Philippine Sea and East Asian plate tectonics since 52 Ma constrained by new subducted slab reconstruction methods

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The Philippine Sea plate is a large marginal sea between the major Pacific, Indo-Australia and Eurasia/Sundaland plates. The history of Philippine Sea plate motions since its inception around 52 Ma is controversial and uncertain, due in large part to lost lithospheric record at the circum-Philippine Sea plate subduction zones and other East Asia convergent plate boundaries. Nonetheless, continued research on the Philippine Sea plate is motivated by its importance for northeast Asia tectonics, including Taiwan, the Philippines, SW Japan-Ryukyus, the South China Sea, the Izu-Bonin-Marianas arcs, and other southeast Asia marginal seas.

In this study we show a Philippine Sea and adjacent East Asia plate tectonic reconstruction back to 52Ma constrained by twenty-eight slabs mapped in 3D from global tomography, with a total subducted area of ~25% of global oceanic lithosphere. New slab constraints include subducted parts of existing Pacific, Indo-Australian, and Philippine Sea oceans, plus the wholly subducted proto-South China Sea and the newly discovered "East Asian Sea" ocean. Mapped slabs were structurally restored to a spherical Earth surface using newly-developed unfolding methodologies and input to globally-consistent plate reconstructions using Gplates software.

Important new constraints include:
(1) the northern Philippine Sea Ryukyu slab is short (~1000 km) relative to >2000km northward Philippine Sea motion constrained by paleomagnetism. This requires an intervening, now-subducted ocean south of the Ryukyus and SW Japan in the Eocene. Our plate reconstructions show this to be the 'East Asia Sea' and the Pacific;
(2) the Marianas Pacific subduction zone remained within ±200 km of its present location since 48±10Ma based on a slab wall extending to >1000km depths;
(3) a major (8000 km x 2500 km) swath of lower mantle flat slabs represents a vanished "East Asia Sea" ocean that existed between the Pacific and Indian Oceans at 52Ma. The northern East Asia Sea played the role of the proto-Philippine Sea;
(4) the Caroline backarc basin moved with the Pacific based on an overlapping and coeval Caroline LIPS and hotspot track and proto-Caroline slab locations.

Our preferred plate model involves a Philippine Sea origin near the Manus plume (150°E/0°) at a Pacific-East Asian Sea junction. Large westward motion and post-40Ma clockwise rotation (~60°) were driven by late Eocene-Oligocene collision with the Caroline/Pacific plate. We predict a Miocene arc-arc collision between a northern Philippine Sea arc and the SW Japan-Ryukyu continental margin. Our observed slab age-depths fit within a 1.8±0.8 cm lower mantle sinking rate. Digital files, including plate-model animations and Gplates compatible unfolded slab shapes and rotation files will become publically available to serve as a platform for further refinements or testing alternative tectonic scenarios.

Keywords: Philippine Sea plate, plate tectonic reconstructions, subducted slabs

Early Cenozoic large plate tectonic reorganization in the Pacific Ocean and its record in accretionary complex in western Pacific margin

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Late Paleocene to early Eocene (~50 –42 Ma) is regarded as a period of large organization of the Pacific and other plates and appears to have taken place related tectonic events along the circum-Pacific subduction zone. A hypothesis suggests that it might have been caused by subduction initiation along the Izu-Bonin-Mariana margin following the subduction of the Izanagi-Pacific oceanic ridge, and resulted in the change in moving vector of the Pacific Plate. The hypothesis has been controversial but revived with new observations of stagnant slabs beneath the Asian continent and others.

We examined the geology of the late Cretaceous and early Cenozoic accretion complexes of the Shimanto Belt and others in the Japanese islands. In that period, the Japanese islands were located along the continental margin because it was the before the Oligo-Miocene rifting and opening of the Japan Sea.

The Shimanto belt is subdivided into two subbelts; northern and southern subbelts. The youngest portion of the northern Shimanto belt is the latest Cretaceous to the earliest Paleocene in age and includes N-MORB type basaltic blocks with a short age gap with terrigenous trench filling sediments. Previous studies hypothesized that in-situ magmatic eruption in the trench but it was denied by detailed geological, structural, and chemical investigation for the relationship between the basalt and surroundings. Instead of the in-situ eruption hypothesis, very hot plate subduction and seismogenic megathrusting is proposed. Other parts of the late Cretaceous northern Shimanto Belt indicate oceanic plate older than the terrigenous trench filling sediments was subducted. This observation is inconsistent with the commonly popular ~80 Ma Kula-Pacific ridge subduction hypothesis.

