Frontiers of Technology, Exploring Earth's Seafloor and Beyond

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Planet Earth is unique in many ways compared to other planets in our Solar System. Not only is it the only one to date known to harbor life, plate tectonics only occurs on Earth. However, there are volcanic constructs that do not conform to plate tectonic theory, such as intraplate volcanic chains, continental flood basalts (CFBs), and oceanic plateaus. At least some of these "large igneous provinces (LIPs)" appear to have originated at the core-mantle boundary (CMB) in regions of large low shear-velocity provinces (LLSVPs) that could represent plastic lower mantle material heated by the core. Impetus to adiabatically rise may be given by the subduction of old, cold, dense subducted oceanic crust to the CMB. The magma produced when this buoyant plume reaches the base of the lithosphere is unprecedented in its volume, flux, and potential for environmental impact. The thicknesses represent challenges for sampling LIPs to understand source regions as CFBs are invariably contaminated by continental crust and oceanic plateaus (uncontaminated by continental crust) are usually below several kilometers of water and sediment. Generally, <<1 km of material from oceanic LIPs has been recovered, except from the Ontong Java Plateau in the SW Pacific.

Plume volcanism is not common on Earth, but is the norm for other planetary bodies in our Solar System. If plate tectonics indirectly promotes plume volcanism on Earth, how was it initiated on Mercury, Venus, the Moon, and Mars? Using the Moon as an example, the Procellarum KREEP Terrane (PKT) could represent the surface expression of a hot spot that was uncovered by the Imbrium impactor. The PKT is enriched in heat-producing elements (e.g., Th) and the volcanism (which occurs mainly on the near side of the Moon because of the thinner crust) shows two peaks, at ~3.4 Ga and ~3.6 Ga, with a minor outpouring around 3 Ga, after which volcanic activity dramatically declined. Therefore, the internal structure of the Moon remains essentially preserved since initial differentiation. An initiative is underway to establish a globally distributed geophysical network on the Moon to use natural seismicity to explore interior structure and bulk composition. The composition of mare basalts returned by Apollo, Luna, and Chang'e missions indicate that the source regions still record evidence of initial lunar differentiation via a magma ocean. The Lunar Geophysical Network mission will explore the initial stages of terrestrial planet evolution and potentially record fossil plume structures in the lunar mantle.

This talk will examine how drilling at the Ontong Java Plateau and the Lunar Geophysical Network mission could expand our knowledge of deep planetary processes.

What can neutrinos do for geoscience?

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Due to their unique properties, neutrinos can be the ultimate messengers of the universe. Specifically, geoneutrinos can provide insight into the radioactive composition of the planet, and probe the depths of the Earth otherwise out of the reach of other current geological methods.

Geoneutrinos are electron antineutrinos coming from natural radioactive decays inside the earth (such as uranium and thorium). Measurements of the geoneutrino flux coming from the Earth's crust and the mantle can provide a constraint on the amount of heat-producing elements. Such information would help determine the absolute concentration of the refractory elements, as well as the radiogenic heat contribution to the total surface heat flux of the Earth. This talk will give a brief introduction to geoneutrinos, and their detection methods, as well as provide a quick overview of the latest measurements.

Earth dynamics and its future

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With one exception, Earth is the most dynamic of the solar system's terrestrial planets – a function of its size and heat budget, and its rheology. Despite over 50 years of research on the foundations of geodynamic motions, neither of these factors are satisfactorily understood. Earth's rheology is dominated by mechanisms of creep within dominant mineral phases, and most historical work has focussed on the crust and upper mantle, which are most accessible to deformation apparatus. Even within this domain, variations in mineralogy, fluid interactions, strain and damage localisation, and grain size variations, lead to enormous deformational complexity. Within the lower mantle, the situation is compounded by ambiguity in the dominant creep mechanisms, the modal abundances of lower mantle minerals, and their individual rheology, a complete dearth of knowledge on lower mantle – fluid interactions, including with the core, and high-pressure phases within the D" layer.

