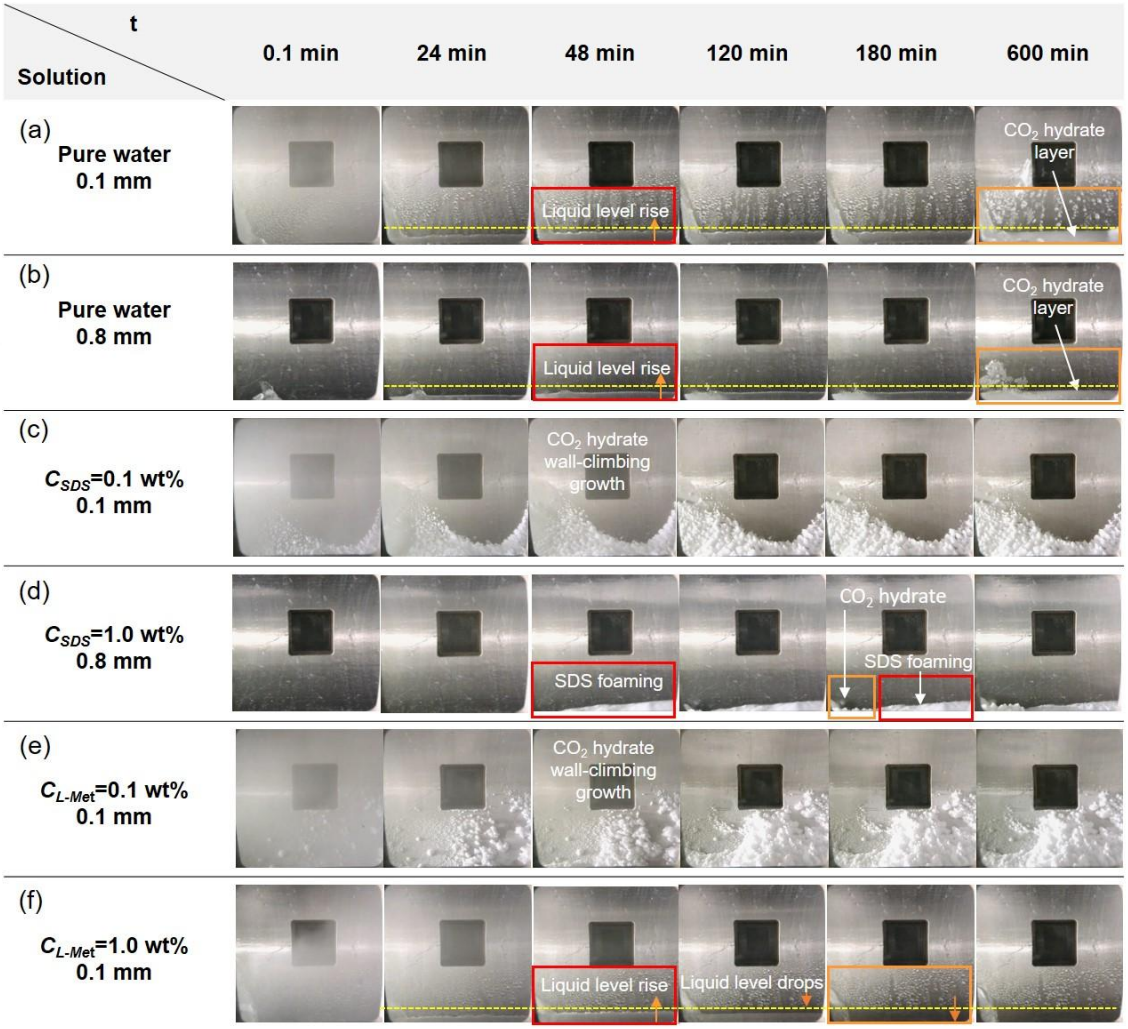
The ocean neutralizes increasing atmospheric CO_2 through seafloor calcium carbonate dissolution, a geochemical reaction that is the dominant negative feedback mechanism by which the ocean regulates atmospheric CO_2 concentrations. This offshore carbon sequestration method can store CO_2 as HCO_3^- in the ocean for tens of thousands of years through accelerated dissolution of calcium carbonate (AWL). Accelerated tuff weathering can capture and sequester carbon in response to point source emissions, but previously the application of this method in coastal power plants has been limited by the required seawater flow rate and the corresponding energy consumption, which has prevented its large-scale practical application. Based on experimental and simulation results, this study proposes a carbon reduction and sequestration scheme for the marine shipping industry, aiming to address the 3% of global carbon emissions occupied by the marine shipping industry and to enable cargo ships to meet the IMO2050 emission reduction standards set by the International Shipping Organization. Through simulation and comparison of the impacts of different reactor designs and material parameters on the reaction efficiency and energy requirements, the optimal scheme to achieve the 50% emission reduction requirement is proposed. The optimal solution is proposed to achieve the 50% reduction requirement. Experimental and simulation results show that after 10 years of continuous operation of the offshore carbon sequestration scheme, the sea surface alkalinity and dissolved inorganic carbon will increase by <1.4%, and the CO_2 flux in the sea air will change by 6.3, which meets all the emission requirements of the International Shipping Organization (ISO) for acid gas absorption equipment.



2.8 Adaptation of different catalysts for CO_2 capture in flue gas with high temperature water vapor by hydrate method

Peng Zhang, Researcher, Northwest Institute of Eco-Environment and Resources, CAS

The flue gas released from CO_2 point sources such as thermal power plants and chemical plants contains not only CO_2/N_2 mixture but also water vapor above 100°C. The flue gas from these plants can be treated by the hydrate method. In addition to the conventional reaction promoter SDS, an amino acid promoter L-Met has recently emerged in the treatment of flue gas by the hydrate method, therefore, to address the specific adaptability of the two promoters under high temperature and water vapor conditions, the present study was carried out by intermittent injection of 640 mL or 160 mL of purified water and catalyst solution at 110°C into the reaction kettle, to increase gas/liquid contact area and enhance the reaction efficiency of hydrate formation, and then to investigate the different hydrate formation reaction efficiency. In this study, we used the method of intermittent injection of 640 mL or 160 mL of pure water and catalyst solution into the reactor at 110°C to increase the gas/liquid contact area and enhance the efficiency of the hydrate formation reaction, and then comprehensively compared and analyzed the reaction mechanism of different promoters. The experimental results showed that: the concentration of 0.1 wt.% SDS, L-Met showed the strongest formation reaction promotion ability, but SDS tends to be suitable for 0.1 mm aperture nozzle, L-Met is suitable for 0.8 mm; L-Met reaction promotion range is smaller than that of SDS, and thus L-Met is easy to promote the rapid nucleation of the hydrate, and SDS is larger in scope and easy to In the reaction system using L-Met, the final hydrate formed has a separated spherical appearance, while the hydrate generated by using SDS has a coarse-grained bulk appearance; the combined use of the two catalysts will provide the best reaction promotion effect when considering the environmental background with the presence of high-temperature water vapor. This study provides a theoretical basis and experimental data for the future application of hydrate technology in the treatment of CO_2 in flue gas.

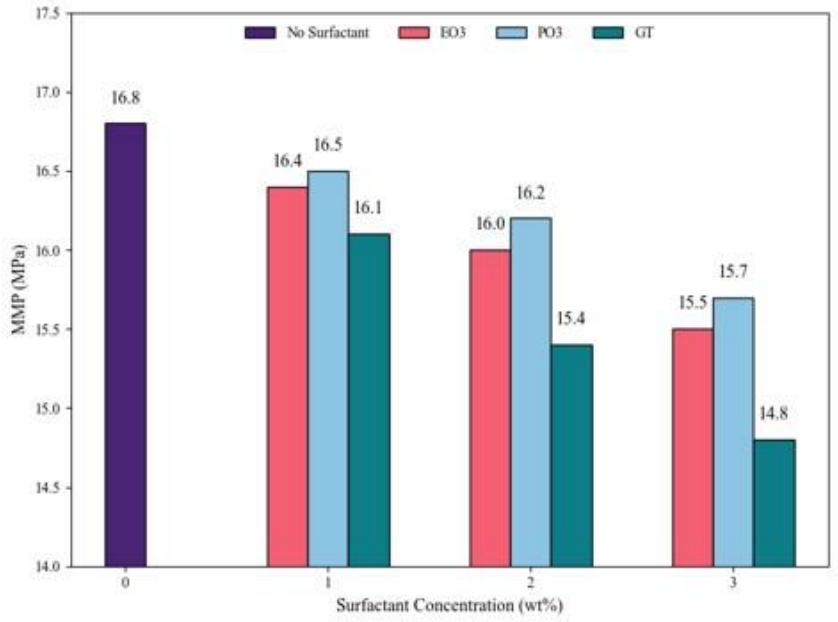

t
Solution
0.1 min
24 min
48 min
120 min
180 min
600 min
(a)
Pure water
0.1 mm
Liquid level rise
CO2 hydrate layer
(b)
Pure water
0.8 mm
Liquid level rise
CO2 hydrate layer
(c)
CSDS=0.1 wt%
0.1 mm
CO2 hydrate wall-climbing growth
(d)
CSDS=1.0 wt%
0.8 mm
SDS foaming
CO2 hydrate
SDS foaming
(e)
CL-Met=0.1 wt%
0.1 mm
CO2 hydrate wall-climbing growth
(f)
CL-Met=1.0 wt%
0.1 mm
Liquid level rise
Liquid level drops

3 Session 2: Synergistic Theory and Technology of Subsea CO_2 Oil Displacement and Storage

3.1 Experimental and molecular simulation exploration of the mechanism of CO_2-oil miscibility enhanced by alcohols and surfactants

Shu-yang Liu, Associate Professor, China University of Petroleum (East China)

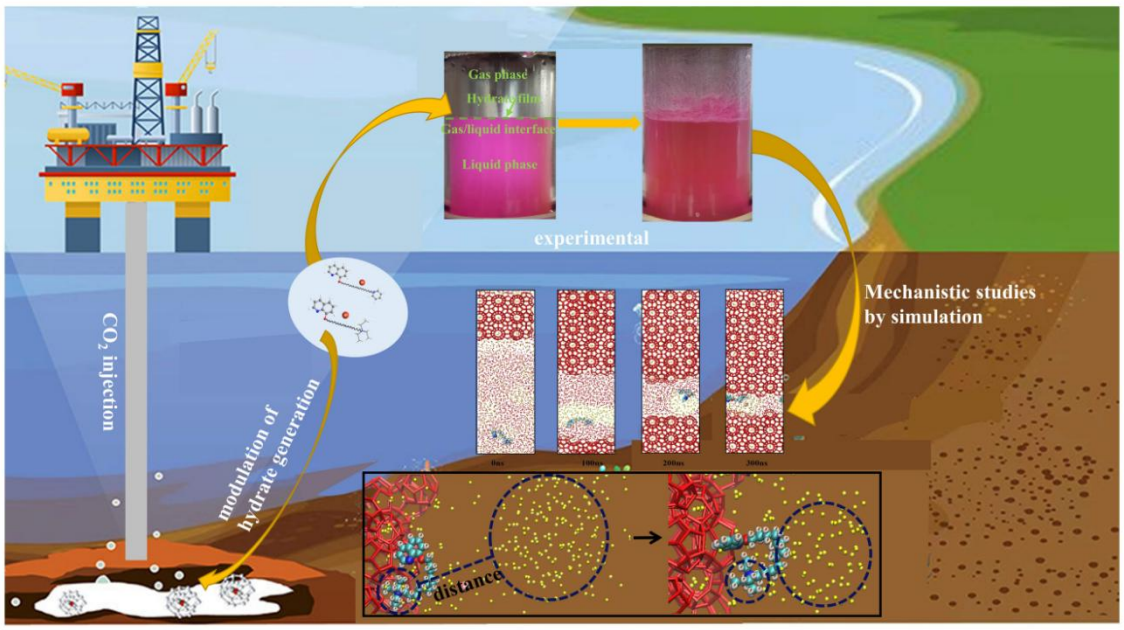
CO_2-Enhanced Oil Recovery (CO_2-EOR) is an important CCUS technology, which can enhance oil recovery while sequestering carbon to help realize the goal of carbon neutrality. Compared with non-mixed-phase drive, CO_2 mixed-phase drive has higher recovery and greater CO_2 storage potential, but the high minimum mixed-phase pressure (MMP) in many reservoirs in China limits its wide application. To address this problem, this study combines experiments and molecular dynamics simulations to investigate the mechanism of surfactants and alcohols to enhance the mixed-phase of CO_2-oil system. The influence law of ethanol in reducing the MMP of CO_2-oil system was analyzed by high-temperature and high-pressure PVT experiments, and molecular dynamics simulations were used to elucidate the micro-mechanism and advantages of ethanol in reducing the MMP. The experimental study clarified that the selected surfactants (EO3, PO3, and GT) can effectively reduce MMP, and further revealed the effect and mechanism of ethanol-compounded surfactants on the reduction of miscibility in the CO_2-oil system, and the results showed that GT compounded with 5 wt.% ethanol had the best effect of miscibility, with a decrease of MMP up to 27.9%. The findings of this study provide new insights for the realization of CO_2 miscible phase drive in our reservoirs, and provide theoretical guidance for the selection of suitable alcohols and surfactants to enhance the effect of CO_2-EOR.



3.2 Research on seabed carbon dioxide sequestration mechanism and regulation methods

Xing-bo Li, Lecturer, Tianjin University of Commerce

Carbon dioxide hydrate (CO_2 hydrate) is a promising technology for carbon dioxide capture and storage (CCS), which can be combined with water molecules to achieve efficient gas storage. The nucleation and growth of CO_2 hydrate cage-like structures involve complex multiphase and multicomponent processes. The introduction of additives has proved to be an effective method to regulate the nucleation and growth of carbon dioxide hydrate at multiphase interfaces. However, uncertainty still exists in the selection of suitable additives through interfacial modulation. In this study, the effect of additives with different groups on the growth of CO_2 hydrates was investigated experimentally. The growth of CO_2 hydrate under different working conditions was analyzed and discussed in the form of both an overall growth kinetics study and a droplet gas-liquid interface study. Their performances were compared with conventional additives using molecular dynamics simulation methods. The results show that the introduction of the additives changes the aggregation of CO_2 molecules, which affects the interfacial growth of CO_2 hydrate. Flexible hydrophilic groups with smaller interactions with water molecules can promote the formation of carbon dioxide hydrates under medium and high-temperature conditions. In addition, at the solid-liquid interface, the additive molecules can exchange positions with the CO_2 molecules and escape from the cage, allowing the CO_2 hydrate to continue to grow. In contrast, additive molecules with more rigid groups are more likely to form hydrogen bonds with water, which can hinder the formation of CO_2 hydrates. This study also shows that the enhancement of hydrophilic groups hinders the formation of CO_2 hydrate cages, while the simple conformation of hydrophobic groups promotes the formation of hydrate cages. These findings provide important guidance for the future use of hydrate-based methods to sequester CO_2.

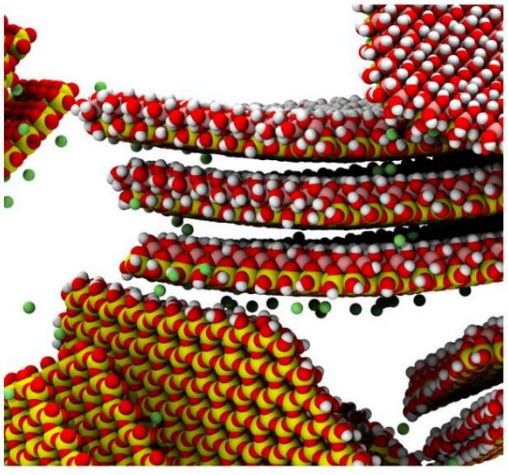


3.3 Carbon dioxide diffusion and adsorption in clay matrix nanoporous networks

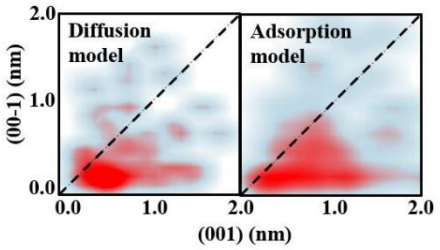
Jiang-tao Pang, Lecturer, China University of Geosciences (Wuhan)

Carbon capture and storage (CCS) is a promising strategy for global carbon reduction. Understanding the complex molecular diffusion and adsorption behavior of carbon dioxide (CO_2) at the nanoscale is particularly critical in the context of CCS implementation. However, conventional molecular modeling typically uses only plate-like slit-pore models, ignoring the complexity of interconnected nanopores. In this study, we use a stacked model of kaolinite layered structure with a large number of nanopores (major pore size r < 2 nm) to quantify the adsorption preference, diffusivity, and retention time of CO_2 molecules in the space of the nanoporous network through molecular simulations and demonstrate the distributional correlations: the movement of CO_2 molecules occurs mainly in the central region and the neighboring region of the silica-oxygen surface, moving from the larger nanopores to the smaller nanopores by diffusion; CO_2 prefers to occupy smaller nanopores. As the pore size increases, the diffusion coefficient increases while the retention time decreases. This phenomenon is related to the shape and interconnectivity of the pores in the nanoporous network compared to the typical slit model. This study bridges the limitations of the traditional slit model in the nanopore perspective, contributes to our understanding of the complex molecular behavior of CO_2 in subsurface clay sediments, and provides new ideas for the development of quantitative assessment techniques at the molecular level throughout the CCS project.

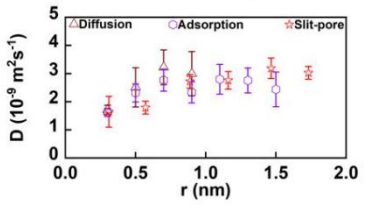
(A) Kaolinite matrix with interconnected nanopores



(B) CO_2 distance to kaolinite surfaces



(C) CO_2 diffusion in clay matrix

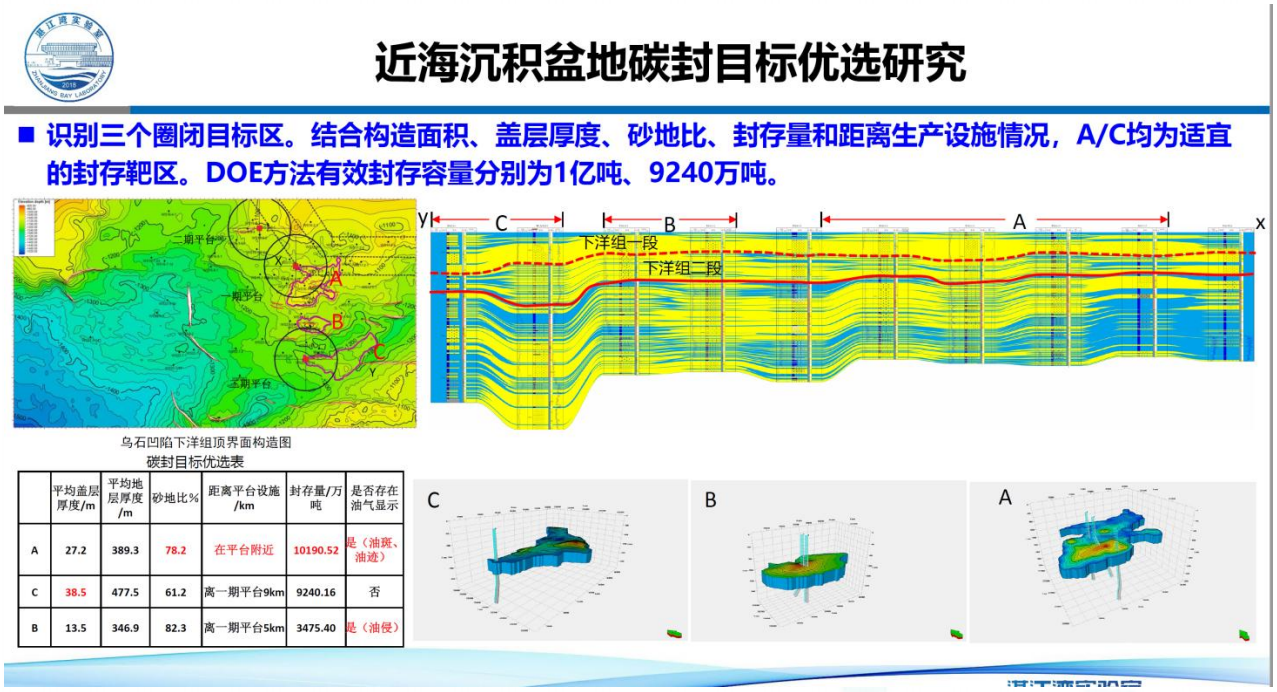


4 Session 3: Site Selection, Monitoring and Evaluation of Marine Carbon Storage

4.1 Research on key technologies for saline aquifer storage offshore western Guangdong Province

Yan-xin Lv, Associate Researcher, The Guangdong Provincial Laboratory of Southern Marine Science and Engineering (Zhangjiang Bay Laboratory)

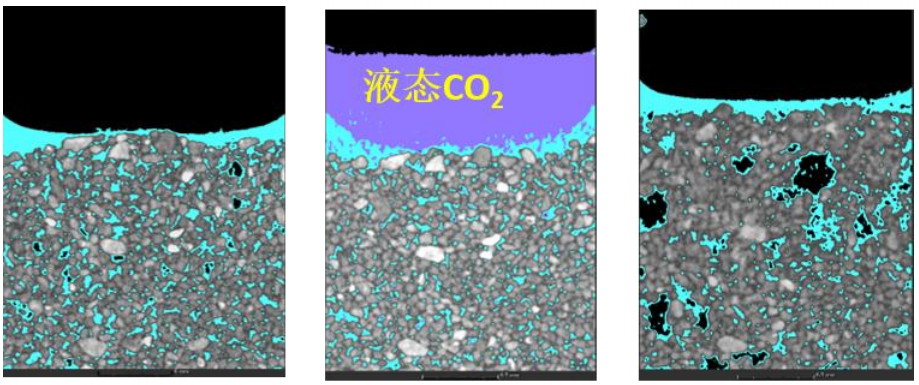
This report focuses on the key technology of carbon dioxide storage in the saline aquifer in western Guangdong, focusing on the analysis of the storage potential of the region and its target preference, and proposing an effective evaluation method. Through an in-depth study of the characteristics of the saline aquifer, its suitability as a CO_2 storage is assessed. Secondly, three common forms of saline aquifer storage in the maritime basin are discussed: tectonic storage, long-distance auxiliary transport, and tectonic storage, and gently sloping layer storage, revealing the migration behavior of CO_2 in the saline aquifer and the differences between the three forms of storage, and providing theoretical support for the actual storage project. Finally, the new understanding of the microseismic activity law in the fault-tectonic zone of CO_2 sequestration is investigated and presented, which provides an important reference framework for the design, implementation, and monitoring of future CCS projects in western Guangdong and helps to promote the widespread application of this technology. This research provides technical support for CO_2 sequestration in western Guangdong, and has important theoretical value and practical application prospects.



4.2 Application of digital core technology in the study of the microscopic mechanism of seabed carbon sequestration

Cheng-feng Li, Senior Engineer, Qingdao Institute of Marine Geology, China Geological Survey

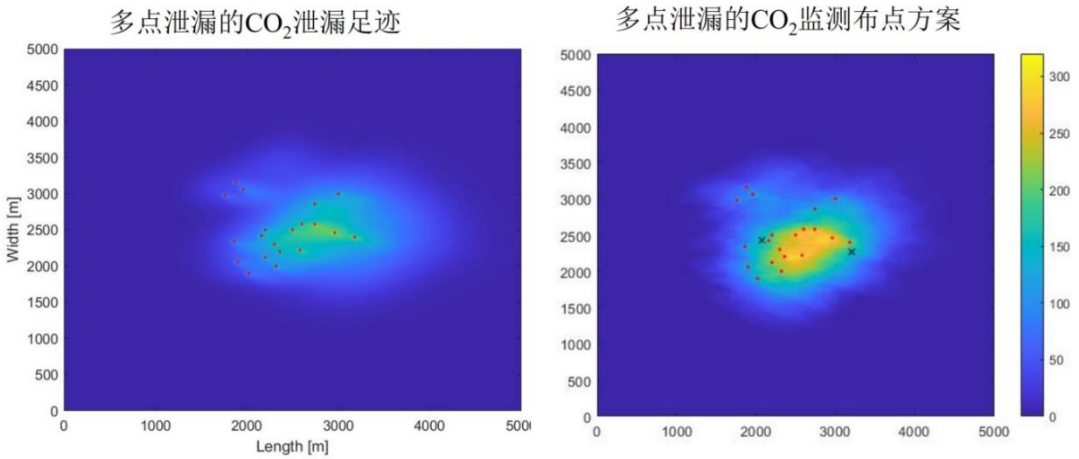
The geological conditions of China's sea area are superior, the crust is more stable, the sedimentary basin is widely distributed, the thickness of the stratum is larger, and there are also more tectonic stratigraphic enclosures, which provide good conditions for CO_2 marine storage. The rock types of marine sediments are mainly dominated by sandstone and basalt, and physical parameters such as sandstone pore structure and permeability are the key indicators for evaluating the effectiveness of CO_2 sequestration. The development of digital core technology has created conditions for observing the microstructural properties of marine sediments from the pore scale and studying the reservoir permeability and other physical properties. In this study, we focus on the basic scientific issues of pore structure characterization of seafloor sandstone, the solid storage pattern of CO_2 fluid and CO_2 hydrate in the pore space, and the transport law of CO_2 in the sediment, etc. Using high-resolution X-ray CT imaging technology and low-temperature SEM imaging technology, we have observed the transport paths of CO_2 injection and analyzed the internal spatial structure of the sediment through indoor physical simulation experiments. We also analyzed the evolution of the internal spatial structure of the sediments, and discussed the role of CO_2 distribution and content on the permeability of the sediments.



4.3 Optimization of leakage monitoring network placement based on microseismic and chemical CO_2 seafloor geologic sequestration

Xue-xing Song, Senior engineer, Shanghai Advanced Research Institute, CAS

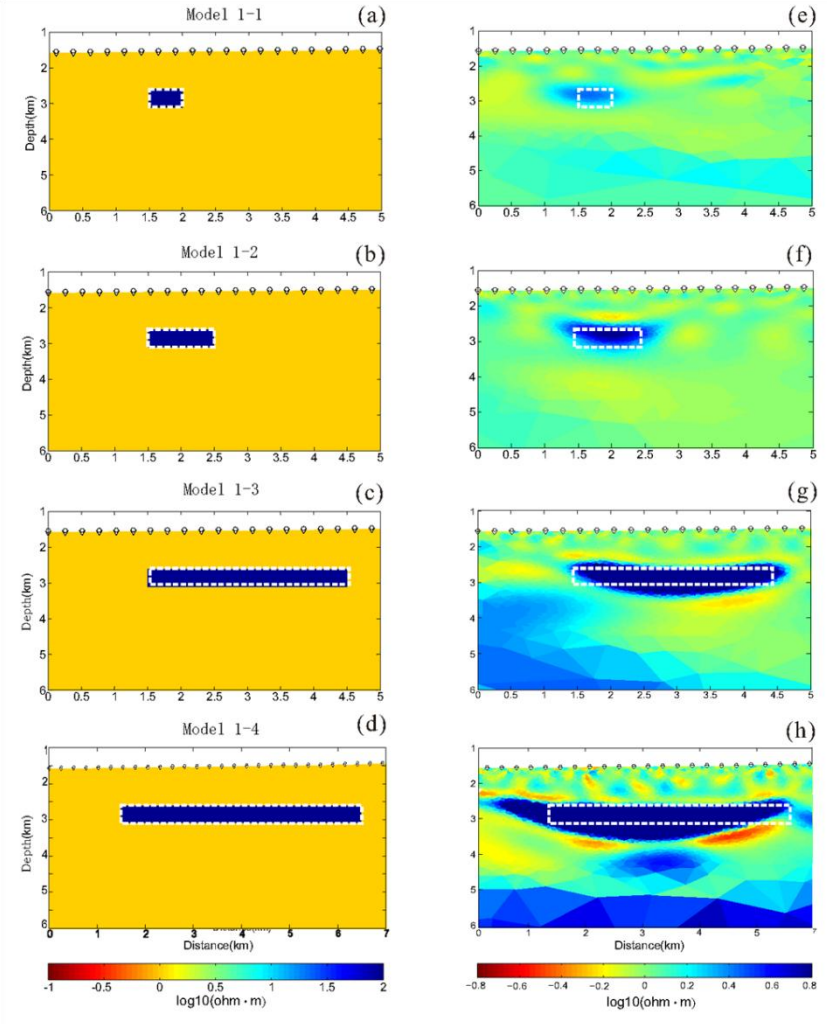
As coastal areas have a high dependence on fossil energy and high carbon emissions but lack suitable sites for terrestrial geological storage of CO_2, geological storage of CO_2 on the seabed is a potential technological pathway to carbon neutrality. To avoid significant impacts on the production and life of society, long-term monitoring is still needed for the leakage scenarios of CO_2 seabed geological storage with a very low probability of occurrence. For the typical maritime environment, this paper firstly establishes the optimization method of CO_2 leakage-induced microseismic monitoring network deployment; then establishes the CO_2 transport and diffusion model in seawater, analyzes the influence of seawater flow and other effects on CO_2 transport and diffusion, and carries out the optimization of the deployment of the sensor network to monitor the concentration of CO_2; and finally, combines with the offshore monitoring environment to estimate the economy of the sequestration monitoring system. The optimization of sensor placement for CO_2 leakage monitoring in submarine geological storage will promote low-cost, long-term, and high-efficiency monitoring, which in turn will promote the development of engineering applications for submarine geological storage.



4.4 Marine offshore saltwater layer CO_2 Electromagnetic response characteristics of Marine controllable source for migration identification of sealed plume

Ning Qiu, Associate Researcher, The South China Sea Institute of Oceanology, CAS

By analyzing the feasibility of Marine CSEM in monitoring plume migration in offshore CO_2 sequestration, the report provides a scientific basis and reference for the monitoring work of offshore CO_2 sequestration engineering. At the same time, this study also has important practical guiding significance for offshore CO_2 injection monitoring and geological sequestration. According to previous studies, the characteristics and influencing factors of plume migration in offshore CO_2 sequestration projects are very worthy of consideration. Through the analysis of theoretical models and practical application cases, we will discuss the Marine CSEM simulation of different offshore CO_2 sequestration plume migration (different injection amount or diffusion length, buried depth, etc.) in a deep saltwater layer, analyze the electric field response characteristics under different emission frequencies, and the variation characteristics of Ey amplitude and phase of Marine CSEM electric field with offset. The results of resistivity imaging are compared and analyzed.



4.5 Evaluation of the suitability of geological storage of carbon dioxide in China's sea area

Jian-wen Chen, Researcher, Qingdao Institute of Marine Geology, China Geological Survey

Carbon dioxide geological storage suitability refers to the degree of suitability for carbon dioxide geological storage under the constraints of storage potential, engineering technology, social economy, and geological security. Internationally, Bachu (2003) and Oldenburg (2005) carried out different levels of suitability evaluation and method studies on Denmark (Anthonsen et al. (2014) and Vangkilde et al. (2009). Among them, the greenhouse gas project of the International Energy Agency (IEAGHG, 2009) had a higher impact. The evaluation index is divided into three categories: decisive index, necessity index, and ideal index. Chinese scholars Shen Pingping (2009), Huo Chuanlin (2014), and Guo Jianqiang (2014) have carried out many studies to establish the suitability evaluation index system. However, these studies fail to systematically consider the suitability evaluation system of CO_2 geological storage in applicable sea basins. Based on systematically summarizing the geological conditions of geological carbon sequestration in China's Marine areas, this work innovates the evaluation index system of the suitability of geological carbon sequestration in China's Marine areas through extensive research, consultation, and discussion. The proposed index system consists of key indexes and necessary indexes, which are coupled to determine the suitability of geologic carbon dioxide storage in Marine basins and zones. The key index is the key constraint index to carry out the geological storage of CO_2 in the sea area. Whether the constraint of the key index is met determines the suitability of the geological storage of CO_2 in the sea area, which consists of two indexes: seismic activity and implemensibility. The necessary indexes represent the advantages and disadvantages of the basic geological conditions of carbon dioxide geological storage, and are composed of three primary indexes, including storage potential, geological conditions and engineering conditions, and several secondary indexes.

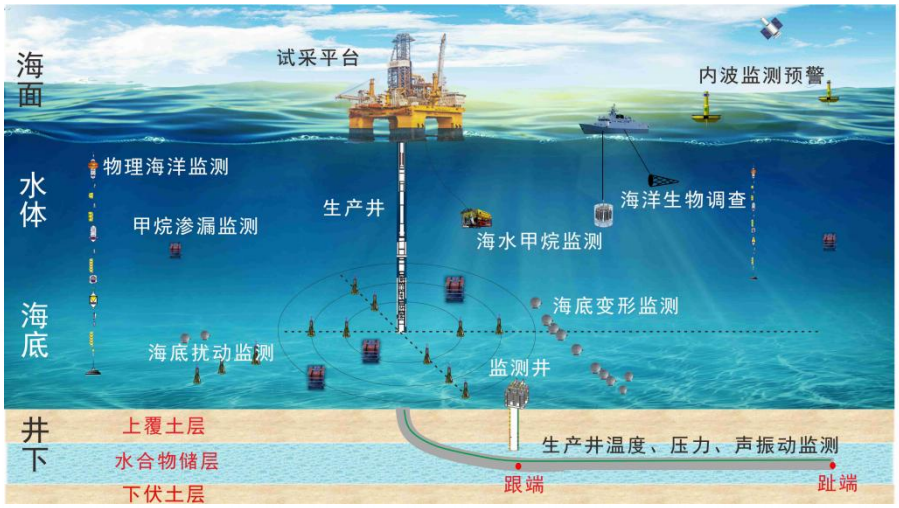

北京市
上海市
广州
广东省
台湾省

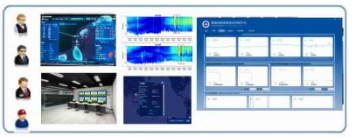
5 Session 4: Monitoring and Accounting Methods for Marine Carbon Storage Risks

5.1 Key technologies for environmental monitoring of gas hydrate test mining in the South China Sea and prospects for their application in the field of seabed carbon storage

Qian-yong Liang and Yi-fei Dong, Senior Engineer, Guangzhou Marine Geological Survey Bureau

Seabed carbon storage is an important way for China to realize the strategic goal of "double carbon", but in the process of CO_2 injection and sequestration, we will face the risks of seabed geological disasters and ecological environment damage caused by gas leakage, therefore, carrying out the monitoring and evaluation of the geological environment in the sequestration area is a necessary measure for realizing safe and environmentally friendly sequestration, which is of great practical significance. During the two rounds of test mining of natural gas hydrate in China's waters in 2017 and 2020, China Geological Survey has independently innovated and formed environmental risk prevention and control technologies covering the whole process of test mining, developed key equipment such as fluid transport monitoring in mining wells, in-situ monitoring of temperature and pressure in monitoring wells, monitoring of methane/CO_2 seepage at the sediment-water interface, seafloor deformation monitoring, and monitoring of and early warning of internal isolated waves, and established a "seafloor" monitoring and evaluation program of the atmosphere, water, seafloor, and wells. The company has established a "four-in-one" environmental monitoring system for atmosphere, water, seabed, and downhole, and realized the monitoring of 11 elements such as temperature, pressure, methane and CO_2 content, seabed deformation, and internal isolated wave, which effectively guaranteed the environmental safety of the two rounds of test mining, and provided a certain degree of accumulation of technology for the environmental monitoring of the seabed carbon sequestration. Given the potential impact on the marine environment in the process of seabed carbon sequestration, based on the existing environmental monitoring technology system, relying on the injection wells and monitoring wells, we will build a more perfect intelligent monitoring system of the marine environment in the sequestration area from the land to the ocean and from the well to the sea surface, to monitor the key environmental issues such as secondary geologic hazards, pollution of the water system and damage of marine organisms in the process of carbon sequestration, and to ensure the safety of the environment in two rounds of test mining. It will carry out real-time monitoring and risk early warning of key environmental issues such as secondary geological disasters, water system pollution, marine life damage, etc. during the process of carbon storage, and provide technical support for the realization of green and safe carbon storage on the seabed.


海面
试采平台
内波监测预警
水体
物理海洋监测
甲烷渗漏监测
生产井
海洋生物调查
海水甲烷监测
海底
海底变形监测
海底扰动监测
监测井
井下
上覆土层
水合物储层
下伏土层
生产井温度、压力、声振动监测
跟端
趾端

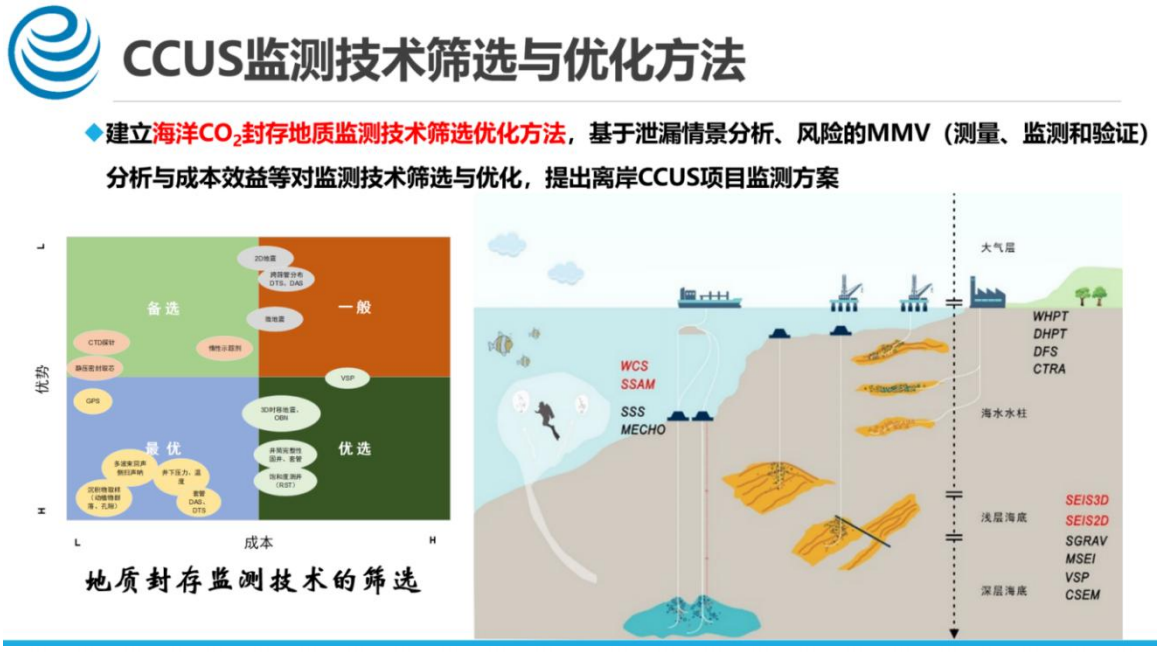


安全防控中心

5.2 Several issues in the drafting of technical standards for monitoring geological storage of carbon dioxide

Qi Li, Professor, Wuhan Institute of Rock and Soil Mechanics, CAS

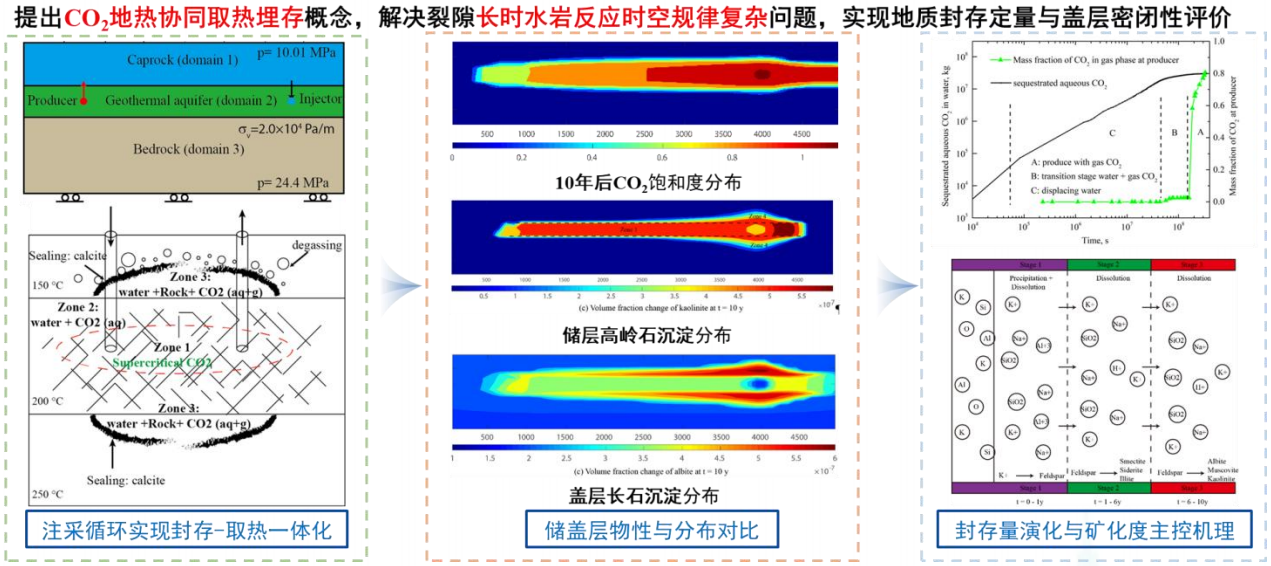
The primary premise of a CO_2 sequestration project is to ensure that the probability of CO_2 leakage is minimized. After the injection of carbon dioxide into the formation, the carbon dioxide will be transported and diffused due to the concentration gradient and other factors, and at the same time increase the formation pressure in the diffusion area and change the reservoir environment. This change in the reservoir environment may lead to unstable changes in the stable formation, such as local pressure increases or complex mineralization, which causes some carbon dioxide to migrate along the unstable channels and eventually lead to leakage. Therefore, to ensure that the carbon dioxide injected into the seabed is sealed in the deep geological space for a long time as expected, without formation deformation and leakage, and does not pose a threat to the environment and human living space, it is necessary to continuously monitor the storage process and migration space of the carbon dioxide injected into the seabed, and timely detect possible anomalies, to initiate storage correction or remedial measures. At present, many monitoring technologies can be applied to CCUS projects. For the monitoring technology of CCUS projects, there is a lack of effective industry norms to provide professional guidance. Therefore, according to the characteristics of CCUS projects, we need to consider at least the following aspects in the process of leading the preparation of carbon dioxide geological storage monitoring technical standards: (1) Monitoring stages and objectives, monitoring categories, monitoring techniques and monitoring indicators; (2) The general process of monitoring work, monitoring program design requirements, monitoring layout principles and requirements, stage monitoring work requirements, monitoring data interpretation requirements and monitoring instrument management requirements; (3) Report preparation and review, including requirements for the preparation of outcome reports, report review and data archiving.



5.3 Evaluation of Long-Term Reactive Transport and Closure of Carbon Dioxide Saltwater Sequestration

Quan Gan and Si-da Jia, Professor, Chongqing University

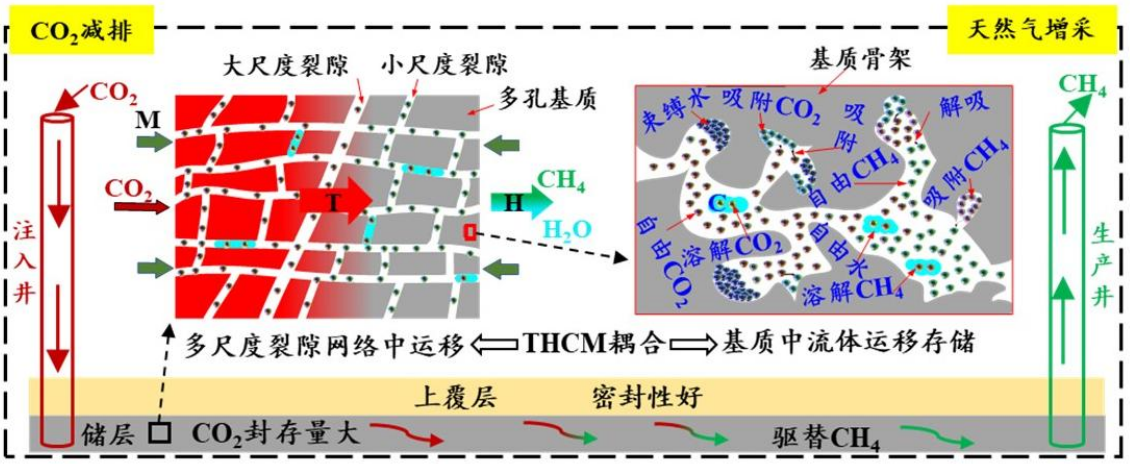
The geological storage of CO_2 in saline aquifers involves an extremely complex CO_2 water-rock reaction process, which reacts with different types of rocks and minerals to achieve CO_2 mineralization and storage, and at the same time affects the distribution of CO_2 transport. Therefore, it is necessary to establish a model that considers the dynamic water-rock reaction coupled with the evolution of rock physical properties, to accurately predict the storage potential and transport leakage pattern. In the brackish water reservoir storage work, through the establishment of a fully coupled heat flow solidification multi-field coupling model to evaluate the use of supercritical carbon dioxide as a heat extraction medium, based on the study of the dynamic mineral dissolution and precipitation behavior on the pore permeability evolution of the reservoir cover layer, it was found that the dissolution and precipitation behavior in the reservoir can be divided into three transition regions, in the ten years of storage in the reservoir, the pH value of the reservoir is reduced from 7 to between 4-4.5, due to the rapid dissolution of calcite. rapid dissolution of calcite. In the near-well region, the reaction process is inhibited due to the high concentration of CO_2 from drainage. Sufficient ionic sources of Na^+, K^+, and Ca^{2+} in the capping layer produced precipitation of quartz and secondary clay minerals, which ensured closure of the capping layer. Continuous CO_2 injection resulted in a 1.4-fold and 1.2-fold increase in fracture and matrix permeability due to dissolution and thermal depressurization effects. Meanwhile, 3D reconstruction of the cap core and CO_2 multiphase flow based on micro-digital cores was carried out to realize the prediction of CO_2 breakthrough pressure in the cap, revealing the correlation between cap permeability and breakthrough pressure.



