Program, mini-presentations

Day 1: Constituents of the lower mantle:
15:15 - 15:29

Daniel Helman - College of Micronesia-FSM - danielhelmanteaching@gmail.com
The Stability of Mantle Minerals Based on Their Dielectric Permittivity and Index of Refraction

Ashim Rijal - Utrecht University - a.rijal@uu.nl
Inferring equations of state of the lower mantle minerals using neural networks.

Grace Shephard - CEED, Univ. Oslo - grace.shephard@geo.uio.no
Mapping out the lower mantle - the iron spin crossover and the ambient mantle.

Min Chen - -Michigan State University - chenmi22@msu.edu
Existence of a low-viscosity layer beneath the 660-km discontinuity based on the orphan slabs imaged beneath East Asia

Vernon F. Cormier - University of Connecticut - vernon.cormier@uconn.edu
Mantle Phase Change Detection from Stochastic Tomography

Christine Houser - Earth-Life Science Institute, Tokyo Institute of Technology - chouser@elsi.jp
Tomography's relevance for future deep Earth studies

Anne Davaille - CNRS, University Paris-Saclay - davaille@fast.u-psud.fr
LLSVPs: bundles of mantle thermochemical plumes rather than thick stagnant "piles"

Day 2: Flow in the mantle:
1510 - 15:28

Lara Kalnins - University of Edinburgh - lara.kalnins@ed.ac.uk
Volcanism in east Australia and the Tasman Sea: Mechanisms behind three parallel hotspot trails

Björn Heyn - CEED, Univ. Oslo - b.h.heyn@geo.uio.no
How thermochemical piles control plume formation and core-mantle boundary topography

Kevin Konrad - Oregon State University - Kevin.Konrad@oregonstate.edu
Mapping the History of Potentially Long-Lived Northern and Eastern SOPITA Hotspots

Federica Restelli - Royal Holloway University of London - federica.restelli.1994@gmail.com
Towards robust characterisation of mantle flow using the SOLA method

Edward Clennett - University of Texas, Austin - edward.clennett@utexas.edu
Reconstructing western North America using lower mantle slabs.

Scarlett Jesybet Montoya Rivera - Instituto Politécnico Nacional - jesy.montoya21@gmail.com
Preliminary petrographic study of ultramafic xenoliths from Fresnillo, Zacatecas (Mesa Central, México)

Gabriele Morra - University of Louisiana, LaFayette - morra@louisiana.edu
Hierarchical Plate Organization of the Earth and Relationship with Deep Interior Dynamics

Diogo Lourenco - University of California, Berkeley - dlourenco@berkeley.edu
Efficient cooling of rocky planets by intrusive magmatism

Keely O'Farrell - University of Kentucky - k.ofarrell@uky.edu
Deep mantle composition and early Earth surface mobility

Day 3: Reservoirs and mixing in the lower mantle:
15:00 - 15:20

Fabio Crameri - CEED Univ. Oslo - fabio.crameri@geo.uio.no
Diagnosing ambient mantle

Seema Kumari - Indian Institute of Technology Kanpur - seema091089@gmail.com
^{182}*W*-^{142}*Nd isotope evolution in an open-system model of the Earth: Implication for geodynamic processes on early Earth*

Reidar G. Trønnes - CEED, Univ. Oslo - r.g.tronnes@nhm.uio.no
Deep-rooted plumes sample Hadean refractory domains

Maxim Ballmer - UCL - m.ballmer@ucl.ac.uk

Reactive crystallization of the Basal Magma Ocean

Margo Regier - University of Alberta - margo@ualberta.ca
The lithospheric to lower mantle carbon cycle in sublithospheric diamonds

Doyeon Kim - University of Maryland - dk696@cornell.edu
Sequencing Seismograms: A Panoptic View of Scattering in the Core-Mantle Boundary Region

Jamie Ward - University of Leeds - eejwa@leeds.ac.uk
Analysing Lower Mantle Structure using Slowness Vector Measurements

Tim Jones - University California San Diego - t6jones@ucsd.edu
Burying Earth's primitive mantle in the slab graveyard

Anna Gülcher - ETH Zürich - anna.guelcher@erdw.ethz.ch
The coexistence of recycled and primordial heterogeneity in Earth's lower mantle: a geodynamical perspective

John Hernlund - Earth-Life Science Institute, Tokyo Institute of Technology - hernlund@elsi.jp
Does mantle convection mix the mantle?

