地下水で見つかる異常に軽いリチウム同位体組成の謎
Enigmatic ground water enriched in isotopically light lithium

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地殻深部流体は，地震や火山といった地殻活動に大きく関わる。「地殻内の流体分布」を可視化できる地震波トモグラフィーや電気比抵抗構造探査といった地球物理学的手法は，地殻流体の起源や挙動の解明において極めて強力なツールであるが，流体がある程度濃集していないと検出できない。そこで，地下水の同位体組成といった地球化学的情報と併せることで，地殻流体の起源に関して，より高度な知見が得られることが期待される。しかし，湧水や井戸水といった地表で採取できる地下水試料の地球化学的情報を基に，地殻流体の起源に迫った研究はこれまで極めて限られていた。これは，地下水の地球化学研究に用いられてきた元素同位体指標の多くが，表層水混入の影響を非常に受けやすかったためである。また，地下水試料から地殻深部流体の情報を得ようとした場合，深部流体上昇時における地殻との反応の影響も大きい。加えて，深部流体が上昇して温度が低下する際に，流体が高温時に獲得した地球化学情報は時間の経過と共に失われていく。リチウム（Li）は，非常に流体相に分配されやすい元素の１つである。系の温度が上昇するにつれて，流体相の濃度は急速に上昇する。その結果，高温を経験した深部流体は，低温しか経験していない表層水に比べて著しくに富むため，他の元素に比べて深部流体表層水間の濃度のコントラストは極めて大きくなり，表層水混入の影響を他の元素に比べると受けにくい。また，高温となって流体相に分配されたは，他の元素に比べると温度降下の際も流体相に保持される。そして，は質量数との安定同位体比の情報が利用できる。反応温度が高温になるほど，流体の同位体組成は反応した固相側の値に近づいて，軽い同位体組成を持つようになる。私達の研究グループでは，温泉水や鉱泉水等の地下水試料の同位体結果を用いて，地殻深部流体の地球化学的研究を行ってきた。これまでの同位体研究を通して解明できていない大きな謎の１つに，ある種の地下水試料の中に地殻やマントルより有意に軽い同位体組成が見つかることがあげられる。前述の通りに，高温を経験した流体ほど軽い同位体組成を持つが，固相側の値より低くはならない。よって，地殻やマントルより有意に軽い同位体組成は，他の物質と反応した結果といえる。は，木曽御嶽火山の南東麓の地下水に地殻やマントルより有意に軽い同位体組成を発見した。この場所では，年から群発地震が続いており，比抵抗の調査結果からも深部流体の上昇が指摘されていた。では，木曽御嶽山周辺の群発地震域と非群発地震域のとストロンチウム（Sr）の同位体データと比較することで，群発地震域（南東麓）で見つかった軽い同位体組成は，表層水が浅部マグマと反応した火山性流体では説明できないことを指摘した。しかしながら，群発地震域の地下水がどのようにして地殻平均より有意に軽い同位体組成を獲得したかについては不明のままであった。その後，木曽御嶽山南東麓で見つかったような著しく軽い同位体組成は，神戸や高知で見つかった。本発表では，この幾つか見つかってきた地下水中の軽い同位体組成の成因についての可能性を議論する。

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キーワード：リチウム同位体、地殻深部流体、スラブ起源流体、地球化学温度計
Keywords: lithium isotope, deep crustal fluid, slab-derived fluid, geochemical thermometer

地殻応力場と地質構造の関係から考える西南日本紀伊半島陸域での深部流体の上昇
Relationships between crustal stress fields and geological structures on pathways of upwelling deep-seated water at Kii Peninsula, southwest Japan

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The natural and hot springs with ^{3}He/^{4}He ratios higher than the atmospheric values are recognized to occur in nonvolcanic regions on the Kii Peninsula in the forearc regions of southwestern Japan arc (Sano & Wakita, 1985; Wakita et al., 1987; Matsumoto et al., 2003; Umeda et al., 2006, 2007), indicating that there are upwelling paths of the mantle-derived fluids in this region. A number of deep groundwater and natural spring water in this region are found to contain the slab-derived deep-seated fluid component, whose isotopic composition is similar to magmatic with the high Li/Cl ratio (>0.001 in wt. ratio) (Kazahaya et al., 2014). The upwelling of the deep-seated water provides significant information to understand the fluid movement in the crust and the water cycle in the subduction system (e.g. Hacker, 2008).

In this study, we present the upwelling of water and gas along the fractures and the relationships between orientations of the veins and the upwelling of the deep-seated water in the Shiotakibashi outcrop located to the north of Median Tectonic Line (MTL). And, we discuss the upwelling process of the deep-seated water at Kii Peninsula by using the relationships between crustal stress field and geological structures.

The Shiotakibashi outcrop along the Ishikawa river at the Kawachinagano city of Osaka prefecture is one of regions where the upwelling of the water and gas containing deep-seated water along the fractures can be observed (Tanaka et al., 2013). In the upwelling points at the outcrop, the patches of fractures that cut the Cretaceous granite belonging to the inner zone are filled by the calcite crystalized from the water. Furthermore, the water and gas are flowing so as to avoid the filled fractures. And, we can observe many mineral veins with several orientations in this outcrop. Mineral veins can provide evidences of the ancient fluid migration along the fractures.

