International Workshop

Lithospheric Evolution and Earth's Habitability

WORKSHOP MANUAL

21-25, July 2025

Beijing, China

INSTITUTE OF GEOLOGY AND GEOPHYSICS,
CHINESE ACADEMY OF SCIENCES (IGGCAS)

About the workshop

This workshop seeks to transcend traditional disciplinary boundaries by integrating geology, geophysics, geochemistry, and climate science to unravel the first-order controls of lithospheric dynamics on the Earth system's volatile cycle and their cascading impacts on Earth's climate system and habitability. We aim to foster a holistic understanding of the coupling between deep mantle processes, surface tectonics, and climate feedbacks, with a focus on the Tethyan orogenic belt as a natural laboratory for studying these interactions.

The workshop format will allow for open discussion on a wide range of topics related to the lithospheric evolution and habitability of the Earth. The Organizing Committee of the workshop aims to bring together geologists, geophysicists, and geochemists for a comprehensive exchange that will guide our future work on the ongoing studies of the Tethyan tectonic domain.

Hosts

State Key Laboratory of Lithospheric and Environmental Coevolution, Institute of Geology and Geophysics, Chinese Academy of Sciences

National Natural Science Foundation of China

International Lithosphere Program (ILP)

**Funded by the "Major Research Project on Tethys Geodynamic System"*

Organizing committee

Chairs: Liang Zhao, Bo Wan

Co-Chairs: Ling Chen, Huaiyu Yuan

Members: Chenxi Xu, Jianfeng Yang, Yang Chu, Lingtong Meng

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Conference venue

The Lecture Hall on the second floor of the D3 Building, Institute of Geology and Geophysics, Chinese Academy of Sciences

No. 19 Beitucheng western Road, Chaoyang District, Beijing

Accommodation and Transportation

Workshop partner hotel:

LeafIN Hotel Beijing Minzuyuan

1 Minzuyuan Rd , Chaoyang District , Beijing, China

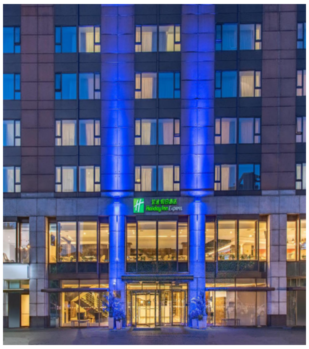
(The organizing committee has already reserved rooms at this hotel for the presenters)

Grand Hotel Yuanshan Beijing

2 Yumin Road, near China Science and Technology Museum, Beijing, China

Excemon Beijing Hongxiang Hotel

No.15 Longxiang Road, Haidian District, Beijing, China



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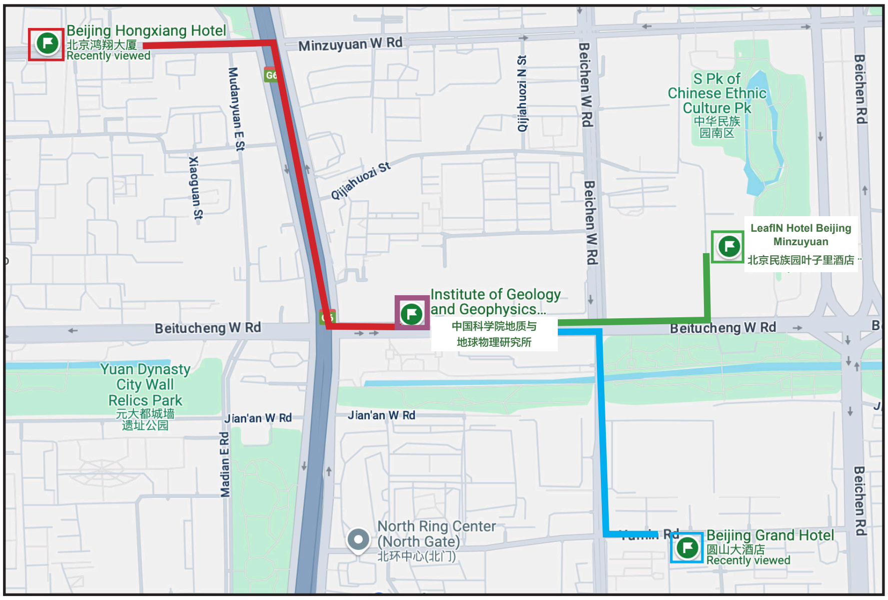

Program

Date	Activity
21 July	Registration
22 - 23 July	Scientific presentation sessions
24 - 25 July	Field Trip, @ Yunmeng Mountain, Beijing **Limited to keynote presenters only*

Registration and Check-in Information

- On July 21, the registration and check-in desk will be located on the first floor of D3 Building and in the lobby of the LeafIN Hotel, open from 10:00 to 19:00. All presenters are requested to upload their presentation slides during this time.
- On July 22, presenters will assemble in the lobby of the LeafIN Hotel at 8:00 and staff will escort the group to IGGCAS.
- On July 22, the check-in desk will be set up on the second floor of D3 Building, open from 07:30 to 10:00.

About the Field Trip

The Late Mesozoic Yunmengshan metamorphic core complex (MCC) is the first recognized MCC in China. Late Jurassic dioritic to granitic rocks and Early Cretaceous granodiorite to granite intruded the Archean basement and its sedimentary cover. They make up the core of the Yunmengshan MCC. The ductile extensional shear zone along the southeastern margin developed between 131–114 Ma (Dashuiyu Shear Zone). It is overprinted by the brittle Hefangkou normal fault, which is associated with the development of the Huairou rift basin on the hanging wall. There will be plenty of opportunities to examine the relationships between the emplacement of the granitic plutons and the ductile–brittle structures that they contain. Multi-phase metamorphism, syn-tectonic magmatism, and crustal thinning provide a natural laboratory for studying lithospheric evolution and the cycling of volatiles.

22 July

Deep Earth and Carbon Cycle

Time	Speaker	Title
	Chair: tbd	
8:30-8:35	Welcome and opening remarks	
8:35-9:00	Gerya, Taras	Long-term biogeodynamical carbon cycle and implications for future climate change
9:00-9:20	Li, Zhengxiang	A living Earth: Its evolution and dynamic inner workings
9:20-9:40	Cloetingh, Sierd	Coupled surface to deep Earth processes: Perspectives from TOPO-EUROPE with an emphasis on climate- and energy-related societal challenges
9:40-10:00	Frezzotti, Maria Luce	Direct insights into diamond formation from deep C-O-H fluids in subduction zones
10:00-10:20	* Scotese, Christopher	Plate Tectonic Reconstructions for the Mesoproterozoic, Neoproterozoic, and Early Paleozoic (1600 Ma – 400 Ma)
10:20-10:50	Break + Group Photo	
	Chair: Artemieva, Irina	
10:50-11:05	3 short presentations	Liu, Jin (10:50-10:55) Chen, Wei (10:55-11:00) Zhang, Lijuan (11:00-11:05)
11:05-11:25	Hu, Qingyang	Monovalent calcium sulfide in Earth's lower mantle
11:25-11:45	Chen, Chunfei	Sulfide-rich continental roots at cratonic margins formed by migration of carbonated melts and their implications for sulfide deposits
11:45-12:05	Vitale Brovarone, Alberto	Tracking fluid inclusion-mediated deep carbon fluxes across orogenic cycles
Lunch		

** : Online*

Earth's System Coupling and Habitability

Time	Speaker	Title
Chair: Spicer, Robert		
14:00-14:20	Zhao, Liang	Revealing Cenozoic climate shifts using seismo-geodynamic constraints
14:20-14:40	Liu, Yonggang	Supercycle: Progress on the Modeling of Surface Processes
14:40-15:00	Cao, Wenrong	Phanerozoic Continental Magmatism: Linking Spatiotemporal Evolution, Isotopic Composition, and Chemical Weathering
15:00-15:20	Man, Wenmin	Hydroclimate responses over global monsoon regions to volcanic eruptions during the last millennium
15:20-15:40	* Ramstein, Gilles	From lithosphere to atmospheric CO_2, a longstanding interactive process regulating Earth's climate
15:40-15:55	Break	
Chair: Zhao, Liang		
15:55-16:10	3 short presentations	Zhao, Mingyu (15:55-16:00) Gao, Liang (16:00-16:05) Deng, Linpei (16:05-16:10)
16:10-16:30	Wu, Haibin	Impact of the Sunda Shelf carbon cycle on interglacial CO_2 concentrations during the Mid-Brunhes Event
16:30-16:50	Spicer, Robert	The Intimate Links between Leaves and Lithosphere
16:50-17:10	Chen, Jiubin	Tracing metals trajectories from lithology to life
17:10-17:30	Zhang, Yige	Sub-century Timescale Carbon-Climate Coupling Dynamics during Middle Miocene Volcanism
17:30-17:50	Yuan, Xiaoping	Linking deep Earth processes to surface climate for the Himalayas

23 July

Tethys Evoluvtion: Tectonics, Carbon and Climate

Time	Speaker	Title
Chair: Wu, Fuyuan		
8:30-8:55	Wan, Bo	Anoxic Equatorial Tethys ocean and Its Magmatic-Metallogenic Implications
8:55-9:15	Zhu, Dicheng	Accumelting and its impacts on Earth's Habitability
9:15-9:35	Chu, Xu	Carbon Release from Contact Metamorphism in the Gangdese Arc: Implications for Arc-Climate Linkages
9:35-9:55	Houseman, Gregory	The Tibetan Plateau: Inference of Gravitational Instability of Metasomatised Continental Mantle Lithosphere
9:55-10:15	Ji, Weiqiang	Carbon Cycle in the Tethyan Orogenic Belt
10:15-10:30	Break	
Chair: Thybo, Hans		
10:30-10:50	4 short presentations	Wu, Jing (10:30-10:35) Luo, Yun (10:35-10:40) Hencz, Mátyás (10:40-10:45) Guo, Pengyuan (10:45-10:50)
10:50-11:10	Malusà, Marco	Evolution of cold continental subduction and its potential impact on the tectonic carbon cycle: an Alpine perspective
11:10-11:30	Rawlinson, Nicholas	Lithospheric evolution in Southeast Asia: Recent results from seismic imaging
11:30-11:50	* Sternai, Pietro	New constraints on Neo-Tethyan carbon cycling and its forcing of early Cenozoic climate
Lunch		

Early Earth and Habitability Evolution		
Time	**Speaker**	**Title**
Chair: Gerya, Taras		
14:00-14:20	Cawood, Peter	Tectonic carbon cycle in deep time – constraints from Earth's secular evolution and implications for habitability
14:20-14:40	Liu, Lijun	Periodic instability and restoration of cratonic lithosphere
14:40-15:00	Yuan, Huaiyu	Echoes of Ancient Earth: Seismic Insights into Early Crustal Dynamics
15:00-15:20	Thybo, Hans	Eclogites as a trigger of the Phanerozoic explosion in onshore life
15:20-15:40	* Stagno, Vincenzo	Eclogitic diamonds from the Siberian craton are witnesses of redox heterogeneities and volatile recycling in the Archaean upper mantle
15:40-15:55	Break	
Chair: Weinberg, Roberto		
15:55-16:10	3 short presentations	Tang, Chunan (15:55-16:00) Wu, Sensen (16:00-16:05) Huang, Min (16:05-16:10)
16:10-16:30	Wilde, Simon	Multi-mineral dating of lamproites derived from an enriched lithospheric mantle source: Walgidee Hills, Western Australia
16:30-16:50	Artemieva, Irina	Lithosphere heterogeneity from geophysical data and kimberlites
16:50-17:10	Song, Haijun	The causes of the Permian-Triassic mass extinction
17:10-17:30	Hu, Xiumian	Oceans in the Tethys: some old, some young; some big, some small
17:30-15:30	Wang, Shuijiong	Ghost carbonate in Archean granitoids marks a geodynamic transition in the Mesoarchean

Long-term biogeodynamical carbon cycle and implications for future climate change

Taras Gerya[1], Julian Rigger[1], Benjamin Mills[2],
Loic Pellissier[3], Robert J. Stern[4]

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Earth's long-term climate and environmental changes are driven by the cycling of carbon between deep geologic reservoirs and the superficial atmosphere-ocean-biosphere-system, into which the unique human technological civilization (Stern and Gerya, 2024) became recently involved. We evaluate the importance and timescales of the continuous biological adaptation of vegetation to climate and environmental changes as a regulation mechanism in the biogeodynamical carbon cycle since the establishment of forest ecosystems. Using new hybrid biogeodynamical numerical modeling framework, we show that the vegetation's climate adaptation capacity, through biological evolution and geographic dispersal, critically influences global rates of CO_2 sequestration by organic carbon burial and vegetation-enhanced silicate weathering (Rogger et al., 2024a). Adaptation capacity of the vegetation imposes key controls on the close balance of carbon fluxes into and out of the atmosphere-ocean-biosphere system, which is a prerequisite to maintain habitable conditions on Earth's surface on a multimillion-year timescale. This long-term evolution included multiple episodes of extreme volcanism related to large igneous provinces (LIP) emplacement, which drastically affected Earth's climatic and biological history. We further demonstrate that the vegetation's climate adaptation capacity is a major determinant of the severity and longevity of LIP-induced hyperthermals and can promote the emergence of a new warmer climatic steady state. The LIP-related plants-mediated climate evolution typically lasts for few million years and demonstrates drastically faster global warming rates at the initial stage compared to much slower global cooling rates at the subsequent climate relaxation stage. We confirm this predicted climate evolution duration and asymmetry with proxy-based temperature reconstructions of the Permian-Triassic, Triassic-Jurassic, and Paleocene-Eocene hyperthermals, which match the modeled trajectories of bioclimatic disturbance and recovery. We therefore conclude that biological vegetation dynamics shape the multimillion-year Earth system response to sudden carbon degassing and global warming episodes.

