Academic Visit to Russia

北京大学能源研究院
INSTITUTE OF ENERGY

Deep Fluids and Multi-Sphere Interactions – Resource & Environment Effects

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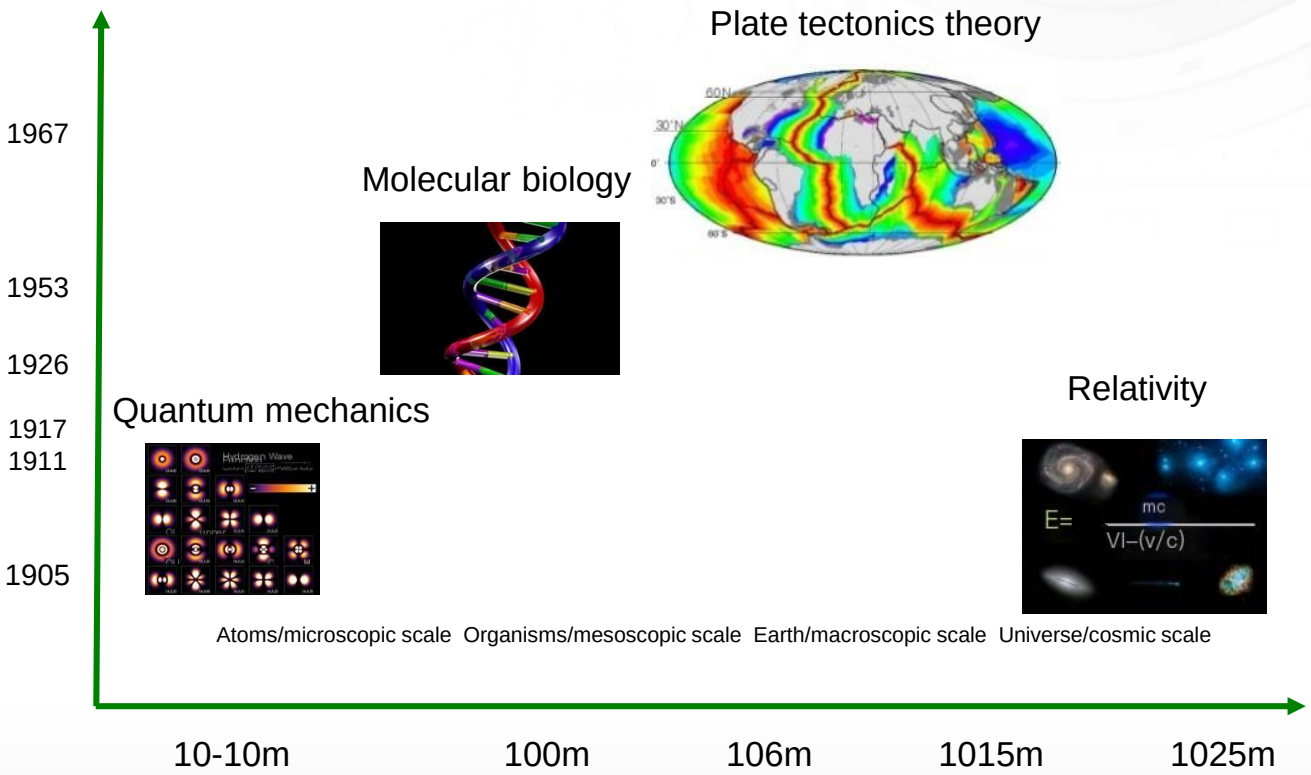
Outline

1. Basic Concept & Research Background

2. Scientific Questions & Research Status

3. Future Directions & Scientific Objectives

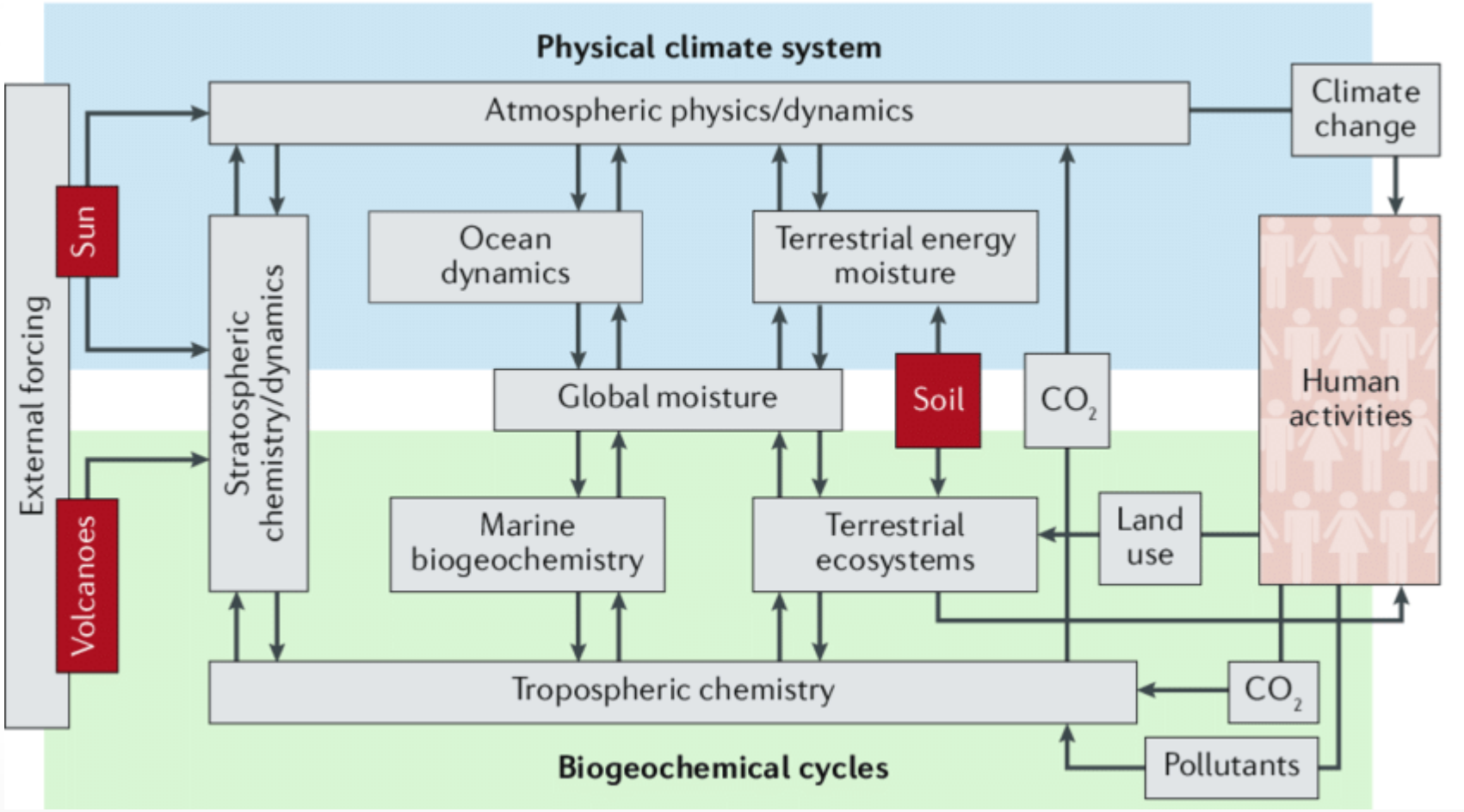
1. Basic Concept & Research Background



- ✓ **GEOSCIENCE is of paramount importance for national demands, including energy and mineral security, and disaster prevention**
- ✓ **<u>Plate Tectonics Theory</u> is one of the four major achievements of natural science in the 20th century, on par with Quantum Mechanics and Relativity, and Molecular Biology**
- ✓ **WHAT is the breakthrough of Geoscience in the post-plate tectonic era?**

1. Basic Concept & Research Background

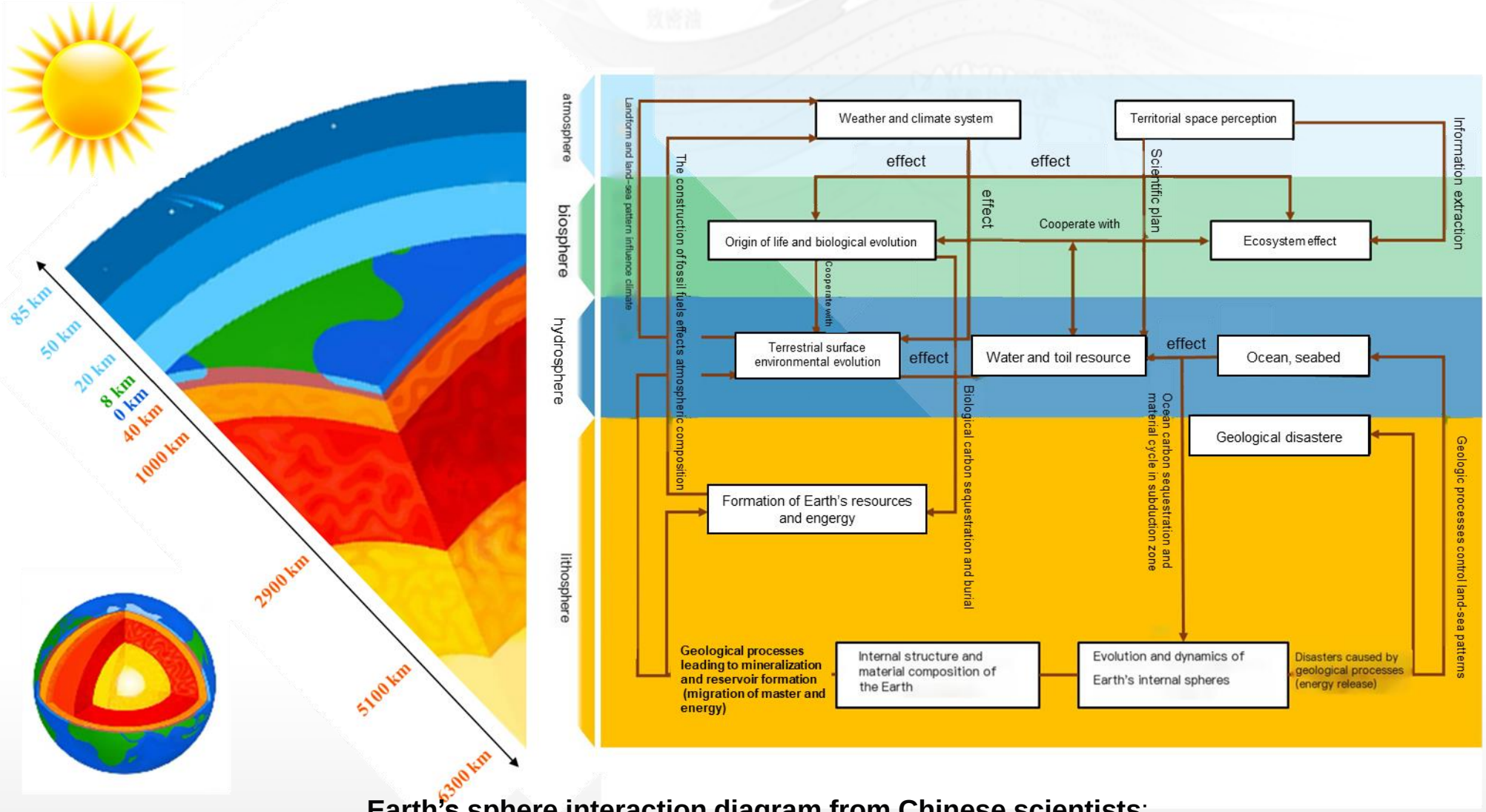
Earth system



NASA Bretherton Diagram: a classic depiction of the Earth system and its interactions.
Interactions among the atmosphere, ocean, and biosphere, focusing on the geosphere-biosphere interactions, with human activities as an external force.
Reproduced from NASA (1988), "Earth System Science: A Closer View".