In this study, we measured the strike, dip and width of the veins in a single outcrop of the Shiotakibashi outcrop (~100 veins). On the veins, the fractures that cut the cretaceous granite are filled by the calcite. The veins have thicknesses with a few mm to 2 cm. The most of the veins have NNE-SSW and ENE-WSW striking and dip with high angle while some veins have horizontal dip. The dilation tendency (Ferrill et al., 1999) for the filled fractures in the present stress inferred from the major active faults in the eastern part of the southwestern Japan including the Kii Peninsula (Tsutsumi et al., 2012) indicate that the fractures with upwelling of water and gas have high tendency on the pass ways of deep-seated water. Hence, the present tectonic stress may be feasible for upwelling of the deep-seated water along the fractures for a part of the fractures.

At the map scale, the Cretaceous-Paleogene accretionary complex, Shimanto Belt is exposed in the region located to the south of MTL in Kii Peninsula. The most of deformation structures of the Shimanto Belt have northward plunging thrusts. Based on the relationships between crustal stress field and attitudes of the geological structures, the dilation tendency is high on the geological structures. Hence, we suggest that the geological structures of the region under the present crustal stress are favorable pathways for deep-seated fluids.

キーワード：応力、流体移動、断層、地殻、深部低周波微動、沈み込み帯
Keywords: stress, fluid migration, fault, crust, deep low-frequency tremors, subduction zone

紀伊半島西部における3次元地震波減衰構造の推定
Three dimensional attenuation structure beneath the northwestern part of Kii peninsula, central Japan

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紀伊半島の下に沈み込んだフィリピン海プレート上面の深さ30～40㎞付近では非火山性の低周波地震の発生している[Kato et al.,2010]．また，紀伊半島西部の和歌山市周辺では深度10㎞以浅で非常に活発な群発地震活動が報告されている[溝上他，1983；Kato et al.,2010]．既存研究から，これらの地震イベントの発生には流体が関与していることが指摘されている[Hirose et al.,2008;Kato et al.,2010&2014]．本研究ではクラックや流体の存在や温度に敏感な地震波の減衰パラメターQ値を3次元的に求めることにより，詳細な地下構造を求めることを試みたので報告する．

地震波減衰構造はTsumura et al.(2000)の震源パラメター，減衰，観測点近傍の影響を同時推定するインバージョン法を適用して推定した．インバージョンに使う地震は，防災科学技術研究所のHi-net定常観測点及び2009年～2010年に紀伊半島南部に設置された東西群列地震観測点と2010～2011年に紀伊半島西部に設置された南北群列地震観測点で記録されたものから選択した．また，波線分布の偏りを少なくするため，上述の期間以外に2004年6月～2010年5月にHi-net観測点で観測された地震もあわせて解析を行った．113観測点で得られた247個の地震の8616本の波線についてP波に関する減衰インバージョンを行った．

得られたQp構造を見ると，深さ15㎞までの浅部では紀伊半島北西部にQp値が200以下となる高減衰域が存在する．その高減衰域は群発地震発生域とほぼ同じ広がりを持つ．それ以外の領域のQp値は400～800程度で，半島南端部にもQp<400となる領域が存在する．深さ15～38㎞の層でも紀伊半島北西部に地震波減衰域が存在するが．深さ25㎞以深ではその広がりは浅部に比べて小さくなる．フィリピン海プレートの等深度線30～40㎞付近の直上に高Qpを示す領域がパッチ状に分布する．これらの高Qp領域は低周波地震の発生場所と空間的に対応することがわかった．特に観測点密度の高い紀伊半島西部の北西―南東断面で見ると，群発地震域の直下に高減衰域が存在することと，その高減衰域が走時トモグラフィで求められた地震波低速度域に一致することが明らかになった．レシーバ関数解析から群発地震域の下のフィリピン海プレート海洋地殻ではエクロジャイト化が進んでいると指摘されており，群発地震直下からマントル部分に続く高減衰域はその脱水過程で出た流体と関係しているかもしれない．さらに低周波地震の発生域直上のマントルウェッジ部分は低減衰域となり，その領域の地震波速度は高速度であることも示された．他の地球物理学的データと合わせ，これらの領域の物性についての議論を行いたい．

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キーワード：地震波減衰、群発地震、非火山性低周波地震、紀伊半島
Keywords: Q attenuation, seismic swarm, non-volcanic low frequency earthquake, Kii peninsula, southwest Japan

スロー地震発生域における高圧流体の存在：ScSp波による新しい制約

Control of episodic tremor and slip by high-pressurized fluids: a new constraint from ScSp waves

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1. Introduction

High-pressurized fluids are thought to play an important role in controlling episodic tremor and slow slip (ETS) in subduction zones [e.g., Shelly et al., 2006; Audet et al., 2009]. Therefore, constraining the along-dip distribution of ETS is necessary to better understand its source mechanism, and particularly the role played by fluids in ETS generation. Here, we report clear observations of coherent *ScSp* phases with a dense seismic array in western Shikoku, Japan. To reproduce these observations, we performed numerical simulations of elastic-wave propagation using a finite difference method (FDM) that incorporated a three-dimensional structural model. The combination of coherent *ScSp* phases and numerical simulations allows us to investigate the depth dependence of Poisson's ratios within the LVZ, and to quantitatively estimate local changes in fluid pressure in the ETS zone.