Abstracts, mini-presentations:

DAY 1

Daniel Helman - College of Micronesia-FSM - danielhelmanteaching@gmail.com
The Stability of Mantle Minerals Based on Their Dielectric Permittivity and Index of Refraction
Daniel Helman
For dielectric materials where polarization is due entirely to electronic charging, the dielectric permittivity is approximately equal to the square of the index of refraction for the material. Photons, as gauge bosons for the electromagnetic force, are fundamentally connected to electrons, so it makes sense that the state of electrons in a material would affect both the transmission of light through that material and the transmission of electric charge. Thus, dielectric values may sometimes be approximated with refraction data, and one may imagine the indicatrix for the dielectric constant of biaxial and uniaxial crystals as being similar to the indicatrix for the refractive index of those crystals. More optically refractive minerals have higher capacitance, provided that the dielectricity is caused by the electron configuration. What does this mean for the formation of mantle minerals? Simply that the minerals formed may radiate photons (and heat) more or less easily, and thus may set up feedback mechanisms to favor the stability of certain minerals.

Ashim Rijal - Utrecht University - a.rijal@uu.nl
Inferring equations of state of the lower mantle minerals using neural networks.
Ashim Rijal, Laura Cobden, Jeannot Trapmert, Jennifer Jackson and Andrew Valentine
In order to infer the elastic/seismic properties of minerals, the convention is to fit high pressure-temperature-volume (P-T-V) experimental data to some assumed EOS (such as 3rd order finite strain, Vinet, etc.). Due to uncertainties in experimental measurements as well as in the choice of pressure scale and thermodynamic models, an appropriate quantification of uncertainties in mineral properties is desirable. Assuming a certain mathematical form injects a priori information on the EOS, and thus calculated uncertainties are specific to the underlying functional form. In order to establish whether such assumptions are robust we use neural network (NNs) based approach. The idea is to learn P-T-V relationships implicitly from the experimental data without any prior assumption on the form (or thermodynamic model) of the relationship. We demonstrate the feasibility of this approach by using experimental data for periclase (MgO). We also extract bulk modulus and thermal expansivity by computing the derivatives of NN predicted EOS. The results show that within the prior range of experimental data NNs are capable of resolving the EOSs (and its uncertainties) at any given P and T. Moreover, we find that the training data locally (in P-T-V space) influence the uncertainties in predicted EOSs. This provides us an improved understanding of full uncertainties in EOSs in the lower mantle.

Grace Shephard - CEED, UiO - grace.shephard@geo.uio.no
Mapping out the lower mantle - the iron spin crossover and the ambient mantle.
Grace E. Shephard, John Hernlund, Christine Houser, Reidar G. Trønnes, Fabio Crameri, Juan Valencia-Cardona, Renata Wentzkovitch.
The mantle can be mapping into high, low, and average (i.e., ambient) seismic velocity domains at each depth, based on the amplitude and polarity of wavespeed perturbations. This can be achieved for individual tomography models or across a swathe of models – such as via P-wave and S-wave "vote maps". The vote maps easily, and

rather simply, cull out the most uncommon features between the models, leaving the most common signal to be analysed. In this short mini-preso, I will showcase recent work in extending tomographic vote maps (Shephard et al., 2017; Hosseini et al., 2018) for unraveling lower mantle structure and composition; including detection of the iron spin cross-over in relatively ferropericlase-rich domains, and mapping the out ambient portion of the mantle, which may host viscous bridgmanite-rich domains.

Min Chen - Michigan State University - chenmi22@msu.edu
Existence of a low-viscosity layer beneath the 660-km discontinuity based on the orphan slabs imaged beneath East Asia
Min Chen, Ziyi Xi, and Antoniette Grima
It is debated whether full mantle convection or layered convection dominates the mass and heat exchange between the upper and lower mantle through the transition zone. Previous work indicates that the different modes of mass exchange through the subducting slab are controlled by the slab rigidity and variations in mantle viscosity. However, this relationship is complicated by the unresolved radial viscosity structure of the mantle.
The latest geodynamic modelling shows slab orphaning (breakoff) across the 660-km discontinuity, controlled by the slab rigidity and the presence of a low-viscosity layer beneath the transition zone. Due to the lack of data coverage and less accurate seismic tomography method, only the orphan slabs long after the breakoff have been imaged in the deep lower mantle. However, our most recent seismic model of East Asia (EARA2020), based on an unprecedented seismic data set and an advanced full waveform inversion, for the first time clearly captures the ongoing orphaning of the subducted pacific slab right below the 660-km depth. This seismic observations of orphan slabs at the top of the lower mantle directly confirms the presence of a low viscosity layer underlying the 660-km discontinuity.