1. Basic Concept & Research Background

Earth system and multi-sphere interaction



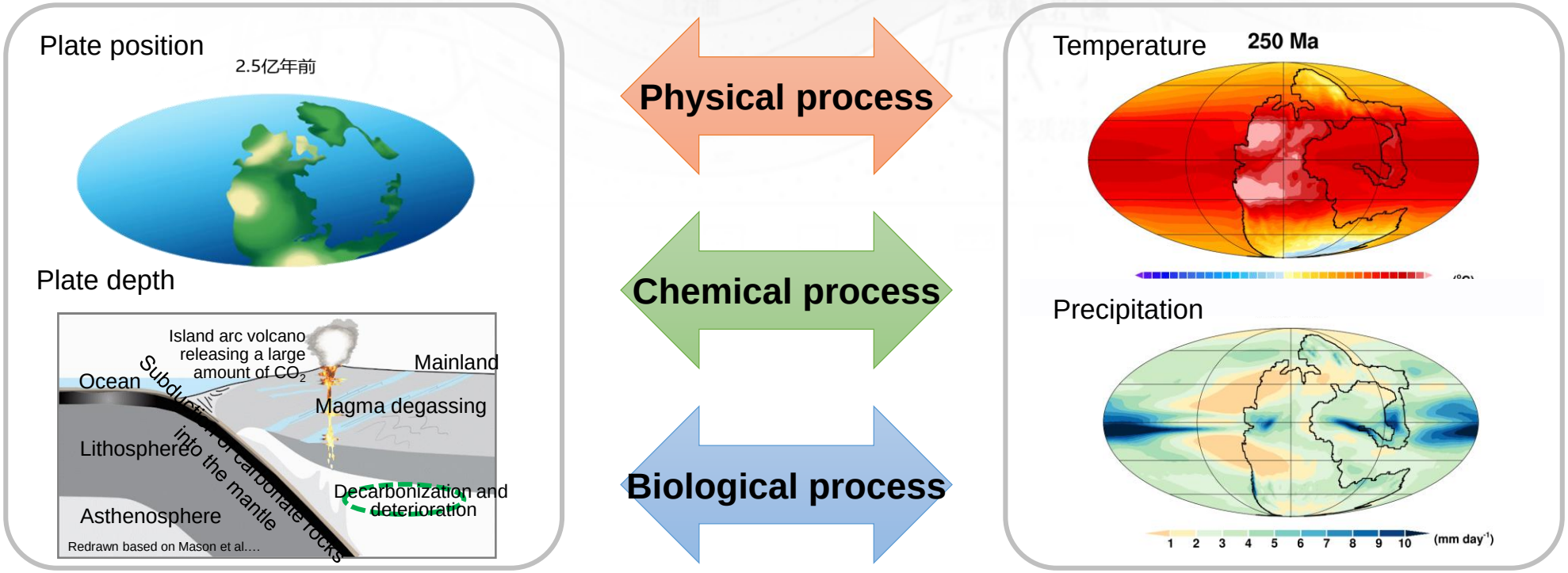
Earth's sphere interaction diagram from Chinese scientists:

Main interactions among Earth's internal structure and the lithosphere, hydrosphere, biosphere, atmosphere, with solid Earth as carrier.

(National Key Laboratory System Layout Geoscience Group B, 2023)

1. Basic Concept & Research Background

Multi-sphere interaction - A new breakthrough in Earth Science



Plates's continuous drifting, colliding, and subducting, changing the location, depth, and nature on Earth

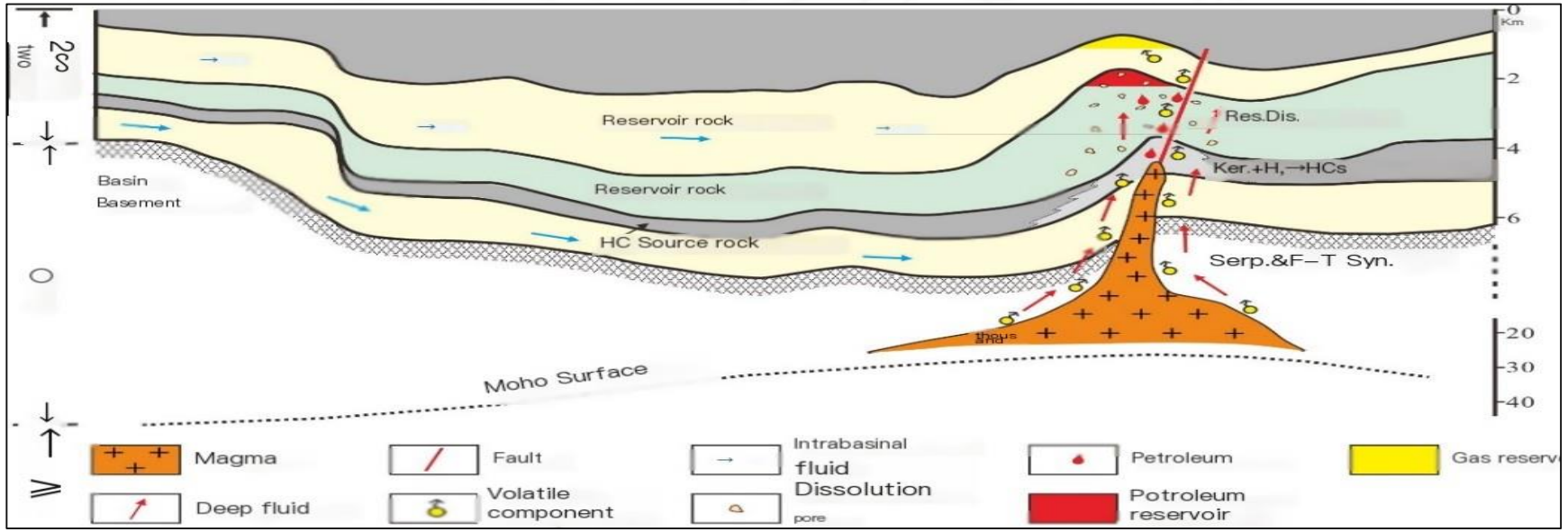
Climate's continuous changing, affecting on the continental environment and resources

Solid sphere + surface sphere: two 4D (time + space) material & energy flows
accompanying interactions among physical, chemical, and biological processes influence the Earth's climate, environment, resources, and energy, etc.

1. Basic Concept & Research Background

Deep fluids – key to multi-sphere interaction

- **Deep fluids are key to studying multi-sphere interaction –** if multi-sphere interaction is key to studying Earth system science
- Deep fluids – a critical key to understanding multi-layer interaction and their impacts on resources and environment, with profound implications for Earth's internal dynamics and habitability (interdisciplinary integration and significant scientific value) .



Interactions between deep fluids and the generation and accumulation of oil and gas in basins (Zhijun Jin, et al., 2007)

Direct impact (matter and energy)

- Deep fluids with volatiles (CO_2, H_2, CH_4, He, etc.) can directly accumulate into basins
- Hydrogenation enhances the hydrocarbon generation rate; promotes hydrocarbon expulsion from source rocks and oil and gas migration; dissolves and reforms (carbonate) reservoirs
- Geothermal/hot dry rock and various metallic deposits

Indirect impact (energy)

- Promote hydrocarbon generation from organic matter, forming hydrothermal petroleum
- Promote kerogen thermal evolution in hydrocarbon source rocks
- Promote crude oil thermal alteration to produce heavy oil or pyrobitumen

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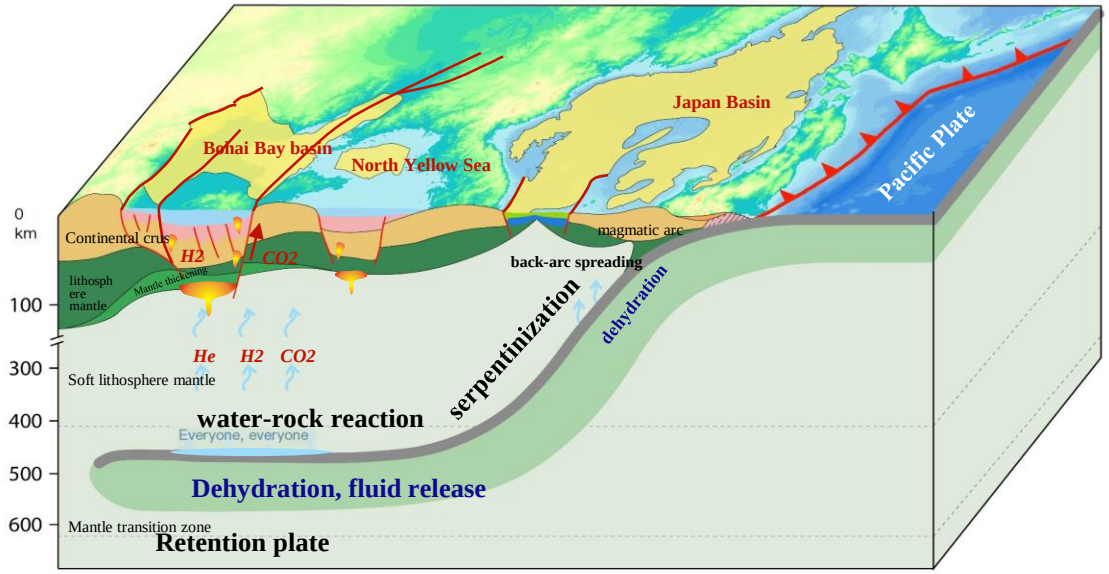
2. Scientific Questions & Research Status

◆ **Scientific question: Earth's multi-sphere interaction and its impact on resources & environment**

1. **Crust-mantle geological structure and deep fluids formation and evolution?**
2. **Impact of deep fluid activity on sedimentary environment and climate evolution?**
3. **Formation and distribution of deep fluids and various energy resources (oil, natural gas, natural hydrogen, geothermal energy, gold, etc.)?**



Q1: Crust-mantle geological structure and deep fluids formation and evolution?

◆ **Crust-mantle interaction – KEY to the formation of molten fluids in crust and mantle.**

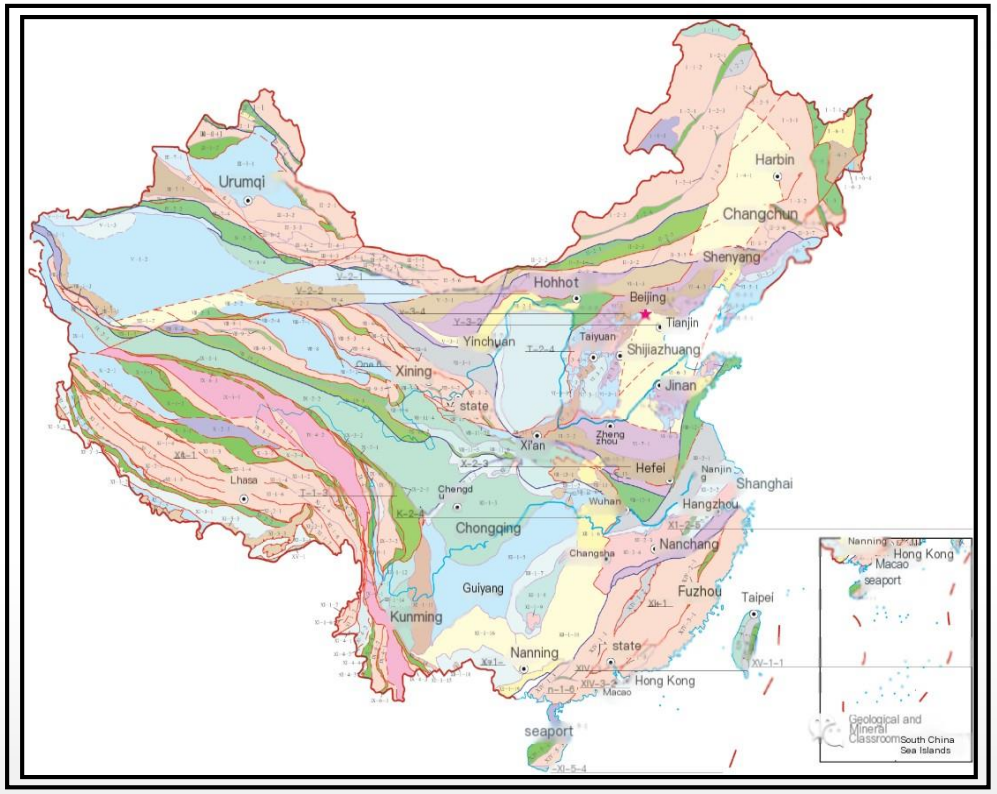
- ☐ **Mantle fluids formation**
- ☐ **Water impact on plate tectonics**
- ☐ **Water cycle and deep fluids formation**
- ☐ **Interaction between subducting plate and transition zone of hydrous mantle**

2. Scientific Questions & Research Status

Q1: Crust-mantle geological structure and deep fluids formation and evolution?