2. Data and Method

We deployed a dense linear seismic array from October 2011 to April 2013 on western Shikoku Island, SW Japan. We also used permanent stations near the array from the Hi-net network, operated by the National Research Institute for Earth Science and Disaster Prevention [Okada et al., 2004], and stations of the Japan Meteorological Agency. During the deployment period, we visually inspected seismograms of Mw ≥6 deep earthquakes with focal depths greater than 90 km and epicentral distances D < 25°. Using the transverse components of rotated seismograms from the array, we shifted the *ScS* phases relative to the arrival at the station having the highest S/N ratio by cross-correlating the *ScS* phase from the station with other *ScS* waveforms to achieve the maximum correlations. The vertical component data at each station were then time shifted by the corresponding time lags, relative to the station.

3. Results and Discussion

Based on comparisons of transverse and vertical component waveform data, we found clear, coherent signals arriving before *ScS* on the vertical components of most stations in the array. The travel time differences between *ScS* and *ScSp* increase along the direction of subduction. This means that the *ScS-to-ScSp* conversion point deepens to the northwest, indicating in turn that the converted waveforms propagate from the top of the subducting PHS Plate. Then, we simulated the propagation of synthetic *ScSp* waveforms using the JIVSM model [Koketsu et al., 2012]. However, the calculated *ScS -ScSp* travel time differences were systematically smaller than predicted by our observations. To improve the goodness of fit, we partitioned the LVZ into shallower and deeper parts around the upper corner of the mantle wedge, because the travel time difference between the observed and simulated waveforms was larger at the northern stations, toward which the LVZ is subducting. This change gave two different *S*-wave velocities in the LVZ. We conducted a grid search over the three-parameter space defined by two velocities, and the layer thickness *h* of the LVZ. To quantify the fit, we averaged the cross-correlation coefficients between observed and simulated *ScSp* phases. From the grid search results, the Vp/Vs ratio must be higher beneath the mantle wedge

corner than at shallow depths, regardless of the assumed LVZ thickness. In the best model, Vp/Vs ratios within the subducting oceanic crust increase by 0.3 beneath the mantle wedge corner, where ETS has been observed. This high-Vp/Vs layer indicates the presence of high-pressurized fluids confined at ETS source depths. Based on extrapolation of laboratory measurements [Peacock et al., 2011], we infer that the observed changes in Vp/Vs ratios correspond to an increase in fluid pressure of ~20 MPa relative to the updip, locked zone (Figure 1).

キーワード：スロー地震、ScSp波、高圧流体
Keywords: episodic tremor and slow slip, ScSp phase, high-pressurized fluid
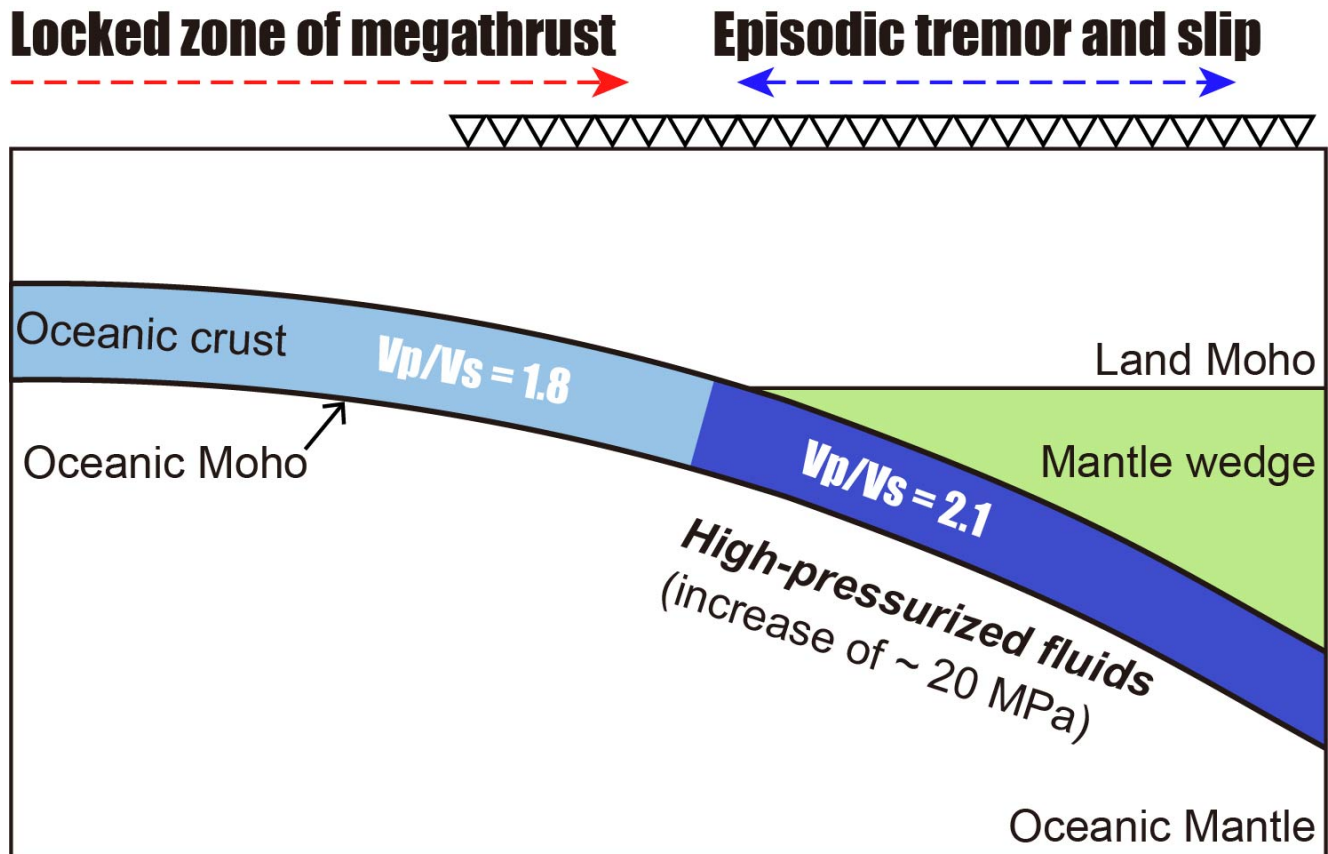
微小地震から探る岩石き裂浸透率ダイナミクス
Dynamics of rock fracture permeability explored through MEQs

