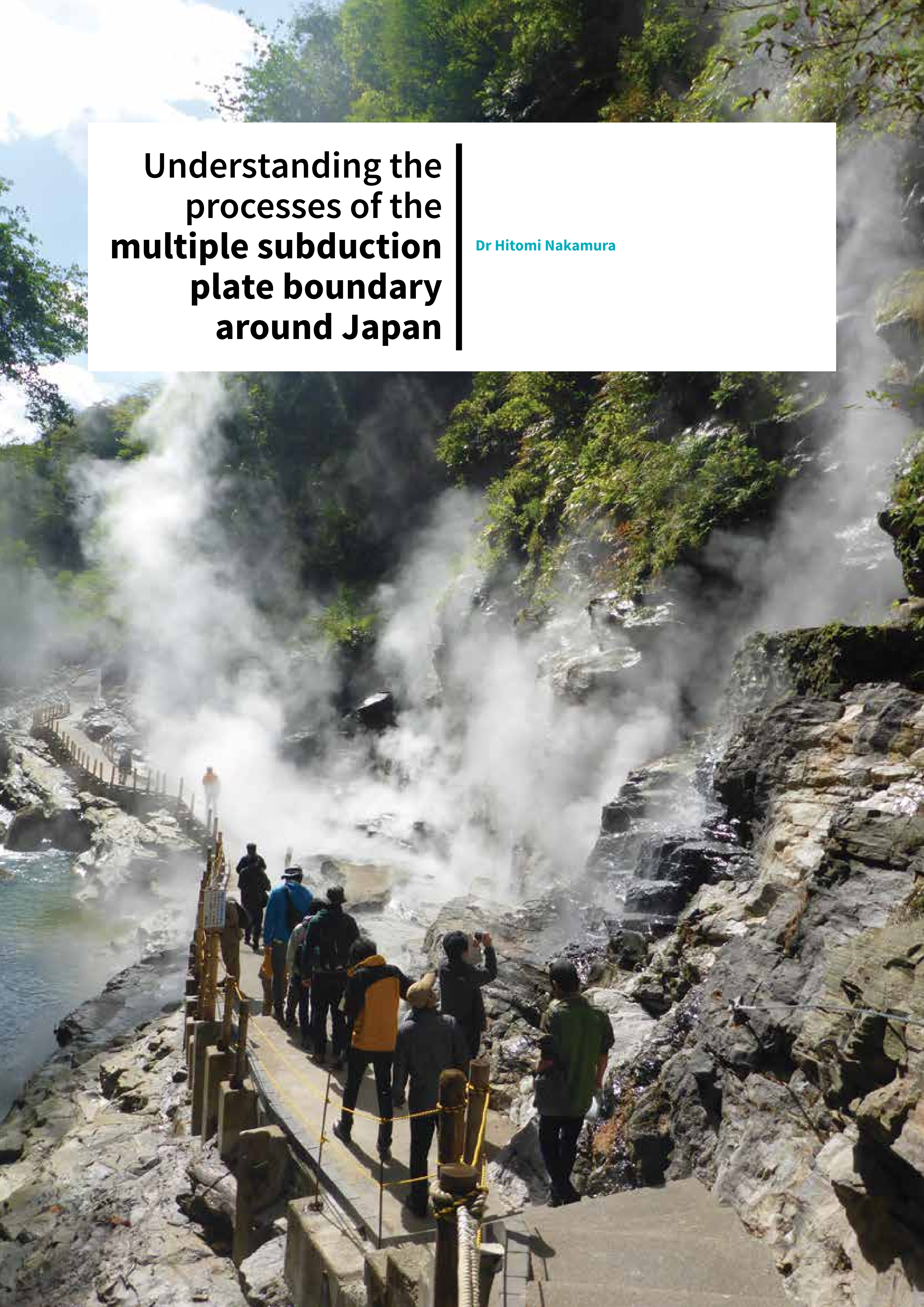
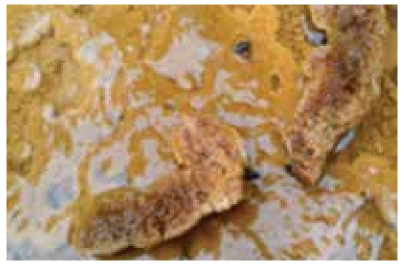
Understanding the processes of the multiple subduction plate boundary around Japan

Dr Hitomi Nakamura



UNDERSTANDING THE PROCESSES OF THE MULTIPLE SUBDUCTION PLATE BOUNDARY AROUND JAPAN



Dr Hitomi Nakamura uses knowledge from studying slab fluids in magma formation and applies it to study spring waters formed from a similar process. In this interview, she discusses what is special about the Japanese plate system and why such fluids are important.