Heat flow suffers from a similar malaise in that whilst the current terrestrial heat flux is to some degree constrained, it is not in steady-state, and the relative contributions of core heat flow, secular cooling and radioactive heating are unclear. This is of fundamental cosmochemical importance.

In this presentation I summarise the state of the field and outline ways forward into these fundamental issues. Enormous increases in computing power have led to the development of ever-more sophisticated numerical models of Earth's interior, and, together with improved numerical implementation of high-pressure rheologies, offers predictive hypotheses testing on dynamic behaviour. Developments in ab-initio molecular dynamic simulations have offered an alternative and promising route to constraining lower mantle rheologies. Lastly, improved cosmochemical models, including those from upcoming geoneutrino results, can provide constraints on modal abundances and thermal budgets. Together, these may allow the development of sophisticated whole-Earth models encapsulating the gamut of complexity inherent in Earth processes, isolating dominant mechanisms, and allowing comparison with macro-physical observations of planetary geoid, surface dynamics, heat flow, and evolution.

Exploring the Limits of the Deep Subseafloor Biosphere

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Beneath the ocean on our planet lies the spatially vast deep biosphere inhabited by abundant evolutionary diverse microbial life. Recent transdisciplinary investigations through IODP Expedition 337 “The Deep Coalbed Biosphere off Shimokita” and Expedition 370 “The Temperature Limit of the Deep Biosphere off Muroto (T-Limit)” have expanded our fundamental understanding of environmental factors that control biomass, diversity, and activity of sedimentary microbial communities in a temperature/tectonic window securing planetary habitability beneath the ocean. In this talk, some recent findings regarding the limits of the subseafloor biosphere will be highlighted, and future challenges that require scientific ocean drilling will be discussed.

Life in the deep biosphere

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Studies of deep sea and deep subsurface environments have illustrated a picture of the distinctive biosphere built on the complex chemical, physical, and biological interactions that exist in the vast space.While varities of deep subsurface biospheres have been reported, I will focus on the deep subsurface biosphere associated with water-rock reation. Almost all the microbial ecosystems on present-day Earth are supported by photosynthesis including the subsurface biosphere as organic carbons from the photosynthesis have been accumurated and delivered into the deep subsurface ecosystem. Oxygen and oxidative compounds also have distributed everywhere on the Earth through the water and contributed to creating chemical gradients that can support microbial energy metabolisms. Therefore, opportunities are rare to address microbial ecosystems that are isolated from the effects of photosynthesis, but the effe ct of photosynthesis has been minimized in several settings, one of which includes a serpentinized ecosystem. Here I will introduce the microial strategies to survive in the deep-rock environments, and discuss the relations to the early evolution of life and also the possibilities of life beyond Earth.

A new journey to the Earth's center with global correlation wavefield

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Abstract

Understanding how Earth's inner core forms and evolves, including fine details of its structure and energy exchange across the boundary with the liquid outer core, helps us constrain its age, relationship with the planetary differentiation, and other significant global events throughout Earth's history, as well as the changing magnetic field. Global seismology has provided insights into the inner core's internal structure and dynamics, including 3D heterogeneity, attenuation, anisotropy, and differential rotation. Relatively recently, global seismologists confirmed that its innermost part contains distinct seismic anisotropy. Several new studies probed the inner core with probabilistic tomography, which reveals further complexities. However, progress has been impeded by the lack of uniform geometric coverage of body waves from large earthquakes and the fact that the inner core is buried beneath multiple Earth shells that are still not fully mapped. Furthermore, regarding material properties, it is still uncertain which type of iron crystal is stabilized in the inner core, making seismological and other inferences challenging.

In seeking ways forward, we started experimenting with earthquake coda correlation. This contributed to the rise of a new paradigm – the coda-correlation wavefield – a type of seismological data based on waveform similarity. The new data probes the Earth with periods ranging between 15 and 50 s, thus representing a new class of information that falls between body-wave and normal-mode methods. The first application proved the inner core's solidity by unambiguously detecting shear waves. As I hope to demonstrate in this lecture, further advances in this field may hold the keys to refined measurements of all inner core properties, informing dynamical models and strengthening mineral physics interpretations of the inner core's anisotropic structure and viscosity. The correlation wavefield also serves as a powerful tool for probing the interiors of other planets. Apart from these novel probes of the deep interior, the proliferation of seismographs and other geophysical instruments, especially in remote areas and the ocean bottom, remains one of the priorities of 21st-century global geophysics.

