Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)


SIT05-01 Room:315 Time:April 28 09:00-09:15

# Lithospheric Rheology and Stress and the Dynamics of Plate Tectonics

ZHONG, Shijie[1*]

[1]Department of Physics, University of Colorado

Plate tectonics is a kinematic theory that describes relative motions of Earth′ s surface tectonic plates. However, with the subduction of cold lithosphere into mantle interiors, plate tectonics has profound implications on the thermal and dynamic evolution of planets. Earth appears to be the only planetary body in the solar system that has active plate tectonics. The cause of plate tectonics remains one of the most important unresolved questions in Earth and planetary sciences. The recent discovery of a large population of exoplanets further raises the question on how common plate tectonics is to planetary bodies and what causes plate tectonics. In this presentation, I will discuss two issues that are important to understanding the origin of plate tectonics: lithospheric rheology and stress. Lithospheric rheology is important for understanding crustal and lithospheric dynamics, and the conditions for plate tectonics. For example, numerical modeling studies suggest that plate tectonics emerge from the dynamics of mantle convection when a small coefficient of friction $\mu$ (<0.1) or small yield stress for lithosphere is used [Moresi and Solomatov, 1998]. However, both in-situ borehole stress measurement (to ˜10 km depth) and laboratory studies suggest that $\mu$˜0.6 [Kohlstedt et al., 1995; Zoback and Townend, 2001]. A recent study that models the seismically observed elastic flexure and seismicity at Hawaiian islands in response to volcanic loading indicates $\mu$>0.25 [Zhong and Watts, 2013]. The loading study [Zhong and Watts, 2013] also suggests that lithospheric rheology related to low-temperature plasticity is significantly weaker than laboratory studies [Mei et al., 2010] and that lithospheric stress at Hawaiian islands is 100-200 MPa, possibly largest lithospheric stress on the Earth, given that Hawaiian islands represent the largest uncompensated surface loads on the Earth. These studies highlight the importance to understand the evolution of lithospheric stress and rheology from plate interiors to plate boundaries, in order to understand the cause of plate tectonics. I will also discuss the convection-driven stress in the top thermal boundary (lithosphere). Convection-driven stress scales with Rayleigh number and hence mantle viscosity. A larger mantle viscosity or smaller Rayleigh number leads to a larger viscous stress in the lithosphere in mantle convection models. Some recent mantle convection studies for plate tectonics generation reported >500 MPa stress in lithosphere. It is important to develop independent observable measures to examine the relevance of modeled lithospheric stress. I will discuss possible measures that may be developed and used in this context.

Keywords: Mantle Convection, Plate Tectonics, Lithospheric Stress, Lithospheric Rheology, Brittle Deformation

SIT05-02 Room:315 Time:April 28 09:15-09:30

# 3D numerical modeling of thermal regime and mantle flow associated with subduction of the two oceanic plates

JI, Yingfeng[1*] ; YOSHIOKA, Shoichi[1]

[1]RCUSS, Kobe University, [2]Graduate School of Science, Kobe University

Based on a thermal convection model for an arbitrarily curved oceanic plate, we newly constructed a 3D model for subduction of two oceanic plates, and investigated its thermal regime and mantle flow. The 3D parallelepiped modeled domain for numerical simulations is a length of 840 km, a width of 840 km, and a depth of 300 km, with 72$*$72$*$72 grids, and the total calculation time up to 15 Myr. Geometry of one continental plate and two oceanic plates are prescribed in the simulation. The two oceanic plates subduct with prescribed velocities beneath the continental plate along neighboring two trenches, adjoining with a right angle. The upper oceanic plate and the lower oceanic plate contact each other at their intersection zone. Both of the oceanic plates are assumed to be 30 km in thickness. Giving boundary conditions of adiabatic and permeable walls, half-space cooling and rigid upper surface, and stratified initial temperature condition, we solved equations of mass conservation, momentum, and energy, using the finite difference method (FDM) and Finite Volume Method (FVM). In this study, the dynamical properties of the thermal regime associated with double subduction are investigated in detail. In our numerical simulation for the subducting two oceanic plates, the convergent rate of the upper oceanic plate should be paralleled to the intersection line of the two plates so as to reach a stable and sustainable subduction. Dip angles of the two oceanic plates, obliquity of the lower oceanic plate, and subduction velocity are assumed to be 10 deg, 0 deg ~75 deg, and 5 cm/yr, respectively. As a result of numerical simulation, we found that there are remarkable low temperatures in the inter-slab zone due to subduction of the two cold oceanic plates. We also found that obliquity and relative directions of plate subduction velocities contribute to the obliquity of subduction-induced mantle flow convection adjacent to the two oceanic plates, and spiral mantle convection may be produced by the difference of the obliquity of two oceanic plates.