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For the success of unconventional geothermal reservoirs (i.e. EGS), maintaining conduits with high-fluid-throughput is desirable. Hydraulic stimulation for such reservoirs is recognized as one of the most general ways to improve or maintain their crustal permeability, which is known as the key parameter controlling crustal fluid flow [*Ingebristen and Manning*, 2010]. During the hydraulic stimulation, in-situ microearthquakes (MEQs) data are basically recorded to capture the underlying active processes and the permeability evolution within the reservoir [*Majer et al.*, 2007], and these MEQs are in general regarded as signals that somehow represent permeability change in a fractured reservoir. If we have an insight into quantitative linkage between the permeability change and MEQ, such an insight is definitely useful for mapping in-situ permeability evolution in a reservoir. However, it remains ambiguous how much the fracture permeability is enhanced by a MEQ.

In the present study, we explore a linkage between fracture permeability change and MEQs. For this purpose, we first prepared heterogeneous aperture distributions for rock fractures with various combination of fracture length (m), l, and shear displacement (m), d, according to the method of *Ishibashi et al* [2015]. Through the analyses of these aperture distributions, scale dependencies of fluid flows through joints, i.e. fractures without shear displacement, and faults, i.e. fractures with shear displacement of d (m), are predicted as followings. Both joint and fault aperture distributions are characterized by a scale-dependent geometric mean and a scale-independent geometric standard deviation of aperture. Changes in the geometric means of joint and fault apertures (mm), $e_{m, joint}$ and $e_{m, fault}$, with fracture length (m), l, are approximated by $e_{m, joint} = 1.3 \times 10^{-1} l^{0.10}$ and $e_{m, fault} = 1.3 \times 10 (d/l)^{0.59} l^{0.71}$, whereas the geometric standard deviations of both joint and fault apertures are approximately 3. Fluid flows through both joints and faults are characterized by formations of preferential flow paths (i.e., channeling flows) with scale-independent flow areas of approximately 10%, whereas the joint and fault permeabilities (m^2), k_{joint} and k_{fault}, are scale dependent and are approximated as $k_{joint} = 9.8 \times 10^{-13} l^{0.16}$ and $k_{fault} = 2.3 \times 10^{-6} (d/l)^{1.18} l^{1.08}$. By coupling these scaling laws with the concept of moment magnitude [*Hanks and Kanamori*, 1979], quantitative change in mean aperture ($e_{m, fault}/e_{m, joint}$) and fracture permeability (k_{fault}/k_{joint}) are successfully linked with moment magnitude of MEQs (M_w) during hydraulic stimulation for a reservoir as $e_{m, fault}/e_{m, joint} = 1.0 \times 10^{0.35 Mw}$ and $k_{fault}/k_{joint} = 116.4 \times 10^{0.46 Mw}$. Validity of the equation will be discussed through comparisons with some data of real field development/experiments (e.g., EGS system in Basel and Soultz-sous-Fôret).

In summary, such linkages may enable rough inverse-mapping of evolving fracture permeabilities using in-situ MEQ data. This mapping will facilitate new insights into transport phenomenon within the Earth's crust and it relevant to engineering and scientific applications such as the development of geothermal or hydrocarbon reservoirs and clarification of earthquake mechanisms.

キーワード：岩石き裂、浸透率、表面粗さ、微小地震
Keywords: rock fracture, permeability, surface topography, microearthquake

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かんらん石の交代作用時に発達する双方向の反応進行フロント：メッシュ組織形成過程への示唆
Bidirectional replacement zoning developed in metasomatic reaction of olivine and its implication for development of mesh zoning of serpentinites

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蛇紋岩化作用は元素移動，表面反応及び体積膨張を伴う複合プロセスであり，マントルの化学的・物理的特性を大きく変化させる．海洋底の蛇紋岩化したかんらん岩には，しばしばメッシュ組織と呼ばれる産状が観察される．メッシュ組織はリムとコアで構成鉱物が異なることが多く，メッシュリムは蛇紋石に過飽和な流体が外部から流れてきて析出した(Andreani et al., 2004; Andreani et al., 2007)，もしくは最初に形成したコアが後のステージに流れてきた流体によって置換されてリムが生成した(Beard et al., 2009; Schwarzenbach et al., 2016)といった解釈がなされているが，メッシュの形成過程やそれに伴う体積変化や物質移動を，天然組織から読み解くことは難しい．

