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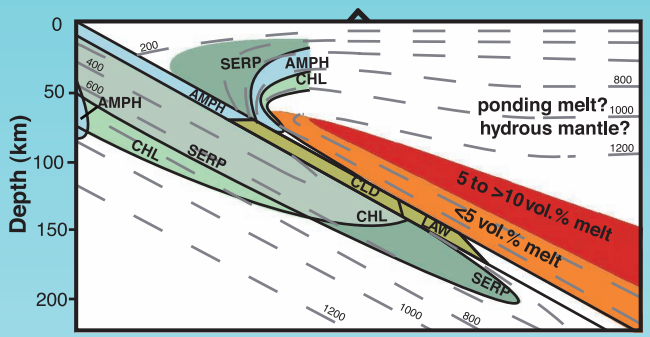
Geofluid processes in subduction zones and mantle dynamics



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PREFACE Open Access

Special issue 'Geofluid processes in subduction zones and mantle dynamics'

Tatsuhiko Kawamoto[1*], Junichi Nakajima[2], Bruno Reynard[3,4] and Hiroaki Toh[5]

Introduction

Almost all physico-chemical characteristics of earth-forming materials are influenced by the presence of H_2O. As N. L. Bowen stated in 1928, H_2O plays the role of Maxwell's demon - it does just what a petrologist may wish it to do [p. 282, *The evolution of the igneous rocks* (Bowen 1928)]. In the following decades, this has been proven to be the case not only in petrology but in every field of solid Earth science.

H_2O is the most abundant fluid in the Earth, except for liquid iron alloys present in the outer core. Volcanoes emit magmas and volatiles, which include COH ± S ± N species, halogens (F, Cl, I, Br), rare gases (He, Ne, Ar, Kr, Xe), fluid-mobile elements such as alkali elements (Li, Na, K, Rb, Cs), B, possibly Pb and U, and less likely Th. In the Earth's interior, these volatile components exist as geofluids, affecting various phenomena and acting as effective tracers for the respective phenomena. Seawater and atmosphere are geofluids that have accumulated on the surface of the Earth, and they hydrate and carbonate lithosphere through chemical reactions and depositions. Geofluids are released from subducting lithospheres, migrate upward, and play vital roles in various subduction-zone phenomena, such as magma genesis (Kawamoto et al. 2012; Kimura and Nakajima 2014), seismic activity (Mitsui and Hirahara 2009; Shiina et al. 2013), rock deformation (Katayama et al. 2004; Hilairet et al. 2007), and electromagnetic response (Yoshino and Katsura 2013). Geofluids also affect mantle dynamics (Korenaga 2013; Reynard 2013), including global material circulation and chemical differentiation (Tatsumi 2005), and the transportation of mainly C-O-H fluids into the Earth's interior (Deschamps et al. 2013). This special issue is a collection of 30 studies on such geofluid processes.

Fluids in the mantle wedge and crust originating from the subducting slab

Kusuda et al. (2014) report on the chemical composition of non-volcanic hot springs in the forearc region of the Southwest Japan arc. The forearc hot springs have been studied by means of aqueous chemistry for over 40 years (Kazahaya et al. 2014). By comparing the analyzed chemical composition of hot water with modeled composition of dehydrated materials from downgoing oceanic crustal materials, the authors conclude that the water originates in the subducting oceanic plate (Matsumoto et al. 2003; Kawamoto et al. 2013; Kazahaya et al. 2014). Within the same forearc region in the Kii peninsula, Japan, Kato et al. (2014) report on an intensive non-volcanic seismic swarm and estimate a fine-scale seismic velocity structure of the region. The results indicate the presence of geofluids such as partial melt or water beneath the swarm. Such fluids may potentially be released from the subducting crust of the Philippine Sea plate.

In the near-trench area in the Northeast Japan arc, Togo et al. (2014) report on the isotopes of hydrogen/deuterium, oxygen, iodine, and chlorine, as well as tritium concentrations of deep groundwater. They propose that these are derived from subducting sediments. Okamoto et al. (2014) describe CH_4-CO_2-H_2O fluid inclusions in quartz veins from the Shimanto belt, a near-trench Tertiary accretionary prism in the Southwest Japan arc. Such fluids may represent fluids degassed from crystallizing near-trench magmas generated during subduction of hot oceanic lithosphere.

Mori et al. (2014) evaluate bleaching processes of pelite in serpentine mélanges by studying the chemical composition of a bleached and unaltered sedimentary rock at the reaction boundary between the surrounding chlorite schist and metapelite. Regarding reactions that take place inside subducting slabs, Zheng and Hermann (2014) summarize major and trace element features of slab-derived fluids based on an analysis of high-pressure and ultra-high-pressure metamorphic rocks. Koga et al. (2014) demonstrate that vibrational spectroscopy can be

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used to determine halogen content in Ti-clinohumite, a high-pressure hydrated phase formed from fluids produced by dehydration reactions in ultramafic rocks.

Within the deeper subducting slab, geofluids released from the slab trigger the melting of the mantle wedge. Ikemoto and Iwamori (2014) model trace element transport in volcanic rocks and show that disequilibrium transport through channels likely plays an important role in element cycling in subduction zones. Such fluid transport without further chemical changes is also seen in the hot springs in the forearc region that originated from subducting slabs (Kusuda et al. 2014).

Hydrous melting of the mantle produces hydrous magmas, leaving behind residual mantle minerals that have distinct compositions compared to those formed through anhydrous melting. Matsukage and Kawasaki (2014) compare the chemical composition of cratonic garnet peridotites and experimental peridotite residue under various H_2O contents from 100- to 200-km depth. The results suggest heterogeneity of H_2O content in the upper mantle during the early history of the Earth and raise the question of how much H_2O is present in current arc magmas. Hamada et al. (2014) describe differentiation processes of low-K tholeiite basaltic magma having H_2O content of 3 wt.% in a shallow magma chamber at approximately 4-km depth and propose possible differentiation processes of the magma at deeper crustal levels. Based on Ca/Na partitioning between plagioclase and melt, Ushioda et al. (2014) estimate the H_2O content in erupted basaltic magmas in the Northeast Japan and Izu arcs. According to their results, the frontal volcanoes appear to have higher H_2O content than the rear-arc volcanoes.

Rose-Koga et al. (2014) report on the abundance of H_2O, CO_2, F, Cl, and S and Pb isotopes in basaltic melt inclusions in a frontal-arc volcano in the Northeast Japan arc and discuss temperatures of slab surface and phase relationships of the dehydrating slab materials. Kawamoto et al. (2014) conducted synchrotron X-ray fluorescence (XRF) experiments to determine the effects of salinity and pressure on partitioning of large-ion lithophile elements such as Pb, Rb, and Sr between silicate melts and aqueous fluids. They propose a process of separation of Cl-bearing supercritical fluids from the slab and their subsequent incorporation into hydrous melts and saline fluids to explain the geochemical features of island arc basalts (Kawamoto et al. 2012).

The 2011 Tohoku-oki earthquake: friction, strength, and post-seismic deformation

Den Hartog et al. (2014) evaluate an experimental physical model of phyllosilicate-rich fault gouges in the megathrust. The results imply that water-assisted thermally activated quartz deformation is one of the major controlling factors of seismogenic properties in such megathrusts. Shimizu (2014) proposes a rheological profile across the source area of the 2011 Tohoku earthquake and argues that the large tsunamigenic slip during the Tohoku earthquake can be explained by a large gradient in fault strength on the up-dip side of the hypocenter. Based on a long-term multiscale earthquake cycle simulation on a three-dimensional (3D) plate boundary model, Ariyoshi et al. (2014) suggest that activation and quiescence of shallow, very low-frequency earthquakes following the 2011 Tohoku earthquake are closely associated with plate coupling perturbations resulting from the stress shadow effect of the Tohoku earthquake. By modeling the effect of poroelastic rebound on surface deformation following the 2011 Tohoku earthquake, Hu et al. (2014) show how the effect is restricted to the vicinity of the rupture area. They also show that the viscosity in the lower crust beneath the volcanic front is several orders of magnitude lower than the surrounding areas.

Geofluids detected with magnetotelluric and seismic observations

Kanda and Ogawa (2014) estimate a 3D distribution of fluids and melts under the Northeast Japan arc using geomagnetic transfer functions. Their results suggest the presence of a deep crustal conductor that may correspond either to partial melts and/or high-salinity fluids. Ichihara et al. (2014) present a 3D electrical resistivity model beneath the focal zone of the 2008 Iwate-Miyagi Nairiku earthquake that shows a shallow conductive zone beneath the Kitakami Lowland and several conductive patches beneath active volcanic areas. Yoshida et al. (2014) determined pore fluid pressure distribution in the focal region of the above earthquake and suggest that geofluids supplied from the mantle wedge have contributed to the generation of high pore pressures and to the lowering of frictional strengths of seismic faults in this region. Ogawa et al. (2014) conducted a densely distributed magnetotelluric survey around the Naruko Volcano in Northeast Japan and produced a shallow resistivity model of the Quaternary volcano. They found a southward-dipping, sub-vertical conductor that may imply the presence of geofluids just below the volcano. Okada et al. (2014) found seismic low-velocity zones beneath the same volcano and in the aftershock region of the 2008 Iwate-Miyagi Nairiku earthquake, both of which can be attributed to the presence of geofluids. The former, having a diameter of 10 to 20 km, resides in the lower crust. Kosuga (2014) observed the migration of seismicity for a seismic cluster near the Moriyoshi volcano in the Northeast Japan arc and identifies distinct seismic scatters above low-frequency earthquakes in the lower crust. He argues that the observed migration is associated with geofluids supplied from the uppermost mantle.