Between the northern and southern Shimanto Belts, is recognized a large tectonic gap named the Nobeoka thrust in Kyushu and the Aki Tectonic Line in Shikoku. Several m.y. age gap is common between the subbelts and northernmost portion of the southern Shimanto belts is composed dominantly of Eocene terrigeous sediments of accretionary complex. Locally they include basaltic blocks without thick pelagic sediments but just hemipelagic shale. Thermal overprints reconstructed by illite crystalinity, vitrinite reflectance, and fission track ages of zircons are high in general and dated mainly in Eocene just after the deposition.

These facts suggest the rapid development of accretionary prism after the tectonic break in earliest Paleocene took place with thermal event.

The other prominent Eocene event is the development of the coal mine fields from Kyushu, mainland Honshu to Hokkaido, and Sakhalin, Russia along the Asian continental margin more that 2,000 km. These regional developments of coal fields along the Asian margin after the Paleocene tectonic break in the accretion complex are quite prominent and informative. We suggest that all these events in early Cenozoic might have been related to global scale reorganization of plate tectonics.

Dynamic of the Japan subduction system

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The geometry of the Mariana-Izu-Bonin (IBM)-Japan slab consists of a large cusp where the undulation of the trench is accompanied by a corresponding variation in slab dip, varying form sub-vertical beneath the Marianas to shallow dipping beneath Japan. The origin and the cause of these variations are still poorly understood.We reconstruct the backarc extensional system of the Philippine plate, showing that the triple junction between the IBM, Ryuku, and Japan migrated northward during the last 40 Ma reaching its present-day position. We balance back the subduction system on time, starting from recent tomographic models and using an absolute reference frame plate reconstruction model. Our kinematic model suggests that the evolution and the geometry of the Japan slab is controlled by the interaction with the surrounding slabs. We test this hypothesis with simple laboratory experiments. Our preliminary results suggest that the slab geometry is influenced by local and plate-scale mantle flow.

Keywords: subduction, Mariana-Izu-Bonin, geodynamic modeling

Joint inversion of body-wave and surface-wave data for the fine 3-D structure of Japan subduction zone

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We determined high-resolution P and S wave velocity tomography of the Japan subduction zone down to a depth of 700 km by conducting joint inversions of a large number of high-quality arrival-time data of local earthquakes and teleseismic events which are newly collected for this study. We also determined 2-D phase-velocity images of fundamental-mode Rayleigh waves at periods of 20 to 150 s beneath Japan and the surrounding oceanic regions using amplitude and phase data of teleseismic Rayleigh waves. A detailed 3-D S-wave tomography of the study region is obtained by jointly inverting S-wave arrival times of local and teleseismic events and the Rayleigh-wave phase-velocity data. Our inversion results reveal the subducting Pacific and Philippine Sea slabs clearly as dipping high-velocity zones from a 1-D starting velocity model. Prominent low-velocity (low-V) anomalies are revealed in the mantle wedge above the slabs and in the mantle below the Pacific slab. The distinct velocity contrasts between the subducting slabs and the surrounding mantle reflect significant lateral variations in temperature as well as water content and/or the degree of partial melting. The low-V anomalies in the mantle wedge are attributed to slab dehydration and corner flows in the mantle wedge. A sheet-like low-V zone is revealed under the Pacific slab beneath NE Japan, which may reflect hot upwelling from the deeper mantle and subduction of a plume-fed asthenosphere as well. Our present results indicate that joint inversions of different seismic data are very effective and important for obtaining robust tomographic images of the crust and mantle.

Reference
Liu, X., D. Zhao (2016) P and S wave tomography of Japan subduction zone from joint inversions of local and teleseismic travel times and surface-wave data. *Phys. Earth Planet. Inter*. 252, 1-22.

Keywords: Japan subduction zone, Pacific slab, Philippine Sea slab

Structural evolution of the southern margin of the Sea of Japan: implications from recently obtained seismic data

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The Japan arc is located in a highly active tectonic region, with earthquakes and tsunami hazard on both the Pacific and Sea of Japan side. After the tsunami disaster as the result of the 2001 Off-Tohoku earthquake (M9) along the northeast coast of Japan, the Japanese government initiated an extensive evaluation of the tsunami hazard. Not only does this evaluation span the Pacific coast of Japan, but also the western shore of the Japan arc along the Sea of Japan. To develop a tsunami source-fault model of this area, a better understanding of the present-day structural geometry of this region is necessary. Therefore, the structural evolution of the Sea of Japan is assessed. Here, we examine the development offshore of the San'in region, Kyushu, using a subsurface dataset that covers ~1,000 km^2 including well log data and recently obtained 2D seismic reflection profiles.