Frontiers of sampling the mantle by drilling to the Moho

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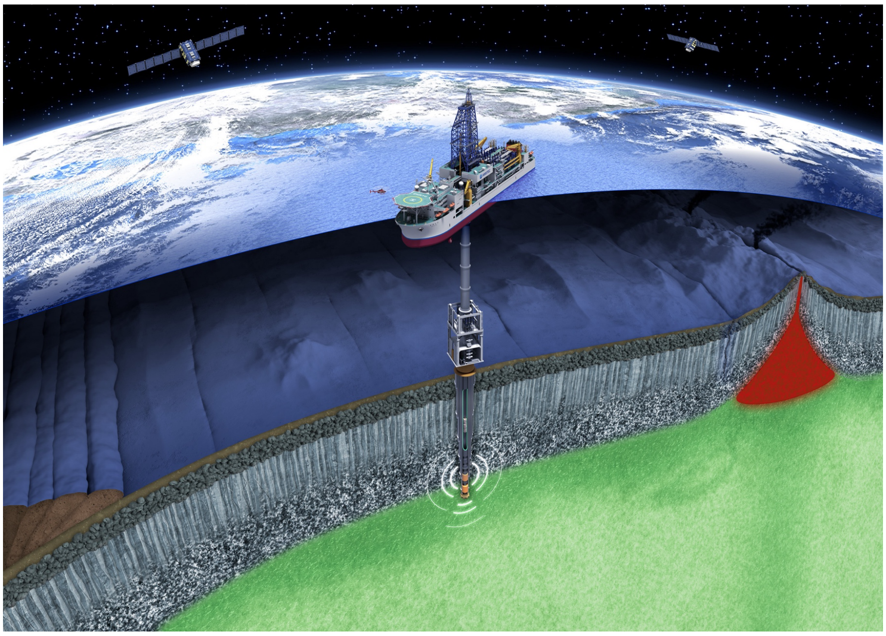
Drilling into the mantle from the ocean floor was initially launched in the late 1950s by US scientists as the "Mohole Project" and consequently developed into ocean scientific drilling. Since the start of the Integrated Ocean Drilling Program (IODP Phase I) in 2003, the international science community has been working toward the realization of drilling to the mantle with the D/V Chikyu and submitted a proposal "Moho to Mantle (M2M*)" to IODP in 2012. Drilling entire sections of the oceanic crust and the upper mantle into the fast-spreading lithosphere is expected to address primary scientific questions such as the structure and composition of the Earth's convective mantle, the geological nature of Moho, the contribution of the oceanic lithosphere to the global chemical cycle including carbon and water, the formation and evolution of the oceanic crust, and the limits and controlling factors of life. This presentation will introduce the universal scientific objectives that led to the proposal for mantle drilling, the technologies necessary for drilling and can be developed in the near future, the three selected candidate sites for drilling, and a strategy** for drilling into Mantle.
*IODP active proposal #805-MDP (Umino and 66 proponents); **Umino et al. (2020) SD29, 69-82.



A geoneutrino "telescope" to view the inaccessibly deep interior of the Earth: Ushering in a new era of multi-messenger geophysics

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The deepest portions of the Earth remain a frontier to science. The deep oceans remain largely unmapped, the deepest crust and upper mantle has never been sampled by drilling, and the deepest mantle is so inaccessibly deep that its composition and thermal evolution remain speculative. On the last point, the abundance and distribution of radioactive heat producing elements (HEPs: U, Th, and K) in the deep Earth is fundamental to constraining the thermal evolution and bulk composition of the planet. A mobile geoneutrino detector will enable key advances on both fronts by constraining the abundance of HEPs in the Earth and evaluate whether they are concentrated in regions of the deepest mantle that have the lowest seismic velocities. Recent geochemical research suggests that subduction of continental crust, host to a large fraction of the HPEs in the planet, may have been focused into the southern portion of these low seismic velocity regions. If so, seismic low-velocity regions will have higher geochemically-constrained HPE abundances and, thus, higher geoneutrino luminosities. Combining constraints from geophysics, geochemistry and geoneutrinos will revolutionize deep Earth science in much the same way that the gravity wave-neutrino-optical astronomy trio has ushered in a new era of multi-messenger astronomy.