本研究では，かんらん石と斜長石の鉱物粉末を用いた水熱実験により，かんらん石と斜長石の境界から離れた箇所では蛇紋石+ブルース石+磁鉄鉱が生成する一方で，境界から約1.5mm内において，SiやAlの交代作用の進行とともに特徴的な組成累帯構造をもったAlに富む蛇紋石（Al蛇紋石）の集合体を生成させることを見いだした．Al蛇紋石のAl量は，コアからリムへかけて一旦減少し再び上昇する傾向をとる．Alの量が低い累帯構造の中心付近では，明瞭な境界が観察される．この明瞭な輪郭は元のかんらん石の外形を示し，反応フロントが元のかんらん石の内側と外側に進行していると解釈される．Al蛇紋石が組成累帯構造を示すのは，かんらん石の交代作用フロントの進行に伴い，反応する流体のSi，Al濃度が時々刻々と変化しているためだと考えられる．かんらん石内部への内側への反応は， Mg，Fe及びSiが除かれる蛇紋石化であり，そのMg，Fe及びSiが空隙まで輸送されて外部から供給されたSiと反応して外側の蛇紋石部分が成長することを見出した．

本実験は鉱物粉末を用いており約４０％の初期空隙率をもつ．そのため本研究の知見はき裂の多いかんらん岩の蛇紋岩化作用へ適用することができると考えられる．メッシュリムとメッシュコアは別のステージで生成したと解釈されることが多いが，本研究の結果は，反応が内側にだけ進行する等体積の変化は大きな元素移動を必要とし，反応が内側に進行してメッシュコアをつくると同時に外側へも進行しメッシュリムをつくる．つまり，メッシュコアとメッシュリムが同ステージで形成しうることを示唆する．この際，メッシュコアが元のかんらん石の外径を保存し，ジャッキアップのようなメカニズムで全体が膨張してメッシュリムが太くなった可能性を示唆する．

キーワード：蛇紋岩化作用、物質移動、置換反応、交代作用、水熱実験
Keywords: serpentinization, mass transfer, mineral replacement, metasomatism, hydrothermal experiment

北海道東部下における海洋性地殻の地震波速度と地震活動
Seismic velocity and seismicity in the subducting crust of the Pacific slab beneath the eastern part of Hokkaido

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沈み込む海洋プレート（スラブ）とともに地球内部へ運び込まれる水は，沈み込み帯における地震・火成活動と密接に関係していると考えられている(e.g., Kirby et al., 1996; Nakajma et al., 2013). 特に，スラブ最上部に存在する海洋性地殻は多量の水を含水鉱物として含み，これらの含水鉱物の脱水を伴う相転移の進行が地震波速度の変化や流体の分布に影響していると考えられている(e.g., Hacker et al., 2003). したがって，海洋性地殻の詳細な不均質構造を明らかにすることは，スラブ内地震の発生メカニズムや沈み込み帯における水循環過程を理解する上で非常に重要である.

日高山脈西部の観測点で観測された北海道東部下の太平洋スラブ内地震の観測波形記録にはしばしば顕著な後続波が観測されることが知られている(e.g.，清水・前田，1980; Abers, 2005). 特に，スラブ上部境界付近で発生する地震に対して観測される後続波は海洋性地殻内部を伝播したガイド波であると解釈されている(Shiina et al., 2014). ガイド波が観測されるためには日高山脈下にスラブ直上まで分布する低速度域(Kita et al., 2010, 2012)の存在が重要であり，同一の観測点で観測されたガイド波は，観測点近傍で同じような伝播経路を持つと考えられる.

そこで，本解析では北海道東部下のスラブ内地震で観測されるガイド波の走時差を用いて海洋性地殻の地震波速度の推定を試みた. 解析では海洋性地殻内部をP波として伝播したガイド波（guided-P波)とS波として伝播したガイド波（guided-S波)の2つの後続相に注目し，guided-P波は315個，guided-S波は275個の地震で到着時刻を読み取った. その結果，深さ50-100 km程度のP波速度は6.5-7.5 km/s，S波速度は3.6-4.2 km/s，Vp/Vsは1.80程度の値が推定された. 特に，深さ80 km以浅のP波・S波速度は岩石学的に期待される地殻の地震波速度(e.g., Hacker et al., 2003)よりも遅く，この速度低下は1 vol%程度の流体の存在により説明することができる. また，深さ80-100 kmでは地震波速度の増加が観測された. この深さ範囲は上面地震帯の分布(Kita et al., 2006)や含水鉱物の脱水(e.g., Hacker et al., 2003)が生じる深さに対応しており，地殻内の地震活動には脱水により生じた水が密接に関係していることが示唆している.

本解析で推定された海洋性地殻のP波速度は，深さ80km以浅では東北地方の結果(Shiina et al., 2013)と同程度であり，それよりも深部（80-100 km程度）では北海道東部のP波速度の方が速い. 太平洋スラブが斜めに沈み込む北海道東部では，東北地方に比べてスラブ上部境界付近の温度が高いと考えられている(e.g., Kita et al., 2010; Abers et al., 2013; Wada et al., 2015). 北海道東部では地殻周辺部での温度が高いことで含水鉱物の脱水反応の進行や流体の移動経路が東北地方とは異なる可能性がある. このような違いにより，北海道東部下の深さ80-100 km付近では東北地方下に比べて速いP波速度が観測されるのかもしれない.