Vernon F. Cormier - University of Connecticut - vernon.cormier@uconn.edu
Mantle Phase Change Detection from Stochastic Tomography
Vernon F. Cormier(1), Yiteng Tian(1), and Yingcai Zheng(2)
(1)Department of Physics, University of Connecticut
(2)Department of Earth and Atmospheric Sciences, University of Houston
Peaks are observed in a depth-dependent power spectrum of P-wave velocity fluctuations determined from an inversion of P wave coherences observed by the USArray. These peaks correlate with the depths of the majority of silicate mineral phase changes predicted by a thermodynamic model of the upper 1000 km of a pyrolitic mantle. To within ± 25 km we identify the phase change of orthopyroxene to HP-clinopyroxene at 275 km, the olivine to wadsleyite phase change at 425 km, the wadlsleyite to ringwoodite phase change at 505 km, and the initiation of an akimotoite phase at 600 km and a signature of a phase change at 775 km, both associated with the existence of fragments of subducted oceanic crust. Non-detection of a phase change at or near 660 is consistent with the phase change of ringwoodite to Mg-perovskite and magnesiowusite occurring over a depth interval much smaller than 25 km.

Christine Houser - Earth-Life Science Institute, Tokyo Institute of Technology - chouser@elsi.jp
Tomography's relevance for future deep Earth studies
Christine Houser
There are now dozens of compressional and shear mantle tomography models using growing data catalogs and increasingly sophisticated inversion methods. This progress would suggest that mantle structure is coming into greater focus, however, the lack of agreement among models on anything besides the most prominent structures is holding back progress in deep Earth studies. Innovation in data variety and inversion techniques may offer some hope, but there is currently no objective measure of how good a model is for a given purpose. While it has been on the user to choose a model for their particular application, here I argue that it should be the tomographer's responsibility to develop the tools necessary for evaluating tomographic models. This level of tool development is beyond any individual and should be a community effort to prevent tomography from becoming irrelevant in the wake of progress in other deep Earth disciplines.

Anne Davaille - Barbara Romanowicz - CNRS, University Paris-Saclay - davaille@fast.u-psud.fr
LLSVPs: bundles of mantle thermochemical plumes rather than thick stagnant "piles"
A. Davaille, B. Romanowicz (Univ. of California, Berkeley)
Based on SEMUCB-WM1 tomographic model, - validated by other recent models-, and fluid mechanics constraints, we show that the large-low shear velocity provinces (LLSVPs) present at the base of the Earth's mantle beneath the Pacific and Africa do not extend as compact, uniform structures very high above the core-mantle boundary. In contrast, they contain a number of well-separated, low velocity conduits that extend vertically throughout most of the lower mantle. The conceptual model of compact piles, continuously covering the areal extent of the LLSVPs is therefore not correct. Instead, each LLSVP is composed of a bundle of thermochemical upwellings probably enriched in denser than average material. It is only when the tomographic model is filtered to long wavelengths

that the two bundles of plumes appear as uniform provinces. Furthermore, the overall shape of the LLSVPs is probably controlled by the distribution of subducted slabs, and due to their thermochemical nature, the position of both LLSVPs and individual upwelling dynamics should be time-dependent on a 100-300 Myr time-scale.

DAY 2

Lara Kalnins - University of Edinburgh - lara.kalnins@ed.ac.uk

Volcanism in east Australia and the Tasman Sea: Mechanisms behind three parallel hotspot trails

L. M. Kalnins, B. E. Cohen, J. G. Fitton, and D. F. Mark

Eastern Australia and the Tasman Sea are home to a unique example of intraplate volcanism: three long-lived, age-progressive volcanic chains that are contemporaneous, sub-parallel, and spaced only ~500 km apart. They therefore show some of the key features of deep-origin plumes, but it is difficult to explain how multiple plumes could remain stable when separated by little more than the radii of plume conduits in the lower mantle. We consider alternative possible explanations for this unusual pattern of volcanism, focusing on potential interaction between upwelling deep mantle and structures in the mantle transition zone and on the lithosphere-asthenosphere boundary.