Big data analysis in geoscience

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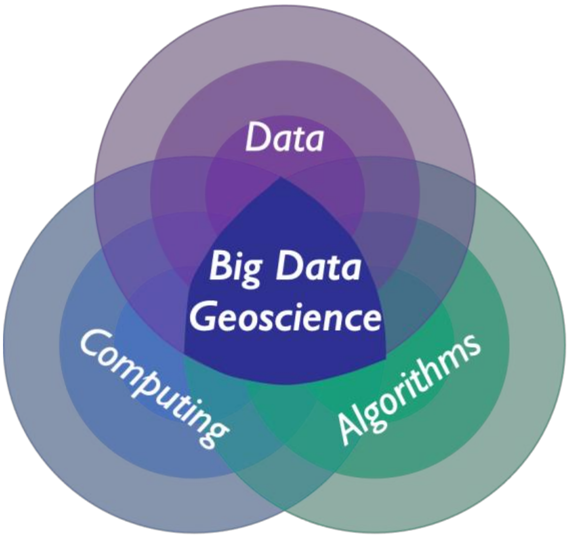
Our ability to understand the complex, interacting physical processes governing the Earth system increasingly depends on the analysis of massive data sets. In this talk, I will outline the challenges associated with Big Data Geoscience and the drivers creating new opportunities in this domain. I will describe how new data mining and deep learning algorithms are playing a key role in advancing research in the geosciences. I will describe recent examples of how these tools have been used to extract new insights from seismic datasets at a scale that was not previously possible. I will conclude the talk with emerging research directions and recommendations for broadening and accelerating progress in Big Data Geoscience.



adapted from **Arrowsmith et al. (2022)**

Planetary Hysteresis

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Abstract

What can be done to a planet, that cannot be undone? How do past events influence future behaviors? Here I will discuss some of the many ways that deep planetary memory can play a dominant role in dynamical evolution, the challenges of capturing the fascinating range of complex planetary behaviors using traditional modeling approaches, and the need for new language and methodologies to study planets as complex systems. I will touch on the concepts of passive and active memory, sub-critical dynamical states, and entanglement between dynamical states and systems. Memory is passive when it only conveys information about past events, and is active when the record influences future behaviors via modifications of physical and chemical properties. Sub-critical dynamical states are commonplace, and include important aspects such as habitability, plate tectonics, magnetic dynamos, and more. Mutual catalysis between multiple dynamical states also occurs, and presents enormous challenges for exoplanet characterization. These are all emerging thoughts, ideas, and directions. Feedback, ideas, and collaborations on tackling these grand challenges are welcome.

Ocean Bottom Detector : frontier of technology for understanding the Mantle by geoneutrinos

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Anti-neutrinos emitted from radioactive isotopes inside the Earth, geoneutrinos, bring unique and direct information on the Earth's composition and yield insights into its heat balance and thermal evolution. KamLAND and Borexino experiments show that geoneutrino measurements can be translated into useful geoscientific insights, leaving a question of the mantle's contribution to the global signal. Distinguishing the mantle flux by current detectors, which are all located on the continents, is challenging, since the crustal signal is about 70 % of the total flux. Given the oceanic crust is thin, simple, and has low Th and U abundances, remotely placing a geoneutrino detector on the seafloor provides the ideal location for identifying those geoneutrinos originating from Earth's mantle. Since 2019, "Ocean Bottom Detector (OBD)" working group, involving physics, geoscience and ocean engineering, has been working on technological developments and detector design simulation in Japan. OBD project broadens our perspective and works across the disciplinary boundaries of particle physics, applied anti-neutrino science, geoscience, and ocean engineering. The kt scale detector will be a breakthrough in the interdisciplinary community.