キーワード：海洋性地殻、地震波速度、ガイド波、上面地震帯
Keywords: Subducting crust, Seismic velocity, Guided wave, Upper plane seismic belt

関東から東北地方で沈み込み熱構造，スラブ脱水、マントルフローについての三次元数値モデリング
Three-dimensional numerical modeling for subduction thermal regime, slab dehydration, and mantle flow beneath Kanto to Tohoku, Japan

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To better understand thermal regimes of the interplate and slab-slab contact zone undergoing subduction upon convergence such as in Kanto to Tohoku, Japan, we developed a parallelepiped three-dimensional thermal convection model to simulate simultaneous subduction of the overlapped Philippine Sea and the Pacific plates. We investigated the interactive slab thermal regime and mantle flow associated with such a unique geodynamic process, using simplified and realistic models. Results showed that: (1) cold anomaly was found to exist predominantly on the slab contact zone, resulting in a cold triple-plate junction corner immediately above the zone with an estimated temperature colder by approximately ~300°C beneath Kanto than Tohoku. As a result, delay in slab dehydration takes place and accounts for the distribution of low seismic velocities in the slab contact zone; (2) a relative subduction direction that yields the obliquity or asymmetry of the thermal structure in the slab contact zone, which corresponds to thermally controlled clustered seismicity on the southwestern half of the slab contact zone probably due to the delayed slab dehydration; (3) induced flow in the continental mantle was related to the straight component of subduction velocity of the lower oceanic plate more than to slab thickness. Interaction between the two oceanic plates determined the induced poloidal and toroidal convections in the continental mantle. In the sandwiched mantle wedge, the mantle flow induced by the Pacific plate is predominant, and reaches depths of 30~100 km beneath Kanto, which is shallower than Tohoku, and attributable to the double subduction; (4) thermal regime and dehydration of MORB near the upper surface of the subducted Pacific plate is considered to control distribution of seismicity beneath Tohoku and Kanto.

キーワード：スラブ脱水、二重沈み込み、数値シミュレーション、熱構造
Keywords: slab dehydration, dual subduction, numerical simulation, thermal regime
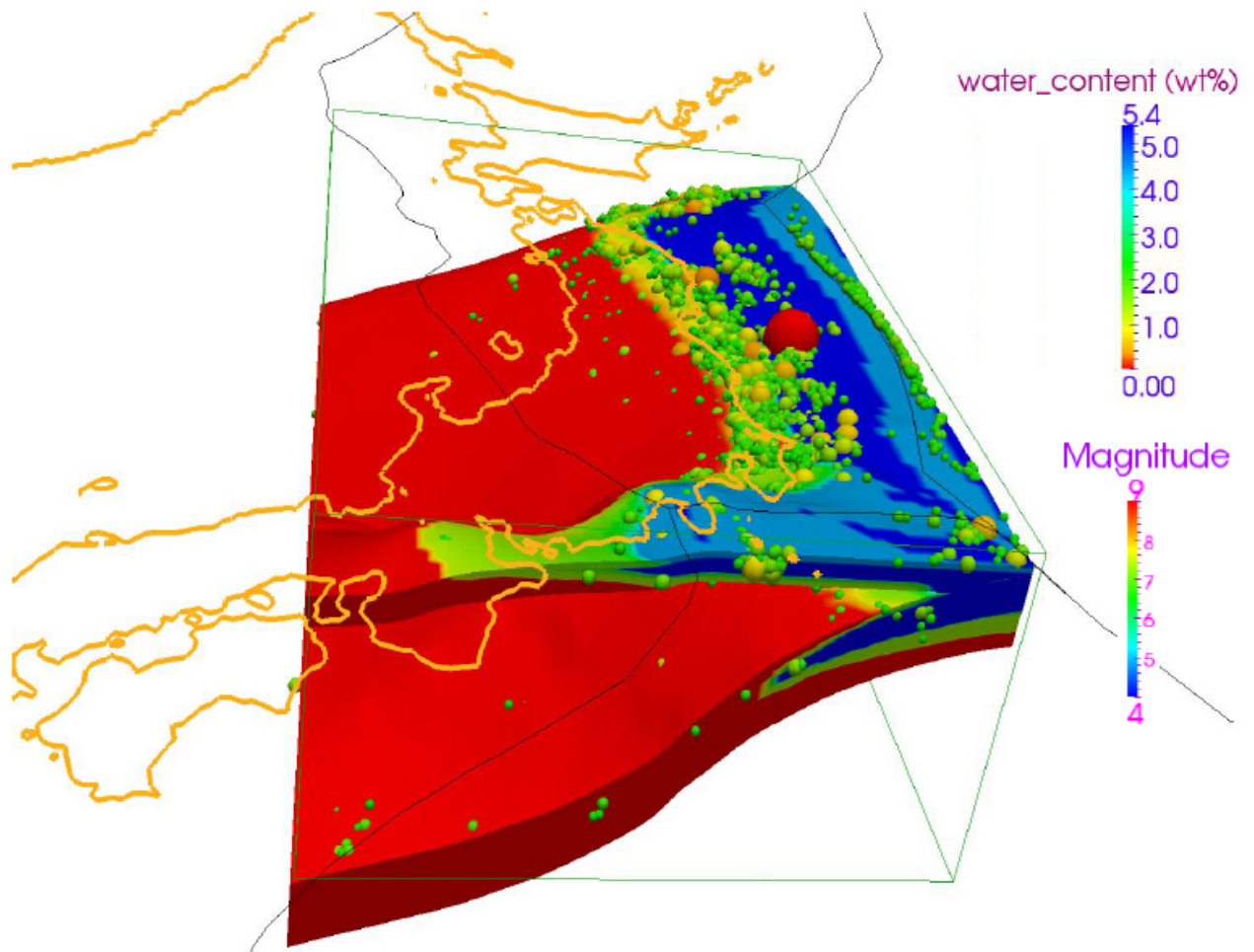
九州地方の電気伝導度構造と温度構造から求められたマントルの流体分布