This finding may also imply similar longevity of the recent climate change related to the establishment of global technological human civilization, which became a new superficial geological power but cannot control deep components of the biogeodynamical carbon cycle. We stress that the biogeodynamical processes controlling climate and environment operate on timescales of millions of years and will likely outlast many hundreds of thousands of human generations. To ensure our survival and longevity, we must align our civilization's activities with the deeper Earth system dynamics, rather than against them. To tackle these unprecedented challenges, we must advance a new scientific frontier - "Future Dynamics" – an interdisciplinary field focused on modeling and understanding the potential trajectories of the coupled evolution of the Earth system and the human civilization over geological timescales. Deep past bears the keys to the deep future.

References

1. Rogger, J., Mills, B., Gerya, T.V., Pellissier, L. (2024a) Speed of thermal adaptation of the terrestrial vegetation alters Earth's long-term climate. Science Advances, 10, eadj4408.

2. Rogger, J., Judd, E.J., Mills, B.J.W., Godderis, Y, Gerya, T.V., Pellissier, L. (2024b) Biogeographic climate sensitivity controls Earth system response to large igneous province carbon degassing. Science, 385 (6709), 661-666.

3. Stern, R.J., Gerya, T.V. (2024) The importance of continents, oceans and plate tectonics for the evolution of complex life: implications for finding extraterrestrial civilizations. Scientific Reports 14 (1), 8552.

A living Earth: Its evolution and dynamic inner workings

Zhengxiang Li

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Earth as a unique habitable planet started as a fireball at initial accretion, but quickly became a waterball with increasing land area. Plate tectonics started over 3 billion years ago, and a billion years later, it evolved into a 600 million-year supercontinent cycle accompanied by the birth and demise of superoceans. This dynamic evolution history was driven by an evolving internal feedback system featuring an early stage of primarily vertical differentiation driven by gravity, then one billion years of early plate tectonics featuring small but increasing-scale convection. The last 2 billion years has been dominated by the supercontinent-superocean cycle and its coupled mantle twin in deep Earth. Such dynamic processes not only drive surface features, but also influence the operation of the core and the geomagnetic field. In this talk I will briefly review some recent findings by combining geological, geophysical and geochemical records with geodynamic modelling to not only reconstruct Earth's plate tectonic history back in time, but also the coupled dynamic evolution of Earth's deep mantle.

Coupled surface to deep Earth processes: Perspectives from TOPO-EUROPE with an emphasis on climate- and energy-related societal challenges

Sierd Cloetingh[1], Pietro Sternai[2] and TOPO-EUROPE Team

1. Department of Earth Sciences, Utrecht University, Utrecht, the Netherlands

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Understanding the interactions between surface and deep Earth processes is important for research in many diverse scientific areas including climate, environment, energy, georesources and biosphere. The TOPO-EUROPE initiative of the International Lithosphere Program serves as a pan-European platform for integrated surface and deep Earth sciences, synergizing observational studies of the Earth structure and fluxes on all spatial and temporal scales with modelling of Earth processes. This review provides a survey of scientific developments in our quantitative understanding of coupled surface-deep Earth processes achieved through TOPO-EUROPE. The most notable innovations include (1) a process-based understanding of the connection of upper mantle dynamics and absolute plate motion frames; (2) integrated models for sediment source-to-sink dynamics, demonstrating the importance of mass transfer from mountains to basins and from basin to basin; (3) demonstration of the key role of polyphase evolution of sedimentary basins, the impact of pre-rift and pre-orogenic structures, and the evolution of subsequent lithosphere and landscape dynamics; (4) improved conceptual understanding of the temporal evolution from back-arc extension to tectonic inversion and onset of subduction; (5) models to explain the integrated strength of Europe's lithosphere; (6) concepts governing the interplay between thermal upper mantle processes and stress-induced intraplate deformation; (7) constraints on the record of vertical motions from high-resolution data sets obtained from geo-thermochronology for Europe's topographic evolution; (8) recognition and quantifications of the forcing by erosional and/or glacial-interglacial surface mass transfer on the regional magmatism, with major implications for our understanding of the carbon cycle on geological timescales and the emerging field of biogeodynamics; and (9) the transfer of insights obtained on the coupling of deep Earth and surface processes to the domain of geothermal energy exploration. Concerning the future research agenda of TOPO-EUROPE, we also discuss the

rich potential for further advances, multidisciplinary research and community building across many scientific frontiers, including research on the biosphere, climate and energy. These will focus on obtaining a better insight into the initiation and evolution of subduction systems, the role of mantle plumes in continental rifting and (super)continent break-up, and the deformation and tectonic reactivation of cratons; the interaction between geodynamic, surface and climate processes, such as interactions between glaciation, sea level change and deep Earth processes; the sensitivity, tipping points, and spatio-temporal evolution of the interactions between climate and tectonics as well as the role of rock melting and outgassing in affecting such interactions; the emerging field of biogeodynamics, that is the impact of coupled deep Earth – surface processes on the evolution of life on Earth; and tightening the connection between societal challenges regarding renewable georesources, climate change, natural geohazards, and novel process-understanding of the Earth system.

Link: https://doi.org/10.1016/j.gloplacha.2023.104140

Haq, B.U. & Cloetingh, S., 2025. Tectonics vs Eustasy: The oceanic container and its contents. Earth Science Reviews, In Press.

Direct insights into diamond formation from deep C-O-H fluids in subduction zones

Maria Luce Frezzotti

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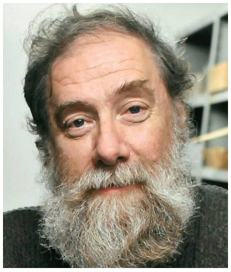
In subduction zones, diamond formation is governed by C–O–H fluids released through decarbonation and carbonate dissolution reactions at 600–900 °C and 3–5 GPa. Buffered near or above the FMQ equilibrium, these fluids are crucial for stabilising oxidised carbon species and facilitating diamond precipitation. To better understand carbon speciation in deep subduction fluids, I present fluid inclusion data in ultra-high-pressure metamorphic rocks from the Lago di Cignana unit (Western Alps, Italy), a rare case of exhumed subducted oceanic lithosphere known to host metamorphic microdiamonds. These inclusions, trapped during peak conditions (~3.2–3.6 GPa; 600–650 °C), provide in situ evidence of the composition of fluids involved in diamond formation.

The Raman spectra reveal HCO_3^- and CO_3^{2-} groups, and short-chain carboxylic acids dissolved in H_2O, with no evidence of CH_4 or graphite, indicating an oxidised fluid composition. The high concentration of dissolved carbon species suggests that carbonate-rich aqueous fluids were present and likely originated from the breakdown of sedimentary carbonates and slab-derived silicates. Data support a redox-controlled mechanism for diamond nucleation, in which the decomposition of carboxylic acids (–COOH) triggers a redox reaction with the surrounding rocks, encouraging carbon species reduction and diamond precipitation under high-pressure conditions.

These findings have significant implications for subduction zone geodynamics. Firstly, they provide direct evidence of oxidised, carbon-rich fluids at depths greater than 100 km, refining current models of redox evolution in subduction channels. Second, they reveal that diamond can nucleate from molecular carbon species, along with other metastable carbon allotropes. Finally, the data underscore the role of complex C-O-H fluids in transferring and redistributing carbon and trace elements within the mantle wedge, supporting their involvement in metasomatism, melt generation, and the long-term carbon cycle.

Plate Tectonic Reconstructions for the Mesoproterozoic, Neoproterozoic, and Early Paleozoic (1600 Ma – 400 Ma)

Christopher R. Scotese[1], Reece P. Elling[2], Wen Du[3]



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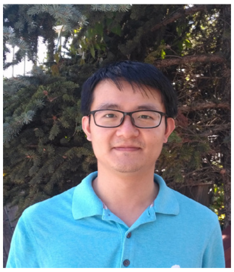
A plate tectonic model describes plate motions and the evolution of plate boundaries from the Mesoproterozoic (1600 Ma) to the Early Dev onian (400 Ma) . The model is based on >300 distinct tectonic elements that are combined into 11 paleocontinents, and 4 supercontinents (Columbia, Terra Borealis, Rodinia, and Pannotia). Approximately 1.5 billion years ago, the supercontinent of Columbia (Nuna) broke apart and the continents reformed at high northerly latitudes creating the supercontinent, Terra Borealis. In the late Mesoproterozoic (1.15 by), Borealis broke into three continents (Balto-Siberia, proto-Rodinia, and the Congo continent) that were separated by the Paleopanthalassic Ocean. The closure of the Paleopanthalassic Ocean, during the Grenville Orogeny, ultimately lead to the formation of the well-known supercontinent Rodinia. Rodinia remained intact until the middle Neoproterozoic (~750 Ma) when it split in two (Northern Rodinia and Southern Rodinia). These two halves rotated over the North and South poles (respectively) and collided at equatorial latitudes on either side of the Congo continent (Pan-African Event) to form the latest Precambrian supercontinent, Pannotia (also known as Greater Gondwana). Pannotia was a relatively short-lived supercontinent that broke apart prior to the start of the Paleozoic (~580 Ma). Laurentia, Baltica, Siberia, and Gondwana were the continental remnants of Pannotia. The early Paleozoic oceans (Iapetus Ocean and Reelfoot Sea) and several back-arc basins between these continents were consumed during the late Ordovician (Taconic orogeny; 465 Ma), middle Silurian (Caledonian orogeny; 425 Ma), and early Devonian (Acadian orogeny; 400 Ma). The plate tectonic reconstructions are based on a selection of over 1500 paleomagnetic paleopoles from the PALEOMAP Paleopole database. 25 global mean poles, at 50 million year intervals, were calculated from 1600 Ma – 400 Ma. The mean paleolatitude of global mean poles was ~87 degrees. The evolving plate boundaries shown in the animation that accompanies this talk provide a framework for better understanding the genesis of ore deposits during the late Precambrian and early Paleozoic.

Day1-6 11:05-11:25 Keynote speaker: *Hu, Qingyang*

Monovalent calcium sulfide in Earth's lower mantle

Qingyang Hu*, Longfei Gong, Yanlei Geng and Ho-Kwang Mao



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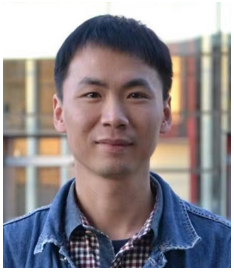
The chemistry of major rock-forming elements, such as calcium, magnesium, and oxygen, is generally described by classical ionic bonding models under Earth surface and shallow mantle conditions. However, the extreme pressure-temperature (P-T) conditions prevailing within the deep lower mantle fundamentally alters the chemical behaviour of these elements, potentially leading to the formation of non-stoichiometric compounds. In this talk, we focus on the chemistry of calcium sulphide in Earth's lower mantle. Using first-principles simulation, we report the stabilization of monovalent calcium sulphide (Ca_2S) across depths spanning approximately 1200 km to the core-mantle boundary. The ionic configuration of calcium in monovalent sulphide is analogous to that of potassium. Further in-situ x-ray diffraction and Raman spectroscopy verified the formation of Ca_2S under the P-T conditions of lower mantle. These results introduce possibilities of non-stoichiometric calcium sulphide and potentially silicates that deviate from the conventional ionic rules. The high densities of these phases suggest their gravitational stability within the lowermost mantle, potentially contributing to the formation of observed large-scale seismic structures and the development of chemical heterogeneities at the core-mantle boundary.