5.4 Evaluation of Carbon Dioxide Storage and Injection Capacity in Marine Depleted Gas Reservoirs

Min Chen, Researcher, Tongji University

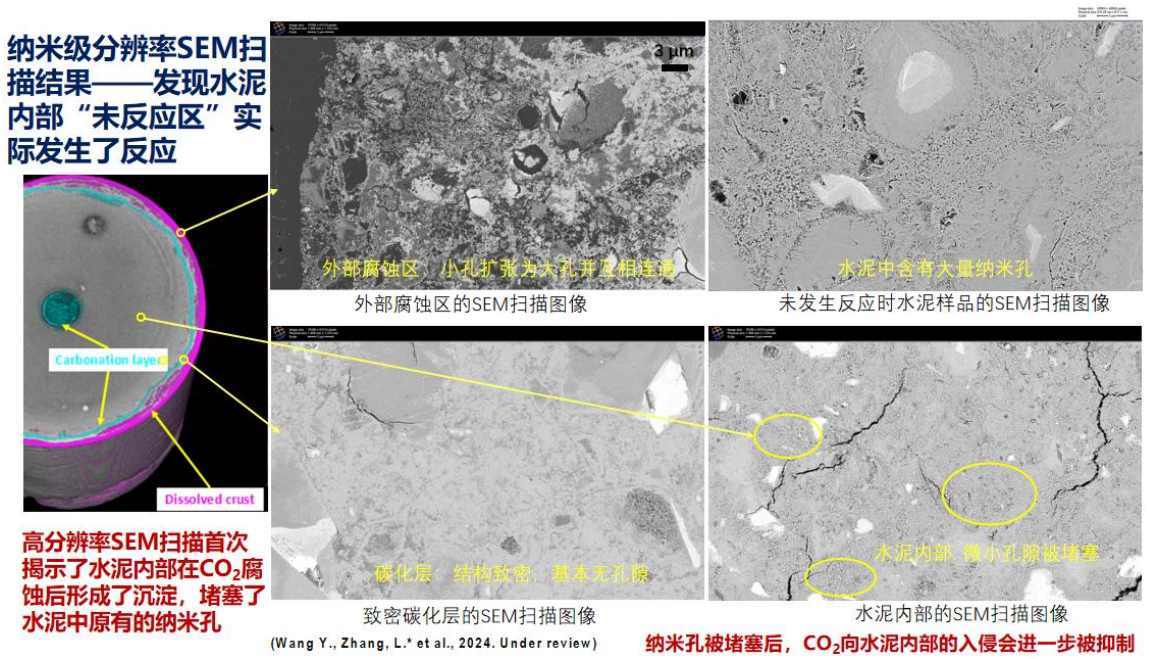
With the increasing severity of the global climate change problem, carbon dioxide (CO_2) storage technology has received widespread attention as an effective means to reduce greenhouse gas emissions. Depleted gas reservoirs are ideal sites for geological storage of CO_2 with broad application prospects due to their large storage capacity, good confinement, known reservoir characteristics, remoteness from densely populated areas, reuse of existing infrastructures, and potential enhanced gas recovery. CO_2 storage in marine depleted gas reservoirs is a complex phase-change, multiphase multicomponent multi-field coupled seepage process. Based on the wellbore-reservoir joint multi-field coupling model established in this paper, the CO_2 storage and injection capacity of offshore depleted gas reservoirs is investigated in terms of reservoir characteristics, pressure conditions, phase behavior, and injection methods, and the results of the study can provide a reference for carbon emission reduction accounting.



5.5 Characterization of pore structure evolution pattern and micro-mechanical strength change of cementite reaction layer for cementing in CO_2-rich environment with offshore sequestration

Li-wei Zhang, Researcher, Wuhan Institute of Rock and Soil Mechanics, CAS

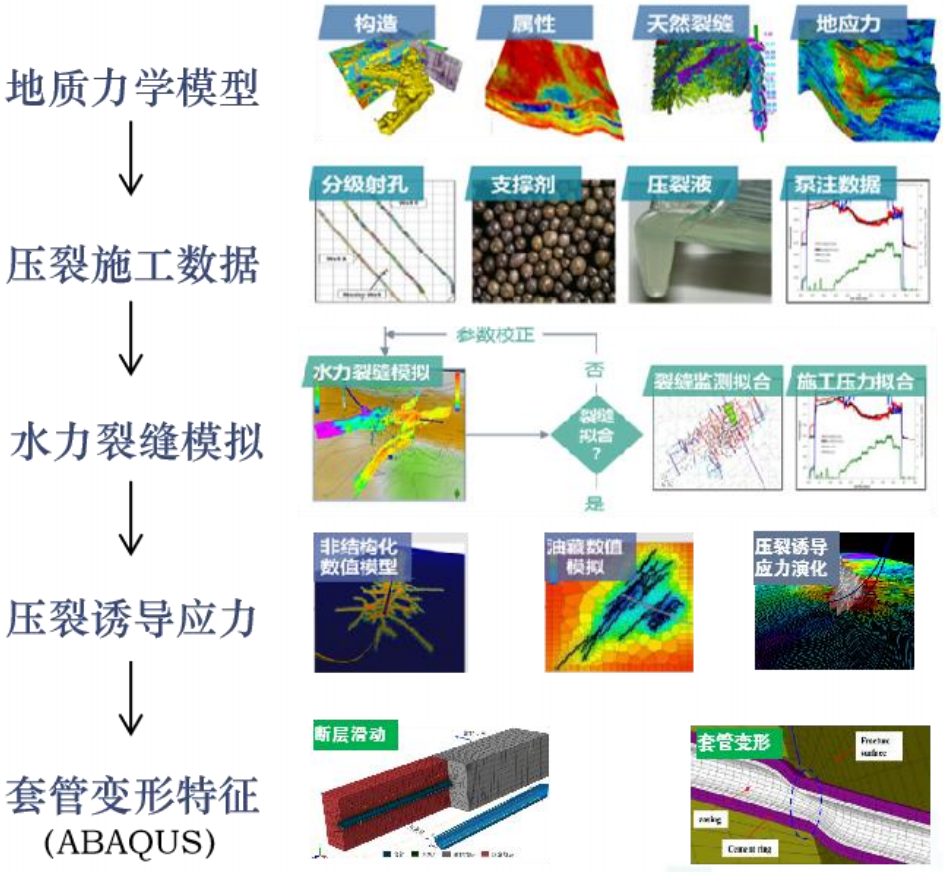
In this work, the evolution of the pore structure in each reaction zone of a wellbore cement sample exposed to a highly concentrated CO_2 solution (CO_2 partial pressure above the solution is 17 MPa) for 14 days was investigated. A new mechanism of CO_2-cement reaction involving hard gypsum/gypsum filling the internal nanopores of the cement was revealed by advanced characterization methods such as high-resolution scanning electron microscopy, QEMSCAN, and CT scanning. Hard gypsum/gypsum is formed due to the release of sulfate ions from the hydration products of sulfur-containing cement, including calomel (AFt) and monosulfur-type hydrated calcium thioaluminate (AFm), as a result of pH reduction. Based on the experimental results, a carbon dioxide-cement reaction model containing four reaction zones, which is different from previous models, is proposed. The model provides a comprehensive framework for understanding the spatial and temporal distribution of minerals in cement due to the CO_2-cement reaction, explains the formation of reaction products such as hard gypsum and gypsum, and ultimately explains the mechanism of filling nanopores within the cement. This study shows that the main damage caused by CO_2 corrosion occurs in the outermost regions of the cement. As the hard gypsum/gypsum fills the nanopores inside the cement, the internal integrity is maintained and the risk of CO_2 penetration into the cement is low.



5.6 Mechanism and countermeasures of fracture destabilization induced by CO_2 pre-fracturing

Xiao-chen Wei, Associate Professor, Southwest Petroleum University

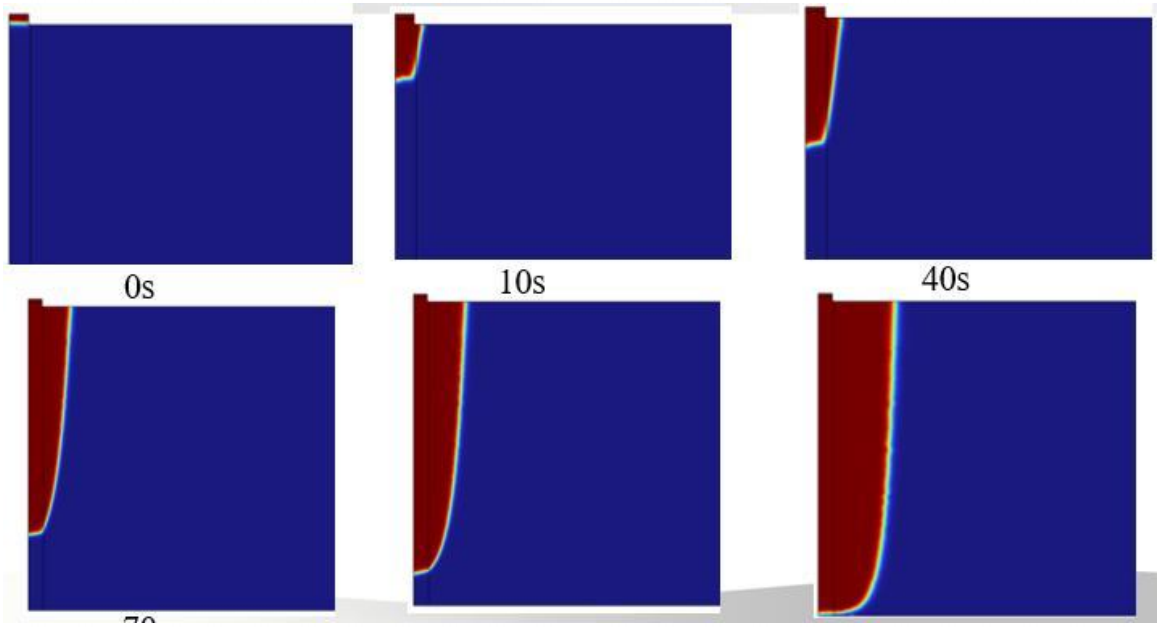
Analysis of fracture destabilization mechanism induced by CO_2 pre-fracturing. In the development of shale oil reservoirs, CO_2 pre-fracturing technology significantly enhances the energy-enhancing effect of subsequent slickwater and the return efficiency by its dual advantages of promoting the formation of complex fracture networks with low to ultra-low viscosities and enhancing the fluid return efficiency and reducing the damage to the formation with its high compressibility. However, shale oil reservoirs often develop a large number of slip fractures and associated fractures, and fracture-induced fracture instability often leads to fluid leakage and casing deformation. Based on the idea of geo-engineering integration, we discuss the range and magnitude of the fracture and fracture surrounding ground stress, clarify the extension characteristics of hydraulic fractures in the slip fracture zones, elucidate the mechanism of fracture destabilization induced by fracturing, and construct a dynamic evaluation method of fracture closure. Based on the challenges and limitations of the current technology, the present study proposes targeted improvements to further optimize the application of CO_2 pre-fracturing technology in shale oil reservoir development.



5.7 Model and application of well-reservoir coupling two-phase flow based on interface tracking theory

Qian-lin Zhu, Associate Researcher, China University of Mining and Technology

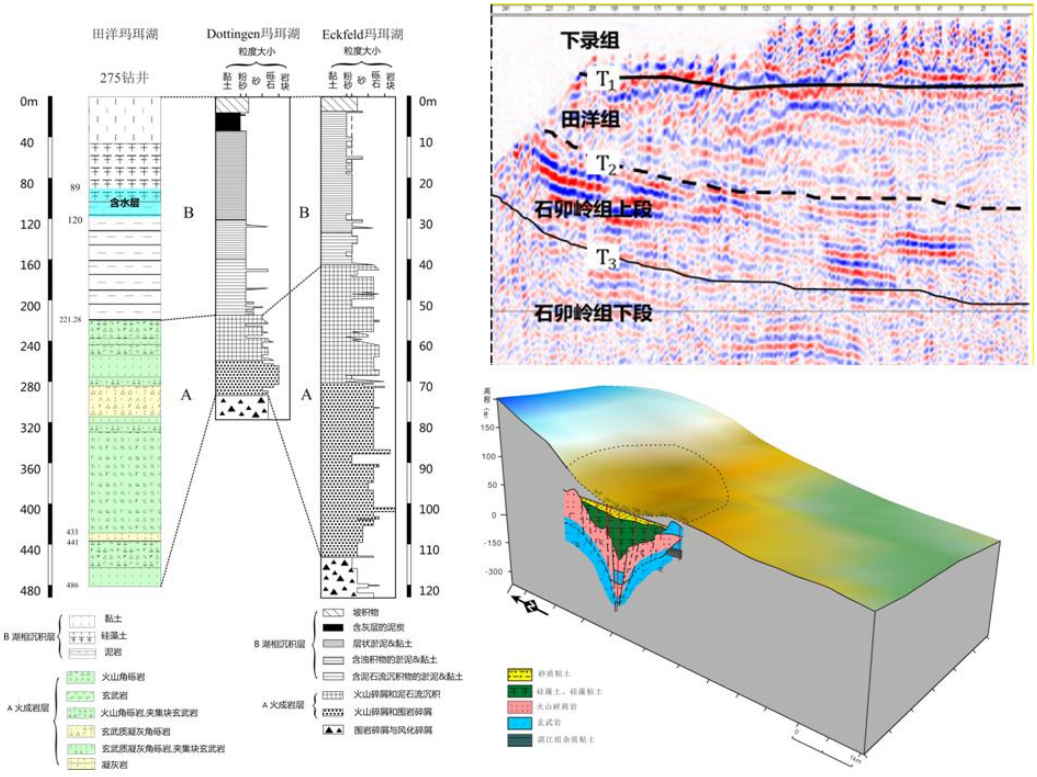
The theory of simulating the two-phase flow process of the well-reservoir system based on the interface tracking method is proposed, and the influence of density and viscosity on the two-phase flow process of the well-reservoir system is revealed, providing the theoretical basis for the risk monitoring of Marine Carbon Storage.



5.8 Geophysical survey and potential evaluation of the Tianyang volcanic fault basin, Leizhou Peninsula, basalt CO_2 mineralization sequestration alternative site

Ning Qiu, Associate Researcher, The South China Sea Institute of Oceanology, CAS

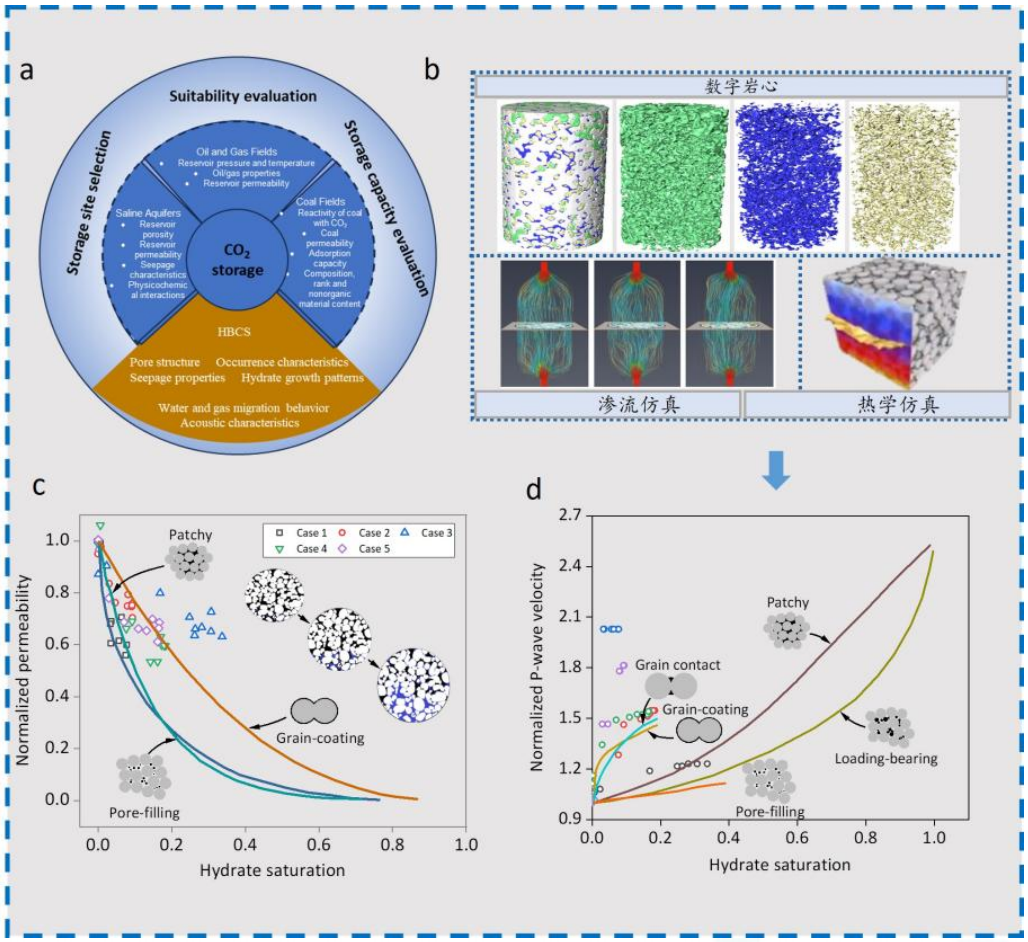
Porous basalts are iron and magnesium-rich and have better mineral trapping capacity compared to sandstones, which can quickly and efficiently convert carbon dioxide (CO_2) into solid carbonate minerals. In basalt CO_2 mineralization sequestration, CO_2 is injected into underground reservoirs and reacts with magnesium, calcium, and other minerals in the basalt to form stable carbonate minerals, such as magnesium-iron carbonates, which are capable of storing CO_2 for a long period and preventing it from escaping into the atmosphere. Basalt CO_2 mineralization storage has become a new class of storage increasingly concerned by academic and engineering research. In this study, we analyzed the distribution of basalt, stratigraphic structure, and physical parameters in the Tianyang area of the Leizhou Peninsula as an alternative site for the basalt CO_2 mineralization and storage experiment, and analyzed the distribution of basalt, stratigraphic structure and physical parameter characteristics by using multi-channel reflection seismic and geomagnetic data in conjunction with the geological outcrops, drilling cores, and petrophysical data to provide the important physical parameters for the basalt CO_2 mineralization and storage experiment, and the important physical parameters for the site selection and injection design of CO_2 mineralization and storage experiment. It also provides important support for the site selection and injection design of the CO_2 mineralization storage experiment.



5.9 Characterization of the microscopic mechanism and dynamic parameter response of CO_2 hydrate generation

Chao Lv, Lecturer, Xi'an University of Science and Technology

Based on the hydrate generation dynamics, the pore structure characteristics and seepage evolution mechanism of porous media during CO_2 hydrate generation are elucidated by CT scanning technology, acoustic wave technology, and numerical simulation, revealing the pore habit of CO_2 hydrate, providing a scientific basis for mastering the hydrate formation mechanism in porous media, analyzing the response characteristics of key physical properties during hydrate generation, and establishing a dynamic analysis model between hydrate phase transition characteristics and key physical properties parameters, providing scientific support for the methodological storage of CO_2 hydrate. We analyzed the response characteristics of key physical properties during the hydrate generation process, established a dynamic analysis model between the hydrate phase change characteristics and key physical property parameters, and provided scientific support for the CO_2 hydrate sequestration.

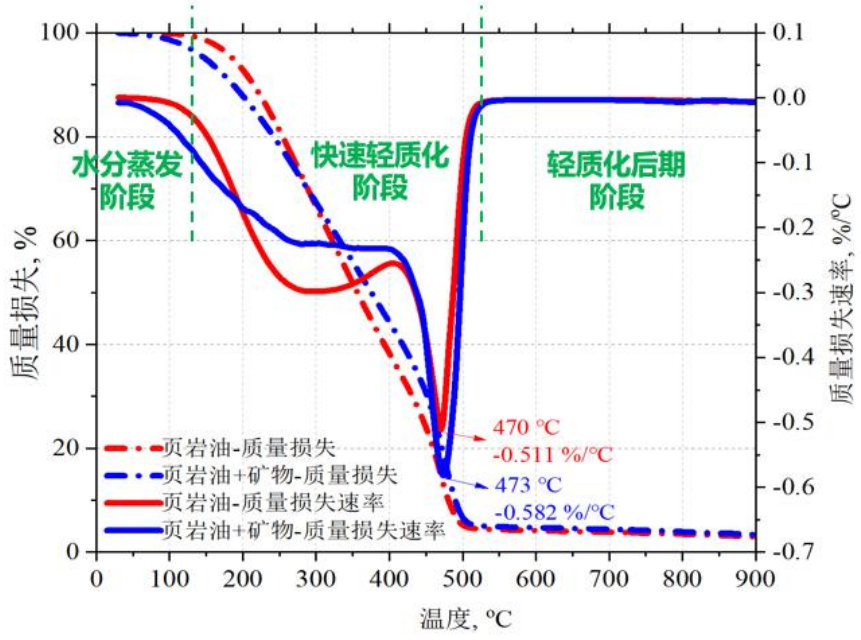


6 Session 5: OCCUS Rock Physics and Fluid Characterization and Simulation

6.1 Experimental study on the feasibility of high-temperature supercritical CO_2 development and storage in shale reservoirs

Xiang Zhou and Lo-jia Si Lang, Associate Professor, Southwest Petroleum University

Aiming at the difficulties of low thermal evolution, predominantly heavy components, and high viscosity of crude oil in medium and low maturity shale oils, which make the existing technologies unable to develop them beneficially. In this study, we carried out research on the integrated technology of in situ lightweight shale oil development and storage in high temperature supercritical CO_2 environment, and investigated the influence of different gas injection media (CO_2, N_2, air), heating rate (5, 10, 20℃/min), and reservoir rocks on the lightweight of shale oil, and then selected the gas injection media (CO_2) and the heating rate (10℃/min) to investigate the light-weighting efficiency and the evolution of light-weighting components of shale oil with low to medium maturity. The lightening efficiency of shale oil and the evolution of lightening components were investigated. Using the numerical simulation research method, we clarified the sealing law and potential of the research block, and explored the changing law of ions in the process of carbon sealing, the law of carbon sealing, and the amount of sealing. The research results will lay a theoretical foundation for the efficient development and carbon sequestration of low and medium-maturity shale oil in China.

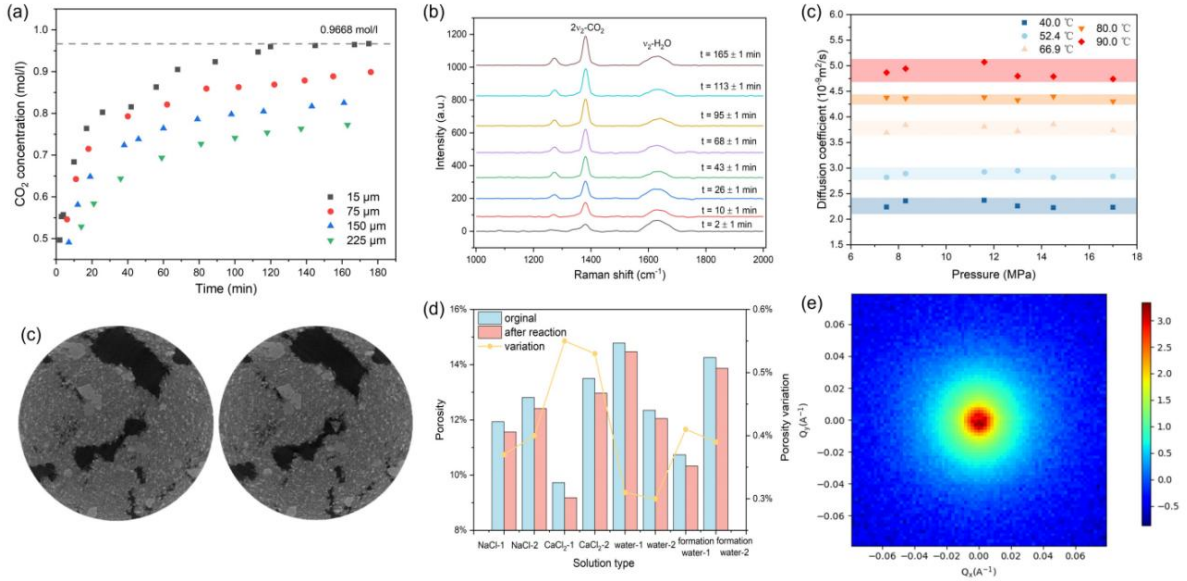


升温速率20℃/min页岩油轻质化失重/失重率曲线

6.2 Characterization of physical properties and pore structure of fluid sequestered by offshore CO_2 mineralization

Peng-fei Wang, Assistant Professor, SUSTech Academy for Advanced Interdisciplinary Studies

CO_2 mineralization and sequestration, as a technology to permanently deal with carbon emissions, is of great significance to China's realization of the “double carbon” goal. The technology achieves sequestration by injecting CO_2 into basalt reservoirs to generate secondary carbonate minerals. Exploring the complex interactions between CO_2, reservoir fluids, and basalt during the mineralization process is an important basis for accurately assessing the sequestration effect. This study focuses on characterizing the reservoir fluid properties and basalt pore characteristics. Firstly, we measured the density and interfacial tension of reservoir fluids under storage conditions, and used Raman spectroscopy to quantitatively calculate the solubility and diffusion coefficient of CO_2 in the reservoir fluids to investigate the transport law of CO_2 in the storage process; secondly, we combined the small-angle neutron scattering and X-ray CT to observe the changes in the pore structure of basalt before and after the mineralization reaction on a multi-scale, to effectively evaluate the storage capacity and storage efficiency. This study combines various complementary techniques to investigate the CO_2 mineralization and storage process, which provides a theoretical basis for safe and efficient storage.



(a) CO_2 concentration with time at different depths from the gas-liquid interface; (b) Raman spectra of CO_2 dissolved in reservoir fluids at different time; (c) Diffusion coefficient of CO_2 in reservoir fluids as a function of pressure; (d) CT slices of the basalt before and after mineralization reaction; (e) Porosity variation of the basalt after mineralization process; (f) Small-angle neutron scattering pattern of the basalt.

6.3 Methodology and Software Development for Wellbore Integrity Evaluation of Offshore CO_2 Sequestration

Yong-sheng Tan and Meng Jing, Assistant researcher, Wuhan Institute of Rock and Soil Mechanics, CAS

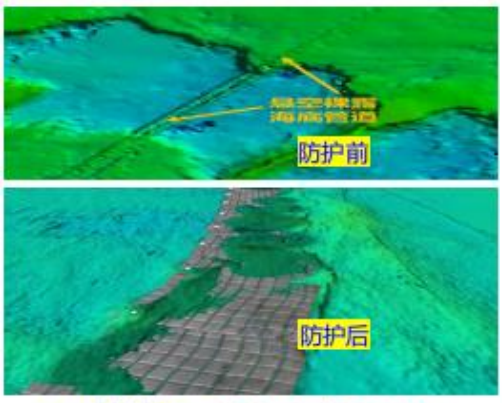
The offshore CO_2 storage wellbore integrity evaluation method is imperfect, combing offshore wellbore leakage pathway, establishing offshore CO_2 storage index system; CO_2 geological storage wellbore integrity numerical simulation results show that: CO_2 wellbore temperature should be the same as the reservoir temperature, to avoid the wellbore to enter the reservoir in the process of producing phase change, stratum-induced generation of hydrate, injectability deterioration; CO_2 storage wellbore axial stress > radial stress > circumferential stress, and the inner wall of the wellbore is the most likely to fail; cement ring elastic modulus and Poisson's ratio increase in contact between two cemented surfaces increase the risk of wellbore failure; yield strength increase of the contact between two cemented surfaces increase the risk of wellbore failure. Radial stress > annular stress, and the inner wall of the wellbore is the most likely to fail; cement ring elastic modulus and Poisson's ratio increase, the contact force of the two cemented surfaces increases, and the increase of yield strength decreases first and then remains unchanged on the risk of failure of the wellbore; casing and cement ring thickness increases, and the contact pressure of the first and second cemented surfaces decreases. The CO_2 sequestration wellbore integrity evaluation software was compiled, realizing the functions of CO_2 wellbore integrity evaluation and old well availability evaluation, providing a technical basis and theoretical basis for realizing the dual-carbon goal of China.

7 Session 6: Safety Assurance Technology for Marine CO_2 Pipeline Transportation

7.1 Structural Safety and Engineering Countermeasures for Offshore CO_2 Pipelines

Jin-kun Liu, Senior Engineer, Sinopec Petroleum Engineering Corporation

The marine CO_2 pipeline is a necessary path and key link to implement offshore carbon capture, utilization, and storage (CCUS). The report analyzes the environmental characteristics and installation process of the marine CO_2 pipeline, draws on the design technology of offshore oil and gas pipelines, and puts forward engineering countermeasures to ensure the structural safety of Marine CO_2 pipeline from the aspects of routing selection, structural strength, in-place stability, corrosion control, structural inspection, and maintenance. In the process of installation and operation at sea, the marine CO_2 pipeline will be affected by multiple factors such as waves, tidal current, sea ice, and the spatial variability of seabed soil, which will bear greater stress, produce greater deformation and vibration, and induce pipeline failure or even fracture. Marine geological disasters such as liquefaction and instability of seabed soil caused by storm surges and extreme waves, erosion, and submarine landslides will lead to pipeline subsidence, bending, and suspension, which are also key causes of pipeline structural failure. Technologies such as installing concrete interlocking rows, covering bionic water grass, and pumping self-flowing slurry solidified soil are effective measures to ensure pipeline stability in place. The high salt content of the external Marine environment and the impurity gas in supercritical CO_2 will cause serious external and internal corrosion of the pipeline. The internal and external corrosion control techniques such as special corrosion inhibitors, external anticorrosive coating, and sacrificial anode blocks are put forward. It is suggested to strengthen engineering technology research on marine CO_2 pipeline structure simulation technology under complex load conditions, pipeline flexion, and crack arrest technology under the combined action of internal and external pressure and bending moment, intelligent detection and monitoring technology suitable for Marine CO_2 pipeline, evaluation. and support for CO_2 pipeline conversion of in-service offshore oil and gas pipelines, and accelerate the transformation of CO_2 pipeline research results into engineering technology. This helps promote the high-quality construction and operation of China's marine CO_2 pipelines.

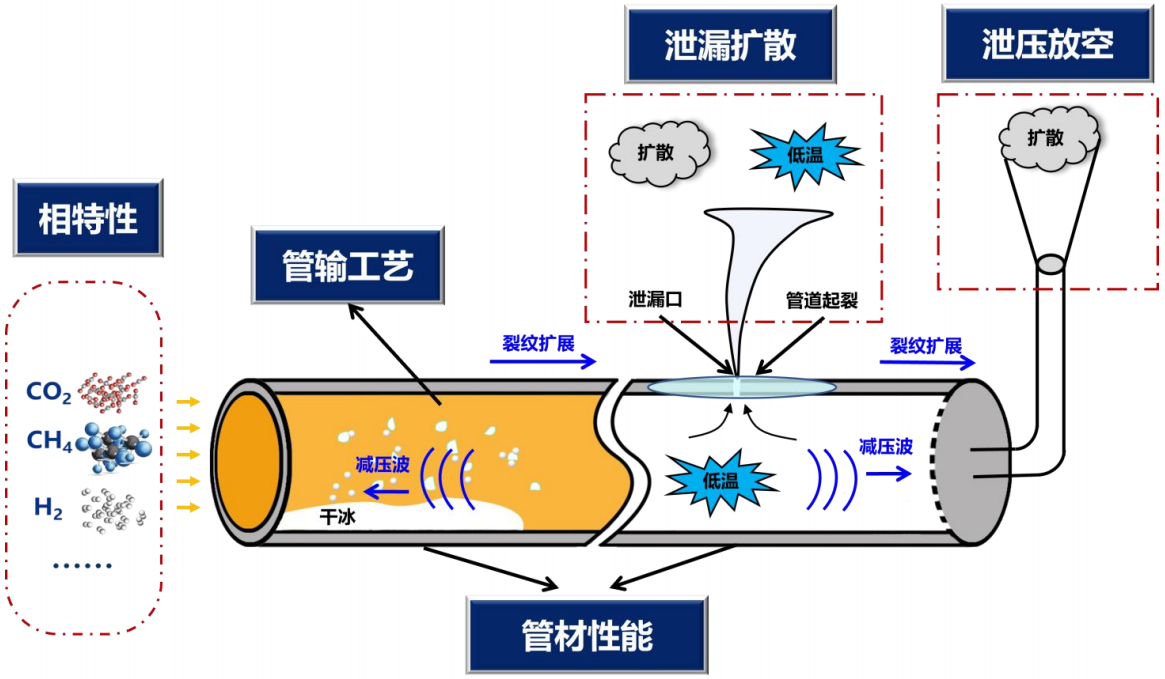


工程防护效果（边缘冲刷降低60%）

7.2 Research Progress on Key Technologies for Safe Operation of Marine CO_2 Pipelines

Qi-hui Hu, Associate Professor, China University of Petroleum (East China)

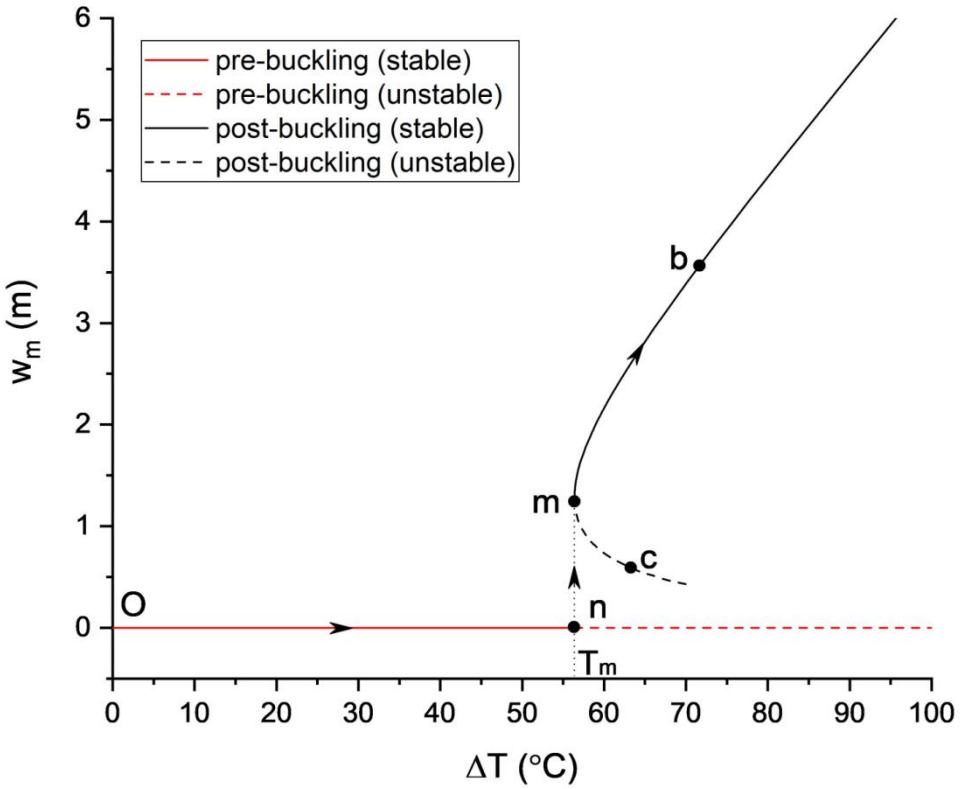
Based on the characteristics of marine CCUS, the research progresses in the calculation of complex phase properties of impurity-containing CO_2, supergravity capture of offshore carbon sources, hydrothermal computational modeling of CO_2 pipeline transport, decompression wave prediction, toughness crack stopping, corrosion control, pressure relief and venting, and leakage diffusion are introduced, which will provide reference suggestions for the safe operation of marine CO_2 pipelines.



7.3 Theoretical modeling of overall buckling of laminated pipes

Zhen-kui Wang, Professor, Zhejiang University

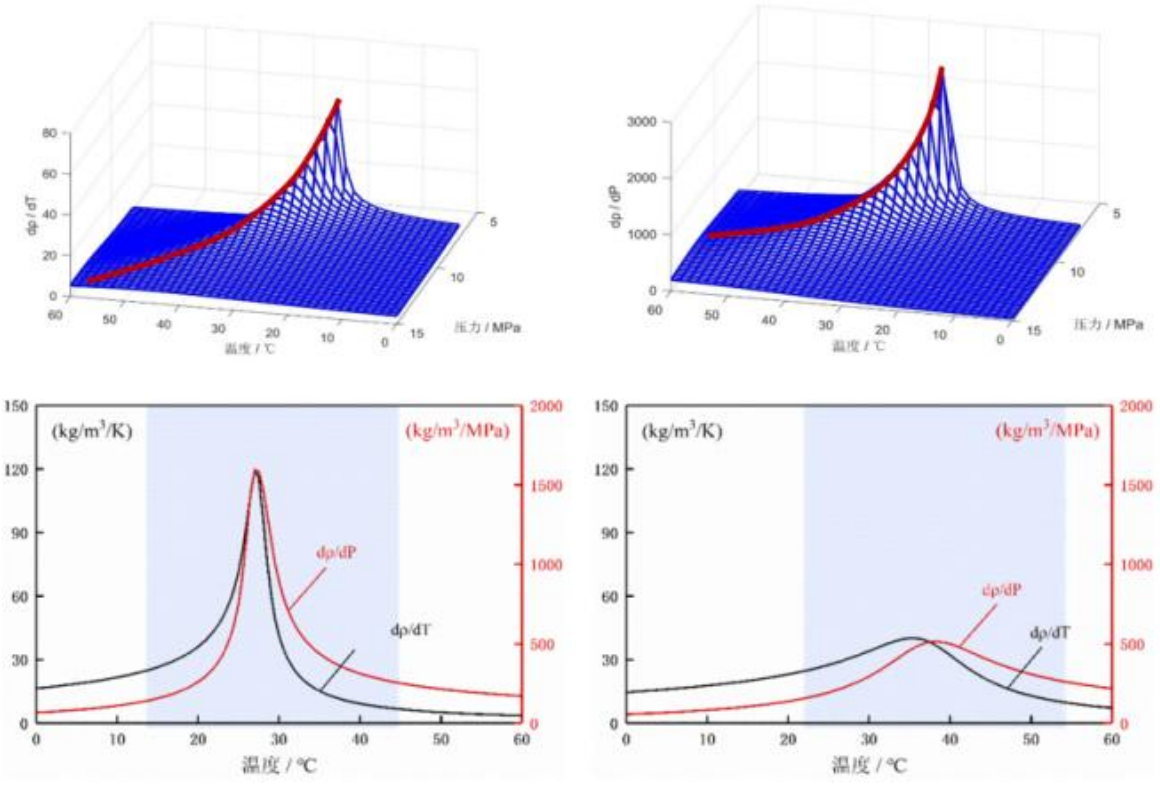
The submarine pipeline is the main channel for oil and gas, carbon dioxide convergence, transfer, and external transmission, and it is an important part and key equipment for marine oil and gas development. The composite pipe becomes a potential solution to replace the traditional single-layer pipe for deep-sea oil and gas transportation due to its good compressive and thermal insulation properties. An analytical solution for the cross-sectional temperature distribution of the laminated pipe is derived using the heat conduction equation. Considering the inhomogeneous temperature distribution and the different material properties of different layers, a theoretical model to simulate the bulging and buckling of the sandwich pipe is proposed based on the Euler-Bernoulli beam theory, and the axial pressures and bending moments of the inner pipe, the sandwich layer, and the outer pipe are solved separately. Finally, a simplified temperature distribution model for the analysis of rumble buckling of laminated pipe is proposed.



7.4 Quasi-criticality criterion for impurity-containing CO_2 and its application to CCUS pipeline technology

Meng Li, Intermediate Engineer, Sinopec Petroleum Engineering Corporation

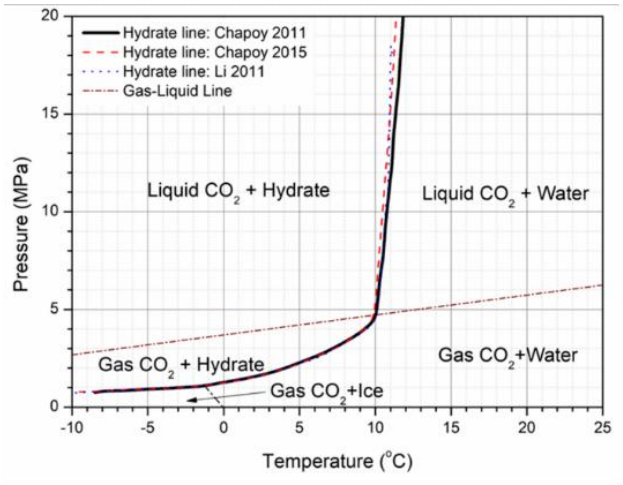
Pipeline transportation is the main transportation method for CO_2 in future carbon capture, utilization, and storage (CCUS) projects, among which CO_2 transportation as the supercritical state has the highest efficiency and the lowest cost, and has good market application prospects. In the near-critical region, drastic physical anisotropy of CO_2 with temperature or pressure changes can be observed, and the operation condition should be avoided to enter into this range. The quasi-critical nature of CO_2 is analyzed with density as the reference parameter. Since the existing quasi-critical temperature relationship formula cannot effectively guide the operation and management of CO_2 pipelines, the quasi-critical criterion for pipeline transmission of CO_2-containing impurities is proposed by taking into account the influence of impurities, temperature and pressure changes, pipe properties, and relevant support reinforcement measures, to provide a basis for the formulation of safety control programs for supercritical pipeline transmission of CO_2. The results show that the impurities make the pipeline CO_2 show a stronger “gas-like” nature; at lower temperatures, it can occur in the physical properties of the anomaly. To ensure the smooth operation of the pipeline, it can be used to transport higher pressure. This report puts forward the quasi-criticality of impurity-containing CO_2 criterion of practicality, and provides more targeted guidance for the engineering application.

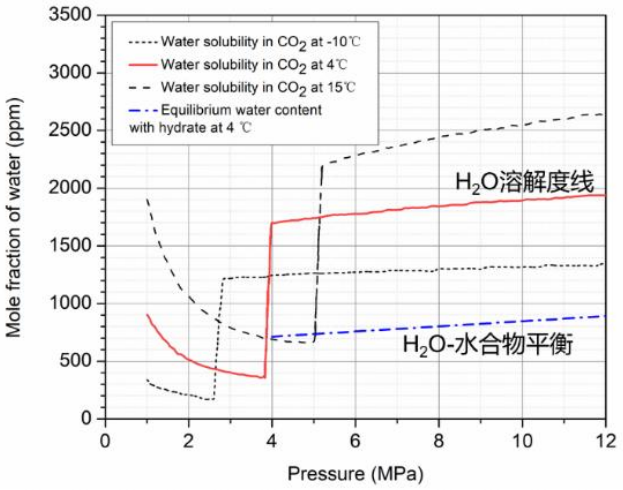


7.5 Discussion on Guidelines for Determining Water Content Thresholds for CO_2 Fluids Transported via Subsea Pipelines

Zi-ming Wang, Associate Professor, Xiamen University

Pipeline transportation is an economical and efficient way to transport CO_2 over long distances, however, it faces safety risks such as hydrate blockage and corrosion during long-term operation, and precise control of water content is one of the effective measures to ensure the stable operation of CO_2 pipeline transportation system. This report analyzes the critical conditions for CO_2 hydrate formation and corrosion under typical CO_2 pipeline operating conditions, and systematically compiles domestic and international recommendations on water content thresholds and the basis for setting them. Based on the trade-off between economy and safety, the technical and economic dilemmas faced by the deep dewatering pretreatment strategy in large-scale CO_2 transportation scenarios, as well as potential strategies for safe CO_2 pipeline transportation, are discussed to guide for optimizing the process, construction, and operation of large-scale onshore and offshore CO_2 pipeline transportation.