Shiina et al. (2014) show that hydrated mineralogy alone cannot sufficiently explain the low velocities observed in the subducting crust beneath Hokkaido, suggesting that fluids may coexist with hydrated rocks down to 80-km depth. Nakajima (2014) provides evidence of the presence of high-attenuation areas in a serpentinized mantle wedge using seismological tomography. These areas are associated with low seismic activity that may be explained by deformation of weak serpentine. Based on numerical simulation, Kirby et al. (2014) suggest that the serpentinized mantle was formed through plate subduction during the Mesozoic and Paleogene that has been sufficiently heated over time, releasing water into the crust over much of the history of the San Andreas Fault system. Kuwatani et al. (2014) apply the Markov random field model to the observed seismic velocity models in the mantle wedge of the Northeast Japan arc and estimate the porosity and pore shapes of rocks. There is a significant difference in the calculated porosity and aspect ratio of geofluids between the forearc side and the volcanic front.

A frontier letter by Pommier (2014) describes how electromagnetic and seismic methods can complement each other in providing information about the storage of fluids in subduction systems. She implies a possible correlation between electrical conductivity and seismic wave attenuation anomalies in the mantle wedge. Jung et al. (2014) studied seismic anisotropy of two fluid-induced peridotite samples collected from wall rock and mylonite fabrics and find that seismic anisotropy becomes significantly weaker as the percentage of mylonite increases. Ishikawa and Matsumoto (2014) measure Vp for quartz aggregate at PT conditions of the middle crust and quantify the effect of pore fluids on Vp. The results show that even a small amount of fluids (0.4 to 1.0 wt.%) reduces Vp by 3% to 4%. Shimojuku et al. (2014) report on the experimental results of conductivity measurement of saline-fluid-bearing rocks. Their set of data will be highly instrumental in distinguishing between magmas and saline fluids and also in determining their possible volumes and geometry based on comparison with the observed conductivity data in subduction zones.

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FRONTIER LETTER Open Access

Geophysical assessment of migration and storage conditions of fluids in subduction zones

Anne Pommier

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Abstract

By enhancing mass transfer and energy release, the cycle of volatiles and melt is a major component of subduction. Investigating this fluid cycle is therefore critical to understand the past and current activity of subduction zones. Fluids can significantly affect rock electrical conductivity and elastic parameters that are measured using electromagnetic and seismic methods, respectively. This letter emphasizes how these geophysical methods complement each other to provide information about the storage of fluids in subduction systems. By compiling electromagnetic and seismic results from various subduction zones, a possible correlation between electrical conductivity and seismic wave attenuation anomalies in the mantle wedge is observed, consistent with fluid accumulation. A possible relationship between geophysical properties and the slab age is also suggested, whereas no significant trend is observed between electrical conductivity or seismic wave attenuation and estimates of water flux in the mantle wedge. These field-based relationships require further constrains, emphasizing the need for new measurements in the laboratory.

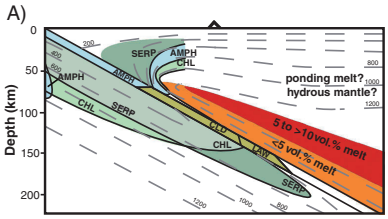

Figure 1

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FRONTIER LETTER Open Access

The roles of quartz and water in controlling unstable slip in phyllosilicate-rich megathrust fault gouges

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Abstract

A recent microphysical model for the steady-state frictional behaviour of wet illite/quartz gouges in subduction megathrust settings predicts that velocity-weakening in the seismogenic zone results from a competition between shear-induced dilatation and compaction involving water-assisted, thermally activated deformation (pressure solution) of quartz clasts. While this model is supported by experimental data, proof that quartz and water are a requirement for velocity-weakening is lacking. Here, we report on shearing experiments on water-saturated (near-)pure illite and dry 65/35 illite/quartz gouges, deformed at *P-T* conditions near those *in situ* at seismogenic depths along subduction megathrusts. We used low sliding velocities relevant to earthquake nucleation and slow slip events (1 to 100 μm/s). Previous experiments on wet illite/quartz gouges under the same conditions documented three regimes of slip stability, with velocity-strengthening at 150°C to 250°C and 400°C to 500°C, and velocity-weakening at 250°C to 400°C. In the present study, wet illite gouge exhibited similar three-regime behaviour, but with velocity-neutral rather than velocity-weakening behaviour at the intermediate temperatures. Dry illite/quartz gouge exhibited near velocity-neutral behaviour at all temperatures investigated. These results confirm that water-assisted, thermally activated quartz deformation is a key process in the velocity-weakening behaviour at intermediate temperatures in wet illite/quartz gouges and support the existing microphysical model. The implication of this model is that seismogenesis occurs under conditions where creep by thermally activated quartz deformation is fast enough to moderate 'brittle' dilatation to remain at subcritical porosity values but too slow to allow ductile shear of clasts.

Keywords: Quartz; Water; Pressure solution; Velocity-weakening; Subduction zone seismicity; Illite friction; Brittle-ductile transition

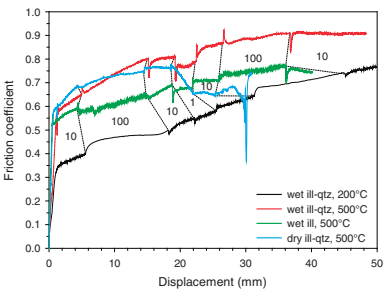

Figure 1

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FRONTIER LETTER Open Access

Geochemistry of continental subduction-zone fluids

Yong-Fei Zheng* and Joerg Hermann

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Abstract

The composition of continental subduction-zone fluids varies dramatically from dilute aqueous solutions at subsolidus conditions to hydrous silicate melts at supersolidus conditions, with variable concentrations of fluid-mobile incompatible trace elements. At ultrahigh-pressure (UHP) metamorphic conditions, supercritical fluids may occur with variable compositions. The water component of these fluids primarily derives from structural hydroxyl and molecular water in hydrous and nominally anhydrous minerals at UHP conditions. While the breakdown of hydrous minerals is the predominant water source for fluid activity in the subduction factory, water released from nominally anhydrous minerals provides an additional water source. These different sources of water may accumulate to induce partial melting of UHP metamorphic rocks on and above their wet solidii. Silica is the dominant solute in the deep fluids, followed by aluminum and alkalis. Trace element abundances are low in metamorphic fluids at subsolidus conditions, but become significantly elevated in anatectic melts at supersolidus conditions. The compositions of dissolved and residual minerals are a function of pressure-temperature and whole-rock composition, which exert a strong control on the trace element signature of liberated fluids. The trace element patterns of migmatic leucosomes in UHP rocks and multiphase solid inclusions in UHP minerals exhibit strong enrichment of large ion lithophile elements (LILE) and moderate enrichment of light rare earth elements (LREE) but depletion of high field strength elements (HFSE) and heavy rare earth elements (HREE), demonstrating their crystallization from anatectic melts of crustal protoliths. Interaction of the anatectic melts with the mantle wedge peridotite leads to modal metasomatism with the generation of new mineral phases as well as cryptic metasomatism that is only manifested by the enrichment of fluid-mobile incompatible trace elements in orogenic peridotites. Partial melting of the metasomatic mantle domains gives rise to a variety of mafic igneous rocks in collisional orogens and their adjacent active continental margins. The study of such metasomatic processes and products is of great importance to understanding of the mass transfer at the slab-mantle interface in subduction channels. Therefore, the property and behavior of subduction-zone fluids are a key for understanding of the crust-mantle interaction at convergent plate margins.

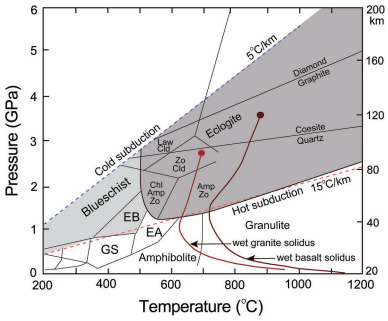

Figure 1

Keywords: Water; Subduction factory; Metamorphic fluids; Anatectic melts; Major elements; Trace elements

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Seismic attenuation beneath Kanto, Japan: evidence for high attenuation in the serpentinized subducting mantle

Junichi Nakajima

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Abstract

The three-dimensional (3-D) *P*-wave attenuation (Q_p^{-1}) structure beneath Kanto, Japan, is estimated by using a large number of waveform data. Corner frequencies of earthquakes are initially calculated from spectral ratios of S-coda waves, followed by an inversion to simultaneously determine attenuation terms and frequency-dependent site amplification factors. The attenuation terms are then inverted for estimation of the 3-D Q_p^{-1} structure. The obtained results show that seismic attenuation is highly heterogeneous, and pronounced high-attenuation areas are located in the continental lower crust and mantle of the Philippine Sea slab. Seismic activity is very low in the high-attenuation lower crust, which is most likely attributable to ductile deformation facilitated by fluids supplied from the underlying Philippine Sea slab. The high-attenuation area in the Philippine Sea slab represents the serpentinized mantle, and two M ~ 7 earthquakes are documented to have occurred along the western boundary of this area. Interplate earthquakes on the Pacific slab are absent in areas overlain by the serpentinized Philippine Sea slab, which is likely due to the low viscosity of serpentine promoting continuous ductile deformation rather than brittle failures along the plate boundary.