Sulfide-rich continental roots at cratonic margins formed by migration of carbonated melts and their implications for sulfide deposits

Chunfei Chen[1*], Michael W. Förster[2,3], Svyatoslav S. Shcheka[2], Isra S. Ezad[4], Joshua J. Shea[2,5], Yongsheng Liu[1,6], Dorrit E. Jacob[3], Stephen F. Foley[2,3]



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The cratons are underlain by thick mantle lithospheres which contain a large volatile inventory including carbon, sulfur, and water, and they are also known to host abundant mineral deposits of metals such as gold, copper and rare earths at their margins. While volatiles are recognized as key components in metallogenesis, the distribution of these volatiles within the cratonic lithospheric mantle and their role in the initial enrichment of metals and in subsequent sulfide deposit formation remain inadequately explored. In this study, we compile sulfur and copper data from global cratonic peridotites, identifying sulfide- and copper-rich continental roots at depths at the depths of 160 to 190 km along the cratonic margins. Our new high-pressure experiments reveal that carbonated silicate melts originating from the asthenosphere undergo a loss of silicate components when interacting with lithospheric peridotite, transforming into carbonatite melts that accumulate at the cratonic margins. Therefore, we suggest that carbonatite melts arise in the deep continental lithosphere mostly as a result of the reaction of parental carbonated silicate melts with the lithospheric mantle. During this rection process, sulfur solubility in the melts dramatically decreases as the SiO_2 content decreases, triggering sulfide precipitation and the formation of sulfide-rich continental roots at the base of the mantle lithosphere, consistent with the compiled peridotite data. The migration of carbonated melts towards the cratonic margins replenishes these roots with sulfur, providing an explanation for the co-location of magmatic metal deposits and carbonatites near cratonic margins, as 93% of magmatic sulfide deposits and 62.5% of carbonatites globally are located within 200 km of craton edges. These findings underscore the critical role of carbonated melts in metallogenesis and suggest a promising avenue for metal ore exploration.

Tracking fluid inclusion-mediated deep carbon fluxes across orogenic cycles

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Estimating global fluxes of carbon within and across different layers of the Earth's system requires a bottom-up approach. In the deep Earth, substantial effort has been made on the identification of mineral and fluid-mineral reactions capable to release carbon and their characteristic conditions and associated carbon fluxes. However, large uncertainty still exists on the fete of these fluids and on their residence time before they reach the surface. In this contribution, the results of a detailed characterization of fluid inclusions from a metamorphosed mafic-ultramafic complex from the Appalachian belt will be presented. Together with fluid speciation and spatial distribution, bulk concentration of CH_4 and CO_2 and their carbon isotope fingerprints were used to reconstruct the amounts, residence time, carbon sources, and respeciation of carbonic fluids across at least two orogenic cycles. The main findings of this study will be presented.

Day1-9 14:00-14:20 Keynote speaker: *Zhao, Liang*

Revealing Cenozoic Climate Shifts Using Seismo-Geodynamic Constraints

Liang Zhao[1], Zhengtang Guo[2], Hao Shen[1], Shaohui Liu[1], Jianfeng Yang[2], Rixiang Zhu[1]

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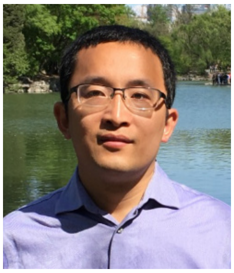
The Earth's climate evolution is intimately linked to the interplay between the carbon sources by solid Earth degassing and carbon sinks by surficial silicate weathering. Cenozoic climate shifts from a hothouse to an icehouse state have profoundly influenced the present-day Earth's climate, yet the tectonic events and surface processes responsible for the carbon source-sink balance remain unclear. Here we reconstruct global input carbon flux using high-resolution global seismic tomography and plate kinematic models since the Cenozoic era. Combined with seawater lithium isotopes, which are proxies for silicate weathering, we establish a first-order relationship between subducted carbon flux, weathering, and atmospheric CO2. Our model results indicate two critical tipping points that shift the Earth's climate system, which are controlled by the carbon source at the first stage and the carbon sink at the second stage. These shifts are coincident with the major changes in tectonic configuration, suggesting an intimate correlation. We further performed 3D global geodynamic numerical modeling by integrating the carbon flux from the plate reconstruction. These model results are consistent with those of seismic constraints. We therefore propose that prolonged large-scale tectonic activities, including continental collisions and volcanism, played a crucial role in disrupting the delicate equilibrium between carbon sources and sinks, ultimately triggering metastable shifts in the climate regime. These tectonic perturbations, by influencing both volcanic activity and surface processes, likely initiated profound and abrupt changes in Earth's climate system, setting in motion long-lasting shifts that led to the destabilization of previously stable climatic conditions.

Supercycle: Progress on the Modeling of Surface Processes

Yonggang Liu



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"Supercycle" is a framework that has been under development in China during the past few years. One of the goals of this framework is to advance our understanding of long-term evolution of climate and carbon cycle, as well as their interactions across geological timescales. To achieve this goal, an integrated Earth system model that couples the deep solid Earth processes with surficial fluid dynamics has to be developed first. In this talk, I will introduce some of the progresses we have made on the modeling of the surface processes that are of critical importance to the establishment of the Supercycle. These progresses include the successful modeling of the evolution of climate, vegetation, dust, and oceanic biogeochemical cycle for the whole Phanerozoic, the improvement to the surface erosion model and the silicate weathering model, and an initial test of the coupled modeling of the climate and silicate weathering for the early Paleogene.

Phanerozoic Continental Magmatism: Linking Spatiotemporal Evolution, Isotopic Composition, and Chemical Weathering

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Chemical weathering plays a critical role in regulating Earth's long-term climate and supplying key nutrients to the biosphere. Weathering tectonically-active continental magmatic belts could contribute significantly to the magnitude and composition of the global weathering flux; however, their contribution remains poorly quantified. To address this gap, we integrate isotopic data within their reconstructed paleogeographic and paleoclimatic contexts to estimate the global weathering flux and isotopic composition of these belts. Our results reveal that the abundance, distribution, and isotopic signatures of magmatic belts are systematically linked to the supercontinent cycle. The magnitude of weathering flux is governed by the interplay between paleogeography and paleoclimate. We show that the global isotopic flux from magmatic belts exhibits a strong statistical correlation with seawater $^{87}Sr/^{86}Sr$ variations throughout the Phanerozoic, suggesting that the weathering of continental magmatic belts dominate the marine isotope composition. Our study provides an interpretable framework offering new insights into the coupled evolution of tectonics, surface processes, and climate.

Day1-12 15:00-15:20 Keynote speaker: *Man, Wenmin*

Hydroclimate responses over global monsoon regions to volcanic eruptions during the last millennium

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Understanding the influence of volcanic eruptions on the hydroclimate over global monsoon regions is of great scientific and social importance. Based on both the observations and model simulations, we show that volcanic aerosols reduce the temperature and cause extreme low temperature events over East Asia. The East Asian summer monsoon circulation is weakened after volcanic eruptions, associated with overall reduced precipitation in eastern China. We further investigated the link between the latitude of volcanic eruptions and related hydroclimate changes over global monsoon regions based on large sets of reconstructions, observations and model simulation. Our results show that northern hemispheric (southern hemispheric) monsoon precipitation is weakened by northern (southern) and tropical eruptions, but is enhanced by the southern (northern) eruptions. Moisture budget analysis and moist static energy (MSE) budget analysis reveal that the dynamic processes related to changes in atmospheric circulation play a dominant role in precipitation responses. Potential volcanic eruptions may lead to a lower-than-expected global mean temperature and reduced global monsoon precipitation during the 21st century in climate model projections. By examining past volcanic eruptions, our research provides valuable insights into how global precipitation may respond to climate interventions such as stratospheric aerosol injection.

Day1-13 15:20-15:40 Keynote speaker: *Ramstein, Gilles*

From lithosphere to atmospheric CO_2, a longstanding interactive process regulating Earth's climate

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When seeking for life on exoplanets, it is important to understand what makes life evolution possible on Earth. It appears that, on Earth, tectonics regulates our climate, constraining temperatures to remain in a narrow window, consistent with the presence of liquid of water. The exospheric equilibrium between the major source (volcanos outgazing) and sink (silicate weathering) in the carbon cycle maintain a climate stability consistent with Darwinian evolution. Therefore, interaction between lithosphere and climate favours the evolution of life at geological time scales. This longstanding equilibrium certainly failed during Neoproterozoic snowball glaciation. This has been demonstrated to be intimately linked with the breakup of Rodinia occurring in the tropical band. This context optimized the silicate weathering and drastically reduced atmospheric CO_2. Moreover, the large traps that occurred during this break-up covered huge continental areas with basalt, further increasing weathering. But, anyway, such a global cold episode cannot be maintained, once again because of tectonics. Indeed, during a snowball episode, volcanic emission continues and CO_2 accumulates in the atmosphere, producing the destabilization of such an episode. Before the emergence of biosphere and soil as an important player for carbon cycle, its regulation between atmosphere and ocean is driven by tectonics through CO_2 concentration.

Day1-14 16:10-16:30 Keynote speaker: *Wu, Haibin*

Impact of the Sunda Shelf carbon cycle on interglacial CO_2 concentrations during the Mid-Brunhes Event

Haibin Wu[1,2], Xinyue Huang[1,2], Yue Yuan[1,2], Shu Xu[1], Lixin Chen[1,2], Guoqiao Xiao[3], Zhipeng Wu[4], Chunxia Zhang[1], Qiuzhen Yin[4]

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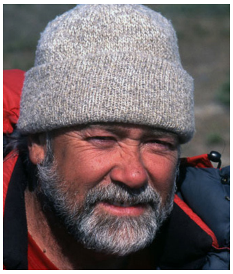
The Mid-Brunhes Event (MBE), occurring approximately 430 thousand years ago, represents a critical climatic transition marked by a significant increase (~30 ppmv) in atmospheric CO_2 concentrations during interglacial periods. Traditional explanations based on orbital forcing and ocean-atmosphere-ice sheet feedback mechanisms do not fully account for this observed rise. In this study, we examine the previously overlooked influence of terrestrial carbon cycling on the Sunda Shelf in Southeast Asia, a region characterized by extensive tropical vegetation and high rates of chemical weathering, both of which substantially affect global carbon budgets. Using simulations with the Paleocarbon Model across nine interglacial periods spanning the past 800 kyr, we document notable decreases in terrestrial organic carbon storage and inorganic carbon sequestration by silicate weathering, closely tied to the progressive subsidence of the Sunda Shelf. These regional carbon cycle alterations account for approximately 70% of the interglacial CO_2 increase recorded during the MBE. Our findings highlight the critical yet understudied role of low-latitude terrestrial processes in regulating global atmospheric CO_2 levels, offering novel insights into regional mechanisms underlying major climatic transitions.

The Intimate Links between Leaves and Lithosphere

Robert A. Spicer



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The argument that the invasion of land by plants approximately 450 million years ago changed fundamentally the chemistry of the lithosphere is yet to be resolved[1,2], but what is not disputed is that since that terrestrial “phyto-invasion” plants have progressively intensified the global water cycle by growing larger, improving the efficiency of their vascular systems, increasing leaf area and thus evapotranspiration. This global amplification of the water cycle has affected weathering, erosion, chemical cycling and even land surface height and thus isostacy. More locally, vegetation type affects erosion and topographic relief, which in turn feeds back into speciation processes.

Plants also play a major role in our understanding of lithospheric processes, specifically mountain building, through their ability to preserve, as leaf fossils, properties of the atmosphere that can be linked not only to climate, but to elevation. Recent major advances in phytopaleoaltimetry[3, 4, 5] now allow us to better quantify paleotopography and thereby not only provide insights to what is happening deep below Earth’s surface, but also more realistic landscape boundary conditions for paleoclimate modelling.

A case in point is how our understanding of the topographic development of the Pan Tibetan Highlands (PTH - the Tibetan Plateau, the Hengduan Mountains, the Himalaya and the Mountains of Central Asia[6]) has changed radically in the last 10 years or so, and how this has informed our modelling of Asian monsoon evolution. Using consilience between plant fossils and isotope paleoaltimetry, we now better understand the strengths and weaknesses of each approach and that the development of the Tibetan Plateau was not a simple case of uplift as a block due to the India-Eurasia collision, but was a more complex process of a landscape gradually being modified from that produced by earlier terrane collisions[7, 8]. When the subduction of continental India began near the start of the Cenozoic[9], an East-West oriented valley occupied central Tibet bounded by the Gangdese Arc mountain chain to the south and the Qiangtang uplands to the North[10]. The India compression-driven Eocene eastward extrusion of the Qiangtang terrane produced near-modern elevations in Eastern Tibet by the beginning of the Oligocene[11-13], and by the end of the Oligocene the narrowing of the and rise of the Central Tibetan Valley floor had produced a nascent plateau with internal drainage. It was not until the mid-Miocene that the Himalaya rose above the Gangdese uplands to form a new southern mountain barrier for the PTH[14].

