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Lithospheric Rheology and Stress and the Dynamics of Plate Tectonics
Lithospheric Rheology and Stress and the Dynamics of Plate Tectonics

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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 μ (<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 μ~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 μ>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.

キーワード: Mantle Convection, Plate Tectonics, Lithospheric Stress, Lithospheric Rheology, Brittle Deformation
Keywords: Mantle Convection, Plate Tectonics, Lithospheric Stress, Lithospheric Rheology, Brittle Deformation

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

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

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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

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SIT05-03 会場:315 時間:4 月 28 日 09:30-09:45

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

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

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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.

キーワード: subduction, mantle flow, slab rollback, overriding plate stress
Keywords: subduction, mantle flow, slab rollback, overriding plate stress

SIT05-04 会場:315 時間:4 月 28 日 09:45-10:00

大西洋ポルトガル沖における磁気スペクトル解析
Magnetic spectral analysis over the Atlantic Ocean off Portugal

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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.

キーワード: 磁気データ, スペクトル解析, キューリー点
Keywords: Magnetic data, spectral analysis, Curie point

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沈み込み過程と地球の「Top-down 半球ダイナミクス」仮説
Subduction Processes and a New Hypothesis for "Top-down Hemispherical Dynamics" of the Earth

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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]

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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.

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

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

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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.

キーワード: CMB heat flux, lateral variation, plate tectonics, material recycling
Keywords: CMB heat flux, lateral variation, plate tectonics, material recycling

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

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

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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.

キーワード: volcano, Hawaii, eruption, historical, magma, basalt
Keywords: volcano, Hawaii, eruption, historical, magma, basalt

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SIT05-08 会場:315 時間:4 月 28 日 11:00-11:15

When did the plate tectonics start on the Earth?
When did the plate tectonics start on the Earth?

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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.

SIT05-09 会場:315 時間:4 月 28 日 11:15-11:30

地球と金星のレオロジー構造における違いとテクトニクス
Difference of tectonics and rheological structure between Earth and Venus

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これまで金星は密度、質量、体積、太陽の距離などから地球とよく似た地球型惑星だと考えられていた。しかし現在では、Magellan mission によって、金星は温度、水、大気、地形、そして生命において地球とはかなり異なり、さらにプレートテクトニクスが働いていないことが明らかにされ、同じ地球型惑星でも金星は全く違う進化を辿ってきたと考えられている。プレートテクトニクスは地球において最も重要な物質循環の 1 つである。そのため、このプレートテクトニクスの欠如が地球と金星の違いを生み出した 1 つの要因であると推察される。プレートテクトニクスを考える上で重要なものとして、惑星内部の強度や変形を考察するレオロジーが挙げられる。なぜなら岩石のレオロジーが惑星内部の強度や変形メカニズムを支配し、テクトニクスに大きな影響を与えるからである。先行研究では、金星のレオロジー層構造は地殻を構成していると考えられるダイアベースの流動則を室内実験から求め、金星内部の温度・圧力に外挿することによって考察されてきた。それらによると金星の下部地殻と上部マントルには大きい強度コントラストが期待され、デカップリングを起こしている可能性が示唆されている。しかし、ケイ酸塩鉱物のような強い化学結合を持つ鉱物において、比較的低温では power-law タイプの流動則は適応できず、パイレスメカニズムが支配的になることが知られている。本研究では、金星のモホにおいて強度コントラストの有無を変形実験によって明らかにし、その強度コントラストの有無がどのように金星のテクトニクスに影響を与えるかを、1 次元と 2 次元の数値シミュレーションから考察する。変形実験を行った目的は、流動則からの外挿ではなく、改良型 Griggs 変形試験機を用い、斜長石とオリビンの 2 相系で変形実験を行い、強度比を直接決定することである。変形実験の条件は T=600-1000oC, P=2GPa て?ある。また金星の表面温度 T=470 ° C であることから、かなりドライな惑星であると考えられ、無水条件で実験を行った。無水条件における変形実験により、全ての温度条件でオリビンが斜長石よりも強度が大きいことが確認された。これは power-law creep の外挿からでは起こりえないことから、オリビン及び、斜長石の変形メカニズムが低温では Peierls メカニズムが支配的になっていることが示唆される。この無水実験より得られた強度比から金星内部のレオロジー構造を推察し、さらに地球の海洋リソスフェアとの違いも考察した。まず地球の場合、海洋リソスフェアのレオロジー層構造は Byerlee's law と power-law creep によってよく制約されている。それによると、海洋リソスフェアのモホ面はまだ脆性領域であり、モホにおいて強度のコントラストは無いと考えられる。 そのため、地殻と上部マントルはよくカップリングし、一緒に地球深部へと沈み込むことができる。一方、本研究の実験結果から金星のレオロジー層構造を考えると、モホに大きい強度コントラストが期待できる結果となった。下部地殻と上部マントルの強度コントラストが大きいとデカップリングを起こす可能性が考えられる。この弱い下部地殻によって起こるデカップリングが強い上部マントルの変形から地殻を切り離し、地殻の水平移動を妨げていることが期待される。さらに強度の小さい物質は強度の大きい物質に沈み込むことは困難であることが予想されるため、リソスフェアの地殻の部分はマントル中に沈み込むことが出来ない。また一次元の数値計算からも、モホにおいて大きい強度差があればあるほど、下面の速度に対して、表面速度は遅くなることがわかった。それゆえ、モホに大きい強度差があるとき、地殻の部分はマントルの変形に巻き込まれそうにない。実際 2 次元のシミュレーションからも、地殻とマントルに強度差がある場合、地殻の部分は沈み込むことができないことがわかった。以上のことから、この地殻とマントルのデカップリングが金星のプレートテクトニクスを阻止した 1 つの要因ではないかと考察される。