Let's start at the beginning so that everyone can understand about more about what you do. What's your research background? And how did you get into your chosen field?

I am a volcanologist/petrologist/geochemist. My PhD thesis concerns Quaternary magmatism in Central Japan where the multiple plates meet and interact, which led me to realize the importance of fluid, particularly salty aqueous fluid derived from the subducting plates, to magma genesis. My research activity includes field works, rock/water sampling, laboratory works (e.g., chemical and isotope analyses utilizing 'clean room' and mass spectrometer), and data analyses using computers. Now I am involved in a project on magmatism in Kamchatka, where again fluids play an important role, collaborating with Dr Tatiana Churikova in IVS FEB RAS. Based on these studies and my background, I have also started to study a new target 'spring water'. Many spring waters are upwelling in Japan, some of which seem to have the same origin with the deep-seated fluid triggering magma generation.

Many people are familiar with tectonic plates, but what is special about the subducting plates found on the islands of Japan?

Two features are highlighted here. First, since the Pacific Plate that subducts beneath Japan is the largest on Earth, the subduction power is the greatest, exposing the islands to the most tectonically active environment in the world. In particular, after the '2011 off the Pacific coast of Tohoku Earthquake', the Japanese islands seemed to enter a tectonically active period: in addition to a series of aftershocks, a number of volcanoes have been and are going to erupt, such as Ontake Volcano and Sakurajima Volcano. One of the important factors for these eruptions is water. When magmas ascend and the pressure is released, water is degassed from magmas and quickly expands, causing explosion and eruption. The water source is a fluid liberated from the subducting plates. Beneath the Japanese islands, the two oceanic plates (Pacific Plate and Philippine Sea Plate) subduct beneath the two continental plates, with complex plate geometry. Therefore, the average amount of water supplied from the plates is greater than in other subduction zones, with complex spatial variations in both amount and composition, through many faults that have been created by tectonic stress applied from the four colliding plates along the Japanese islands.

A lot of your focus is centred around 'slab fluids'. What are slab fluids, and what important role do they play at plate boundaries?

The reason why we have plate boundaries and subduction is probably due to liquid water on this planet, which weakens the rock strength. Therefore, how water interacts with rocks in subduction zones is related to the uniqueness of this planet. Another unique feature of Earth is the presence of the continents, which is thought to be produced also via water-rock interactions. Slab fluid is such water, derived from subducting slabs. Slab fluids are not pure water, but a brine containing abundant metals, as a result of water-slab material interactions at high pressure and temperature. In many arcs, slab fluids are upwelling beneath volcanic region and produce magmas and possibly ore deposits, in which they can be trapped as 'fluid inclusions'. Recent studies suggest that slab fluids are also upwelling in non-volcanic regions, especially through faults in the fore-arc region.

So what is next for your research?

Since I have just started to study spring waters, there are many things to do at the moment. In particular, I will continue to search for deep-seated brines that correspond to slab fluids along the entire Japanese islands, first mapping their distributions. The detailed compositions of the brines will tell us both their origin (from which we may infer the physical-chemical condition of the subducted plates) and ascent processes (from which tectonic settings and aquifer interactions may be discussed). Including these brines, I have a plan to map and geochemically classify all the spring waters in Japan, in order to envisage 'fluid circulation' beneath the Japanese islands, which is important in understanding the geological phenomena and plate dynamics in subduction zones, as well as the Earth's unique features.

CAPTURING THE SLAB-DERIVED FLUIDS IN SPRING WATER

Slab fluids are impure water solutions found at subduction zones at plate boundaries. They have generally been derived to produce magma formation. Dr Nakamura and her colleagues have used their knowledge and applied it to similar principles that occur for the heating of spring water in Japan.