By the end of the Oligocene these topographic changes had brought about the modernization of the Asian monsoon system, prior to which only ITCZ-driven monsoons had affected southernmost Asia. However, an increase in precipitation across large parts of China at around 40 Ma, which modelling shows was driven by the rise of eastern Tibet[13], initiated erosional dissection of that landscape to form the modern high-relief Hanguduan Mountains[8]. This 'great wetting' was quite unlike the modern monsoon, but is often mistaken as such due to the limitations of geological proxies[13]. It is no coincidence that PTH orogeny was a primary factor in it hosting several of the great global biodiversity 'hotspots', and the origin of many taxa now defining Asian ecology and ecosystem services[8].

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Day1-16 16:50-17:10 Keynote speaker: *Chen, Jiubin*

Tracing metals trajectories from lithology to life

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Metals play a critical role in writing the history of life-environment interactions. Certain metals (e.g., Fe, Mn, Cu, Zn, Mo, Ni, Co) are essential to life as they mediate critical metabolic reactions by functioning as cofactors in vital enzymes. Yet, others (e.g., Hg, Pb, Cd, Cr) can act as toxic compounds to interrupt normal metabolism. Since life can neither create or destroy metals and uptake the metals from surrounded environment, the release of metals from lithology and their historical availability might have shaped today's biological landscape. As a result, in geological history, the availability of life-essential metals derived from bedrock weathering has echoed with the environment changes (e.g. the oxygenation of atmosphere and ocean) and may have directly influenced developmental biology such as metabolic pathways. Today, humanities are changing to the availability of metals through unprecedented scales of extraction and release from the lithosphere, threatening the ecological system and even causing unknown effects on future life.

Metal isotopes would be powerful tracers that could be used to distinguish natural from anthropogenic processes and thus to trace the trajectories of metals from lithology to living beings. Metal isotope fractionation is driven by mechanisms at the molecular level regardless of the inorganic or biological nature of the substrates, thus has the potential to elucidate interactions between geosphere, hydrosphere and biosphere. In this talk, we demonstrate how isotope approach could be used to trace the journey of metals from lithology to life. The journey starts from release by volcanism and weathering that could be examined by tracers such as Ga and Hg isotopes. After release, metals are transported and cycled between air, land and ocean, where multiple isotopic tracers are applied to understand the source, fate and biological effects of the metals. The journey ends with the newest attempt to trace biological assimilation, trophic transfer, metabolism and even the progression of disease. The presentation highlights the emerging frontier of metal isotope geochemistry in searching for answers concerning the future habitability of Earth.

Sub-century Timescale Carbon-Climate Coupling Dynamics during Middle Miocene Volcanism

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Deep Earth processes and surface climate systems have traditionally been viewed as operating on vastly different timescales, limiting cross-disciplinary research into their potential coupling. Here, we attempt to bridge this temporal gap by presenting decadal-resolution paleoclimate reconstructions that reveal rapid carbon-climate coupling during periods of intense volcanic activity. We target the middle Miocene (~16 Ma), when Large Igneous Province volcanism drove massive CO_2 degassing and global warming of ~6°C above modern levels. By analyzing fossil leaves and lipid biomarkers from the annually-varved Clarkia Lake deposit in Idaho, USA, we establish concurrent CO_2 and temperature records spanning ~800 years. Statistical analysis reveals that volcanic CO_2 emissions consistently lead temperature variations on multi-decadal timescales, with climate model emulators confirming the role of ocean heat storage in modulating this response. Our findings demonstrate that deep Earth processes can rapidly influence surface climate and habitability on sub-century timescales during volcanically active periods, challenging traditional views of temporal disconnection between geological and climate systems. This work provides insights into the interconnected nature of Earth's interior and surface systems, with implications for understanding both past climate evolution and future environmental responses to changing geological carbon fluxes.

Day1-18 17:30-17:50 Keynote speaker: *Yuan, Xiaoping*

Linking deep Earth processes to surface climate for the Himalayas

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Crustal thickening associated with orogenic growth elevates topography, causing the orographic enhancement of precipitation, which in turn facilitates local erosion and possibly intensifies the localization of deformation. How these three processes—deformation, precipitation, and erosion—coordinate during orogenic growth remains unknown. Here, we present a new numerical model where tectonics, surface processes, and orographic precipitation are tightly coupled. We show that, for the intermediate erosion models, rock uplift rates and precipitation rates correlate well with erosion rates for the formation of orogenic plateaus with high correlation coefficients of ~0.9 between rock uplift and erosion rates, and ~0.8 between precipitation and erosion rates. We propose that three processes (deformation, precipitation, and erosion) take place successively as a consequence of the lateral orogenic growth, and demonstrate a cyclicity of correlation evolution among uplift, precipitation, and erosion rates through the development of new faults propagating outward. These results shed new insights into the relative tectonic or climatic control on erosion in active orogens, and provide a plausible explanation for several conflicting data and interpretations in the Himalayas, which depend on the stage of maturity of the newest fault and the relative locations to old faults.

Anoxic Equatorial Tethys ocean and Its Magmatic-Metallogenic Implications

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The Tethyan tectonic domain comprises of a series of latitudinal orogenic belts extending from the western Alps to northern Australia, which is named after the now-closed Tethyan oceans. The reconstructed Paleo-Tethys and Neo-Tethys oceans were located between fragmented Gondwana blocks in a low-latitude zone during the late Paleozoic to Cenozoic eras.

The low-latitude region of Earth, particularly the tropical oceans, serves as a net-influx zone for the Sun's radiation, thereby driving oceanic and atmospheric circulations from the equator toward the polars. Within this energy gradient framework, key environmental parameters such as temperature, biodiversity, and biomass are largely latitude-dependent. Owing to higher biological productivity, the low-latitude oceans are more prone to be anoxic compared to higher latitude regions. Geological records indicate that the Paleo-Tethys and Neo-Tethys oceans were more anoxic than the Panthalassa Ocean, sharing similar characteristics with modern oceans.

Due to the "Tethyan one-way conveyor belt" mechanism, all the Tethyan oceans were eventually closed by northward subduction. Abundant reduced materials on the ocean floor were transported into the deep Earth beneath the Eurasian continent.

We investigated Tethyan subduction-related magmatism to determine whether the subduction of reduced materials influenced the nature of the magma. Our key findings are as follows: (1) Tethyan subduction suppressed the development of arc magmas due to the large volumes of carbon-rich sedimentary rocks on the ocean floor. (2) The less-developed Tethyan arc magmas are less oxidized compared to typical arc magmatism. (3) Less oxidized magmas could serve as ideal parent sources for reductant mineralization, such as tungsten, tin, and/or rare metals in granite. These insights, drawn from the long and well-studied Tethyan domain, provide a new cognitive framework and enhance our understanding of how Earth has evolved under the coevolution of the lithosphere and environment.

Day2-2: 8:55-9:15   Keynote speaker: *Zhu, Dicheng*

Accumelting and its impacts on Earth's Habitability

Di-Cheng Zhu[1,2*], Qing Wang[1], Peter A. Cawood[3], Roberto F. Weinberg[3], Sheng-Ao Liu[1,2]

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As the only known planet with plate tectonics and felsic continental crust, the secular evolution of the Earth provides habitable environment for life. Plate tectonics stabilizes atmospheric composition through mechanisms such as regulating the carbon cycle and controlling the distribution of volcanic activities. The felsic crust, with its lower density and greater buoyancy than its underlying mantle, forms stable continental plates that provide a physical platform for the evolution of the biosphere. However, the fine details and precise mechanisms linking plate tectonic activity, the preservation of felsic crust, and the emergence of Earth's habitable environment remain poorly understood. Investigations of the Gangdese Batholith (India-Asia collision zone, southern Tibet), combined with comparisons to igneous rocks from other Phanerozoic collision zones, necessitated defining the term accumelting to account for felsic continental crust generation and preservation. Accumelting refers to the formation of voluminous hornblende-rich cumulates during pre-collision and their remelting during late subduction, syn-collision, and post-collision triggered by slab rollback and breakoff. The voluminous cumulates (>30 km thickness for long-lived magmatic arcs) enable accumelting to drive compositional maturation of collision zone upper-plate crust by generating extensive K-rich felsic melts through the breakdown of major rock-forming minerals (olivine, pyroxene, hornblende, plagioclase). The lower-arc-crust cumulates contain abundant metal sulfides and volatiles, allowing accumelting to efficiently regulate Earth's habitability by releasing ore-forming metals (notably Cu, Au, Li) via decomposition of Cu-rich sulfides and Li-bearing biotite and liberating volatiles (primarily H_2O, S, and CO_2) through breakdown of hornblende and biotite. These processes collectively point to the lower crust beneath magmatic arcs as a critical volatile reservoir, with accumelting acting as an efficient regulator of Earth's habitability.

Carbon Release from Contact Metamorphism in the Gangdese Arc: Implications for Arc-Climate Linkages

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The climatic implications of arc activity are increasingly recognized, particularly via CO_2 emissions generated by contact metamorphism in carbonate-rich crust. The arc flare-ups in the Tethyan realm, along with metamorphism on the overriding continental margins, might have effectively increased CO_2 outgassing which coincided with the green-house interval in the Cretaceous-Paleogene. This study explores metamorphic decarbonation in metacarbonate aureoles of the Cretaceous Gangdese Arc, southern Tibet, focusing on the conditions, durations, and fluxes of CO_2 release. To contextualize diverse lithologies, we constructed internally consistent T–XCO_2 petrogenetic grids for metacarbonate systems, which successfully reproduce observed metamorphic zones and quantify prograde CO_2 loss across aureoles. Two contrasting aureole types in the Lhasa Terrane illustrate variable metamorphic and fluid behaviors. In a representative calcsilicate aureole, garnets in the calcsilicate assemblage record dissolution-reprecipitation textures. Diffusion modeling in garnet and diopside indicates short-lived metamorphism yet substantial CO_2 loss—comparable to emissions from other tectonic sources. In contrast, marble-dominated aureoles show minimal decarbonation due to limited fluid infiltration. Isotopic and thermobarometric data suggest that the marble aureole surrounding short-lived intrusions allow rapid fluid escape resulting in limited CO_2 loss, whereas ductile rocks near long-lived intrusions favor sustained fluid-rock interaction and extensive decarbonation. These findings highlight how the spatial and temporal heterogeneity in lithology, intrusion duration, and host-rock rheology collectively govern metamorphic carbon release in continental arcs. We advocate for the integration of field-based constraints with reaction-transport models and phase equilibria to further assess arc-related metamorphic contributions to long-term global CO_2 budget.

Day2-4 9:35-9:55 Keynote speaker: *Houseman, Gregory A.*

The Tibetan Plateau: Inference of Gravitational Instability of Metasomatised Continental Mantle Lithosphere

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Since about 100 Ma, atmospheric CO_2 concentration is thought to have decreased fairly steadily by a factor of about 5 (Berner, Geochemica et Cosmochemica Acta, 2006), following a period of relatively high values that endured through the Mesozoic. An explanation for such long-term variations in atmospheric CO_2 can be sought in large-scale geological processes such as super-continent amalgamation or dispersal, mantle plume volcanism, and tectonic activity. The progressive depletion of atmospheric CO_2 during the past 100 Myr occurred while the components of Gondwanaland were dispersing, accommodated by subduction mainly in the Pacific and Indian Oceans. This period also includes the Laramide orogeny and subsequent extension of the Basin and Range Province in the western USA, the final closure of the Tethyan oceans, the initiation and development of the Alpine-Himalayan orogen, and the end-Cretaceous mass extinction event. If any of these events explains the evolution of the atmospheric CO_2 concentration, we have to infer that it caused CO_2 to be progressively removed from the exogenous carbon reservoir and stored either in continental sediments or in the mantle via subduction.

When the upper plate of a subduction system is continental, melting of carbonates in the subducted oceanic lithosphere is expected to produce fluxing of lighter mobile elements upwards into the upper plate mantle lithosphere. This process would imply a gradual geochemical evolution or metasomatism of the continental mantle on the western margins of the Americas and the southern and eastern margins of the Eurasian continent as the Tethyan oceans closed. High rates of subduction of the Indian Ocean lithosphere beneath the assembled terranes of Central Asia prior to about 55 Ma presumably modified the lithosphere of the Tibetan Plateau. The Tibetan mantle lithosphere can therefore perhaps offer some insights into the impact of long-term metasomatism of continental lithosphere caused by subduction on its margins. The region has been activated by tectonic activity throughout the collision phase, and has been affected by widespread potassium-rich lavas produced from about 50 to 30 Ma in the Qiangtang terrane of northern Tibet, ultrapotassic and adakitic lavas from about 26 to 10 Ma in the Lhasa terrane and semi-continuous potassic volcanism since about 13 Ma in the western Qiangtang and Songpan – Ganze terranes. This volcanic history (Chung et al., Earth Science Reviews, 2005) provides evidence of a lithospheric mantle instability affecting different parts of the plateau at different times.