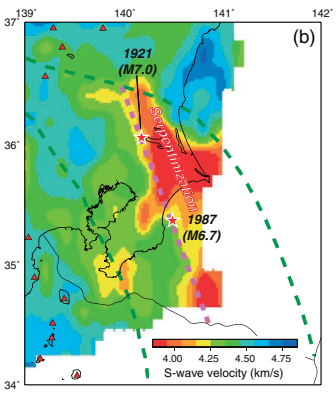

Figure 1

Keywords: Serpentine; Intermediate-depth earthquakes; Interplate earthquakes; Fluids; Ductile deformation; Dehydration

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FULL PAPER Open Access

Polybaric crystallization differentiation of H_2O-saturated island arc low-K tholeiite magmas: a case study of the Izu-Oshima volcano in the Izu arc

Morihisa Hamada*, Yuko Okayama, Takayuki Kaneko, Atsushi Yasuda and Toshitsugu Fujii

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Abstract

Island arc low-K tholeiites are basaltic magmas erupting from frontal arc volcanoes of juvenile arcs associated with the subduction of old and cold plates. We investigated the origins of geochemical variation in volcanic rocks having multiple phase saturated liquid compositions from the Izu-Oshima volcano in the northern Izu arc. The geochemical variations in the liquids fall between two endmember trends, namely higher- and lower-Al/Si trends. Polybaric differentiation of H_2O-saturated melts between a 4-km-deep magma chamber and degassed melts near the surface should be responsible for the observed variation in the liquids.

Keywords: Island arc low-K tholeiite; Volcanic front; Ca-rich plagioclase; Experimental petrology; Izu-Oshima volcano

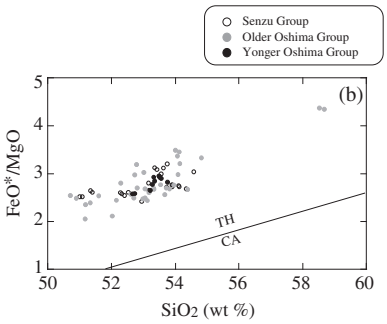

Figure 1

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FULL PAPER Open Access

Characterization of olivine fabrics and mylonite in the presence of fluid and implications for seismic anisotropy and shear localization

Sejin Jung, Haemyeong Jung* and Håkon Austrheim

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Received: 15 November 2013, Accepted: 1 May 2014, Published: 2 June 2014

Abstract

The Lindås Nappe, Bergen Arc, is located in western Norway and displays two high-grade metamorphic structures. A Precambrian granulite facies foliation is transected by Caledonian fluid-induced eclogite-facies shear zones and pseudotachylytes. To understand how a superimposed tectonic event may influence olivine fabric and change seismic anisotropy, two lenses of spinel lherzolite were studied by scanning electron microscope (SEM) and electron back-scattered diffraction (EBSD) techniques. The granulite foliation of the surrounding anorthosite complex is displayed in ultramafic lenses as a modal variation in olivine, pyroxenes, and spinel, and the Caledonian eclogite-facies structure in the surrounding anorthosite gabbro is represented by thin (<1 cm) garnet-bearing ultramylonite zones. The olivine fabrics in the spinel bearing assemblage were E-type and B-type and a combination of A- and B-type lattice preferred orientations (LPOs). There was a change in olivine fabric from a combination of A- and B-type LPOs in the spinel bearing assemblage to B- and E-type LPOs in the garnet lherzolite mylonite zones. Fourier transform infrared (FTIR) spectroscopy analyses reveal that the water content of olivine in mylonite is much higher (approximately 600 ppm H/Si) than that in spinel lherzolite (approximately 350 ppm H/Si), indicating that water caused the difference in olivine fabric. Fabric strength of olivine gets weaker as the grain size reduced, and as a result, calculated seismic properties for the two deformation stages reveal that P- and S-velocity anisotropies are significantly weaker in the mylonite. Microtextures and LPO data indicate that the deformation mechanism changed from dominant dislocation creep in spinel lherzolite to dislocation creep accompanied by grain-boundary sliding in mylonite. Shear localization in the mylonite appears to be originated from the grain size reduction through (1) enhanced dynamic recrystallization of olivine in the presence of water and (2) Zener pinning of clinopyroxene or (3) by ultracomminution during the pseudotachylyte stage.

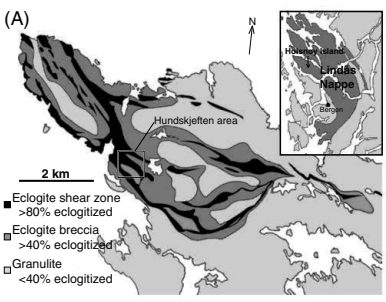

Figure 1

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FULL PAPER Open Access

A trial derivation of seismic plate coupling by focusing on the activity of shallow slow earthquakes

Keisuke Ariyoshi*, Toru Matsuzawa, Ryota Hino, Akira Hasegawa, Takane Hori, Ryoko Nakata and Yoshiyuki Kaneda

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Abstract

To understand the effect of plate coupling on very low-frequency event (VLFE) activity resulting from megathrust earthquakes, we performed long-term multiscale earthquake cycle simulations (including a megathrust earthquake and slow earthquakes) on a 3-D subduction plate boundary model, based on a rate- and state-dependent friction law. Our simulation suggests that quiescence of shallow VLFEs off Miyagi may be explained by the location in the shallow central part of the 2011 Tohoku earthquake because of the locally strong coupling, while observed activation of VLFEs off Iwate (northern part of Tohoku district), Fukushima (southern part of Tohoku district), and Ibaraki (northern part of Kanto district) is explained by the location on the outer rim. The area and duration of the quiescence off Miyagi may be a new clue to evaluate the potential for plate coupling strong enough to cause the next megathrust earthquake.

Keywords: Subduction plate boundary; Megathrust earthquake; Rate- and state-dependent friction law; Superhydrostatic pressure

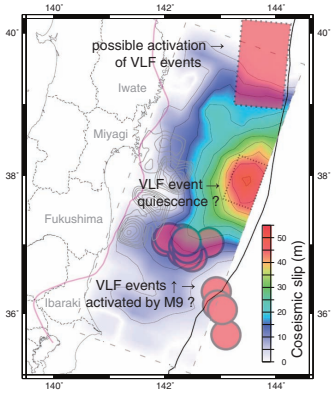

Figure 1

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FULL PAPER Open Access

Large-ion lithophile elements delivered by saline fluids to the sub-arc mantle

Tatsuhiko Kawamoto*, Kenji Mibe, Hélène Bureau, Solenn Reguer, Cristian Mocuta, Stefan Kubsky, Dominique Thiaudière, Shigeaki Ono and Tetsu Kogiso

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Abstract

Geochemical signatures of arc basalts can be explained by addition of aqueous fluids, melts, and/or supercritical fluids from the subducting slab to the sub-arc mantle. Partitioning of large-ion lithophile elements between aqueous fluids and melts is crucial as these two liquid phases are present in the sub-arc pressure-temperature conditions. Using a micro-focused synchrotron X-ray beam, *in situ* X-ray fluorescence (XRF) spectra were obtained from aqueous fluids and haplogranite or jadeite melts at 0.3 to 1.3 GPa and 730°C to 830°C under varied concentrations of (Na, K)Cl (0 to 25 wt.%). Partition coefficients between the aqueous fluids and melts were calculated for Pb, Rb, and Sr ($D^{\text{fluid/melt}}_{\text{Pb, Rb, Sr}}$). There was a positive correlation between $D^{\text{fluid/melt}}_{\text{Pb, Rb, Sr}}$ values and pressure, as well as $D^{\text{fluid/melt}}_{\text{Pb, Rb, Sr}}$ values and salinity. As compared to the saline fluids with 25 wt.% (Na, K)Cl, the Cl-free aqueous fluids can only dissolve one tenth (Pb, Rb) to one fifth (Sr) of the amount of large-ion lithophile elements when they coexist with the melts. In the systems with 13 to 25 wt.% (Na, K)Cl, $D^{\text{fluid/melt}}_{\text{Pb, Rb}}$ values were greater than unity, which is indicative of the capacity of such highly saline fluids to effectively transfer Pb and Rb. Enrichment of large-ion lithophile elements such as Pb and Rb in arc basalts relative to mid-oceanic ridge basalts (MORB) has been attributed to mantle source fertilization by aqueous fluids from dehydrating oceanic plates. Such aqueous fluids are likely to contain Cl, although the amount remains to be quantified.