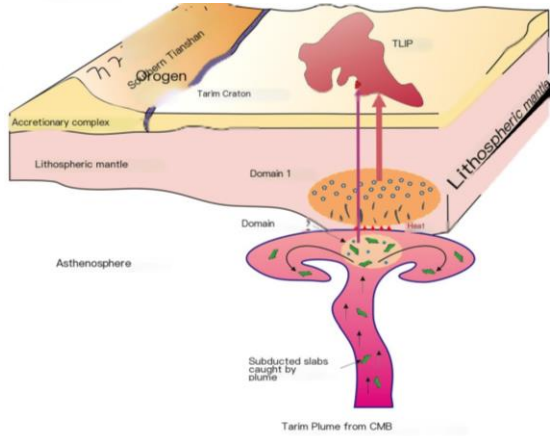
◆ Case study - Deep processes in East Asia-West Pacific

- **Central-Western and Eastern basin's differences in deep geodynamic settings – control the types of deep geological processes and fluid properties.**



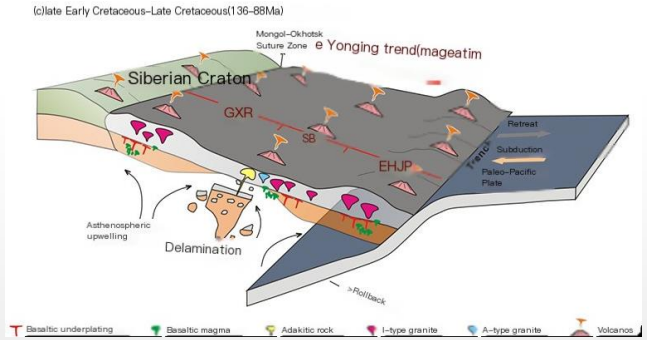
Tectonic Zoning Map of China (Internet Resource)

Central-western Basin:
Mantle plume and collision setting



Zhiguo Cheng, et al., 2018

Eastern Basin:
Ocean-continent subduction setting



Zheng Ji et al., 2019

2. Scientific Questions & Research Status

Q1: Crust-mantle geological structure and deep fluids formation and evolution?

◆ International funding: U.S. NSF and European Commission

U.S. National Science Foundation

Collaborative Research: Crust-Mantle Interactions During Continental Growth and High-pressure Rock Exhumation at an Oblique Arc-Continent collision Zone: SE Caribbean Margin

NSF Org:	EAR Division Of Earth Sciences
Recipient:	WILLIAM MARSH RICE UNIVERSITY
Initial Amendment Date:	September 12, 2001
Latest Amendment Date:	March 17, 2009

Collaborative Research: Dynamics of Crust-Mantle Coupling through Combined Analysis and Modeling of EarthScope seismic, Geodetic, and geologic data

Lead PI: Dr. James L. Davis

Unit Affiliation: Seismology, Geology and Tectonophysics, Lamont-Doherty Earth Observatory (LDEO)

Date: August 2011 - July 2014 ○ Inactive

Location: North America

Project Type: Research

European Commission

European Research Council

AUGURY
Reconstructing Earth's mantle convection

Reconstructing Earth's mantle convection

Project Information

From 2014 to 2020

AUGURY

Grant agreement ID: 617588

Project closed

Start date 1 March 2014

End date 29 February 2020

Funded under

Specific programme: "Ideas" implementing the Seventh Framework Programme of the European Community for research, technological development and demonstration activities(2007 to 2013)

Total cost €1.994000,00

EU contribution €1.994000,00

Coordinated by ECOLE NORMALE SUPERIEURE

France

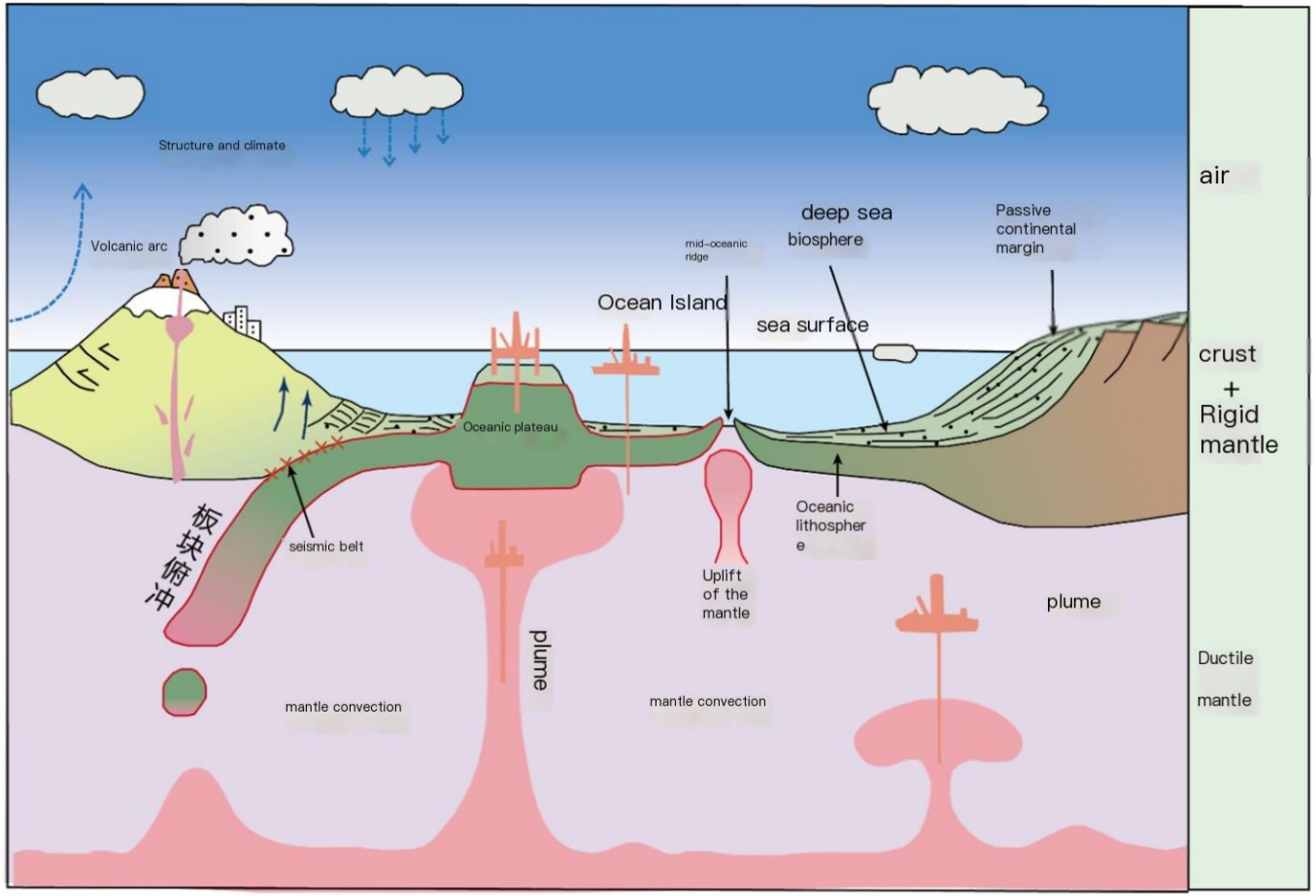
1.94 million euros

Mantle convection theory is the centerpiece to unravel the present and past state of the mantle. **The scope of this project is to produce a new generation of tectonic and convection reconstructions, which are key to improve our understanding and knowledge of the evolution of the solid Earth.** The development of sustainable high performance numerical models will set new standards for geodynamic data assimilation. The outcome of the AUGURY project will be a new generation of models crucial to a wide variety of disciplines.

2. Scientific Questions & Research Status

Q2: How do deep fluid activities impact environment & climate

- Earth's internal tectonic activities primarily involve **plate tectonics** and **mantle convection**, which at the crustal level trigger **earthquakes**, **volcanic eruptions**, **landslides**, **ground fissures**, **mountain uplift**, and **rifting**.
- Above activities not only alter the internal **distribution of matter and energy**, also significantly impact the **surface climate** and **ecosystem** through material and energy exchange.



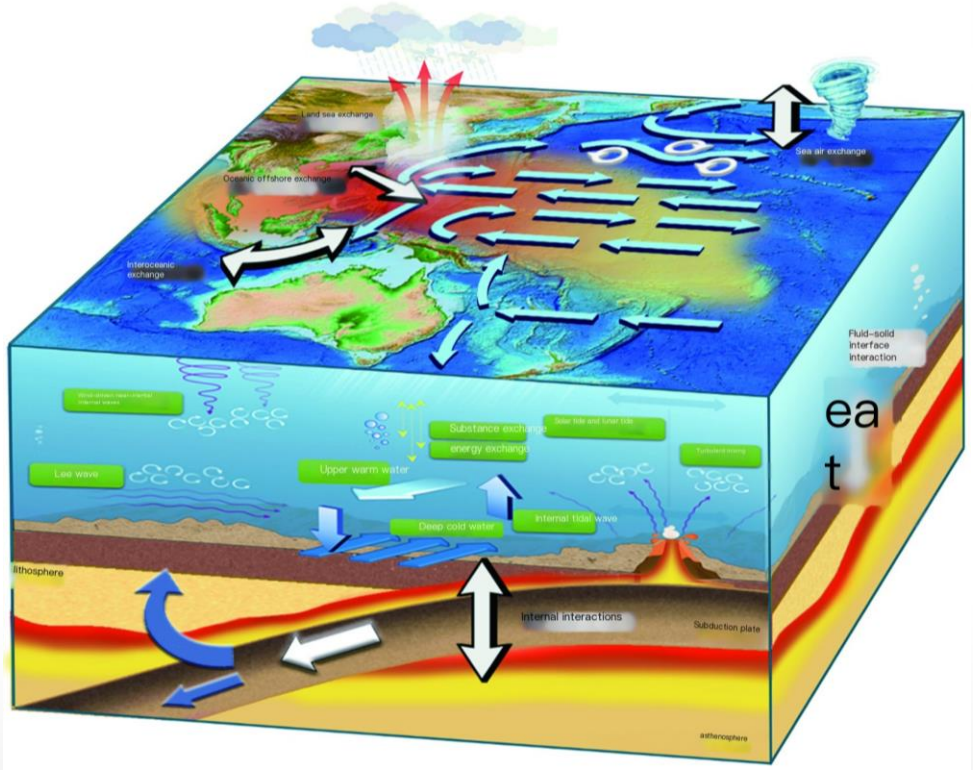
Schematic diagram – impact of perturbations the Earth's internal system on the Earth's surface environment (Zheng et al., 2024)