Based on seismic surface wave measurements, the Tibetan region has been compared to other continental cratons in appearing to have an anomalously thick mantle lithosphere (Priestley et al., J. Geophys. Res., 2006). Yet it differs greatly from other cratons in that it has undergone extensive deformation, magmatism and volcanism since the onset of the India-Asia collision at about 55 Ma. It was previously proposed that the Tibetan mantle lithosphere had been removed entirely by a gravitational instability (Houseman et al., J. Geophys. Res.,1981). While this idea provided an explanation for the high elevation and the sustained and widespread episodes of magmatic activity across the plateau, it does not fit with the evidence that the mantle lithosphere remains in place beneath Tibet. However, the metasomatism that would result from a sustained period of subduction on the continental margin might also have modified the physical properties of the Tibetan mantle lithosphere. Allowing for the possibility that it is positively buoyant because of prior metasomatism (relative to the asthenosphere), it can be argued that a lithospheric gravitational instability has indeed happened, but it has resulted in overturn rather than removal of the Tibetan mantle lithosphere. I describe numerical models of this type of instability which appear consistent with geological and geophysical observations from the plateau and possibly provide indirect evidence on the properties of the metasomatised mantle lithosphere there.

Day2-5 9:55-10:15 Keynote speaker: *Ji, Weiqiang*

Carbon Cycle in the Tethyan Orogenic Belt

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The Tethyan Orogenic Belt is the largest continental collision orogen on Earth. It stretches nearly east-west across low-latitude regions for over 15,000 kilometers. Since the Paleozoic, a series of blocks from the northern margin of the Gondwana continent rifted away, drifted northwards, and accreted onto the southern margin of the Eurasian continent. The formation of the Tethyan Orogenic Belt involved the closure of a series of oceanic basins and continental-continental collisional orogenic processes in low-latitude regions. These oceanic and continental blocks widely developed carbonates and organic carbon. The Tethyan orogenic processes led to the subduction and recycling of carbon-bearing materials. Accompanied by high carbon cycling efficiency, this effectively influenced the global climate. The subduction of Tethyan slab was associated with the activation and release of large amounts of carbon. Simultaneously, carbon from the overriding plate could contaminate magmas, further increasing the carbon release flux of magmatic activity. Consequently, major magmatic flare-ups in the Tethyan Orogenic Belt were accompanied by the development of global greenhouse events. At the same time, Tethyan collisional orogeny caused orogenic uplift, erosion and weathering processes, which act as carbon sinks. The Tethyan orogeny-uplift and magmatic flare-ups were asynchronous in time. This led to an amplified source-sink differential effect, triggering intense climate fluctuations. Taking the India-Asia continental collision process as an example, magmatic flare-ups following the initial collision caused the formation of the Early Eocene Climatic Optimum (52-50 Ma). In contrast, sustained orogeny-uplift-erosion processes led to sustained global cooling after the Middle Eocene (<40 Ma).

Day2-6 10:50-11:10 Keynote speaker: *Malusà, Marco G.*

Evolution of cold continental subduction and its potential impact on the tectonic carbon cycle: an Alpine perspective

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The potential impact of cold subduction on the carbon tectonic cycle, even tens or hundreds of millions of years after subduction has ceased, is suggested by studies that combine tectonic interpretation of geophysical imaging with petrological modeling in the European Alps (e.g., Malusà et al., 2018). In this presentation, I will provide an updated reconstruction of the evolution of the fossil subduction zone of the European Alps, from the shallow crust to the asthenospheric mantle (Malusà et al., 2021; Solarino et al., 2024), and discuss the implications for the tectonic carbon cycle. During Alpine subduction, the low paleogeothermal gradients attested by exhumed (ultra)high-pressure metamorphic rocks allowed for the preservation of carbonates and hydrous minerals in the downgoing slab to asthenospheric depths. After subduction, the thermal re-equilibration of the fossil subduction zone triggered the breakdown of subducted carbonates and hydrous minerals, with consequent production of carbonate-rich hydrous melts. These melts can infiltrate the overlying mantle wedge inducing peridotite partial melting. However, the resulting melt network is frozen when the mantle geotherm crosses the carbonated hydrous peridotite solidus, producing extensive peridotite carbonation and the formation of a long-term carbon reservoir in the asthenospheric and/or lithospheric upper mantle. The hypothesis of a vast carbon reservoir in the upper mantle beneath the Alpine region is supported by recent P and S wave finite-frequency tomography (Mao et al., under review), and by the explosive component of an earthquake source moment tensor that suggests local remobilization of the deep carbon reservoir (Malusà et al., 2022). However, from a plate-tectonic perspective, generalized remobilization can only be attained during episodes of continental breakup by increasing temperature, adiabatic decompression, or redox melting. It is therefore of primary importance to understand where the mantle metasomatized by ancient cold subductions was subsequently involved in continental breakup episodes. The impact of rising isotherms on ancient deep carbon reservoirs could in fact determine peaks of carbon-dioxide outgassing due to massive recycled-carbon release, with global effects on long-term climate trends.

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Lithospheric evolution in Southeast Asia: Recent results from seismic imaging

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Southeast Asia is one of the most tectonically active and seismogenic regions on Earth, thanks to the rapid convergence of the Indo-Australian, Eurasian and Philippine Sea plates. This convergence is largely accommodated by an extensive network of subduction zones, where slabs can descend at rates as high as 10 cm/year, and generate earthquakes as deep as 700 km. The continental core of Southeast Asia – the Sundaland block – includes Borneo, Peninsula Malaysia, Java, Sumatra and parts of the South China Sea, and is juxtaposed against Sulawesi and the Philippines to the east. Apart from subduction, other active processes that can be found in Southeast Asia include arc-continent collision, orogenesis, ingestion of microcontinents, subduction initiation, subduction termination, subduction roll-back, lateral escape and abundant magmatism. With its high rates of seismicity and excellent coverage of broadband seismic stations, passive seismic imaging methods are well placed to shed light on the structural underpinnings of Southeast Asia.

In this talk, I will present recent passive seismic imaging results from Southeast Asia across a range of scales. This includes regional body wave traveltime tomography and adjoint waveform inversion, which reveal the large scale details of subduction zones, including divergent double subduction beneath the Molucca Sea, and strongly curved subduction beneath the Banda Arc. More detailed imaging studies of Sulawesi and Borneo will also be presented. In the latter case, body wave tomography reveals the presence of a lithospheric drip or detachment beneath northern Borneo, where subduction polarity reversal is thought to have taken place in the Miocene. Results from receiver functions and virtual deep seismic sounding will also be presented. Local earthquake tomography and teleseismic tomography results from Sulawesi reveal the presence of multiple overlapping subduction zones, along with distinct low velocity zones that likely represent regions of partial melt that feed active volcanoes at the surface. This collection of results demonstrates how structural signatures from a wide range of processes that effect the lithosphere can be detected by passive seismic imaging techniques.

Day2-8 11:30-11:50 Keynote speaker: *Sternai, Pietro*

New constraints on Neo-Tethyan carbon cycling and its forcing of early Cenozoic climate

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Cenozoic climate trends are classically attributed to long-term changes in the geological carbon cycle related to Neo-Tethyan geodynamics. The mountain uplift associated with the collision of India and Arabia with Asia is widely thought to have enhanced erosion and global silicate weathering rates, ultimately driving post-50 Ma climate cooling. However, multiple major warming events occurred during the early Cenozoic (e.g., EECO, MECO, PETM), a period that preceded rapid mountain uplift by about 30 Ma and that was characterized by intense Neo-Tethyan arc magmatism likely affecting the surface CO_2 budget and, consequently, climate. We present new measurements of the pre-eruptive CO_2 budgets of Neo-Tethyan magmas encompassing the India-Asia and Arabia-Asia collision. We further link these new observational constraints to forward paleoclimate modeling and inverse modeling of the Cenozoic surface CO_2 data. Our results demonstrate that magmatic CO_2 emissions associated with subduction of Neo-Tethyan lithosphere as well as of Indian and Arabian passive-continental-margin successions exerted a primary control on early Cenozoic climate changes.

Tectonic carbon cycle in deep time – constraints from Earth's secular evolution and implications for habitability

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The carbon cycle operates on short and long time-scales (Berner, 2004; Kasting, 2019). The short-term cycle involves the take-up of CO_2 by photosynthesis, which is reversed by respiration and decomposition. It operates on time-scales of days to tens of thousands of years. The long-term carbon cycle, also known as the carbonate-silicate cycle, represents a climate-stabilizing negative feedback loop that operates on million-year timescales and has been essential in maintaining Earth's relatively stable climate over the past 4.5 billion years.

Through the carbonate-silicate cycle, CO_2 outgassed from mantle igneous activity and crustal metamorphism is balanced by CO_2 drawdown via aqueous chemical weathering of silicate rocks, followed by deposition of carbonate precipitates on the seafloor and ultimately subduction and return of carbon into the mantle. The rate of silicate weathering increases with temperature, whereas the solubility of carbonate minerals decreases with temperature, thus, CO_2 drawdown accelerates in response to increasing CO_2 levels and greenhouse warming of the atmosphere. The storage of carbonate rocks on continental crust is an additional component of the cycle and is particularly relevant in orogenic belts such as those associated with the Mesozoic to Cenozoic Alpine-Tethyan and Paleozoic Appalachian-Caledonian orogens which developed in latitudinal parallel settings close to the equator (cf. Macdonald et al., 2019). Tectonic recycling of this crustal carbonate reservoir may have maintained a high CO_2 outgassing flux despite long-term mantle cooling (Alcott et al., 2024).

The carbonate-silicate feedback cycle is well-documented for Earth's current plate tectonic mode (Berner, 2004; Kasting, 2019). However, the geological archive suggests plate tectonics has not always been the modus operandi of the Earth's tectonic system; stagnant lid and sluggish lid modes may have operated in the Hadean and Archean, respectively (e.g., Cawood et al., 2022). In addition, the early Earth was a water-world in which emergent crust along with the volume of continental crust, increased progressively through the Archean and early Proterozoic (Cawood & Hawkesworth, 2019; Chowdhury et al., 2025), limiting terrestrial silicate weathering.The implications of these changes for the long-term carbon cycle are not well known. Models suggest that a tectonic carbon cycle may also have operated under a hot stagnant lid regime on the early Earth (Foley and Smye, 2018), where basaltic-ultramafic crust underwent carbonatization, and CO_2 was recycled back into the atmosphere during crustal stacking and burial-metamorphic heating of altered crust. However, the negative feedback will break down if chemical weathering becomes limited by the supply of fresh bedrock at Earth’s surface. However, the extensive magmatic activity related to heat pipes and mantle plumes that is inferred to have occurred on the early Earth would have provide ongoing fresh igneous crust.

On Earth’s early water world, with a global ocean ~ 4.5 km deep, submarine basalt degassing resulted in CO_2 and CO as the dominant phases with water and sulphur remaining dissolved in the basaltic melt (Gaillard and Scaillet, 2014). Enhanced CO_2 degassing under a higher-pressure submarine dominated regime would help mitigate the effects of the decreased luminosity of the early Sun and also likely lead to increased ocean acidity (Guo and Korenaga, 2025; Kasting and Ackerman, 1986; Walker, 1985). Progressive continental emergence during the inferred phase of sluggish lid behaviour (ca. 3.8 – 2.5 Ga; Cawood and Hawkesworth, 2019; Chowdhury et al., 2025) may have marked the start of widespread subaerial silicate weathering. However, the weak nature of the lithosphere, under the high mantle potential temperatures of the early Earth, limited topography along with associated weathering and material transport.

The Earth’s atmospheric and ocean composition, land-water ratio, continental volume, tectonic mode, and solar flux have evolved through time, but the dynamic nature of the carbonate-silicate feedback loop has been able to maintain clement conditions throughout most of Earth’s 4.5 Ga existence.

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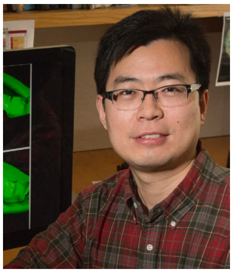
Day2-10 14:40-15:00 Keynote speaker: *Liu, Lijun*

Periodic instability and restoration of cratonic lithosphere

Lijun Liu



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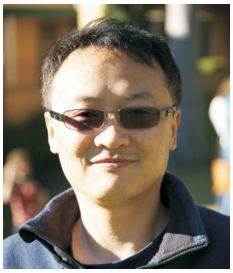
The longevity of cratons implies that the entire cratonic lithosphere remained unchanged over billions of years, attributed to their intrinsically buoyant and strong lithospheric roots. Here we show that the present cratonic roots are notably denser than the ambient mantle, with the compositional buoyancy offsetting only 1/5 of the negative thermal buoyancy relative to mid-ocean ridges as reference. In addition, the presence of a weak mid-lithospheric discontinuity could decouple the upper and lower lithosphere upon perturbation, allowing delamination of the lower portion, while the delaminated lithosphere would eventually relaminate to the base of the lithosphere after sufficient warming inside the convective mantle. This process generates enduring (>100 Myr) and prominent (>1 km) surface uplifts within continents, a mechanism more compatible with data, especially those reflecting lithospheric deformation and delamination, than the model of continents moving across a steady pattern of dynamic topography. Subsequent lithospheric cooling gradually draws the surface down to even below sea level, where the lithospheric mantle density reaches a maximum upon formation of the next supercontinent. We argue that such cratonic deformation happened repeatedly over supercontinent cycles since the Neoproterozoic and largely shaped the properties of the cratonic lithosphere.