Keywords: thermal regime, plate tetonics, subduction, numerical simulation

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)


SIT05-03 Room:315 Time:April 28 09:30-09:45

# Mantle flow and overriding plate stress state in 3-D models of thermo-mechanical subduction

HOLT, Adam[1] ; BECKER, Thorsten[1*]

[1]University of Southern California

The formation of back-arc basins is a fundamental component of plate tectonics, yet the dominant mechanism for their formation, and whether an individual mechanism is dominant over different tectonic settings, is not entirely clear. On top of the classic mechanism of extension being driven by basal tractions due to poloidal return flow, recent numerical and experimental modeling studies have indicated that, for slabs with finite widths, toroidal return flow around slab edges plays an important role. We investigate the relative contribution of poloidal and toroidal flow field components to back-arc extension by examining the overriding plate stress regime in conjuction with the flow field for various model setups. We characterize the velocity field by decomposing it into toroidal and poloidal components at various stages of subduction, and calculating the ratio of the toroidal to polodial RMS velocities (TPR).

Models are carried out using a thermo-mechanical setup of the finite element code, CitcomCU. We find that the presence of an overriding plate reduces the development of trench curvature, and so 3-D modeling studies that neglect the presence of the overriding plate may be significantly overestimating the rate of development of trench curvature. Within the overriding plate, we observe long wavelength back-arc extensional stresses at a large distance from the trench and more localized forearc compressive stresses. Fixing the position of either the subducting or overriding plate causes the amplitude of back-arc extension to be greater than that for the case when both plates are free. This occurs because, for the fixed overriding plate models, all of the slab rollback is forced to occur at the expense of overriding plate thinning/extension, and for the fixed subducting plate models, increased rollback causes heightened toroidal flow. For all models with significant slab rollback, the poloidal RMS velocity is maximum in the very upper and lower portions of the model whereas toroidal flow is maximum at mid-domain depths due to return flow around slab edges, indicating that slab rollback-induced toroidal flow is focussed at sub-lithospheric depths, where it has the potential to contribute to back-arc extension. Reducing the width of the plate vastly reduces the rate of slab rollback, yet increases the degree of back-arc extension and focuses it closer to the trench. In such models, toroidal flow magnitude is approximately constant throughout the domain resulting in only minor TPR variation with depth, and yet the magnitude of overriding plate extensional stress is large, possibly suggesting an alternate control on back-arc extension.

Finally, we investigate the effect that Byerlee plasticity and a laterally confining side plate has on both overriding plate stress state and the flow field. Including a side plate does not modify the slab dynamics and overriding plate stress state, yet significantly reduces the toroidal RMS velocity component throughout the model, while retaining the systematic variation, which results in uniformly reduced TPR throughout the domain. The inclusion of plasticity, intended to approximate brittle failure, gives rise to elevated forearc compression, due to increased plate convergence, and reduced backarc extension.

Keywords: subduction, mantle flow, slab rollback, overriding plate stress

SIT05-04 Room:315 Time:April 28 09:45-10:00

# Magnetic spectral analysis over the Atlantic Ocean off Portugal

MATSUSHIMA, Jun[1] ; OKUBO, Yasukuni[2] ; ANTONIO, Correia[3] ; UCHIDA, Youhei[2*]

[1]Graduate School of Engineering, [2]Geological Survey of Japan, [3]University of Evora