The southern margin of the Sea of Japan is a structurally complex area that formed as a result of several tectonic events during the last 25 Ma including: (i) back arc rifting and rotation, (ii) post-rift compression, (iii) weak thrusting, and (iv) strike-slip deformation. This region is previously studied extensively using gravity, paleomagnetic, borehole, and limited 2D seismic data. However, due to the limited spatial and temporal resolution of the data available and methods applied, the development of this region is not yet well constrained. Nevertheless, multiple hypotheses on its structural evolution were forwarded.

We present preliminary results of comprehensive analyses of well data and the seismic profiles obtained in 2013. The 2D seismic reflection profiles were acquired using 1950 cu. in. airgun and 2100 m streamer cable, and have a total length of ~680 km. The profiles were migrated and depth converted, imaging up to 5 km. On the seismic profiles we observe igneous bodies and large basement blocks, as well as rift-related, syn-rift sediment filled grabens and half-grabens, of which some are inverted. These structures are interpreted to be the result of a complicated development, linked to multiple large-scale tectonic events. During the rifting and opening stage (25 –14 Ma), subduction of the Pacific and Philippine Sea plates along the east coast of Japan resulted in back-arc rifting and the initial opening of the Sea of Japan. The rift event is associated with clock-wise rotation of the southwest Japan arc (17.5 –15.8 Ma), with its pivot point located approximately in the south west of the study area. Rift structures filled by syn-rift sediments formed trending parallel to the southwest Japan arc. The opening of the Sea of Japan ceased due to the collision of the Izu-Bonin-Mariana arc system and the Japan arc along the eastern side of Japan. Soon after this event, the former marginal rift zone along the west coast of Japan was exposed to shortening (14 –5 Ma) due to the northward movement of the young Shikoku basin within the Philippine Sea plate. The high thermal buoyancy of the Shikoku basin resulted in resistance along the Nankai trough causing thrusting and selective inversion along previously developed rift structures and the development of the Shinji fold belt. Subsequently, when subduction of the Shikoku basin began (5 –1 Ma), the shortening rate decreased and the deformed structures were covered by sub-horizontal Pliocene sediments. At 1 Ma, a northwesterly shift of the Philippine Sea plate produced a major change in stress regime, causing reactivation of reverse faults to strike-slip. We use the understanding of the development of the southern margin of the Sea of Japan to improve the current tsunami source-fault model.

Keywords: Tsunami source-fault model, Sea of Japan, Seismic reflection data, Structural evolution, Crustal deformation, San'in region

Crustal and tectonic evolution of accretionary orogens in NE Asia and comparison with the Central Asian Orogenic Belt

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The Northeast Asian Orogenic Belt (NAOB) is a Mesozoic-Cenozoic accretionary orogenic collage, and it constitutes the northern and principal part of the “Nipponides” [1]. The orogenic style of the Nipponides has much in common with that of the Central Asian Orogenic Belt (CAOB) or the “Altaides” [1, 2]. The tectonic framework of the NAOB was formed in Mesozoic and Cenozoic, and it continues to evolve along the modern Pacific arc-trench systems. Generally, an oceanward younging of tectonic units may be discerned, but such a simple pattern is disrupted in many places by extensive strike-slip faulting, most of which is left lateral. In this talk, the issue of crustal evolution in the sector of Sikhote-Alin, Sakhalin and Japanese Islands will be discussed based on the geochemical and isotopic analyses of granitoids that intruded in various tectonostratigraphic terrains.