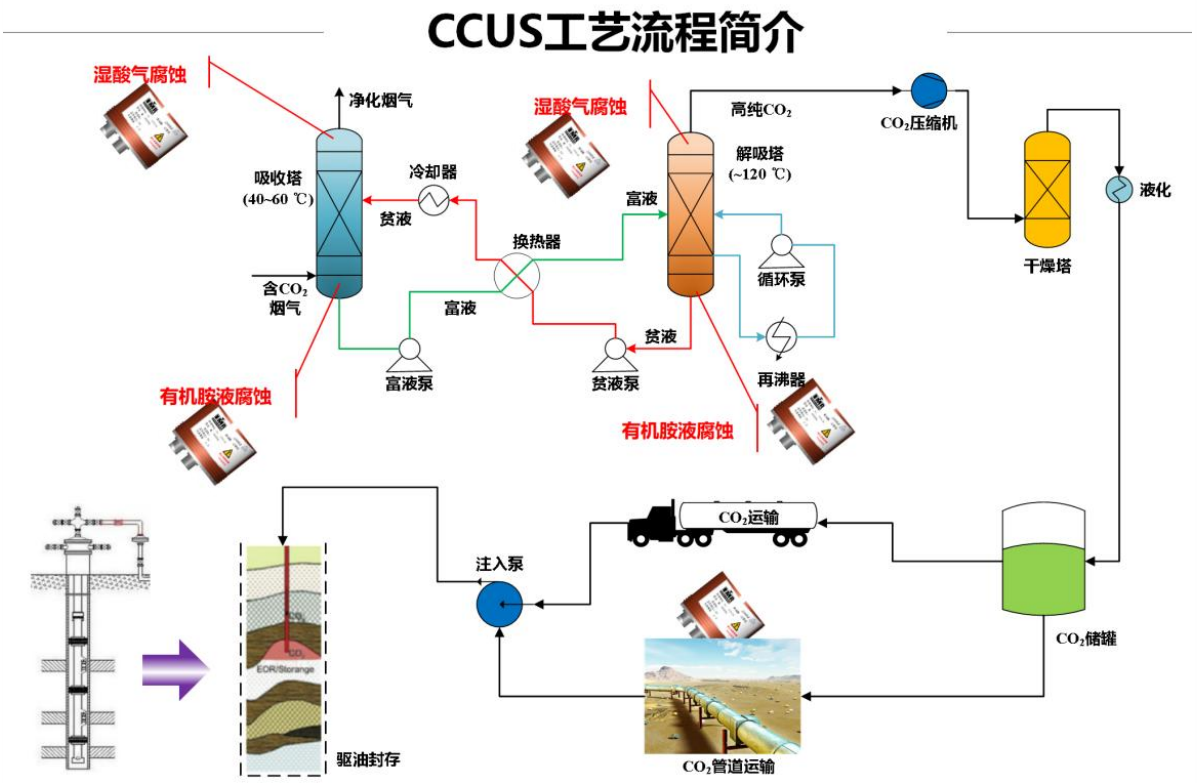




7.6 Research on Corrosion On-line Monitoring and Leakage Early Warning Technology of CCUS System

Chuang Tai, Senior Engineer, Institute of Metal Research, CAS

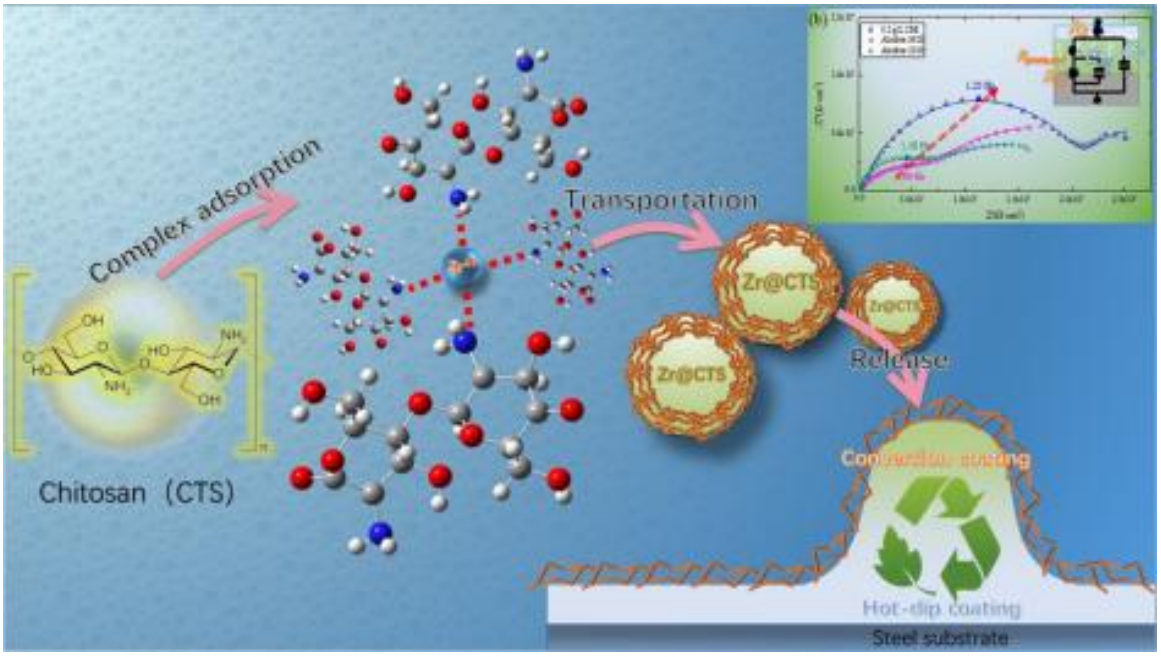
In this report, we first described the corrosive environment, influencing factors, corrosion results, and risk identification in the whole procedure of CCUS applications. It tries to explore the corrosion online monitoring and leakage early warning technology suitable for the CCUS system, and provides strong technical support for the operation and maintenance of the CCUS system in the future. By analyzing the characteristics and application limitations of the current mainstream corrosion online monitoring and leakage early warning technologies, we put forward ideas and suggestions for developing corrosion online monitoring technologies suitable for CCUS systems. At present, there are fewer corrosion online monitoring and leakage warning technologies suitable for CCUS systems, and the maturity of monitor technology is still low. The new generation of ultrasonic thickness measurement, fiber grating, electric field induction, and surface acoustic wave technologies are expected to be applied in the field of CCUS system operation and maintenance. Under the guidance of China's “dual-carbon” strategy, it is imperative to accelerate the innovation and development of online corrosion monitoring and leakage early warning technologies in the operation and maintenance process of CCUS systems.



7.7 Corrosion protection technology and practice of CO_2 long-distance transportation pipeline

Jie Pan, Engineer, Sinopec Petroleum Engineering Corporation

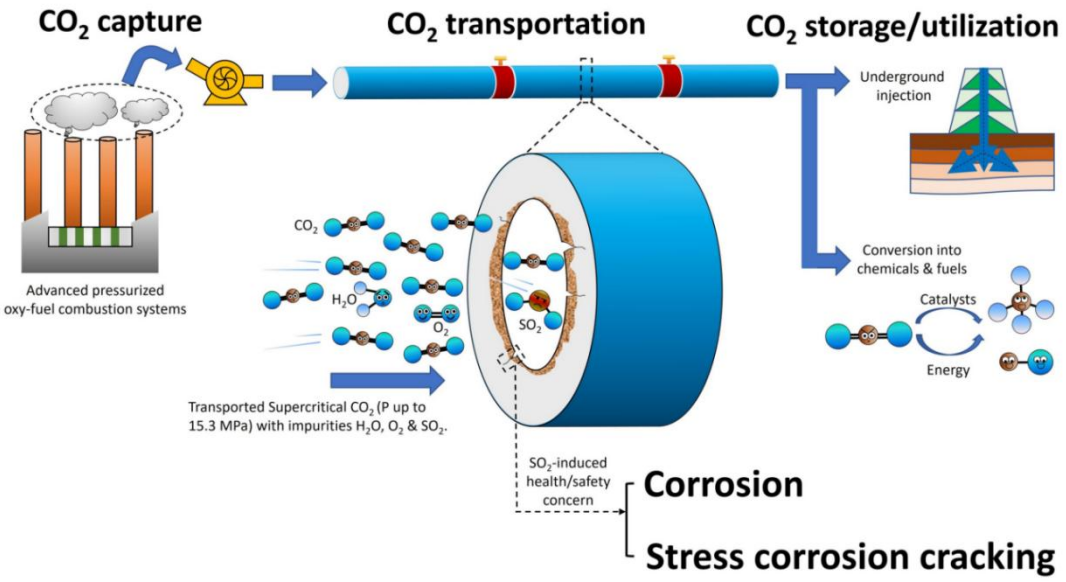
Chemical conversion film is a potential method for surface corrosion protection and treatment of metallic materials, which is widely used in transportation, agriculture, hardware, and marine engineering due to its good corrosion resistance and enhancement of coating bonding force. The long-distance CO_2 pipeline of the CCUS system is facing a harsh environment for localized corrosion, and the present study proves that a nano-crystalline conversion film can effectively form a film on the steel surface of the pipeline and has good passivation effect on the saturated carbonic acid micro-droplets precipitated in the pipeline medium, by using a multi-dimensional physical-chemical characterization means and a micro-area electrochemical technique. It can effectively form a thin film on the steel surface of the transport pipeline and has a good passivation effect on the CO_2-saturated micro-droplets precipitated in the pipeline medium. In addition, this report will introduce the basic situation of the first demonstration project pipeline in China since its operation for one year and the application practice of an intelligent cathodic protection system.



7.8 Corrosion and stress-corrosion study of supercritical CO_2 transportation pipeline

Kai-yang Li, Lecturer, North China Electric Power University

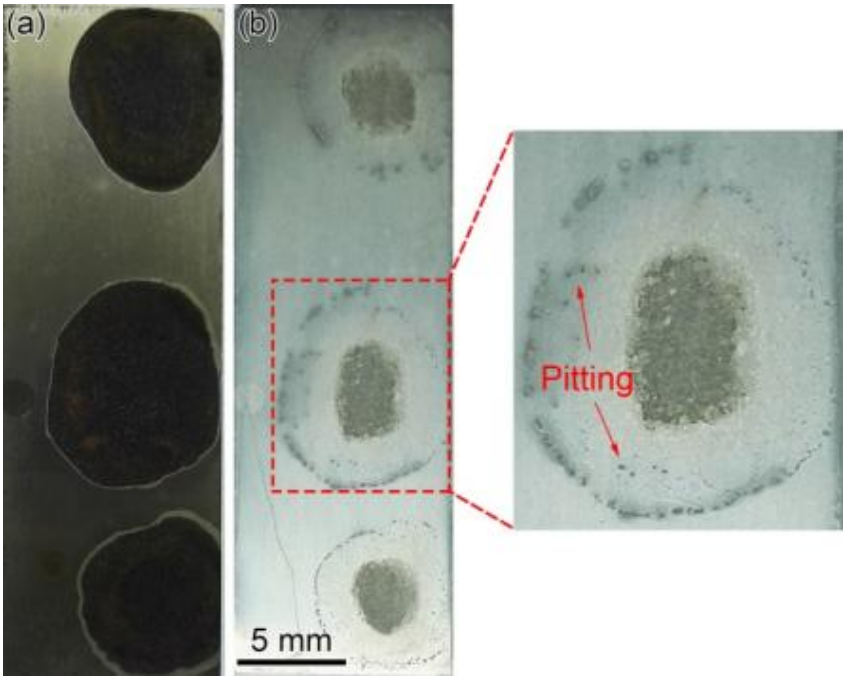
The pipeline steel transportation of supercritical CO_2 is an important part of the carbon capture and carbon harvesting process in the dual-carbon context. However, the captured CO_2 often contains impurity gases such as H_2O, O_2, H_2S, SO_2, and so on. These gases may trigger the corrosion of carbon steel during transportation, but the relevant corrosion mechanisms are not clear. Therefore, this study systematically carries out the following work: analyze the mechanism of different impurities on corrosion and how the impurities further aggravate the corrosion through synergistic effects; propose the critical content of impurities to control corrosion; carry out the stress corrosion cracking detection and analyze the possibility to occur; propose the use of in-situ electrochemical noise to analyze the corrosion mechanism; and establish a long-term corrosion prediction model. This study aims to provide a theoretical foundation and technical basis for understanding the corrosion behavior and the control of corrosion in low-temperature supercritical CO_2.



7.9 Droplet Coalescence and Corrosion Behavior of Pipeline Walls in Supercritical Carbon Dioxide Environments

Liang Wei, Associate Professor, Shanghai University

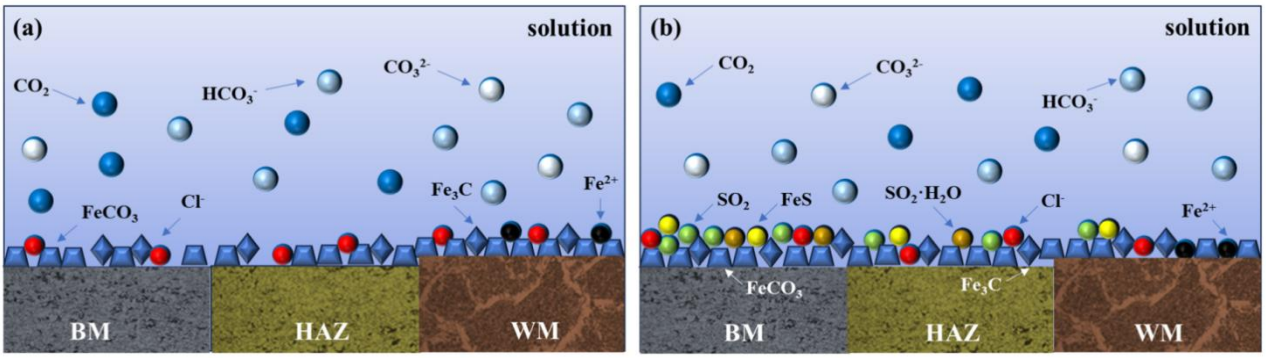
During supercritical CO_2 transportation, H_2O dissolved in the supercritical CO_2 phase condenses inside the pipeline due to small fluctuations in temperature and pressure, leading to corrosion problems. We determined that the condensation process of water in the supercritical CO_2 phase is dominated by droplet condensation, and the exposure angle significantly affects the condensation behavior of water in the supercritical CO_2 phase on the steel surface as well as the corrosion process; accurately derived the maximum dimensions of the droplets in the supercritical CO_2 phase containing saturated water condensing on the surface of carbon steel through the model for the calculation of the critical radius of the droplets and the experimental validation; and revealed that the droplets can be formed in the supercritical CO_2 phase within the pipe. The micro-coupling corrosion mechanism between different substrate regions in the supercritical CO_2 phase is revealed.



7.10 Selective adsorption and corrosion mechanism of SO_2 and its hydrate on X65 steel welded joints in CO_2 solution

Yong Xiang, Professor, China University of Petroleum (Beijing)

Carbon Capture, Utilization and Storage (CCUS) has proven to be an effective way to reduce CO_2 emissions and achieve low carbon use of fossil fuels. However, impurity gases in CO_2 captured from coal-fired power plants can exacerbate internal corrosion in transportation pipelines and their welded joints. In this study, the corrosion mechanisms of different regions of welded joints in saturated aqueous solutions of CO_2/SO_2 were investigated by electrochemical and morphological analyses. The results show that SO_2 and its hydrolysis have some adsorption properties and tend to adsorb on the surface of the base material region and produce FeS products. This region can form dense corrosion products, which effectively reduces the corrosion rate. The selective adsorption increases the potential difference between different regions of the welded joint, which further aggravates galvanic corrosion and eventually leads to corrosion failure of the welded joint.

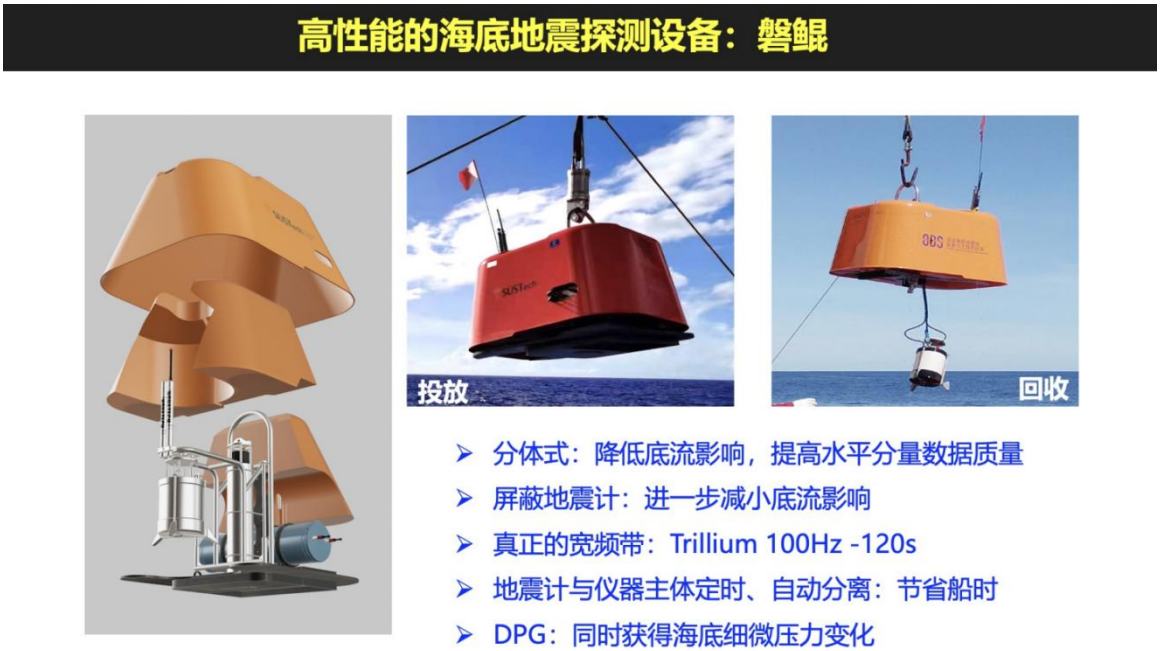


8 Session 7: R&D of Equipment related to Marine Carbon Storage

8.1 Seabed seismograph and OCCUS field monitoring equipment

Ting Yang, Professor, Southern University of Science and Technology

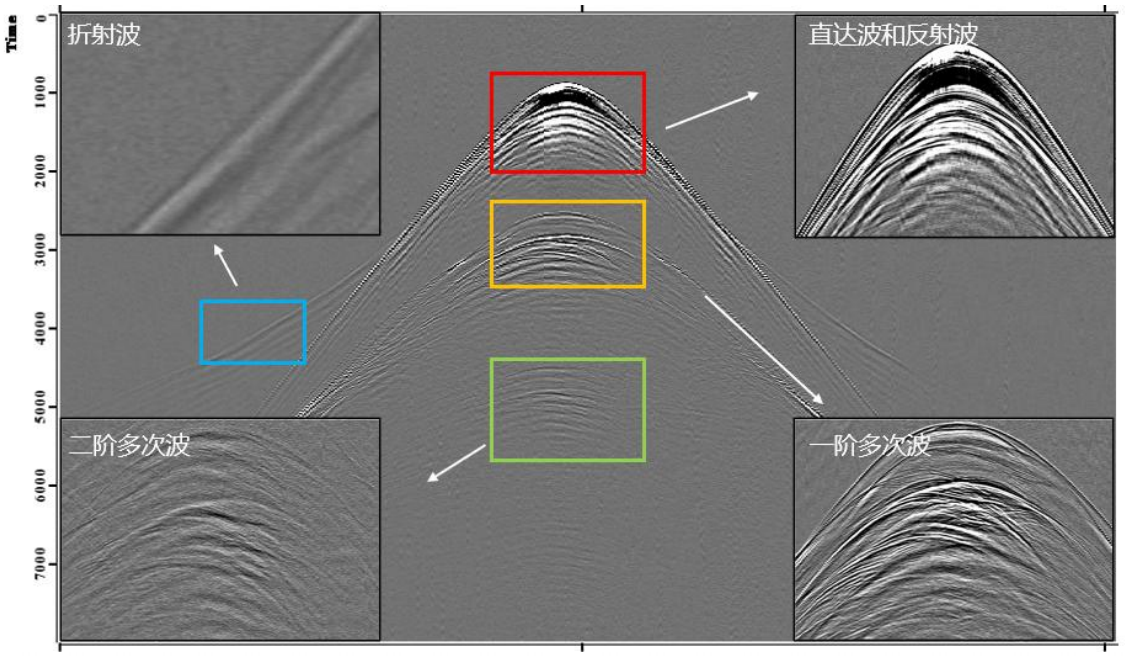
OCCUS is inseparable from seabed monitoring equipment in terms of site selection, stability, and safety assessment, and the development of related equipment should still be in the early stages. Passive source OBS, a long-term continuous natural seismic observation on the ocean floor, is consistent with this equipment in many aspects, such as multi-sensors, low power consumption, reliability, and reducing the impact of the seabed environment. Therefore, passive source OBS serves as the initial research and development platform for offshore CCUS monitoring equipment. In this report, I will introduce the performance features and challenges of the latest generation of the South Black OBS, and discuss the feasibility of transforming it into an offshore CCUS field monitoring equipment.



8.2 Research and development and application of new low-frequency broadband submarine seismometer

Si-qing Liu, Senior Engineer, Guangzhou Marine Geological Survey Bureau

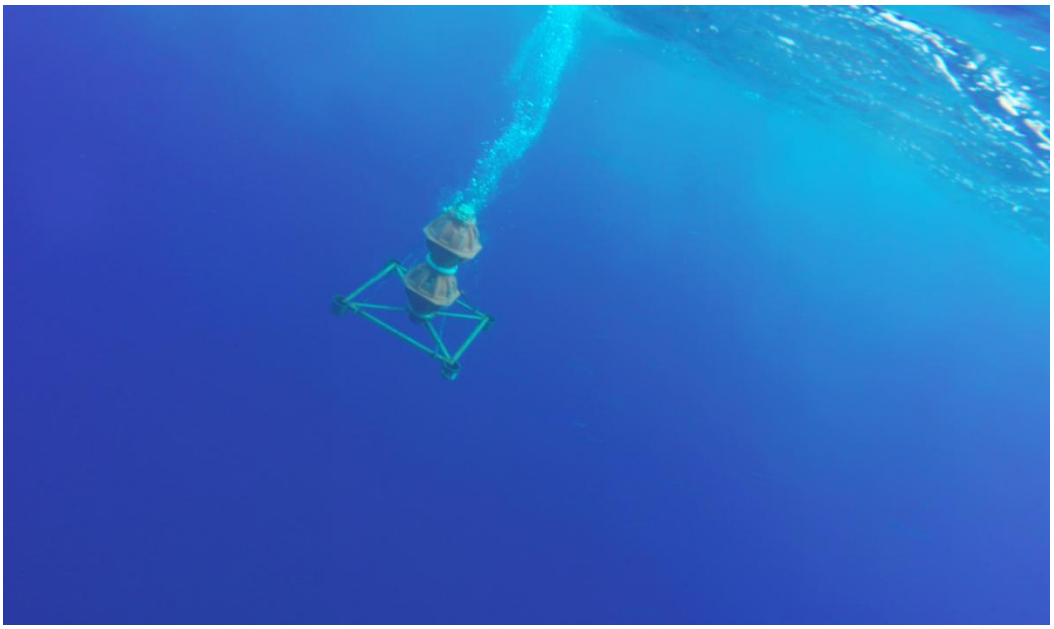
Seafloor carbon sequestration is a technology that permanently stores carbon dioxide in geological formations on the ocean floor. In the process of storage, it should be ensured that the process is safe and effective, and will not cause adverse effects on the environment, mainly including carbon leakage monitoring, geological structure reservoir stability assessment, surrounding environmental impact assessment, etc. Such monitoring is not limited to the initial stage of storage, but throughout the entire storage cycle, and even after storage for some time need to continue. Seafloor carbon sequestration usually occurs in deep strata, and the sequestration process is accompanied by the occurrence of small earthquakes. The use of low-frequency broadband seafloor seismographs can effectively detect deep geological structures, monitor small changes, and evaluate the long-term stability of reservoirs. Based on the above needs, Guangzhou Marine Geological Survey and Guangzhou Weitao Electronic Technology Co., LTD., launched a new low-frequency broadband submarine seismograph (LB-OBS) independent research and development technology, the project relies on the Marine development of the Guangdong Provincial Department of Natural Resources special key project "high resolution seismic and electrical combined physical property detection of natural gas hydrate key technology". Recently, a large number of functional tests and data acquisition tests have been completed, and very good results have been achieved. The project takes the functional test and submarine acquisition test of the newly developed LB-OBS as an example to verify the feasibility of LB-OBS in actual production applications, breaking through the key difficulties such as stable acquisition of high signal-to-noise ratio data, low frequency to 3Hz, high equipment recovery rate, and clear wave signs of PP and PS conversion. On the one hand, through multiple batches of LB-OBS anchorage in the water depth of 2200 meters and recovery, completed the self-developed LB-OBS underwater acoustic ranging, acoustic release fusing, status query, data acquisition, gain verification, and other functional tests; On the other hand, the recovery of LB-OBS in all stations has been completed through sufficient release communication, fusing test and substantial improvement of the release decoupling system. The test results show that the low frequency and high-resolution data quality of LB-OBS developed by the project is good, and the wave signatures of PP and PS conversion are clear. Based on this, this study believes that the research and development of LB-OBS is a model to promote the renewal and iteration of domestic technical equipment, optimization, and upgrading, and also adds strong confidence for the subsequent market promotion and application of LB-OBS, high-quality services for the development of deep-sea energy resources, Marine geological carbon sequestration monitoring and deep earth science research.


Time
0
1000
2000
3000
4000
5000
6000
7000
折射波
直达波和反射波
二阶多次波
一阶多次波

8.3 Equipment and technology of submarine seismograph

Yuan Wang, Senior Engineer, the Institute of Geology and Geophysics, CAS

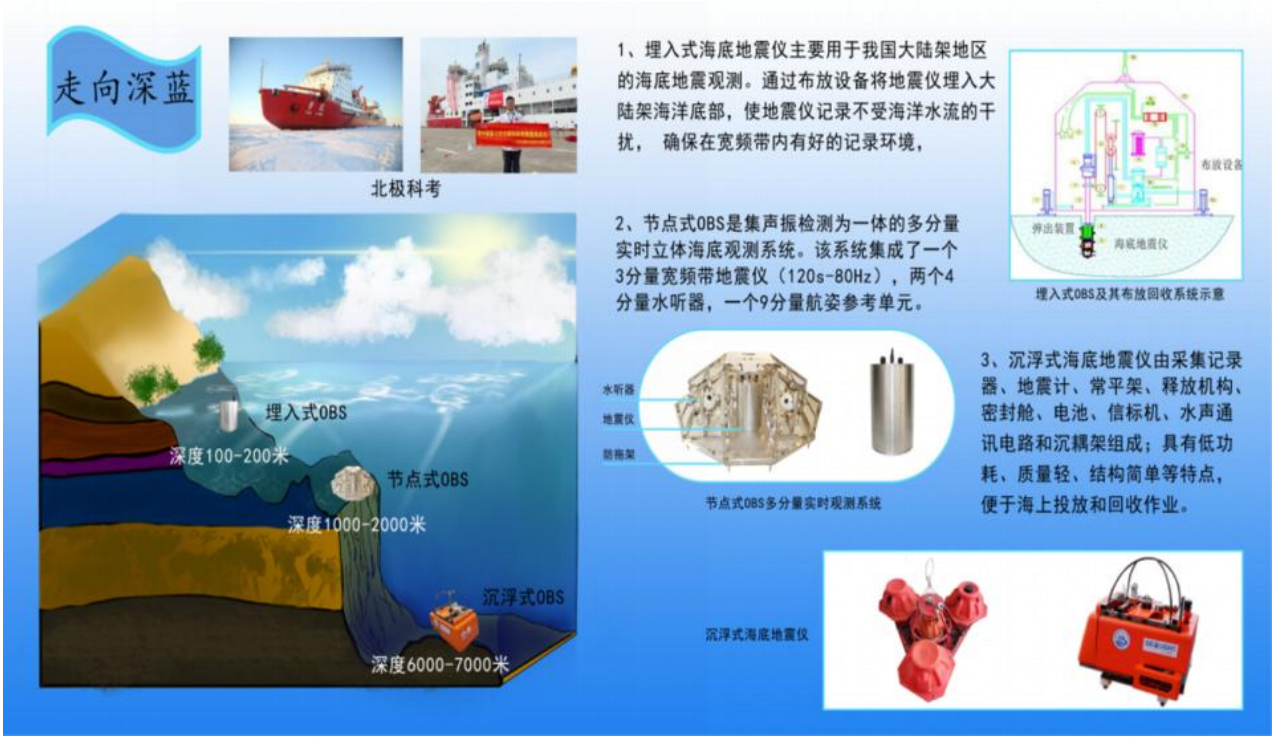
To study the deep crust and mantle structure, the seabed seismic activity, and realize the earthquake and tsunami warning, it is necessary to lay a seabed seismograph on the seabed to carry out seismic observation. Deep sea underwater seismograph involving seismic sensors, deep water hydrometer, acoustic transducer and voltage packaging, and other advanced international technologies, China's high-performance deep sea underwater seismograph has been blank for a long time. To this, the CAS Institute of Geology and Geophysics through years of continuous core technology research and deep-sea test, solved the digital zero broadband seismic sensing technology, the sea deep ceramic piezoelectric water sensing technology, soft collaborative optimization low power consumption acquisition technology and high-reliability recovery technology, independent successfully developed including a portable submarine seismograph, broadband submarine seismograph and real-time submarine seismograph series of underwater earthquake detection equipment (collectively referred to as IGG-OBS). The experimental results show that the self-developed IGG-OBS equipment has reached the international advanced level; in recent years, more than 1400 units and the comprehensive recovery rate is more than 90%; Through the actual observation of various complex seabed zones in the ocean ridge, the qualified rate of data quality is> 98%, with the capability of complex structure imaging, which has entered the substantial application stage, for deep-sea research, ocean investigation and offshore disaster in ChinaHazarm early warning and monitoring provide key technology support.



8.4 Research and development progress of submarine seismograph in China

Ling-hui Niu, Senior Engineer, Beijing Gangzhen Technology Co., LTD

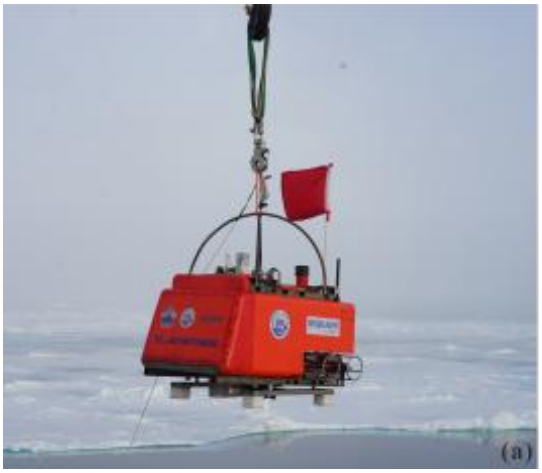
After more than 20 years of development, China has made great scientific and technological achievements in the development of the submarine seismic observation system, and formed a variety of observation forms. According to the communication mode, it is divided into cable type and no cable type, and cable type can supply power and data transmission through an optical fiber cable, which can guarantee long-time work and real-time data recovery. This type of equipment mainly includes optical cable connecting type, connecting node type, buoy type underwater seismometer; no cable type is generally temporary observation, mostly in the deep-sea observation. This type of equipment mainly includes sink coupling frame-ups and down types, split-ups and down types, base types, embedded types, etc. Although our country has developed to adapt to the deep sea and near coastal seismic monitoring equipment, solve the system of low power consumption, small volume, large capacity storage, high punctuality precision, seismometer automatic separation device, broke through the underwater orientation, large Angle leveling function technical difficulties, in engineering implementation and Marine seismic monitoring network system construction, there are insufficient real-time data, not forming network layout, with the large-scale construction of offshore wind power, the domestic-related research team has been studied through wind power platform, oil drilling platform for offshore Marine earthquake monitoring system design research. In addition, along with the submarine optical cable. The construction cost is reduced, can be around the island and important sea around the submarine cable observation network construction, through photoelectric composite cable series connecting the sensor observation chain, seismograph from the photoelectric composite cable, and real-time data transmission to the nearshore base station or island center station. The construction of such a seabed observation system can realize a real-time and long-term seabed seismic monitoring network. Future with the development of the development and application of Marine seismic monitoring instruments, according to different sea depth and observation requirements, can adopt different observation modes of Marine seismic monitoring instruments from temporary, medium, and long-term observatory networks, the whole sea monitoring information collection, Marine seismic monitoring analysis, can also be applied to the Marine basic scientific research, Marine disaster forecast early warning, resources and energy exploration and utilization, navigation and military Marine environment security, for scientific research and production of resources and energy development and utilization, for Marine forecasting, Marine disaster prevention and mitigation, Marine science theory breakthrough test platform, and technology.


走向深蓝
北极科考
埋入式OBS
深度100-200米
节点式OBS
深度1000-2000米
沉浮式OBS
深度6000-7000米
1、埋入式海底地震仪主要用于我国大陆架地区的海底地震观测。通过布放设备将地震仪埋入大陆架海洋底部，使地震仪记录不受海洋水流的干扰， 确保在宽频带内有好的记录环境，
布放设备
弃出装置
海底地震仪
埋入式OBS及其布放回收系统示意
2、节点式OBS是集声振检测为一体的多分量实时立体海底观测系统。该系统集成了一个3分量宽频带地震仪（120s-80Hz），两个4分量水听器，一个9分量航姿参考单元。
水听器
地震仪
防拖架
节点式OBS多分量实时观测系统
3、沉浮式海底地震仪由采集记录器、地震计、常平架、释放机构、密封舱、电池、信标机、水声通讯电路和沉耦架组成；具有低功耗、质量轻、结构简单等特点，便于海上投放和回收作业。
沉浮式海底地震仪

8.5 Submarine seismic detection in dense ice areas of the Arctic Ocean

Xiong-wei Niu, Researcher, The Second Institute of Oceanography, Ministry of Natural Resources

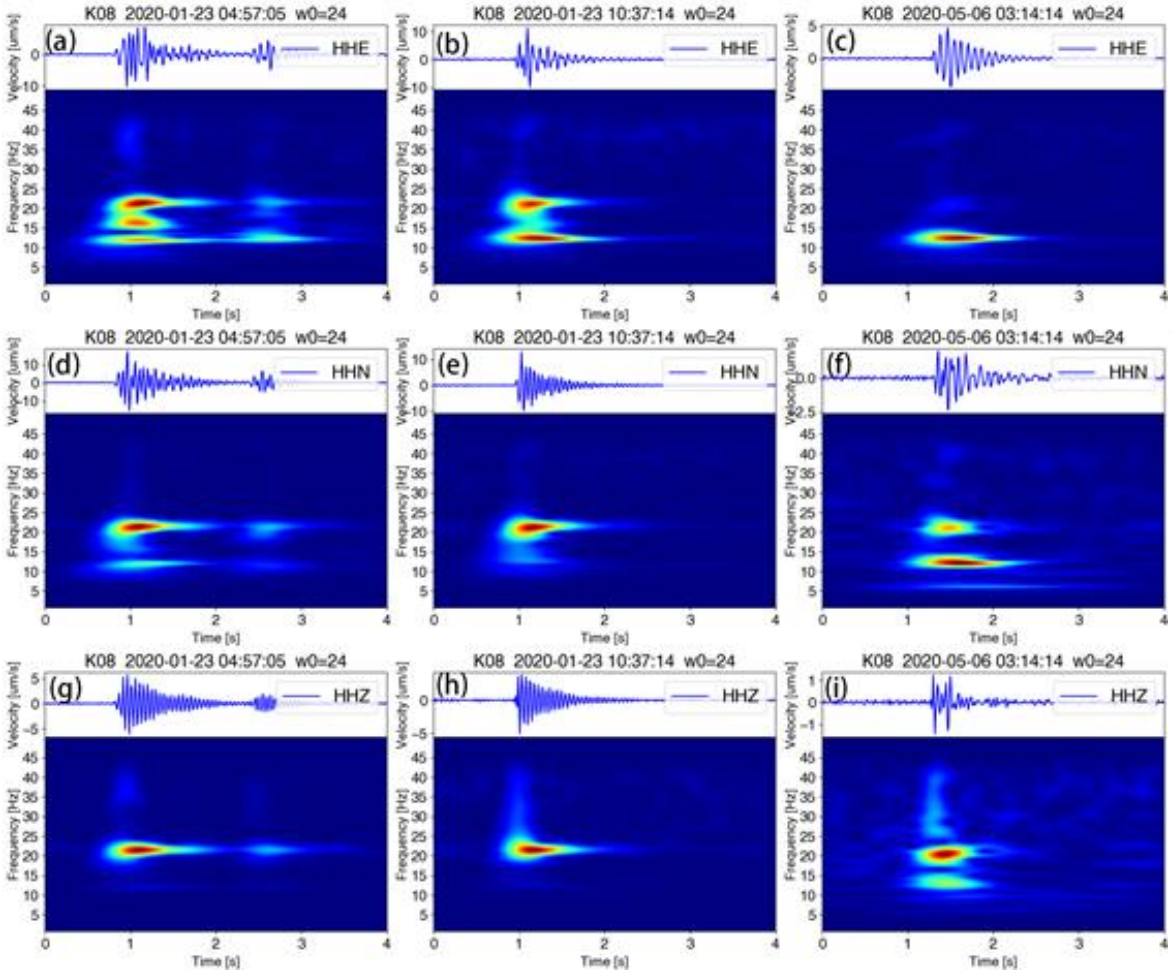
Subfloor seismometer Ocean Bottom Seismograph (OBS) is an important equipment for detecting deep crust and mantle structure. The 12th Arctic scientific expedition of China completed the first large-scale active source OBS detection in the middle ridge of the Arctic Ocean covered by dense floating ice. 42 of 43 OBS were successfully recovered, of which 5 split OBS were successfully recovered. This study introduces a new split OBS developed for the OBS recovery and positioning problems faced in this voyage. Its main features are (1) the integration of ultra-short baseline beacon and acoustic response system to achieve dual positioning guarantee; (2) the coupling of seismometer and seabed to effectively improve the signal-to-noise ratio; (3) the selection of domestic seismometer and buoyancy materials to realize the localization of core components. The low-level seismic background noise energy of the split OBS in the Arctic Ocean, the recorded remote seismic waveforms, two near-source microseismic waveforms, and three-component active source seismic records all have clear seismic phase information, indicating that the OBS can meet the needs of sub-ice seabed exploration.



8.6 Marine gas escape monitoring based on a broadband submarine seismograph

Yi-zhi Wang, Lecturer, Southern University of Science and Technology

The Broadband submarine seismograph (OBS) is a device for seismic observation placed on the sea floor for a long time. It can not only record seismic events, but also record the vibration caused by other geological activity processes from the sea floor. Due to the factors such as temperature and pressure change, the seabed of the gas hydrate or other gas in the sediment of elastic expansion and tensile fracture cycle growth and overflow from the seabed sediment layer, leading to the rupture of geological structure and deformation, causing the small vibration, by OBS record, this kind of signal called short-time events (SDEs). In this study, the data of the broadband submarine seismograph deployed in the northwest South China Sea from October 2019 to May 2020 were analyzed. A large number of random short-time events (R-SDE) were picked up by the short-time window mean ratio algorithm, which was characterized and used the signal to study the shallow geological activity process in this region. The traceability analysis of the R-SDE signal shows that the signal mainly comes from the vibration caused by the gas escape, and the amount of R-SDE collected in the OBS data analyzes the activity degree and time distribution of the R-SDE gas escape, and it is speculated that the signal is mainly from the northwest of the OBS distribution location. This study shows that the long-term deployment of a broad-band submarine seismograph can be used to monitor submarine gas leakage. The widely distributed OBS can be used to estimate the global submarine gas escape flux and provide a basis for the accurate evaluation of global submarine carbon emissions.


K08 2020-01-23 04:57:05 w0=24
(a)
HHE
K08 2020-01-23 10:37:14 w0=24
(b)
HHE
K08 2020-05-06 03:14:14 w0=24
(c)
HHE
K08 2020-01-23 04:57:05 w0=24
(d)
HHN
K08 2020-01-23 10:37:14 w0=24
(e)
HHN
K08 2020-05-06 03:14:14 w0=24
(f)
HHN
K08 2020-01-23 04:57:05 w0=24
(g)
HHZ
K08 2020-01-23 10:37:14 w0=24
(h)
HHZ
K08 2020-05-06 03:14:14 w0=24
(i)
HHZ
Velocity [um/s]
Frequency [Hz]
Time [s]

9 Session 8: Development Technology of Carbon Sequestration and Zero Carbon Biochemicals for Marine Organisms

9.1 Regulation technology and carbon migration mechanism of photosynthetic carbon sequestration coproduction of high protein or high lipid by microalgae driven by CO_2

Dong Wei, Professor, Institutes of Technology of South China

In this study, Chlorella C-169 was selected as the research object. Firstly, an optimized lYE chemical absorption CO_2-photosynthetic carbon sequestration coupling technology system was established, and its photosynthetic carbon sequestration performance was systematically evaluated. Then the key factors affecting the production of photosynthetic carbon sequestration and carbon storage products (protein or oil) were optimized, and the optimal carbon sequestration process was established. Multi-omics analysis technique was used to elucidate the mechanism of carbon metabolism pathway analysis and carbon allocation regulation in photosynthetic cells, construct the photosynthetic carbon metabolism pathway and its regulation model, and create a new CO_2 chemical absorption-microalgae efficient photosynthetic carbon sequestration coupling technology. The research and development of an efficient carbon sequestration process can achieve the highest carbon sequestration rate and protein/oil yield at the same time, providing an effective solution for carbon reduction and solving the food crisis. The distribution pattern of photosynthetic carbon in microalgae cells and the key metabolic branching points that determine the distribution of carbon flow were analyzed comprehensively, which provided a theoretical basis for accurately regulating the directional synthesis of high-value chemical products in microalgae cells.

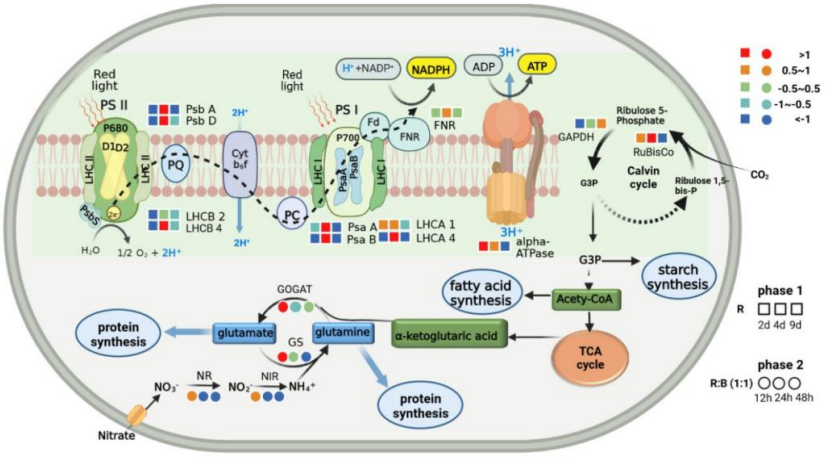


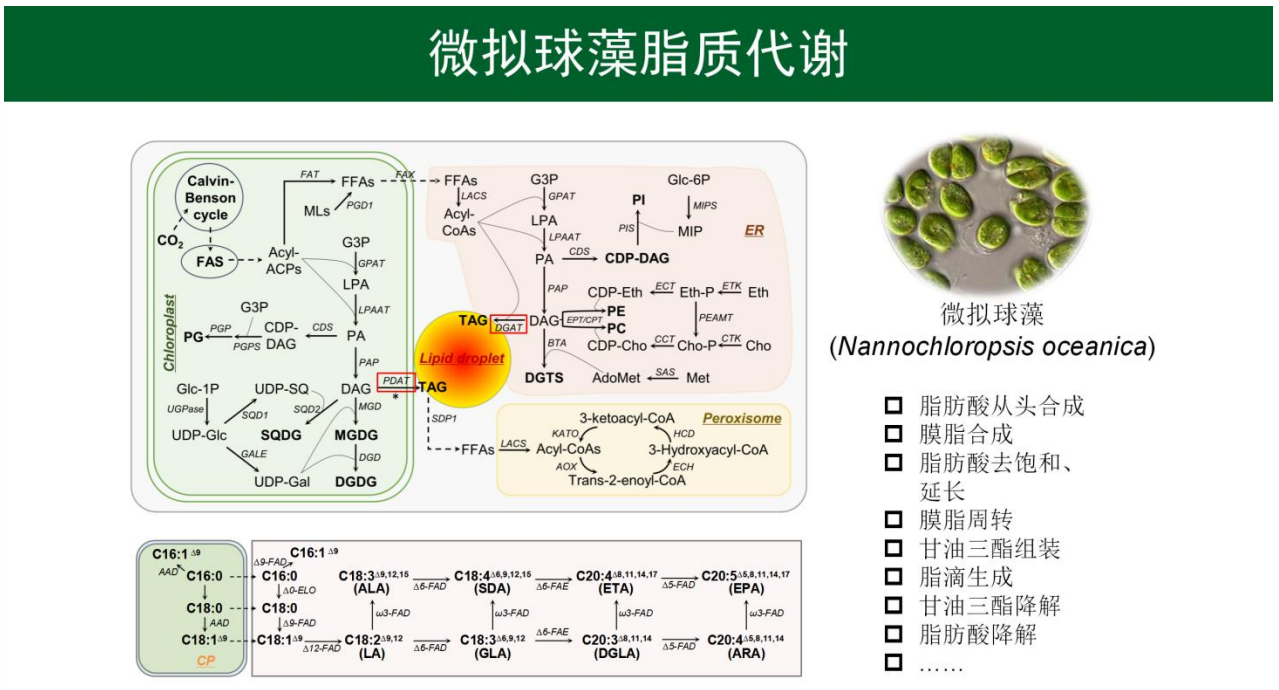
图 15 两阶段培养下与光作用和氮代谢相关基因的时序性表达规律

红色和橙色的方框和圆圈代表上调，蓝色代表下调，绿色代表相对没有变化

9.2 Metabolically remodeled carbon sequestration Marine microalgae synthesize high-value products

Jin Liu, Professor, Nanchang University

Photosynthetic organisms are the natural carbon sinks on Earth. Among the many photosynthetic organisms, algae, an important player in the carbon-oxygen cycle, have fixed more than 40% of the planet's CO_2, which is the vital primary productivity on earth. Algae, especially unicellular eukaryotic microalgae, have obvious advantages over higher plants, including converting light energy into CO_2 With high efficiency, fast growth, strong environmental adaptability, can be cultivated through multi-nutrient mode, and not competing with grain, it is praised as the ideal light-driven cell factory, which has the potential to play an important role in the green and sustainable negative carbon pathway. CO of fixation by light-driven microalgae$_2$Through the Calvin cycle to generate glyceraldehyde 3-phosphate, into a variety of metabolic pathways, and finally synthesize various products, including high-quality protein, starch, oil, long-chain polyunsaturated fatty acids, high-value carotenoids, etc. The high efficiency of photosynthesis and diversification of high-value products make them in CO_2. There is an important application potential in the green high-value utilization. Marine relatively complete genome annotation and rich genetic tools make it a potential light-driven eukaryotic chassis. This report mainly introduces the lipid metabolism and carotenoid biosynthesis of Marine microalgae, as well as the synthesis of high-value products of the algae through synthetic biology.