Magnetic spectral analysis, which has often been applied to estimate Curie point depths, was used to delineate thermal and crustal structure of the Atlantic Ocean off Portugal. The Atlantic oceanic plate covers the study area deepening eastward and volcanic islands rise in the eastern margin. We used EMAG2, the resolution and the altitude of which are 2 arc minute and 4 km above geoid, respectively. Linear magnetic anomalies are dominant over the study area. They are attributed to the seafloor spreading of the oceanic plate. The magnetic lineation forms a strong directional feature not only in the space domain but also in the spectral domain. Taking the directional feature, we developed a pseudo-one dimensional spectral analysis using two dimensional data sets. The gradient of the power spectrum across the lineation depends on the centroid depth of magnetic layer. The bottom depth is easily calculated by the centroid and the seafloor depth, assuming that the top of magnetic layer corresponds to the seafloor. The bottom of magnetic layer over young oceanic plate deepens with time, because the Curie point depth deepens with time. Taking the relationship, we assume that the bottom of magnetic layer over the Atlantic oceanic plate corresponds to the Curie point depth and delineates a thermal structure. The results of spectral analysis show that the bottom depths over the oceanic plate are deepening gradually from the ridge to Europe. The results correlate well with magnetic isochrons and thermal history of the oceanic plate. The bottom depths over the volcanic islands are anomalously shallow indicating a rise of high thermal structure.

Keywords: Magnetic data, spectral analysis, Curie point

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)


SIT05-05 Room:315 Time:April 28 10:00-10:15

# Subduction Processes and a New Hypothesis for "Top-down Hemispherical Dynamics" of the Earth

IWAMORI, Hikaru[1*] ; NAKAMURA, Hitomi[2] ; HANYU, Takeshi[1] ; KIMURA, Jun-ichi[1] ; NAKAKUKI, Tomoeki[3] ; NAKAGAWA, Takashi[1] ; YOSHIDA, Masaki[1] ; TANAKA, Satoru[1] ; SUETSUGU, Daisuke[1] ; OBAYASHI, Masayuki[1]

[1]JAMSTEC, [2]TITEC, [3]Hiroshima University

Water-rock interactions reduce the rock strength, and possibly produce weak plate boundaries, inducing active plate tectonics. Water-rock interactions may also have geochemical impacts, causing the unique differentiation of the Earth (e.g., formation of granitic continental crust and hydrothermal ore deposits). However, how water actually interacts with the rocks and circulates within the solid Earth to contribute to material differentiation and dynamics has been poorly constrained. In this paper, we present numerical models of water and element transport in subduction zones, as well as global geochemical evidences for water and the associated element cycling in the mantle. Then we compare these geochemical evidences with the geophysical observations and modeling to propose "top-down hemispherical dynamics" for the whole Earth's interior.

Water-rock interaction may significantly reduce the viscosity of rocks [1], and affects the subduction zone dynamics. Hydrated subducting slabs release water as the slabs are heated up, which hydrates the bottom of mantle wedge just above the subducting slab, to form a serpentinite layer. In this case, the slab-wedge mechanical coupling is reduced, and weakens the wedge corner flow, decreasing the slab surface temperature. The serpentinite layer is stabilized to extend deeper, enhancing mechanical decoupling between the slab and the wedge. This positive feedback has a large impact on the overall thermal-flow structure and magmatism in subduction zones [2]. We compare the model results and the observations such as position of arc magmatism, heat flow and seismic structures to constrain the actual structure and dynamics.

Water may enhance elemental transport once a fluid phase is formed and
migrates, which potentially causes specific elemental fractionation. We have constructed two-dimensional models of trace element transport in subduction zones, incorporating (i) slab subduction-dehydration, (ii) fluid migration and its reaction with the convecting mantle, (iii) melt generation and (iv) associated elemental partitioning among the solid, aqueous fluid and melt [3]. This model predicts various trace element abundances in solid, fluid and melt, and shows that significant variability in terms of trace element ratios is produced in subduction zones and can be brought down to the deep mantle. The trace element variability must affect long-term radiogenic isotopic evolution of the mantle (e.g., Sr, Nd and Pb isotopic compositions). Recently, a global isotopic structure has been found based on a statistical analysis of a large geochemical data set including MORB, OIB and arc basalts [4]: the eastern mantle hemisphere is enriched in subducted aqueous fluid components compared to the western hemisphere. Magnitude of the radiogenic ingrowth for the hemispherical structure suggests that it has been mostly developed within the last several hundred million years. These observations can be explained by focused subduction towards the supercontinent (Rodinia, Gondwana and Pangea), which has created the large-scale mantle heterogeneity. A strikingly similar pattern is found for the seismic velocity structure of the inner core [5,6]. Such hemispherical structures may be key to understanding the global dynamics of the Earth. We propose that the focused plate subduction governs the flow and thermal structure of the deep interior, in a "top-down" manner.