Björn Heyn - CEED, UiO - b.h.heyn@geo.uio.no

How thermochemical piles control plume formation and core-mantle boundary topography

Björn Heyn, Clint Conrad, Reidar Trønnes

Locations of hotspot volcanism, typically associated with deep-rooted plumes, seem to correlate with the outlines of Earth's Large Low Shear Velocity Provinces (LLSVPs). However, both the role of LLSVPs within mantle convection and their properties are still under debate. While a rather passive role of LLSVPs has been favored for a long time, these structures are now widely interpreted as thermochemical piles. Various observations from seismology and geochemistry indicate the chemical origin of the LLSVPs, and point towards a higher intrinsic density and (potentially) viscosity. Here, we show that piles with a higher intrinsic viscosity will not only act as a passive anchor of mantle flow, but can actively shape the convection system within Earth by periodically initiating plumes along their edges. This process is reflected in a small lateral and vertical motion of the pile margin, yet does not affect the long-term stability of the degree-2 structure of the lower mantle. Furthermore, a depression in core-mantle boundary (CMB) topography can be used as a proxy for determining the viscosity contrast between piles and ambient mantle. The size and shape of the topography also change during plume initiation, related to the motion of the pile edge.

Kevin Konrad - Oregon State University - Kevin.Konrad@oregonstate.edu

Mapping the History of Potentially Long-Lived Northern and Eastern SOPITA Hotspots

Kevin Konrad
College of Earth, Ocean & Atmospheric Science, Oregon State University. Corvallis, OR, USA

The Mid-Pacific Mountains, Hess Rise and Line Islands represent prominent Pacific Basin features with debated geodynamic origins. Most models currently attribute the formation of these features to relatively short-lived, extinct mantle plumes. Here I present a new model for a Pitcairn and Marquesas plume origin for the formation of the Mid-Pacific Mountains and Hess Rise, respectively. The new model also infers an Easter Hotspot origin for the Southern Line Islands region (Boudeuse Ridge). This model is currently based on new Pacific absolute plate motion rotation poles from 100-80 Ma and new 40Ar/39Ar age determinations of Line Island lava flows. Based on the new results we hypothesize that most of the hotspots in the South Pacific Isotopic and Thermal Anomaly (SOPITA) have been active since the Cretaceous. This model has important implications for the dynamics of the Pacific LLSVP and whether it produces numerous short-lived plumes or fewer, long-lived plumes. Further insights will come from active work on recently collected ROV dive samples (E/V Nautilus Expedition NA110) that sampled the deep flanks, and post-erosional volcanic cones from guyots in the Kingman Reef and Palmyra regions of the Line Islands.

Federica Restelli - Royal Holloway University of London - federica.restelli.1994@gmail.com

Towards robust characterisation of mantle flow using the SOLA method

Federica Restelli, Dr.Paula Koelemeijer, Dr. Christophe Zaroli

Seismic tomography is essential for imaging the Earth’s interior and to better understand the dynamic processes at work. Nonetheless, a robust physical interpretation of tomographic images requires the model to have unbiased amplitudes and to be accompanied by uncertainties. Commonly-used techniques, such as damped least-square inversions, break the non-uniqueness by adding a subjective regularization, which causes the amplitudes to be biased, potentially leading to physical misinterpretation. Moreover, uncertainties are usually not computed. The SOLA method (Zaroli, 2016; Zaroli et al., 2017), based on a Backus-Gilbert approach, constraints the amplitudes to be unbiased and efficiently computes the model resolution and its uncertainties.

We aim to build a new tomographic model using the SOLA method. This method will be applied to observations of normal modes, which are not affected by an uneven data distribution and sensitive to multiple seismic parameters. We specifically focus our efforts on seismic anisotropy, which provides more direct information on mantle flow.