Day2-11 14:20-14:40 Keynote speaker: *Yuan, Huaiyu*

Echoes of Ancient Earth: Seismic Insights into Early Crustal Dynamics

Huaiyu Yuan[1,2,3]



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The transition from the Archean to the Proterozoic represents a pivotal phase in Earth's tectonic evolution, marked by a potential shift from vertical-accretion processes, such as mantle plume activity, to horizontal-accretion mechanisms akin to modern-style plate tectonics. Interpreting this transition is complicated by the selective preservation of geological records in the continental crust, which biases our understanding of crustal growth and evolution. Seismic imaging has emerged as a crucial tool for detecting structural imprints of these early tectonic regimes. Features such as inclined Moho discontinuities, dipping mantle reflectors, and variations in crustal Vp/Vs ratios observed in Precambrian terrains suggest that crustal seismic structures can preserve deformation fabrics indicative of past tectonic processes. In this study, we compare results from recent new crustal seismic models derived from dense broadband deployments to investigate cratonic crust beneath northeastern North America, Southeast Asia, and Western Australia. By comparing key seismic features across these stable regions, we examine how crustal structures record the imprint of early crustal formation and subsequent reworking. These findings contribute to a deeper understanding of the diversity and persistence of ancient tectonic regimes and highlight the value of seismic constraints for reconstructing Earth's early geodynamic history.

Day2-12 15:00-15:20 Keynote speaker: *Thybo, Hans*

Eclogites as a trigger of the Phanerozoic explosion in onshore life

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Eclogite formation from lower crustal rocks requires high pressure at relatively low temperature in the presence of water. Due to the high temperature regime in the early Earth and the sparse observations of eclogitic rocks at the surface, it is generally expected that such rocks are rare in cratons. Nevertheless, our recent results show that large amounts of eclogitic lower crustal rocks are present below the seismic Moho in the Baltic Shield (Nature Comm., doi: 10.1038/s41467-021-26878-5). These eclogites in various metamorphic grades may even explain the high topography of the Scandes mountain range in northern Fennoscandia (Nature Comm., doi: 10.1038/s41467-025-55865-3). Our findings suggests that the amount of sub-Moho eclogite may be generally underestimated globally! Eclogitization may also play a major role in plateau formation in Tibet, where new addition of mafic underplate to the overthickened crust may immediately transform into eclogite, which founder each time the eclogite layer exceeds a critical thickness (Nature Comm., doi: 10.1038/s41467-021-21420-z).

Eclogites globally occur at Earth's surface in a large number of locations in Phanerozoic orogens. By interpretation of >18,000 km of seismic profiles, we document that a mafic crustal layer is generally preserved in Proterozoic orogens but absent in Phanerozoic orogens (Geology, doi: 10.1130/G52647.1). This fundamental difference indicates a general change in the global subduction style at the onset of the Phanerozoic, which caused massive eclogitization of newly formed lower crust in orogens and subsequent recycling of the eclogitic rocks into the mantle. The resulting, remaining buoyant felsic crust led to the rise of continents above sea level, which enabled onshore life to develop, thus explaining the Neoproterozoic oxidation event and the explosion of life in the Phanerozoic.

Day2-13 15:20-15:40 Keynote speaker: *Stagno, Vincenzo*

Eclogitic diamonds from the Siberian craton are witnesses of redox heterogeneities and volatile recycling in the Archaean upper mantle

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To date, cratonic eclogites distributed worldwide show redox conditions expressed in oxygen fugacity (fo_2) varying from -6 to -0.1 log units normalized to the fayalite-magnetite-quartz reference buffer (Mikhailenko et al. 2020a; Aulbach et al. 2022). On the other hand, reconstructions of magmatic fo_2 from geochemical analyses of ancient unaltered eclogites suggest that Archaean mantle sources are more reduced than present-day mid ocean ridge basalts (Aulbach and Stagno 2016). Few available data on eclogitic inclusions trapped in lithospheric diamonds are available that also record wide range of fo_2 compatible with the presence of either CO_2-rich melts or methane-bearing fluids.

In this study, we investigated 19 eclogitic diamonds from the Siberian craton (Russia) with coexisting garnet (grt) and clinopyroxene (cpx) unique inclusions both exposed (after polishing) and trapped, with sizes ranging from 20 to 100 µm. Grt and cpx hand-picked from the host eclogite of one diamond were also analysed. The crystal-chemistry (major elements and vanadium) was analysed by electron microprobe of the polished inclusions, while the H_2O content of cpx and grt was measured by Fourier Transform infrared spectroscopy supported by X-ray tomography. The $Fe^{3+}/\sum Fe$ of both exposed and encapsulated inclusions was determined by Synchrotron Mössbauer spectroscopy. Finally, the Raman spectroscopy was employed to identify additional tiny, trapped inclusions of S-bearing minerals.

Chemical variabilities among the reconstructed bulk rocks are observed in terms of Mg#, V concentration and $Fe^{3+}/\sum Fe$ ratio. Inclusion compositions indicate average sampling depths of 180-290 km, temperatures of 1030 - 1540 (± 60) °C supported by the finding of coesite as inclusion, and redox conditions of most of the samples between -4 and -0.4 log units (ΔFMQ) oxidized enough for diamonds to have originated from $H_2O(CO_2)$-rich fluids. Notably, we observed a similar logfo_2 and V bulk rock concentration for the inclusions in one of the investigated diamonds and the corresponding host eclogite, indicating that eclogite mineral assemblages might preserve their redox state even during diamond formation from CO_2 growth media.

The reconstructed bulk composition points to basaltic oceanic crust formed from an Archaean convecting mantle region that was more O_2-depleted than today, providing compelling evidence of redox heterogeneities in the early Earth's melting source rocks. Our results provide evidence of the redox variability of eclogites of Archaean age and suggest the oxidizing nature of the subducted mafic rocks to be a likely consequence of either the mantle source where the magma formed or exposure to the first whiffs of oxygen into the Early Archean atmosphere.

Day2-14 16:10-16:30 Keynote speaker: ***Wilde, Simon A***

Multi-mineral dating of lamproites derived from an enriched lithospheric mantle source: Walgidee Hills, Western Australia

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Lamproites and kimberlites have the distinction of being the key primary sources of diamonds, with the former only recognised as such since the late 1970s. Because of their depth of generation in the mantle, their invariable interaction with continental crust, and their susceptibility to alteration upon eruption, identifying the composition of the source magmas has proven to be extremely difficult[1]. The same is applicable to their mineralogy, as it necessary to distinguish minerals that have grown in the magma from those entrained as xenocrysts during upward passage through both the mantle and the crust. In a study of the World's largest known lamproite intrusion, at Walgidee Hills in the West Kimberley Province of Western Australia, we selected a suite of K-rich minerals from the matrix of the fine-grained marginal facies of the lamproite for $^{40}Ar/^{39}Ar$ dating, to test their applicability to constrain its eruptive age. The minerals chosen were phlogopite, potassic richterite, wadeite, jeppeite, and priderite. All minerals recorded the same age, within uncertainties, with a mean age of the combined data of 17.487±0.083 Ma, making this the youngest lamproite so far dated in the Kimberley Province, and the youngest known diamondiferous pipe in the World[2]. These minerals can, therefore, be used either singly or in combination to provide precise ages for lamproites.

Walgidee Hills is an olivine lamproite for which the temperature of the initial magma has been modelled at ~1260-1300°C[3]. However, the cooling rate has been less well defined, with alternative suggestions that the central, coarse-grained portion of the diatreme may be either the result of slow cooling[3], or perhaps related to an increase in volatile content[2]. For the initial eruptive phase, the argon age dates indicate rapid cooling of the analyzed mineral suite within ~0.2 Ma, and certainly within 0.7 Ma when proxies for the various minerals were modelled using diffusion rate simulations[2].

Although not part of this study. trace element and isotope analysis are widely used in order to place constraints on the source and evolution of lamproitic magmas. For Walgidee Hills, $^{87}Sr/^{86}Sr(i)$ values of 0.71232-0.71233 have been recorded[4], consistent with similarly high values for other West Kimberley lamproites. In addition, εNd of -8.2 and -10.2 for Walgidee Hills lamproite[4] indicates the significant contribution of a long-term enriched lithospheric mantle component. The TNd_{DM} of 970 and 1100 Ma for these samples[4] confirms the Proterozoic age of the source. It is pertinent to note here that the lamproite pipes in the whole of the Kimberley Province are located in or adjacent to Proterozoic mobile belts that surround the Paleoproterozoic Kimberley Craton[2], suggesting that the enrichment of the lithosphere was related to subduction during assembly of the mobile belts. This would imply a significant sedimentary component in the subducted slab.

Finally, what was the trigger causing the elevated heat and subsequent mantle melting required to generate the Kimberley lamproites? For several decades, this was attributed to a mantle plume, at least for the ~20 Ma diatremes, although recent work has questioned this[5]. Walgidee Hills is especially important here, as it is the youngest intrusion, yet lies south of slightly older intrusions of 20-22 Ma, yet the plume model required the northward movement of Australia over a stationary hotspot. Recently, more local tectonics have been proposed to explain the lamproite magmatism[5].

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Lithosphere heterogeneity from geophysical data and kimberlites

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Detailed information on the structure, composition and secular evolution of the lithosphere is pivotal to understanding key processes in the Earth's interior, which still remain insufficiently understood and debated. While the top of the lithosphere, obviously, coincides with the topographic surface, there is the multiplicity of the existing practical definitions of the lithospheric base due to the multiplicity of (geo)physical and (geo)chemical parameters by which it can be defined, the multiplicity of methods that can measure these parameters, and the transitional (diffuse) nature of the lithospheric base[1]. Most properties of the upper mantle change gradually with depth and do not exhibit sharp boundaries that could be uniquely associated with the lithospheric base. For this reason, the lithosphere-asthenosphere boundary (LAB) has a diffuse nature and is always a transition zone over which a gradual change of physical and chemical characteristics occurs. As a result, the lithosphere thickness can be significantly different even for the same model of physical parameter variation with depth[2].

Lithosphere structure is known largely from remote geophysical studies, which employ a multitude of methods that are sensitive to various degree to various physical and chemical rock properties. This results in broad variability of geophysical models of lithosphere thickness and internal structure. However, nearly all geophysically measured rock properties are temperature- and composition-dependent. For this simple reason, apparent disagreements between various geophysical models of the lithosphere structure may be overcome if one focuses on physico-chemical properties of the lithosphere, specified by the lithosphere thermal boundary layer (TBL), chemical boundary layer (CBL), and much more shallow mechanical boundary layer (MBL)[1]. Structure of MBL can be assessed from depth distribution of seismicity and it is not discussed here.

Structure of TBL may be assessed by several methods, that are not based on seismic, nor electric data[2-5]. As such, models of the lithosphere thermal structure allow for meaningful removal of temperature signal from the observed seismic, gravity, and electrical resistivity models, thus allowing for reliable estimates of lithosphere composition and fluid (melt) content. Thermal models will be illustrated on a global scale[6] in comparison with mantle-derived xenolith data, and detailed

Europe[5], the Central Tethyan Belt[7], and Tibet[8]. One of the illustrated approaches allows estimates of lithosphere thermal structure in regions with poor geophysical coverage, illustrated by the estimated basal melting of the ice sheet masses in Greenland[4] and Antarctica[9].

Compositional heterogeneity of the cratonic lithospheric mantle is known from the Nature's sampling, such as by kimberlite-type magmatism in Precambrian cratons. Joint analysis of geophysical data demonstrates that magmatism-related thermo-chemical processes contribute to significant lateral and vertical heterogeneity of the cratonic lithospheric mantle worldwide (the Canadian Shield, the North China, East European, Siberian, Kaapvaal and Antarctica cratons), which is reflected in its thermal, density, and seismic velocity structure[6, 10-15]. This heterogeneity reflects the extent of lithosphere reworking by regional-scale kimberlite-type magmatism and large-scale tectono-magmatic processes associated with LIPs and subduction systems.