References: [1] S. Karato, H. Jung, Philos. Mag. 83, 410 (2003). [2] S. Horiuchi, Ph.D. thesis, U. Tokyo (2013). [3] A. Ikemoto, H. Iwamori, Earth Planet. Space, in revision. [4] H. Iwamori, H. Nakamura, Geochem. J. 46, e39 (2012). [5] S. Tanaka, H. Hamaguchi, JGR 102, 2925 (1997). [6] L. Waszek et al., Nature Geo.4, 264 (2011).

Keywords: subduction, water, trace element, isotope, hemisphere, mantle

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)


SIT05-06 Room:315 Time:April 28 10:15-10:30

# Effects of plate-like behavior and material recycling on lateral variation of CMB heat flux

NAKAGAWA, Takashi[1]*

[1]IFREE, JAMSTEC

We studied the relationship between heat flux across the core-mantle boundary (CMB) and seismic anomalies in the CMB region in numerical mantle convection simulations in a 3-D spherical shell with a simple temperature- and depth-dependent viscosity [Nakagawa and Tackley, 2008]. That study suggested that the relationship between CMB heat flux and seismic anomalies was not simple linear function because of the post-perovskite phase transition and/or compositional heterogeneous structure in the deep mantle. However, in that study, we did not include the complicated rheology that occurred to the plate tectonics-like behavior and the segregation of oceanic crust in the deep mantle because they would be important for regulating the heat flux across the CMB [e.g. Nakagawa and Tackley, 2010].

Here we revisit to investigate the relationship between heat flux across the CMB and seismic anomalies in the deep mantle including plate tectonics-like behavior and material recycling. Preliminary result suggests that the heat flux tends to be more linear relationship with seismic anomalies in the deep mantle including plate tectonics-like behavior and material recycling but the uncertainty of this relationship between two quantities is very strong. The peak-to-peak of lateral variation of CMB heat flux is much larger than that obtained from our previous study. This is still problematic for magnetic field generation caused by geodynamo.

Keywords: CMB heat flux, lateral variation, plate tectonics, material recycling

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)


SIT05-07 Room:315 Time:April 28 10:30-10:45

# Petrology and Geochemical Evolution of Lavas from the Ongoing and Voluminous Puu Oo Eruption of Kilauea Volcano, Hawaii

GARCIA, Michael[1*] ; PIETRUSZKA, Aaron[2] ; GREENE, Andrew[3] ; MARSKE, Jared[4] ; RHODES, Michael[5]

[1]Dept. Geology-Geophysics, Univ. of Hawaii, [2]USGS, Denver, [3]Depart. Natural Sciences, Hawaii Pacific University, [4]Dept. Terrestrial Magnetism, Carnegie Institution of Washington, [5]Dept. Geoscience, Univ. Massachusetts

The Puu Oo eruption of Kilauea Volcano is one of the longest-lived (31 years and continuing) Hawaiian eruptions. Volumetrically, it is the most significant historical eruption. It has produced over 4 km3 of lava from several vents along its east rift zone. We have continually monitored the compositional and isotopic signatures of its lavas, which have shown remarkable variations. These variations resulted from diverse crustal and mantle processes including crystal fractionation, magma mixing and storage, assimilation of crust and melting of a heterogeneous plume source. Crystal fractionation is an important process in these lavas based on their wide range of MgO contents (5-10 wt.%) and normally zoned minerals (mostly only olivine). During the first two years, the effects of crystal fractionation were superimposed on hybrid magmas created by mixing two evolved, rift zone-stored magmas with a new, mantle-derived magma. Later lava erupted show no signs of mixing except for one-day, uprift events in 1997 and 2011. Small, systematic variations in Pb and Sr isotopes, incompatible trace element ratios and MgO-normalized (10 wt.%) major element abundances of post-mixing lavas document rapid changes in the parental magma composition unrelated to crustal processes. Lavas erupted between 1985-1998 continued the post-1924 composition trend of Kilauea lavas towards more depleted composition. This trend was initiated by the collapse of summit crater during a period of very low magma supply. Puu Oo lavas showed a systematic temporal evolution towards historical Mauna Loa lava composition from 1998-2003. This trend reversed in 2003 and again in 2008 creating a cyclic pattern of geochemical variations. These reversals in composition are contrary to previous models for geochemical trends during sustained basaltic eruptions. The cyclic variations of Pb isotopic and some trace element ratios during the Puu Oo eruption suggest melt extraction from a mantle source with thin strands of vertically-oriented source heterogeneities. These strands may be 1-3 km in diameter in order to explain the scale of isotopic variations for the Puu Oo eruption. This continuing eruption provides a dynamic laboratory for evaluating models of the generation and evolution of basaltic magmas.