Keywords: Subduction zone magmatism; Mantle wedge; Water; H_2O; Brine; Trace element; Chlorine

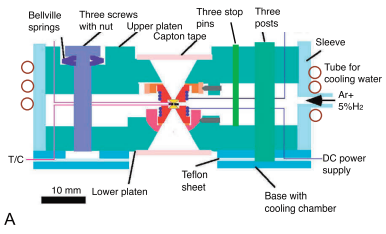

Figure 1

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FULL PAPER Open Access

A large mantle water source for the northern San Andreas fault system: a ghost of subduction past

Stephen H Kirby*, Kelin Wang and Thomas M Brocher

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Received: 14 December 2013, Accepted: 20 May 2014, Published: 7 July 2014

Abstract

Recent research indicates that the shallow mantle of the Cascadia subduction margin under near-coastal Pacific Northwest, USA is cold and partially serpentinized, storing large quantities of water in this wedge-shaped region. Such a wedge probably formed to the south in California during an earlier period of subduction. We show by numerical modeling that after subduction ceased with the creation of the San Andreas Fault System (SAFS), the mantle wedge warmed, slowly releasing its water over a period of more than 25 Ma by serpentine dehydration into the crust above. This deep, long-term water source could facilitate fault slip in San Andreas System at low shear stresses by raising pore pressures in a broad region above the wedge. Moreover, the location and breadth of the water release from this model gives insights into the position and breadth of the SAFS. Such a mantle source of water also likely plays a role in the occurrence of non-volcanic tremor (NVT) that has been reported along the SAFS in central California. This process of water release from mantle depths could also mobilize mantle serpentinite from the wedge above the dehydration front, permitting upward emplacement of serpentinite bodies by faulting or by diapiric ascent. Specimens of serpentinite collected from tectonically emplaced serpentinite blocks along the SAFS show mineralogical and structural evidence of high fluid pressures during ascent from depth. Serpentinite dehydration may also lead to tectonic mobility along other plate boundaries that succeed subduction, such as other continental transforms, collision zones, or along present-day subduction zones where spreading centers are subducting.

Keywords: Serpentinite; Antigorite; Lizardite; Chrysotile; Ophiolite; Mantle water; San Andreas Fault System; Subduction; California Coast Ranges; Non-volcanic tremor

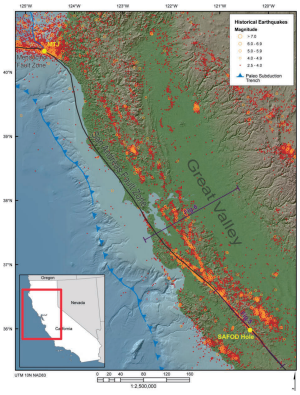

Figure 1

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FULL PAPER Open Access

Rheological profile across the NE Japan interplate megathrust in the source region of the 2011 M_w9.0 Tohoku-oki earthquake

Ichiko Shimizu

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Abstract

A strength profile across the NE Japan interplate megathrust was constructed in the source region of the 2011 Tohoku-oki earthquake (M_w9.0) using friction, fracturing, and ductile flow data of the oceanic crustal materials obtained from laboratory experiments. The depth-dependent changes in pressure, temperature, and pore fluid pressure were incorporated into a model. The large tsunamigenic slips during the M9 event can be explained by a large gradient in fault strength on the up-dip side of the M9 hypocenter, which was located 17 to 18 km beneath sea level. A large stress drop (approximately 80 MPa) induced by the collapse of a subducted seamount possibly triggered the M9 earthquake. In the deep (>35 km) part of the thrust fault, where M7-class Miyagi-oki earthquakes have repeatedly occurred, plastic deformation occurs in siliceous rocks but not in gabbroic rocks. Thus, the asperity associated with the M7-class earthquakes was most likely a gabbroic body, such as a broken seamount, surrounded by siliceous sedimentary rocks. The conditionally stable nature of the surrounding region can be explained by the frictional behavior of wet quartz in the brittle-ductile transition zone. In contrast to the deep M7-class asperity, the M9 asperity (i.e., a region that was strongly coupled before the M9 Tohoku-oki earthquake) extended to a large area of the plate interface because shear strength is relatively insensitive to lithological variation at intermediate depths. However, the along-arc extension of the M9 asperity was constrained by fluid-rich regions on the plate interface.

Keywords: Fault strength; Rheology; Friction; Pore pressure; Seamount; Interplate earthquake

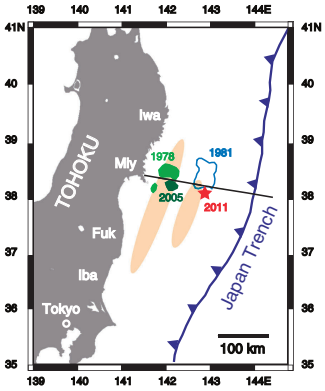

Figure 1

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FULL PAPER Open Access

Seismic activity near the Moriyoshi-zan volcano in Akita Prefecture, northeastern Japan: implications for geofluid migration and a midcrustal geofluid reservoir

Masahiro Kosuga

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Received: 22 November 2013, Accepted: 15 July 2014, Published: 25 July 2014

Abstract

The 2011 off the Pacific coast of Tohoku (Tohoku-oki) earthquake caused increased seismicity in many inland areas in Japan. A seismic cluster north of the Moriyoshi-zan volcano in Akita prefecture, Tohoku District, is of interest in light of the contribution of geofluids to seismic activity. We observed a seismic cluster characterized by the migration of seismicity and reflected/scattered phases. We relocated hypocenters of the cluster using data from temporal observations and the hypoDD location technique, which significantly increased the hypocentral accuracy. We interpreted a complex spatiotemporal variation of seismicity in the cluster as the migration of pore fluid pressure from multiple pressure sources. The hydraulic diffusivity of the cluster was in the range of 0.01 to 0.7 m^2/s and increased with time, implying that the migration of hypocenters accelerated after a pathway for fluids was formed by fracturing of the wall rock during the initial stage of seismic activity. A prominent feature of the seismograms is a reflected/scattered phase observed at stations around the volcano. We regard the phase as *S*-to-*S* scattered waves and estimated the location of the scatterers using a back-projection method. The scatterers are inferred to be located about 5 km northwest of the Moriyoshi-zan volcano, at an approximate depth of 13 km. The Moriyoshi-zan area is one of the source areas of deep low-frequency earthquakes that have been interpreted as events generated by the migration of geofluids. The depth of the scatterers is close to the upper limit of the depth at which low-frequency earthquakes occur. Thus, we interpret the observed scatterers to be a reservoir of geofluid that came from the uppermost mantle accompanying contemporaneous low-frequency earthquakes.

Keywords: The 2011 off the Pacific coast of Tohoku earthquake; Triggered seismicity; Hypocenter migration; Scattering, Geofluid

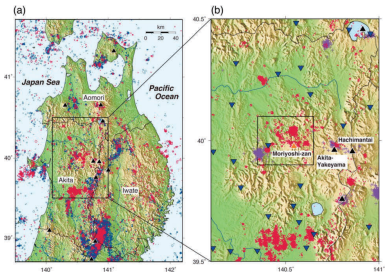

Figure 1

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FULL PAPER Open Access

Volatile (F and Cl) concentrations in Iwate olivine-hosted melt inclusions indicating low-temperature subduction

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Abstract

Investigation of olivine-hosted melt inclusions provides information about the abundance of volatile elements that are often lost during subaerial eruptions of lavas. We have measured the abundances of H_2O, CO_2, F, Cl, and S as well as Pb isotopes in 29 melt inclusions in the scoria of the 1686 eruption of the Iwate volcano, a frontal-arc volcano in the northeast Japan arc. Pb Isotope compositions identify that Iwate magma is derived from a mixture of depleted mantle, subducted basalt, and sediment. Systematics of F in comparison to MORB and other arc magma indicates that (1) the slab surface temperature must be among the lowest on Earth and (2) hydrous minerals, such as amphibole, humites, and/or mica, must be present as residual phases during the dehydration of the slab.

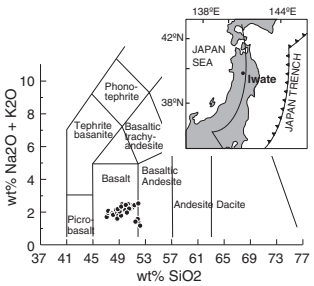

Figure 1

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FULL PAPER Open Access

Contributions of poroelastic rebound and a weak volcanic arc to the postseismic deformation of the 2011 Tohoku earthquake

Yan Hu*, Roland Bürgmann, Jeffrey T Freymueller, Paramesh Banerjee and Kelin Wang

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Abstract

A better understanding of fluid-related processes such as poroelastic rebound of the upper crust and weakening of the lower crust beneath the volcanic arc helps better understand and correctly interpret the heterogeneity of postseismic deformation following great subduction zone earthquakes. The postseismic deformation following the 2011 M_w9.0 Tohoku earthquake, recorded with unprecedented high resolution in space and time, provides a unique opportunity to study these 'second-order' subduction zone processes. We use a three-dimensional viscoelastic finite element model to study the effects of fluid-related processes on the postseismic deformation. A poroelastic rebound (PE) model alone with fluid flow in response to coseismic pressure changes down to 6 and 16 km in the continental and oceanic crusts, respectively, predicts 0 to 6 cm uplift on land, up to approximately 20 cm uplift above the peak rupture area, and up to approximately 15 cm subsidence elsewhere offshore. PE produces up to approximately 30 cm of horizontal motions in the rupture area but less than 2 cm horizontal displacements on land. Effects of a weak zone beneath the arc depend on its plan-view width and vertical viscosity profile. Our preferred model of the weak sub-arc zone indicates that in the first 2 years after the 2011 earthquake, the weak zone contributes to the surface deformation on land on the order of up to 20 cm in both horizontal and vertical directions. The weak-zone model helps eliminate the remaining systematic misfit of the viscoelastic model of upper mantle relaxation and afterslip of the megathrust.