Geo-fluids distribution in mantle inferred from the electrical conductivity and simulated thermal structures beneath Kyushu

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The Kyushu Island, at which the oceanic Philippine Sea Plate subducts into the mantle beneath the continental Eurasia Plate, is characterized by the northern and southern volcanic regions and the central non-volcanic region. Magmatism in the subduction zones is triggered by the addition of the oceanic slab-derived aqueous fluids (water) to the mantle, because solidus of the mantle rock falls by the addition of the aqueous fluids and partial melting of the mantle occurs. Thus the determination of geo-fluids (the aqueous fluids and the melts) distribution is essential to understand the magmatism in the Kyushu subduction zone including the non-volcanic region between the two volcanic regions.

We obtained an electrical conductivity structure (model) beneath the entire Kyushu Island using three-dimensional inversion analyses and found three conductive anomalies, which indicate the different intensity and spatial extent for the three regions, at the mantle in the model [Hata et al., 2015]. The difference is considered to originate in the content of geo-fluids in the mantle.

We determined the temperature and melt fraction distributions (structures), as a function of a fixed water content, inferred from the electrical conductivity structure beneath the Kyushu Island by using petrological laboratory-derived results [Hata and Uyeshima, 2015]. The laboratory-derived results are the relation between electrical conductivity and temperature for four nominally anhydrous minerals (Olivine, Orthopyroxene, Clinopyroxene, and Garnet) and hydrous basaltic melt in solid and liquid phases of the mantle, and the relation between melt fraction and temperature for mantle rocks (peridotites) under a condition of isobaric hydrous mantle melting.

In this study, we aim to determine the content of both geo-fluids in the mantle beneath the Kyushu Island. Thus we use a fixed thermal structure, which is a simulated thermal model associated with the subduction of the Philippine Sea Plate [e.g., Yoshioka et al, 2008]. Then we determine the geo-fluids distribution by integrating the simulated thermal structure of the mantle, field-derived electrical conductivity structure of the mantle, and laboratory-derived electrical conductivity of the four mantle minerals and the basaltic melt. We will describe our approach to determine the content of the geo-fluids and show the water content distribution and the melt fraction distribution in the mantle beneath the Kyushu Island.

瀬戸内火山帯における沈み込み開始期の熱および物質輸送のダイナミクス
Dynamics of heat and material transportation during subduction initiation in the Setouchi Volcanic Belt

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Kowledge of subduction initiation is critical for better understanding dynamics of plate tectonics, but is difficult to obtain because of its episodic and transient nature resulting in incomplete and fragmental records. The key issue is elucidation of heat and material transportation in a subduction zone during the subduction initiation. The aim of this study is clarify spatial and temporal changes of thermal state and material distribution involved in volcanisms of the Setouchi Volcanic Belt to scrutinize subduction initiation by exploiting its excellent records of the processes of subduction initiation.

 The Setouchi Volcanic Belt (SVB) in the Southwest Japan arc has a record of igneous activities which show temporally and spatially continuous distributions in the forearc region in the Miocene period. The SVB is characterized by the occurrence of primitive volcanic rocks such as high-Mg andesite (HMA) and basalt. Previous studies in the Shodoshima Island and Osaka argued that HMA magmas are generated by highly wet melting of the wedge mantle involving slab melt from the subducting young and hot Shikoku Basin in the early stage of subduction initiation (Furukawa & Tatsumi, 1999; Shimoda & Tatsumi, 1999; Tatsumi et al., 2006). However, there are several issues that must be addressed: (1) HMAs are very poor in water; (2) the estimated melting conditions for HMA and basaltic magmas are very disparate: hydrous and 1050 to 1150 ℃ vs. less hydrous and 1300 ℃, which are supposed to have been close in time and space in the mantle; and (3) the proposed magma genesis is highly dependent on data in a particular and restricted domain (< 20 km in width) in spite of the wide extension of SVB (600 km in width) consisting of several domains with higher concentration of volcanisms.

 There are three sectors of higher frequency of volcanic rock distribution in the SVB on the scale of about 100km scale, each of which may correspond to a separated domain of magma generation. We selected north-eastern part of the Shikoku (NE Shikoku), as study area, where magma genesis has not scrutinized yet. We measured whole rock composition of lavas by using XRF, LA-ICP-MS, and ICP-MS and mineral chemical compositions of phenocrysts with EPMA, and obtained K-Ar ages for samples collected from this sector in the SVB.

 Our estimation of a primary magma for HMAs in the north-eastern Shikoku, which is based not only on whole rock major element compositions but also on chemical zoning of phenocrysts, is more magnesian (> 11.6 wt% MgO) than that of the previous study. Geothermometer of Sugawara (2000) combined with liquidus drop after Méderd & Grove (2008) and alpha MELTS program (Ghiorso et al., 2001; Asimow et al., 2003) constrains melting condition of the primary magma as 1GPa and 1200-1240 ℃ with 1.5-0.9 wt % H2O. The pressure and temperature are close to the basaltic magma generating conditions proposed by Tatsumi (1982). Because of the similarity of major element compositions, the generation conditions of the HMA magma could be common throughout the SVB. By contrast, the whole

rock trace element compositions and K-Ar ages show spatial and temporal variations, which suggest variability in timing and extent of supply of a slab-derived component (marked by high LILE/HREE) and/or an enriched mantle component (marked by high HREE abundance). There is a tendency that these components were added in a later stage in a given area.