Keywords: volcano, Hawaii, eruption, historical, magma, basalt

SIT05-08 Room:315 Time:April 28 11:00-11:15

# When did the plate tectonics start on the Earth?

MARUYAMA, Shigenori[1*]

[1]ELSI Tokyo Institute of Technology

Initiation of plate tectonics on the Earth is a key to make life-sustaining rocky planet Earth, because primordial ocean was highly toxic and primordial atmosphere had high XCO2. Transportation of huge amounts of CO2 into mantle by plate subduction depends on pH of seawater and composition of oceanic slab.

Plate tectonics has been proposed from the data set of the ocean-floor, firstly by ocean-floor spreading theory followed by rigid lithosphere. Yet, the oldest lithosphere goes back to only 200Ma, hence demonstration of plate tectonics on the Earth is restricted to the Earth after 200Ma.

Hence, we need to make logical framework of pre-200Ma plate tectonics of the Earth. The principle of Accretionary Complex Geology (ACG) is an only key issue which is centered by Ocean Plate Stratigraphy (OPS). ACG is a technology which separates the subducted oceanic slab from trench turbidites, and offers the MORB, OIB, pelagic sediments, and subduction zone magmatic rocks from the mixture of rock units formed at trench.

Application of this technology to 3.8Ga Isua ACs clarified Early Archean plate tectonics which had different aspects of plate tectonics from the modern plate tectonics, e.g., thickness and composition of lithosphere (Komiya et al., 1999). Specifically, thickness of MORB was 20km which seems to be buoyant to prohibit subduction (e.g., Davies, 1992). But if slab-melting is common, the buoyancy turns to be negative to cause more rigorous slab-pull force at subduction zone (Komiya et al., 2002).

For the Hadean Earth, there are no geologic units remained on the modern Earth, except for zircons with back to 4.4 Ga. Mineral inclusions within the Hadean zircons suggest the host melt with granitic magma. Formation of granitic melts could be most probable for the operation of plate tectonics. But this is logically imperfect, because small amounts of granitic melts can be formed and actually present on the Moon. Conversely, the forward modelling of planetary tectonics could be more important than zirconology. Formation of primordial ocean causes the formation of rigid lithosphere, and hydrous minerals on the slab surface would act as liberated lubricants along Benioff plane. This is plate tectonics and plays even in the state of magma pods remains in the asthenospheric mantle (Sleep et al., 2011). If so, initiation of plate tectonics on the Earth could be back to Hadean Earth, presumably back to 4.4Ga.

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)


SIT05-09 Room:315 Time:April 28 11:15-11:30

# Difference of tectonics and rheological structure between Earth and Venus

AZUMA, Shintaro[1*] ; KATAYAMA, Ikuo[1] ; NAKAKUKI, Tomoeki[1]

[1]Department of Earth and Planetary Systems Science, Graduate School of Science, Hiroshima University