New technologies provide transformative insights into global geochemistry

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Controversy remains regarding the composition of the silicate Earth (e.g., Mg/Si = sun; upper = lower mantle composition). Measuring Earth's geoneutrino flux constraints its U and Th content and in turn that of Ca and Al, and tests compositional models of the upper and lower mantle. However, geological understanding of the local lithosphere is essential to calculate the U and Th content of the mantle. Results from Borexino (Agostini et al., 2020) and KamLAND (Abe et al, 2022) experiments are at odds. I will discuss how local lithology contributes to the observed discrepancies.

Models of the chemical composition and structure of the Earth, e.g., pyrolite model (McDonough and Sun, 1995) versus bridgmanite-enriched ancient mantle structures (BEAMS) model (Ballmer et al., 2017), do not converge to a unique composition. The BEAMS model requires global differentiation. We evaluated and discussed the existing constraints of the Earth from geoneutrino studies.

Abe et al. (2022), Geophys. Res. Lett. *in press*; Agostini et al. (2020), Phys. Rev. D92, 031101; Ballmer et al. (2017), Nat. Geosci. 10, 236-240; McDonough and Sun (1995), Chem. Geo. 120, 223-253.

Looking for Dark Matter with Olivine

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Dark Matter makes up 85% of our Universe's matter content, yet we do not know what this mysterious substance is made out of. So-called direct detection experiments search for Dark Matter via nuclear recoils that could be induced by Dark Matter particles scattering of ordinary nuclei. Paleo-detectors are a proposed alternative to this approach — in lieu of using a large experiment to search for Dark Matter induced nuclear recoils in a real-time laboratory experiment, the idea behind paleo detectors is to use small detectors that could integrate signals from nuclear recoils over large timescales. Many natural minerals found on Earth are excellent solid state track detectors, i.e., they record damage tracks from nuclear recoils. Minerals commonly found on Earth are as old as a billion years, and modern microscopy techniques may allow one to reconstruct damage tracks with nanometer scale spatial resolution. Thus, paleo-detectors would constitute a technique to achieve keV recoil energy threshold with exposures comparable to a kiloton-scale conventional "real-time" detector. In order to suppress backgrounds from cosmic rays and radioactivity, radiopure mineral samples obtained from deep underground are best suited as paleo detectors. Olivine and similar ultra-basic rocks obtained from deep boreholes are promising candidates. I will also discuss the possible application of paleo-detectors as tools to search for astrophysical neutrino sources such as supernovae or atmospheric neutrinos produced by cosmic rays interacting with Earth's atmosphere.

The Earth's thermal evolution

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Heat in the Earth's interior is transported dominantly by convection in the mantle and core, and by conduction at thermal boundary layers. The thermal conductivity of the bottom thermal boundary layer of the solid mantle determines the magnitude of heat flux from the core, and is intimately related to instability of the boundary layer and the formation of mantle plumes, the long-term thermal evolution of both mantle and core, and the driving force for generation of the geomagnetic field. I review recent experimental and theoretical studies examining the thermal conductivity of the Earth's lower mantle. Existing results of thermal conductivity measurements were combined to construct self-consistent models for the lowermost mantle conductivity. These models were used to conduct simulations of the temperature profiles at the base of the mantle and the CMB heat flux. The averaged global CMB heat flow is estimated to be approximately 10 TW, which is in line with traditional estimates. The total heat flow of approximately 10 TW with large regional flux variations promotes interaction and coevolution of the core and mantle.