2. Scientific Questions & Research Status

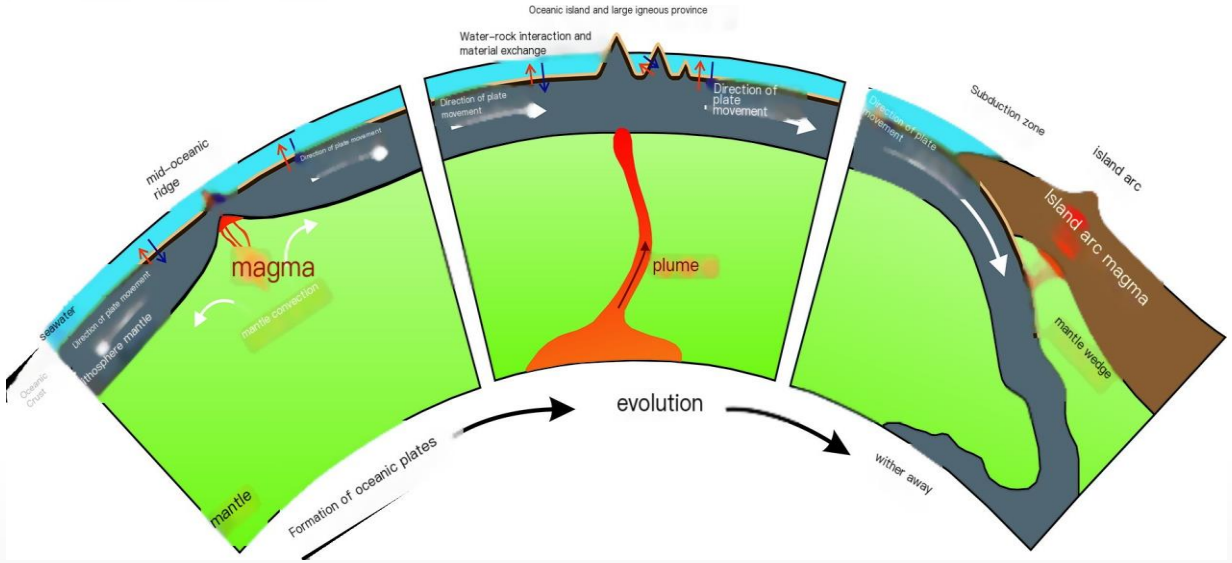
Q2: How do deep fluid activities impact environment & climate

◆ Major Project - Multi-sphere interaction of Earth system in the Western Pacific(Wu et al., 2022)

- ☐ Significant climatic effects of marine material and energy circulation;
- ☐ Coupling process between ocean and lithosphere and Earth's habitability;
- ☐ Control laws of plate subduction processes on element migration and mineralization.



Schematic diagram of multi-sphere coupling in the Earth system
Source: Major Research Plan on Multi-sphere Interaction in the Western Pacific Earth System



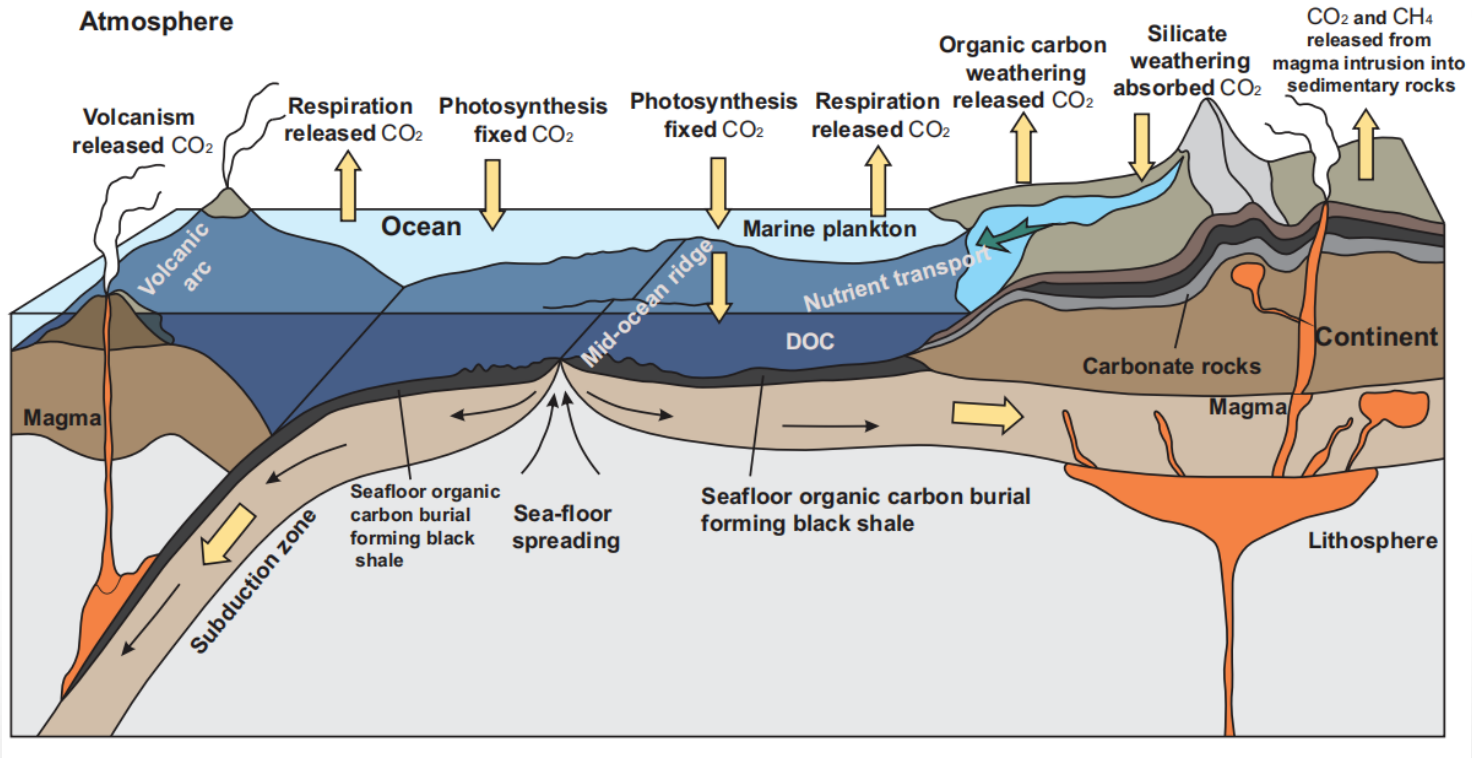
Coupling processes of the oceanic lithosphere and the formation, evolution, and disappearance of oceanic plates (Wu, et al., 2022)

2. Scientific Questions & Research Status

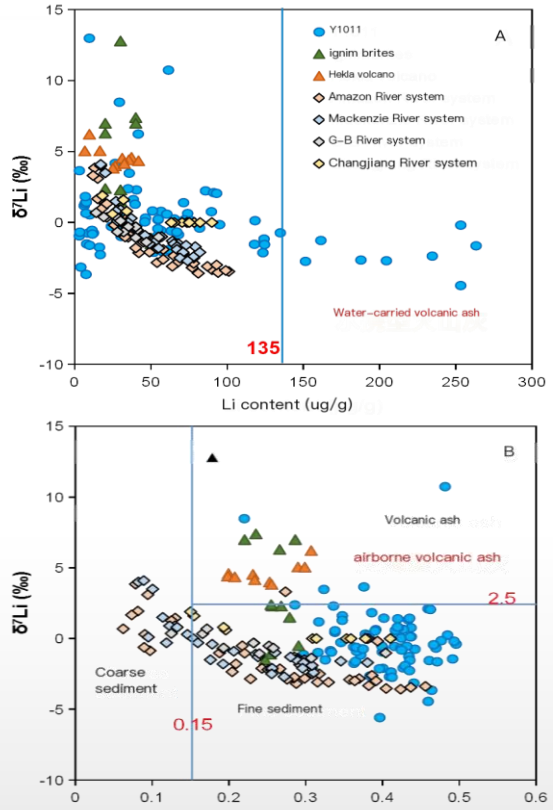
Q2: How do deep fluid activities impact environment & climate

◆ Case study - Impact of volcanic activity on climate and environment and its relationship with organic-rich black shale

- Deposition mode of black shale under the influence of sphere interactions, where volcanic activity affects the evolution of the atmosphere, hydrosphere, and biosphere, promoting the formation of organic-rich shale
- A volcanic ash type identification chart, where high δ^7Li (> 2.5‰) indicates airborne volcanic ash, and high lithium content (> 135 μg/g) indicates water-carried volcanic ash



Organic carbon cycle and black shale development driven by Earth's sphere interactions (Jin et al., 2023. NSR)



(Liu et al., 2024 SA)

2. Scientific Questions & Research Status

Q2: How do deep fluid activities impact environment & climate

◆ International project: Deep Carbon Observatory plan – National Academy of Science

- **Recent years, growing international attentions to deep-fluid-associated resources, with active efforts on the exploration and utilization.**

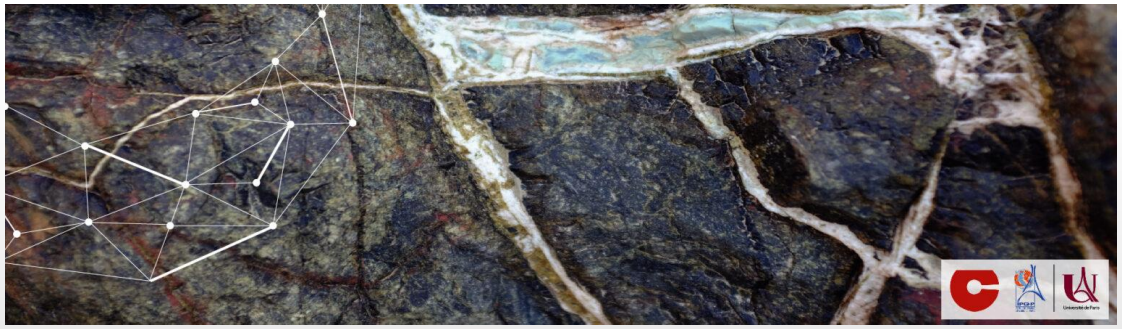
- **Deep Carbon Observatory (DCO, 2011-2020, $500 million)**
- **Four major themes**

Extreme Physics and Chemistry

Reservoirs and Fluxes

Deep Energy

Deep Life



DEEP CARBON OBSERVATORY

Abbreviation	DCO
Formation	2009
Purpose	Transforming our understanding of carbon in Earth's interior
Membership	957 scientists from 47 countries (as of January 2017)[1]
Website	"deepcarbon.science".