Venus has been regarded as a twin planet to the Earth, because of density, mass, size and distance from the Sun. However, the Magellan mission revealed that plate tectonics is unlikely to work on the Venus. The plate tectonics is one of the most important mechanism of heat transport and material circulation of the Earth, consequently, its absence might cause the different tectonic evolution between Earth and Venus. Rheological structure is a key to inferring mantle structure and convection style of planet interiors because the rock rheology controls strength and deformation mechanism. In previous study, the behavior of Venusian lithosphere has been inferred from the power-law type flow law of dry diabase. They indicated that lower crust can be weaker than upper mantle, which might result decoupling at the crust-mantle boundary (Moho depth) and mantle convection without crustal entrainment. However, the power-law creep cannot be applicable to infer the rheological structure at Moho depths, because the dislocation-glide control creep (Peierls mechanism) is known to become dominant at relatively low temperatures in materials with a relatively strong chemical bonding such as silicates. In this study, we conduct two-phase deformation experiments to directly investigate rheological contrast between plagioclase (crust) and olivine (mantle) and discuss the difference between these planets in terms of rheological behaviors. Moreover, one-dimensional and two-dimensional numerical calculation is performed to evaluate the influence of the strength contrast on the Venusian tectonics. Our experiments using solid-medium deformation apparatus directly determine the relative strength between plagioclase (crust) and olivine (mantle) without any extrapolating of flow law. The experimental conditions were ranging 2GPa and 600-1000 degrees under dry conditions. The experimental results show that olivine is expected to always be stronger than plagioclase. This result contradicts to that inferred from power-law creep of olivine and plagioclase, suggesting that Peierls mechanism could be dominant deformation mechanism in both olivine and plagioclase at relatively low temperatures. In the case of the Earth, rheological structure of oceanic lithosphere is constrained well by Byerlee's law and power-law type flow law. The oceanic crust and mantle lithosphere are strongly coupled mechanically because the Moho has no strength contrast, so that they could move and subduct together into the deep. In contrast, our experimental results imply that large strength contrast exists at Moho in Venus, resulting decouple of the motion between the crust and mantle lithospheres because the weak lower crust acts as a lubricant. Also one-dimensional numerical calculations show us that the surface velocity becomes more sluggish in the model with larger strength contrast (from two-digit to four-digit difference in viscosity) at Moho. Therefore the crustal part is less likely to be involved to mantle convection when strength contrast gets larger and larger. In fact, two-dimensional simulations suggest that the crustal portion cannot subduct with the mantle lithosphere if the strength contrast exists at Moho

Keywords: plagioclase, olivine, Venus, rheology, plate tectonics

Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)


SIT05-10 Room:315 Time:April 28 11:30-11:45

# On the origin of plate tectonics: Thinking outside of the convective box

SOLOMATOV, Viatcheslav[1*]

[1]Washington University in St. Louis

From the observational point of view, there is no evidence of plate tectonics on other planets in the Solar System. Remote sensing methods for detecting plate tectonics on exoplanets are yet to be developed and are unlikely to be as robust as the surface observations that were conducted for Venus, Mars, and Mercury. The observational constraints on the tectonics of the early Earth are probably the most important clues to the plate tectonics origin and yet, their interpretations remain ambiguous. Some researchers see a very early start of plate tectonics in the data while others do not exclude a relatively late start. From the theoretical point of view, the absence of plate tectonics is easy to explain and can be considered as a normal state of any rocky or icy body. Two decades ago, both the observational data and theoretical studies led to the reversal of the question “why do other planets not have plate tectonics” to “why does the Earth have plate tectonics”. Since then various theories and numerical models focused on the latter question and investigated how plate tectonics began and what conditions are required for plate tectonics to occur on a planet. In most models the starting state of a planet is a non-plate tectonics regime (e.g. stagnant lid convection) which then transitions to plate tectonics. The forces responsible for the transition can be caused by convective motions below the lithosphere and with thermal (e.g. lithospheric relief) and compositional density variations (e.g. continents) near the surface. The role of the factors involved can be complicated. For example, the crust can both hinder and help plate tectonics. The transition to plate tectonics can also be caused by external factors, such as impacts and tidal forces. Similar to the previous, internal factors, these external factors can also either help or hinder plate tectonics initiation. For example, even though impacts are sometimes considered as a possible cause of plate tectonics, they can create conditions that would hinder plate tectonics initiation later on or stop it in case if plate tectonics was previously initiated by other mechanisms. Plate tectonics could also have emerged from a magma ocean, bypassing the stagnant lid regime. In this scenario plate tectonics is a continuation of convection in the magma ocean. As the magma ocean crystallizes, the surface boundary layer, which has little difficulty to recycle in the liquid magma, eventually transforms into tectonic plates as the crystallizing magma ocean undergoes a transition from turbulent convection controlled by melt viscosity to laminar convection predominantly controlled by solid-state creep. Regardless of the origin of the first episode of plate tectonics, the question of how plate tectonics survived and evolved into a relatively stable regime is a challenge for any of these models and may require a combination of many factors such as asthenosphere, surface oceans and volatile cycling.

Keywords: Plate tectonics, Stagnant lid convection, Giant impacts, Magma oceans, Exoplanets