Keywords: Poroelastic rebound; Weakened lower crust beneath the arc; Giant earthquake; Subduction zone; Viscoelastic postseismic deformation; Finite element model; Numerical simulation

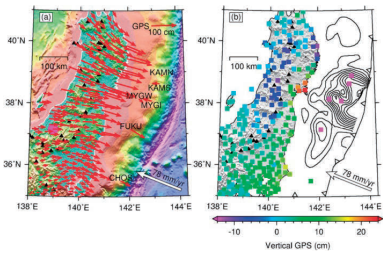

Figure 1

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FULL PAPER Open Access

Seismic velocity structure in and around the Naruko volcano, NE Japan, and its implications for volcanic and seismic activities

Tomomi Okada*, Toru Matsuzawa, Junichi Nakajima, Naoki Uchida, Mare Yamamoto, Shuichiro Hori, Toshio Kono, Takashi Nakayama, Satoshi Hirahara and Akira Hasegawa

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Abstract

Geofluids is important for understanding volcanic and earthquake generation processes. In this study, we obtained a detailed seismic velocity structure in and around the Naruko volcano, northeastern Japan, using data from a dense seismic observation network. We found a distinct seismic low-velocity zone (LVZ) beneath the Naruko volcano, with a diameter of nearly 10 to 20 km in the lower crust. This LVZ could correspond to a magma chamber. We also found a seismic low-velocity zone beneath the aftershock region of the 2008 Iwate-Miyagi Nairiku earthquake. This LVZ could correspond to an area with overpressurized fluid, which promoted the occurrence of the 2008 Iwate-Miyagi Nairiku earthquake.

Keywords: Geofluids; Seismic velocity structure; Seismicity; Naruko volcano; 2008 Iwate-Miyagi Nairiku earthquake

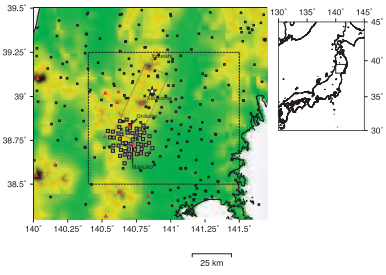

Figure 1

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FULL PAPER Open Access

Arima hot spring waters as a deep-seated brine from subducting slab

Chiho Kusuda, Hikaru Iwamori*, Hitomi Nakamura, Kohei Kazahaya and Noritoshi Morikawa

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Abstract

Non-volcanic hot springs are generally believed to originate through circulation of meteoric or buried sea water heated at depth. In this study, we report the geochemical characteristics of the Arima and Takarazuka hot spring waters, known as Arima-type deep brine, in a forearc region of southwestern Japan. We examine 14 water samples to determine the levels of 12 solute elements or components and the isotopic ratios of H, He, C, O, and Sr, and we perform correlation analysis of the data to deduce the source materials and origin of the deep brine. Moreover, we perform numerical modeling of oxygen and hydrogen isotopic fractionation along subducting slabs to examine the composition of slab-derived fluid as a possible candidate of the deep brine. The results suggest that the high salinity and solute concentrations with characteristic oxygen, hydrogen, carbon, and strontium isotope compositions, as well as high $^{3}He/^{4}He$ ratios, can be explained by a dehydrated component of the subducted Philippine Sea slab. Hence, this study may provide an invaluable understanding of geofluid processes over a significant depth range.

Keywords: Subduction; Geofluid; Slab-fluid; Hot spring; Arima

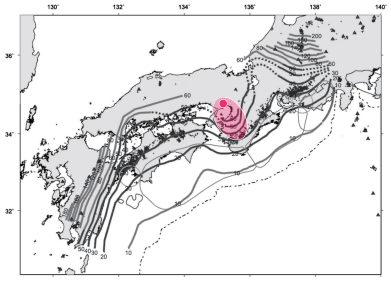

Figure 1

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FULL PAPER Open Access

Groundwater, possibly originated from subducted sediments, in Joban and Hamadori areas, southern Tohoku, Japan

Yoko S Togo*, Kohei Kazahaya, Yuki Tosaki, Noritoshi Morikawa, Hiroyuki Matsuzaki, Masaaki Takahashi and Tsutomu Sato

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Abstract

We studied the origin of deep groundwater in the Joban and Hamadori areas in southern Tohoku, Japan, based on δD, $\delta^{18}O$, $^{129}I/I$, $^{36}Cl/Cl$, and ^{3}H concentrations. Deep groundwater was collected from the basement rocks (Cretaceous granite) and from the margin of the Joban sedimentary basin (latest Cretaceous to Quaternary sedimentary rocks deposited on the basement rocks). We sampled groundwater pumped from depths ranging from 350 to 1,600 m in these areas. A hypothetical end-member of deep groundwater was estimated from the relationship between $\delta^{18}O$ and Cl concentrations, and our data reveal a much higher iodine concentration and lower Br and Cl concentrations than found in seawater. The iodine ages inferred from $^{129}I/I$ are quite uniform and are about 40 Ma and $^{36}Cl/Cl$ almost reached the secular equilibrium. The relationship between iodine and Cl can be explained by mixing a hypothetical end-member with meteoric water or seawater. Moreover, the I/Cl ratio increases linearly with increasing water temperature. The water temperature was high in Joban, with a maximum of 78°C at a depth of 1,100 m. The geothermal gradient in the Joban basin is 18°C km^{-1}, and the temperature even at a depth of 3 km in the basin was not high enough to supply thermal water to the sampling sites. Thus, sedimentary rocks in the Joban basin are unlikely to be the source of iodine in the deep groundwater. Several active faults such as the Futaba Fault are developed in and around the studied areas. The Iwaki earthquake occurred 1 month after the 2011 Tohoku-oki earthquake, and normal-fault type surface ruptures formed and discharged hot groundwater in Joban. The deep groundwater we studied probably came up through the basement rocks from greater depths. There are no sedimentary rocks younger than Tertiary age beneath the pre-Cretaceous basement rocks, and the subducted sediments in the Japan Trench are a possible source of iodine in the groundwater. The Joban and Hamadori areas may be an ideal window to look into the water circulation in the forearc of the Tohoku subduction zone.

Keywords: Iodine age; $^{36}Cl/Cl$; Source of iodine; Subducted sediments; Halogen; Joban; Hamadori; Tohoku

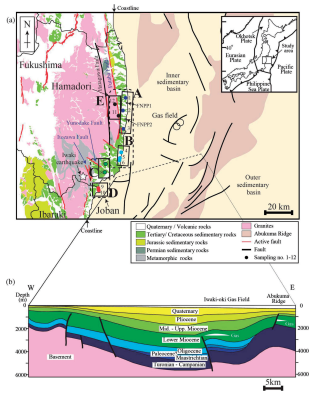

Figure 1

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LETTER Open Access

Electrical conductivity of brine-bearing quartzite at 1 GPa: implications for fluid content and salinity of the crust

Akira Shimojuku*, Takashi Yoshino and Daisuke Yamazaki

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Abstract

The electrical conductivity of brine-bearing quartzite with fluid fractions of 0.19 to 0.30 and salinity of 3 to 17 wt.% was measured at 800 to 1,100 K and 1 GPa. The conductivity of the brine-bearing quartzite increases with salinity and fluid fraction, but is almost independent of temperature. Our results suggest that regions of high conductivity (10^{-3} to 10^{-2} S/m) in the crust could be explained by the presence of quartzite with fluids of salinity similar to that of seawater. To account for those regions with the highest conductivity of 10^{-1} S/m, quartzite with fluid of high salinity (>10 wt.%) is required.