We argue that achievement of temperature over 1200℃ just beneath the crust for generation of HMA and basalt magmas with temporal changes of source material and involvement of slab-derived fluid components were caused by several local mantle upwellings. Such upwelling induced by the subduction initiation might have entrained slab and/or enriched source components at the leading edge of subducting slab.

キーワード：沈み込み開始期、高Mg安山岩、瀬戸内火山帯
Keywords: subduction initiation, high-Mg andesite, The Setouchi Volcanic Belt

ピナツボカンラン岩の微細組織観察：交代作用及び変形履歴の推定
Deformation and metasomatic histories of Pinatubo peridotite estimated from microstructural observation

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Deformation microstructures of olivine in naturally deformed peridotites are useful for examining the rheological properties and deformation history in the upper mantle. Particularly, slip system of deformed olivine is especially well known as an indicator for the deformation conditions, such as temperature, stress, pressure or water content. Here, we try to estimate the deformation history of deformed peridotite by means of the microstructural observation and slip system determination. Two types of amphibole-bearing harzburgite samples (namely P-3 and P-4) collected from Pinatubo volcano were analyzed using optical microscope, SEM, EBSD, TEM and STEM. Kawamoto et al. (2013) suggests that these peridotites were affected by the intense metasomatism. We report the relationship between the deformation history and metasomatic reaction.
Pinatubo peridotites are composed of relatively coarse olivine grains with several mm in size, and partly fine orthopyroxene and amphibole aggregate with tens to hundreds μm in size. The fine grained aggregate in P-4 is more than in P-3. The grain boundaries of the coarse grains exhibit irregular shapes. And these grains show the undulose extinction and well-developed subgrain boundaries. The coarse olivine grains contain a lot of fluid inclusions. Additionally, the fine olivine grains exist along the secondary inclusions within some coarse olivine grains.
The LPO patterns of the coarse olivine grains in the both samples imply the dominant activation of [100]{0kl} slip system, which is developed under high temperature, low pressure and dry deformation conditions. On the other hand, the dominant slip systems obtained from the direct characterization of dislocations by TEM are [100](001), [001](010) or [001](100), which activate under moderate to high water content condition. The discrepancy of the obtained slip systems is probably caused by the overprinting due to the changing of deformation conditions. Dislocation microstructures are more easily modified by later deformation events than LPOs.
We conclude from the characterization of microstructures in combined with the result of Kawamoto et al. (2013) that Pinatubo peridotite experienced deformation and metasomatic events in the following manner. Pinatubo peridotites have originally deformed under high temperature, low pressure and dry conditions in the back-arc region. Then, they have moved to the fore-arc region due to the corner flow, and have been affected by the fluid-related metasomatism. Finally, they have undergone the annealing process within the upwelling magma.
Referenece: Kawamoto et al. (2013) PNAS, 110, 9663.

キーワード：カンラン石、変形、交代作用、すべり系
Keywords: Olivine, Deformation, Metasomatism, Slip system

背弧拡大のダイナミクス
Dynamics of back-arc spreading

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背弧拡大は数1000万年の時間スケールで間欠的に起きており、そのような周期性のメカニズムを理解することは、地球全体のテクトニクスや物質循環を理解する上でも重要である。本研究では、数値モデルにより背弧拡大とスラブ-マントル間相互作用の関係を検討し、実際の沈み込み帯の背弧拡大史や地震波トモグラフィーから推定されるスラブの形状と比較することにより、背弧拡大のダイナミクス、とくに背弧拡大の開始や停止の条件について検討した。

数値モデルは深さ1200 km、幅4000 kmの領域で、大陸地殻、海洋地殻、上部マントル、マントル遷移帯、下部マントルからなり、さらにスラブ表面深度が80〜200 kmの範囲の上部マントルをより粘性の低いマントルウェッジとしている。各物質に対して、温度圧力に依存する粘性と有効摩擦係数と最大降伏応力によって決まる粘塑性の構成則を仮定し、最大降伏応力（スラブの強度）、410km相転移のクラペイロン勾配、および海洋地殻の有効摩擦係数（プレート境界の強度）の条件を変えて計算を行った。

多くの計算条件において、スラブ−マントル相互作用を通して、スラブ形状の変化と背弧拡大が周期的に起こる結果が得られ、その周期は計算条件に応じて変化する。最大降伏応力が小さい（200 MPa）と、座屈を繰り返し折りたたまれたスラブの形状を示すのに対し、最大降伏応力が大きい（800 MPa）とあまり座屈せず背弧が拡大し続ける結果となった。多くの背弧海盆は10〜20 Myrの期間で形成されていること、および最近の地震波トモグラフィーでは折りたたまれたスラブの形状は認められないことから、最大降伏応力500 MPaの計算結果が実際の沈み込み帯の現象をよく再現していると考えられる。これらの結果を伊豆–小笠原–マリアナ弧のスラブの形状や背弧拡大の歴史と比較することにより、背弧拡大の開始や停止の条件について議論する。

キーワード：沈み込み帯、スラブ−マントル相互作用、数値モデル
Keywords: subduction zones, slab-mantle interaction, numerical model