The majority of granitoids in the NE Asian Orogenic Belt formed from Jurassic to late Cenozoic, with Cretaceous as the dominant period of granitic magmatism and silicic volcanism. Though remnants of Paleozoic granitoids have been preserved in Japan [3], most granitic rocks were emplaced in the Mesozoic and Cenozoic times. Cretaceous granitoids are widespread in Sikhote-Alin [4] and Japan. However, granitoids were emplaced only in the Cenozoic in Sakhalin (ca. 44 - 42 Ma) and Hokkaido (45, 37 and 18 Ma) [5]. Most granitoids from Sikhote-Alin have I_{Sr} = 0.7040 to 0.7083, and $e_{Nd}(T)$ = +3.0 to -6.0 (mostly 0 to -5). The Sr-Nd isotopic data fall within the range of granitoids from SW Japan (0.704 to 0.712; +5.0 to -13.0), and the data of Cretaceous granitoids from Sikhote-Alin and SW Japan overlap almost completely. Cenozoic granitoids of Hokkaido are characterized by I_{Sr} = 0.7044 to 0.7061, $e_{Nd}(T)$ = +1.0 to +4.7, and Sm-Nd model-1 ages = 400-1000 Ma. They are remarkably similar to Sakhalin granitoids with I_{Sr} = 0.7047 to 0.7050, $\varepsilon_{Nd}(T)$ = +2.8 to +3.7, and model-1 ages of 700-1100 Ma. The isotopic data suggest that the granitoids of NAOB were generated by partial melting of sources with mixed lithologies, including subducted accretionary complexes and probably some hidden Paleozoic to Proterozoic basement rocks. The Nd isotopic data also suggest a proportion of 30-77% of juvenile component in the generation of Sikhote-Alin granitoids, whereas the proportion is much higher for the Cenozoic granitoids of Hokkaido and Sakhalin (about 65-95%). In any case, a significant amount of juvenile crust was produced and added to the NE Asian Orogenic Belt.

Many workers have proposed a geological correlation between Sikhote-Alin and Japan, as well as between Sakhalin and Hokkaido, based on several lines of evidence including lithostratigraphy, biostratigraphy (radiolarian assemblages) and geological structures [6]. The present work lends support to the general scenario. However, the significant difference between SW Japan and NE Japan in their crustal composition and probably tectonic evolution has to be reckoned. The two geologic entities might have evolved in very different ways. A brief comparison of crustal evolution in the NAOB and CAOB will be presented. (Supported by MOST 104-2913-M-002-005, Taiwan)

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Keywords: NE Asia, accretionary orogen, Nipponides, grantoid, Sr-Nd isotopes, crustal evolution

Greater South China: it was larger than previously believed

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Long-remaining unsolved issues include the Neoproterozoic to Paleozoic geotectonics of proto-Japan, in particular, precise timing of the onset of the Pacific sudbduction (or tectonic turnover from a passive to an active margin) and the homeland o f Japan (North China or South China). To date, the nascent development of an arc-trench system of proto-Japan is reasonably constrained in timing to the early Cambrian or slightly older age. The other new view recently given by zircon chronology was the identification of older Precambrian detrital zircons and xenocrysts, in particular, the Neoproterozoic grains with similar ages to those of the South China basement. The North China block has been tradi tionally regarded as the homeland continent, along which Japan evolved. Detrital zircons of so-called Pan-African ages (ca. 1200-600 Ma) are identified, however, in various Paleozoic sandstones (Nakama et al., 2010; Isozaki et al., 20 14); in addition, zircon xenocrysts of the similar ages were also recognized in the Paleozoic granitoids (Aoki et al., 2015) . These ages are extremely rare in the North China block, whereas dominant in South China. The latest identification of the extensive Paleo- to Mesoproterozoic crusts in the Cathaysian part of South China cleared the difficulty in correlating Japan with South China. These data confirmed that Paleozoic Japan corresponded to an eastern extension of South China block prior to the Triassic collision with North China. This requires that the original South China block was much larger than the present conterminous mainland part, i.e., longer for more than 200 km to the northeast up to NE Japan, and the Greater South China (GSC) was proposed particularly for proper paleogeographic reconstruction of East Asia (Isozaki, 2014). The lastest information on the detrital zircon age spectra from the Paelozoic sandstones of the Sergeevka belt in Primorye (Far East Russia) further suggests that this domain resembles Japan, and South China in terms of sedimentary settings and provenance . In short, the GSC becomes much larger, nealry twice larger, than previsouly imagined.