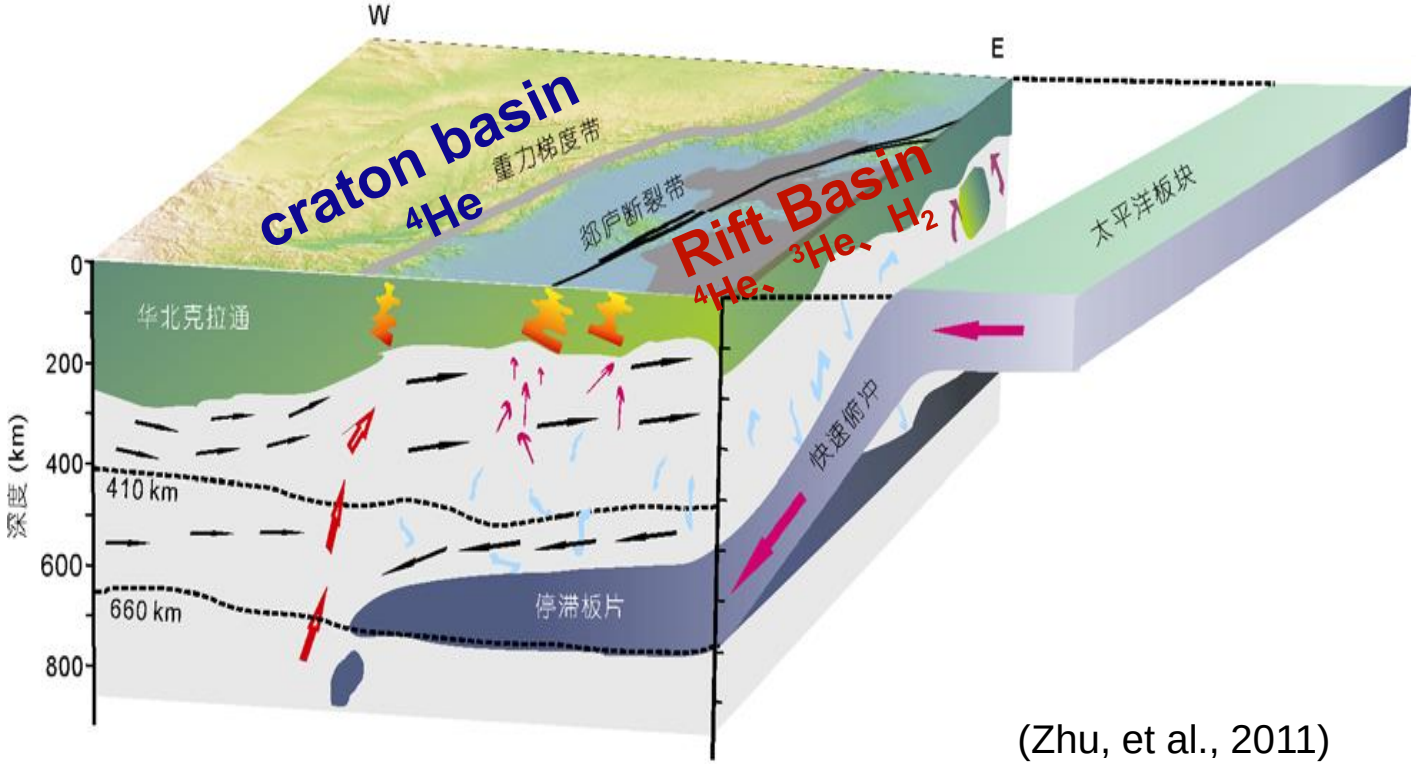
1,000 scientists from over 47 countries have participated in the program

2. Scientific Questions & Research Status

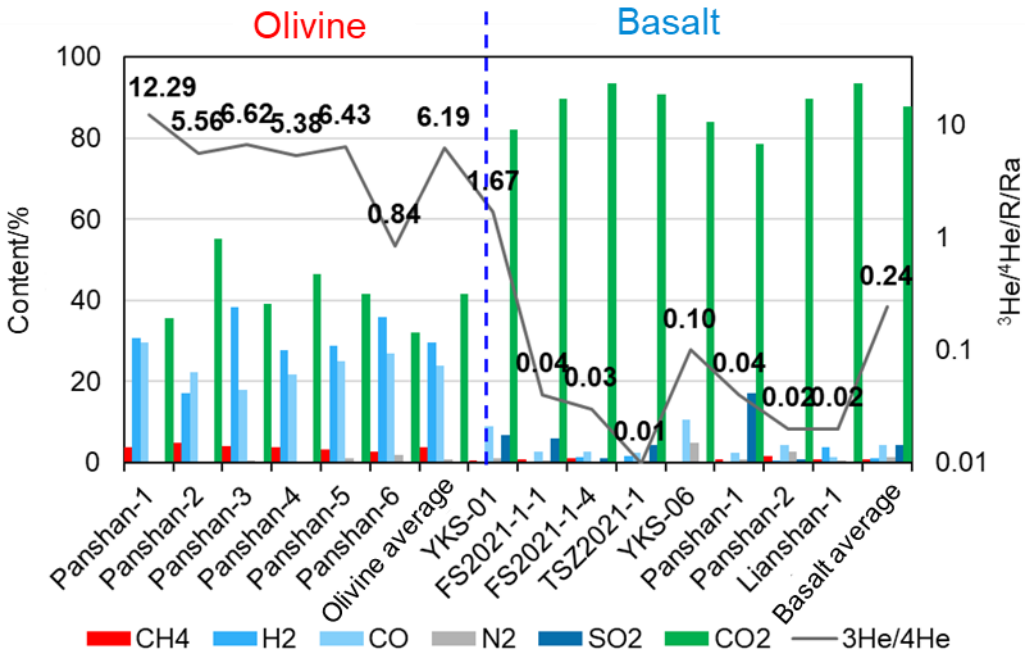
Q3: The relationship between Deep fluids migration and energy resources distribution?

◆ Case study - Sedimentary basins with the deep flow influence

- The Bohai Bay and Songliao Basins are large oil and gas basins where deep fluids are most active in China, featuring diverse types of oil and gas resources and immense potential.
- The subduction of the western Pacific promotes the interaction between deep fluids and surrounding rocks in different lithospheric layers, which is expected to lead to the discovery of H_2, geothermal, and metallic mineral deposits.



(Zhu, et al., 2011)



Thermal release gas components of volcanic rocks in eastern China

2. Scientific Questions & Research Status

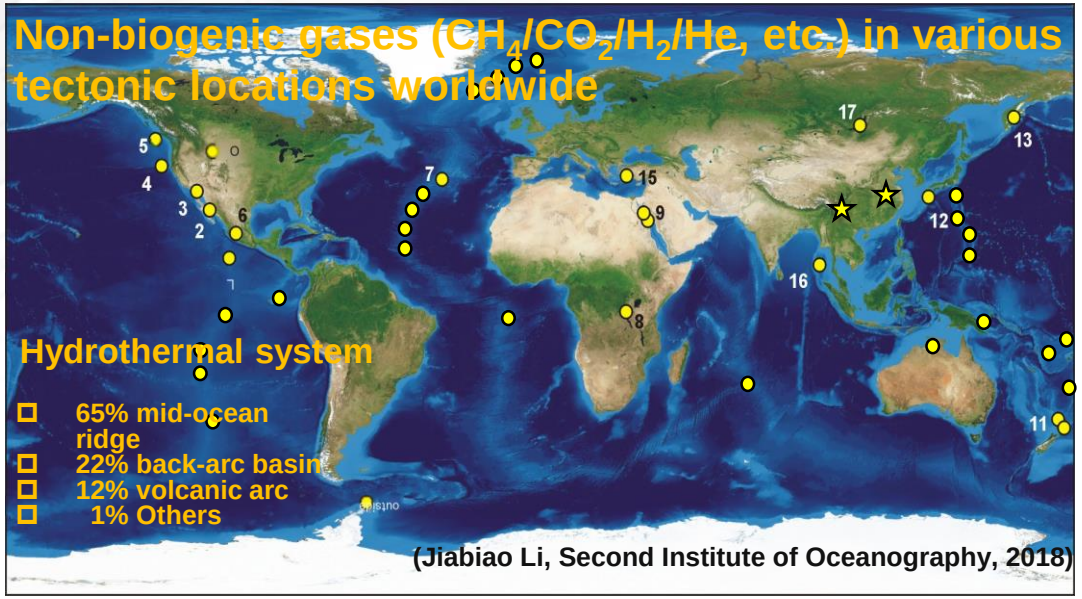
Q3: The relationship between Deep fluids migration and energy resources distribution?

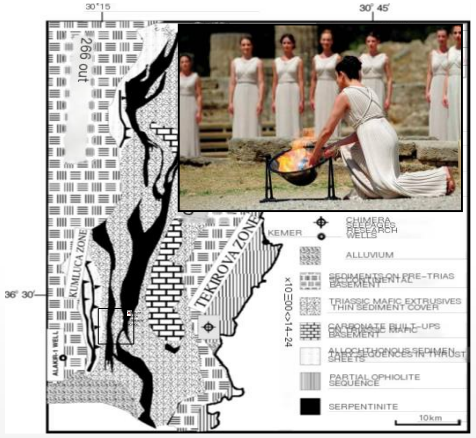
◆ **Case study - Non-biogenic gases (He, H_2, CH_4, etc.)**

◆ **Abundant production of deep non-biological resources**

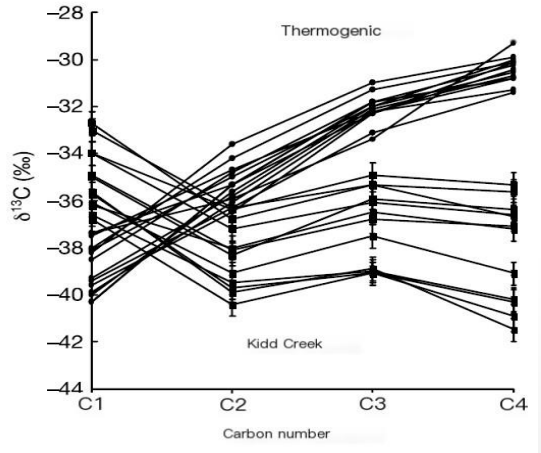
- Special oil and gas indications (such as hydrothermal oil, CH_4, CO_2, H_2, He, etc.) different from those found in traditional oil and gas reservoirs have been discovered in tectonic locations such as continental/oceanic drilling sites, mid-ocean ridges, volcanic vents, and hot springs
- Geochemical characteristics of oil and gas differ from those formed by typical organic genesis, specifically non-biogenic gas (inorganic gas)
- Combustible gases found in nature have been burning continuously for thousands of years

Specific research has been conducted for over 200 years





Origin of the Chimera Olympic Flame in Türkiye
(Hosgormez et al., 2007)



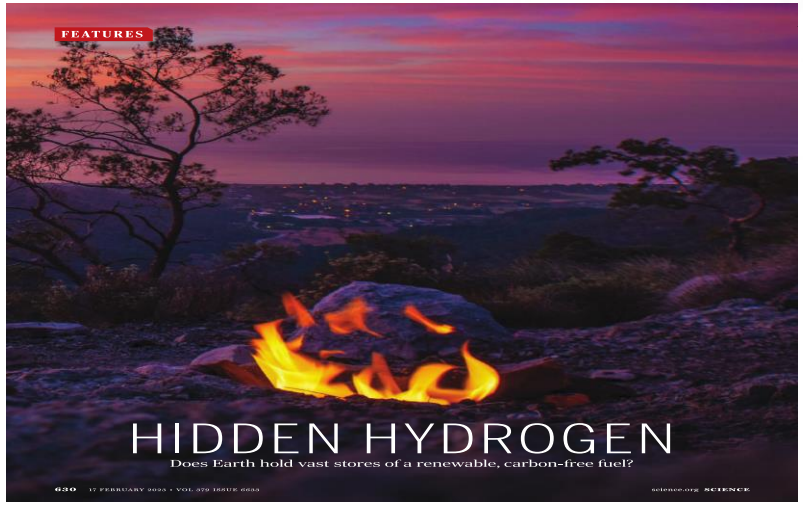
Canadian Shield non-biogenic alkanes
(Sherwood Lollar et al., Nature, 2002)

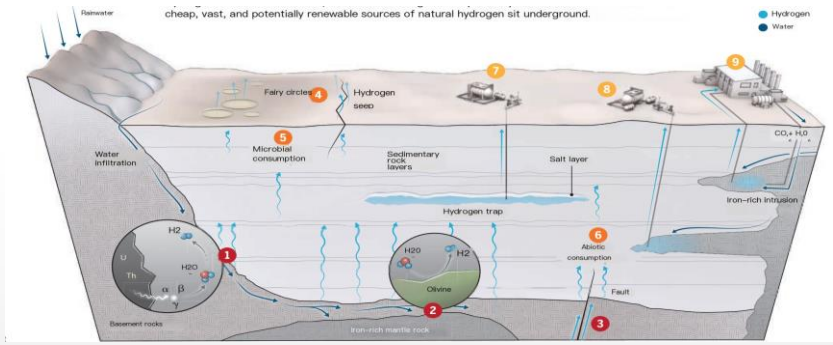
2. Scientific Questions & Research Status

Q3: The relationship between Deep fluids migration and energy resources distribution?