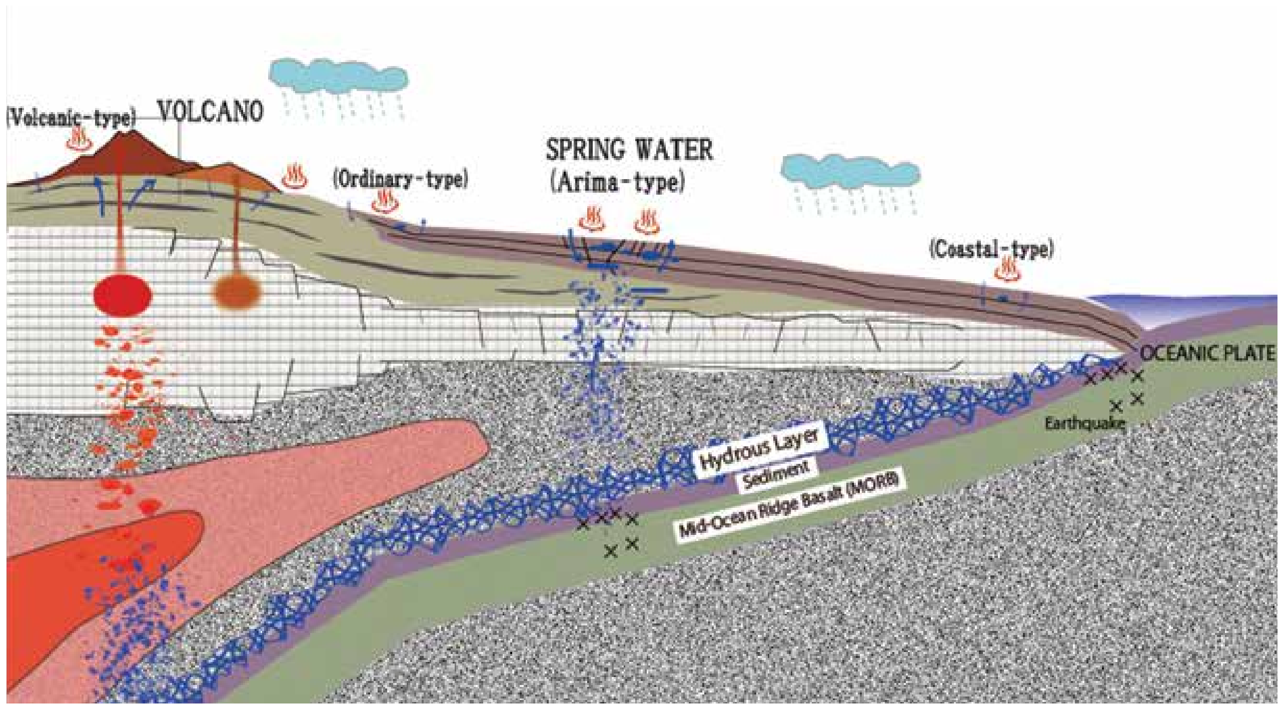
Tectonic Tales

As many people are aware, unlike other planetary bodies in our solar system, the Earth is made up of multitude of massive rock slabs which move over each other known as Tectonic plates. Tectonic plates interact with each other at plate boundaries and most commonly occur in two ways: The first, where the plate is constructive and the plates move away from each other. And second, where the plates move towards each other where one plate becomes submerged under the other. This article is concerned with the latter upon which they occur between an oceanic plate and a continental plate (at boundaries between land and sea). The oceanic plate is much heavier than the continental plate due to heavier elements making up the composition in the rocks (and they generally a more mafic composition), so the oceanic plate submerges (subducts) beneath the continental plate under gravity. If you have two plates which are of the same composition (oceanic-oceanic and continental-continental) then you get a 'collision' plate boundary where it concerned with making geological structure such as mountain building (like Himalaya). Around the Japanese islands, the tectonic activity is concerned with subduction plate boundaries.

What makes the Japanese subduction zone so special is the fact that the oceanic plate is the largest on Earth, giving the greatest subduction power in the world

Japan's Special Environment

But did you know that this can occur for more than one plate simultaneously? This is the case in Japan where the Pacific Plate submerges at the Japan Trench under multiple continental volcanic arc-magma with multiple continental shelfs containing less dense rock. This phenomenon is not exclusive to Japan as it also occurs at various points over the Pacific Islands and is known as 'the Ring of Fire' because of the amount of induced volcanoes and earthquakes caused by the multiple plate system. However, beneath the Japanese islands, the two oceanic plates (Pacific Plate and Philippine Sea Plate) subduct partly overlapping beneath the two continental plates, which leads to complex plate geometry and



unstable torque balance. Especially near the junctions where these plates meet, northward progress of the subducted Philippine Sea Plate was stuck by the geometrical constraints (no space for progress, being sandwiched by the upper and lower plates), which resulted in a significant change in motion of the Philippine Sea Plate in the past (~3 million years ago). What makes the Japanese subduction zone so special is this complex geometry and interaction among the plates, in addition to the fact that the Pacific Plate is the largest and the most powerful on Earth, and therefore exposing Japan to immense levels of tectonic activity. Because of this activity, the Japanese Islands are susceptible to both earthquakes and volcanic activity.

Slab fluids? Hot Springs? What's occurring under the surface?