The results show a strong correlation between the calculated density of the lithospheric mantle, the crustal structure, the spatial pattern of kimberlites, and their emplacement ages. In all studied cratons, blocks with the lowest values of mantle density are not sampled by kimberlites and may represent the "pristine" Archean mantle. Kimberlite magmatism is restricted to anomalous lithosphere, so that the isopycnicity (equal density condition, when compositional anomalies are compensated by temperature anomalies) is satisfied only in kimberlite provinces[12]. An important conclusion is that the Nature's sampling by kimberlite-hosted xenoliths is biased and therefore is non-representative of pristine cratonic mantle.

Finally, if time allows, the results of numerical modeling of the lithosphere deformation on the hot Archean Earth[16] and at present[17] will be used to argue for the processes that may have created the mid-lithospheric discontinuity caused by channel flow in proto-cratonic Archean mantle due to the inverted thicknesses of TBL and CBL[16] and are presently forming incipient ocean spreading beneath the Arabian Shield[17], which is supported by geological and geophysical observations.

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Day2-16 16:50-17:10 Keynote speaker: *Song, Haijun*

The causes of the Permian-Triassic mass extinction

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The Siberian Traps and concurrent volcanos around the Tethys led to a significant hyperthermal event during the Permian-Triassic interval. This presentation synthesizes fossil and geochemical evidence to establish a robust causal link between global warming and its synegetic effects (such as ocean anoxia and acidification) and major biotic extinction during the Permian-Triassic boundary interval. Integrating stratigraphic (temporal) and ecological evidence confirms that hyperthermal events drive extinction via interconnected stressors: warming, anoxia, and acidification. (1) The flat latitudinal diversity gradient in the Early Triassic was likely caused by the Permian-Triassic hyperthermal eveent. The collapse of the latitudinal diversity gradient—evidenced by higher tropical extinction rates and poleward migration/origination—directly correlates with global warming. Tropical taxa exceeded thermal tolerance limits, whereas high-latitude refugia facilitated survival. (2) Extinction selectivity was likely driven by ocean anoxia. Taxa with high-oxygen-affinity respiratory proteins (e.g., hemoglobin, hemocyanin) suffered lower extinction rates than those relying on diffusion or low-efficiency proteins (e.g., hemerythrin). Body size reduction ("Lilliput effect") in groups such as foraminifera further confirms the presence of oxygen stress, modeled by diffusion limitations under hypoxia. (3) Shell simplification (reduced ornamentation in ammonoids/ brachiopods, thinning in foraminifera) coincides with ocean acidification (ΔpH $\approx$ -0.5) in the Permian-Triassic interval. Bioenergetic calculations show these adaptations saved 20–50% of calcification energy—a critical advantage during acidification-driven carbonate crises. In conclusion, our findings emphasize that hyperthermal events, characterized by rapid warming, oceanic anoxia, and acidification, have played crucial roles in shaping extinction dynamics in Earth's history. Ongoing research is necessary to further clarify additional environmental factors and their roles in extinction events.

Day2-17 17:10-17:30 Keynote speaker: *Hu, Xiumian*

Oceans in the Tethys: some old, some young; some big, some small

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Understanding the nature of the ancient oceans that disappeared to give birth to orogenic belts is crucial for elucidating the dynamics of our planet. We here propose a novel approach to categorize ancient oceans based on the knowledge of current oceanic crust's ages and sizes. We use 100, 50, and 20 Ma duration ages as thresholds for classifying oceans into old, intermediate, young, and embryonic categories. A further category − presently including the eastern Mediterranean, the Black Sea and the southern Caspian Sea − can be named as aborted oceanic, because seafloor spreading aborted soon after mantle exhumation on the sea floor. The Pacific Ocean encompasses several oceanic plates: Cocos and Nazca oceans are embryonic and relatively small, Juan De Fuca is young and small, whereas the Pacific plate is old and huge. The Atlantic Ocean is old and wide in contrast with the Gulf of Aden that is embryonic and very small. The Red Sea is in transition from the "aborted oceanic" stage in the north to the embryonic stage in the south. Backarc oceans are typically embryonic. In this framework, we summarize our present understanding of paleo-oceanic basins formed in the central and eastern Tethys and entirely subducted during the Indosinian-Cimmerian and Alpine-Himalayan orogeneses. In Tibet, the Yarlung and Bangong-Nujiang oceans have been old and large, whereas the Yongzhu, Jinshajiang, and Litang oceans were small and young. In central Asia, the Arabian Ocean was intermediate in both age and size when it was subducted beneath Asia. In the Alps, instead, Piemont-Liguria Ocean was still in the "aborted oceanic" stage when it was subducted beneath Adria. High-quality multidisciplinary data are required to shed light on the history of ancient oceans and reconstructing their dynamics and lifetimes.

Day2-18 17:30-17:50 Keynote speaker: *Wang, Shuijiong*

Ghost carbonate in Archean granitoids marks a geodynamic transition in the Mesoarchean

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The Urey reaction on the early Archean seafloor leads to intensive silicification and carbonation. The earliest evidence for silicified surface materials involved in the production of continental crust dates back to ca. 3.8 Ga, but the geodynamic regime in which these early continents formed remains controversial. Here, we show that tonalite-trondhjemite-granodiorites (TTGs) older than 3.26 Ga have invariant Mg isotopic compositions falling within the range typical for igneous rocks, whereas younger TTGs partially evolve towards lower Mg isotope values. This is best explained by recycling of carbonate-derived, light Mg isotopes into the source of < 3.26 Ga TTGs. Phase equilibria modelling demonstrates that ~ 20 % to 30 % melting of decarbonated basalt along high geothermal gradients produces TTGs, with its solidus about 50 - 100 °C higher than that of silicified basalt. The > 3.26 Ga TTGs were likely formed by silicified basalt melting in a restricted pressure-temperature window (P = 10 – 14 kbar; T = 850 – 950 °C), with negligible participation of decarbonated basalt melting. A geodynamic transition in the Mesoarchean may have facilitated enhanced carbonation of the deep portion of oceanic crust and extensive contribution of melts from subducted decarbonated basalts to continent production for the first time.

Day 1, 10:50-10:55 **Speaker:** ***Liu, Jin***

Mechanisms of Unconventional C Conversion in Shallow Subduction Zones

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Calcium carbonate is the major oxidized carbon carrier in subducted slabs. Dissolution, melting and metamorphic decarbonation have been proposed as the main mechanisms for recycling subducting carbon back to the surface, which could have dictated the long-term evolution of surface-interior carbon exchange. Consequently, deep carbon processes have implications for global climate change and long-term planetary habitability. In this presentation, we report on the phase stability of calcium carbonate and its novel chemical reactions with subduction fluids under high pressure-temperature conditions as well as under varying oxygen fugacities of the shallow subduction zones. These results provide insight into the efficiency and pathway of recycling subducted carbonates back into mantle wedges and arc volcanoes.

Short presentation

Day 1, 10:55-11:00 **Speaker:** ***Chen, Wei***

An essential role of oxygen fugacity in dictating water and carbon recycling at subduction zones

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Clarifying factors controlling the recycling efficiency of CO_2 and H_2O at subduction zones is crucial for understanding Earth's interior dynamics and climate evolution. Although marine sediments exhibit substantial variations in oxygen fugacity (fO_2), it remains unknown whether fO_2 can influence the devolatilization efficiency of subducted sediments. Here, we experimentally determined melting phase relations of a hydrous, carbonated sediments under various fO_2 conditions. We find that the solidus, along with the stability field of carbonate and phengite, is significantly depressed with increasing fO_2. Within the context of rising atmosphere-ocean O_2 levels over Earth's history, we evaluated the recycling efficiency of CO_2 and H_2O for subducted sediments since the onset of plate tectonics. Our findings indicate that the subduction of reduced sediments prior to Neoproterozoic Oxygenation Event (NOE) dominated recycling of H_2O and particularly CO_2 into the deep mantle, whereas the highly oxidized sediments underwent complete devolatilization. The subduction of reduced sediments in the Precambrian significantly lowered atmospheric CO_2 levels, thereby facilitating the establishment of Earth's habitable environment.

Short presentation

Day 1, 11:00-11:05 **Speaker:** ***Zhang, Lijuan***

The ability of eclogitization to produce abiotic CH_4

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The abiotic methane (CH_4) hypothesis has a long history, with various proposed origins, including Precambrian crystalline basements, volcanic and sedimentary hydrothermal systems, and serpentinization in diverse geological settings. Understanding the formation mechanisms and accumulation potential of abiotic methane gas is of great significance for exploring new energy frontiers. This study expands the sources of abiotic CH_4 to high- and ultrahigh-pressure eclogites in cold subduction zones, opening a new frontier in abiotic CH_4 research.

In this study, abundant CH_4-rich primary fluid inclusions were discovered in eclogites from the Western Tianshan subduction zone. Petrological characteristics and carbon-hydrogen isotopic compositions confirm the abiotic origin of this methane. Phase equilibrium calculations indicate that methane formation occurred under conditions of 500–560°C and 2.1–3.4 GPa, with oxygen fugacity (fO_2) ranging from FMQ-2 to FMQ-3.5. The global flux of abiotic CH_4 in modern subduction zones is estimated to reach 10.8 Mt/year, making it the largest known source of abiotic CH_4.

Further research reveals the immiscibility of H_2O and CH_4 under high-pressure conditions, establishing a pressure-dependent miscibility/immiscibility scale for CH_4-H_2O fluids. Carbon from subducting slabs may be transported into the overlying mantle wedge as supercritical CH_4-rich fluids. When encountering suitable conditions, these fluids could potentially form deep abiotic natural gas accumulations. This study provides a theoretical foundation for exploring and developing deep inorganic hydrocarbon reservoirs. These findings suggest that subduction zones may serve as a major yet previously underestimated source of abiotic CH_4, with significant implications for deep carbon cycling and future energy resource exploration.

Short presentation

Day 1, 15:55-16:00 **Speaker:** ***Zhao, Mingyu***

The Influence of Sulfate on Organic Carbon Cycle Throughout Earth History

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The degradation of organic matter is a key control on Earth's carbon and oxygen cycles, with atmospheric oxygen levels closely tied to organic carbon burial. However, the mechanisms governing organic matter degradation—and the fraction of carbon ultimately sequestered—remain poorly constrained. Here, we use microcosm experiments to show that sulfate availability exerts a primary control on degradation rates, revealing a pronounced suppression of organic matter breakdown under anoxic, low-sulfate conditions. Our findings suggest that sulfate-deficient environments—analogous to Precambrian oceans and modern euxinic basins—promote efficient organic carbon and phosphorus burial while limiting nutrient recycling, thereby restricting primary productivity. We propose that increases in marine sulfate concentrations during the late Archean, Great Oxygenation Event, and Neoproterozoic Oxygenation Event expanded Earth's biospheric capacity, creating favorable conditions for early life diversification.

Short presentation

Day 1, 16:00-16:05 **Speaker:** ***Gao, Liang***

Cenozoic ocean-climate reconfiguration driven by episodic orogenesis in the Drake Passage

Liang Gao[1,2*], Chenguang Zhu[1,2*], Liping Zhou[3], Xuan Ding[1,2], Teal R. Riley[4], Joaquin Bastias-Silva[5,6], Javier N. Gelfo[7], Carolina Acosta Hospitaleche[7], Xinwei Hu[1,2], Mengwei Zhang[1,2], Xiaoqian Guo[1,2], Yunying Zhang[8], Xiaohan Gong[1,2], Huaichun Wu[1,2], Junling Pei[9], Zhenyu Yang[10], Jun Deng[1,11], Yue Zhao[1,2]

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The Drake Passage, a critical oceanic gateway, has long been recognized as instrumental to Cenozoic global change. However, existing studies present conflicting interpretations regarding both its opening process and oceanographic-climatic impacts. Previous work has largely assumed a monotonic deepening of the passage, overlooking critical tectonic complexities and their consequences. Here, we integrate crustal thickness and paleoelevation reconstructions of the Patagonian-Scotia Sea-Antarctic Peninsula utilizing Sr/Y, La/Yb, and Ce/Y geochemical proxies with Earth System Modeling to demonstrate that the Drake Passage experienced multiple phases of subsidence and uplift driven by Phoenix Plate subduction dynamics, which fundamentally modulated Antarctic Circumpolar Current (ACC) intensity. Our data demonstrate that bathymetric variations

governed Cenozoic abyssal water circulation, redox conditions, and surface heat redistribution, with deeper passages intensifying northward ocean heat transport to drive land-dominated Northern Hemisphere warming and precipitation increases—ultimately enhancing silicate weathering that sequestered atmospheric CO_2 and contributed to Cenozoic cooling. Our study emphasizes the pivotal role of tectonic processes in regulating ACC intensity and their profound implications for global climate dynamics. This comprehensive approach not only resolves previously conflicting hypotheses on Cenozoic climate change but also offers novel perspectives into the intricate mechanisms linking tectonic evolution, ocean circulation, and atmospheric CO_2.