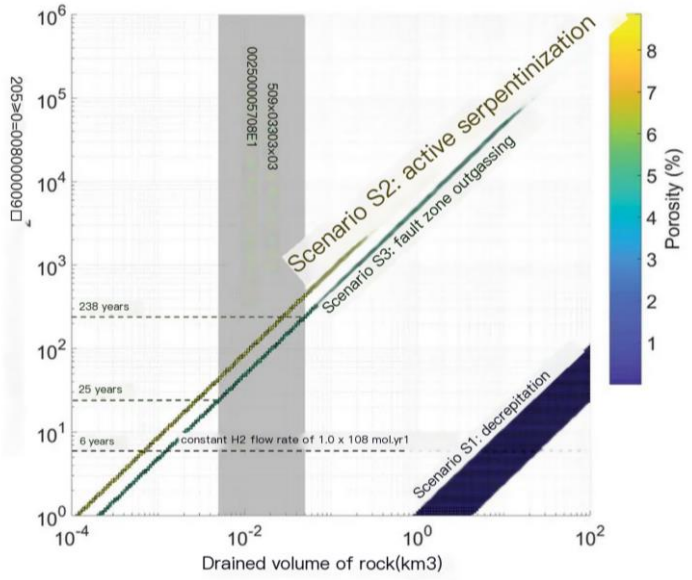
◆ Case study - Non-biogenic gases such as He, H_2, CH_4, etc.

- H_2 is not only a scarce and precious resource, also a frontier in global energy research Selected as ten scientific breakthrough by Science (2023)



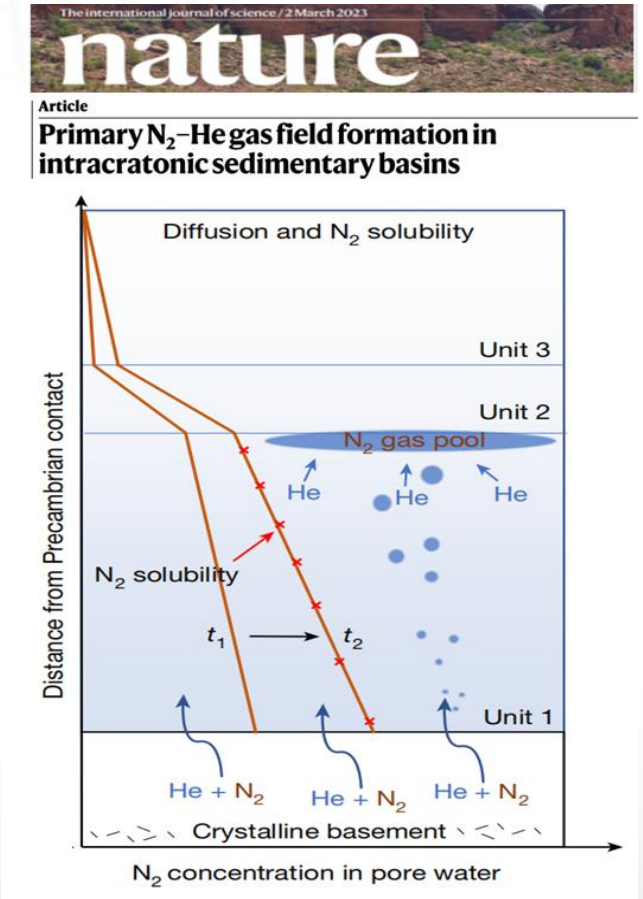


Schematic diagram of underground hydrogen production facility (Hand Erick, Science, 2023)



H2 outgassing site	H2 flow (t/yr)	H2 (vol%)
Oman, Haylayn pool (bubbles + diffuse)	0.158	86.4
Oman, Misfah pool (bubbles + diffuse)	0.056	66.9
Turkey, Chimaera (diffuse dry seeps)	3.5	9.9
Albania, Bulqize mine. L19 pool (focused bubbling)	11	84.0
Albania, Bulqize mine, L17 tectonic zone (boreholes)	42	1.20
Albania, Bulqize mine, level L19(shaft N9)	158	0.40

High-flow H_2 was discovered in the Bulqizë chromite mine in Albania (Truche Laurent et al., Science, 2024)



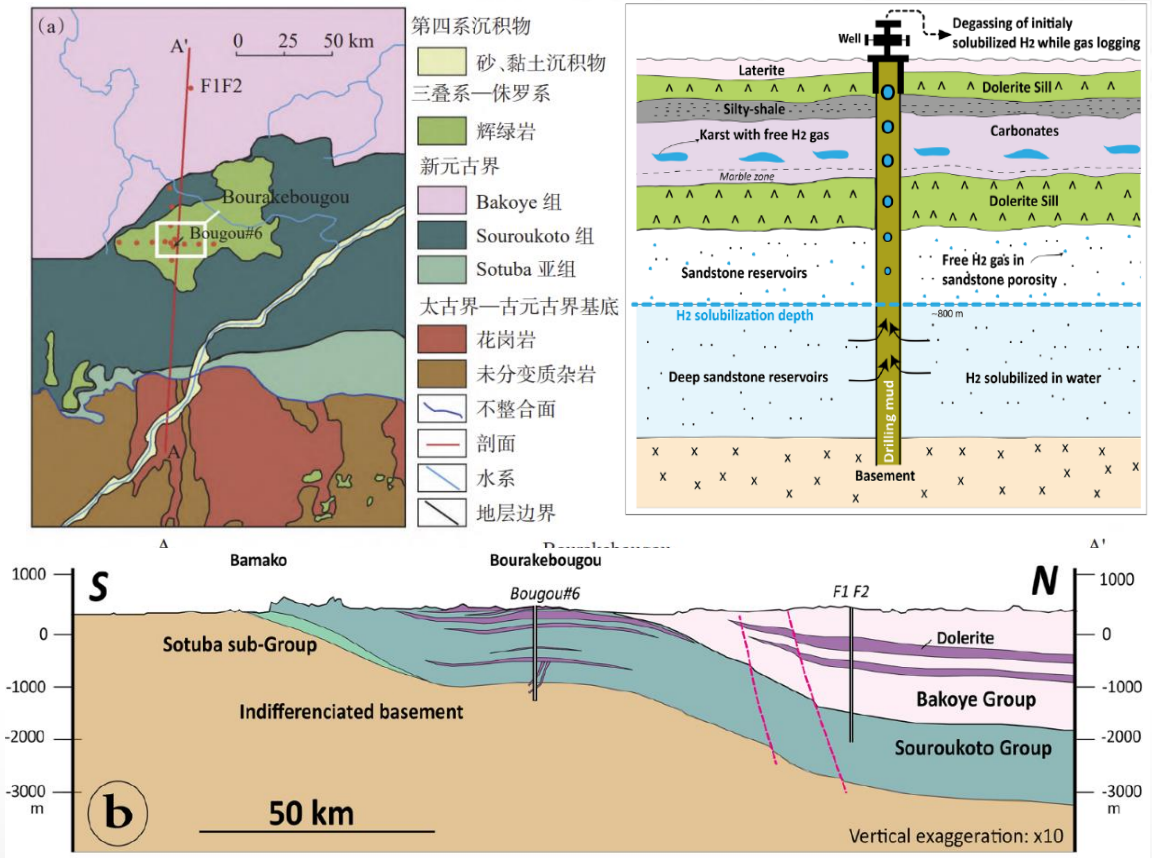
He is associated with the formation of mineral deposits (Cheng Anran et al., Nature, 2023)

2. Scientific Questions & Research Status

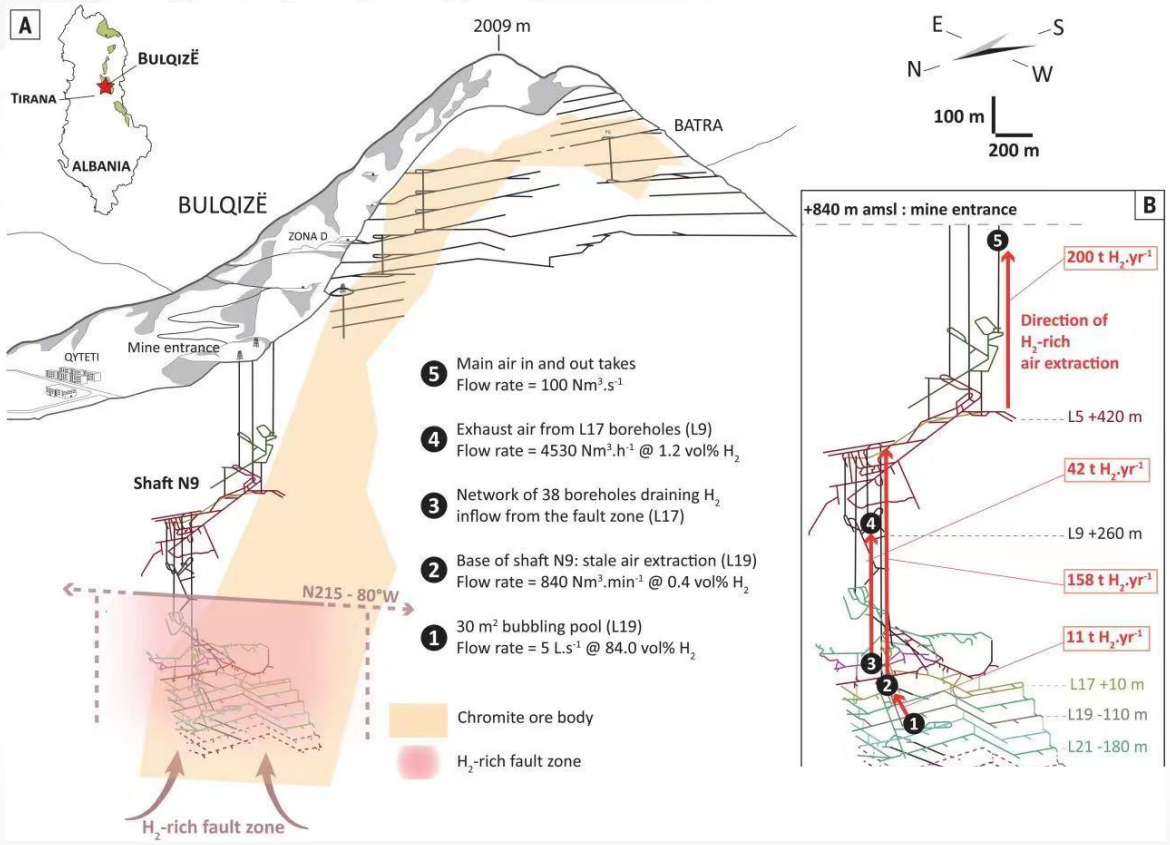
Q3: The relationship between Deep fluids migration and energy resources distribution?

◆ Case study - Non-biogenic gases such as He, H_2, CH_4, etc.