Keywords: South China, Japan, Primorye, CAOB

The influence of upper plate tectonic inheritance in the southern Taiwan arc-continent collision

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Seismogenic strain inversions offshore SE Taiwan suggest that the Luzon forearc is detached from the Philippine Sea Plate (PSP) creating a forearc sliver. Both the origin and the fate of the forearc sliver remain unresolved, although tomographic work suggests that it exists at depth in the suture zone of the Taiwan orogen. I suggest this forearc material might play a role in the geodynamics of the collision. Recent studies of seismogenic strain, metamorphic fabrics and brittle deformation in the southern Taiwan mountains reveal non-recoverable strain patterns that are difficult to understand in the context of the ongoing collision. In spite NW motion of the Luzon volcanic arc at ~80 mm/yr relative to the Eurasian passive margin, the dominant expression of seismogenic strain and brittle faults is NE-SW maximum principal stretching. Extension is at a high angle to the PSP convergence vector and at a low angle to the strike of the slate and schist that dominates the southern Central Range. The stretching is expressed in inversions of focal mechanisms as preferred nodal planes with steep WSW and ENE dips accommodating normal motion, and as near vertical preferred nodal planes accommodating strike slip motion. These structural geometries are focused where peak temperature proxies reveal maximum temperatures, and leveling data reveal short-term uplift rates at their highest. To date, nearly all studies of the southern Central Range have sought to explain the uplift history and thermal structure in profiles constructed normal to the strike of the range. The predominance of structures accommodating NE-SW stretching suggests the possibility that crustal thinning and strike slip are playing a role in bringing metamorphic rocks to the surface. If this is correct, the rocks very clearly record non-plane finite strain and it is important to examine profiles constructed at high angles to the dominant strike of these structures (~N15W). Recent unpublished Ar-Ar ages suggest that these kinematics may be relatively young. In the Yuli belt, just west of the Longitudinal Valley, and in the easternmost slate belt the youngest metamorphic foliations generally dip shallowly and are marked by stretching lineations that plunge gently NE to NNE. Preliminary crystallization ages for minerals defining these fabrics are ~1 Ma. Importantly, the Yuli belt includes mantle-derived, high-pressure metamorphic blocks that tomographic, seismic and petrophysical data suggest are connected to their source at ~40-50 km by an east-dipping seismic (high) velocity anomaly. Exhumation of mantle-derived, high-pressure metamorphic rocks from such depths in a subduction channel would not necessarily predict shallow plunging stretching lineations. The relation between the shallow plunging stretching direction and the recrystallization depths for these rocks therefore remains an important question. It is possible that the shallow fabrics are a relatively recent transpressional overprint superimposed on a longer history of updip subduction channel flow. The influence of a tectonically buried forearc sliver is also important. The rocks of the forearc sliver may in effect form the leading edge of the Luzon volcanic arc backstop, making them a viable source for the high-pressure mantle rocks now at the surface in the Yuli belt. In addition to hosting a putative subduction channel marked by a coherent seismic velocity anomaly, this part of the collision is noteworthy for a voluminous aseismic zone that appears to reach the Earth surface in the Central Range east of the Yuli belt. Seismogenic strain in the rocks that span this enigmatic shoaling of the brittle-ductile transition varies systematically, suggesting a relatively strong contrast in rheology. Establishing the nature and origin of this aseismic volume will likely shed light on the geodynamics of the Taiwan arc-continent collision.

Keywords: Taiwan, seismogenic strain, collision, exhumation, normal fault

Orogenic processes in Taiwan and the role of changes in motion of the Philippine Sea Plate

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The Taiwan orogenic belt is often treated as a steady, southward propagating orogenic system with a steady erosion rate of 4-6 mm/yr since the collision began, 6-5 Ma. A few recent studies of the exhumation history, however, suggest that the collision was initially simultaneous and that the tectonic setting may have been more complicated. To better understand orogenic processes in Taiwan and their relation to past plate motions we evaluate the exhumation history in more detail and compare this history to different interpretations of orogenic evolution and to possible changes in motion of the Philippine Sea Plate 15 Ma to present. A more detailed view of the exhumation history comes from four new age-elevation transects from, north to south, the Central Cross-Island Hwy, the South Cross-Island Hwy, Mt Yu and an area around Small Ghost Lake in southern Taiwan. Mt Yu, is from the western Central Range whereas the remaining three are from the eastern part of the range. The age-elevation transects are based on 106 new and previously published (U-Th)/He and fission track ages of detrital zircon and apatite grains. The results show that all four sites record similar exhumation histories from about 5 Ma to the present, with slow apparent exhumation cooling (~ 0.1 mm/yr) from 5 Ma to about 1.5 to 2 Ma, moderate apparent exhumation cooling (3-5 mm/yr) from about 2 to 0.5 Ma and relatively fast exhumation cooling (5-8 mm/yr) from 0.5 Ma to present. Although several interpretations of the progressively increasing rate of exhumation cooling since 5 Ma are possible, we focus on two end-member hypotheses: 1) progressively thicker crust, possibly continental in composition, is subducted and possibly underplated and 2) the rate of convergence between the PSP and Eurasia plates increases at ~2 Ma and again at 0.5 Ma, which leads to greater shortening and higher rates of exhumation in the Central Range. To evaluate these hypotheses we examine the crustal structure in Taiwan using Vp and Vs tomography (Huang et al., 2015) and re-examine geologic and geophysical evidence for changes in motion of the PSP 15 Ma to present.