Edward Clennett - University of Texas, Austin - edward.clennett@utexas.edu
Reconstructing western North America using lower mantle slabs.
Edward Clennett, Karin Sigloch, Mitch Mihalynuk, Maria Seton, Martha Henderson, Kasra Hosseini, Afsaneh Mohammadzaheri, Stephen Johnston, Dietmar Muller.
Plate reconstructions since the breakup of Pangaea are mostly based on the preserved spreading history of ocean basins. However, the evolution of destructive plate margins, such as western North America, is difficult to constrain from surface observations as much of the evidence has been subducted. We used seismic tomography to image subducted lithosphere in the lower mantle and calculated a vertical sinking rate to constrain palaeotrench locations. This new evidence, combined with the geological surface record of subduction, suggests that several intraoceanic arcs existed between the Farallon Ocean and North America during late Mesozoic times. We present a continuously closing plate model for the eastern Pacific basin from 170 Ma to present, constrained using “tomotectonic analysis”—the integration of surface and subsurface data. We model simultaneous eastward and westward subduction of oceanic plates under an archipelago of Cordilleran arc terranes. North America was pulled westward into this archipelago and diachronously collided with its microcontinents, which form the North American Cordillera. This model provides a detailed, quantitative tectonic history for the eastern Pacific domain, paving the way for tomotectonic analysis to be used in other paleo-oceanic regions.

Scarlett Jesybet Montoya Rivera - Instituto Politécnico Nacional - jesy.montoya21@gmail.com
Preliminary petrographic study of ultramafic xenoliths from Fresnillo, Zacatecas (Mesa Central, México)
Scarlett Jesybet Montoya-Rivera(1), Vanessa Colás-Gines(2), María Guadalupe Dávalos-Elizondo(3), José Jorge Aranda-Gómez(4), Augusto Antonio Rodríguez-Diaz(5).
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(2) Instituto de Geología, Universidad Nacional Autónoma de México, Ciudad Universitaria, 04510, Ciudad de México, México.
(3) Facultad de Ciencias, Departamento de Ciencias de la Tierra, Universidad Nacional Autónoma de México, 04510, Ciudad de México, México.
(4)Centro de Geociencias, Universidad Nacional Autónoma de México; Campus Juriquilla, Juriquilla, 76320, Querétaro, México.
(5)Instituto de Geofísica, Universidad Nacional Autónoma de México, Ciudad Universitaria, 04510 Ciudad de México, México.
In Mexico, mafic alkali rock with xenoliths crop out in many isolated areas located along the northwestern margin of the Mesa Central (Central Mexico). The study area is located near the city of Fresnillo (Zacatecas) where xenoliths occur in mafic lavas issued from the Cerro El Xoconostle volcano. These ultramafic xenoliths are spinel lherzolites and lherzolites and might register metasomatic processes that may have affected the mobilization of metals in the subcontinental lithospheric mantle (SCLM). These metasomatic processes can be registered in the chemical composition of silicates, as well as, oxides and sulfides in the lherzolites.
The objective of this research is to characterize the possible metasomatic processes that have modified the SCLM located below the Mesa Central, based on the petrology and mineral chemistry of ultramafic xenoliths collected at this location. Likewise, the possible presence of sulphides with significant concentrations of noble metals in the ultramafic xenoliths could be consequence of the metasomatic processes that modified this portion of the Mexican SCLM. This might help to establish the concentration mechanisms of these metals and their possible relationship with the formation of world class Ag-Au-Pb epithermal deposits in central Mexico, such as those in the nearby Fresnillo district.

Gabriele Morra - University of Louisiana, LaFayette - morra@louisiana.edu
Hierarchical Plate Organization of the Earth's Plate and Relationship with Deep Interior Dynamics
Gabriele Morra
The present tessellation of the Earth's surface into tectonic plates displays a remarkably regular plate size distribution, described by either one or two power laws, which implies a hierarchical structure from the largest to the smallest plate. Using reconstructions from the last 200 Myr, I show that small plates size statistics is determined by upper mantle dynamics while the large plates size and geometry is controlled by deep mantle dynamics and I determine the exact cut off. Speculations on the role of true polar wander (TPW) and the Earth's magnetic field inversion frequency follow.

Diogo Lourenco - University of California, Berkeley - dlourenco@berkeley.edu

Efficient cooling of rocky planets by intrusive magmatism

D. L. Lourenço (1), A. B. Rozel (2), M. D. Ballmer (2,3), T. Gerya (2), and P. J. Tackley (2)
(1) University of California, Berkeley, USA. (2) ETH Zürich, Switzerland. (3) University College London, UK.