Keywords: Electrical conductivity; Fluid; Brine; High-conductivity anomaly

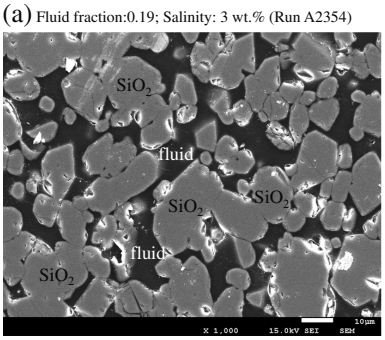

Figure 1

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LETTER Open Access

Markov random field modeling for mapping geofluid distributions from seismic velocity structures

Tatsu Kuwatani*, Kenji Nagata, Masato Okada and Mitsuhiro Toriumi

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Abstract

We applied the Markov random field model, which is a kind of a Bayesian probabilistic method, to the spatial inversion of the porosity and pore shape in rocks from an observed seismic structure. Gaussian Markov chains were used to incorporate the spatial continuity of the porosity and the aspect ratio of the pore shape. Synthetic inversion tests were able to show the effectiveness and validity of the proposed model by appropriately reducing the statistical noise from the observations. The proposed model was also applied to natural data sets of the seismic velocity structures in the mantle wedge beneath northeastern Japan, under the assumptions that the fluid was melted and the temperature and petrologic structures were uniformly distributed. The result shows a significant difference between the volcanic front and the forearc regions, at a depth of 40 km. Although the parameters and material properties will need to be determined more precisely, the Markov random field model presented here can serve as a basic inversion framework for mapping geofluids.

Keywords: Bayesian estimation; Markov random field; Geofluid; Mantle wedge; Data-driven science

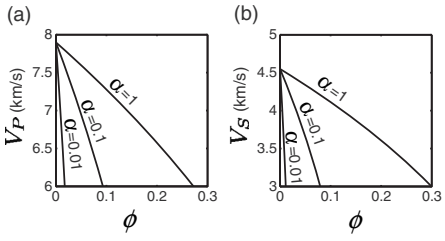

Figure 1

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LETTER Open Access

Numerical modeling of trace element transportation in subduction zones: implications for geofluid processes

Akihiko Ikemoto* and Hikaru Iwamori

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Received: 29 November 2013, Accepted: 24 March 2014, Published: 30 April 2014

Abstract

This study presents the first numerical model for trace element transportation associated with dehydration and fluid migration from the subducting slab and aims to incorporate both fluid dynamical processes (e.g., flow mode and mass fluxes) in subduction zones and associated geochemical evidence (e.g., chemical compositions of arc lavas). The model includes temperature and flow structures associated with slab subduction and mantle-fluid two-phase flow, as well as phase relations of hydrous phases (e.g., dehydration-hydration reactions and melting) and trace element partitioning among the phases (solid, aqueous fluid, and melt). The model calculations show that if instantaneous chemical equilibrium is achieved associated with porous flow of slab-derived fluid, the elements expelled with the ascending fluid (e.g., Pb) are absorbed into the down-going hydrated mantle layer developed above the slab. As a result, these elements are considerably depleted in the resultant magma generated by fluid-flux melting in the core part of the mantle wedge, and it therefore fails to reproduce the geochemical characteristics of arc lavas. In contrast, if disequilibrium element transport (e.g., associated with channel flow) is assumed when the hydrated mantle layer liberates the fluid, then the key elements are delivered to the melting region to reproduce certain arc lava signatures. These results suggest that disequilibrium fluid transport in the wedge mantle, such as through channels, plays an important role in element cycling in subduction zones.

Keywords: Subduction; Slab-fluid; Arc magma; Numerical modeling; Trace element

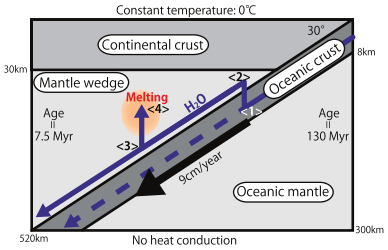

Figure 1

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LETTER Open Access

Hydrous origin of the continental cratonic mantle

Kyoko N Matsukage* and Toshisuke Kawasaki

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Received: 7 October 2013, Accepted: 11 April 2014, Published: 1 May 2014

Abstract

We performed melting experiments of hydrous pyrolite at pressures from 3 to 8 GPa and temperatures from 1,100°C to 1,800°C to identify the origin of chemical variation in cratonic garnet peridotites with high contents of magnesian orthopyroxene. In hydrous conditions, the stability field of residual orthopyroxene expands relative to olivine above solidus, and the harzburgitic residue contains large amounts of Mg-rich (Mg# > 0.92) orthopyroxene at 4.5 to 6 GPa. The residual chemistry obtained from our experiments indicates that the chemical variation of the cratonic garnet peridotites possibly reflects formation by melt depletion under various water contents from almost anhydrous to a maximum of approximately 1% to 2% in the upper mantle at depths of about 100 to 200 km.

Keywords: Cratonic mantle; Peridotite; Hydrous pyrolite; Partial melting; Residue; High-pressure experiment

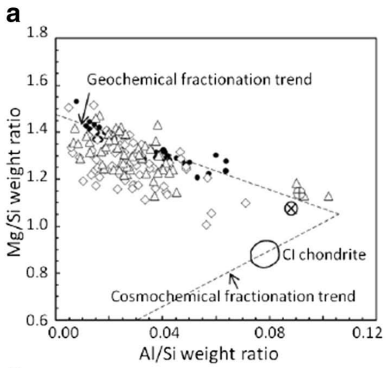

Figure 1

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LETTER Open Access

Distribution of CO_2 fluids in the Shimanto belt on Muroto Peninsula, SW Japan: possible injection of magmatic CO_2 into the accretionary prism

Atsushi Okamoto*, Michimasa Musya, Yoshitaka Hashimoto and Noriyoshi Tsuchiya

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Received: 18 November 2013, Accepted: 14 April 2014, Published: 15 May 2014

Abstract

Carbon dioxide and methane are major components in geofluids; however, there is little evidence showing how C-H-O fluids evolve in a subduction zone. We investigated fluid inclusions in quartz veins from the Eocene-Oligocene Shimanto belt (Murotohanto subbelt) on Muroto Peninsula, SW Japan using microthermometry and laser Raman spectroscopy. Quartz veins that cut the cleavage of the host rocks in the Murotohanto subbelt contain one-phase carbonic inclusions (CH_4) and two-phase aqueous inclusions ($CH_4 \pm CO_2$ vapor and H_2O liquid). The vapor in the two-phase inclusions is essentially CH_4 in the northern part of the belt and a CO_2-CH_4 mixture in the southern part; values of X_{CO_2}(=CO_2 / (CO_2 + CH_4)) vary from 0 to 0.9. Within a single CO_2-bearing vein, X_{CO_2} values decrease from the vein wall (X_{CO_2} = 0.5 to 0.9) to the vein center (X_{CO_2} = 0), and the homogenization temperature increases from approximately 180°C to 240°C-250°C, indicating a transition of the carbonic species from CO_2-CH_4 to CH_4 during vein formation. CO_2-dominant fluids are rare in most accretionary prisms formed under low-grade metamorphic conditions, and the generation of CO_2 cannot be explained by diagenesis of organic matter in sediments under the *P-T* conditions of formation of the CO_2-bearing veins (235°C to 245°C, 165 to 200 MPa). The CO_2 fluids are distributed preferentially near an out-of-sequence thrust that brings the Murotohanto subbelt into contact with the late Oligocene-early Miocene Nabae subbelt and its many volcanic and intrusive rocks. We therefore suggest that the CO_2 fluids were generated in association with near-trench magmatism during the middle Miocene and that the fluids were injected and mixed with the CH_4 pore fluids of the sediments in the accretionary prism.

Keywords: C-H-O fluid; Fluid inclusion; Shimanto belt; Magmatic CO_2; Quartz vein

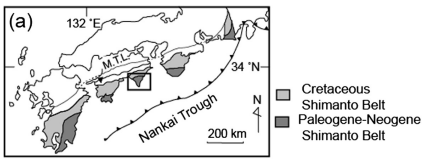

Figure 1

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LETTER Open Access

Effect of fluid H_2O on compressional wave velocities in quartz aggregate up to 500°C at 0.5 GPa

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Abstract

Compressional wave velocities (*Vp*) in quartz aggregate were measured to quantify the effect of pore fluid (H_2O) on *Vp* at high pressure-temperature (*P-T*). Ultrasonic measurements were conducted on dry and wet quartz aggregate from room temperature to 500°C at 0.5 GPa using a piston cylinder apparatus. The experiment showed a 4% decrease in measured *Vp* in quartz aggregate with increasing H_2O content to 1 wt.%, whereas the temperature derivative of *Vp* ($\partial Vp/\partial T = -2.8$ to -4.9×10^{-4} km s^{-1} °C^{-1}) in wet quartz aggregate remained almost the same as for the dry quartz aggregate ($\partial Vp/\partial T = -5.2 \times 10^{-4}$ km s^{-1} °C^{-1}). Our high-pressure, high-temperature experiments show that a small amount of pore fluid (0.4 to 1.0 wt.% H_2O) can significantly reduce *Vp* under the *P-T* conditions of the middle crust.