微拟球藻
(*Nannochloropsis oceanica*)

- 脂肪酸从头合成
- 膜脂合成
- 脂肪酸去饱和、延长
- 膜脂周转
- 甘油三酯组装
- 脂滴生成
- 甘油三酯降解
- 脂肪酸降解
- ……

9.3 Sedimentation characteristics and mechanism of Mirco class phytoplankton —— lab and field studies

Qiang Hao, Associate Researcher, The Second Oceanography Institute, Ministry of Natural Resources

Plankplankton settlement is a key link in Marine organic carbon transfer and burial, and its settlement rate (Sv) is crucial to carbon flux. However, phytoplankton Sv is regulated by community structure and physiological state, exhibits high variability, and currently has limited knowledge of its relationship to marine biogeochemical processes. Recent studies have shown that the Sv of phytoplankton communities in the Yangtze Estuary show significant spatial and temporal differences, especially in the phosphorus-exhausted freshwater front area, where Micro-class phytoplankton (i. e., 20-200 microns) contribute the highest sedimentation rate. The order of Sv for phytoplankton is Micro> Nano> Pico. However, Sv showed a significant negative correlation with dissolved inorganic phosphorus (DIP), and the particle structure relationship with algae was not obvious. Among the types of environmental factors, Sv showed the highest correlation with limiting nutrient salts. The field phosphorus enrichment experiment showed that the increased DIP concentration will lead to a rapid decline of Sv and even negative values, suggesting that the nutrient limitation may be a "switch" of phytoplankton settlement, and when the nutrient salt exceeds a certain threshold, the settlement will be extremely slow or stop. In the laboratory, the sedimentation mechanism of various Micro-grade diatoms was analyzed by novel HD imaging equipment, which showed that Sv was mainly regulated by cell's physiological state, and there was no significant correlation with the concentration of siliceous shell and extracellular material. Studies have also found that lipid changes could explain ~ 80% of the sedimentation rate variation, especially under nutrient limitation conditions, where the excess photosynthesis energy is dissipated by lipid accumulation and elevated stearid concentration leads to increased phytoplankton density, thereby enhancing Sv. This study reveals the key regulatory role of nutrient supply on diatom settlement, provides new insights into understanding carbon pump mechanisms in marine organisms, and provides potential parties for developing algal capture techniques.

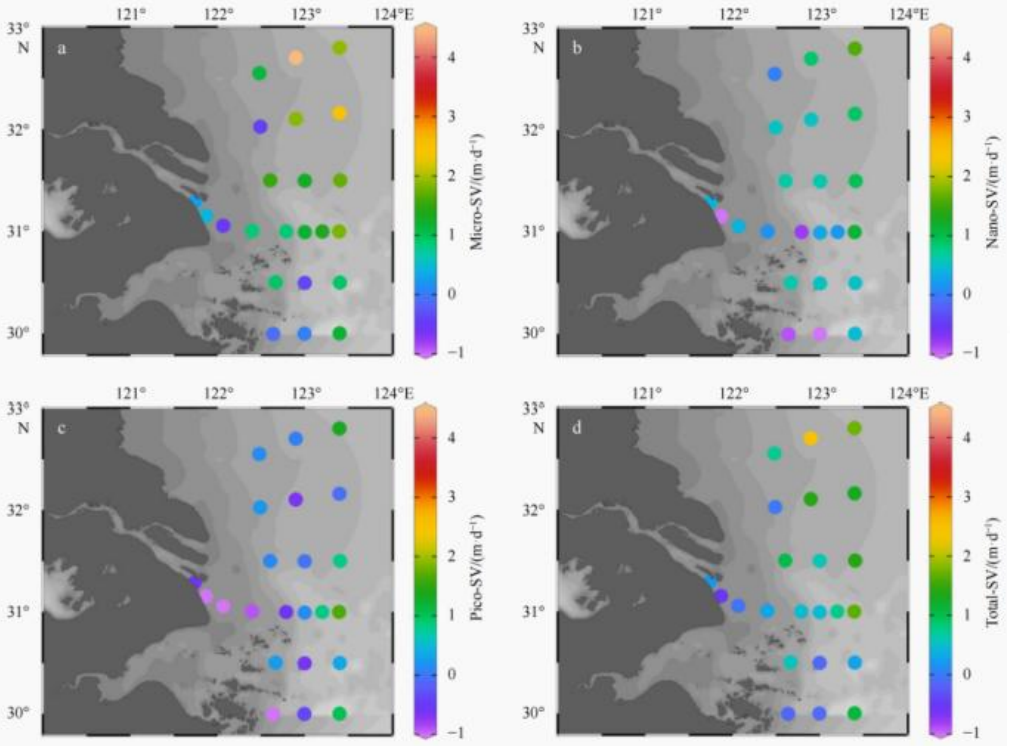
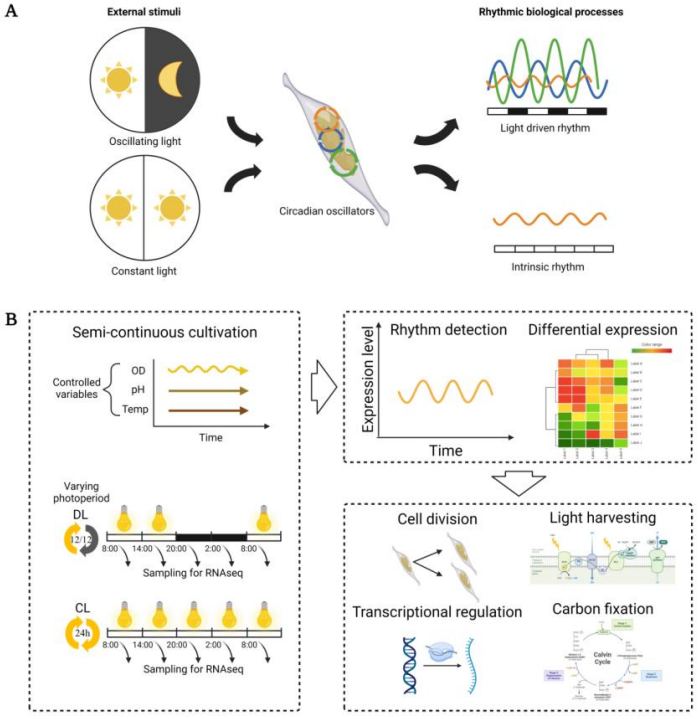


Fig. 5. Spatial distribution of surface micro- (a), nano- (b), pico- (c), and total- (d) SV in the surveyed area.

9.4 Molecular circadian biological clock regulation of photosynthetic carbon sequestration in phytoplankton

Wei-qi Fu, Researcher, Zhejiang University

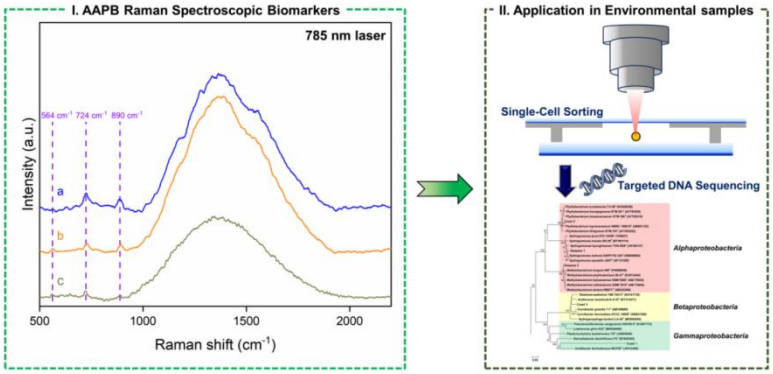
Circadian clocks exist in all types of organisms and coordinate key biological processes, e.g. photosynthesis in phytoplankton (microalgae) and land plants. We asked whether a circadian rhythm sustains in phytoplankton when living under constant illumination without environmental cues. Here, we report the first transcriptomic architecture of persistent oscillatory gene expression in the model marine diatom, Phaeodactylum tricornutum living under constant illumination and temperature without environmental cues. We show that cyclic expression of a considerable number of genes involved in light harvesting and carbon fixation sustained after 24 hours of constant illumination, which could pose additional constraints on cell growth under constant light conditions. Over long-term adaptation to constant illumination (free-running conditions), the majority of the rhythmic genes identified under diel light conditions lose their oscillatory expression in the absence of external entrainers, and the genes potentially controlled by persistent circadian clocks are primarily involved in transcriptional regulation and cell division. We find constant illumination leads to an increased average expression of transcription factors and cell division genes, while genes involved in the Calvin-Benson cycle and pigment biosynthesis are kept at low expression levels, which plays a role in the down-regulation of photosynthetic efficiency. By manipulation of the dark rest period, we confirm a fine-tuned light/dark cycle could dramatically improve photosynthetic efficiency in microalgae. Our results unveil a novel persistent circadian rhythm on photosynthetic regulation in marine phytoplankton and provide critical insights into the interaction between environmental signals and inheritable internal circadian clocks in diatoms.



9.5 Development of aerobic non-oxygen-producing photosynthetic bacteria resources based on genome and single cell Raman spectroscopy

Lin Xu, Associate Professor, Institutes of Technology of Zhejiang

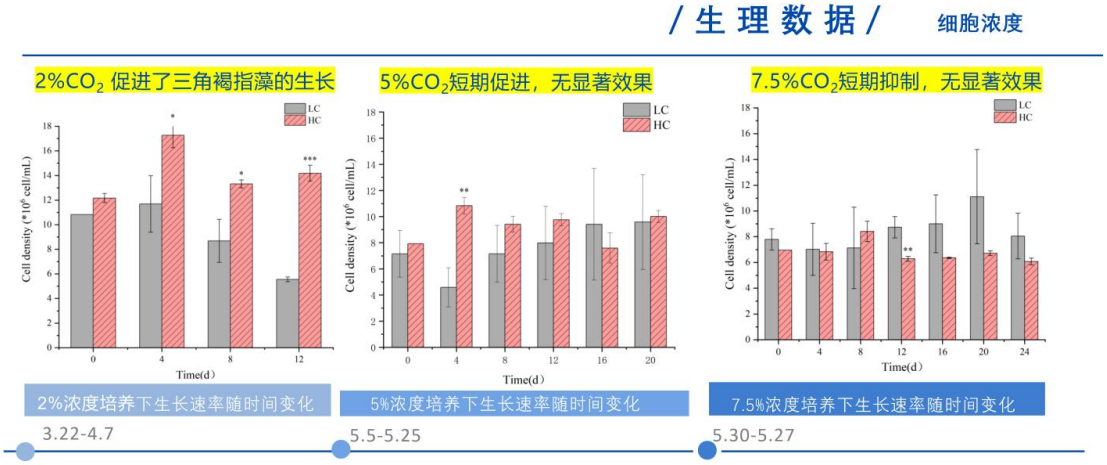
Aerobic non-oxygen-producing photosynthetic bacteria (AAPB) are a kind of heterotrophic microorganisms that have the characteristics of aerobic heterotrophic survival and can supplement their energy requirements by photosynthesis using light energy. AAPB plays an important role in the hydrosphere material cycle due to its unique ability to use light energy. Erythrobacteriaceae is a representative group of AAPB, which is characterized by a large number and wide distribution. Most of them are isolated from euphotospheric seawater or lake water, and some have photosynthetic functions, which is a good material for studying the evolutionary mechanism of Marine bacteria. Based on the model strains of Erythrobacteriaceae, this study has obtained a series of new understandings in classification theory, resource mining, and evolutionary mechanisms. The main work is as follows: (1) Through comparative genomic and phylogenetic analysis, the family was divided into 16 genera, and it was found that the AAI of the same genus-group was usually higher than 70% and the clad length was lower than 0.4. Based on this, a new index and threshold value of the gene-level taxonomic unit were proposed. (2) a Raman spectroscopy detection method based on bacterial chlorophyll A was constructed, and single cells with characteristic peaks of photosynthetic groups were obtained, it was found that they all contained photosynthetic genes and more unique genes encoding metabolic amino acids and inorganic ions. (3) For the photosynthetic taxa of this family, it was found that the PGC gene arrangement was conservative, and the GC content was consistent with the GC content of the genome. The phylogenetic clustering relationship between PGC and genomic phylogenetic development was similar, indicating that the evolutionary process of PGC was similar to that of genome evolution. (4) Ancestral genome inference showed that there were 2,400 homologous genes in the common ancestor of photosynthetic taxa. Transcriptome sequencing revealed that 560 genes in the no-sucrose/sugar-containing group were differentially expressed under light exposure, and 209 genes in the no-sucrose group were up-regulated. The expressions of bchLY, pufLM, puhE, and acsF belonging to the photosynthetic gene cluster were up-regulated. In this study, we improved the classification system of Erythrobacteriaceae, established a Raman spectroscopy detection method based on bacterial chlorophyll A, traced the evolution of photosynthetic groups of Erythrobacteriaceae, and laid a foundation for a comprehensive understanding of the carbon storage mechanism of AAPB.



9.6 Response of algal fat and polyunsaturated fatty acid production to high CO_2 concentration

Guang Gao, Associate Professor, Xiamen University

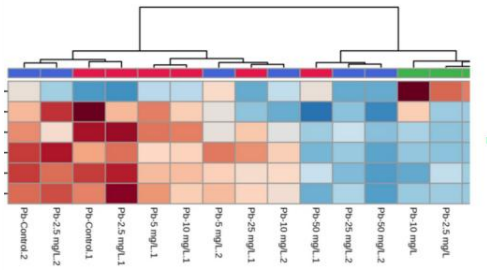
Using high CO_2 in industrial waste gas to culture microalgae can not only effectively fix CO_2, but also harvest microalgae for bioenergy or biological products. Previous studies in this field mainly focused on the use of chlorella and other freshwater algae, and the study of Marine diatoms with high productivity is relatively lacking. Aiming at the current situation of diatoms' intolerance to high concentration CO_2, this study domesticated Phaeodactylum tricornutum for the first time by gradually increasing CO_2 concentration (2%-5%-7.5%). The experiment period was 341 days to explore the physiological response of Phaeodactylum tricornutum to high concentration CO_2. Coupled nitrogen was used to restrict and induce the production of oil and fatty acids at different CO_2 concentrations, to reveal the best carbon and nitrogen induction strategies, and to explore the optimal conditions for the production of oil and fatty acids in high CO_2 (HC) culture. The results showed that at each CO_2 concentration, 2% and 5%CO_2 promoted the growth of Phaeodactina triangulata, while 7.5%CO_2 had no significant effect on the growth. HC promoted the accumulation of lipids and increased the total lipid content and yield, and with the increase in CO_2 concentration, HC had a more significant effect on the increase of total lipid yield. The results of induction experiments coupled with nitrogen restriction under 5% and 7.5%CO_2 respectively showed that the short time of nitrogen restriction induction (6, 12, 24 h) had no significant effect on the growth of Phaeodactanthus trigonis. Nitrogen restriction increased the total lipid content and yield, and the coupling with HC led to a further increase in total lipid content. 5% and 7.5%CO_2 significantly increased the contents and yields of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) in Phaeodactyla trigonata, and the combination with nitrogen restriction led to further increase of EPA and DHA contents. For EPA, the maximum content (24.65±0.58 μg/mg DW) and yield (94.25±6.49 fg/cell/h) were obtained by 5% CO_2-coupled nitrogen restriction for 24 hours and 6 hours, respectively. For DHA, 7.5% CO_2-coupled nitrogen restriction-induced the highest content of 2.41±0.03 μg/mg DW for 6 hours, and 7.5%CO_2 treatment for 6 hours obtained the highest yield of 8.93±0.60 fg/cell/h. The results of this study provide the necessary experimental data and theoretical support for the use of Phaeodactyla trigonata for biological carbon sequestration, and production of oil and polyunsaturated fatty acids.



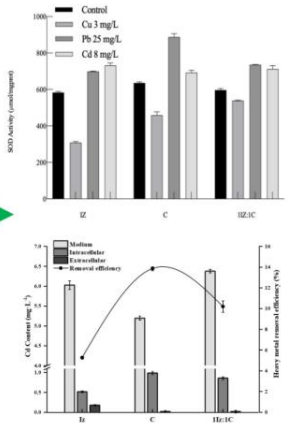
9.7 Characteristics of response of food microalgae to contaminants in cultured water and migration mechanism in shellfish system

Peng-fei Cheng, Professor, Ningbo University

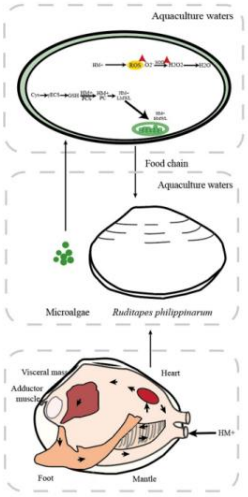
Shellfish is a typical aquaculture product, but because of its extensive feeding behavior and special ecological status, it has become the main object of water pollution such as heavy metals. Microalgae is a common food for shellfish, which not only helps to improve the yield and quality of shellfish, but also can adsorb and enrich heavy metals, reduce carbon emissions of aquaculture water, and play a role in regulating water quality. However, many kinds of microalgae often exist in the natural aquaculture water. This report mainly discusses the characteristics of tolerance, enrichment, and heavy metal conversion of food microalgae in aquaculture water, explores the possible carbon emission reduction paths of food microalgae in the culture process, and evaluates the mechanism of heavy metal migration in the algae-shellfish system, to provide a theoretical basis for improving the ecological environment of aquaculture water and improving the quality of aquaculture shellfish products.



Heavy metal tolerance of microalgae



Interactions between algae and heavy metals

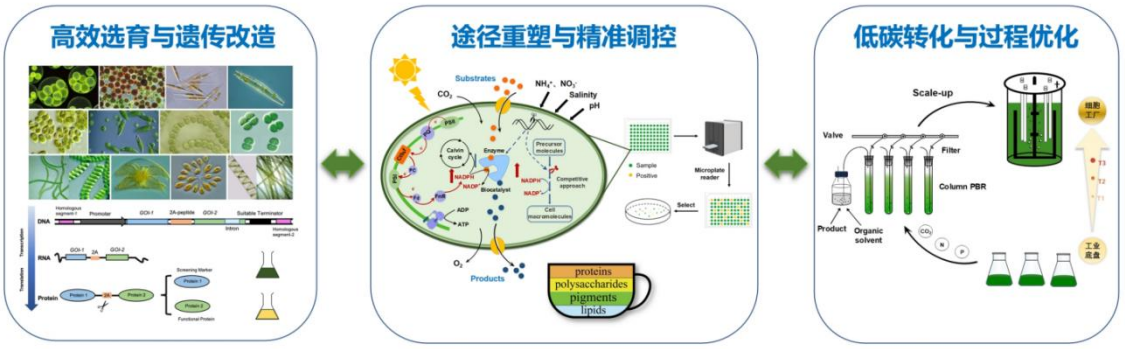


Migration mechanism of heavy metals in algae-shell system

9.8 Potential and challenges of CD-driven carbon-setting microalgae as a future food product

Jian-hua Fan and Peng-fei Cheng, Professor, East China University of Science

Microalgae use solar energy to fix CO_2 and convert it into organic matter, provide more than 50% of the earth's primary productivity and oxygen with less than 1% of the biomass of higher plants, and are the biological group with the highest photosynthetic carbon fixation efficiency. Through the research and breakthrough of microalgae carbon fixation synthesis compound technology, the direct use of microalgae to fix CO_2 is expected to establish a future emerging green bio-manufacturing industry that uses CO_2 as raw material and solar energy as energy to produce high-value products on a large scale, which has important strategic significance for solving the current problems such as food security and protein shortage. As a new food source for the future, microalgae is attracting more and more attention. With the development of microalgae biotechnology, microalgae products, such as algae powder, plant-based proteins, pigments, polysaccharides, polyunsaturated fatty acids, and other high-value compounds, have shown many interesting advantages in functional properties and nutritional value, and are gradually penetrating the traditional food market. However, microalgae as a future food source there are still many problems to be solved, high production costs, low product acceptance, unknown safety, and other challenges are currently restricting the practical application of the bottleneck, the need for the joint efforts of people in all fields to promote the development of microalgae food.



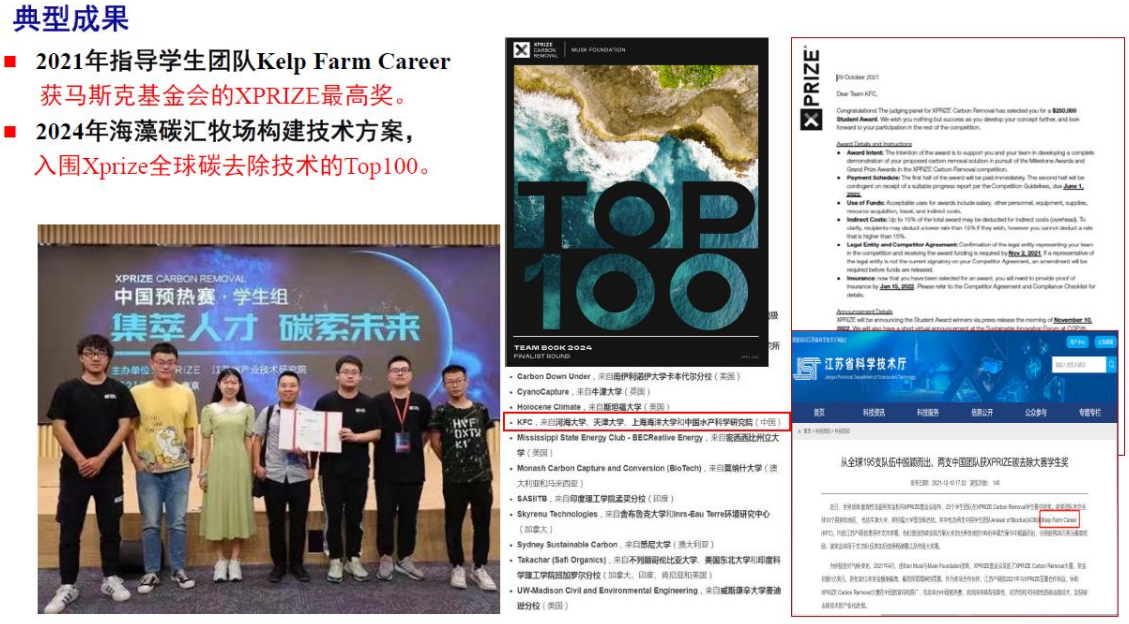
光驱固碳绿色细胞工厂的构建与应用

10 Session 9: Design and Technology Research and Development of Deep Sea CCUS Marine Ranch

10.1 Algal carbon sink pasture construction technology to help achieve the national dual-carbon target

Yu-shun Lian, Professor, River Sea University

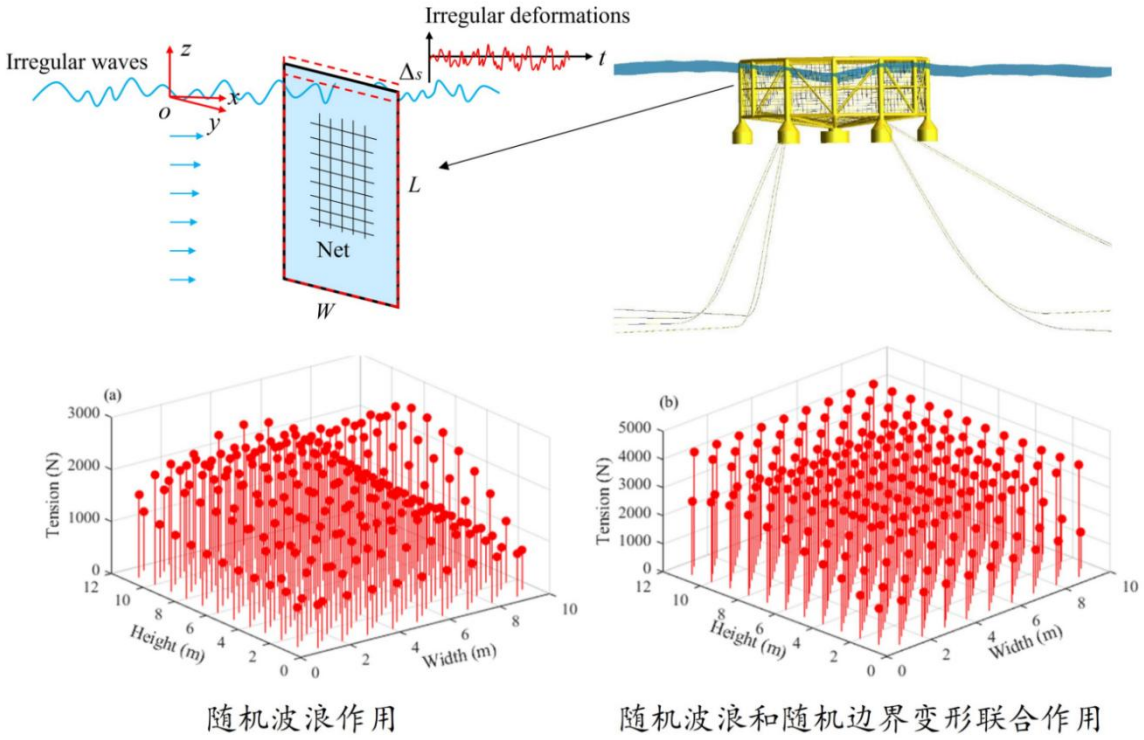
Large-scale seaweed carbon sink pasture will help to achieve the national two-carbon target and tackle the global climate change problem. Therefore, the construction technology of Marine carbon sink pasture is being actively developed at home and abroad, and the seaweed breeding industry shows a development trend from nearshore to offshore, seaweed farms and offshore wind farms. To build a safe and reliable deepwater mooring seaweed carbon sink pasture, it is necessary to explore and grasp the mechanical properties of the cable, the dynamic response of mooring seaweed pasture, and the economic benefit evaluation of carbon sink. In this study, we will explore the feasibility of applying high-strength polyethylene fiber cable to seaweed pasture, propose the design and analysis process of mooring seaweed pasture, construct and verify the numerical model of seaweed, and explore the influence of the submerged depth of Bing rope and the spacing of seaweed cultivation on the dynamic characteristics of seaweed pasture. In addition, based on the sum of the whole life cycle carbon sink of seaweed pasture, the economic benefit of mooring seaweed carbon sink pasture is evaluated. The results of this study can provide an important reference for the construction of large-scale mooring seaweed carbon sink pastures.



10.2 Study on dynamic characteristics of netgarment under the combined action of random wave and random boundary deformation

Wu-de Xie, Lecturer, Shandong University (Weihai)

It is an inevitable trend in the development of the mariculture industry. In the far-reaching sea waves that are bigger, more urgent sea currents, the safety of aquaculture cages has more stringent requirements. In this study, the centralized mass method is used to simulate the 3-D nonlinear motion of large area garment, and the potential flow theory is used to depict the external random wave field, calculate the hydrodynamic load based on the Morison formula and Screen model, and the dynamic response characteristics of the garment under the combined action of random wave and random boundary deformation of random network are analyzed in detail. The study shows that the random elastic deformation of the cage frame structure will make the motion response of the mesh garment more complex, more abundant frequency, more network cable tension, and more likely to damage.



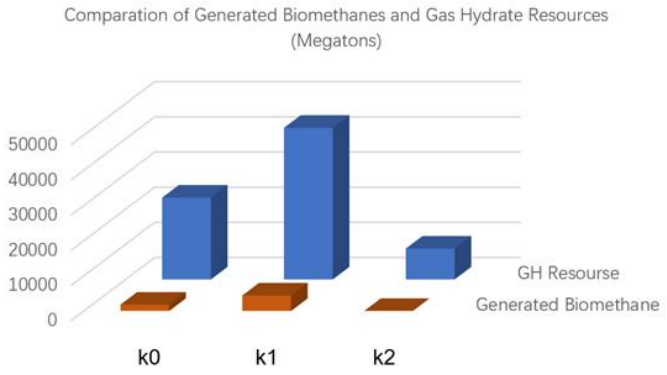
随机波浪作用　　随机波浪和随机边界变形联合作用

11 Session 10: Deep-sea Material Energy Cycle and Carbon Sequestration

11.1 Uncertainty analysis of biological gas generation and natural gas hydrate accumulation in Baiyun Sag, South China Sea

Pi-bo Su, Huai Cheng, and Zuo-wen Zhu, Senior Engineer, Sanya Nanhai Geology Institute, Guangzhou Marine Geological Survey

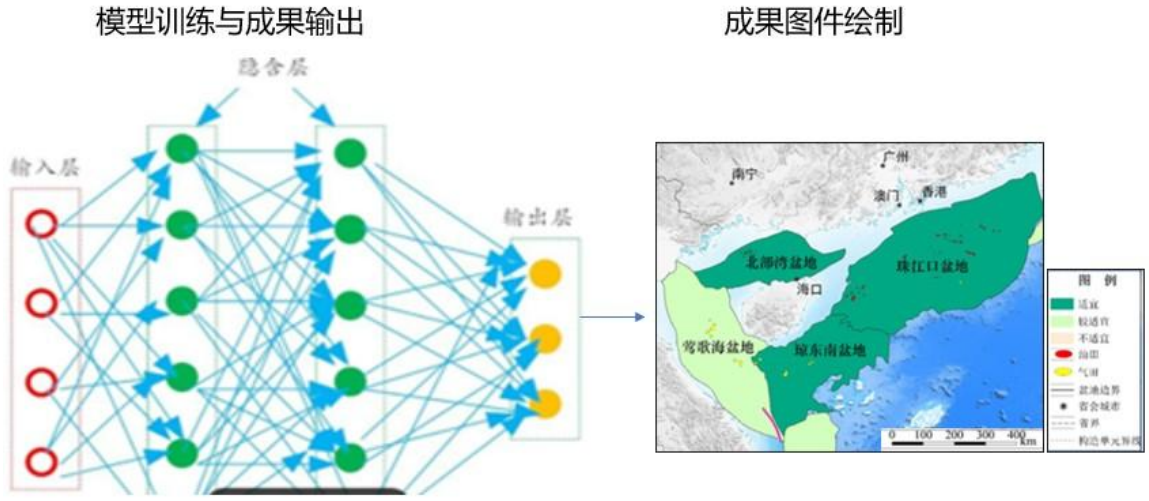
Natural gas hydrate is considered one of the ideal clean energy sources in the 21st century, and it has the advantage of rich resources. A large number of studies have shown that the gas of natural gas hydrate mineral bodies mainly comes from biogenic gas and thermogenic gas produced by organic matter in seabed sediments. However, due to the different origins, the contribution of both to hydrate accumulation is not clear, which directly affects the evaluation of hydrate resource potential and subsequent exploration and prospecting deployment. In this study, PSM was used to quantitatively simulate the uncertainty of biogenic gas generation patterns and their impact on the gas hydrate spatial distribution and resource assessment in the South China Sea. Simulation results show that (1) the generation of biological gas is significantly affected by the thermal state and organic type, in shallow sediment, when there is enough methane gas, low gas is one of the main causes of gas hydration, this may be gas hydrate accumulation layer over the high thermal conductivity of sediment, sediment slow burial speed or other geological processes. (2) Gas hydrate resources are significantly controlled by the amount of biogenic gas production. In addition to the thermal conditions of hydrocarbon source rocks or sediments, the nature of organic matter is another important life control factor. In general, low-temperature methanogens can produce more methane gas because they require less energy. (3) The biogenic gas heating model is the key factor in controlling the aggregation location and resource amount of gas hydrate. The three possible gas modes of K0, K1, and K2 produce different amounts of biogas at different times, and eventually produce different gas hydrate resources. In addition, the preservation of various methanogens in the biological gas source rocks will also change the reservoir position.



11.2 Basin-scale CO_2 sequestration site evaluation based on machine learning

Yu-tong Fu, Senior Engineer, Sanya Nanhai Geology Institute, Guangzhou Marine Geological Survey

Carbon dioxide (CO_2) geological sequestration is an effective climate change mitigation technology, and one of the key steps is to select a suitable storage site. A large number of studies on the siting of CO_2 storage at the basin scale have been carried out by predecessors, and rich data and research results have been accumulated. A machine learning approach was used to evaluate the siting of CO_2 sequestration at the basin scale: First, a comprehensive dataset was built by collecting open source data such as geological, geophysical, geochemical, and production data; Then, data preprocessing techniques, including data cleaning, feature selection and data standardization, are used to improve the accuracy and efficiency of the model. In the model training stage, this study compared a variety of machine learning algorithms, including artificial neural network (ANN) and extreme gradient Lift (XGBoost). Through cross-validation and parameter optimization, the optimal model was selected, and independent test data sets were used to verify the trained model. The verification results showed that the XGBoost model has the best performance in prediction accuracy and generalization ability. Finally, the trained model is applied to the siting evaluation of basin-scale CO_2 sequestration in the southern sea area of China, and the basin suitable for CO_2 sequestration must be selected. The model can accurately identify regions with high sequestration potential, demonstrating the potential of machine learning in CO_2 geological sequestration siting.



11.3 Deep-sea sedimentary differences and organic carbon burial in marginal seas: a case study of the South China Sea

Ming Su, Professor, Zhongshan University

In this study, gravity column core samples from the Shenhu Sea in the north and Zhongjiannan Sea in the west of the South China Sea were taken as the research object. Based on core sediology description, CT scanning, XRF test, total organic carbon content, and organic carbon and nitrogen isotope test, the effects of different geological environments and sedimentary dynamics on organic carbon burial in the marginal sea since the last ice Age were studied. The results show that the sediment organic carbon burial flux of the last glacial period was significantly higher than that of the last glacial period (about 12 ka BP), which is directly related to the higher organic matter deposits of terrigenous and Marine sources in the area during the last glacial period. During the last glacial period, relatively low sea level led to the enhancement of terrigenous sediment input, strong winter winds promoted the increase of Marine primary productivity, and deep seabed currents led to the intensification of the anoxic environment in deep water, all of which effectively improved the efficiency of organic carbon burial. In the west, the organic carbon burial flux in sediments of the last glacial period is higher than that of the last glacial period, which is significantly related to the development of the two sets of turbidity sediments. Although the organic carbon content in turbidites is low due to the relatively coarse particulate matter, event-induced turbidites increase the organic carbon flux due to the relatively short duration of sedimentary evolution. In particular, evidence of deep seabed current deposition was also found in turbidity current sediments. It can be seen that turbidity current-bottom current interaction plays an active role in promoting deep-sea organic carbon burial. Therefore, deep-water sedimentary dynamic processes such as sea level change, regional organic matter source supply, and turbidity current/undercurrent in geological history are the core factors restricting the characteristics of organic carbon burial in the northern and western South China Sea, but their complex coupling correlation and organic carbon burial patterns remain to be further studied.

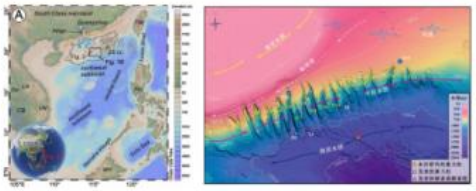
边缘海深海沉积差异与有机碳埋藏：以南海为例

苏明[1]，马文斌[1]，罗坤文[1]，高雅[1]，李亚丽[2]，欧贺杰[1]，翟惟东[2]
1 中山大学海洋科学学院
2 南方海洋科学与工程广东省实验室（珠海）

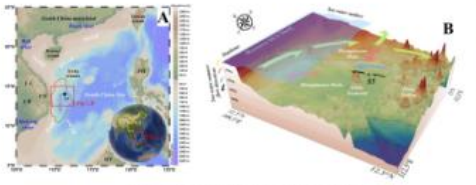
1 研究简介

深海有机碳埋藏是全球碳循环中极其重要的组成环节，其主要发挥碳汇吸收的作用，在一定条件下又可作为碳源释放，并在地质时间尺度上推动大气二氧化碳与氧气含量的改变，进而深刻影响全球气候与地表环境格局。作为西太最大的边缘海之一，南海具有重要的碳储库作用与碳埋藏意义。本研究以南海北部神狐海域和西部中建南海域的重力柱岩芯样品为研究对象，基于岩芯沉积学描述、CT扫描、XRF测试、总有机碳含量和有机质碳氮同位素测试等方法，尝试研究末次冰期以来边缘海不同地质环境和不同沉积动力过程对于有机碳埋藏的影响。

2 研究区域与背景

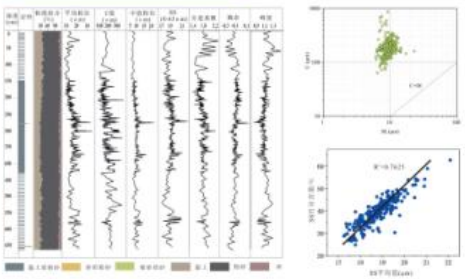


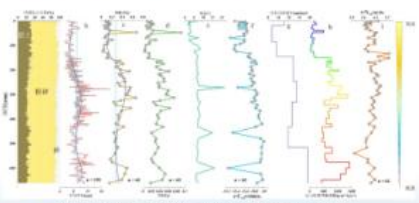
研究区域 1 中国南海北部神狐海域



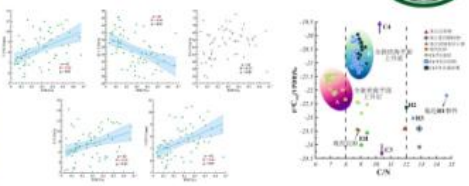
研究区域 2 中国南海西部中建南海域

3 研究材料、方法与结果

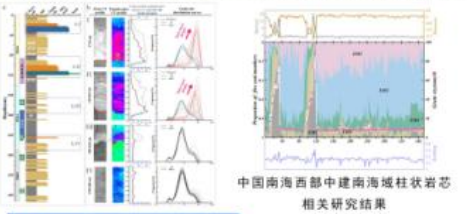




中国南海北部神狐海域柱状岩芯相关研究结果



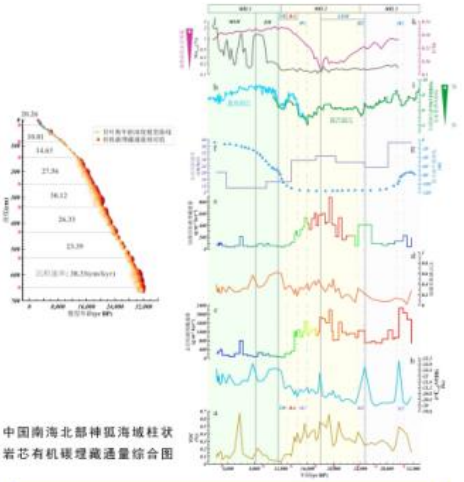
中国南海北部神狐海域柱状岩芯相关研究结果



中国南海西部中建南海域柱状岩芯相关研究结果

4 研究核心认识与结论

研究结果显示，南海北部神狐海域，末次冰期沉积物有机碳埋藏通量要显著高于末次冰后期（约12ka BP至今），这与该区域陆源和海源有机质埋藏量在末次冰期均较高有直接关联。末次冰期，相对较低的海平面导致了陆源沉积物输入增强、冬季风强盛促进了海洋初级生产力增高、深海底流引起了深层水缺氧环境的加剧，均有效提升了有机碳埋藏效率。西部则表现出与之相反的特征，末次冰后期沉积物有机碳埋藏通量高于末次冰期，这与两套浊流沉积的发育有显著关联。尽管受相对较粗颗粒物质的影响，浊积层中有机碳含量较低，但事件性成因的浊流因其沉积演化时间持续相对较短导致有机碳通量增加。尤其是在浊流沉积层中也发现了深海底流沉积的证据，可见浊流-底流交互作用对于深海有机碳埋藏起到积极促进作用。



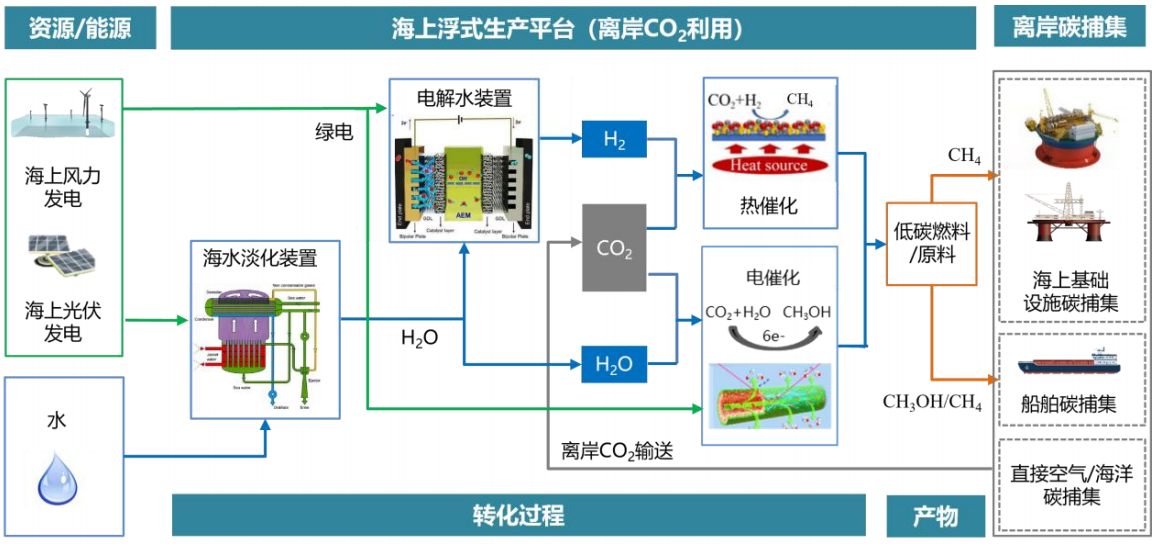
中国南海北部神狐海域柱状岩芯有机碳埋藏通量综合图

核心结论：地质历史时期海平面变化、区域有机质物源供给、浊流/底流等深水沉积动力过程是制约南海北部和西部有机碳埋藏特征的核心因素，但其复杂的耦合关联与有机碳埋藏模式仍待进一步研究。

11.4 Offshore CO_2 Research on capture and transformation and utilization technology

Wei-sheng Yu, Engineer, China Ocean Engineering Equipment and Technology Development Co., LTD

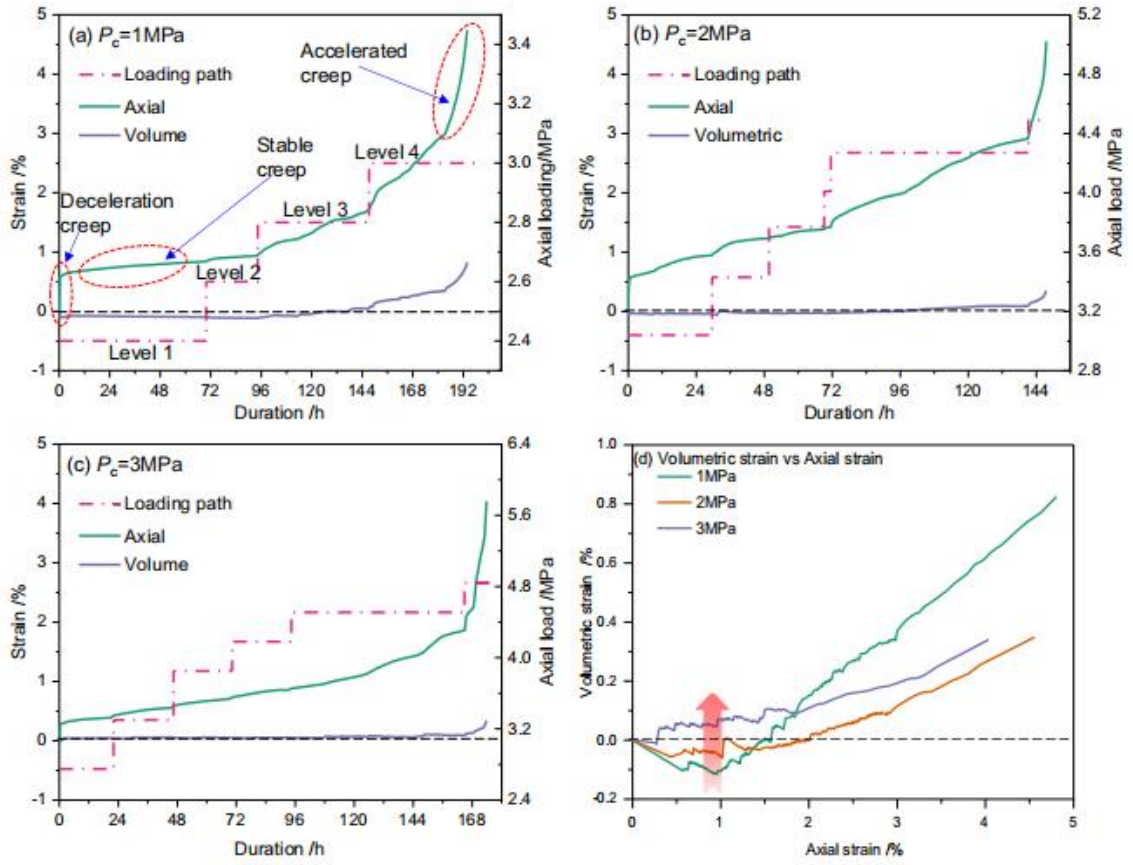
The establishment of carbon neutrality targets in the global maritime and oil and gas industries and the rapid development of the offshore renewable energy industry have led to the need for offshore CO_2 capture and chemical utilization (OCCCU). Based on the analysis of the matching degree between OCCCU technology and ship transportation, offshore oil and gas and offshore renewable energy industry chain, the key development direction of offshore CO_2 capture technology and offshore CO_2 chemical utilization technology is defined, and the development status and innovation path of offshore stationary, mobile, distributed CO_2 capture technology and offshore CO_2 reducing chemical conversion and utilization technology are evaluated. Combined with typical application scenarios, the technical routes of CO_2 hydrogenation to methane and CO_2 electrocatalysis to methanol based on a floating production platform were proposed. Through the cross-field coupling of Marine engineering and chemical engineering, OCCCU technology can effectively promote the low-carbon collaborative development of different industries such as offshore oil and gas and ship transportation, while providing feasible technical paths and commercialization basis for the development and utilization of Marine renewable energy, and injecting a large number of innovative and green elements into the cultivation of new quality productivity in the Marine field.