- **natural hydrogen systems in Mali and Albania show commercial viability**



The geologic background of the hydrogen systems in Mali and its accumulation pattern (Maiga et al., 2024)

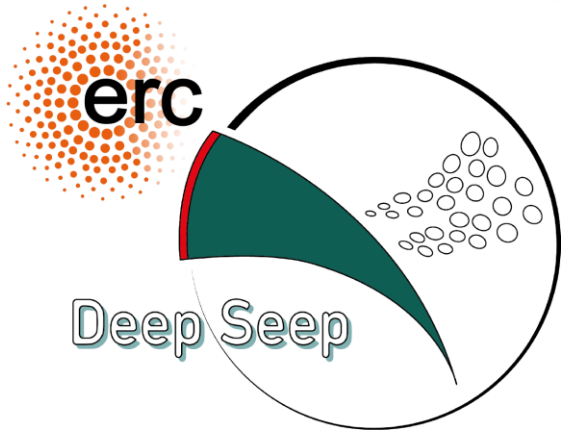


Schematic diagram of underground chromite mine in Bulqizë, Albania, (A) underground deep section indicating the location of H_2 fault zone, (B) location for measuring H_2 degassing rate (Truche et al., 2024)

2. Scientific Questions & Research Status

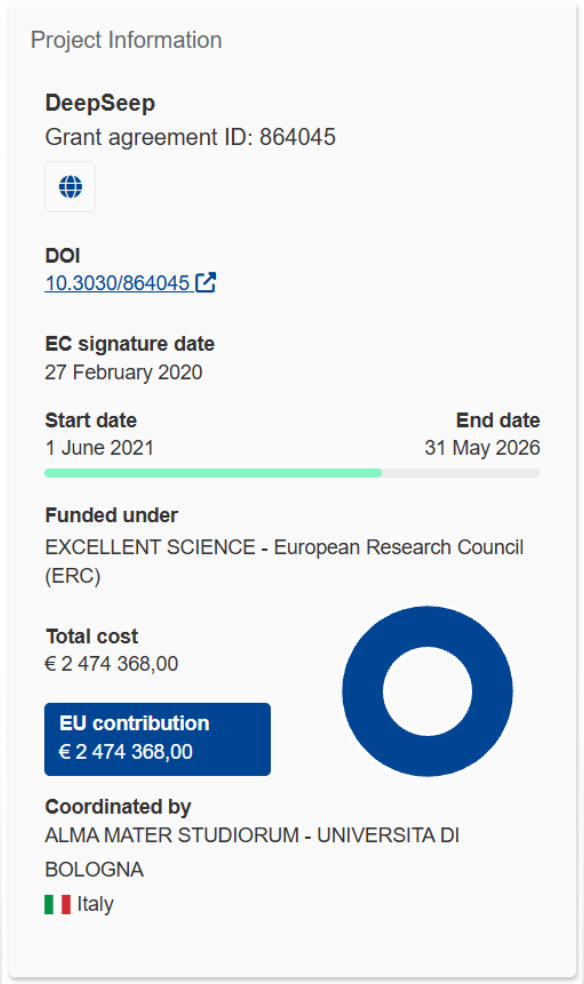
Q3: The relationship between Deep fluids migration and energy resources distribution?

- **International project: European Research Council's Deep Seep Program, focusing on non-biogenic H_2 and CH_4 resources**
  - **Growing international focus on deep fluids, given that deep crust–mantle material cycling profoundly influences the enrichment of near-surface resources.**



ERC "Deep Seep" 2020 Horizon Project

Deep Serpentinization and H_2 and High-Pressure Abiotic CH_4 (June 2021 - May 2026) (EUR 2.47 million)

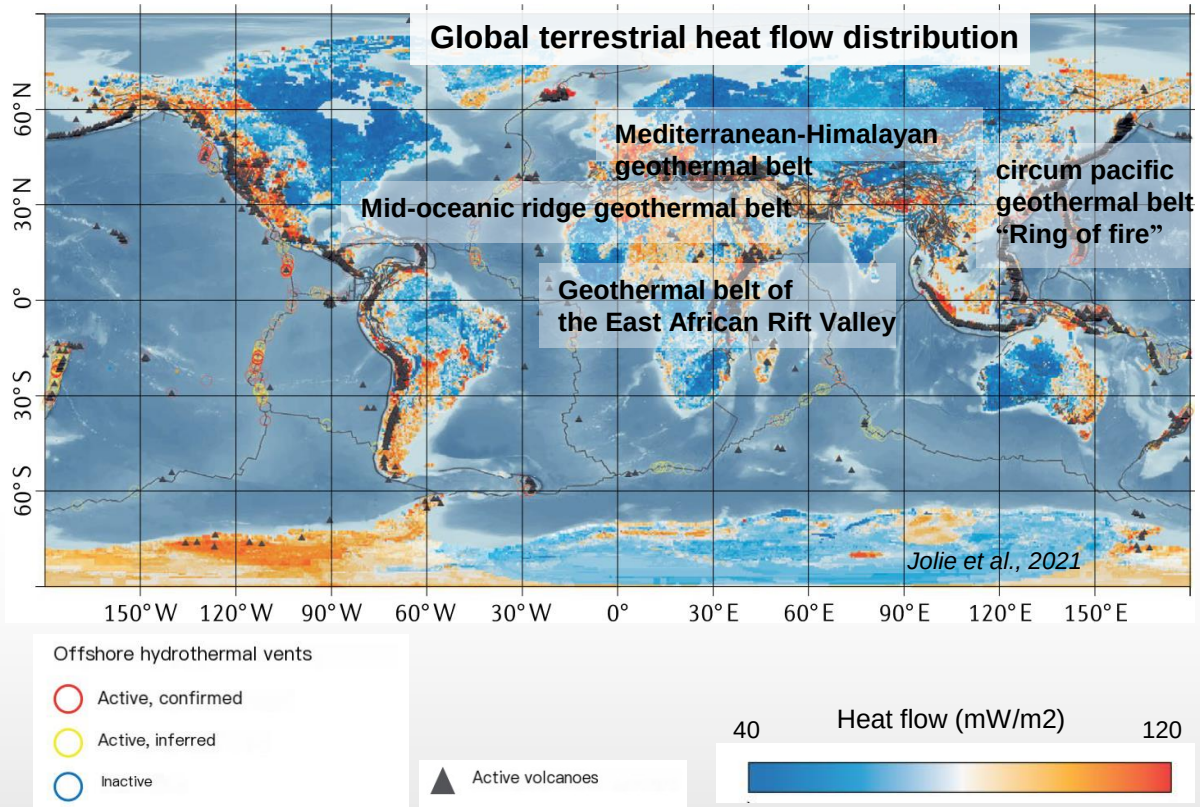


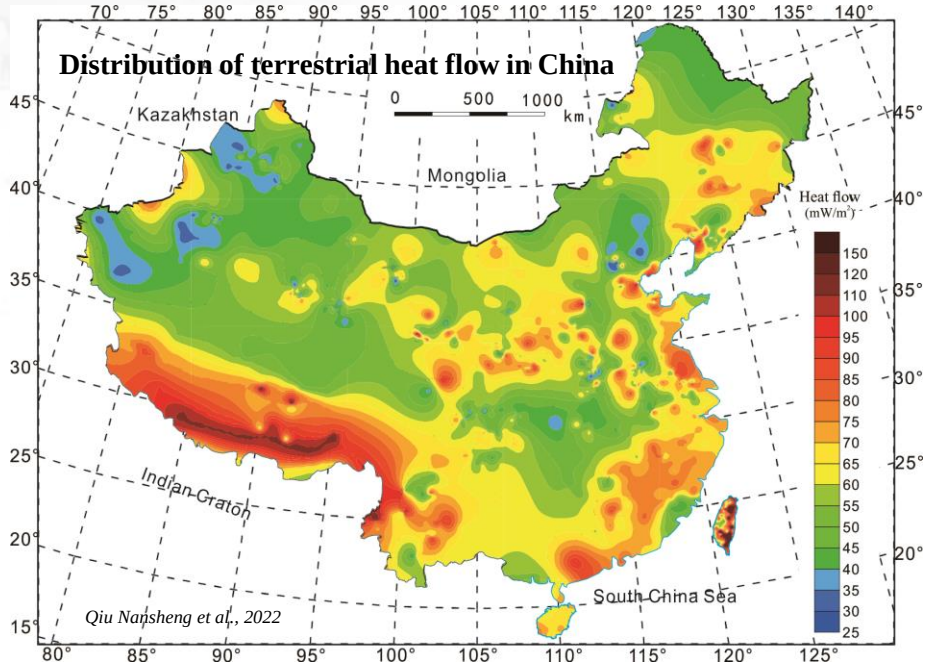
2. Scientific Questions & Research Status

Q3: The relationship between Deep fluids migration and energy resources distribution?

◆ Case study – geothermal resources

- Global deep geothermal resources are primarily distributed across four key geothermal belts
- China's deep geothermal resources are primarily controlled by the Mediterranean-Himalayan geothermal belt and the circum-Pacific geothermal belt, with significant development potential in the Qinghai-Tibet Plateau and eastern coastal areas

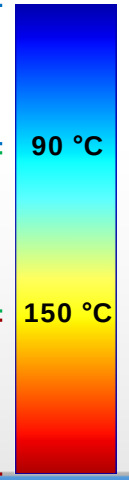




Shallow geothermal resources
9.49 billion tons of SCE

Medium-deep geothermal resources
860 billion tons of SCE

Deep geothermal resources
860 trillion tons of SCE



China is estimated to possess 860 trillion tons of standard coal equivalent (SCE) in deep geothermal resources. Assuming a recoverability rate of 2%, the exploitable amount is equivalent to 3000 times China's total energy consumption in 2023.

2. Scientific Questions & Research Status

Q3: The relationship between Deep fluids migration and energy resources distribution?

◆ Foreign plans: geothermal resources

BRIEFING

Requested by the ITRE Committee

European Parliament

Innovative technologies in the development of geothermal energy in Europe

KEY FINDINGS

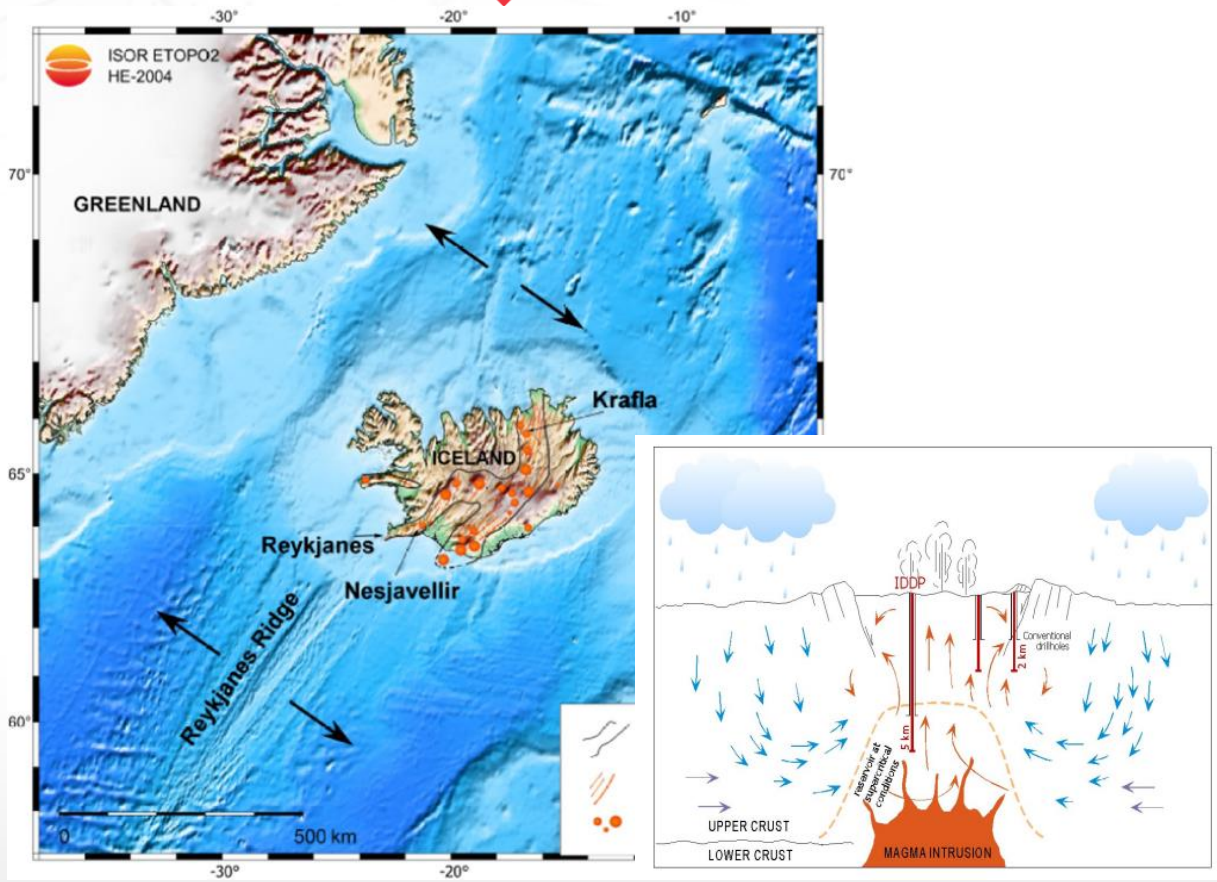
Innovative technologies in the field of geothermal energy focus on three areas: (i) resource assessment, (ii) resource development, and (iii) resource utilisation and management for electricity, heat supply and mineral extraction (lithium). They include increased electric power system efficiency, novel and optimised drilling technologies, underground thermal energy storage, new exploration methods, closed loops, smart systems, and 3D models.