Keywords: *Vp*; Fluid; Quartz

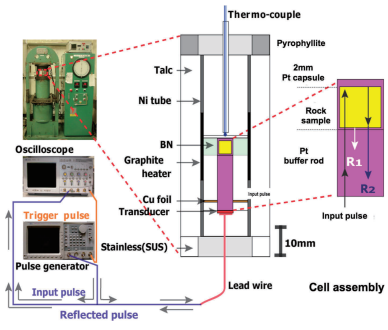

Figure 1

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LETTER Open Access

Three-dimensional electromagnetic imaging of fluids and melts beneath the NE Japan arc revisited by using geomagnetic transfer function data

Wataru Kanda* and Yasuo Ogawa

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Received: 15 January 2014, Accepted: 12 May 2014, Published: 27 May 2014

Abstract

The three-dimensional distribution of fluids and melts under the NE Japan arc was imaged using its resistivity structure, modeled with geomagnetic transfer functions. The data were collected at 37 stations located on a 20-km grid, at periods ranging from 16 to 256 s. In spite of the narrow period band nature, these periods turn out to be sensitive to conductors in the deep crust and upper mantle. The geomagnetic transfer functions represent lateral resistivity variations, which yield inherently nonunique model results when using the geomagnetic transfer functions alone. However, by fixing the resistivity structure of the surrounding seawater distribution, the intrinsic nonuniqueness is alleviated. In this study, we show an inversion result using a 100-Ωm uniform Earth with fixed resistivity of surrounding oceans. As a result, it was found that the features of the short period transfer function require shallow conductors in the upper crust, which is suggested to represent the northern Tohoku conducting belt of a previous study. The final model is characterized by a highly conductive zone along the quaternary volcanic arc in the depth range of the lower crust to the upper mantle. The conductor, which is obtained mainly from the features of longer-period data, is particularly clear beneath the Sengan geothermal area. The deep crustal conductor implies the existence of partial melt and/or high-salinity fluids.

Keywords: NE Japan; Quaternary volcanoes; Arc magma; 3-D modeling; Electrical resistivity

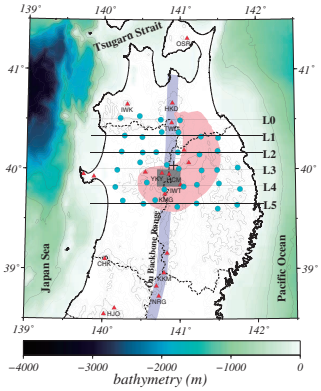

Figure 1

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LETTER Open Access

Fluid-metapelite interaction in an ultramafic mélange: implications for mass transfer along the slab-mantle interface in subduction zones

Yasushi Mori*, Miki Shigeno and Tadao Nishiyama

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Received: 10 December 2013, Accepted: 16 April 2014, Published: 4 June 2014

Abstract

The slab-mantle interface in subduction zones is a site of tectonic mixing of crustal and mantle rocks. It is the interface for fluid flow of slab-derived components into the mantle wedge. To assess the fluid-rock interaction along the slab-mantle interface, we studied the bleaching of pelitic schist in an ultramafic mélange. The Nishisonogi metamorphic rocks in Kyushu, Japan, comprise ultramafic mélanges intercalated with epidote-blueschist facies schists. The ultramafic mélange consists of tectonic blocks of various lithologies and a matrix of chlorite-actinolite schist and serpentinite. Along the contact with the mélange matrix, pelitic schist blocks are bleached mainly due to the modal increase of albite and the consumption of carbonaceous material. The bleaching is probably attributed to infiltration of Na-rich external fluid from the mélange matrix. Mass balance analysis indicates losses of C, Rb, K_2O, Ba, Pb, and SiO_2 from the bleached pelitic schist, although Al_2O_3, TiO_2, Sc, Y, Zr, Nb, La, Ce, and Nd remain immobile. This suggests fractionation of large-ion lithophile elements (LILE) and Pb from the high-field-strength elements and rare earth elements during the bleaching. If this ultramafic mélange is analogous to the slab-mantle interface, similar infiltration metasomatism will promote liberation of C, Si, LILE, and Pb from subducting metapelites and enhance metasomatism of the mantle wedge.

Keywords: Element fractionation; Fluid-rock interaction; Metapelite; Subduction zone mélange; Nishisonogi metamorphic rocks

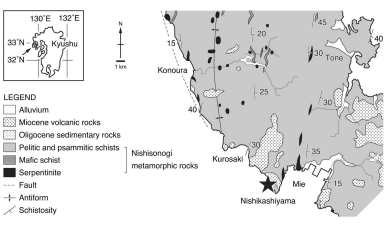

Figure 1

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LETTER Open Access

A 3-D electrical resistivity model beneath the focal zone of the 2008 Iwate-Miyagi Nairiku earthquake (M 7.2)

Hiroshi Ichihara*, Shin'ya Sakanaka, Masaaki Mishina, Makoto Uyeshima, Tadashi Nishitani, Yasuo Ogawa, Yusuke Yamaya, Toru Mogi, Kazuhiro Amita and Takuya Miura

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Abstract

The 2008 Iwate-Miyagi Nairiku earthquake (M 7.2) was a shallow inland earthquake that occurred in the volcanic front of the northeastern Japan arc. To understand why the earthquake occurred beneath an active volcanic area, in which ductile crust generally impedes fault rupture, we conducted magnetotelluric surveys at 14 stations around the epicentral area 2 months after the earthquake. Based on 56 sets of magnetotelluric impedances measured by the present and previous surveys, we estimated the three-dimensional (3-D) electrical resistivity distribution. The inverted 3-D resistivity model showed a shallow conductive zone beneath the Kitakami Lowland and a few conductive patches beneath active volcanic areas. The shallow conductive zone is interpreted as Tertiary sedimentary rocks. The deeper conductive patches probably relate to volcanic activities and possibly indicate high-temperature anomalies. Aftershocks were distributed mainly in the resistive zone, interpreted as a brittle zone, and not in these conductive areas, interpreted as ductile zones. The size of the brittle zone seems large enough for a fault rupture area capable of generating an M 7-class earthquake, despite the areas distributed among the ductile zones. This interpretation implies that 3-D elastic heterogeneity, due to regional geology and volcanic activities, controls the size of the fault rupture zone. Additionally, the elastic heterogeneities could result in local stress concentration around the earthquake area and cause faulting.

Keywords: Magnetotelluric; Iwate-Miyagi earthquake; 3-D resistivity; Inland earthquake

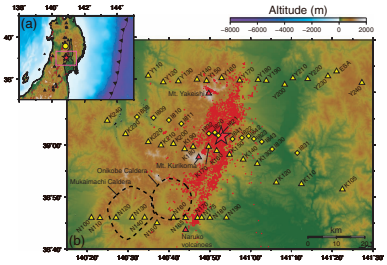

Figure 1

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LETTER Open Access

Pore pressure distribution in the focal region of the 2008 M7.2 Iwate-Miyagi Nairiku earthquake

Keisuke Yoshida*, Akira Hasegawa, Tomomi Okada, Hiroaki Takahashi, Masahiro Kosuga, Takaya Iwasaki, Yoshiko Yamanaka, Hiroshi Katao, Yoshihisa Iio, Atsuki Kubo, Takeshi Matsushima, Hiroki Miyamachi and Youichi Asano

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Abstract

The pore fluid pressure distribution in the focal region of the 2008 Iwate-Miyagi Nairiku earthquake was investigated through an analysis of the diversity of focal mechanisms. We inverted stress orientations and focal mechanisms directly from P-wave polarity data obtained from a dense aftershock observation network and other temporarily and routinely operated stations. The estimated stress orientation is consistent with that typical of NE Japan. Specifically, the σ1 axis is oriented WNW-ESE nearly parallel to plate convergence, and the σ3 axis is nearly vertical, consistent with a reverse-faulting stress regime, with some exceptions in the central part of the aftershock area. We obtained 2,497 well-determined focal mechanisms whose average number of P-wave polarity data is more than 70. The spatial distribution of pore fluid pressure was estimated by using the obtained orientations of the principal stresses and earthquake faults. The pore pressure ratio for each earthquake fault was calculated under the assumption that reduced frictional strength was caused by pore fluid pressure. The results showed that the diversity of the focal mechanisms here obtained requires high pore fluid pressures at many of the earthquake faults in the focal region. The spatial pattern of pore pressure ratio shows that areas of higher pore pressure ratio are distributed around the large coseismic slip area near Kurikoma volcano. Immediately beneath these high pore pressure areas, there exists a distinct seismic low-velocity zone that continues down to the mantle wedge below. These observations suggest that crustal fluids supplied from the mantle wedge have contributed to producing high pore pressures and to lowering the frictional strengths of those faults. Crustal fluids may also have contributed to generating the mainshock rupture.

Keywords: 2008 Iwate-Miyagi Nairiku earthquake; NE Japan; Focal mechanism; Pore fluid pressure; Stress tensor inversion

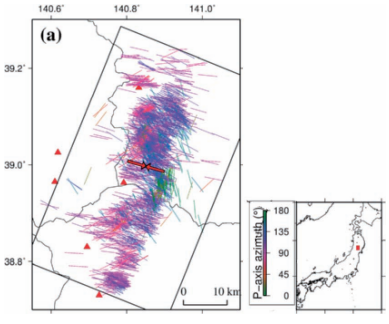

Figure 1

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LETTER Open Access

FTIR and Raman spectroscopy characterization of fluorine-bearing titanian clinohumite in antigorite serpentinite and chlorite harzburgite

Kenneth T Koga*, Carlos J Garrido, José A Padrón-Navarta, Vicente López Sánchez-Vizcaíno and María T Gómez-Pugnaire

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Abstract

Titanian clinohumite is an accessory phase found in peridotites, and it can be a key repository of volatile and other trace elements in sub-arc mantle. To characterize spectroscopic variations due to volatile elements in the phase, we have investigated the infrared spectroscopic characteristics of a suite of naturally occurring Ti clinohumite minerals with varying F and Ti concentrations. Samples were ultramafic rocks from Cerro del Almirez, Spain and Cima di Gagnone, Switzerland. The infrared spectra corresponding to OH vibrations showed systematic variation in regard to the abundance of F in Ti clinohumite. In particular, the intensity ratios of infrared absorption spectra at 3,565 and 3,390 cm^{-1} correlated linearly with the abundance of F independently of the crystal orientation. Raman spectra did not corroborate the Fourier transform infrared (FTIR) results. This intensity ratio provides an alternative analytical criterion for the characterization of Ti clinohumite.