The Earth is in a plate tectonics regime with high surface heat flow concentrated at constructive plate boundaries. Other terrestrial bodies that lack plate tectonics are thought to lose their internal heat by conduction through their lids and volcanism: hotter planets (Io and Venus) show widespread volcanism whereas colder ones (modern Mars and Mercury) are less volcanically active. However, studies of terrestrial magmatic processes show that less than 20% of melt volcanically erupts, with most melt intruding into the crust. Signatures of large magmatic intrusions are also found on other planets. Yet, the influence of intrusive magmatism on planetary cooling remains unclear. Here we use numerical magmatic-thermo-mechanical models to simulate global mantle convection in a planetary interior. In our simulations, warm intrusive magmatism acts to thin the lithosphere, leading to sustained recycling of overlying crustal material and cooling of the mantle. In contrast, volcanic eruptions lead to a thick lithosphere that insulates the upper mantle and prevents efficient cooling. We find that heat loss due to intrusive magmatism can be particularly efficient compared to volcanic eruptions if the partitioning of heat-producing radioactive elements into the melt phase is weak. We conclude that the mode of magmatism experienced by rocky bodies determines the thermal and compositional evolution of their interior.

Keely O'Farrell - University of Kentucky - k.ofarrell@uky.edu

Deep mantle composition and early Earth surface mobility

Keely O'Farrell (Univ. of Kentucky) , Sean Trim (Univ. of Saskatchewan), Sam Butler (Univ. of Saskatchewan)

Did the early Earth have plate tectonics, a stagnant lid, or something in between? The surface dynamics of the early Earth remain poorly understood. Current numerical models of mantle convection are constrained by present-day observations, but the behavior of the hotter, early Earth prior to the onset of plate tectonics is less certain. The early Earth may have possessed a large hot magma ocean trapped near the core-mantle boundary after formation during differentiation, and likely containing different elements from the surrounding mantle. We examine how composition-dependent properties in the deep mantle affect convection dynamics and surface mobility in high Rayleigh number models. Our Newtonian models indicate that increased conductivity or decreased viscosity flattens basal topography while also increasing the potential for surface yielding. We vary the viscosity, thermal conductivity, and internal heating in a compositionally distinct basal magma ocean and explore the compositional topography, insulation effects and surface stresses. Since convective vigour is very strong in the early Earth, specialized tracer methods are employed for increased accuracy. Models are run using a variety of crustal compositions, such as the inclusion of primordial continental material before the onset of plate tectonics and we monitor the surface for plate-like behavior.

DAY 3

Fabio Crameri - CEED, Univ. Oslo - fabio.crameri@geo.uio.no

Diagnosing ambient mantle

Fabio Crameri & Grace Shephard

An open-source StagLab algorithm to automatically extract, track, and diagnose ambient mantle based on diagnostics introduced in Crameri (2018, GMD) will be presented.

Seema Kumari - Indian Institute of Technology Kanpur - seema091089@gmail.com

^{182}W-^{142}Nd isotope evolution in an open-system model of the Earth: Implication for geodynamic processes on early Earth

Seema Kumari(1,2), Andreas Stracke(1), and Debajyoti Paul(2)
(1)Institut für Mineralogie, Westfälische Wilhelms Universität, Münster, Germany.
(2)Department of Earth Sciences, Indian Institute of Technology, Kanpur, India.

We present an open-system model of Earth evolution, which incorporates ^{146}Sm-^{142}Nd (half-life: 103 Ma) and ^{182}Hf-^{182}W (half-life: 8.9 Ma) systematics, to probe aspects of planetary differentiation processes, such as metal-silicate differentiation leading to core formation, silicate-melt differentiation leading to early continental crust formation, as well as the addition of late accreted material and its effect on the elemental and isotopic composition of the terrestrial reservoirs. These short-lived isotope systems probe the early evolution of Earth, which has remained obscure due to limited rock record.

To reproduce the observed positive ^{142}Nd and ^{182}W anomalies in the Hadean-Archean mantle, our model requires an early core formation between 45-60 Myr and thereafter, late accretion for the first 400 Myr and concurrent silicate differentiation in the initial 50 Myr after Earth formation. Results indicate a significant amount of crust formation in the Hadean. Our study suggests a complex interplay of early geodynamic processes in an energetic Earth, responsible for producing distinct isotopic signatures detected in the early-formed rocks.

Reidar G. Trønnes - CEED, Univ. Oslo - r.g.tronnes@nhm.uio.no

Deep-rooted plumes sample Hadean refractory domains.