Testing the Ontong Java Nui hypothesis

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The Ontong Java Nui is a super plateau inferred to comprise three of the largest volcanic edifices in the Pacific Ocean, the Ontong Java (OJP), Manihiki and Hikurangi plateaus. If true, the massive volcanism may have covered >1% of Earth's surface. OJP, the largest of the three, has been drilled at seven sites, at Deep Sea Drilling Project (DSDP) Site 289 and Ocean Drilling Program (ODP) Sites 289, 803, 807, 1183, 1185, 1186, and 1187. However, the size, volume, and formation rate of the OJP are not yet well constrained. Various models for its origin have been proposed, such as a surfacing mantle plume head, bolide impact, and fusible mantle melting, but none satisfies all observational data. Volcanological studies also indicate that long lava flows (or sills) from the OJP may have reached the adjacent Nauru, East Mariana, and possibly Pigafetta basins, indicating that the maximum extent of OJP-related volcanism may be even greater than currently estimated. To examine the true extent of the OJP, i.e., the ~200 km long flows, and its inferred connection with the Manihiki and Hikurangi plateaus to form the OJN, we propose drilling in the Eastern Salient and adjacent basins to recover basement samples.

Rheology and water cycle in the Earth and planetary interiors

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In the present Earth, outer-rise fault zones, which extend from the seafloor to the oceanic mantle, can be a major fluid pathway from the ocean to the deep of the Earth. Rheology of olivine in the mantle peridotites controls the mechanism of the outer-rise seismicity and its depth limit as well as the overall dynamics of the plate tectonics. While various flow laws of olivine aggregates have been reported/proposed at various conditions, deformation behavior of olivine aggregates at the brittle-plastic transition, which could also control the outer-rise seismicity, is poorly understood. In this presentation, I will talk on the deformation behavior of olivine aggregates at pressure-temperature conditions of the base of the seismogenic zone around outer-rise regions around the Japan trench. Audible and violent stick-slips followed by acoustic emissions were observed even at the temperature of 800˚C. However, the nominal friction coefficient at this condition is ~0.35, which value is significantly lower than that expected from the Byerlee's friction law (i.e., 0.6–0.85). Comparison between mechanical data and microstructural observation indicates that the strain was localized along R1-shear connected to Y- (or B-) shear with some contents of crystal-plastic deformation. These weak but seismic deformation could be dominant in the oceanic lithosphere. Initial results on high coffining and pore fluid pressures deformation experiments of olivine aggregates under drained condition will also be talked.

Mantle structures and their origins

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GFZ German Research Centre for Geosciences

The mantle contains both thermal and chemical structure. Convection creates thermal structure, but erases chemical structure through mixing. Chemical structure is continuously re-created through melting processes. Subducted slabs of lithospheric plates sink towards the base of the mantle, thinning the thermal boundary layer (TBL) beneath, and thickening it elsewhere. The Large Low Shear Velocity Provinces (LLSVPs) at the base of the mantle are probably chemically distinct, and have been rather stable in their position since at least 200 Ma, possibly longer. They may be partly primordial, partly represent subducted slab material. Upwelling plumes get generated at the base of the mantle, mostly above LLSVPs and primarily above their margins and rise to the surface. Plume conduits become tilted and distorted in the mantle. Although these basic ingredient of mantle structure and dynamics are largely agreed upon, there are considerable uncertainties, to a large part because mantle viscosity is very poorly known. It may depend on pressure (depth), temperature, strain rate and composition. Hence it remains uncertain to what extent the lower mantle between slabs and plume and above the TBL is convecting.

Thermal Conductivity of Hydrous Stishovite and Phase A

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The buoyancy of subducting plates is controlled predominately by the forces of slab pull, which is due to the density-driven thermomechanical contrast between slab and mantle. As this contrast increases, the seismicity of a subduction zone should generally exhibit a larger ***b***-value. This would result in more numerous and smaller magnitude earthquakes, which the Japanese Trench Subduction Zone does not exhibit. We hypothesize that the presence of large abundances of hydrous minerals in a typical MORB lithology may cause tectonic plates at cold subduction zones to exhibit a younger thermal age due to thermal insulation or structural instability within the slab. We conducted *in-situ* high-pressure thermoreflectance experiments on dense hydrous magnesium silicate (DHMS) phase A and stishovite of varying levels of H_2O weight percentage up to 50 GPa (20 GPa for phase A) at 300 K. The presence of H_2O within stishovite's crystal structure lowers its thermal conductivity by up to 40%. This reduction constitutes a drop in average bulk thermal conductivity of subducting slabs by up to 13%, depending on distribution and stishovite hydration percentage within the slab. It is further hypothesized that future thermal and subduction modeling will determine if this reduction is capable of generating positive up going buoyancy and stress accumulation at cold subduction zones.