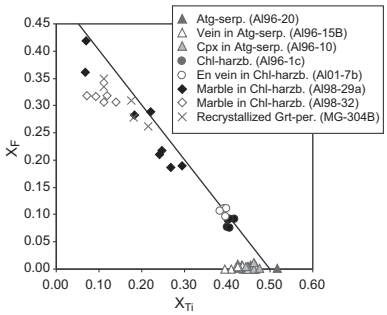

Figure 1

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LETTER Open Access

Guided wave observations and evidence for the low-velocity subducting crust beneath Hokkaido, northern Japan

Takahiro Shiina*, Junichi Nakajima, Genti Toyokuni and Toru Matsuzawa

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Abstract

At the western side of the Hidaka Mountain range in Hokkaido, we identify a clear later phase in seismograms for earthquakes occurring at the uppermost part of the Pacific slab beneath the eastern Hokkaido. The later phase is observed after P-wave arrivals and has a larger amplitude than the P wave. In this study, we investigate the origin of the later phase from seismic wave observations and two-dimensional numerical modeling of wave fields and interpret it as a guided P wave propagating in the low-velocity subducting crust of the Pacific plate. In addition, the results of our numerical modeling suggest that the low-velocity subducting crust is in contact with a low-velocity material beneath the Hidaka Mountain range. Based on our interpretation for the later phase, we estimate P-wave velocity in the subducting crust beneath the eastern part of Hokkaido by using the differences in the later phase travel times and obtain velocities of 6.8 to 7.5 km/s at depths of 50 to 80 km. The obtained P-wave velocity is lower than the expected value based on fully hydrated mid-ocean ridge basalt (MORB) materials, suggesting that hydrous minerals are hosted in the subducting crust and aqueous fluids may co-exist down to depths of at least 80 km.

Keywords: Guided wave; Subducting crust; Pacific slab; Hokkaido; Finite difference method; Dehydration; Intermediate-depth earthquake

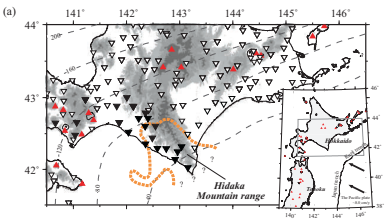

Figure 1

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LETTER Open Access

Non-volcanic seismic swarm and fluid transportation driven by subduction of the Philippine Sea slab beneath the Kii Peninsula, Japan

Aitaro Kato*, Atsushi Saiga, Tetsuya Takeda, Takaya Iwasaki and Toru Matsuzawa

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Abstract

To understand the mechanism of an intensive non-volcanic seismic swarm in the Kii Peninsula, Japan, we used a dense seismic linear array to measure fine-scale variations of seismic velocities and converted teleseismic waves. A low-velocity anomaly confined to just beneath the seismic swarm area is clearly imaged, which correlates spatially with an uplifted surface area and a highly conductive and strong attenuative body. These results suggest that fluids such as partial melt or water are present beneath this non-volcanic seismic swarm area. It is notable that the island arc Moho below the seismic swarm area is at a depth of approximately 32 km in the northern part of the seismic swarm area and shallows to approximately 20 km towards the south, due to the raised structure of the serpentinized mantle wedge. In addition, we show that the hydrated oceanic crust of the subducting Philippine Sea slab is characterized by low velocities with a high Poisson's ratio at depths of less than 40 km. In contrast, dehydration conversion from oceanic basalt to eclogite takes place at depths greater than 50 km. Water released from the subducting oceanic crust could cause serpentinization of the mantle wedge and infiltration into the forearc base of the overlying plate. The interaction between dehydration of the subducting oceanic crust and hydration of the mantle wedge and overlying plate exerts an important role in driving the non-volcanic seismic swarm activity in the Kii Peninsula.

Keywords: Non-volcanic seismic swarm; Fluid; Dehydration of oceanic crust; Serpentinized mantle wedge

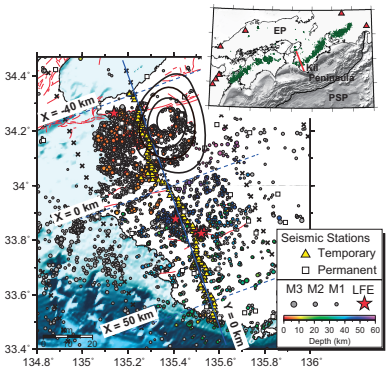

Figure 1

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LETTER Open Access

Water content in arc basaltic magma in the Northeast Japan and Izu arcs: an estimate from Ca/Na partitioning between plagioclase and melt

Masashi Ushioda*, Eiichi Takahashi, Morihisa Hamada and Toshihiro Suzuki

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Abstract

The variation in water content of arc basaltic magmas in the Northeast Japan arc and the Izu arc was estimated using a simple plagioclase phenocryst hygrometer. In order to construct a plagioclase phenocryst hygrometer optimized for arc basalt magmas, we have conducted high-pressure melting experiments of relatively primitive basalt from the Miyakejima volcano, a frontal-arc volcano in the Izu arc. As a result of the experiments, we found that the Ca/Na partition coefficient between plagioclase and hydrous basaltic melt increases linearly with an increase in H_2O content in the melts. We then selected from literature geochemical data sets of relatively primitive basaltic rocks with no evidence of magma mixing and the most frequent Ca-rich plagioclase phenocrysts from 15 basaltic arc volcanoes including both frontal-arc and rear-arc volcanoes. In the 15 volcanoes studied, plagioclase phenocrysts of high anorthite content (An > 90) were commonly observed, whereas plagioclase phenocrysts in rear arc volcanoes usually had a lower anorthite content (90 > An > 80). In all volcanoes studied, the estimated H_2O content of basaltic magma was at least 3 wt.% H_2O or higher. The magmas of volcanoes located on the volcanic front have about 5 wt.% H_2O in magma whereas those from the rear-arc side are slightly lower in H_2O content.

Keywords: Island arc basalt; Water content; Plagioclase; Hydrous melting experiments; Across-arc geochemical variation

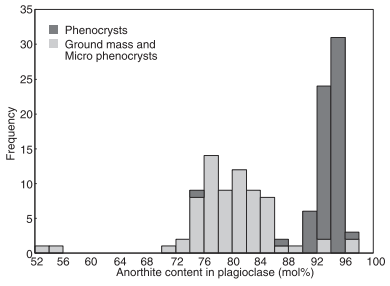

Figure 1

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LETTER Open Access

Three-dimensional magnetotelluric imaging of crustal fluids and seismicity around Naruko volcano, NE Japan

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Abstract

We analyzed the 3-D resistivity structure beneath Naruko volcano, northeastern Japan, with the aim of imaging 3-D distribution of fluids in the crust for its volcanic and seismogenic implications. The data were recorded at 77 sites in total: 30 sites are new and are arranged in an approximately 5 × 5 km grid whereas the remaining older sites constitute two separate east-west profiles. We ran a 3-D inversion using full components of impedance tensors in the period range between 0.13 and 400 s. The resulting model showed that a sub-vertical conductor exists a few kilometers below Naruko volcano. The conductor extends from the surface of the volcano and dips towards the south, away from the volcano towards the backbone range. High levels of seismicity are observed in the upper crust above and around the conductors. We suggest that the seismicity is fluid driven and that a fluid trap is created by the precipitation of quartz owing to a reduction in solubility at shallow depth. The Quaternary volcanic front is characterized by a sharp resistivity contrast and a high-resistivity zone and extends 10 to 15 km towards the east. A fore-arc conductor was observed at mid-crustal levels even farther towards the east. The sub-vertical conductors along the arc and the fore-arc conductor have resistivities of 1 to 10 Ωm. Assuming a Hashin-Shtrikman model with saline fluids of 0.1-Ωm resistivity, a porosity of 1.5% to 15% is required to explain the observed conductive anomalies.

Keywords: Magnetotellurics; 3-D modeling; Saline fluids; Northeastern Japan; Quaternary volcanoes; Seismicity

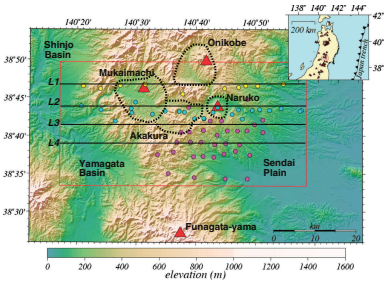

Figure 1

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