11.5 Study on the valve effect of gas hydrate on deep-sea methane cycle

Yan-long Li, Researcher, Laoshan Laboratory

In this report, the regulation effect of global methane hydrate distribution on methane concentration in water and atmosphere is briefly discussed, and the regulation mechanism of seasonal dormancy in polar hydrate system cold spring system on methane concentration in water weight is reviewed. A method for analyzing the creep behavior of hydrate formation by acoustic response behavior and its implications are discussed.



11.6 Marine carbon dioxide geological sequestration technology path —— from shallow sea to deep sea

Peng-chun Li and Ning Qiu, Associate Researcher, The South China Sea Institute of Oceanology, CAS

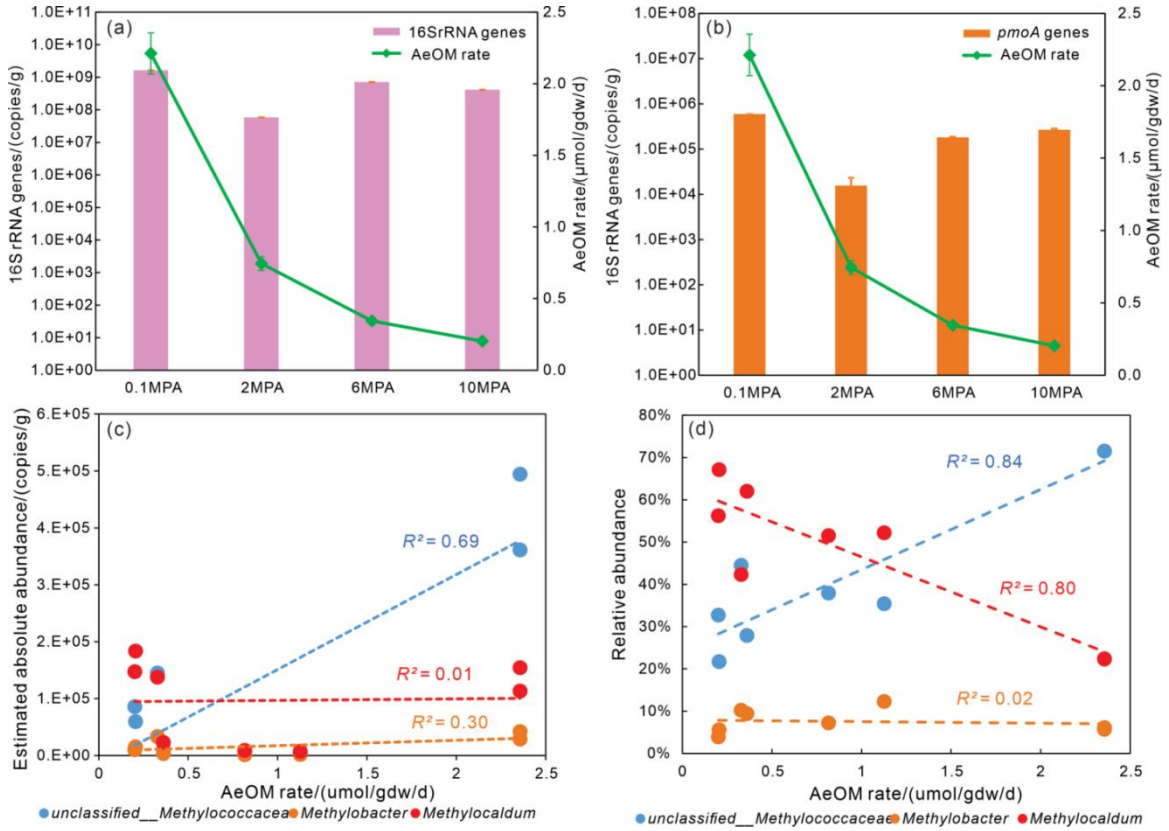
The ocean is the largest active carbon reservoir on earth, with great potential for carbon storage. Coastal economy developed zone, carbon source concentration, emission intensity, strong demand for large-scale Marine geological carbon storage, therefore, offshore geological carbon sequestration is becoming the main path of coastal developed countries and regional carbon sequestration, Marine geological carbon storage technology, industry is accelerating iteration, will become a global CCUS and achieve the goal of "double carbon" important support. The North Sea, the Gulf of Mexico, the Pearl River Estuary, and others are successively exploring offshore CCUS project clusters. At present, China's first offshore carbon sequestration project is - "Enping 15-1" CO_2The storage demonstration project has been put into operation, multiple offshore saltwater layers have been sealed and CO_2The oil recovery improvement project has also been launched, and the development trend of regional Marine geological carbon sequestration cluster in Chinas coastal areas has been highlighted. At present, with the continuous advancement of carbon neutrality goal, Marine geological carbon sequestration technology is also expanding and innovating. It has expanded from offshore shallow sea sequestration to deep sea, including deep sea carbon sequestration, hydrate carbon sequestration, etc. However, Marine geological CO is conducted. The systematic research on storage technology systems and the development path is still lacking. This study by reference and analyzing advanced experience and technology progress at home and abroad, given the Marine geological carbon storage technology system, according to the sealed geological properties, Marine saltwater storage, offshore oil and gas field storage, underwater volcanic mineralization storage, and seabed shallow sediment storage four types of technology, assess its carbon sequestration potential, analysis of medium and long-term development vision goals, preliminary Marine carbon storage technology system and the overall development path.

注：根据自然资源部标准地图服务系统GS(2019)4346号的标准地图制作，底图边界无修改。

11.7 The physiological properties of aerobic methane oxidation bacteria in the deep sea and their potential of driven methane "sink"

Jing Li, Associate researcher, Qingdao Institute of Marine Geology, China Geological Survey

The methane "sink" process driven by aerobic methane-oxidizing bacteria is one of the important links of Marine methane migration and transformation, and plays an important role in the Marine carbon cycle. Taking the shallow surface sediments of the hydrate zone in the South China Sea as an example, a laboratory simulation experiment based on microbial enrichment culture was carried out. It was found that deep-sea aerobic methane-oxidizing bacteria have unique physiological characteristics, revealing the characteristics of methane biological "sink" under the influence of deep-sea high pressure.

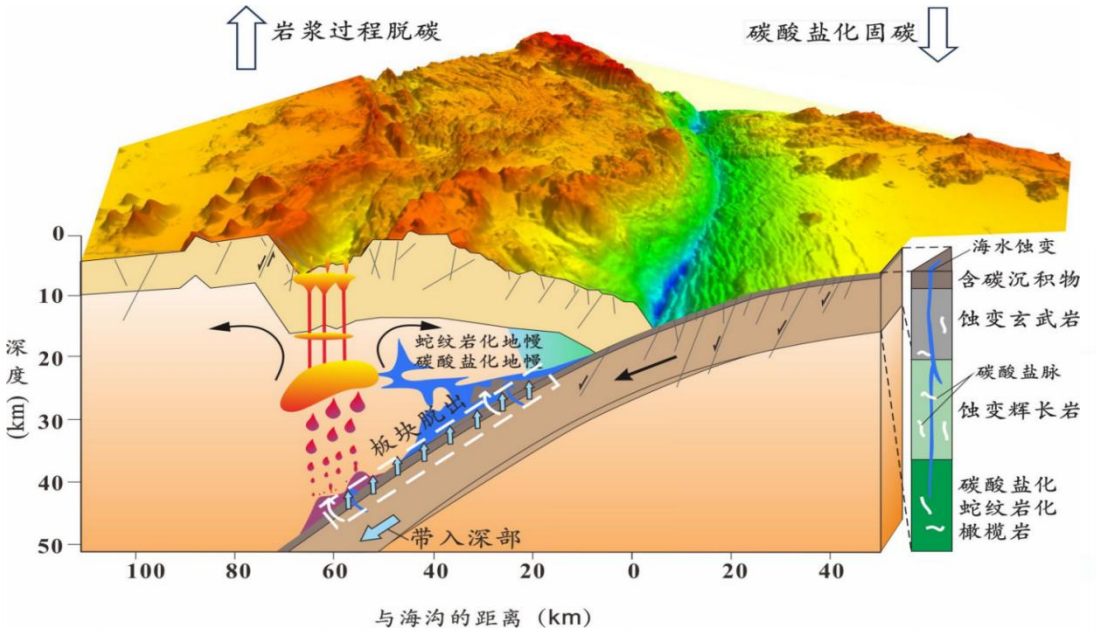


12 Session 11: Polar Multi-layer Carbon Cycle

12.1 Research status and challenges of multi-layer carbon cycle in abyss subduction system

Ming-hui Zhao, Researcher, The South China Sea Institute of Oceanology, CAS

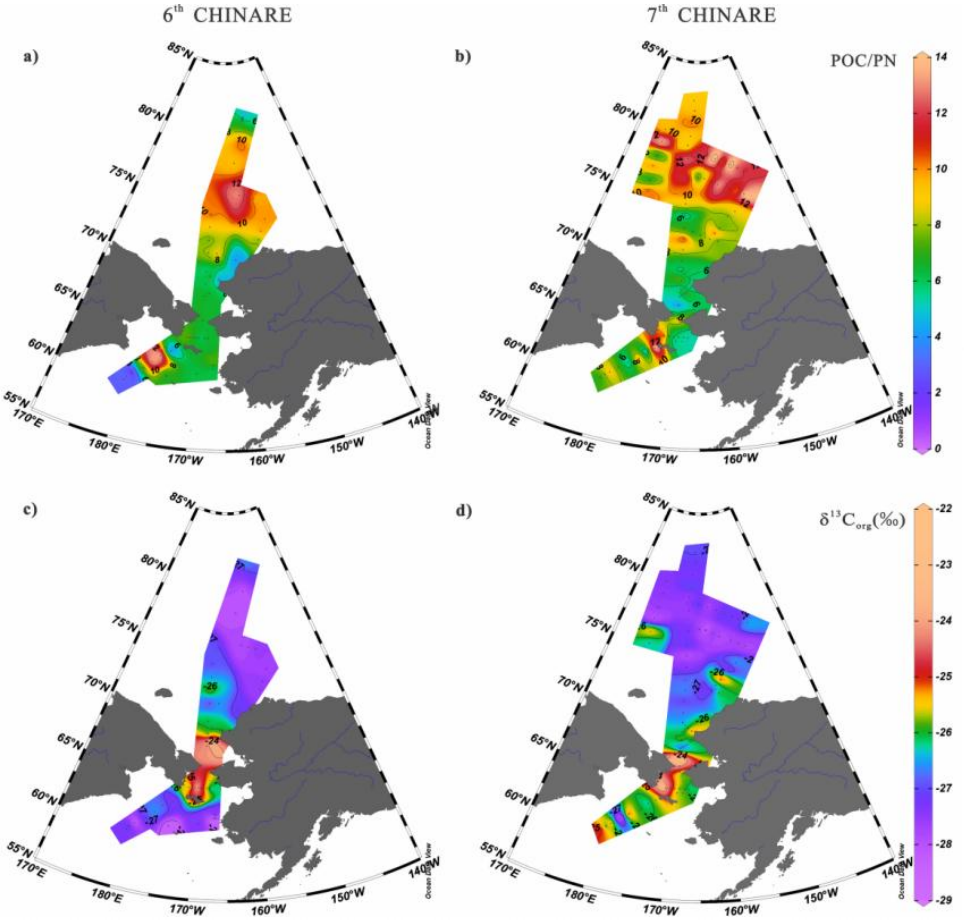
The multi-sphere carbon cycle involves carbon transfer between the atmosphere, waters, and rocks, and plays a crucial role in controlling the livability of the earth’ s climate. In the early 2000s, the scientific community recognized that the interior of the earth (mantle/core) could be a huge carbon reservoir, and that more than 90% of the earth’s carbon could be stored deep in the Earth (Dasgupta & Hirschmann, 2010). Carbon can achieve energy material cycle through a variety of ways and ways, and the subduction process and magma are the main ways of carbon cycle between the surface system and the interior of the earth. The deep carbon cycle process of the subduction zone mainly includes: surface carbon is brought into the deep earth (carbon input flux) in the form of carbonate minerals and organic carbon (Kelemen & Manning, 2015; Plank & Manning, 2019; Liu, et al., 2019), while deep carbon is decamorphic decarbonization, fluid dissolution, water-rich melting and other functions, to promote the carbon out of the subduction plate and contain carbonate melt and CO_2Gas, etc., returns to the surface (carbon output flux) (Kerrick & Connolly, 2001; Poli, 2015; Wei and Zheng, 2020). Carbon recycling efficiency (i.e., the ratio of released carbon flux to input carbon flux) can change CO in the atmosphere$_2$Concentration, controlling the earth's carbon storage flux, affecting long-term and short-term changes in global climate, is critical in the process of shaping the habitable earth (Duncan et al et al., 2017; Zhu et al., 2021; Xu et al., 2024; Shen et al., 2024). However, due to the limitation of deep-sea exploration technology and sampling technology, there are serious cognitive errors in the input/return form, migration mechanism, and input/output flux of carbon during the "Challenger Abyss" subduction process. The "Challenger Abyss" system is a case of the subduction zone, which provides an opportunity and a stage for Chinese scientists to achieve leading advantages and breakthroughs in the field of international earth science. In the future, multi-disciplinary joint research can be carried out in the following aspects: (1) How to accurately restrain the carbon cycle flux? (2) How to trace the carbon cycle path and process? (3) What is the destination and decarbonization mechanism of the calculated and simulated subduction carbon input? Thus, a complete geological model of the carbon cycle process with multidisciplinary data is established, which serves the frontier scientific problem of the livability of the earth in the world.


岩浆过程脱碳
碳酸盐化固碳
0
10
20
30
40
50
深度 (km)
蛇纹岩化地慢
碳酸盐化地慢
板块脱出
带入深部
海水蚀变
含碳沉积物
蚀变玄武岩
碳酸盐脉
蚀变辉长岩
碳酸盐化
蛇纹岩化
橄榄岩
100
80
60
40
20
0
20
40
与海沟的距离（km）

12.2 Sea ice transport and organic matter composition and source of surface water particles in the Arctic Ocean Basin

Xiao-guo Yu, Researcher, The Second Institute of Oceanography, Ministry of Natural Resources

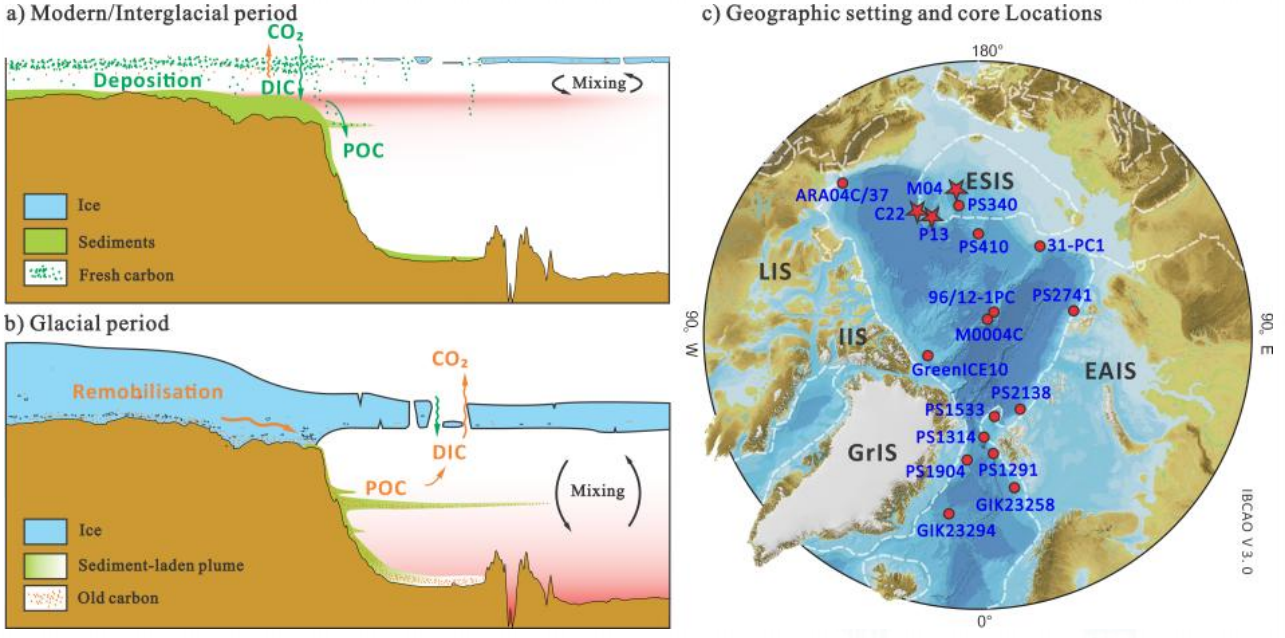
In the context of global warming, the distribution area and thickness of sea ice in the Arctic Ocean have decreased year by year, profoundly affecting the transmission of material and energy in the Arctic Sea, as well as the changes in the ecosystem. The primary productivity of the Arctic Ocean basin is low, and the source of organic matter from its surface seawater particles has been controversial. On the one hand, the particulate matter has a mild carbon isotope composition and high C/N ratio (> 12), mainly the source of land organic matter; meanwhile, away from land and estuary, the source and transport mechanism of land organic matter need to be further explored. On the other hand, field observation found that algae rose under the ice in the basin, and the primary productivity of the ocean increased. As an important part of the Arctic Ocean ecological environment, sea ice can not only serve as a carrier to transport the coastal terrestrial material to the Arctic Ocean Basin area, among which the ice algae is also an important part of the primary productivity of the basin area. Understanding the composition and source of particulate organic matter in the basin area, especially the contribution of sea ice to particulate organic matter, will help us to have a deeper understanding of the sedimentation process and carbon cycle in the Arctic Ocean, and the response of organic matter in the sea ice to changes in the Marine environment. This study is based on the seventh (August 2016, relatively high surface water temperature, low salinity, less sea ice distribution area) and the 9th (20188Month, surface water temperature is relatively normal, salinity is slightly higher, sea ice distribution area is more) China arctic scientific investigation (hereinafter referred to as 7 north and 9 north) during the collection of 15 stance of ice core samples, combined with 5 north (2012), 6 north, 7 north and 9 north (2018) in the particulate matter concentration, particle organic carbon content and its stable isotope analysis, and scanning electron microscopy observation. The results show that the upper and bottom particles of the ice core have different compositions and sources. The upper part of the sea ice (within the depth of 60-80 cm from the ice surface) has a low concentration of particulate matter (generally <-27 ‰ PDB), with the characteristics of land-based organic matter; while the bottom of the sea ice (10-60 cm) has high concentration of particulate matter (up to 12.3mg/L), mainly diatoms, containing some dinoflagellae, with heavy carbon isotopic composition (δ 13C value: -12.2~ -26 ‰ PDB), with the characteristics of Marine self-origin. TOC / TN (wt%) is mostly> 15 in the Arctic Ocean, which is well comparable with the particulate organic matter in the Arctic Ocean Basin. In addition, the length of ice cores in the adjacent areas collected by 7 Bei is generally shorter than 9 north, and the concentration of particulate matter is relatively low, which is speculated that may be related to the early melting of sea ice in the study area in 2016 and the release of particulate matter in the sea ice into the water, reflecting the response of particulate organic matter content in ice cores to changes in the marine environment.


6th CHINARE
7th CHINARE
a)
b)
c)
d)
POC/PN
δ13Corg(‰)

12.3 Burment and release of organic carbon in the Arctic Ocean since late Pleistocene

Li-ming Ye, Associate Researcher, The Second Institute of Oceanography, Ministry of Natural Resources

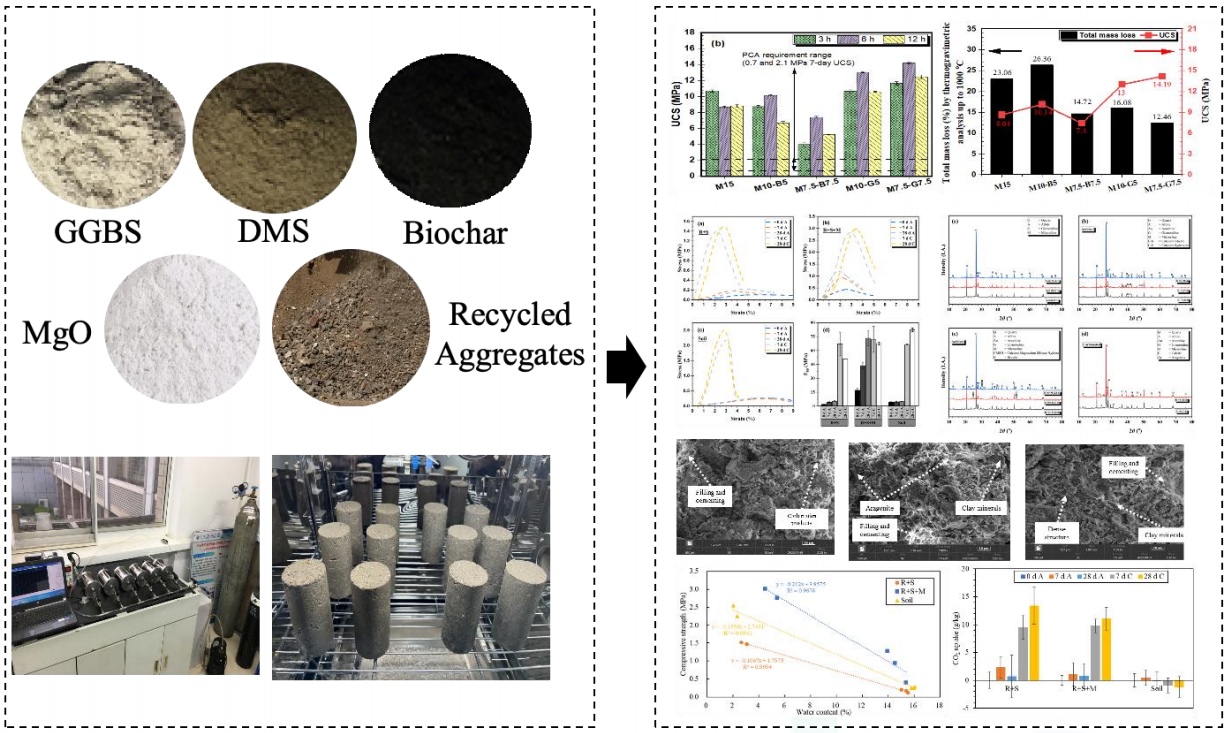
The ability of the Arctic Ocean to absorb atmospheric CO_2 is also controlled by the burial and release of organic carbon. Investigating the temporal and spatial changes of the primary productivity, transport, burial, and degradation degree of organic carbon in the Arctic Ocean since the late Pleistocene helps analyze the source and sink characteristics of the Arctic Ocean during the climate transition period and its driving effect on global change. The results show that the dynamic separation of terrestrial and Marine organic carbon in the upper water is the primary factor regulating its spatial distribution, degradation degree, and climate feedback. The easily suspended terrestrial organic carbon will be strongly degraded in water bodies and topmost sediments and return to the climate system within hundreds of years, while the rapidly settling Marine organic carbon has a greater probability of being buried in sediments and enduring degradation. This part of organic carbon can effectively enhance the carbon sink capacity in the Arctic region on a millennium-time scale. However, organic carbon buried in the Arctic Ocean and the northern Nordic Sea is mainly derived from land and shelf sediments eroded by glaciers, rather than primary productivity. The degradation of remigrated organic carbon can significantly increase the content of dissolved inorganic carbon (DIC) in seawater, which can reach 15-26% of the existing DIC stock. The release of such large amounts of DIC poses a challenge to the ocean's ability to absorb atmospheric CO_2, with the potential to transform the Arctic Ocean and the northern Nordic Sea into a carbon source. Our findings provide new insights into the role of the Arctic Ocean and the northern Nordic Sea in regulating atmospheric CO_2 concentrations, underscoring the urgent need for more precise studies of Arctic carbon release and its wide-ranging climate impacts.



12.4 Marine soil stabilization and CO_2 solidification by dredging: a new approach to carbon emission reduction and resource recycling

Yun-lu Hou, Postdoctoral Researcher, Wuhan Institute of Rock and Soil Mechanics, CAS

With the increasing awareness of environmental protection and the growing demand for resource recovery, dredged marine soil (DMS) as an important resource has attracted wide attention. In the context of achieving the "dual carbon" goal, this study explores the feasibility of achieving carbon reduction and resource recycling in the process of stabilizing DMS, and proposes an innovative approach to improve the stability of DMS and the effect of CO_2 solidification. Reactive magnesium (rMgO) containing supplementary cementing material (SCMs) was used to stabilize DMS under different environmental conditions. The experimental results show that the treated DMS can reach the compressive strength required for building applications (0.7-2.1 MPa). By partially replacing rMgO with biochar and granulated blast furnace slag (GGBS), soil engineering performance and CO_2 absorption capacity were significantly improved. Among them, biochar increased porosity, and improved CO_2 absorption and ductility, while GGBS increased dry density and strength. These improvements reduce the system's carbon footprint and energy consumption while enhancing environmental benefits. Combined with the use of recycled aggregate and MgO, the mechanical stability and CO_2 curing capacity of the DMS are further enhanced, with a carbon sequestration efficiency of 27 g/kg. The study showed that the combined use of MgO and solid waste not only consolidated the stability of DMS, but also promoted the dual benefits of CO_2 storage and waste recovery, providing strong support for carbon emission reduction and resource recycling.



13 Session 12: R&D of OCCUS Standards

13.1 Preferred survey of target area

Ke Cao, Senior Engineer, Qingdao Institute of Marine Geology, China Geological Survey

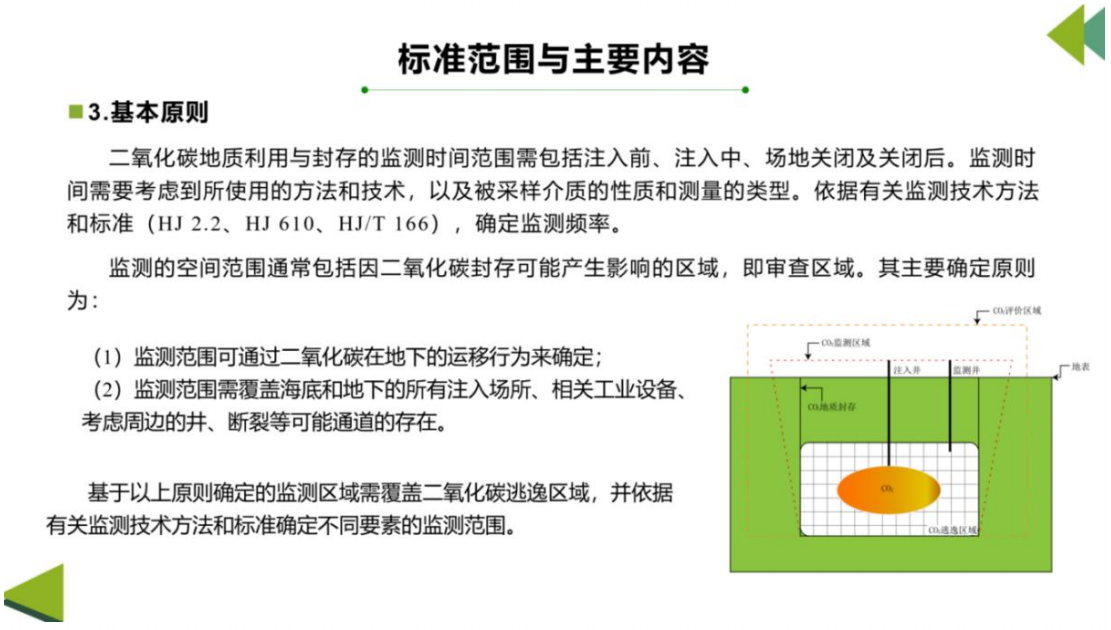
Carbon dioxide geological storage is a basic technology to achieve the peak of carbon peak and carbon neutrality. Geological storage of carbon dioxide in sea areas is characterized by great storage potential, high safety, and small environmental risk, and has been highly concerned by many governments, industries, and academia. In China, there is good crustal stability, wide distribution of sedimentary basins, large stratum thickness, many tectonic stratum traps, and great potential for carbon dioxide geological storage, but systematic constituency work has not been carried out yet. To further develop the carbon dioxide geological storage survey in China, support our country achieve carbon peak carbon neutrality, propose sea carbon dioxide geological storage target area optimization survey specification, optimization of the purpose of the survey, survey content, design preparation, and review, investigation method and technical requirements, potential calculation and target area optimization method, database construction and results report preparation requirements of technical requirements.

分类要素	类型		
	I类	II类	III类
区域碳封存地质条件	区域构造、地层、沉积及地球物理解译结果等表明区域碳封存地质条件有利	区域构造、地层、沉积及地球物理解译结果等表明区域碳封存地质条件较有利	区域构造、地层、沉积及地球物理解译结果等表明具备区域碳封存地质条件
地质构造落实程度	构造和断裂落实程度高，构造稳定、经历的强烈构造运动次数少、断裂不发育	构造和断裂落实程度中等，构造较稳定、破坏性断裂不发育	构造和断裂落实程度低
圈闭落实程度	圈闭落实程度高，可靠程度高	圈闭落实程度中等，可靠程度中等	圈闭落实程度低，可靠程度中低
储层地质条件	储层地质条件好，分布稳定，孔隙度、渗透率高、连通性好、孔隙水水文地质条件好	储层地质条件中等，分布较稳定，孔隙度、渗透率中等、连通性中等、孔隙水水文地质条件较好	储层地质条件不好，分布不稳定，孔隙度、渗透率低、连通性差、孔隙水水文地质条件差
盖层地质条件	盖层地质条件好，厚度大，分布稳定，封盖性好	盖层地质条件一般，厚度中等，分布较稳定，封盖性较好	盖层地质条件差，厚度小，分布不稳定，封盖性差
储盖组合条件	储盖组合条件好，空间配置关系好	储盖组合条件中等，空间配置关系中等	储盖组合条件差，空间配置关系差

13.2 Technical guidelines for the determination of the monitoring scope of the carbon dioxide geological utilization and storage project

Qi Li, Professor, Wuhan Institute of Rock and Soil Mechanics, CAS

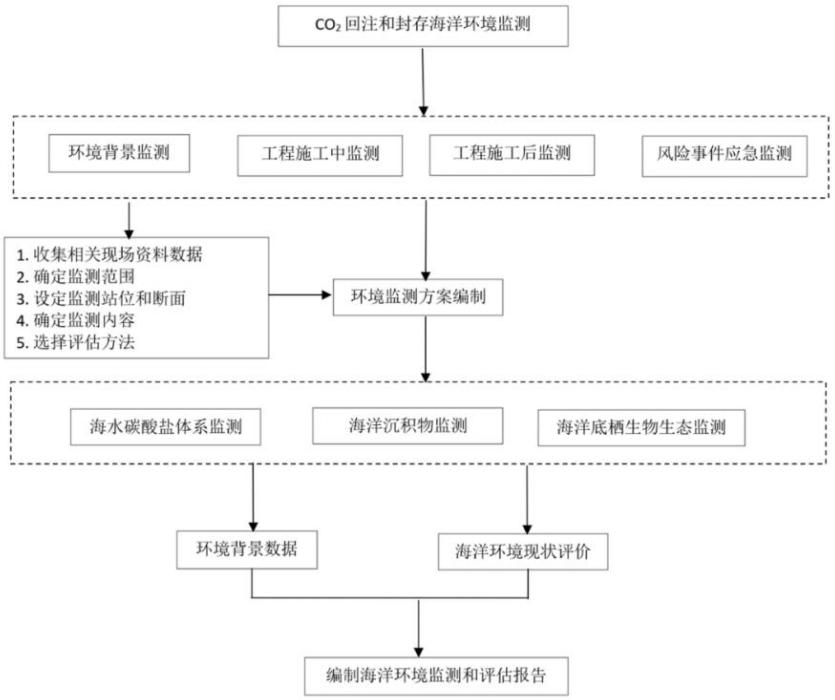
At present, the research on environmental risk management of carbon dioxide geological utilization and storage projects in China stays in the preliminary stage of risk identification, mainly analyzing the possible risks but lacking the determination of the spatial scope of risk management for carbon dioxide geological utilization and storage projects. The monitoring scope of geological utilization and geological storage projects needs to take into account the above and underground space that may be affected by injection activities, due to complex underground conditions and the invisibility of underground space, as well as the lack of actual engineering data support due to the limited number of pilot projects. More work is therefore needed to refine the scope of environmental risk management in support of the Technical Guidance on Environmental Risk Assessment for Carbon Dioxide Capture, Utilization and Storage (Pilot). At the same time, most of the existing standards are for the development of monitoring methods for carbon dioxide geological utilization and storage projects. At present, many carbon dioxide geological utilization and storage projects need to be monitored, and the monitoring scope needs to be defined, but there is a lack of systematic monitoring regional standards. The Technical Guide for Determining the Monitoring Scope of Carbon Dioxide Geological Utilization and Storage will become the first industry standard for the monitoring scope of carbon dioxide geological utilization and storage projects in China. The release of this standard will guide the in-depth study of the monitoring scope of domestic carbon dioxide geological utilization and storage, provide a risk assessment basis for the development of future carbon dioxide geological utilization and storage projects in China, effectively solve the current carbon dioxide geological utilization and storage projects in the practice process of the lack of relevant technical specifications and other urgent problems, reduce the concerns of stakeholders. To ensure the smooth development of CO_2 geological utilization and storage projects.



13.3 Preparation ideas and discussion of Guidelines for Ecological Environment Monitoring and Evaluation of Offshore Carbon Dioxide Reinjection Project

Hong Tang, Engineer, The South China Sea Ecological Center of the Ministry of Natural Resources

The geological storage of offshore carbon dioxide has great potential, which can provide important support for the realization of carbon peak and carbon neutrality. However, the development of the offshore carbon dioxide storage project is bound to affect the complex Marine ecological environment. To ensure that the project will not cause irreversible damage to the Marine ecosystem, it is very important to carry out comprehensive ecological environment monitoring and evaluation. Although international Marine carbon sequestration projects have been carried out for many years, there are relatively few materials available for reference for the related Marine ecosystem monitoring and evaluation work, and no systematic norms or standards have been formed. Therefore, we through reference to domestic laws and regulations and standards, combined with the sea-gas carbon dioxide exchange flux monitoring results, summarize the domestic first offshore carbon dioxide injection project typical gas carbon dioxide background monitoring experience, based on the actual ecological environment monitoring, from the monitoring scheme design, field investigation, data processing analysis, ecological environment evaluation and report preparation of technical indicators, wrote the offshore carbon dioxide injection engineering ecological environment monitoring and evaluation guidelines, and will gradually improve the guide in the subsequent work. The guidelines can provide scientific, standardized, and operational guidance for the ecological environment monitoring of offshore carbon dioxide geological storage, and ensure that the project contributes to the realization of the carbon peak carbon neutral goal.



13.4 Build a platform to let China's Marine technical standards quickly go to the world

Le-tian Ma and Xu-wen Feng, Associate researcher, The Second Institute of Oceanography, Ministry of Natural Resources

Marine technology is not only the application of Marine theoretical research results, but also the condition and means of deepening research, and is bound to become an important frontier of global scientific and technological competition. The process of Marine technology development needs to realize cross-industry and cross-technical disciplines. In recent years, its development has shown two hot spots: on the one hand, the intelligent upgrade of traditional Marine equipment, and on the other hand, the rapid application of emerging technologies. In the process, consensus-based standards provide the necessary support for the practice of new ideas and technologies. International standards of Marine technology are an important way to expand technological advantages in the international market, and all maritime powers attach great importance to them and actively integrate them into the global development of Marine technology with the help of international standardization platforms. The international standard of Marine technology includes three parts: basic commonality, key technology, and industrial application. Conform to hot spot demand, the Subcommittee on Marine Technology approved by our country, by the International Organization for Standardization (International Organization for Standardization, ISO) technology management authority (ISO/TC8/SC13, SC13 was formally established in 2014, with both the President and the secretariat based in China. Relying on this development opportunity, the sub-committee focuses on realizing the synergistic interaction of standards in the fields of ocean observation, ocean development, and Marine environmental protection, and at the same time gives full play to the guiding, standardizing, leading, and guaranteeing role of standards in promoting the orderly development of the Marine equipment manufacturing industry. Combined with the national development strategy of "Marine power", China is committed to building SC13 into a platform that not only promotes international cooperation in professional fields, but also helps the growth of China's Marine technology and equipment industry. From the perspective of international cooperation, SC13 will, based on the existing 20 member states and 6 working groups, attract Marine technical experts from more countries to participate in the revision of international standards, and actively build a bridge between international organizations such as the International Seabed Authority and the industry. From the perspective of promoting the formulation of international standards, under the premise that 16 international standards have been published and 6 standard proposals have been approved, SC13 will continue to expand the types of standards in the fields of appropriate technological maturity such as submersibles, deep-sea resources development, Marine environmental protection, Marine observation instruments and equipment, Marine survey, seawater desalination, and coastal blue carbon. Make its application field more systematic, and the use of groups more extensive. In the future, China will improve the strategic planning in the field of Marine technology standardization, actively and orderly participate in the governance of international standards organizations, promote the interconnection of domestic and international standards, and promote China's advanced Marine technology with independent intellectual property rights to "go out" through standardization.

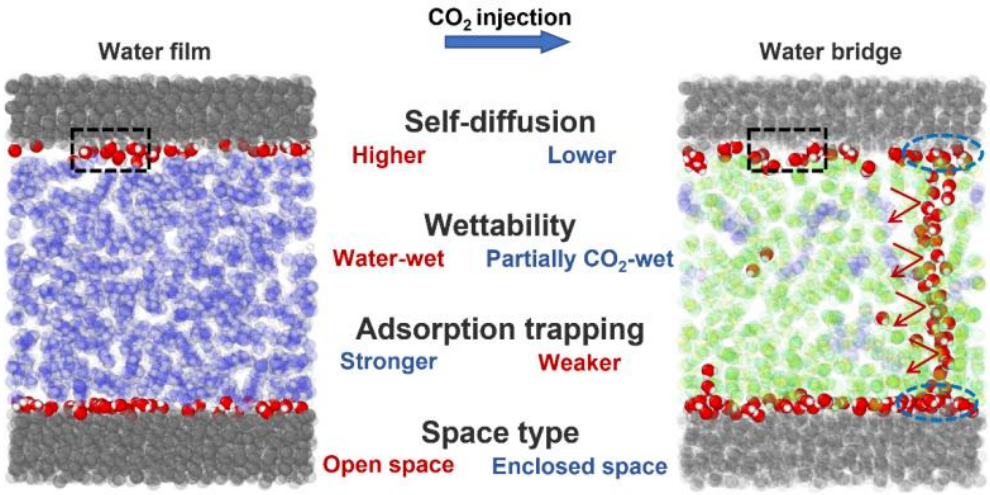

ISO/TC 8/SC 13国际标准化组织 / 船舶与海洋技术委员会 / 海洋技术分委会
国家需求
• 准确把握“以标准引领高质量发展”主攻方向
标准促进
可持续发展
共建更加
美好的世界
SHARED VISION FOR
A BETTER WORLD
国际平台
• ISO唯一全面从事海洋领域国际标准制定的分委会
• 聚焦海洋观测、开发、保护领域的标准
ISO/TC 8/SC 13
Marine technology
标准引领
• 16项标准已出版
• 其中11项由我国主导
• 其中2项由海洋二所牵头完成

14 Student Oral Presentation

14.1 Molecular scale insights into nanoconfined water-CO_2 interactions in geological carbon sequestration

Jian-jie Niu, PhD Student, Peking University

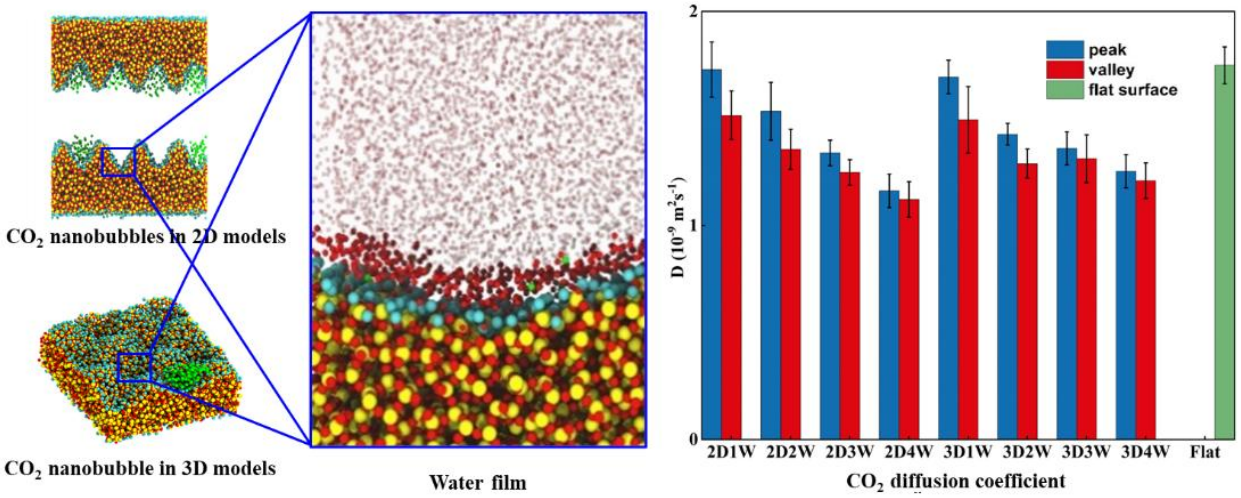
Water molecules in nano-pores usually exist in the form of "water film" and "water bridge", and their aggregation form is mainly affected by water molecule concentration, pore size, pore type, and other factors, and is crucial for oil and gas recovery and CO_2 storage. However, a large amount of CO_2 fluid will be introduced in the process of geological carbon sequestration, but its influence on the formation of nanoconfined water has not been deeply studied and understood. Based on this, a series of typical water film (10 vol%) and water bridge (30 vol%) scenarios were designed in this study, in which water-CO_2-n-octane fluid was filled in different scenarios, and CO_2 molecular concentration was adjusted to study the nanoconfined water-CO_2 interaction in the nanopores and its influence on oil and gas recovery and CO_2 geological storage. The results show that the competitive adsorption of nano-limited water and CO_2 will lead to the reduction of adsorbed water molecules, and promote the formation of new water Bridges in both the water film (75.50 mol.% CO_2) and water bridge (5.85 mol.% CO_2) scenarios. In addition, the nanoconfined water-CO_2 interaction also leads to the transformation of the substrate surface from water wetting to partial CO_2 wetting, the reduction of the self-diffusion coefficients of CO_2 and hydrocarbon fluids, and the formation of illite-water-CO_2 "sandwich" adsorption layer, which will affect the oil and gas recovery and CO_2 storage from different aspects of fluid occurrence and mass transfer. Overall, the study reveals the mechanism by which CO_2 influences the distribution and accumulation of nanoconfined water, which also provides molecular-scale insights into nanoconfined water-CO_2 interactions during geologic CO_2 storage and utilization.