Keywords: plate tectonics, orogenic processes, collisions

Arc volcanism, forearc seismogenesis and interplate coupling in the Kuril-NE Japan subduction zone

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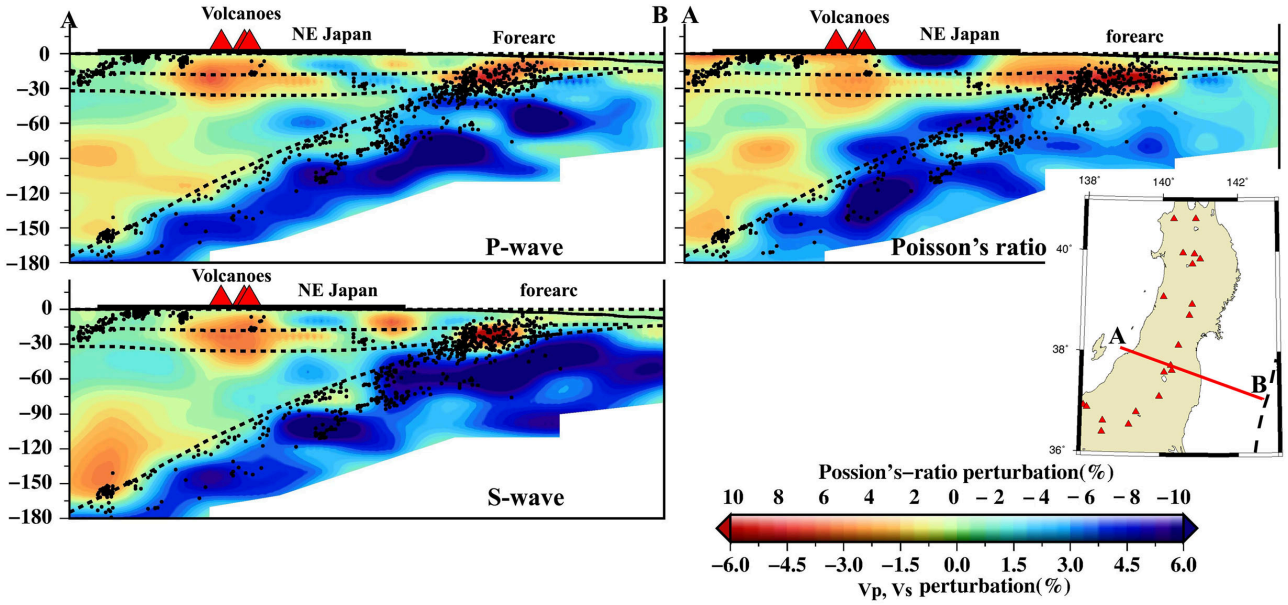
Subduction of the Pacific plate into the entire Kuril–NE (northeastern) Japan arc plays important roles in tectonic evolution, repeated occurrences of megathrust earthquakes (M >7.5) and arc volcanism and genesis of inland earthquakes. To improve our knowledge of crustal and upper mantle structures through tomographic imaging, we determined the three-dimensional (3-D) velocity (Vp, Vs) and Vp/Vs structures under the Kuril–NE Japan subduction zone. In this study, three groups of data sets are included in the hypocenter location process simultaneously with tomographic inversion. The first data group includes 385 offshore earthquakes, from which 2843 sP depth phases were identified. The second data group includes 3546 offshore earthquakes that occurred close to the first data group. The third group includes 13,603 onshore earthquakes that are located within the land-based seismic stations. The offshore hypoceters were relocated using the Master event location method (Wang and Zhao, 2006b, c). As a result, 3546 offshore earthquakes were selected from a large number of offshore earthquakes. Finally, a total of 413,032 P- and S-wave source-receiver pairs were collected from the 17,534 onshore and offshore earthquakes for imaging the P- and S-wave velocity and Vp/Vs structures.
A new method to invert Vp and Vp/Vs images simultaneously using a large number of high-quality arrival times of P-wave and S-wave source-receiver pairs from both onshore and offshore earthquakes is presented, indicating that the inverted Vp and Vp/Vs models are mutually correlative compared with the previous models. The hypocenters of the offshore earthquakes relocated by using sP phases jointly with the master-event location (MEL) method, enabling us to reliably image seismic structures not only under the onshore areas but also under the offshore areas. The Vp, Vs and Vp/Vs models provide compelling evidence for a highly hydrated and serpentinized forearc mantle and the fluids related to low-velocity and high-Vp/Vs anomalies associated with the slab dehydration (Figure 1). Significant slow anomalous Vp and Vs with a high-Vp/Vs ratio are clearly imaged along the volcanic front with an extended depth of ?100 km under the Kuril–NE Japan arc, showing good consistency with the results of previous studies, which is caused mainly by the fluids associated with the extensive dehydration of the subducting Pacific slab. More than 85% of the historical megathrust earthquakes (M >7.5) occurred in or around the high-velocity areas along the upper interface of the subducting slab under the forearc regions, suggesting strong interplate coupling (asperities) with the subducting slab. Alternatively, prominent low-velocity areas with high-Vp/Vs anomalies are revealed along the slab’s upper boundary in the offshore regions, which may reflect weak coupled or decoupled patches (aseismicity) of the plates caused by serpentinization of the forearc mantle wedge. Our study suggests that the fluid-related anomalies under the Kuril–NE Japan arc system, attributed to various processes such as slab dehydration and serpentinization of the forearc mantle wedge, are contributed mainly by arc magmatism, interplate coupling and the repeated generation of megathrust earthquakes.