The equations of state of B2 and bcc $Fe_{1-x}Si_x$

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The Earth's inner core is thought to be an iron alloy containing nickel and a few percent of light element(s) (Birch 1952). Si is one of the candidates for light elements. In Fe–Si alloys that contain a large amount of Si, the cubic phase becomes stable at high temperatures and pressures in a B2 or body-centered cubic (bcc) structure (Fischer et al. 2013, Ikuta et al. 2021). In the previous experiments, the phase identification was performed by X-ray diffraction structure analysis and observation of diffraction lines in the 001 and 111 planes, which are characteristic of the B2 structure. However, these diffraction lines do not disappear unless the phase is completely bcc, and even the B2 phase can have a finite degree of disorder. In this study, we combined the Korringa-Kohn-Rostoker method with the coherent potential approximation to obtain the equations of state of $Fe_{1-x}Si_x$ with B2 and bcc structures. The pressures and bulk sound velocities obtained in this study were compared with the Preliminary reference Earth model (Dziewonski and Anderson 1981). This leads to an understanding of the differences in physical properties between the two structures and constraints on the composition of the Earth's inner core.

Large strain deformation experiments of FeO polycrystals under the the lower mantle pressures

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Seismic tomography has revealed the existence of Large Low Shear Velocity Provinces (LLSVP) with seismic anisotropy from the mid-lower to the lowermost mantle beneath the African and South Pacific. Previous studies suggested that the development of crystallographic preferred orientation (CPO) of constitute minerals causes the seismic anisotropy observed at the edges of LLSVP. In this study, we conducted high-pressure large strain deformation experiments on FeO (wüstite) polycrystals to investigate the relationship between the CPO development of minerals and the seismic anisotropy of the LLSVP. Our deformation experiments were performed using a newly developed rotational diamond anvil cell under the high-pressure of 46-63 GPa, temperature of 300 K, and high-strain of more than 100%. The stress and CPO patterns of FeO during deformation experiments were observed by *in-situ* X-ray diffraction (XRD) measurements. The strain of deformed samples were determined from the reconstructed cross-sectional images obtained using X-ray laminography imaging techniques. We report the CPO development and slip system of FeO polycrystals obtained from analysis of the XRD patterns.

A Preliminary CMB Heat Flux map

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Estimating heat flux at Core-Mantle Boundary(CMB) is very important for understanding mantle thermal convection. Thanks to the discovery of perovskite post-perovskite transition in the deep mantle, using Clapeyron slope has a possibility that can constrain thermal gradient and geotherm above CMB. Seismic data is very useful in estimating geotherm, but still have a lot of uncertainties, such as effect of composition heterogeneity in the lower mantle, spin transition of iron, radioactive heat, partial melt effect and thermal conductivity in high pressure condition. Using the maximum heat flux assumed from the hypothesis 'Double-crossing'(Hernlund,2010) and P-wave velocity map which is highly effected in temperature, we can simply estimate the heat flux near the CMB. This method is useful in its simpleness, but the problem is assuming linear correlation between P-wave velocity and temperature.

Non–thermal heterogeneity in the lowermost mantle and constraints on convection parameters

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Seismic observation has suggested low-velocity anomalies near the core-mantle boundary beneath the Pacific and Africa, where shear wave velocity (V_S) is uncoupled with compressional wave velocity (V_P). Previous studies associate the large low shear velocity provinces (LLSVPs) with superplumes, accumulation of basaltic crust, and/or reservoirs of primordial materials. Su et al. (in revision) found that the uncorrelated V_S and V_P cannot be explained as artifacts of relative resolution of the models and instead purposed large uncorrelated moduli provinces (LUMPs) to map the chemical heterogeneity. The map reveals patchy and complicated structures in the lowermost mantle (D" layer), but the dynamics remain unknown. In this study, we measure the length scale of LUMPs in various geodynamical models and show that it is sensitive to a few convection parameters that were poorly determined. Therefore, we can infer the convection parameters for Earth by comparing the outcome of mantle circulation models and non-thermal heterogeneity in the observation.