キーワード: 斜長石, かんらん石, 金星, レオロジー, プレートテクトニクス
Keywords: plagioclase, olivine, Venus, rheology, plate tectonics

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

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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.

キーワード: Plate tectonics, Stagnant lid convection, Giant impacts, Magma oceans, Exoplanets
Keywords: Plate tectonics, Stagnant lid convection, Giant impacts, Magma oceans, Exoplanets

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マルチモード表面波によるリソスフェア-アセノスフェア境界の推定
Estimation of the lithosphere-asthenosphere transition from multi-mode surface waves

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The lithosphere-asthenosphere transition (LAT) is a key to the understanding of the present-day plate motion, but its seismological determination is not straightforward unlike material boundaries such as the Moho and core-mantle boundary. Some recent works on the LAT using body-wave receiver functions have revealed evidences for clear converted signals at the bottom of lithosphere, particularly in oceanic region. To the contrary, receiver functions normally do not show clear converted signals from the expected bottom of cratonic lithosphere at about 200 km depth, where surface wave studies indicate fast wave speed anomalies of the thick continental lithosphere.

In this study, we investigate a quantitative way to estimate the depth and thickness of the LAT from S-wave speed models derived from surface waves. Although surface waves are inherently not very sensitive to the sharpness of boundaries due to their long-wavelength features, the depth of LAT can be roughly estimated from the depth of either the negative peak of velocity gradient or the slowest shear velocity beneath the lithosphere. In this study, we consider that the former represents an upper bound of LAT and the latter a lower bound. The thickness (or sharpness) of LAT can be deduced from the differences between the upper and lower bounds.

We have performed synthetic experiments using several types of S-wave models including different smoothness (or sharpness) of LAT. Synthetic experiments using multi-mode surface waves (including up to fourth higher modes) result in a successful recovery of the smooth LAT (with a depth range over 50 km), which is expected at the base of the cratonic lithosphere. However, if we use the fundamental mode only, the recovery is unsatisfactory even for the smooth boundary, and the effects of the sharpness of boundary are almost indistinguishable in the recovered models. Surface waves have less sensitivity to a sharp boundary (with a transition thickness less than 25 km), but our experiments indicate that the estimated depth from the velocity gradient (upper bound of LAT) are found to be coincide well with the depth of sharp boundary, which may indicate the distribution of oceanic LAT can be well represented by the negative peak of vertical gradient in S-wave speed profiles derived from surface waves.

キーワード: lithosphere, asthenosphere, surface wave, higher mode
Keywords: lithosphere, asthenosphere, surface wave, higher mode