14.2 Study on the effect of nano-scale surface roughness of silica micropores on the molecular behavior of CO_2

Hong-ye Xu, Graduate student, China University of Geosciences (Wuhan)

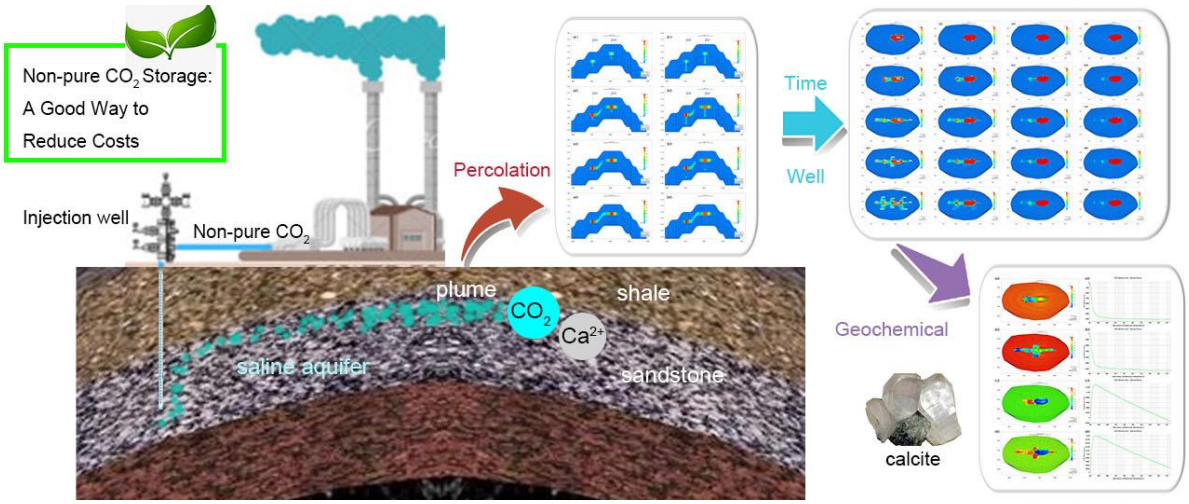
Carbon capture, utilization and storage (CCUS) is an effective way to achieve carbon neutrality. In carbon sequestration, the nanoscale roughness of the reservoir sediment surface will affect the molecular behavior of CO_2, thus affecting the effectiveness and safety of sequestration. In this study, we construct a series of geological models with different surface roughness. The results show that the diffusion coefficient of CO_2 in the sunken Nani Valley region (including 2D grooves and 3D depressions) is lower than that in the prominent nano moaks region (including 2D and 3D configurations), resulting in a higher CO_2 molar concentration in the nano valley region. We also observed that on the sediment surface, CO_2 molecules tended to line up parallel to the surface; When they move to a position more than 0.4 nm from the surface, they appear to deviate from the parallel state, where a water film is sandwiched between them. In addition, with the increase of surface roughness, more and smaller CO_2 nanobubbles appear, most of which are located in 2D grooves or 3D sinks. The findings of this study deepen our understanding of the effect of nanoscale roughness on the CO_2 adsorption process, and thus can extend more cognition on the effectiveness of carbon geological sequestration and CO_2 mineralization.



14.3 Simulation and leakage risk assessment of impure carbon dioxide brackish water reservoirs

Xing-zhi Liu, Master's student, China University of Geosciences (Beijing)

CO_2 geological storage is an important means to reduce greenhouse gas concentration and promote a carbon neutrality strategy. Due to the high cost of CO_2 capture, direct injection of industrial flue gas is a possible way to reduce costs. The migration and evolution of CO_2 plumes in brackish water and the complex underground gas-water-rock mineralization are the key problems in CO_2 sequestration. The different components and concentrations of the sequestration gas and the design of the gas injection pattern will affect these problems and may bring some safety problems. In this study, the permeability and chemical coupling numerical simulation method was used to study the comparative simulation of pure CO_2 and non-pure CO_2 geological storage in a brine layer in Poland, and the morphological evolution and geochemical reaction characteristics of the plume fluid were analyzed. Different gas injection well patterns are designed to discuss the gas injection scheme and the effect of gas injection volume. The study also analyzed the factors influencing the mineralization curve, used a variety of methods to evaluate the storage safety of pure and impure CO_2, and calculated the leakage rate. The results show that gas will flow and accumulate to the trap center after injection into the formation, and the migration speed is related to the formation dip. Gas injection well pattern has little influence on plume migration trend and final morphology. The impure CO_2 plume occupies a larger area and migrates at a faster rate. The curves of mineralization rate and mineralization amount change with injection composition, gas injection, well location, and other external conditions, and the curve shape is controlled by gas migration, pH, and other factors. The difference in reaction characteristics between pure CO_2 and non-pure CO_2 injection is very large, which is mainly related to the composition and concentration. In the case of diffusion, CO_2 will diffuse upward and downward, and upward through the cap layer is its main leakage route. When the injected gas is non-pure CO_2, the leakage rate is much higher than that of pure CO_2. The study revealed the migration trend of CO_2 plume fluid under the combined action of permeation-chemical field, analyzed the controlling factors of gas-water-rock mineralization reaction, evaluated the safety of impure CO_2 storage, and discussed the influence of gas injection scheme and gas injection volume. The research results can provide some valuable references for practical CO_2 geological storage engineering, especially for non-pure CO_2 storage.



14.4 Research on the mechanism and path of Zhanjiang to promote the construction of the CCUS cluster in West Guangdong from the perspective of a coordinated innovation network

Kai-long Feng, PhD Student, Marine Resources Research Center, Tongji University

In the context of the global response to climate change, carbon capture, utilization and storage (CCUS) technology is seen as one of the key solutions. As the core city of West Guangdong, Zhanjiang is committed to promoting the construction of the CCUS cluster in West Guangdong. From the perspective of a coordinated innovation network, this study studies the mechanism and path of Zhanjiang in promoting the construction of a CCUS cluster in western Guangdong. By analyzing the cooperation mode of various stakeholders in the region, the integration of innovative resources, and policy support, this study explores the key factors and implementation paths that promote the development of CCUS clusters. The results show that establishing an efficient innovation network, strengthening regional cooperation, and optimizing policy support are the keys to achieving the goal of CCUS cluster construction in western Guangdong. This study provides a useful reference for other regions to promote the application of CCUS technology and cluster development.

14.5 Establishment of controlled source electromagnetic forward modeling in the process of CO_2 geological storage monitoring on the seabed

Wen-ke Tang, PhD student, China University of Geosciences (Wuhan)

CCUS (Carbon Capture, Utilization and Storage) has attracted worldwide attention as one of the key technologies for achieving net zero emissions and transitioning to a net zero future. As an important part of CCUS technology, CO_2 monitoring runs through the whole life cycle. To ensure efficient and safe storage of CO_2 in the seabed, it is necessary to explore, assess, and monitor the potential migration space of CO_2 before, during, and after storage, and predict the risk of leakage and the distribution of migration. The geophysical method can obtain the relevant data of the submarine reservoir and cap layer, which helps grasp the migration information of CO_2 fluid in the formation and the updating information of storage potential. The relevant technologies supporting each monitoring method have their advantages and disadvantages, and the challenges brought by the limitations of technology application, technology integration and cost reduction and efficiency improvement, risk assessment, and program optimization should be comprehensively considered. Large and small cracks in the seabed rock formation can be used as migration channels for CO_2 fluid, or even storage space, while electromagnetic signals are relatively sensitive to CO_2 fluid passing through the cracks. According to the difference in resistivity, different fluids and changes in their quantities can be distinguished, CO_2 storage locations and reservoir resistivity can be obtained, CO_2 saturation can be estimated, and CO_2 migration and storage changes can be monitored. Although electromagnetic resolution is low, it is also low cost to use, so a combination of seismic and electromagnetic methods is often used to assess seafloor formation structure, rheology, lithology, and CO_2 transport. When CO_2 is continuously injected into the reservoir, it will cause changes in resistivity, dielectric constant, porosity, etc. With the increase of injection time, the formed CO_2 flow will migrate upward from the deep, and the temperature and pressure conditions of reservoirs at different depths will be inconsistent, and their phase states will also change. In this report, geological, geophysical, and petrophysical data related to CO_2 storage are used to establish formation models with different resistivity, and the Marine controlled source electromagnetic method (MCSEM) is carried out to analyze the response rules of different depths, layers, reservoir shapes, and resistivity. FIG. 2 shows a simple CO_2 reservoir model with a high resistance plate. The initial model is iteratively optimized through forward response analysis and inversion until the fitting difference meets the requirements, as shown in FIG. 4. However, the CO_2 fluid resistivity will change with the change of depth, temperature pressure conditions, etc. In the future, it is necessary to study multiple reservoir models with different depths, layers, shapes, and time, and provide theoretical reference for the evaluation of CO_2-sealed storage layers according to the response analysis of different reservoir combination models.

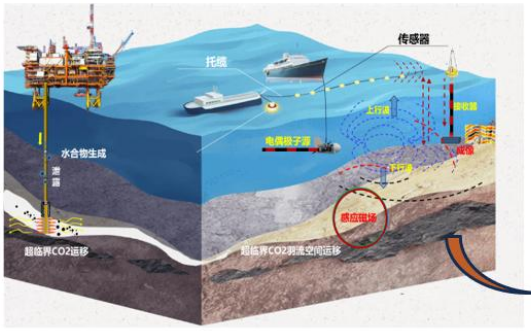


图 1· 海底碳封存电磁法监测示意图↵

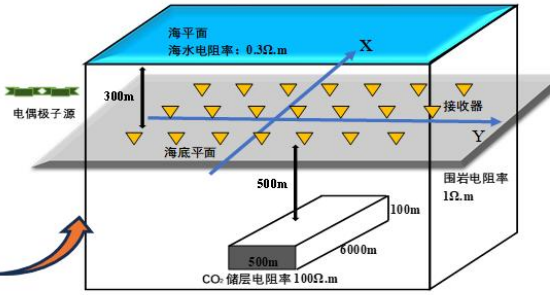


图 2· 高阻板状体 CO_2 储层模型图↵

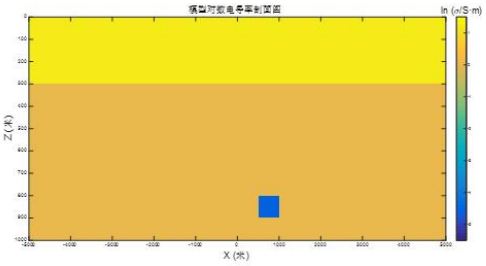


图 3·y=0m 测线电导率剖面示意图↵

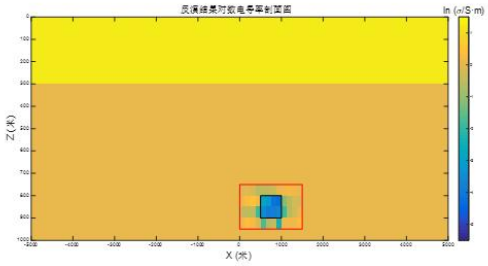
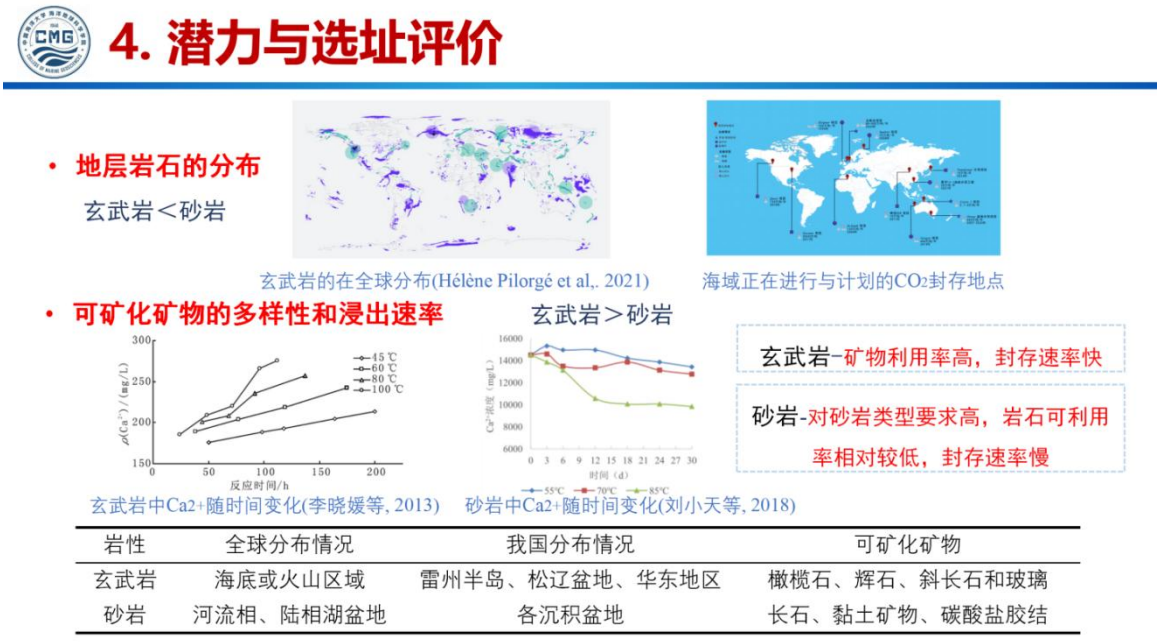


图 4·y=0m 剖面反演结果↵

14.6 CO_2 mineralization storage potential and site selection

Xin-rui Ma, Master's student, Ocean University of China

As a carbon sequestration method to convert CO_2 into solid carbonate rock, carbon dioxide mineralization storage is the safest and most stable storage method to realize permanent carbon solidification, and has attracted attention since it was proposed. Domestic and foreign scholars have proposed that rocks with mineralization and storage potential are mainly volcanic rocks, and the chemical reaction of olivine, pyroxene, and other minerals in volcanic rocks with CO_2 can quickly form stable carbonate minerals. Meanwhile, volcanic rocks have high porosity and permeability conditions, which are conducive to the migration and reaction of carbon dioxide. However, the distribution of igneous rocks in sedimentary basins in China is less extensive than that of clastic rocks, so it is necessary to understand the mineralization and storage potential of this widely distributed clastic rock reservoir. A clastic rock reservoir is an important structurally sealed storage layer in offshore sedimentary basins in China. The sedimentary rock contains feldspar, clay, and other minerals, which can also undergo CO_2-water-rock reaction under stratigraphic conditions, and have important mineralization and storage potential. Taking sandstone in sedimentary rock as an example, this study systematically summarized the domestic and foreign progress, key influencing factors, main minerals, carbon sequestration potential, and efficiency of mineralized storage in this lithology. Combined with the development of clastic rock reservoirs in offshore sedimentary basins in China, the clastic rock mineralization sequestration potential was proposed. To provide reference for the fine evaluation of carbon sequestration potential of sedimentary basins in Marine areas and the construction of demonstration projects.

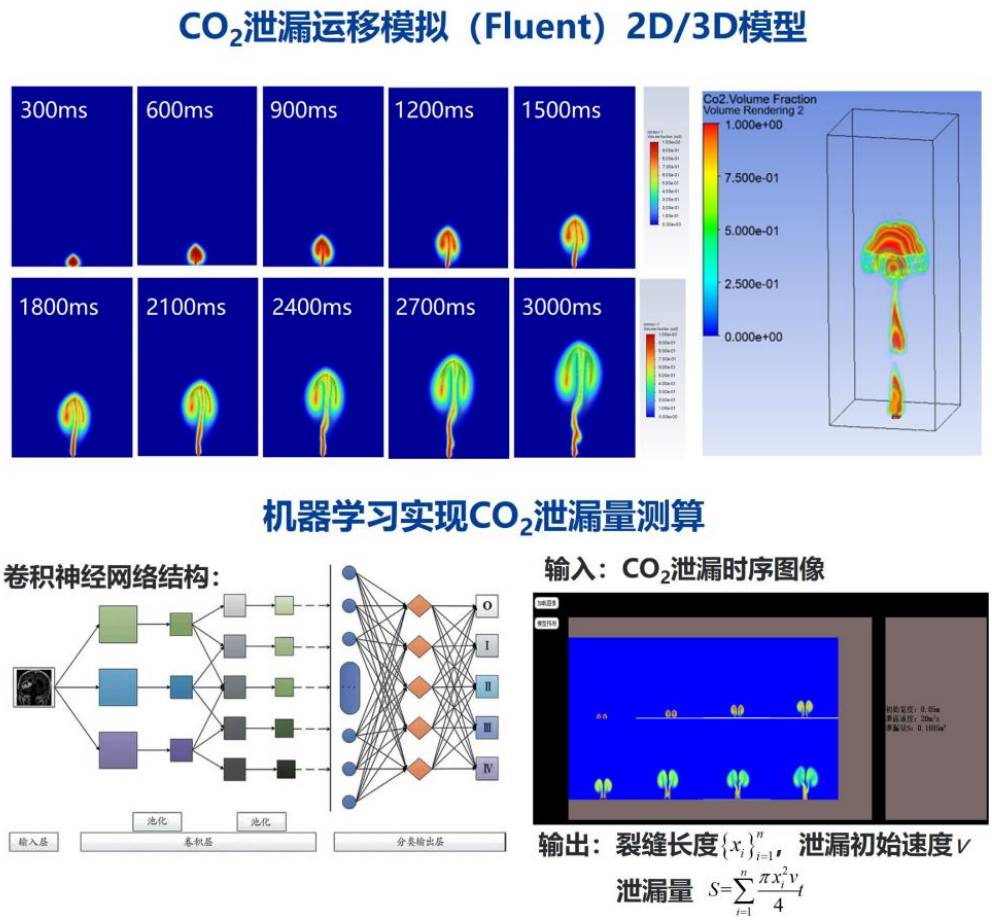


岩性	全球分布情况	我国分布情况	可矿化矿物
玄武岩	海底或火山区域	雷州半岛、松辽盆地、华东地区	橄榄石、辉石、斜长石和玻璃
砂岩	河流相、陆相湖盆地	各沉积盆地	长石、黏土矿物、碳酸盐胶结

14.7 Rapid leak assessment of CO_2 subsea sequestration based on machine learning

Feng-pu Gao, Master's student, Shanghai Institute for Advanced Study, CAS

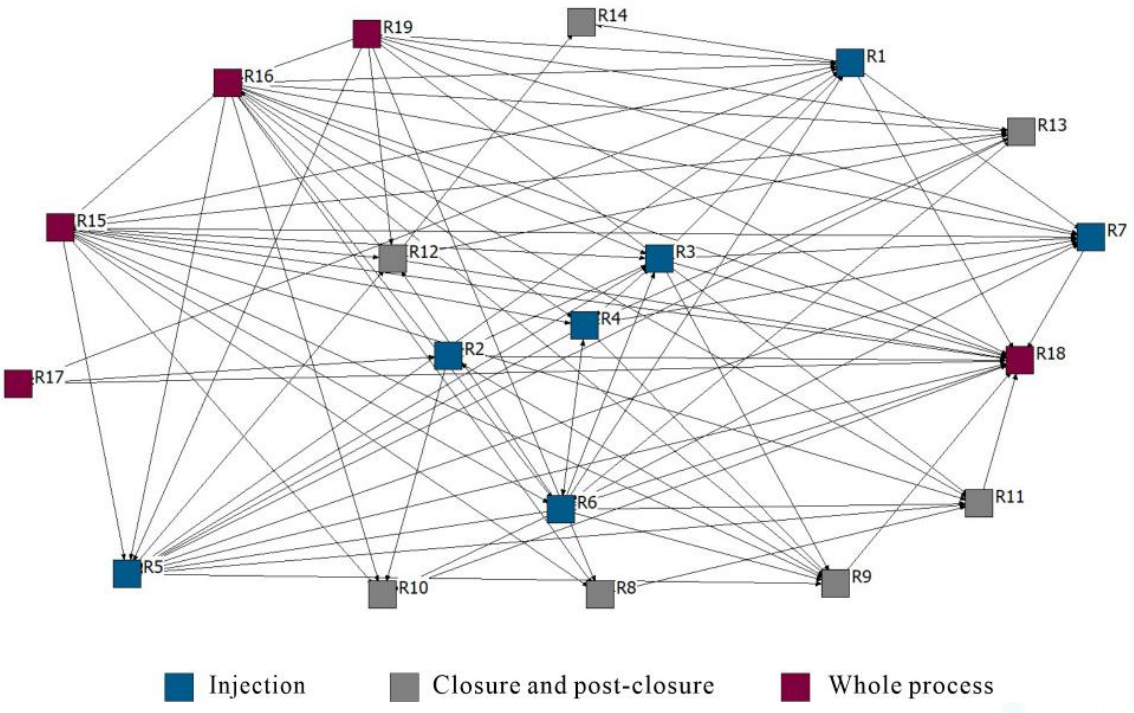
In the face of the dilemma of high carbon emissions in coastal areas and limited storage sites on land, CO_2 offshore storage is undoubtedly an effective solution. Although the probability of rapid leakage of CO_2 in seabed geological storage is very low, it is very important to understand the law of CO_2 diffusion and transport in seawater for the assessment of rapid CO_2 leakage. Based on the typical Marine environmental data of the Bohai Sea and the South China Sea, the fluid dynamics simulation analysis was carried out. The characteristics of CO_2 bubble groups were simulated by the VOF model, and the transport and diffusion characteristics of CO_2 in seawater were analyzed by the Euler-Euler model. A convolutional neural network-based CO_2 leakage assessment algorithm was developed, and a physical information neural network model was built to solve the inverse fluid migration problem. According to the bubble shape and distribution range of CO_2 leakage in different Marine environments obtained by numerical simulation, the crack width and leakage velocity of seafloor leakage are obtained, and the leakage quantity is calculated. Rapid leakage assessment of CO_2 seabed geological storage will improve the offshore geological storage monitoring system and promote the application of storage engineering.



14.8 Quantitative assessment and transmission mechanism of carbon dioxide geological storage technology risk: a study based on social network analysis

Meng Jing, PhD student, Wuhan Institute of Rock and Soil Mechanics, CAS

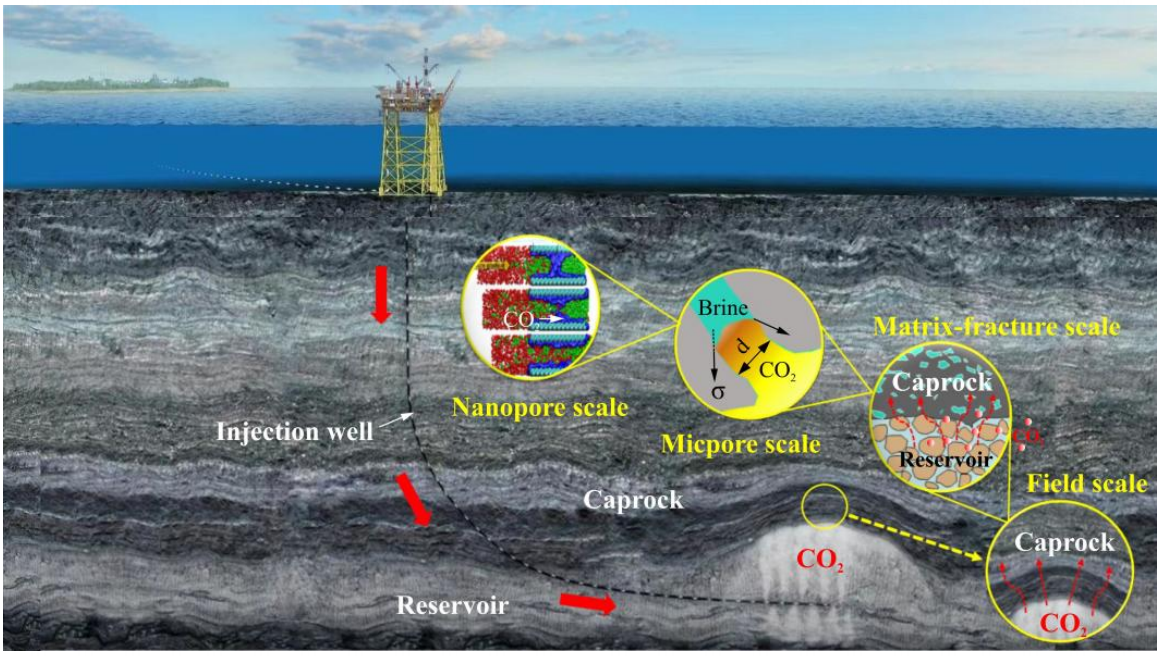
Long-term reservoir sealing is a key prerequisite for successful climate change mitigation of carbon dioxide geological storage (CCS). However, the complexity of the geological system implementing CCS is subject to a variety of technical risks, and accurate identification and analysis of these risks and their interrelationships are critical to optimizing the injection process, ensuring safe storage, and building public confidence. This study comprehensively summarizes the risk identification methods of CO_2 geological storage and successfully identifies 19 related technical risks by selecting the risk inventory method. The relationship between risks is illustrated by constructing a structural matrix, and the risks are quantified by the social network analysis method. The results show that key initial risks include volcanic damage, undiscovered geological structures (such as faults), and seismic damage, while key failure risks include lower than expected carbon storage and poor CO_2 injection, as well as mechanical damage around injection Wells, CO_2 well corrosion and regional overpressure as core transmission risks. Given these risks, feasible mitigation measures are put forward. On this basis, three transfer chains are constructed to reveal the complex relationship of risks in the whole life cycle. The findings help to effectively manage CCS risks and guide the development of long-term injection and monitoring plans, thereby facilitating the widespread adoption of safe and scalable CCS technologies.



14.9 Sealable leakage risk and evaluation method of seafloor carbon sequestration cap

Bo-wen Chen, PhD student, Wuhan Institute of Rock and Soil Mechanics, CAS

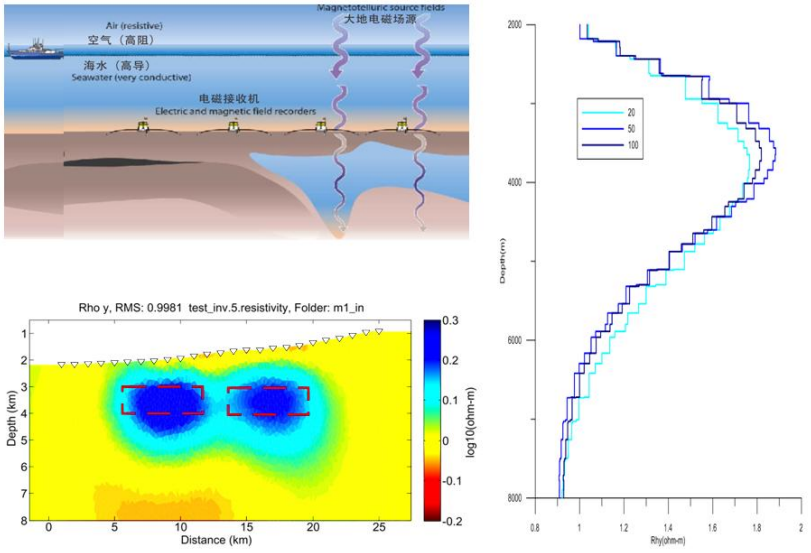
Subsea CO_2 geological sequestration is an important part of China's "dual carbon" goal, but CO_2 injection into subsea reservoirs may induce cap leakage risk and seriously threaten the Marine ecological environment. Therefore, the evaluation of subsea cap tightness is an important part of the implementation of the Marine carbon sequestration strategy. In this study, the cap characteristics of typical subsea CO_2 geological storage demonstration projects are briefly introduced, the sealing mechanism, leakage mechanism, and evaluation method of submarine cap are clarified, and the breakthrough pressure test method and the safety limit value of submarine cap tightness are analyzed. The results show that the seafloor cover has capillary sealing, pressure sealing, hydrocarbon concentration sealing, and hydrate sealing mechanisms. Capillary sealing and hydrate sealing only block the CO_2-free phase, concentration sealing only blocks the CO_2 diffusion phase, and pressure sealing can block the CO_2-free phase and water-soluble phase. The breakthrough pressure is the most intuitive evaluation index to evaluate the sealability of seafloor cover. When the breakthrough pressure is less than 1 MPa, diffusion leakage occurs in the cover layer. When the breakthrough pressure is 1-20 MPa, the cap layer permeates and leaks. When the breakthrough pressure is greater than 20 MPa, crack leakage occurs in the cap layer.



14.10 Image guided Marine controllable source electromagnetic method for modeling monitoring and analysis of CO_2 sealed storage layer in the seabed

Qi Cai, Master's student, South China Sea Institute of Oceanology, CAS

Global climate change is indeed a pressing issue, with increasing greenhouse gas emissions leading to rising global temperatures, more extreme weather events, and serious consequences such as rising sea levels. Subsea CO_2 sequestration technology is a solution that removes carbon dioxide from the atmosphere and stores it deep underground. This technique usually involves injecting CO_2 into geological layers underground, such as depleted oil and gas fields, deep saltwater layers, etc. When CO_2 is injected into an underground reservoir, if CO_2 begins to leak upward, the resistivity of the rock will change significantly according to the Arzi formula. Marine controllable source electromagnetic method can well distinguish the high resistance of underground media due to its high resolution, sensitivity to high resistance bodies, and not shielded by carbonate high resistance layer, etc. Therefore, the study of Marine controllable source electromagnetic method is of great significance for CO_2 monitoring. In this paper, an image-guided Marine controllable source electromagnetic method is proposed to monitor the geological modeling of the seabed CO_2 storage layer. First, we add a series of seismic data and logging data to establish different geoelectric models, set up a series of gas saturation gradient models, use the image-guided inversion method to calculate normalized anomalies on Marine controllable source electromagnetic data, and then analyze the impact of different saturation CO_2 on inversion results. Finally, we evaluated and analyzed the modeling results to verify the effectiveness and accuracy of the method. The experimental results show that this method can monitor the leakage of the CO_2 storage layer well. Future research can further explore how to optimize the parameter setting of the modeling method to improve the modeling effect. In addition, other geological data and methods can be combined to further improve the accuracy and reliability of geological modeling of CO_2 sequestration.



14.11 Feasibility study on time-delay gravity monitoring of carbon dioxide plume migration

Bin Liu, Master's student, South China Sea Institute of Oceanology, CAS

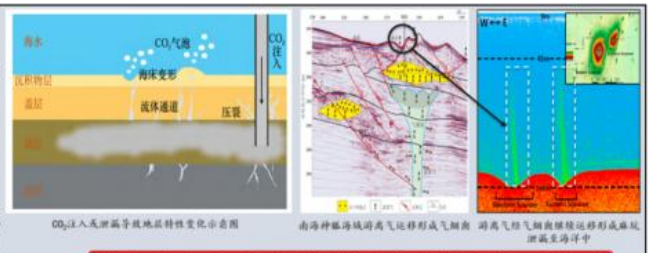
Carbon dioxide capture, utilization and storage (CCUS) technology is an important part of China's achievement goal of "double carbon", but the leakage of CO_2 may lead to geological risks such as fault activation and earthquake, and may also destroy the ecological environment and affect the ecological balance. At the same time, considering that it takes a lot of time to monitor the storage area after CO_2 injection, it is of great practical significance to implement CCUS technology to monitor the storage area with long time series and low-cost monitoring technology. CO_2 injection will affect the change of formation p-wave velocity and resistivity. Seismic and electromagnetic exploration methods are widely used and effective in monitoring CO_2 sequestration plume migration. However, long-term monitoring by seismic and electromagnetic exploration methods involves high construction difficulty and high cost. Gravity exploration uses gravimeters to measure small gravitational changes on the Earth's surface, and when CO_2 is injected into an underground reservoir, if CO_2 begins to leak upward, it changes the density distribution of the area, resulting in a change in the gravity field. The gravity exploration method has the characteristics of non-invasive, wide coverage, time delay monitoring, and low cost, which can meet the requirements of CO_2 storage monitoring. However, at present, there are few feasibility studies on the monitoring of CO_2 sequestration leakage by gravity exploration method, and relevant simulation studies are needed to support the evaluation of the feasibility of gravity exploration method. In this study, geological density modeling and forward and inverse gravity research were conducted by combining petrophysical methods, stratigraphic data from the Sleipner working area in Norway, and previous chimney leakage CO_2 saturation simulation results to evaluate the feasibility of surface time delay gravity for monitoring vertical migration of CO_2 fluid leakage along the chimney and revealing underground CO_2 fluid migration. The results show that CO_2 storage monitoring by time-delay component gravity anomaly is feasible to reveal the vertical migration of underground CO_2 plumes, and the obtained results are characterized by high resolution and high accuracy. It shows that the gravity prospecting method is of great value and feasibility to be used as a long-time series real-time monitoring technology in carbon dioxide storage area and incorporated into the baseline survey of the storage area.

研究背景

□ CO_2的烟囱泄漏可能会导致断层活化、地震等地质风险，也有可能破坏生态环境，影响生态平衡。

□ 采用长时序及低成本的监测技术对封存工区进行时延监测对CCUS技术的实施具有重要的现实意义。

□ CO_2的泄漏会改变区域的密度分布，从而导致重力场变化。重力勘探方法具有非侵入性、覆盖范围广、可进行时延监测与低成本等特点，满足CO_2封存监测需求。



类似于甲烷泄漏，CO_2泄漏可能在薄弱处突破盖层，在海底沉积层形成气烟囱泄漏

图1. CO_2烟囱泄漏示意图

研究方法

时延重力监测二氧化碳羽流运移可行性研究主要步骤如图2所示：

（1）收集典型CO_2封存工区的地质资料以构建真实可靠的地层模型与孔隙度模型，共同构成骨架模型。

（2）结合前人烟囱泄露CO_2饱和度模拟成果，构建时延的CO_2烟囱泄漏模型及饱和度模型作为基质模型。

（3）通过岩石物理公式将所构建的CO_2饱和度模型转换为密度模型用于后续的重力正反演研究。

（4）通过对所构建的密度模型进行重力正反演研究以评价地表时延重力对于揭示地下CO_2流体运移情况的可行性。

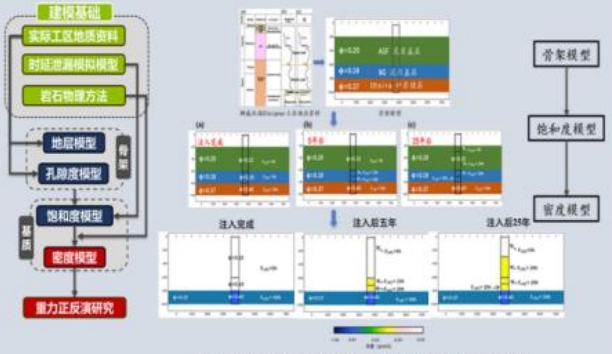


图2. 技术路线及正演模型建立流程

正演结果

通过上述建模过程，最终完成地表重力监测二氧化碳封存模拟研究的正演模型的建立。设置整个地下模型空间的尺寸为1100mx7000m，将地下场源空间分为23x17=391个50mx500m大小的矩形网格，其中地表设置了15个重力观测点，每个观测点间距固定为500m。

□通过重力异常曲线可以很好地识别烟囱直径情况，但不能有效揭示CO_2泄漏所达深度。

□时延重力异常幅值差异显著，通过时延迟重力异常监测CO_2烟囱泄漏具有可行性。

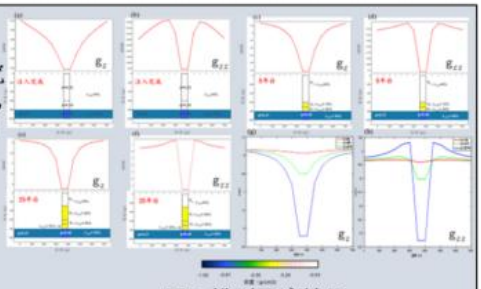


图3. 模型正演结果

反演结果

□ g_{zz}分量重力异常主要突出浅部异常，而CO_2流体的垂向运移通常发生在深部，因此从图4-g、4-h、4-i g_{zz}分量重力异常反演结果来看，所得的反演结果准确性与分辨率都不高，且存在着聚焦不充分的问题。

□ g_z分量重力异常所得的反演结果准确性与分辨率更高，与正演模型的吻合度较高。

综上所述，根据上述聚焦反演结果可知，采用时延g_z分量重力异常监测CO_2羽流运移，对于揭示地下CO_2羽流运移情况具有较大可行性，所得结果具有高分辨率与高准确性的特点。

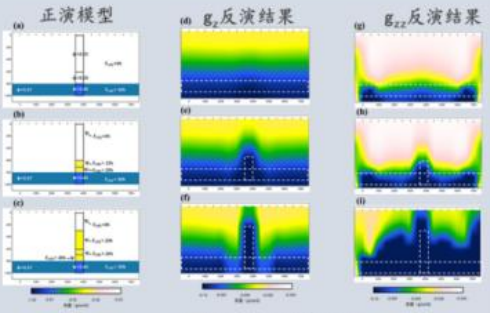
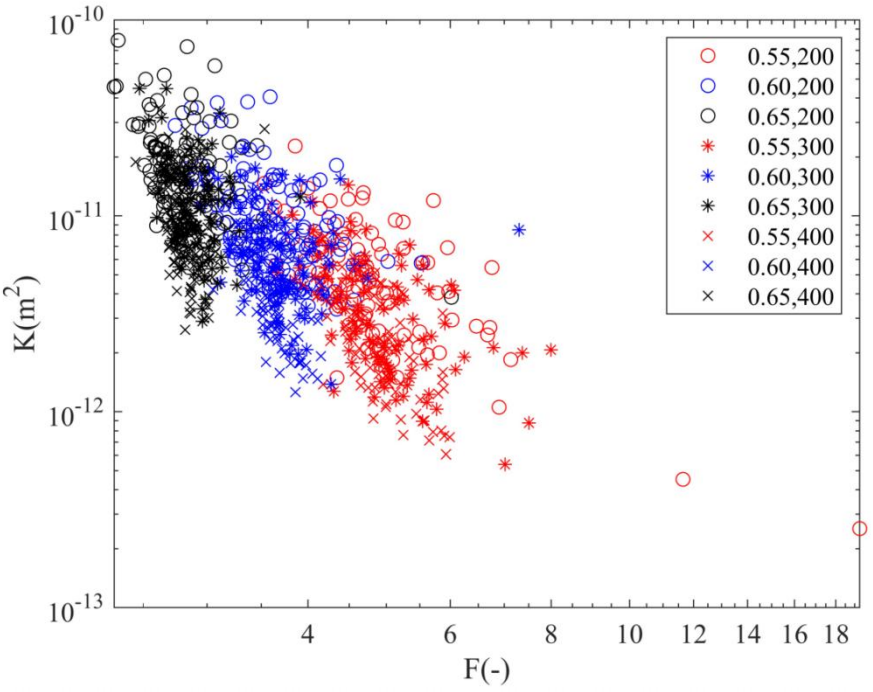


图4. 模型反演结果

14.12 Study on the influence of pore heterogeneity on rock transport properties

Yun-mao Jiang, Undergraduate student, Chengdu University of Technology

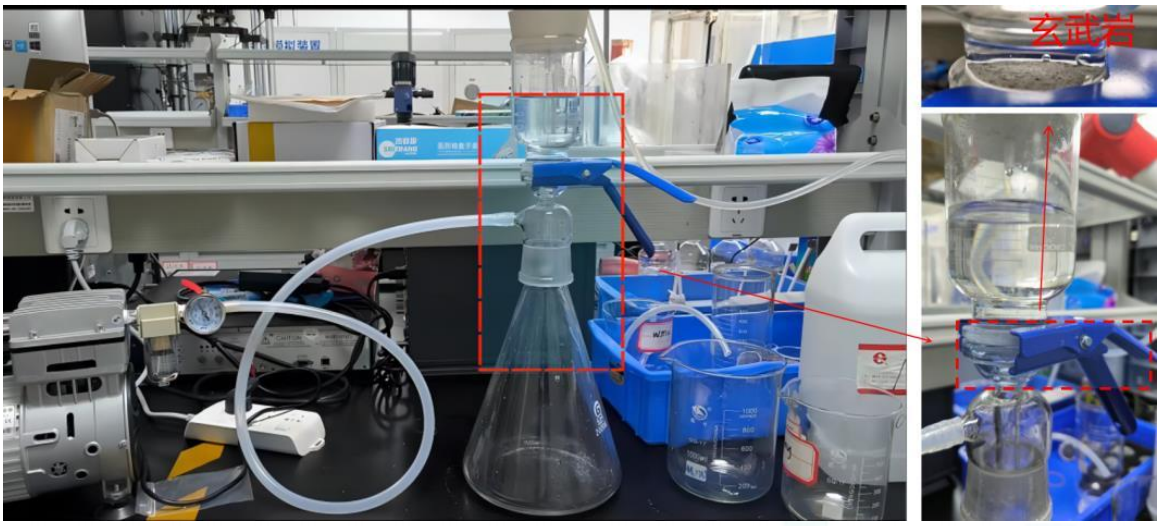
Rock permeability is an important evaluation index for underground reservoirs of carbon dioxide. Subsurface fluid space reservoirs can be divided into fracture type and pore type in a broad sense, and the relationship between the permeability of fractured rock and the fracture geometry has been studied extensively. However, the study of pore type is lacking. Porous rocks with different geometric structures are artificially generated by a linear Boolean model, and permeability and conductivity are calculated by the lattice Boltzmann method and finite element method. By analyzing the quantitative relationship between permeability (K) and formation factor (F) of porous rocks with different scales and the same geometric structure. We find that the influence of rock size on the K-F curve is weak, and the influence of rock porosity heterogeneity on the K-F curve is significant. Finally, a mathematical model of the K-F curve and pore heterogeneity is obtained through data fitting. This model can obtain permeability values from rock structure and conductivity data.



14.13 Study on basalt dissolution and ion synergistic deposition effect under enhanced percolation of CO_2-containing seawater

Xi-xi Wang, Master's student, Xiamen University

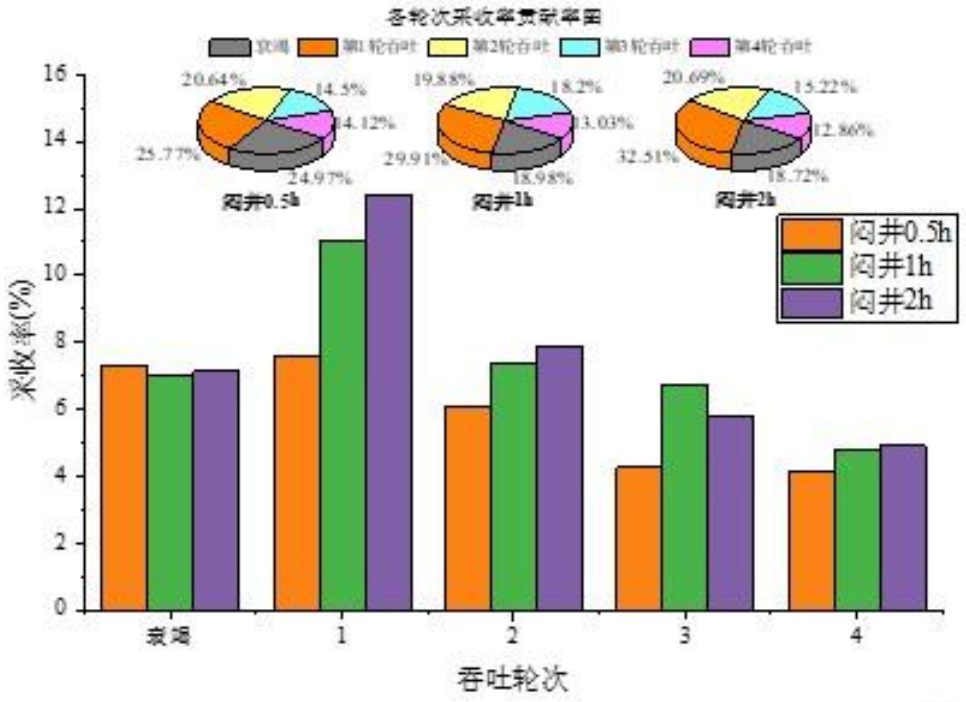
Industrial emissions such as carbon dioxide are the main cause of global warming. Carbon capture, utilization and Storage (CCUS) is considered an effective means to achieve carbon peak and carbon neutrality by injecting CO_2 into geological reservoirs, such as porous brackish water deep in sedimentary basins and depleted oil and gas fields for long-term storage. However, the large-scale application of this technology faces problems such as CO_2 leakage, limited reservoirs that can be trapped, and the high cost of risk assessment and monitoring. Basalt mineralization technology is a new technology to injects CO_2 into the formation of basalt and achieves permanent carbon sequestration through chemical reactions with the rock to form carbonate minerals. Its feasibility has been verified by the Wallula project in the United States and the Carbfix project in Iceland. Basalt is widely distributed in underground formations and requires a large amount of aqueous solution to maintain the reaction during mineralization. Therefore, basalt in deep-sea environments provides good conditions for CO_2 in situ mineralization. At present, the acceleration mechanism of CO_2 in situ mineralization of basalt and the possibility of engineering application remain to be studied. This report will simulate and accelerate the in-situ CO_2 mineralization process of deep-sea basalt by using a designed drainage filter flow device, explore the key factors affecting the dissolution rate of basalt, and propose an efficient mineralization method to accelerate the efficient dissolution of active rocks by regulating seawater flows. In addition, another experiment was designed to simulate mineralization and deposition, where in-situ and quasi-in-situ CO_2 mineralization under pH value regulation were carried out, aiming at improving the reaction rate of coordinated mineralization of multiple dissolved ions in submarine basalt. The results verify the feasibility of acid-base zoning-induced mineralization, and provide a basis for Marine CO_2 mineralization storage site selection. It also provides the theoretical basis for CO_2 quasi-situ high-efficiency mineralization technology in deep-sea environments.