Advanced plants and technologies include ultra-deep geothermal systems, enhanced geothermal systems, advanced geothermal systems, supercritical geothermal systems. They allow access to vast geothermal resources, which would otherwise remain largely unexploited. Advanced geothermal systems have ongoing commercially viable projects in the US and Europe.

Ground source geothermal heating and cooling is a well-established technology, which is currently experiencing the opening of new markets and continuous growth. Geothermal heat pumps are among the most-performant energy-efficient technologies to transfer heat from/to the ground for heating and cooling buildings. Innovation focus here is on new materials and investment costs reduction.

Innovative technologies for the development of geothermal energy in Europe

IDDP Iceland Deep Drilling Project



Geothermal plan of Iceland Deep Drilling Project (IDDP)

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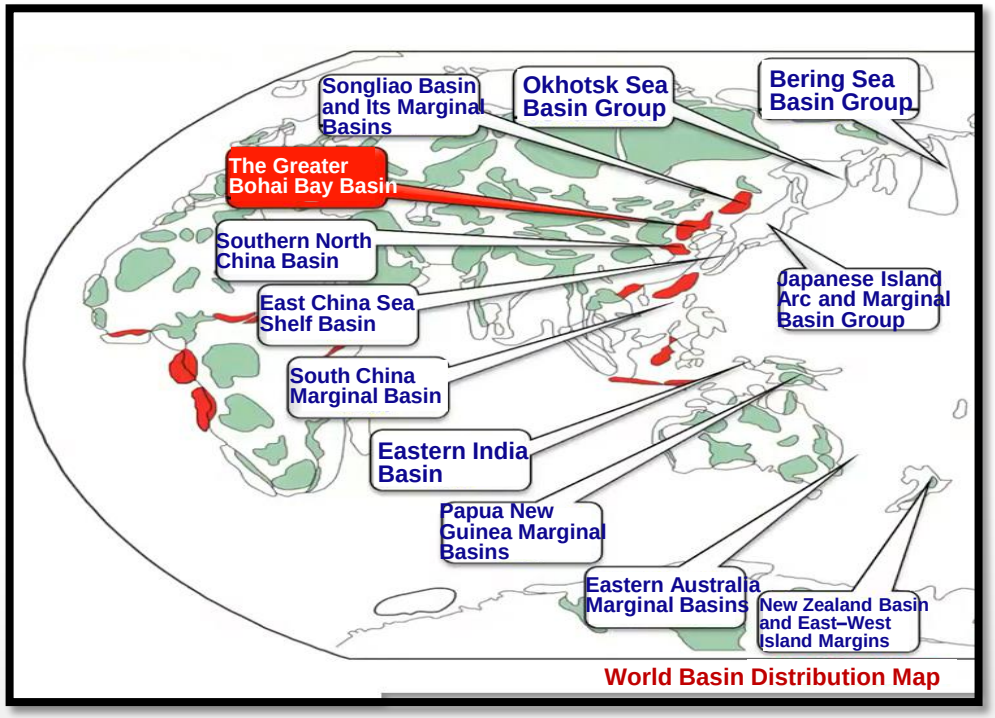
3. Future Directions & Scientific Objectives

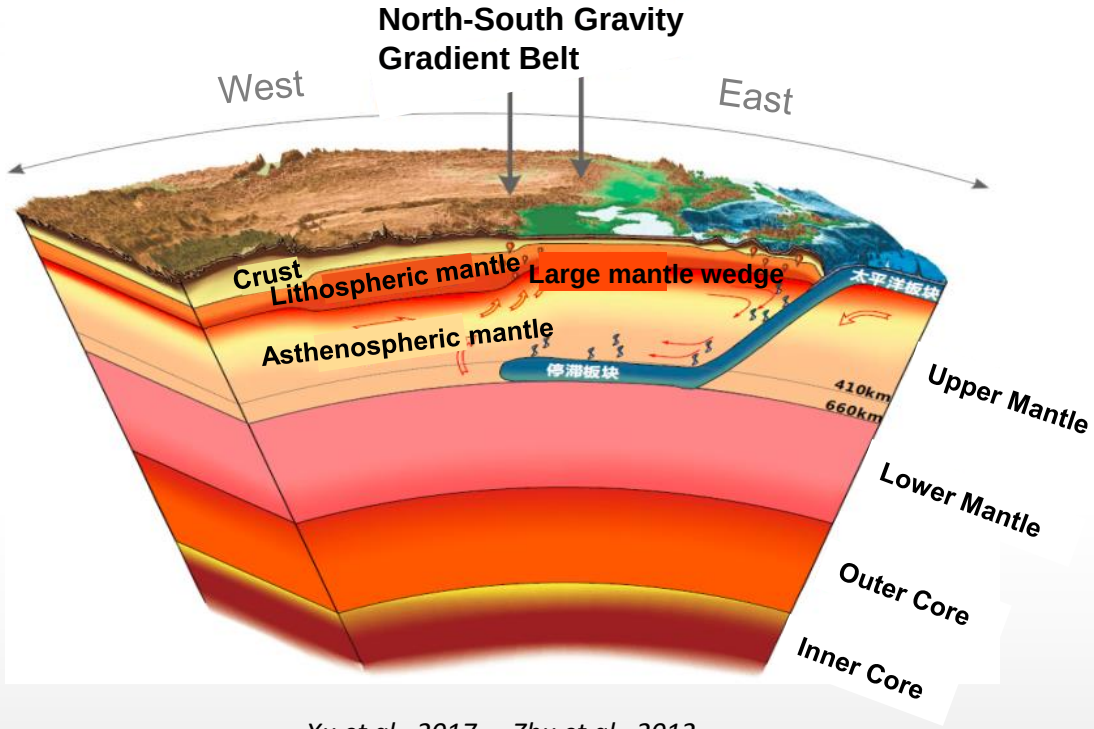
Why East Asia–Western Pacific?

◆ **East Asia–Western Pacific region offers an optimal setting for investigating deep fluids, multi-sphere interaction and their impacts on resources and environment.**

Deep earth processes and basin formation & evolution in the East Asia–Western Pacific land–ocean transition zone

Pacific Plate subduction triggered Meso-Cenozoic tectonic evolution and magmatic activity, contributing to the destruction of the eastern North China Craton and the formation of a series of rift basins, with significant implications for resources and the environment.





Xu et al., 2017； Zhu et al., 2012

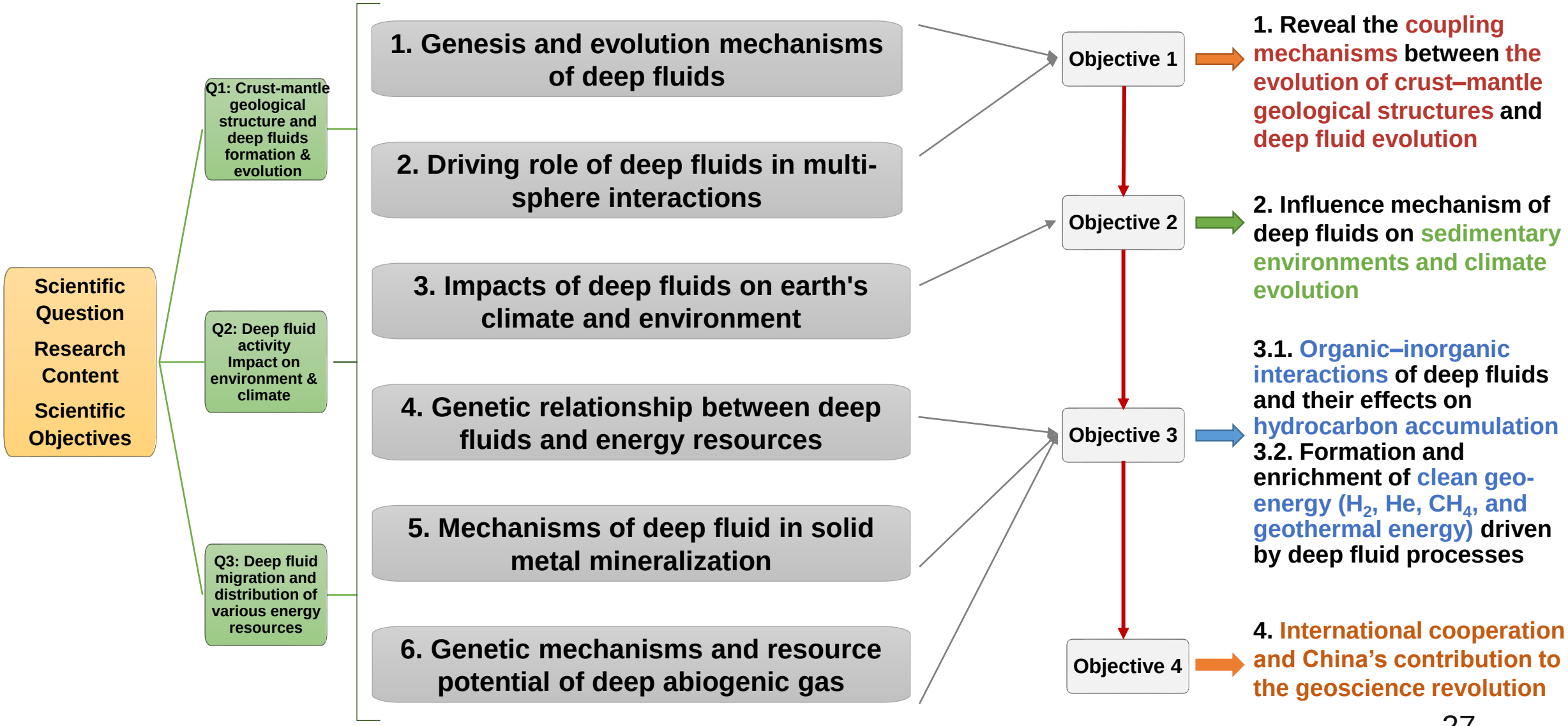
Significant impact of Western Pacific subduction and the evolution of the overlying mantle wedge on the formation of East Asian basins

Research Framework

Deep fluids provide essential pathway for probing the multi-sphere interactions.

1. **Focus on the coupled evolution mechanisms of geological, physical, chemical, and biological processes;**
2. **Focus on the mechanisms of organic–inorganic interactions;**
3. **Focus on the interactions between crust–mantle and intra-basin fluids;**
4. **Focus on the mechanisms linking abrupt environmental changes to the formation and enrichment of various types of resources.**

3. Future Directions & Scientific Objectives



Invitation

Warmly Welcome Russian scholars (Professors, Engineers, Postdocs, Graduate students) to join our research program!

Thank you!