Keywords: Subduction zone, Forearc seismotectonics, Arc magmatism



Lithospheric structure and composition of the Southern Marianas

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The 3000 km long Izu-Bonin-Mariana (IBM) arc system is an outstanding example of an intraoceanic convergent plate margin. The IBM forearc is a typical nonaccretionary convergent plate margin; the inner trench slope exposes lithologies found in many ophiolites including several km of mantle. To more clearly delineate the geology of the forearc, we have been investigating a ~700 km long region of the Mariana forearc south of ~13°N near Guam to the Yap Trench junction in 6 expeditions with the DSV Shinkai 6500 and deep-tow camera since 2006. Except for a few expeditions in 1970's, there have been no studies of the southern Mariana forearc west of the Challenger Deep. Data from our expeditions therefore provide a new perspective on the lithospheric structure and composition of the southern Mariana forearc. Most strikingly, mantle peridotite extensively crops out and has been sampled from the inner trench wall along the southernmost Mariana forearc.
Peridotites from the southwesternmost Mariana forearc near the Yap Trench junction area are strikingly fresh and have fertile compositions similar to those from the Parece Vela backarc basin [Ohara et al., 2003, G3]. The freshness of the peridotites indicates continuing protrusion of backarc-basin peridotite along the inner trench slope near the Yap Trench junction, possibly as a result of continuing backarc extension or collision of the Caroline Ridge.
Peridotites from near the Challenger Deep are exposed below the Moho as shallow as ~4500 m bsl and are heterogeneous, ranging from fertile lherzolites (i.e., backarc basin-like) to depleted harzburgites (i.e., forearc-like). In addition, we found that the forearc northeast of the Challenger Deep experienced rifting unusually close to the trench axis, exposing young (~ 3 Ma) basaltic lava with Mariana Trough backarc basin affinity [Ribeiro et al., 2013, Island Arc]. Earthquake foci also indicate that the forearc northeast of the Challenger Deep is a region of strong extension, and bathymetric data indicate that multiple tectonic rifts dissect it, indicating that diffuse extension occurs in the forearc.
We now argue that the southern Mariana forearc northeast of the Challenger Deep has heterogeneous lithospheric structure and composition, a mixture of those of backarc and forearc. A serpentinite-hosted ecosystem, the Shinkai Seep Field [SSF; Ohara et al., 2012, PNAS] is located in this area. SSF is a diffuse cold seep, serpentinite-hosted system that hosts an ecosystem mainly consisting of vesicomyid clams. We have tried to find other such seeps along the southern Mariana forearc during 2013 to 2015 expeditions, but no such seeps have yet been found, partly because these seeps are low-T and do not provide much of a thermochemical plume in the water column. We hypothesize that SSF vent fluid originated from seawater circulated within the shallow crust driven by the heat of young backarc-like magmatic intrusions. This mechanism is similar to that proposed for the Lost City hydrothermal field in the Mid-Atlantic Ridge [Allen and Seyfried, 2004, GCA]. We hypothesize that lithospheric mantle associated with forearc rifting is necessary for SSF-type seeps. This in turn suggests that finding where recent igneous activity has occurred in the southern Mariana forearc northeast of the Challenger Deep is the best strategy for finding new SSF-like seeps.