14.14 Experimental study on seepage law and extraction mechanism of supercritical CO_2 injection in heavy oil

Lo-jia Si Lang, Master's student, Southwest Petroleum University

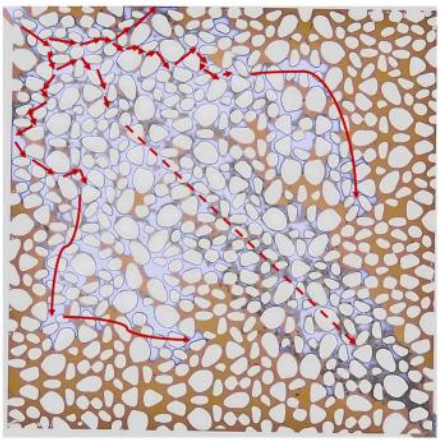
In the field of heavy oil development, CO_2 huff and puff technology can not only improve oil recovery, but also achieve the purpose of CO_2 storage. To explore the mechanism of CO_2 injection and huff and puff development parameters of heavy oil in the research block, high temperature and high-pressure PVT equipment and long core huff and puff experimental equipment were used to carry out CO_2 diffusion in heavy oil, supercritical CO_2 extraction of heavy oil and huff and puff experiment of high temperature and high-pressure long core under 50℃ ground conditions. The experimental results show that: 1) the diffusion coefficient of CO_2 in heavy oil is positively correlated with the injection temperature and pressure. 2) With the increase in extraction times, the content of medium-light component C6 ~ C12 significantly decreased, and the content of medium-heavy component C14+ gradually increased, especially in the first three rounds of extraction. 3) Through the huff and puff experiment, the optimal smothering time is 1-2h and the optimal pressure drop rate is 50kPa/min. The research results are helpful to clarify the mechanism of CO_2 injection and recovery in middle and deep heavy oil, and guide the design of injection and production parameters for the field CO_2 injection development in the study block, providing a reference for the subsequent large-scale promotion and application of CO_2 throughput.

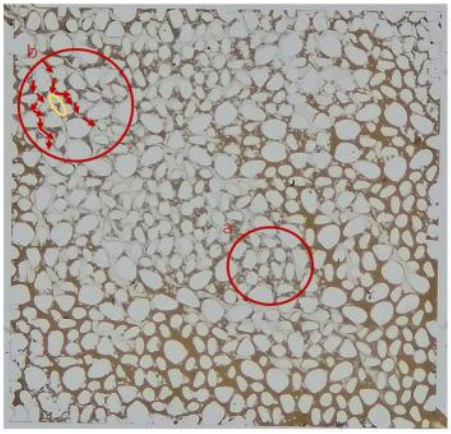


14.15 Study on microscopic percolation of supercritical CO_2 in compact storage

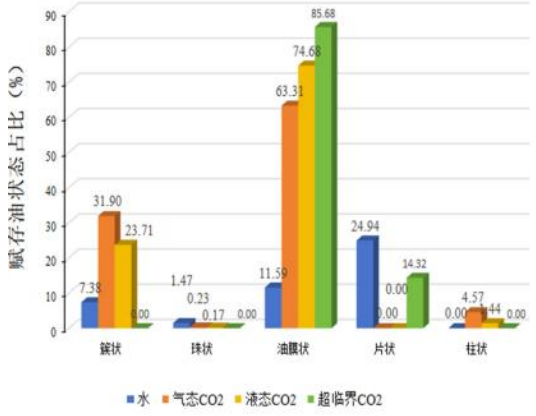
Huan Li, Master's student, Southwest Petroleum University

Aiming the problems that micro-seepage mechanism and residual oil occurrence rule in low permeability conglomerate reservoir is not clear, and injection medium needs to be optimized, taking tight conglomerate reservoir in Xinjiang oilfield as the research object, the micro-visual physical experiment model of high temperature and high pressure developed by itself is used to carry out micro-visual displacement experiment of low permeability conglomerate reservoir under different injection medium and gas injection phase conditions. The experimental results show that: 1) under the condition of low injection pressure, the recovery rate of water drive is 1.92% higher than that of gas drive. 2) In the gas phase state, the displacement characteristics and effects of different gas injection media are similar, and the effect of CO_2 gas displacement is relatively good; The displacement effect of supercritical CO_2 is much higher than that of gas and water. 3) The remaining oil of the water drive is mostly in flake form, followed by oil film form; The remaining oil of the gas drive is mostly deposited in the form of oil film. The research results are helpful to clarify the mechanism of injection medium development in low permeability conglomerate reservoir, and guide the field injection medium development.

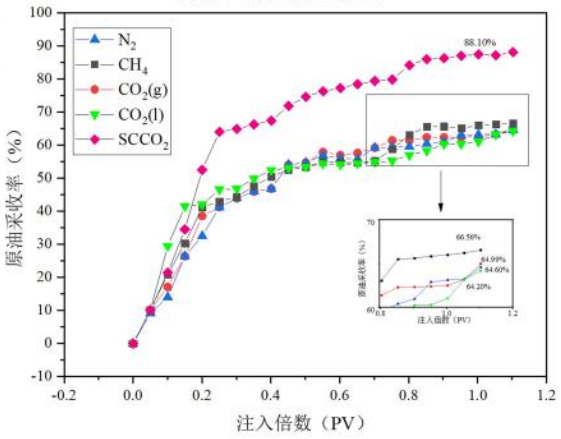




不同残余油赋存状态占比图



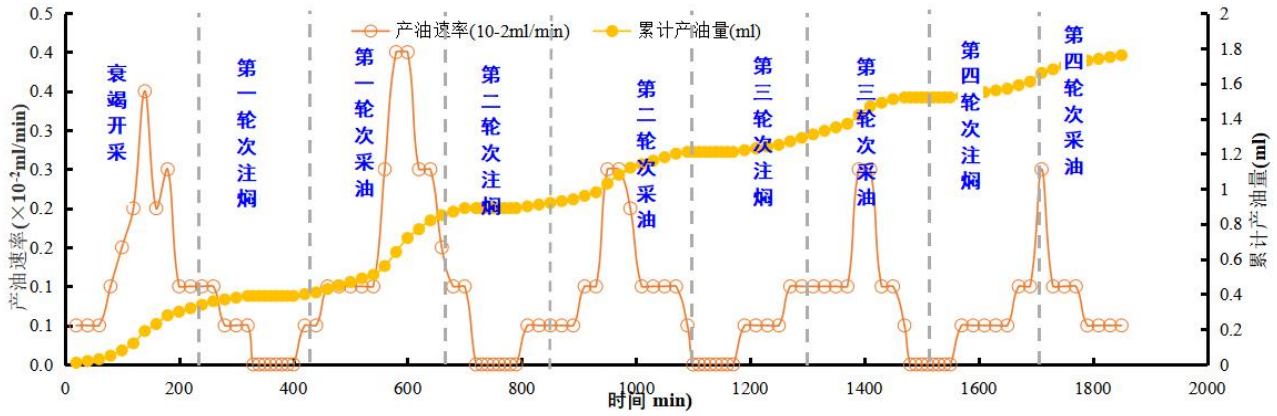
不同注入介质采收效果图



14.16 Experimental study on CO_2 injection and energy recovery in tight conglomerate reservoir

Yi Kang, Master's student, Southwest Petroleum University

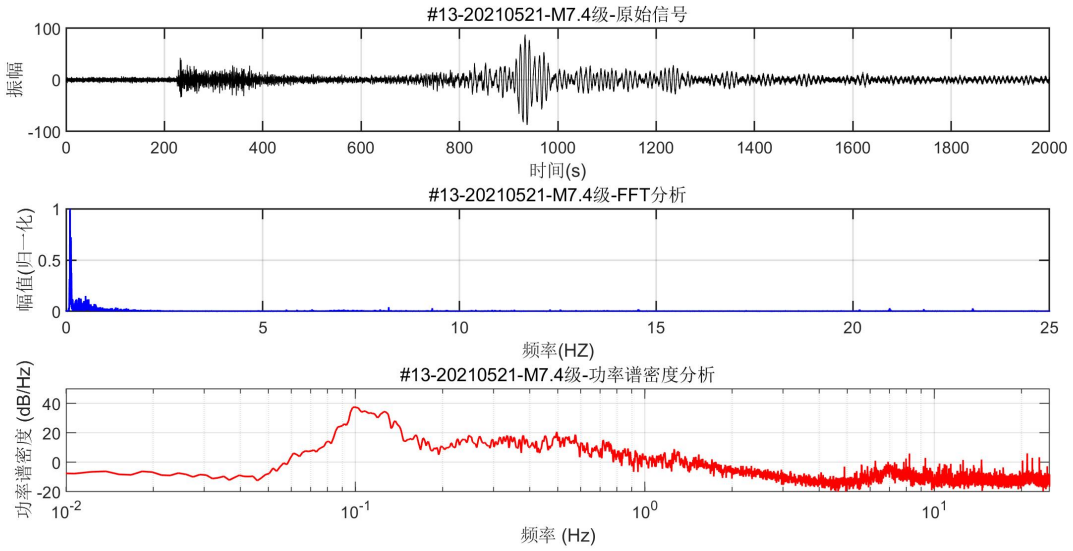
The mechanism of CO_2 replenishment is to reduce oil interfacial tension, reduce displacement resistance, and reduce oil viscosity. To expand the volume of crude oil, extract and vaporize light hydrocarbons in crude oil; It can make crude oil expand and reduce viscosity, remove plugging and increase injection, improve the ratio of oil-water flow, and produce foam by synergistic action with surfactants. At this time, the density of CO_2 is close to that of liquid, while the viscosity is close to that of gas, and the diffusion coefficient is between gas and liquid, which is several hundred times that of liquid, and has strong solubility. The main function of CO_2 flooding is to reduce the seepage resistance of crude oil and reduce the starting pressure gradient, supplement energy, improve displacement efficiency, and improve the oilfield development benefit. At present, the main characteristics of a tight conglomerate reservoir are low formation pressure, insufficient liquid supply capacity, and no effective energy supplement. In the process of development, there are some problems, such as a low recovery rate, unclear understanding of the remaining oil between Wells, and an inability to maintain pressure. To solve the above problems, the screening experiment of the CO_2 injection hubble-up energy replenishment method was carried out. The research showed that CO_2 diffusion and dissolution in crude oil would gradually precipitation to achieve energy replenishment when the pressure was reduced, the medium injection amount was positively correlated with the hubble-up cycle, the oil change rate of a single cycle decreased with the injection cycle, and the optimal hubble-up cycle for CO_2 injection development was 3-4 cycles. The optimal filling time is 2h. The experimental research results can provide field theoretical support for CO_2 injection energy recovery of tight conglomerate reservoir, and provide reference for CO_2 injection development of the same type of reservoir.



14.17 Development and application of "Dolphin" mobile ocean seismograph

Fei Hou, PhD student, China University of Geosciences (Wuhan)

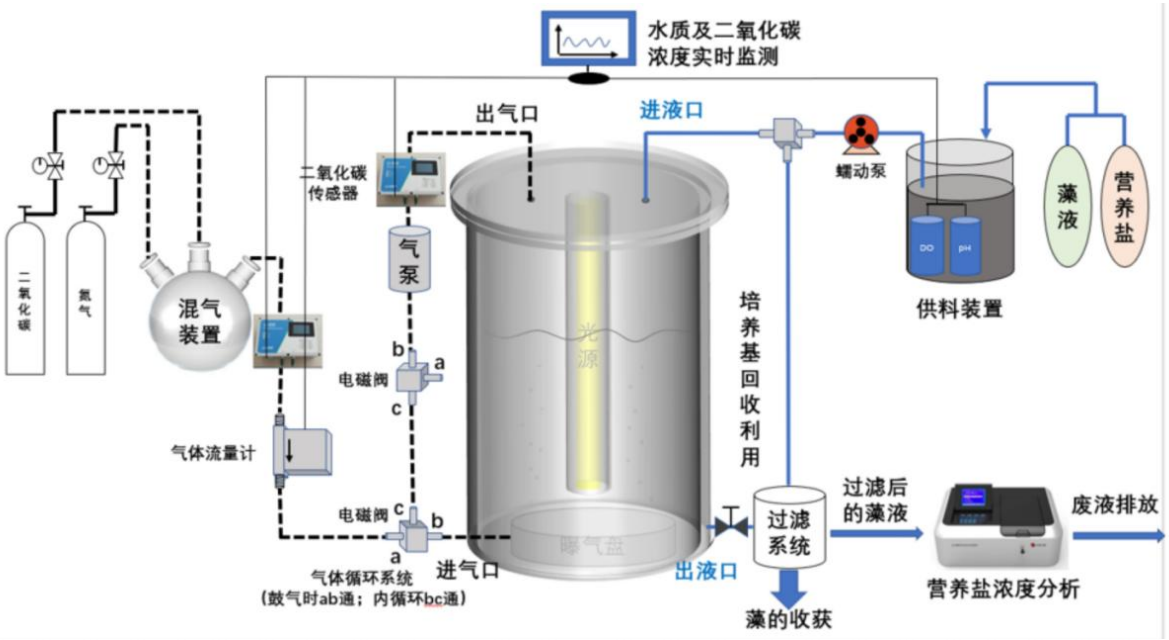
Due to the uneven distribution of natural seismic observation stations and the high operating cost of submarine seismographs, the ocean area covering 70% of the Earth's surface lacks seismic ray coverage, which brings great difficulties to seismic tomography on a global scale. Based on this situation, the international development of a new type of Marine seismic monitoring equipment - the snorkeling Marine seismograph (MERMAID), its working mode is similar to the profile buoy, and can be suspended in the underwater set depth drift with the ocean current, and record natural seismic signals. The report introduces the development work of the self-developed mobile ocean seismograph and the three sea trials conducted from 2020 to 2022, as well as the analysis of the seismic data recorded by the equipment. After sea test certification, the domestic "dolphin" seismometer has the conditions for actual use, reaching the level of the second generation of international ocean seismometers (MERMAID).



14.18 Research and development of microalgae carbon sequestration equipment and optimization of culture conditions

Yu-nan Mo, Master's student, College of Oceanography, Zhejiang University

With the continuous advancement of modernization and the massive consumption of energy, human demand for fossil fuels continues to rise, and the greenhouse effect and waste disposal have become serious environmental problems. Microalgae is a kind of photosynthetic microorganism with high carbon sequestration efficiency, fast growth rate, and short growth cycle. Because it can synthesize a variety of bioactive substances with unique functions, it has been widely used in medicine, cosmetics, food, biofuels, environmental monitoring, and other fields. To enhance the carbon fixation capacity of microalgae and reduce the culture cost of microalgae, optimizing the microalgae culture conditions such as light and nutrient concentration, and developing automated microalgae culture devices are ideal ways to sustainably produce algae feedstock, because they can save a lot of energy and nutrients required for algae culture, and significantly reduce the associated life cycle burden. Previous studies have shown that red and blue light are two kinds of light colors that can significantly affect the growth of chlorella. By mixing red and blue light for culture, the biomass of chlorella grows from the initial inoculation concentration of 0.4 gL-1 to 1.3 gL-1, and the dry weight increases by 3.25 times. By switching the light color of the light source used in the chlorella culture process (blue light for two days and red light for three days), the production of chlorella can be increased by 20% compared with the white light culture condition. Based on previous research results, to further improve the biomass accumulation and nutrient removal rate of chlorella, this study first developed and constructed a microalgae culture device with controlled red-blue intensity, and cultured chlorella with a 500 ml conical bottle in the light-controlled device to optimize the environmental factors (light mode and nutrient ratio) affecting chlorella growth. Then, to reduce the cost of the reactor and explore the optimal red-blue switching frequency and nutrient salt conditions of chlorella culture, a 20-l column bubble photobioretor was developed and modified to expand the suspension culture of chlorella, providing data support for the large-scale cultivation of microalgae by the reactor. The main research results are as follows: (1) The initial cell density of microalgae was 0.05 g L-1, the aeration rate was 0.2 L air L-1 culture min-1(vvm), the white light intensity was 10 μmol m-2 s-1, and the ratio of nitrogen and phosphorus was 39:1. The maximum biomass, growth rate and biomass productivity of Chlorella were 1 g L-1, 0.33 d-1 and 0.1 g L-1 d-1, respectively. The removal rates of nitrate and phosphate in the medium were 99.9% and 99.47%, respectively, which were significantly higher than the previous results. (2) With the change of microalgae culture conditions (i.e. initial cell density, nutrient ratio, and red-blue switching frequency), the chemical composition of algal cells will also change. The content of protein and chlorophyll (a+b) in the cell components of chlorella was 35.32% and 2.3125 mg L-1, respectively, when cultured under optimal growth conditions for 11 days. (3) The 20 L automated bioreactor designed and constructed in this experiment for cultivating C. vulgaris has certain feasibility and operability. The optimized three environmental factors (initial cell density, blue-red light switching frequency, and nutrient ratio) were also suitable for the culture of chlorella in the cylindrical photobioreactor. Finally, the maximum specific growth rate of 0.84 d-1 was obtained.


水质及二氧化碳
浓度实时监测
出气口
进液口
二氧化碳
传感器
蠕动泵
藻液
营养盐
二氧化碳
氮气
混气
装置
气泵
供料装置
光源
电磁阀
培养基回收利用
气体流量计
过滤后的藻液
过滤系统
废液排放
电磁阀
曝气盘
营养盐浓度分析
气体循环系统
(鼓气时ab通；内循环bc通)
进气口
出液口
藻的收获

15 Poster Presentation

15.1 Carbon isotope characteristics of authigenic carbonates in ultra-deep oceanic sediments and their implications for deep carbon cycle

Yong xin Liu, PhD student, Ocean University of China

This study reports the discovery of authigenic carbonate minerals at hole M0084 in the >7000 m water depth during the International Ocean Discovery Program (IODP) Expedition 386. We used synchrotron soft X-ray to analyze the element distribution of authigenic carbonates and surrounding sediments, as well as the carbon isotopic characteristics (^{14}C and ^{13}C) of authigenic carbonates and surrounding sedimentary organic carbon (SOC) in the Japan Trench sediments. The $\delta^{13}C$ value of authigenic carbonate minerals is lower than that of dissolved inorganic carbon (DIC) in interstitial water, indicating that authigenic carbonate has other carbon sources besides DIC in ultra-deep oceanic sediments. However, the ^{14}C age of authigenic carbonates is more similar to that of $DO^{14}C/SO^{14}C$ at the same depositional depth, and the results of synchrotron soft X-ray images on the distribution of calcium and carbon in the authigenic carbonate crystal are inconsistent, and these results suggest that OC-derived authigenic carbonates are the main carbonate sink in the ultra-deep oceanic sediments. In addition, our machine learning analysis suggests that more authigenic carbonates may precipitate in the deeper layers of a hadal trench. Therefore, we propose that the OC-sourced authigenic carbonates over long-time scales played a significant role in the deep-Earth carbon cycle.

超深海沉积层中自生碳酸盐的碳同位素特征及其对深部碳循环的意义

刘永欣[1]，刘明志[1]，Michael Strasser[3]，Ken Ikehara[4]，Joel Johnson[5]，罗敏[6]，徐立[7]，陶仁彪[8]，关勇[9]，包锐[1,2*]

[1] 中国海洋大学海洋化学理论与工程技术教育重点实验室，青岛 266100；[2] 青岛海洋科学与技术试点国家实验室海洋生态与环境科学功能实验室，青岛 266237；
[3] 国际海底资源大学地质研究所，奥地利国际布鲁克；[4] 日本产业技术综合研究所，日本茨城；
[5] 新罕布什尔大学地球科学系，美国新罕布什尔州，03824；[6] 上海海洋大学海洋科学学院，上海；
[7] 伍兹霍尔海洋研究所，国家海洋科学加速器质谱实验室，美国；[8] 北京基因科学研究中心，北京 100193；[9] 中国科学技术大学，国家同步辐射实验室，合肥 230029

1. 前言

自生碳酸盐的起源和演化是了解深海碳循环的独特地质记录档案。由于受碳酸盐补偿深度的影响，超深海沉积环境中自生碳酸钙矿物的地球化学特征和碳源尚不清楚。在国际大洋发现计划（IODP）第 386 航次期间，我们在水深超过7000米的日本海沟沉积物中发现了些许自生碳酸盐矿物，我们通过测试日本海沟沉积岩芯中自生碳酸钙矿物、颗粒有机碳（POC）、溶解无机碳（DIC）和溶解有机碳（DOC）的稳定性和放射性碳同位素（$\delta^{13}C$ 和 ^{14}C）特征，确定自生碳酸盐的碳来源。同时，本研究通过分析孔隙水中的地球化学参数，研究影响自生碳酸盐矿物形成的主要控制因素。最终对超深海沉积物中自生碳酸盐的主要碳源以及生长模式展开探究，并讨论其对地球深部碳循环的潜在影响。

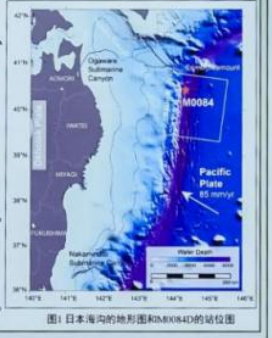


图1 日本海沟的地形图和M0084D的站位图

2. 结果与讨论

2.1 自生碳酸盐的沉积学特征和微观形态

- IODP 386航次采集的沉积物岩芯中，在M0084D-sec26-(14-19 cm)层位发现了大约5*3厘米的琥珀色自生碳酸盐矿物，初步判定是六水合碳酸钙矿物，也称之为ikaite。

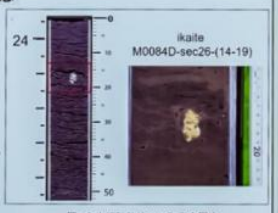


图2 自生碳酸盐的XCT和真实图像

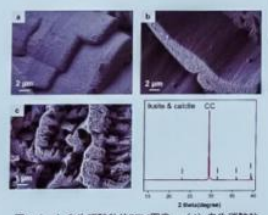


图3（a-c）自生碳酸盐的SEM图像；（d）自生碳酸盐的XRD数据图

- 通过XRD测试表明琥珀色的自生碳酸盐矿物为亚稳相ikaite和方解石的混合物。虽然亚稳相ikaite在 > 0 ℃ 和大气压力下有可能转化成方解石或其他晶型碳酸钙矿物，但在日本海沟原位沉积层中ikaite 占主导地位。

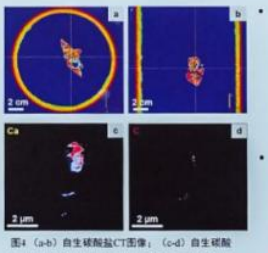


图4（a-b）自生碳酸盐CT图像；（c-d）自生碳酸盐的同步辐射软X射线重构的钙和碳元素的分布图

- 琥珀色矿物的 CT 图像显示矿物内部存在孔洞，说明矿物的基质比较松散。自生碳酸盐矿物内部断层增强了它们与周围环境的相互作用，促进孔隙水环境对微晶碳酸盐矿物的生长影响。
- 碳和钙元素的软 X 射线三维重建图像显示碳和钙的分布位点并不完全重合，这表明除了无机碳，矿物上还存在其他含碳物质。

2.2 超深海沉积层中自生碳酸盐的碳来源

- 这些自生碳酸盐矿物的$\delta^{13}C$值在-7.52至-2.88‰之间，低于孔隙水中DIC的$\delta^{13}C$值，表明在超深海沉积物中自生碳酸盐矿物具有额外的碳源。
- 自生碳酸盐矿物的^{14}C年龄与同一沉积层位的DO^{14}C /PO^{14}C 年龄比较接近，两者可以推断日本海沟中的自生碳酸盐的主要碳来源是有机碳。

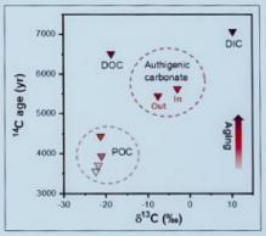


图5 $\delta^{13}C$ 和 ^{14}C年龄图谱

2.3 自生碳酸盐对深部碳循环的影响

- 在超深海环境中，甲烷的厌氧氧化可导致孔隙水的碱度增加。总的来说，相对偏高的碱度、Mg^{2+}浓度和甲烷含量有利于自生碳酸盐的沉淀，而pH的变化对形成自生碳酸盐影响不大。

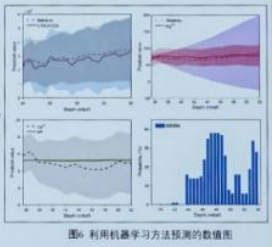


图6 利用机器学习方法预测的数值图

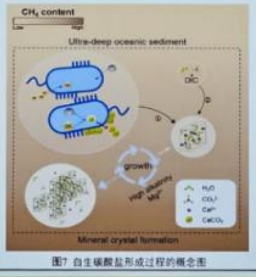


图7 自生碳酸盐形成过程的概念图

- 通过机器学习方法预测了更深层孔隙水中的Mg^{2+}、Ca^{2+}、碱度、pH值、甲烷含量、以及甲烷/乙烷+丙烷 ($C_1/(C_2+C_3)$)的变化趋势，进而计算出深层沉积物中形成自生碳酸盐矿物的概率可达 40%。

3. 总结

本研究在碳酸盐补偿深度以下的日本海沟岩芯中发现了些许自生碳酸盐矿物。通过碳同位素的数据，我们推测超深海环境中自生碳酸盐的碳来源主要是海洋有机碳。地震触发的浊流沉积引入的大量POC通过扩散或溶解过程转化成溶解碳，促进了超深海沉积物中自生碳酸盐的形成。此外，机器学习模型的预测结果表明俯冲带中的自生碳酸盐通量可能比目前报道的通量大。在超深海沉积环境中，有机碳来源的自生碳酸盐会影响总碳酸盐岩的积累和埋藏，并且是地球深部碳循环的一个重要碳汇。目前，针对海沟深渊地区碳酸盐的相关研究较少，未来有必要进一步计算自生碳酸盐在俯冲带中的埋藏通量。

基金项目支持：
国家自然科学基金（42076037；92058207）；山东省自然科学基金（ZR2021JQ12）

15.2 Application of laser Raman spectroscopy in the monitoring of carbon sequestration fluid

Qing-guo Meng, Senior Engineer, Qingdao Institute of Marine Geology, China Geological Survey

Subsea carbon sequestration is one of the important ways to reduce global greenhouse gas emissions. CO_2 injection into the seafloor storage area must be accompanied by complex physical and chemical transformation processes. It is necessary to develop technologies and methods suitable for monitoring carbon sequestration fluid at the bottom of the sea, effectively monitoring the seabed fluid before, during, and after sequestration, studying and mastering the CO_2 migration path, and providing effective support for efficient and safe CO_2 sequestration. Laser Raman spectroscopy is a nondestructive and efficient analytical technique, which has been widely used in many fields such as deep-sea exploration. In the process of carbon sequestration, the CO_2 transition process is relatively complex, which may exist in various forms such as gas, liquid, dissolved state, and supercritical state, and can also occur in dissociation or mineralization reaction, and can also be hydrated and solidified into gas hydrate under specific conditions. Starting from the morphological changes of carbon dioxide involved in seafloor carbon sequestration, this study combined literature and experimental data to compare and analyze the Raman spectral characteristics of different forms of CO_2 such as gas, liquid, solid hydrate, ionic state, and supercritical state, and found that different forms of CO_2 can be distinguished well according to the Raman spectral lines of CO_2 characteristics. Raman spectroscopy can effectively monitor the CO_2 transition process in carbon sequestration fluid, which preliminarily validates the feasibility of Raman spectroscopy technology in CO_2 seabed sequestration monitoring. Laser Raman spectroscopy technology is expected to be deeply integrated with the current relevant technologies for subsea carbon sequestration monitoring, and realize the integrated application of Raman distributed fiber optic sensors and other related monitoring technologies and research methods, providing strong technical support for the identification and research of CO_2 migration characteristics in injected formations.

激光拉曼光谱技术在海底碳封存流体监测中的应用

孟庆国，孙建业，李承峰，卜庆涛，郝锡荦

自然资源部天然气水合物重点实验室，青岛海洋地质研究所，青岛，266237

Background

海底碳封存是减少全球温室气体排放的重要途径之一。CO_2注入海底封存区域，必然伴随着复杂的物理和化学的迁变过程。有必要研发适用于海底碳封存流体监测的技术方法，在封存前、封存期间和封存后对海底流体进行有效监控，研究掌握CO_2迁变路径，为高效安全地封存CO_2提供有效支撑。

Objective

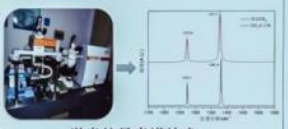
▲ 厘清海底碳封存过程中CO_2的迁变过程，明确涉及流体的相态和组成。

▲ 研究不同形态CO_2的拉曼光谱特征并探讨拉曼光谱技术在CO_2海底封存监测中的应用可行性。

Methods

▲ 基于自行研制的微型透明可视高压反应釜，通过控制系统的温度、压力等条件，模拟海底碳封存过程CO_2的不同相态。

▲ 利用激光拉曼光谱在线分析技术对不同相态CO_2进行测定，对比分析不同相态CO_2的拉曼特征。



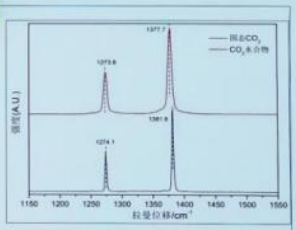
激光拉曼光谱技术

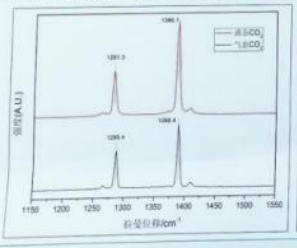
Results and Discussion

▲ 海底碳封存过程中CO_2迁变过程较为复杂，可能存在气态、液态、溶解态以及超临界等多种形态，还可发生解离或矿化反应，特定条件下还可水合固化为气体水合物。综合文献和实验数据，对比研究了气态、液态、固态水合物、离子态及超临界等不同形态CO_2的拉曼光谱特征。

▲ CO_2的典型拉曼光谱特征是费米共振双峰。费米双峰产生的机理不同，~1285cm^{-1}的峰对应于CO_2分子的对称伸缩振动模式，而~1388cm^{-1}则为CO_2分子弯曲振动模式的倍频峰。

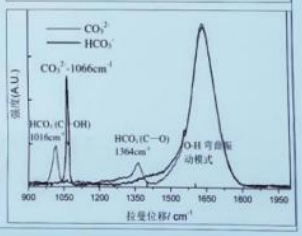
▲ 结果显示，不同相态CO_2的特征拉曼位移差异明显，拉曼光谱能够很好识别CO_2迁变过程。





不同相态CO_2拉曼光谱特征

序号	CO_2相态	拉曼位移/cm^{-1} 伸缩振动模式	拉曼位移/cm^{-1} 弯曲振动倍频	实验条件	来源
1	气态	1285.4	1388.4	3.0MPa，4.0℃	本实验
2	液态	1281.3	1386.1	4.5MPa，2.0℃	
3	固态	1274.1	1381.8	常压，-150℃	
4	水合物	1273.8	1377.7	常压，-150℃	
5	超临界	1283.9	1387.7	14MPa，95℃	文献1
6	离子态	HCO_3^- 1016 1364	—	常温常压	文献2
		CO_3^{2-} 1066	—		



Key Findings

▲ 海底碳封存过程可能涉及气态、液态、固态水合物、离子态及超临界等不同形态的CO_2，拉曼光谱可以有效识别、监控碳封存流体中CO_2的迁变过程。

▲ 激光拉曼光谱技术有望与当前海底碳封存监测相关技术深入融合，实现与拉曼分布式光纤传感器等相关监测技术和研究方法的集成应用，在注入海底地层CO_2的运移特征识别和研究方面提供有力技术支撑。

References

1. Zhang, X., Li, L. F., Du, Z. F., Hao, X. L., Cao, L., & Luan, Z. D., et al. Discovery of supercritical carbon dioxide in a hydrothermal system. Science Bulletin, 2020, 65(11): 958-964.

2. 田陟贤, 张鑫, 刘昌岭, 孟庆国, 阎军. 溶解无机碳的拉曼光谱定量分析可行性研究[J]. 中国环境科学, 2014, 34(10) : 2631-2636.

Contact details: mengqimg@126.com

15.3 Geological conditions of carbon dioxide sequestration in Yantai Depression, South Yellow Sea Basin

Di Luo, Associate Researcher, Qingdao Institute of Marine Geology, China Geological Survey

Marine geological carbon sequestration, as one of the application scenarios of CCUS, is an effective way to achieve carbon emission reduction in coastal areas. Shandong Province is one of the provinces with the largest carbon emissions in China, especially in the coastal areas. Qingdao alone will emit 67 million tons of carbon in 2020, and there is a huge demand for Marine carbon sequestration. The Yantai Depression in the South Yellow Sea Basin is adjacent to Shandong Province, which is an important choice for carbon sequestration in Shandong Province. The results of early carbon sequestration potential evaluation show that the Yantai Depression is the region with the greatest sequestration potential in the South Yellow Sea basin. To select a suitable storage site, it is very important to evaluate the storage conditions in this region. This study deeply analyzes the geological conditions of carbon storage in the Yantai Depression from the aspects of structural trap characteristics and reservoir conditions, etc., and provides an important basis for the evaluation of carbon storage selection.

南黄海盆地烟台坳陷二氧化碳封存地质条件分析

骆迪[1,2,3,4]，陈建文[1,2,3,4]，梁杰[1,2,3,4]，袁勇[1,2,3,4]，李清[1,2,3,4]，赵化淋[1,2,3,4]

1 中国地质调查局青岛海洋地质研究所 2 海洋地质碳封存山东省工程研究中心 3 青岛市海洋地质碳封存重点实验室 4 青岛市海洋地质碳封存工程研究中心

引 言

离岸碳封存作为CCUS的应用场景之一，是沿海地区实现碳减排的有效途径。山东省是中国碳排放量最大的省份之一，尤其是沿海地区，仅青岛市2020年碳排放总量达6700万吨，开展离岸碳封存需求巨大。南黄海盆地烟台坳陷毗邻山东省，是山东省沿海地区实现碳封存的重要选择。前期碳封存潜力评价结果表明，烟台坳陷是南黄海盆地封存潜力最大的区域，本文深入分析了烟台坳陷开展离岸碳封存的适宜性和基础地质条件，为碳封存选区评价提供重要依据。

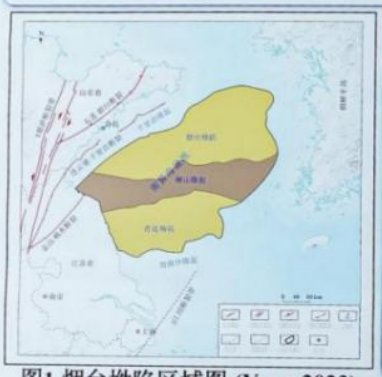


图1 烟台坳陷区域图 (Yuan,2023)

烟台坳陷二氧化碳封存适宜性

1. 离岸最近，距山东省沿海城市约100千米(图1)；
2. 地温梯度介于2.4~3.0℃/100m，大地热流值介于61~66mW/m²，**属于“冷盆”**；
3. 500年来南黄海盆地共发生18次6级以上地震，其中16次在盆地西南部（青岛坳陷和崂山隆起西部），烟台坳陷仅有2次记录。**从地震活动性来看，烟台坳陷的稳定性好。**
4. 南黄海盆地二氧化碳封存潜力平均为155.25Gt，其中，青岛坳陷平均为46.83Gt，烟台坳陷为99Gt，**封存潜力约为青岛坳陷的2倍**。

烟台坳陷二氧化碳封存基础地质条件

□ 烟台坳陷发育多种类型构造圈闭

自中生代以来，烟台坳陷经历多期构造运动，区域应力场改变，地层变形强烈，发育多种类型的构造圈闭(图2)，为二氧化碳地质封存提供有效的存储空间。

□ 烟台坳陷发育4套储盖组合(图3、图4)

1. 下盐城组优质储碳层与其上覆上盐城组泥岩
2. 三垛组河流相砂岩与上部的泥岩
3. 戴南组和三垛组形成的储盖组合
4. 阜宁组内部储盖组合

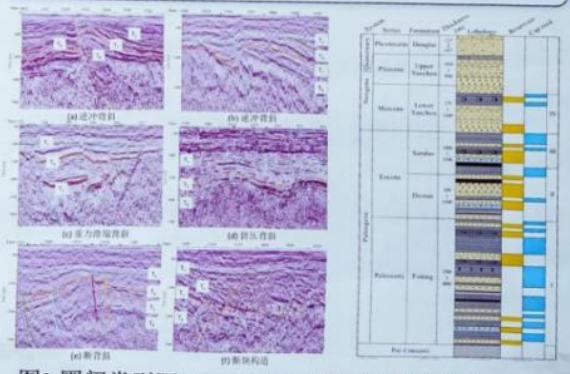


图2 圈闭类型图 (Luo, 2024)

图3 岩性柱状图 (Yuan,2023)

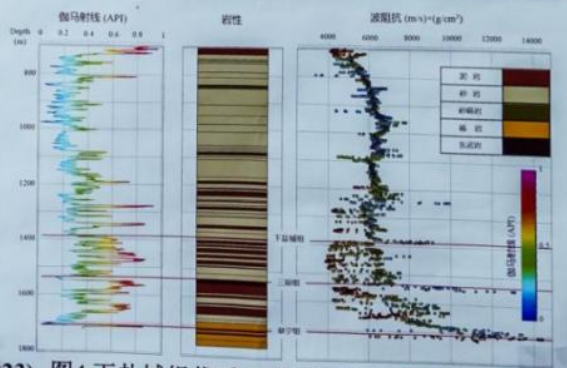


图4 下盐城组优质储碳层测井分析 (Luo, 2024)

15.4 Acoustic response characteristics during the formation and decomposition of carbon dioxide hydrate: implications from the study of combined acoustic and CT detection

Qing-tao Bu, Associate Researcher, Qingdao Institute of Marine Geology, China Geological Survey

The acoustic characteristics of hydrate are important parameters for hydrate geophysical exploration and hydrate resource evaluation. The microscopic distribution of hydrate has an important effect on the acoustic response of water-bearing reservoirs. Although microscale hydrate distribution can be determined by means such as X-ray computed tomography (X-CT), it is difficult to obtain acoustic parameters for the same sample. In this study, we developed an experimental system integrating pore-scale visualization and ultrasonic testing systems for carbon dioxide hydrate-containing sediments. X-ray CT observation and acoustic detection can be achieved simultaneously in the same hydrate sample, which provides a new concept for simultaneous monitoring of microscopic distribution during acoustic testing of natural gas hydrate samples. Hydrate formation and deionization experiments were carried out in sandy sediments, during which acoustic characteristics of hydrate-containing sediments were detected and X-ray computed tomography was performed. It was found that the hydrate formed mainly at the gas-water interface in the early stage, in the pore fluid in the middle stage, and contact with sediments in the late stage. The study also found that the hydrate dissociation stage is divided into three stages. The hydrate begins to dissociate at the point where it comes into contact with the sand grains early in the dissociation process. At this stage, the main factor affecting the acoustic velocity of hydrate is the change in the microscopic distribution of hydrate. In the middle stage, a large amount of hydrate decomposes, and the main factor affecting the acoustic velocity of hydrate is the change in hydrate content. In the late stage of hydrate dissociation, the distribution form of hydrate is mainly pore filling type, and the microscopic distribution of hydrate in this stage is the main factor affecting the acoustic velocity. The development of this experimental device solves the difficult problem of determining the quantitative relationship between microscale hydrate distribution and reservoir acoustic characteristics.

第四届离岸碳捕集、利用与封存（CCUS）论坛

二氧化碳水合物形成和分解过程中声学响应特征：来自声学和CT联合探测研究的启示

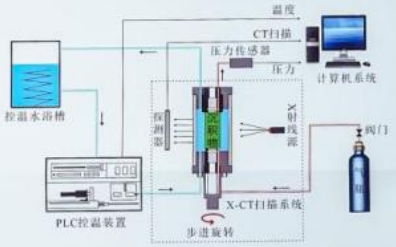
卜庆涛[1,2]，孙建业[1,2]，李承峰[1,2]，陈强[1,2]，孟庆国[1,2]，郝锡荦[1,2]

1.自然资源部天然气水合物重点实验室，中国地质调查局青岛海洋地质研究所，青岛 266237

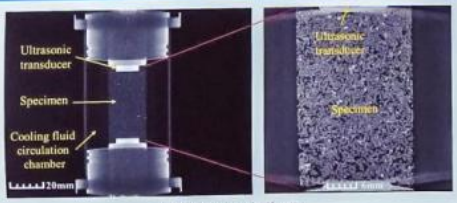
2.青岛海洋科技中心海洋矿产资源评价与探测技术功能实验室，青岛 266237

夹持器两端内置超声发生器与接收器，同时进行X-CT扫描成像和声学探测，采用X-CT扫描技术监测沉积物中水合物的微观分布情况，声波测试仪获得含水合物沉积物岩心的纵横波速度。该技术方法可应用于天然气水合物、常规岩心样品的微观分布观测与超声信号同步采集，开展声学特性与样品微观分布的联合响应研究。

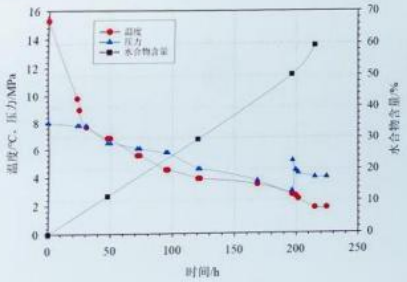
实验装置示意图



水合物声学探测模拟实验过程

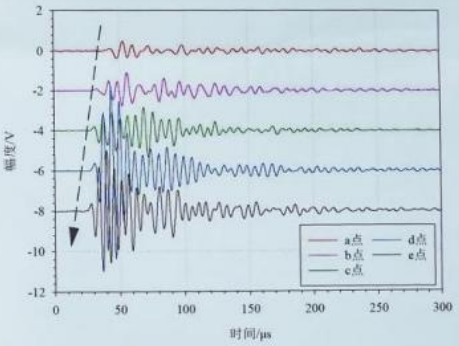


实验样品总览图

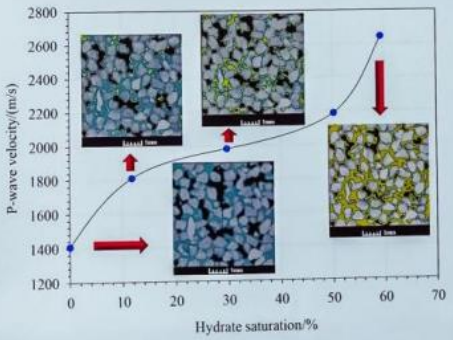


实验样品总览图

模拟实验结果



水合物生成过程中声波变化情况



水合物形成过程中的微观空间分布和声学特性的变化。黄色代表甲烷水合物，蓝色代表水溶液，浅灰色代表砂子，黑色代表二氧化碳气体

小结

水合物初期主要在气水交界处生成，中期沿着气水交界逐渐生长，主要生长于孔隙流体中，后期接触沉积物，一起构成沉积骨架。

Corresponding author: bqt881110@163.com

15.5 Numerical simulation of carbon dioxide sequestration in brackish water layer in Fushan Depression

Yuan Chen, PhD student, Institute of Deep Sea Science and Engineering, CAS

Carbon Capture and Storage (CCS) is a technology that processes CO_2 emissions from industry and related energy sources and stores them safely in the ground. On this basis, CCUS (Carbon dioxide Capture, Utilization and Storage) increases the CO_2 reuse process to make CO_2 resources and improve economic benefits. CO_2 sequestration in brackish water layer is a potential solution. The brackish water layer is widely developed in the Fushan Depression, which is a favorable geological carrier for CO_2 sequestration. This study conducted a numerical simulation of CO_2 sequestration in this region, established a two-dimensional model of CO_2 sequestration in the brackish water layer, and considered four sequestration mechanisms. The migration rule of CO_2 after injection into the brackish water layer and the contribution of four storage mechanisms to the total storage capacity were analyzed. In addition, the sensitivity analysis of the physical properties of the saltwater layer, formation water properties, and operating parameters was carried out to determine the influence of each parameter on carbon dioxide storage. The simulation results show that the amount of carbon dioxide stored by different mechanisms varies with time. The main physical parameters that have a significant influence on the sealing effect are porosity, permeability, formation temperature, and brine depth, and different parameters have different degrees of influence on each mechanism. The increase of formation water salinity will increase the amount of carbon dioxide in structural storage and residual gas storage, but has the opposite effect on dissolution storage and mineral storage. For operating parameters, there are thresholds for bottom-hole pressure and injection rate, which need to be adjusted within a suitable range to ensure the sealing effect. Injection location determines the dominant sequestration mechanism, and injection in the middle and bottom of the brackish water layer helps to improve the safety of carbon dioxide sequestration. In addition, the influence of different injection well types on each mechanism is also different. The simulation results of actual injection beds in the Fushan Depression show that when the target layer is buried deep, the low permeability cap is conducive to the storage of carbon dioxide. This study can provide a reference for the selection of the target layer and the formulation of the storage scheme, and is of great significance for promoting the safe and efficient CCUS of the saltwater layer.