R.G. Trønnes

Petrological evidence indicates that the solidification of the magma ocean produced voluminous domains of early bridgmanite-dominated cumulates, as well as later residues from localised remelting just above the basal magma ocean. Such viscous material, neutrally buoyant in the mid-lower mantle, can be convectively aggregated into bridgmanite-enriched ancient mantle structures (BEAMS), located outside the margins of rising mantle columns above the LLSVPs. In the hot Hadean Earth, rapidly diffusing He and Ne would recharge such U- and Th-depleted material, mostly before its aggregation into BEAMS. The Mm-sized BEAMS would preserve primordial-like He and Ne isotopic compositions during subsequent Earth evolution and cooling. Deep-rooted plumes may entrain such bridgmanitic material, which becomes pyroxenitic and slightly less refractory in the upper mantle melting zone. Primordial He in PREMA/FOZO-like OIBs is associated with refractory source materials, characterised by high Mg#, MgO and ε^{143}Nd and low μ^{182}W and $^{136/129}$Xe. Whereas the isotopic signals of Xe (tenuous) and W are easily ascribed to minor core contamination, the elevated μ^{142}Nd and $^{3/4}$He observed for the Iceland plume head (Baffin Island), as well as for the plumes under Reunion, Samoa (Ofu) and Hawaii (Loihi), are most likely caused by melt contributions from Hadean refractory source components.

Maxim Ballmer - UCL - m.ballmer@ucl.ac.uk

Reactive crystallization of the Basal Magma Ocean

M. Ballmer, R. Spaargaren, A. Mallik, D. Bolrao, A. Morison, M. Nakajima

The basal magma ocean (BMO) and the related crystallizing cumulates are thought to become progressively enriched during the BMO crystallization sequence, ultimately stabilizing a strongly FeO-enriched (and still molten?) layer at the CMB >50 km thick. Such an outcome, however, is ruled out by geophysical observations. Here, we investigate the consequences of BMO reactive crystallization on the initial condition of solid-state mantle convection. Once the BMO-mantle boundary is exposed by entrainment of cumulates, the BMO reacts with the mantle due to chemical disequilibrium. For a wide range of BMO initial compositions, the final reactive cumulate package consists of two discrete layers: (1) ~MgSiO3 bridgmanite, and (2) FeO-enriched pyrolite. The first layer is readily entrained by mantle convection, but may resist efficient mixing due to its intrinsic strength, providing a candidate origin for long-lived blobs or BEAMS. The second layer is swept up into thermochemical piles due to moderate intrinsic denisty anomalies, providing a candidate origin for LLSVPs. The relevant timescales of reactive crystallization may be several billion years, if controlled by solid-state diffusion across a sharp BMO-mantle boundary, or much shorter if a two-phase region of any significant thickness (>meters) exists at the boundary. These predictions have important implications for the long-term thermal evolution and compositional structure of terrestrial planets.

Margo Regier - University of Alberta - margo@ualberta.ca

The lithospheric to lower mantle carbon cycle in sublithospheric diamonds

M.E.Regier, D.G.Pearson, T.Stachel, R.W.Luth, R.A.Stern, J.W.Harris

The transport of carbon into Earth's mantle by subduction affects the redox conditions and magma generation of the convecting mantle. Mineral inclusions in superdeep diamonds can be used to constrain this exchange. Oxygen isotope measurements of mineral inclusions within diamonds from Kankan, Guinea that are derived from the lithosphere to the lower mantle demonstrate profound differences in the modes of diamond formation and in the behavior of volatiles through these mantle regions. Sublithospheric inclusions are distinctly enriched in 18O relative to eclogitic lithospheric inclusions. The increased 18O content of these sublithospheric inclusions is derived from their crystallization from melts of carbonate-rich subducted oceanic crust. In contrast, lower mantle mineral inclusions and their host diamonds have a narrow range of isotopic values that are typical of convecting mantle. Because carbon is hosted in metals in the reduced, volatile-poor lower mantle, we suggest a model in which the hydration of the uppermost lower mantle by subducted oceanic lithosphere destabilizes carbon-bearing metals to form diamond. This transition from carbonate slab melting in the transition zone to slab dehydration in the lower mantle supports a lower-mantle barrier for carbon subduction in the Kankan deposit.