As we are concerning ourselves with not only the geological environment but also the slab fluids that these environments produce, you may be wondering what slab fluids are and why they are relevant. To put it simply, a slab fluid is water that is derived form a subducting plate. Slab fluids are the water that get submerged with the plate during the submersion process (there is always so water lubrication present). However, it is unlike the water that we are accustomed to in everyday living, but an impure water form with a high salinity and are earth elements (REEs) concentration- essentially if you mixed 'hard water' with salt water, it would loosely represent the composition of slab fluids. The reason for the impure fluid is due to the intense heat and pressure it is subjected to during the submersion. Slab fluids then travel upwards, generally through aquifer rocks and can produce magmas or ores.

When slab fluids ascend from the plate beneath the non-volcanic region, upwelling velocity and total time to reach the surface seem to be fast and short where they have no interaction with magmas on the way. This can be observed as is observed by a special type of earthquake, called 'non-volcanic tremor'. Such deep-seated brines could have ascended to a rather shallow depth without being significantly modified until it meets the aquifer water/meteoric water. This can be shallower than several hundred meters in depth. This means that two very different fluids: a high-temperature brine with abundant metals formed under an oxygen-poor conditions and a low-temperature meteoric water formed under an oxidized condition, meet to react and precipitate the metals from the former that is significantly oxidized and cooled by the meteoric water. On the other hand, the meteoric water in the aquifer receives gas components (e.g., CO_2 and helium) degassed from the cooled brine. This combination of liquids is what forms the spring waters in regions and faults between the rocks cause the springs to physically form by upwelling from the aquifers. There is a higher spring water abundance around Japan because there are two oceanic plates being submerged, causing the amount of slab fluid at the boundary to be doubled, resulting in a larger quantity of spring water produced. The Arima Springs is one such area of spring water accumulation where this is physically shown.

How to determine the composition of slab fluids to give an accurate representation?

Because Slab fluids have a high amount of rare earth elements (REEs) it means that the ions in solution behave uniquely and coherently and are sensitive to changes in temperature, pH, fO_2 (oxygen environment) and fCO_2 (CO_2 environment). This sensitivity can provide key information on the process at shallow levels where these variables may significantly change. In spite of such usefulness of REEs, the analysis of spring waters is not trivial. Partly due to the variations and due to mixing with meteoric waters, the concentrations of REEs in the spring waters are variable, being very low (a ppb level) on average, which requires an analytical method with a very high sensitivity and a wide dynamic range, such as Inductively Coupled Plasma - Mass Spectrometry (ICP-MS). High salinity and other dissolved metals and elements interfere the REE analysis (even more so with a high-sensitivity method like ICP-MS), but procedures have been developed by the group to cope with the difficulties so that cataloguing of compositions is possible.

Meet the researcher

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Dr Hitomi Nakamura is a scientist in igneous petrology and geochemistry at Japan Agency for Marine-Earth Science and Technology (JAMSTEC). She is also a researcher in Department of Earth and Planetary Sciences at Tokyo Institute of Technology (TITECH). Nakamura works within the group of Dr Hikaru Iwamori and her research focuses around the multiple subducting plates around Japan and related slab fluids and magmatism, as well as global mantle heterogeneity. More recently she extended these fluid studies to include spring waters formed from slab fluids. She has published 14 international and 4 domestic peer-reviewed publications to date.

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FUNDING

JSPS KAKENHI Grant Number 25400524, Capture of slab-derived fluid by using spring water
JSPS KAKENHI Grant Number 24654160, Microbiological weathering of rocks and its effect on global material circulation
JSPS KAKENHI Grant Number 22244069, Heterogeneity of subduction zone mantle: Towards geochemical tomography
JSPS KAKENHI Grant Number 21109006, Generation and migration dynamics of geofluids
Cooperative Research Program of Earthquake Research Institute, 2012–2015, The University of Tokyo

REFERENCES

H. Nakamura, K. Chiba, Q. Chang, S. Nakai, K. Kazahaya and H. Iwamori, Rare earth elements of the Arima spring waters, southwest Japan: Implications for fluid-crust interaction during ascent of deep brine, Journal of Geology & Geosciences, 2015, 4, 4:217, doi:10.4172/jgg.1000217.
H. Iwamori and H. Nakamura, Isotopic heterogeneity of oceanic, arc and continental basalts and its implications for mantle dynamics, Gondwana Research, 2015, 27, 1131–1152.
H. Nakamura and H. Iwamori, Generation of adakites in a cold subduction zone due to double subducting plates, Contribution to Mineralogy and Petrology, 2013, 165, 1107–1134.
H. Nakamura and H. Iwamori, Contribution of slab-fluid in arc magmas beneath the Japan arcs, Gondwana Research, 2009, 16, 431–445.
H. Nakamura, H. Iwamori and J.I. Kimura, Geochemical evidence for enhanced fluid flux due to overlapping subducting plates, Nature Geoscience, 2008, 1, 380–384.

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