Lateral Chemical Reactions at the Core-Mantle Boundary

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Lateral variations in temperature and composition at the outer core near the core-mantle boundary (CMB) are projected to be orders of magnitude smaller than their radial counterparts, due to the viscous boundary between the core and mantle. However, regions of FeO-poor ultra-low velocity zones (ULVZs) and FeO-rich subducted slabs have a chemical potential gradient between them which is suspected to contribute to lateral flows near the CMB. In future research, we will be modeling chemically-driven flows in a 3D rotating spherical model in with hopes of understanding some possible transport mechanisms at the CMB.

Toward New Methods for modeling complex mantle dynamics

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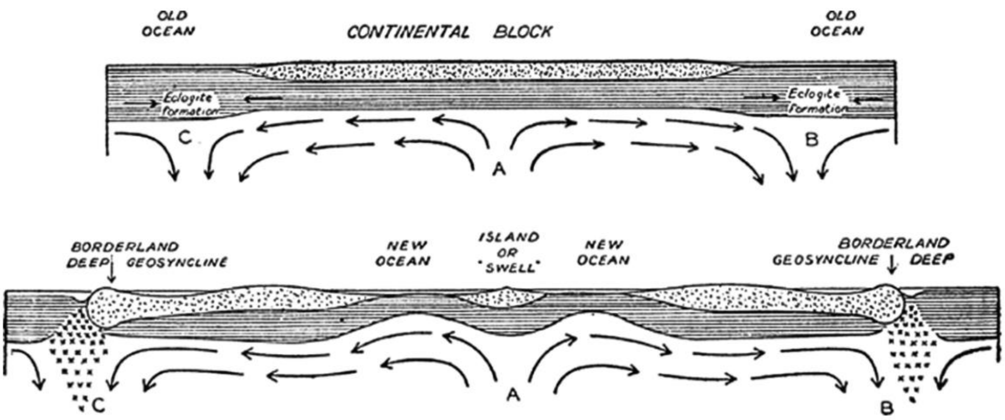
How does the rocky majority of the Earth's interior move and deform to produce plate tectonics, earthquakes, volcanic eruptions, circulate its inventory of elements in and out and create suitable conditions for the origin and evolution of life?

A century ago, geophysicists made a rough analogy between the movements of the thick, rocky mantle shell of the Earth and thermal convection in ordinary fluids, which came to be known as "mantle convection".
However, the description of solid rocks as "a fluid" has limitations in accounting for observations bearing on the physical and chemical state of the interior.

Mantle convection theory is presently based on experimental analogue study of fluids in the laboratory and in numerical models. While such an approach is easy to implement, deterministic, and reproducible, the critical weakness is that such a simplistic analogue is intrinsically incapable of capturing important behaviors of rock and explaining key observations.

Today the field is due for a modeling approach that allows for degrees of complexity that is up to the challenge of describing real rocks.



Classic conceptual sketch of fluid-like motions in the rocky mantle that would accompany tectonic activities in the Earth crust (Holmes 1931).

Current status of OBD development and prediction of observation sensitivity for mantle geo-neutrino

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Observation of geo-neutrinos originating from radioactive isotopes in the Earth can be converted to the number of radioactive isotopes and the heat generated by their decays which governs the Earth dynamics.

To date, two experiments (KamLAND and Borexino) have measured geo-neutrinos and constrained the range of acceptable models for the Earth's chemical composition but distinguishing the mantle flux by land-based detectors is challenging as the crust signal is about 70% of the total anti-neutrino flux.

Given the oceanic crust is thinner and has lower concentration of radioactive elements than continental crust, geo-neutrino detector in the ocean, Ocean Bottom Detector (OBD), makes it sensitive to geo-neutrinos originating from the Earth's mantle.
Our working group was jointly constructed from interdisciplinary communities in Japan which include particle physics, geoscience, and ocean engineering. We have started to work on technological developments of OBD.

In my presentation, current development status and performance evaluation result.