Short presentation

Day 1, 16:05-16:10 **Speaker:** ***Deng, Linpei***

The sustained influence of subduction-derived volatiles on collisional orogenesis

Linpei Deng[1,2], Jianfeng Yang[1,2], Huaiyu Yuan[1,4],Liang Zhao[2,3], Weiqiang Ji[1,2], Xiaofeng Liang[1,2]

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After ocean closure, there remains a lack of systematic understanding regarding the long-term behavior of oceanic volatiles. In particular, whether collisional orogenic belts can continuously retain subduction-derived volatiles, and whether subduction relics influence orogenic evolution, are still open questions. This study compiles post-ocean-closure magmatic data from both sides of the Jinsha suture in northern Tibet (i.e., the Qiangtang and Songpan–Ganzi terranes). The results reveal oceanic subduction signatures and evident carbonate metasomatic features in the magma source regions, indicating contributions from subduction-related volatile remnants.Seismic observations in northern Tibet reveal prominent velocity anomalies that spatially coincide with the distribution of magmatic rocks. Using data from stations across the Jinsha suture, we inverted two S-wave velocity profiles. These profiles show low-velocity anomalies at the top of the upper mantle, interpreted as water-bearing mantle minerals. The integration of geochemical records and seismic anomalies suggests that subduction-related volatiles can be retained in collisional orogens through hydrous mantle minerals and carbon accumulation.We employ petrological–thermodynamic numerical modeling, incorporating rock decarbonation processes (including H_2O and CO_2 release) during oceanic subduction, to reconstruct the migration, retention, and distribution patterns of these volatiles. The residual volatiles not only modify the rheological properties of the lithospheric mantle and influence orogenic evolution, but also constitute an essential component of material cycling within orogenic belts. This study provides a new framework for understanding water-carbon fluxes and deep resource formation in continental evolution.

Short presentation

Day 2, 10:30-10:35 **Speaker:** ***Wu, Jing***

Fault zone related seismic anisotropy revealed by a dense-linear broadband array in southeast Tibet

Jing Wu[1*], Yinshuang Ai[2], Peixi Huang[1], Fansheng Kong[3], Deke Xu[1], Jianguo Song[4], Mengyi Wei[1], Gao Xinyu[1], Li Long[5], Zhang Jien[1], Zhang Yanbin[1], Zhang Yingying[6]

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Southeast Tibet, as the major path of Tibet's expansion towards southeast, is disputed on its tectonic deformation under the collision between Indian and Eurasian plates. The prominent characteristic is multiple large-scale faults intersecting together. However, it is not clear whether the fault zones play a more predominant role in tectonic deformation. Seismic anisotropy may help us to understand the issue. In this study, we applied core-refracted phases SKS/SKKS/PKS (XKS) splitting to a new dense array (MCD) and six permanent stations. We reveal that a single layer anisotropic model with an origin depth center of 280~350 km exists, suggesting that the seismic anisotropy origins from the asthenosphere and it matches with southeastward extruded mantle flow. Additionally, we find that delay times near large-scale faults or tectonic borders are relatively larger compared with those further away. This means that large-scale faults, compared with lower-velocity-zones, play a more predominant role on XKS splitting.

Short presentation

Day 2, 10:35-10:40 **Speaker:** ***Luo, Yun***

The response of the river system to the faulting activity in southeastern Tibet

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The river system is the result of interactions among tectonic events, climate change, and surface processes. The Three Rivers Region, where these factors converge, exhibits a phenomenon in which the Salween River, Mekong River, and Yangtze River flow in parallel and are closely spaced, with distances that are an order of magnitude lower than the theoretical distances. Due to the complex cross-sphere response, the formation mechanisms of the Three Rivers Region remain unclear. Two end-member models explain this phenomenon: one is the indentation of India, and the other is the river capture model. However, the tectonic mechanisms of river system formation remain unclear due to the lack of numerical methods that link tectonic events to surface processes. We develop a method that couples a thermo-mechanical code, LaMEM, and a landscape code, FastScape, to design a 3D coupled thermo-mechanical-landscape model. Our models indicate that the river systems form in response to the faulting systems caused by the indentation of India. We find that the three parallel rivers form when there is a moderate lower crust and a relatively weak upper crust in southeastern Tibet, which favors a special faulting system. A moderate erosion rate is also necessary due to the low likelihood of river capture at a low erosion rate. This new coupling method could link tectonic events and surface processes, providing new insights into the understanding of cross-sphere responses.

Short presentation

Day 2, 10:40-10:45 **Speaker:** ***Hencz, Mátyás***

Quantifying geological CO_2 accumulation in the subcontinental lithospheric mantle during post-rift evolution of a sedimentary basin (Bakony-Balaton Highland Volcanic Field, Pannonian Basin, Central Europe)

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The subcontinental lithospheric mantle (SCLM) is a potentially significant but poorly constrained carbon reservoir. In this study, we quantify CO_2 accumulation in the SCLM beneath the Bakony–Balaton Highland Volcanic Field (BBHVF), Hungary, during the post-rift evolution of the Pannonian Basin (10 Ma - today). Using 172 upper mantle xenoliths with known sampling ages, and equilibrium temperatures, we derived their depth of origin based on newly modelled paleogeotherms for 2, 4.5, and 8 Ma. Our findings demonstrate that peridotite xenoliths encompass the entire vertical range of the SCLM (34–69 km), indicating a depth dichotomy between equigranular textures, which are found at shallower depths (37–55 km), and protogranular textures, which occur at greater depths (52–68 km). In other words, the xenoliths proved to represent full-depth SCLM sampling. When considering the xenolith textures, a progressive deepening trend of protogranular xenoliths through time reflects lithospheric thickening during the post-rift phase. We estimate CO_2 accumulation within newly accreted lithospheric mantle volumes using diverse density and CO_2 content scenarios. The most probable scenario (2000 ppm CO_2, 3.2 g/cm³ SCLM density) suggests an average CO_2 accumulation rate of ~3700–16300 tons/year in the BBHVF area (25x40 km), totaling ~103 Gt over 10 million years. Whereas the contribution of deep mantle CO_2 to atmospheric carbon could be more significant than expected, our results provide essential constraints on long-term carbon cycling within the evolving continental lithosphere, supporting more accurate global carbon budget models.

Short presentation

➤ **Day 2, 10:45-10:50** **Speaker:** ***Guo, Pengyuan***

The nature of lower mantle unraveled by plume-ridge interaction

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While the composition of the upper (most) mantle is well constrained by the mid-ocean ridge basalt (MORB), the lower mantle composition remains ambiguous. Here we present a systematic He isotope study on Easter-Salas y Gomez seamount chain basaltic glasses, presumably resulting from the Easter plume interaction with East Pacific Rise (EPR), and EPR mid-ocean ridge basaltic glasses to characterize the composition of the lower mantle. These lavas have a large $^{3}He/^{4}He$ variation with their values as high as 18.3 Ra, confirming the Easter plume lower mantle origin. The inverse longitudinal $^{3}He/^{4}He$ variation with the abundances and ratios of more-to-less incompatible elements demonstrates that the high-$^{3}He/^{4}He$ endmember, originated from less-processed lower mantle, is depleted in nature. In contrast, the low-$^{3}He/^{4}He$ endmember is expected to be highly enriched in incompatible elements and physically more fusible, consistent with the interpretation of recycling of time-integrated low-degree melt metasomatized mantle materials. We emphasize the hot, buoyant and compositionally depleted peridotitic upwelling plume could incorporate those more fusible, compositionally enriched metasomatic veins, blobs and/or streaks orphan that dispersed in the matrix mantle during its journey from the lower to upper mantle. Melting of such a heterogeneous mantle plume beneath gradually thinner oceanic lithosphere could produce decoupled He isotopes spatial variations with other geochemical parameters. This study also highlights the importance of the off-axis plume-ridge interaction that acts as a natural process to unravel the nature of the lower mantle through gradually consuming plume enriched feasible components beneath gradually thinner lithosphere from plume center towards spreading axis.

Short presentation

Day 2, 15:55-16:00 **Speaker:** ***Tang, Chunan***

Earth Evolution as a Thermal System
—Effect of Earth breakup on climatic oscillations

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Despite more than six decades of plate tectonic theory, the fundamental drivers of Earth's extreme climatic oscillations—from "Snowball Earth" episodes to hyperthermal mass extinctions—remain elusive, with prevailing carbon cycle-centric models struggling to fully explain the magnitude and synchronicity of these events. We propose a paradigm shift, arguing that large-scale lithospheric breakup during supercontinent fragmentation, rather than primarily atmospheric CO_2 fluctuations which may be a consequence or secondary effect, is the dominant trigger for major global climate transitions through fundamental alterations to the planetary heat budget. Our model posits that the expansion, uplift, and ultimate collapse of the lithosphere under critical stress reaches a tipping point, triggering a cascade of shallow processes: this rupture induces massive pressure release at the lithosphere's base, driving widespread decompression melting— an intensely endothermic phase change that absorbs vast quantities of heat from the surrounding mantle and lithosphere, causing intrinsic cooling. Concurrently, the resulting catastrophic volcanism and magmatism, manifested as colossal Large Igneous Provinces (LIPs), flood the surface with lava that acts as a planetary radiator, rapidly transferring immense geothermal energy from the molten rock directly into outer space via radiation. This dual mechanism—endothermic cooling at depth and massive radiative heat loss at the surface — constitutes a rapid, large-scale extraction of internal Earth heat, fundamentally resetting the global thermal equilibrium. We conclude that these lithospheric rupture events, particularly during supercontinent breakup, are the primary mechanisms capable of terminating prolonged greenhouse warming phases and abruptly initiating new global cooling cycles, potentially culminating in ice ages; while carbon cycle perturbations and CO_2 levels play a modulating role, they are subordinate within this overarching geodynamic framework where the thermal consequences of planetary-scale lithospheric failure directly govern Earth's deepest climatic extremes and habitability rhythms. Understanding these lithosphere-driven heat budget dynamics is therefore crucial for deciphering Earth's climatic past and its habitable evolution.

Short presentation

Day 2, 16:00-16:05 **Speaker:** ***Wu, Sensen***

The role of subducted organic carbon in the long-term evolution of Earth's habitability

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The deep carbon cycle plays pivotal role in shaping Earth's habitability. However, the fate of subducted organic carbon remains poorly constrained. Here, we investigate the decarbonation and structural transformation of kerogen, the most representative sedimentary organic matter, under shallow upper mantle conditions. Using an integrated approach combining redesigned gas chromatography, Raman spectroscopy, NMR, and SEM, we demonstrate that subducted kerogen releases methane-dominated carbon-bearing fluids (< 10%), while residual solids undergo transformation into mantle-inert graphite phases. Our results demonstrate that temperature exerts primary control on graphite structural evolution and carbon-bearing fluid composition, establishing new quantitative constraints for deep carbon cycle. The sequestration of reduced organic carbon in deep Earth reservoirs enhanced surface oxidation, while degassed carbon-bearing fluids sustained surface warming—dual processes that established the fundamental conditions for Earth's habitability.

Short presentation

Day 2, 16:05-16:10 **Speaker:** ***Huang, Min***

Channels or waves: controls on melt migration through the upper mantle

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Melt extraction from partially molten mantle is a fundamental process for the evolution of the solid Earth. The reaction-infiltration instability has been identified as an important mechanism responsible for the formation of high-porosity melt channels in the upper mantle. To better understand this mechanism, we perform linear stability analysis and nonlinear numerical simulations in a compacting, chemically reactive porous medium. Strong interactions between compaction and reaction lead to two distinct unstable features: (1) high-porosity channels and (2) compaction-dissolution waves. Here we present a regime diagram to show that, compared to high-porosity channels, compaction-dissolution waves are favored in systems with lower reaction rate, lower compaction viscosity (i.e., more easily compactible medium), and smaller solubility gradients.

This regime diagram predicted by linear stability analysis shows good agreement with the nonlinear numerical simulations. Linear stability analysis predicts a dominant wavelength for wave instability but shows no wavelength selection for channeling instability. This result corrects previous studies which reported a preferred wavelength for channel formation. We attribute earlier conclusions to an artifact of the variable elimination, which neglects the dominant mode in linear stability analysis. In the channel regime, the dominant wavelength observed in nonlinear numerical simulations is instead controlled by the spectrum of the initial perturbations.

Under geologically relevant conditions, both high-porosity channels and compaction- dissolution waves may form in the mantle, although channels are more commonly expected. The relationships between high-porosity channels and compaction-dissolution waves in this study may shed new light on the geochemical and petrological observations related to magma migration in the mantle.

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