Doyeon Kim - University of Maryland - dk696@cornell.edu

Sequencing Seismograms: A Panoptic View of Scattering in the Core-Mantle Boundary Region

Doyeon Kim, Ved Lekić, Brice Ménard

Scattering of seismic waves can reveal subsurface structures, but usually in a piecemeal way focused on specific target areas. We used a manifold learning algorithm, the Sequencer, to simultaneously analyze thousands of seismograms of waves diffracting along the core-mantle boundary and obtain a panoptic view of scattering across the Pacific region. In nearly half of the diffracting waveforms, we detected seismic waves scattered by 3D structures near the core-mantle boundary. The prevalence of these scattered arrivals shows that the region hosts pervasive lateral heterogeneity. Our analysis revealed loud signals due to a plume root beneath Hawaii and a previously unrecognized ultralow-velocity zone beneath the Marquesas islands. These observations illustrate how

approaches flexible enough to detect robust patterns with little-to-no user supervision can reveal unique insights into the deep Earth.

Jamie Ward - University of Leeds - eejwa@leeds.ac.uk
Analysing Lower Mantle Structure using Slowness Vector Measurements
Jamie Ward, Andy Nowacki, Sebastian Rost
Large Low Velocity Provinces (LLVPs) are enigmatic features of the lower mantle with questions such as whether they are purely thermal or possess some chemical heterogeneity remaining uncertain. Regional seismology studies use travel time residuals and identify multipathing in the waveforms to infer properties of LLVP boundaries. Multipathing occurs when a wavefront is incident on a sufficiently strong lateral velocity gradient, resulting in two arrivals arriving at different times, directions and inclinations. Multipathing is usually only analysed in the waveforms and information such as the direction and inclination of multipathed arrivals are not fully explored. This information could further constrain LLVP properties and aid in determining their role in the Earth.
We use array seismology to identify multipathed arrivals using their backazimuth (direction) and horizontal slowness (inclination) properties of waves sampling the African LLVP. Following this, we use full wavefield modelling to constrain lateral velocity gradients capable of producing multipathing. We find relatively weak lateral velocity gradients (0.7% Vs per 100 km) are sufficient to produce multipathing similar to our observations. As these gradients are less than those possible for purely thermal and thermochemical structures, we argue observing multipathing is not necessarily evidence for chemical heterogeneity.

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Burying Earth's primitive mantle in the slab graveyard
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When oceanic plates pull apart the mantle melts to form slabs of lithosphere, which are later recycled back into the mantle at subduction zones. This process of melting and subduction destroys the initial chemical signature of the mantle. Geochemical analyses reveal that some portion of the mantle has avoided this process and retained a chemically ‘primitive’ signature. How this material has survived vigorous convection for ~4.5 Gyr is an open question. Here we propose that it may be preserved at the base of the mantle in the slab graveyard, which is dominated by accumulations of dense oceanic crust but can comprise up to 30% primitive material. The intermingling of oceanic crust and primitive material may explain why the chemical signatures of both coexist volcanic eruptions at Earth's surface.

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The coexistence of recycled and primordial heterogeneity in Earth’s lower mantle: a geodynamical perspective
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The nature of compositional heterogeneity in Earth’s lower mantle is a long-standing puzzle that can inform about the long-term evolution of our planet. On relatively small scales (<1km), the concept of a “marble cake” mantle has gained wide acceptance, emphasizing that streaks of recycled oceanic crust (ROC) and lithosphere make up much of the mantle. On larger scales (10s-100s of km), compositional heterogeneity may be preserved by delayed mixing of this marble cake with either intrinsically-dense or -strong materials of e.g. primordial origin. Intrinsically dense materials may accumulate as piles at the core-mantle boundary, while intrinsically viscous (e.g., enhanced in the strong mineral $MgSiO_3$ bridgmanite) may survive as “blobs” in the mid-mantle for large timescales (i.e., as plums in the mantle “plum pudding”).
Here, we address the coexistence of recycled and primordial heterogeneity in Earth’s mantle using state-of-the-art 2D numerical models of global-scale mantle convection in a spherical geometry. Recycled crustal heterogeneities are robustly predicted to co-exist with primordial blobs, suggesting that the modern mantle may be in a hybrid state between the “marble cake” and “plum pudding” styles. This new style of mantle convection including preserved $MgSiO_3$-enriched domains along with recycled piles has the potential of reconciling recent geophysical and geochemical observations of lower-mantle heterogeneity, and may also be linked to geological and geochemical indications of a major shift in geodynamic style in the Archean Earth.

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Does mantle convection mix the mantle?
John Hernlund
I don't know. All of the models performed to assess mantle mixing by convection have assumed an unrealistic fluid-like rheology. Fluids are materials that have limited memory, and can be readily mixed. But do actual rocks in the mantle behave in such a manner? There is ample reason to doubt it, and I will briefly discuss it.