福山凹陷咸水层二氧化碳封存数值模拟研究

陈缘[1,2]，吴时国*[,1]，周雪晴[1]，朱林奇[1]
1. 中国科学院深海科学与工程研究所；2. 中国科学院大学

1. Introduction

碳捕集与封存（Carbon dioxide Capture and Storage，CCS）技术是将工业或相关能源产业排放的CO_2经过处理后输送并安全封存于地层中，CCUS（Carbon dioxide Capture, Utilization and Storage）在此基础上增加了CO_2再利用过程，使CO_2资源化，提高经济效益。咸水层封存二氧化碳是一种潜力巨大的方案，福山凹陷咸水层普遍发育，为有利CO_2封存地质载体，对此区域咸水层二氧化碳封存进行数值模拟研究，可为封存方案的制定提供参考，对推进咸水层CCUS具有重要意义。

图1 CCUS流程及分类

2. Methodology

图2 福山凹陷位置图

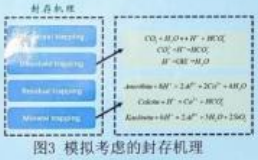


图3 模拟考虑的封存机理

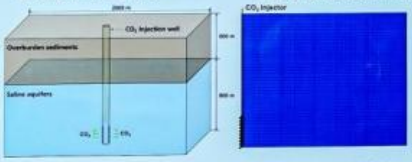


图4 福山凹陷咸水层二氧化碳封存模型示意图及二维模型

利用CMG-GEM建立模型，模拟周期200年，前2年为二氧化碳注入阶段，注入结束即关闭注入井。

3. Simulation results

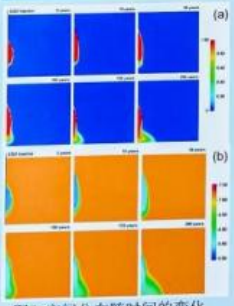


图5 空间分布随时间的变化
(a) 二氧化碳分布；(b) pH值

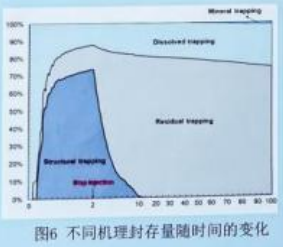


图6 不同机理封存量随时间的变化

- 初期构造封存和溶解封存为主；
- 关井后残余封存逐渐成为主导，矿物封存开始比较晚。

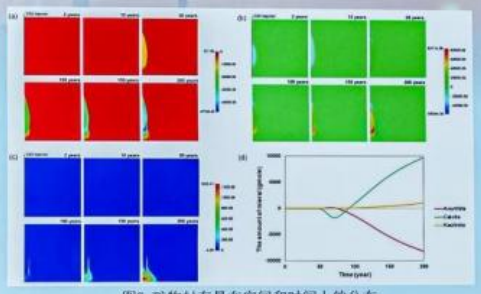


图7 矿物封存量在空间和时间上的分布

矿物封存开始作用的时间晚，但是储存安全性最高的一种封存机制，时间足够长的情况下CO_2将以矿物沉淀的形式长期封存在咸水层中。

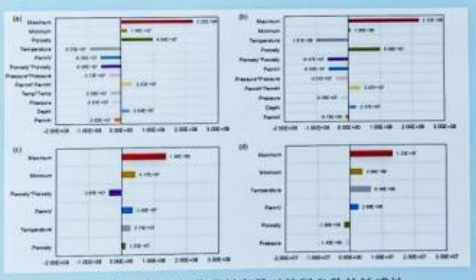


图8 不同机制的二氧化碳封存量对储层参数的敏感性
(a) 构造封存；(b) 残余气封存；(c) 溶解封存；(d) 矿物封存

储层参数对不同封存机制的影响程度不同，对于构造封存，孔隙度、温度和垂向渗透率的影响程度递减；对于残余气封存，影响从大到小分别为温度、孔隙度和垂向渗透率，埋藏深度对以上两种机理的影响不大；对于溶解封存，主控参数为孔隙度和渗透率；矿物封存受温度和垂向渗透率影响较大。

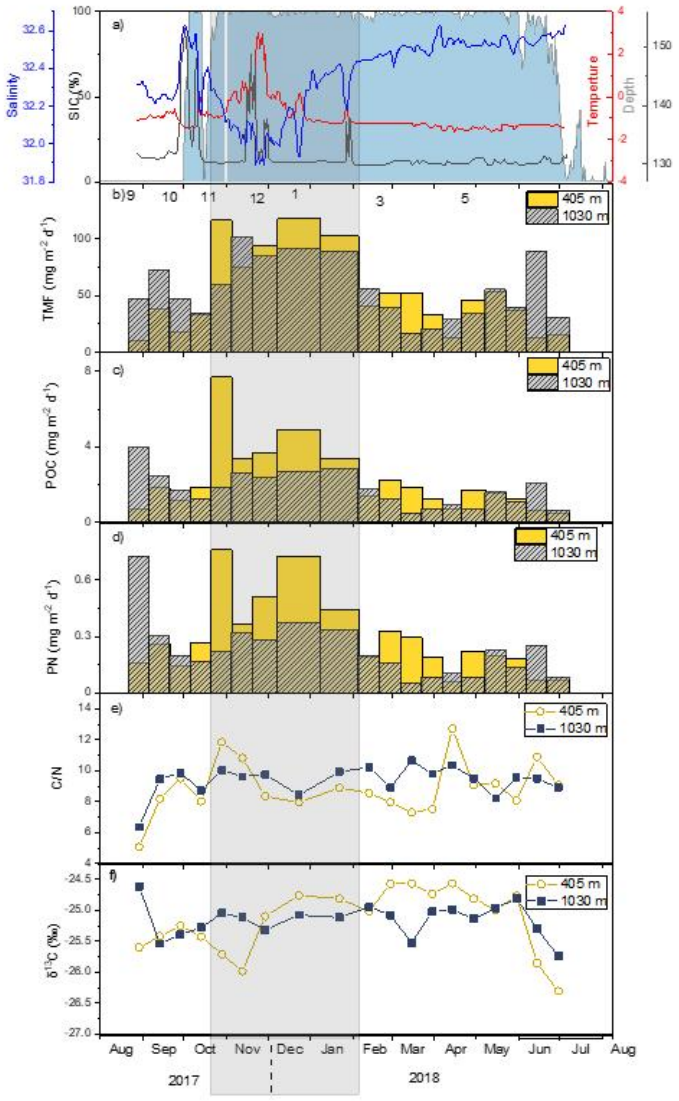
4. Conclusions

（1）在CO_2注入阶段和关井后四种机理的封存量占比随时间不断变化，不同阶段主导的封存机理不同；
（2）四种封存机理受不同储层参数的影响程度不同；
（3）在封存选址时需要根据储层参数优选目标层位。

15.6 The composition and transformation of particulate organic carbon in winter in the north wind abyssal plain of the Western Arctic Ocean were investigated based on fatty acids

Jia-qi Wu, PhD student, Second Marine Institute, Ministry of Natural Resources

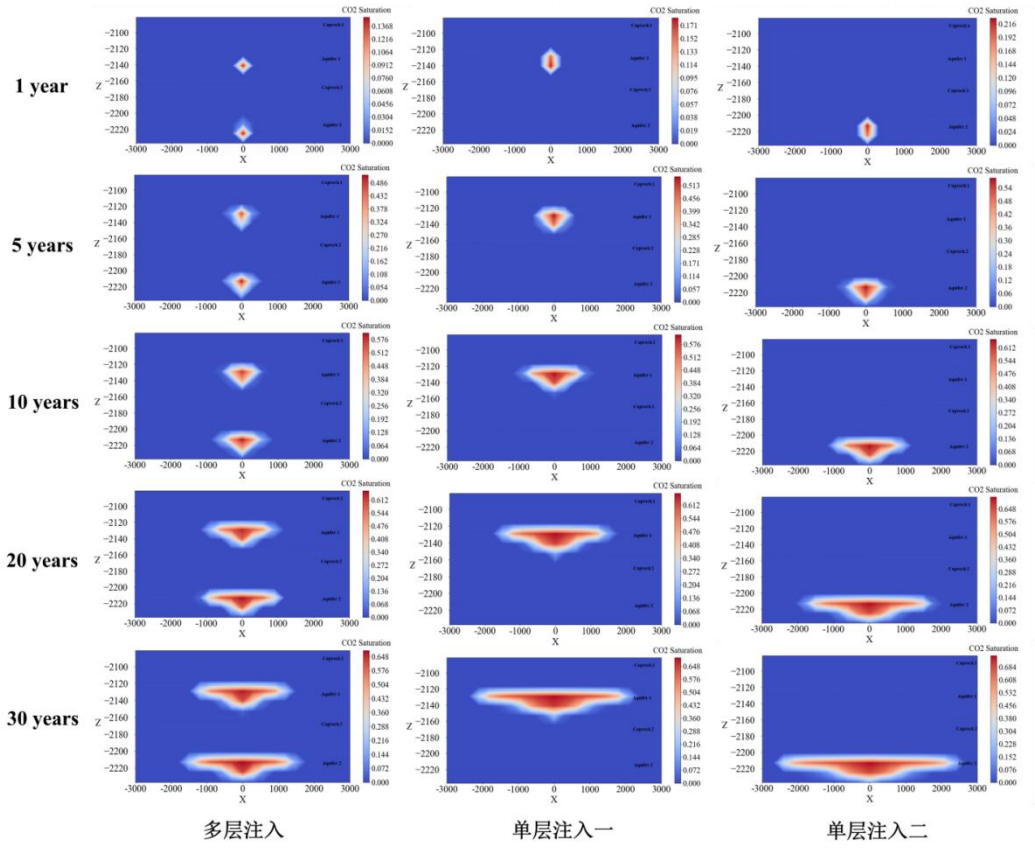
Particulate organic carbon (POC) is an important food source for heterotrophs, and different sources of POC have different effects on high-trophic organisms. Due to light limitations, Arctic POC fluxes are usually much lower in winter than in summer. However, recent studies have shown that the flux of POC in winter is comparable to that in summer in the boreal abyssal plain of the Western Arctic Ocean. The composition of winter POC and its transformation in the water column of the Boreal abyssal plain in the Western Arctic Ocean were analyzed by analyzing the fatty acids in the settling particles in a set of double-layer traps and related temperature and salinity data.



15.7 Comparative analysis of CO_2 Marine geological sequestration simulation under single - and multi-layer injection conditions

Fu-tao Mo, Master's student, Zhejiang University

The CO_2 geological storage areas of Marine sedimentary basins in China usually have the characteristics of small reservoir thickness, significant differences in permeability characteristics, and cross-distribution of reservoir caps, which makes the traditional CO_2 single-layer injection method low efficiency. To study the feasibility of CO_2 multi-layer injection technology for carbon storage in Marine sedimentary basins, Lishui Sag of the East China Sea shelf basin was selected as the target area for carbon storage in this study. By using a TOUGH-FLAC coupling simulator to construct a carbon storage geological model, and taking CO_2 saturation, pore water pressure, reservoir cap displacement, and Coulomb failure stress (CFS) as evaluation indexes, the CO_2 transport characteristics under single-layer and multi-layer injection conditions were studied respectively. The numerical simulation results show that: (1) under the same injection rate, the migration distance of CO_2 in deep reservoir is greater than that in shallow reservoir; (2) Compared with single-layer injection, pore water pressure in multilayer injection is lower and increases slowly, resulting in smaller vertical displacement of the reservoir; (3) The low CFS value of the reservoir cap under multi-layer injection conditions indicates that the risk of CO_2 breaking through the cap to produce leakage is relatively small, thus making the site more secure.



15.8 Deep-sea exploration and exploitation of strategic key metals in China in the context of sustainable Marine development: reflections and prospects

Zi-heng Chen, Master's student, Shanghai Ocean University

Strategic critical metals are those rare metals, rare earth metals, rare metals, and other metals (e.g. copper, gold, cobalt, nickel, rare earth elements, etc.) that are vital to modern society but are at high risk for the security of supply. These metals are widely used in the development and manufacturing of new batteries, new energy vehicles, special glass, and its products, as well as in the fields of national defense and military industry. Polymetallic nodules in deep-sea basins, cobalt-rich crusts on seamounts and island slopes, and polymetallic sulfides in seafloor hydrothermal systems are important sources of strategic critical metals. They provide the necessary guarantees for China to ensure the security of its strategic metals supply chain in the future. At present, the exploration and research of deep-sea metal mineral resources are deepening, and the demand and competition of major countries for strategic key metal raw materials are also growing. Therefore, the development of deep-sea mining will become one of the important trends in the high-quality development of China's Marine economy. However, large-scale exploitation of deep-sea mineral resources may cause long-term and irreversible damage to Marine ecosystems, bringing a series of persistent environmental challenges, which is contrary to the concept of sustainable development of the ocean. This study mainly discusses the exploration technology background, current situation, potential development trends, and research hotspots of strategic key metals in the ocean in China. Combining with and drawing on the "green mine" concept and advanced mode of land mining, this study proposes that China should continue and further implement the research on the theory of strategic metal mineral exploitation in the ocean in the future, and vigorously promote the innovation of deep-sea mining methods and the development of deep-sea geological environment restoration and treatment technology, to improve the efficiency of resource exploitation and utilization and break through the technical bottleneck. Open the door to the era of commercial mining.

海洋可持续发展背景下的中国战略性关键金属的深海勘探与开采：思考与展望

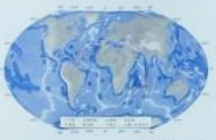
陈子恒
上海海洋大学 海洋科学与生态环境学院，上海，201306

1.研究背景

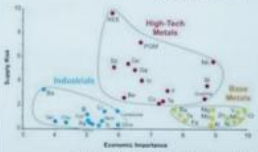
战略性关键金属是指为当今社会发展所必需但安全供应存在高风险的稀有金属、稀土金属、稀散金属以及其它部分种类的金属（如Cu，Au，Co，Ni，REE等），被广泛应用于新型电池、新能源汽车、新型玻璃及其制品等的开发制造以及国防军事工业等领域。分布于深海盆地的多金属结核、海山以及岛屿斜坡上的富钴结壳以及海底热液系统的多金属硫化物是战略性关键金属的重要来源，同时也将为中国未来维持战略金属的安全供应链提供必要保障。

2.研究现状与意义

Achezel et al., 2011



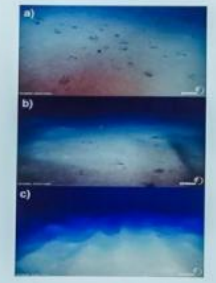
刘淑等，2021



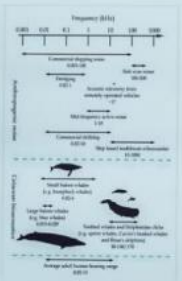
欧盟原材料战略及蓝色增长项目（2020）

□各大国对战略性关键金属原材料的需求与竞争在日益增加；
□发展深海采矿业将是未来海洋经济高质量发展的一大重要经济增长点。

3.存在的问题与挑战



de Jonge et al., 2020



Thompson et al., 2023

□大规模的深海采矿会产生沉积物羽流，破坏底栖生物的栖息地，从而破坏海洋生态系统食物网；
□深海采矿过程产生的人为噪音会对鲸类等海洋哺乳动物的繁衍、捕食以及信息交流等产生干扰；
□深海采矿会降低海山的生产力水平，对鲸类等远洋生物的栖息地和生物量产生负面影响。

4.思考与展望

矿种	消费量/万吨	对外依存度
铜	1117	75%
镍	119	91%
钴	6.5	96%
锰	1246	90%

部分中国战略性关键金属的对外依存度（来源：中国有色金属工业协会，2018）

Nature Geoscience Oct. 2016

□要保证新时代国民经济高质量发展，深海采矿时代的到来大势所趋；
□遵循可持续发展的基本原则，结合并借鉴当今陆地采矿行业的“绿色矿山”理念与先进模式，例如绿色采矿工艺与先进复垦绿化技术的伊敏模式，资源高效开采和矿区集中连片治理的鄂尔多斯模式，特殊地区生态修复的霍林河模式以及绿色勘察示范的锡林郭勒模式等，于未来的深海采矿业领域中践行习近平新时代生态文明思想，推动深海矿业绿色发展；
□我国未来应持续并深入贯彻落实大洋战略性金属矿产开发领域的理论与技术研究工作；
□大力推进深海采矿方法的革新与深海地质环境修复治理技术的开发，同时降低环境污染，提高资源利用效率，降低矿山成本，从而推进采矿行业的可持续发展；
□提高资源开发利用效率，突破技术瓶颈，以期开启商业化开采时代的大门。

5.作者简介

作者：陈子恒（1998.6-），男，安徽蚌埠人，硕士研究生毕业（2024年6月，师从宫尚桂副教授），硕士阶段从事冷泉沉积地球化学研究，博士阶段意向从事海底资源及其成矿作用研究（热液系统）。E-mail：cher_so2025@163.com

欢迎交流！

15.9 Study on solubility difference of CO_2 in different storage environment based on molecular dynamics simulation

Qun Lin, Master's student, Southwest Petroleum University

In the context of carbon neutrality, carbon capture, utilization and storage (CCUS) technology has become one of the important ways to deal with global climate change, especially in the context of offshore storage, where the solubility of carbon dioxide (CO_2) in seawater is a key influencing factor. Existing studies mainly focus on the dissolution behavior of CO_2 in monovalent salt solutions, but there are relatively few studies on saline environments containing divalent salts (such as Mg^{2+}). In this study, the molecular dynamics simulation method and LAMMPS software were used to systematically investigate the dissolution behavior of CO_2 in $MgCl_2$-containing brine at different salinities. The results showed that: (1) under the same temperature and salinity conditions, the solubility of CO_2 in $MgCl_2$-containing brine decreased by about 20% compared with NaCl only; (2) As the salinity increased from 1mol/kg to 5mol/kg, the solubility of CO_2 in NaCl solution decreased by 22%, while the solubility in $MgCl_2$ solution decreased by 33%; (3) Through the radial distribution function and hydrogen bond analysis, it was found that the presence of Mg^{2+} significantly affected the hydrogen bond structure between water molecules, resulting in more hydrogen bond breaks, thus weakening the dissolution ability of CO_2. The strong hydration of magnesium ions is an important reason for the solubility difference. This study provides a new theoretical basis for the behavior of CO_2 in complex offshore brine systems, and can provide an important reference for OCCUS Earth system science research, blue economy development, and related engineering practice.

第四届 离岸碳捕集、利用与封存论坛

THE FOURTH OFFSHORE CARBON CAPYURE, UTILIZATION AND STORAGE FORUM

基于分子动力学模拟的CO_2在不同封存环境下的溶解度差异研究

林群[1]

1. 西南石油大学，四川 成都，610500

介绍

在碳中和背景下，碳捕获、利用与封存（CCUS）技术成为应对全球气候变化的重要途径之一，特别是在离岸封存的情境中，二氧化碳（CO_2）在海水中的溶解度是关键影响因素。现有研究主要集中于CO_2在一价盐溶液中的溶解行为，然而对于含二价盐（如Mg^{2+}）的盐水环境的研究相对较少。本研究利用分子动力学模拟方法，借助LAMMPS软件，系统探讨了CO_2在不同盐度下的含$MgCl_2$盐水中的溶解行为。

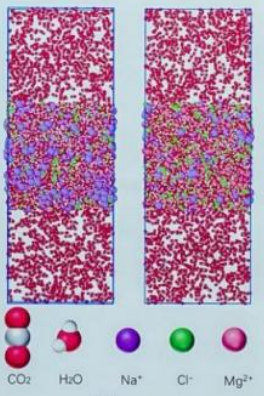


图1

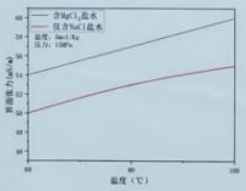


图2

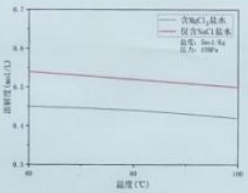


图3

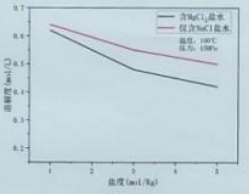


图4

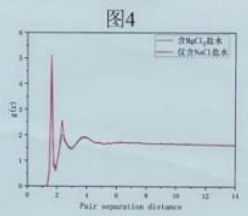


图5

图1分子模拟图（左NaCl，右NaCl+$MgCl_2$）
图2同一盐度、压力下界面张力随温度变化
图3同一盐度、压力下CO_2溶解度随温度变化
图4同一温度、压力下不同盐度的CO_2溶解度变化
图5 H_2O中H原子与CO_2中O原子径向分布函数

结果与讨论

（1）盐度5mol/kg、压力15MPa时，升高温度会降低CO_2的溶解度；

（2）温压条件一定时，盐度越高界面张力值越高，溶液盐度的增加对CO_2的溶解具有抑制作用。随着盐度从1mol/kg提升至5mol/kg，CO_2在仅含NaCl盐水中的溶解度下降了22%，而在含有$MgCl_2$盐水中的溶解度下降幅度更大，达到33%；

（3）在相同温度和盐度条件下，含$MgCl_2$盐水的界面张力大于仅含NaCl盐水的界面张力，其CO_2的溶解度较仅含NaCl盐水的溶解度下降最低约20%；

（4）通过径向分布函数和氢键分析发现，含有Mg^{2+}的径向分布函数第一峰值更低，且影响了水分子之间的氢键结构，导致更多氢键断裂，从而削弱了CO_2的溶解能力。

结论

盐度与温度都会影响CO_2的溶解度，在一定压力下，盐度与温度越高、CO_2溶解度越低。Mg^{2+}对气液间 IFT 增加的贡献率大于Na^+，Mg^{2+}的加入会降低CO_2的溶解度。

参考文献及其他信息

[1]周守为, 李清平, 朱军龙, 等. CO_2 海洋封存的思考与新路径探索[J]. Natural Gas Industry, 2024, 44(4).

[2]林元华, 邓宽海, 宁华中, 等. 二氧化碳在地层水中的溶解度测定及预测模型 [J]. 中国石油大学学报 (英文版), 2021, 45(1): 117- 126.

[3]Adam A M, Bahamon D, Al Kobaisi M, et al. Molecular dynamics simulations of the interfacial tension and the solubility of brine/H_2/CO_2 systems: Implications for underground hydrogen storage[J]. International Journal of Hydrogen Energy, 2024, 78: 1344-1354.

基金项目:四川省国际合作创新项目“玄武岩地层CO_2加速矿化封存机制与关键技术”（编号：2023YFH0005）

15.10 Research on standardization of carbon emission reduction accounting for CO_2 capture, oil displacement and storage projects

Qi Zhang, Engineer, Experimental testing Research Institute, Xinjiang Oilfield Company, petrochina

CO_2 capture, oil displacement, and storage is the type of CCUS project with the highest level of technological development and commercialization in China, but the lack of emission reduction accounting standards has hindered its large-scale development. To forge a competitive edge in the industry, Xinjiang Uygur Autonomous Region has actively carried out relevant standardization research. In terms of the calculation boundary and baseline scenario, the three links of capture, transportation, and oil displacement storage are modularized, and the baseline scenario is screened respectively, to facilitate the distribution of emission reduction benefits by multiple operators. According to the engineering practice, six emission sources are identified and the method of obtaining accounting data is specified. For the difficulty of quantification of cavitation and escape, the import and export difference subtraction method is used to replace the monitoring in the capture and transportation stage to avoid excessive accounting costs. In the displacement and storage stage, the emission of ground facilities and equipment is quantified through concentration and flow measurement. In particular, the guidance of instrument selection, sampling and measurement, results, and calculation are given for the unorganized escape. For the difficulty of how to guarantee safety and effectiveness, explore the risk monitoring mechanism, stipulate that the four environmental risk receptors around the regular monitoring and environmental impact restoration, when the impact is defined as mild and no impact can be carried out accounting. The relevant standardization work aims to promote the quantification and industrialization of the benefits of CO_2 capture, oil displacement, and storage projects in the region.

CO_2捕集、驱油与封存项目碳减排量核算标准化研究

王兴华，张琦，宋涛涛，王雨，林莉莉
中国石油新疆油田分公司实验检测研究院，克拉玛依，834000
新疆维吾尔自治区油气田环保节能工程研究中心

中国石油

背景

CO_2捕集、驱油与封存是中国当前技术发展水平和商业化程度最高的CCUS项目类型，但减排量核算标准的缺失阻碍了其规模化发展。新疆维吾尔自治区积极开展相关标准化研究，自治区地方标准《二氧化碳捕集、驱油与封存项目碳减排量核算技术规范》即将发布，是当前国内进程最快的CCUS全流程碳核算标准，标准旨在推动区域内CO_2捕集、驱油与封存项目效益的量化与产业化发展，锻造地区产业竞争优势。

标准制定过程

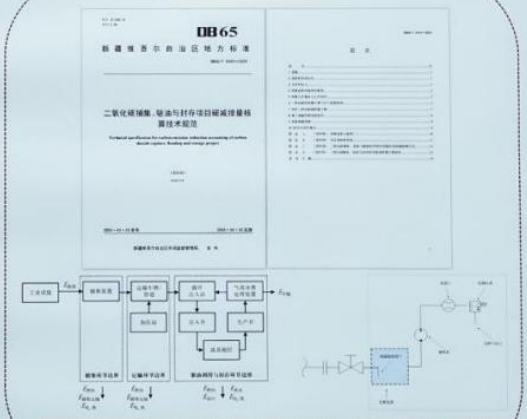
2023年4月，依托新疆油田公司科研课题，形成标准草案，地方标准正式立项

2023年9月，CCUS地方标准（草案）通过专家开题论证审查

2024年6月，完成公开征求意见，标准（征求意见稿）通过专家技术审查会

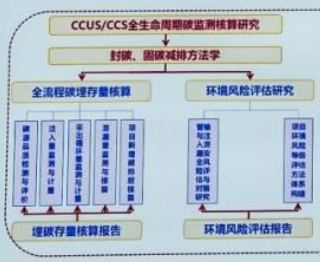
2024年9月，标准（送审稿）通过市场监督管理局组织的专家技术审查会，即将发布

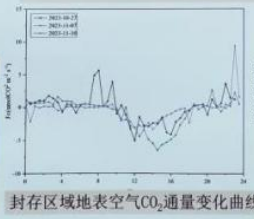
地方标准



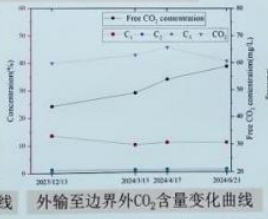
地方标准《二氧化碳捕集、驱油与封存项目碳减排量核算技术规范》报批稿封面、目录、核算边界示意图、逸散监测示意图

CCUS碳减排量监测核算研究工作

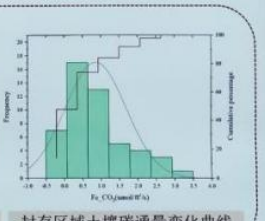




封存区域地表空气CO_2通量变化曲线



外输至边界外CO_2含量变化曲线



封存区域土壤碳通量变化曲线

标准摘要

1. 在核算边界和基准线情景上，探索将捕集、运输、驱油封存3个环节进行模块化划分，分别甄别基准线情景，便于多个运营方分配减排效益；
2. 根据工程实际识别了6个排放源并规定了核算数据获取方法。对于放空和逸散的量化这一难点，运用进出口差减法代替了捕集与运输阶段的监测以避免过高的核算成本，在驱油与封存阶段通过浓度与流量实测量化了地面设施设备的排放，尤其针对无组织逸散给出了仪器选择、采样与测定、结果与计算的指导；
3. 为了保障项目的安全有效性，探索风险监控机制，规定对周边4种环境风险受体开展定期监控与环境影响修复，当影响界定为轻度及无影响时才能开展核算。

16 Summary and Suggestions for Future Development

16.1 Session 1: The Earth System Science Theory Behind OCCUS Engineering Technology

The session explores several issues related to the geographical sciences, including the use of ocean systems for carbon dioxide sequestration, water purification processes, and ocean circulation systems. To address these issues, we must minimize human intervention on the planet, conserve resources, and apply the laws of nature to the CO_2 problem and CCUS challenge. Through the support of Earth system science theories, it provides a scientific basis for the future development of CCUS, solves key scientific problems, and is committed to building a harmonious symbiotic relationship between humans and nature.

Suggestions:

(1) In the future, CCUS will give more consideration to the theoretical support of Earth system science and the construction of a long-timescale and interfacial technical system.

16.2 Session 2: Synergistic Theory and Technology of Subsea CO_2 Oil Displacement and Storage

CO_2 flooding is not a new session. In the past, we have mainly focused on improving oil recovery technology and studying it from the perspective of oil and gas resources. However, with the increasing attention of the country to the "dual carbon" strategy, the rational use of subsea carbon dioxide oil displacement and storage technology, to achieve the collaborative operation of large-scale demand and engineering, has become the key direction of future development. This field has already attracted the attention of peers, including contributions from schools, enterprises, research institutes, and students, who are expected to contribute in this direction through this conference platform.

Suggestions:

(1) Strengthen interdisciplinary cooperation and promote the integration of carbon dioxide displacement technology with environmental science and geology;

(2) Promote policy research to provide policy support and guidance for the commercial application of carbon dioxide flooding and storage technology;

(3) Establish industry standards to ensure the implementation quality and environmental safety of carbon dioxide flooding projects.

16.3 Session 3: Site Selection, Monitoring, and Evaluation of Marine Carbon Storage

China's first marine carbon storage demonstration project is being implemented to meet the strategic needs of coastal provinces and cities to achieve carbon peak and carbon neutrality. Next, a series of new demonstration projects will start the pre-study phase. Siting and monitoring techniques are critical for the effective installation of CO_2 into subsurface geological bodies and for ensuring the safety and stability of the sequestration process. This session focuses on the theories, technologies, monitoring methods, and evaluation criteria related to the location of Marine carbon dioxide geological sequestration sites, aiming to identify key issues affecting the effectiveness, safety, and stability of perfusion, and determine the direction of future research to support the research and implementation of Marine geological carbon sequestration demonstration projects in China. The experts in this session have conducted in-depth discussions on major scientific issues such as the siting problem of Marine brackish layer sequestration, the evaluation method of siting effect, and the monitoring technology of sequestration results, and reached the following consensus:

(1) Marine geological carbon sequestration is of great significance for the realization of dual-carbon goals. Like the coastal areas of developed countries in the world, China's coastal provinces and cities have dense populations, highly developed industries, and commerce, and it is difficult to find suitable storage sites on land. At the same time, Marine geological carbon sequestration is an important choice for coastal provinces and regions to achieve carbon neutrality due to the characteristics of large potential for Marine storage, high safety, and low environmental risks.

(2) China's coastal provinces and cities have begun to pay attention to the pre-study of Marine geological carbon sequestration demonstration projects. Enping 15-1 Demonstration project, the first demonstration project of Marine carbon dioxide geological storage in Chinese waters, has been successfully implemented and accumulated a lot of experience. CNOOC, in cooperation with two large commercial oil companies in Guangdong Province and abroad, is discussing the site selection of Daya Bay CCS/CCUS project, a ten-million-ton demonstration project. Sinopec, Shanghai, and many domestic enterprises are carrying out a pre-site study of CCS/CCUS demonstration project in the East China Sea shelf basin; Qingdao Institute of Marine Geology, with the support of Qingdao Municipal Development and Reform Commission and Science and Technology Bureau, is conducting a study on the location of CCS project in Yantai Depression of the South Yellow Sea. With the support of the Guangdong Provincial Development and Reform Commission, Zhanjiang Bay Laboratory is cooperating with relevant units to carry out the evaluation of CO_2 geological carbon sequestration potential and the site selection of a demonstration project in the Beibu Gulf Basin. CNOOC Research Institute and the Tianjin Branch are conducting a pre-study of the CCUS project in the Bohai Sea area. The above shows that after the Enping 15-1 demonstration project, several Marine carbon dioxide geological storage demonstration projects in China have entered the pre-research stage.

(3) More and more attention has been paid to Marine geological carbon sequestration monitoring. Determine the safety of the demonstration project is an effective means of judgment is monitoring, and whether the long-term stability of Marine geological carbon sequestration is related to the success of the demonstration project.

Suggestions:

In the future, we should focus on the research and development of low-cost, long-cycle, high-precision

monitoring technology and equipment.

16.4 Session 4: Monitoring and Accounting Methods for Marine Carbon Storage Risks

This Session focuses on the risk monitoring and accounting methods of Marine carbon sequestration, in-depth analysis of the risk assessment, monitoring technology, and accounting and measurement methods of Marine carbon sequestration from multiple perspectives, providing a wealth of CCUS perspectives and the latest research results. From micro-mechanisms to technical standards, this session not only showcases the latest scientific research in the field of Marine carbon sequestration, but also highlights the critical role of risk monitoring and accounting methods in ensuring the safety and effectiveness of carbon sequestration projects.

Suggestions:

(1) Identify monitoring issues requiring attention in Marine carbon sequestration through risk assessment;
(2) Provide real-time data through monitoring activities to observe and validate potential risks;
(3) Quantitative evidence of the sequestration effect is provided based on monitoring results through accounting methods.

16.5 Session 5: OCCUS Rock Physics and Fluid Characterization and Simulation

This session focuses on the challenges of efficient use and safe storage of carbon dioxide (CO_2) in offshore complex oil and gas reservoirs, including the difficulty of scientific prediction and effective control of CO_2 storage safety, unclear mechanical mechanisms affecting cap stability, and difficult quantitative characterization of micro/nano-scale reservoir fluid flow laws. The research covers many aspects, such as CO_2 flooding (gas) and storage mechanism of complex oil and gas reservoirs, CO_2 storage safety evaluation of oil and gas reservoirs/saltwater reservoirs, CO_2 geological storage leakage risk and monitoring technology, CO_2 injection well integrity, multi-factor coupling mechanical influence mechanism, main control factors of cap stability, CO_2 phase effect, storage process impact on reservoir physical properties evolution, etc. This study aims to explore the theory and technology of efficient utilization and safe storage of CO_2 in complex hydrocarbon reservoirs, and provide technical support for CO_2 flooding and storage projects in China.

The thematic content includes rock physical property research, fluid flow simulation, storage effect assessment, and other aspects, through multi-angle and multi-level research, to provide a solid theoretical foundation and experimental support for the development of offshore carbon capture, utilization, and storage (CCUS) technology. The experts discussed the influence of different rock types on the CO_2 sequestration effect, as well as the changes in the physical properties and pore structure characteristics of the CO_2 mineralized fluid and the evaluation of wellbore integrity. The effects of CO_2 on the reservoir, the injection, diffusion, storage, and storage of CO_2 in different phases were analyzed in detail by using advanced physical model experimental equipment and numerical simulation technology. The study revealed the mechanism of CO_2 injection in the development and utilization of offshore unconventional reservoirs, the characteristics of phase behavior, the law

of seepage, and the characteristics of reservoir evolution. The storage characteristics of CO_2 in underground reservoirs and well integrity during long-term storage are predicted, which provides a scientific basis for formulating an effective storage strategy.

Suggestions:

(1) Strengthen interdisciplinary cooperation: encourage closer cooperation between experts in different fields such as geology, chemistry, and engineering to promote integrated innovation and application of technologies;

(2) Upgrade simulation technology: Invest in more advanced simulation software and hardware to improve the accuracy of predictions of complex geological conditions and fluid behavior;

(3) Strengthen field tests: Increase the frequency and scale of field tests to verify the practical application effect of laboratory research results and obtain valuable data from them.

16.6 Session 6: Safety Assurance Technology for Marine CO_2 Pipeline Transportation

Concerning the safety of offshore carbon capture, utilization, and storage (CCUS) pipelines, this Session provides an in-depth analysis of the technical challenges and strategies encountered by Marine carbon dioxide (CO_2) pipelines in terms of structural safety, flow safety, and material corrosion resistance. The focus is on the following aspects:

(1) The structural safety hazards of Marine CO_2 pipelines are systematically analyzed, and the key factors affecting the safety of submarine pipelines are considered as seabed dissolution, anchor impact, and pipeline buckling expansion. The buckling behavior of flexible pipelines is explored in detail, and the testing and maintenance of submarine pipelines are emphasized as extremely challenging sessions.

(2) The key technologies of Marine CO_2 pipeline flow safety are comprehensively sorted out, a multi-dimensional model of pipeline flow safety prediction is established, and the key factors affecting the safety and stability of pipeline transportation such as impurity gas and water content are deeply discussed. It is believed that to ensure the safety and economy of the Marine CO_2 pipeline, reasonable fluid criteria should be further investigated.

(3) Focusing on the corrosion mechanism of CO_2 pipelines, systematic researches were carried out on the aspects of the influence of impurity gas on pipeline corrosion, the synergism of multiple impurity gases, and the microscopic mechanism of corrosion of a single condensate drop, etc., and the applicability of the advanced online corrosion monitoring technology of the oilfield system was also discussed. At the same time, the successful experience of corrosion control measures in the whole process of the Sinopec Shengli Oilfield - Qilu Petrochemical CCUS project was introduced, and the technical challenges Sinopec faced in emerging fields such as dry hot rock were introduced.

In the discussion session, we had a hot discussion on the application of the crack arrest ring of CO_2 pipe, the influence of impurity gases, model prediction, and submarine pipeline corrosion monitoring. This session contributes to the OCCUS Forum on leading-edge technologies and empirical practices in CO_2 pipeline safety and identifies the technical challenges of development in this area.

Suggestions:

(1) Focus on structural safety: developing buckling control and crack arrest technology under the combined action of internal and external pressure and bending moment of pipeline leakage;

(2) Focus on flow safety: developing multi-impurity fluid transient hydraulic thermodynamic calculation and pipeline operation safety data intelligent control technology;

(3) Pay attention to material corrosion: developing dynamic simulation, in-situ characterization of CO_2 corrosion in the pipeline, and monitoring technology for internal and external corrosion in long-distance pipelines;

(4) In view of the safety of Marine CO_2 pipelines, we will continue to strengthen basic research work and focus on the development of new technologies balancing safety and economy.

16.7 Session 7: R&D of Equipment related to Marine Carbon Storage

Given the independent research and development and engineering application of seismic instruments and equipment for subsea carbon sequestration, this session deeply discusses the challenges and solutions faced by subsea seismic instrument technology for subsea carbon sequestration leak monitoring and microseismic monitoring, OBN carbon sequestration microseismic monitoring technology, and OBS+DAS new real-time microseismic monitoring equipment.

Suggestions:

(1) The development of subsea seismic nodes (OBN), especially subsea flight nodes (OBFN), as efficient equipment for testing and verification of subsea carbon sequestration microseismic or leakage monitoring;

(2) The development of seabed seismograph (OBS) equipment technology, especially real-time OBS equipment technology, is the core equipment of seabed carbon sequestration monitoring;

(3) Self-developed middle and high-frequency band seismometer, integrated into OBS or OBN, to provide China's independent technical support for the independent development of subsea carbon sequestration equipment.

16.8 Session 8: Development Technology of Carbon Sequestration and Zero Carbon Biochemicals for Marine Organisms

The development of offshore carbon capture, utilization, and storage technology depends on breakthroughs in basic research and continued advances in engineering technology. Session 8 focuses on Marine biological carbon sequestration mechanisms and technologies for the development of low-carbon biochemicals, including the two application areas of ecological carbon capture and storage (CCS) and carbon capture and utilization (CCU).

Suggestions:

(1) Strengthen the standardization of ecological carbon sink (CCS) measurement and accounting methods. Promote Marine phytoplankton carbon sink into the blue carbon inventory, and expand the connotation and extension of blue carbon. It is estimated that the photosynthetic carbon sequestration efficiency of global phytoplankton can be increased by 10%, which can obtain more than 40 billion tons of additional Marine carbon sink, equivalent to the industrial carbon emissions of the whole year in 2021.

(2) Further promote the application of low-carbon and high-value Marine organisms, including seaweed farming and microalgae-based product development. Develop microalgae liquid fertilizer to promote the organic integration of agricultural carbon sink and Marine carbon sink; At the same time, the development technology of high value-added microalgae refining and biological chemicals should be strengthened, and the industrialization chain of OCCUS should be integrated to improve economic benefits.

16.9 Session 9: Design and Technology Research and Development of Deep Sea CCUS Marine Ranch

The large-scale CCUS carbon sequestration ranch plays an important role in achieving the country's dual carbon goals and addressing global climate change issues. Therefore, the construction technology of Marine Carbon Sink Ranch is being actively researched and developed at home and abroad. The development trend of the CCUS carbon sink ranch in the Far-reaching Sea is manifested as the expansion from nearshore to offshore, and the joint layout of seaweed ranch, high-value shellfish ranch, and offshore wind power. This session brings together research data on the dynamic response characteristics of Marine pastures, cage farming facilities, and seaweed farming facilities under wind and wave currents. In particular, this session aims to build a safe and reliable deep-water mooring seaweed carbon sink pasture, and introduces the current research status of the mechanical properties of mooring seaweed pasture in offshore deep water under complex sea conditions, the dynamic response characteristics of mooring seaweed pasture, and the evaluation of the economic benefits of carbon sink. This paper discusses the feasibility of using high-strength polyethylene fiber cable in seaweed pasture, and puts forward the design and analysis flow of mooring seaweed pasture. In addition, this session constructed and verified a numerical model for the boom boom pasture, and studied the effect of the subjugation depth of the boom rope and the spacing of seaweed cultivation on the dynamic characteristics of the boom pasture. Based on the life-cycle carbon sequestration of seaweed pastures, economic benefits were also assessed. The research results of this session will provide an important reference for the construction of a large-scale mooring CCUS carbon sink ranch.

Suggestions:

(1) In-depth study of the stability and safety of seaweed pastures in extreme Marine environments to ensure that the pastures can withstand the effects of strong winds, waves, and complex currents;

(2) Explore more efficient seaweed cultivation and harvesting techniques to improve the productivity and economic efficiency of pastures;

(3) Strengthen the long-term monitoring and assessment of seaweed carbon sinks to ensure that the carbon absorption and storage capacity of pastures meet the expected targets;

(4) Consider the impact of rangelands on Marine ecosystems and ensure that the sustainable development of rangelands does not have a negative impact on Marine biodiversity.

16.10 Session 10: Deep-sea Material Energy Cycle and Carbon Sequestration

The session content mainly involves knowledge points in the field of natural science, covering the time scale from micro to ten thousand years. In addition, two parts are closely related to the marking OCC, including the multiple methods used by Central South Sea to determine the operation of the clothing system, and the communication process and intelligent weighting strategy of the Marketing Department, which are critical to stabilizing the internal processing state and achieving the objectives. Although the number of reports is small, they are of great significance to CCUS standardization efforts.

Suggestions:

(1) Establish relevant standards in the future and translate these results into formal standards;
(2) Strengthen interdisciplinary cooperation and promote the integration of natural science and engineering technology to ensure the comprehensiveness and practicality of CCUS technology;
(3) Establish a clear timetable and milestones to ensure the orderly conduct of standardization work, and timely update and revise standards to adapt to technological progress and changes in market demand.

16.11 Session 11: Polar Multi-layer Carbon Cycle

This session covers the carbon cycle process in the polar lithosphere, hydrosphere, cryosphere, and other spheres, as well as the carbon cycle in the abyssal subduction system, which is inclined to the basic research field of natural science. The time scales studied include tectonic scales, 10,000-year scales, and modern processes. In addition, two reports focused on dredged Marine soil stabilization and CO_2 sequestration issues closely related to OCCUS, and injection modeling for geological sequestration. The OCCUS program is rich in content and covers a wide range of sessions. As a key component of the Earth's climate system, polar regions are one of the frontiers of scientific research, especially their multi-layer interactions, especially their impact on the carbon cycle.

Suggestions:

(1) Improving observational techniques, particularly in extreme environments, to monitor and analyze more precisely the dynamics of the polar carbon cycle;
(2) Increase research investment in new technologies and new materials, such as exploring more efficient and environmentally friendly materials and methods in the stabilization of Marine dredged soil and CO_2 solidification.

16.12 Session 12: R&D of OCCUS Standards

Suggestions:

(1) Develop a system of standards for carbon capture, utilization, and storage (CCUS), and identify the standards that need to be developed in the future, especially those closely related to security risks, which should be prioritized;

(2) Encourage more institutions to translate research findings into standards, including industry standards, inventory standards, and even international standards;

(3) Make full use of resources such as the five planned working groups and look forward to seeing more research findings translated into standards at the next session.

CCUS 2024 Hangzhou

Sponsor

近海海洋环境科学国家重点实验室（厦门大学）
State Key Laboratory of Marine Environmental Science (Xiamen University)

中国太平洋学会

Organizer

自然资源部第二海洋研究所
SECOND INSTITUTE OF OCEANOGRAPHY, MNR

Co-organizer

中国科学院南海海洋研究所
SOUTH CHINA SEA INSTITUTE OF OCEANOLOGY, CHINESE ACADEMY OF SCIENCES

中国科学院武汉岩土力学研究所
Institute of Rock and Soil Mechanics, Chinese Academy of Sciences

怀柔实验室
HUAIROU LABORATORY

浙江大学海洋学院
OCEAN COLLEGE, ZHEJIANG UNIVERSITY

CSO
Chinese Society for Oceanography

中国地质调查局
青岛海洋地质研究所

GEOLIGHT 北京港震

杭州市科学技术协会
Hangzhou Association for Science and Technology

中国海洋工程咨询协会
China Association of Oceanic Engineering