Keywords: southern Mariana forearc, peridotite, Shinkai Seep Field

The dynamics of double slab subduction from numerical and semi-analytic models

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Regional interactions between multiple subducting slabs have been proposed to explain enigmatic slab kinematics at a number of subduction zones, a pertinent example being the advancing motion (i.e. toward the upper plate) of the Izu-Bonin trench (Cizkova & Bina, 2014). An additional, important example is the rapid pre-collisional plate convergence of India and Eurasia during the Late Cretaceous, which is hypothesized to be due to the existence of two north-dipping subduction zones (e.g. Jagoutz et al., 2015). However, dynamically consistent 3-D numerical models of double subduction have yet to be explored, and so the physics of such double slab systems remain poorly understood. Here we augment fully numerical finite element models (CitcomCU) with semi-analytic subduction models (FAST: updated from Royden & Husson, 2006) to explore how subducting slab kinematics, particularly trench and plate motions, can be affected by the presence of an additional slab, with all of the possible slab dip direction permutations. A second subducting slab gives rise to more complex dynamic pressure and mantle flow fields and, for double slab systems within which the two slabs dip in the same direction (e.g. Izu-Bonin and Ryuku trenches, Late Cretaceous India-Eurasia), an additional slab pull force that is transmitted across the subduction zone interface. While the general relationships among plate velocity, trench velocity, asthenospheric pressure drop, and plate coupling modes are similar to those observed for the single slab case, we find that multiple subducting slabs can interact with each other and indeed induce slab kinematics that deviate significantly from those observed for the equivalent single slab models. Double subduction therefore provides a geodynamic mechanism to induce slab kinematics which differ drastically from those predicted from single slab experimental/modeling studies.
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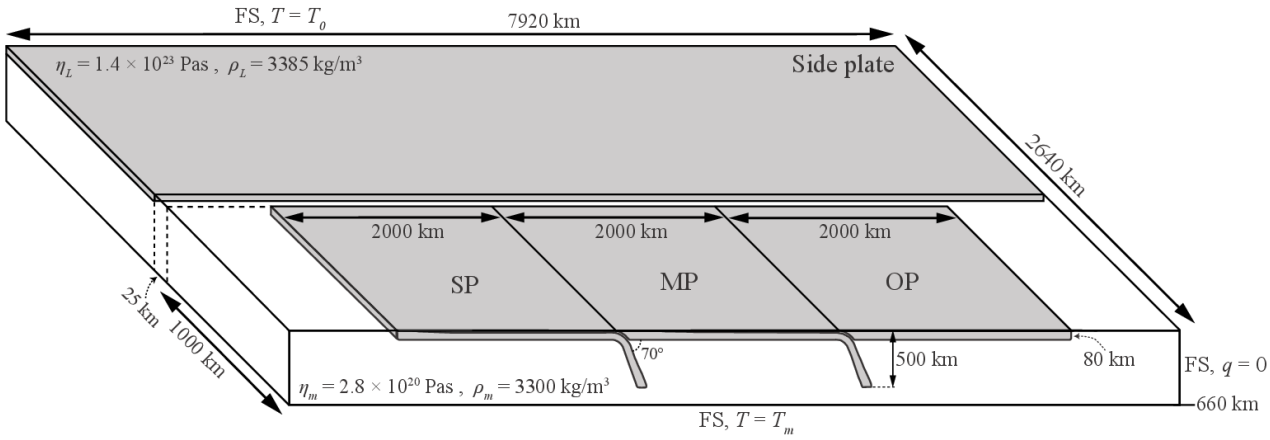
Keywords: Subduction, Convergence rates, Trench motion, Mantle wedge, Slab coupling

a) Schematic illustration of reference (numerical) model setup



b) Snapshot of modeled dynamic pressure, and mantle velocity (arrows), field