Proto-Japan and tectonic erosion: Evidence from zircon geochronology of blueschist and serpentinite

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ABSTRACT

Blueschist facies rocks in the Shikoku island of southwest Japan were extruded from depth as blocks in the Kurosegawa serpentinite mélange, where they occur in association with other tectonic blocks of tonalite-trondhjemit-granodiorite (TTG) rocks and calc-alkaline volcanics. Here we report magmatic zircons in the blueschist that yield 206Pb/238U mean ages in the range 505 ± 3 to 503 ± 3 Ma. These zircons crystallized at a mid-ocean ridge within basaltic rocks, and migrated to the continental margin of paleo-Asia. Subduction of the oceanic lithosphere into the mantle at a depth of ~40 km resulted in metamorphism under jadeite-glaucophane facies conditions at 250 Ma. The blueschist facies rocks were then exhumed to the surface along a splay fault connected with the forearc region through tectonic extrusion. Zircons separated from serpentinite yielded a 206Pb/238U mean age of 152 ± 3 Ma, marking the timing of serpentine protrusion to the surface, consistent with geologic constraints. The serpentinites also contain minor ca. 500 Ma zircons, similar to those in the blueschist. The predominance of detrital magmatic zircons from mid-oceanic ridge basalts (MORBs) metamorphosed and recrystallized into lawsonite-jadeite-glaucophane assemblages from the Kurosegawa zone in the Shikoku island of Japan. This zone is a typical serpentinite mélange belt that marks a large tectonic break in the accretionary complex, which has long been considered to grow oceanward continuously during continued subduction (Isozaki, 1997). However, such continuous growth of the continental margin is rare, and instead, extensive tectonic erosion occurs at convergent margins, leading to the destruction of continental crust (von Huene and Scholl, 1993; Clift and Vannucchi, 2004; von Huene et al., 2004; Yamamoto et al., 2013). The most representative geological units in this zone are exposed in the central part of Shikoku island (Fig. 2), where a chaotic zone of tectonically disrupted serpentinite mélangé occurs. The members of the zone are divided into 2 groups on the basis of scale; one is larger than 1.5 × 0.3 km, and the others, smaller than this, are called tectonic blocks.

INTRODUCTION

Pacific-type orogenic belts that incorporate typical accretionary complexes also carry potential information on oceanic slabs, including those that have been destroyed and are older than 200 Ma (Isozaki et al., 2010; Kusky et al., 2013; Safonova and Santosh, 2014). Thus, these accretionary orogens provide valuable information for reconstructing lost oceans, as illustrated in the case of the paleo–Pacific Ocean dating to 600 Ma (e.g., Maruyama et al., 1984, 1996, 1997). Oceanic crust generated at mid-ocean ridges or ocean island basalts in the Pacific domain were transported to subduction zones, consumed by subduction, and underwent blueschist facies metamorphism, returning to the surface along the Pacific margin through extrusion (Maruyama et al., 2009; Zhao et al., 2009, and references therein). Reconstructing the travel history of the oceanic lithosphere from ridge to trench and decoding the protolith ages as well as the timing of metamorphism are important challenges in understanding convergent margin processes and in evaluating paleogeography.

In this paper we show an example using magmatic zircons from mid-oceanic ridge basalts (MORBs) metamorphosed and recrystallized into lawsonite-jadeite-glaucophane assemblages from the Kurosegawa zone in the Shikoku island of Japan. This zone is a typical serpentinite mélange belt that marks a large tectonic break in the accretionary complex, which has long been considered to grow oceanward continuously during continued subduction (Isozaki, 1997). However, such continuous growth of the continental margin is rare, and instead, extensive tectonic erosion occurs at convergent margins, leading to the destruction of continental crust (von Huene and Scholl, 1993; Clift and Vannucchi, 2004; von Huene et al., 2004; Yamamoto et al., 2009). However, deciphering tectonic erosion in the past is a challenge, and here we demonstrate, through U-Pb geochronology of detrital magmatic zircons in blueschist facies rocks and serpentinite mélange, the timing of past tectonic erosion, and the time when erosion destroyed the hanging wall of tonalite-trondhjemite-granodiorite (TTG) crust.

GEOLOGICAL OUTLINE AND SAMPLING

The Kurosegawa zone of southwest Japan (Fig. 1) extends northeast-southwest for >1000 km along the strike of the southwest Japan arc parallel to the trench called the Nankai Trough, under which the Philippine Sea plate is being subducted (Isozaki, 1997; Maruyama, 1981a, 1981b; Maruyama et al., 1984; Hada et al., 2001; Hara et al., 2013). The most representative geological units in this zone are exposed in the central part of Shikoku island (Fig. 2), where a chaotic zone of tectonically disrupted serpentinite mélangé occurs. The members of the zone are divided into 2 groups on the basis of scale; one is larger than 1.5 × 0.3 km, and the others, smaller than this, are called tectonic blocks.

A north-south cross section of the southwest Japan arc including the Philippine Sea plate slab, subducting to 80 km, shows a prominent tectonic gap, suggesting missing accretionary complexes through time (Isozaki et al., 2010). Such age gaps might represent a break in the subduction-accretion system, or extensive removal through subduction erosion. Among the various age gaps, the largest is marked by a serpentinite mélange belt as a stratigraphic gap in the formation of the accretionary complex. This serpentinite mélange and its components define the Kurosegawa zone with a width of as much as 20 km that is widely developed in central Kochi, southwest Japan (Maruyama, 1981a, 1981b).
The dominant geological units in this belt are defined by Triassic, Permian, and Silurian tectonic units and smaller tectonic blocks and blueschist facies rocks (Maruyama et al., 1981a, 1981b). Serpentinite is one of the major constituents of the zone and is widely exposed in southwest Japan. In some places it forms large masses, whereas in others it forms discrete belts that extrude along faults and are several meters wide, and extend to several kilometers along the faults bordering tectonic units or large tectonic blocks. These tectonic units and blocks are also intruded by serpentinite. Small (<1 m³) tectonic blocks of amphibolite, albite-epidote-amphibolite, basic granulite, garnet-amphibolite, paragneiss, and glaucophane schists are also enclosed by serpentinite.

In the area north of Kochi, a large serpentinite mass extending westward for more than 18 km occurs in fault contact with mudstone and minor amounts of chert, sandstone, and greenstone that make up a typical accretionary complex that probably formed in the Jurassic. The contact between the serpentinite and the sedimentary sequence is concordant at some places but discordant elsewhere. Several tectonic blocks of high-pressure–high-temperature (P-T) schists occur in the northern part of the large serpentinite mass at the northeast corner of the study area (Fig. 3). The largest of these is 100 m³, although the other blocks are usually smaller, ~0.5 m³. The youngest tectonic blocks in the serpentinite belt are represented by the Triassic Kochigatani Formation (forearc sediments), and the belt is underlain unconformably by the lower Cretaceous Monobegawa Formation, formed ca. 120 Ma.

Representative samples for this study aimed at detrital zircon geochronology were collected from Engyoji, near Kochi, where blocks of these rocks occur within serpentinite mélangé belonging to the Kurosegawa zone (Fig. 4). This unit is covered on the top by sediments of the Chichibu belt. In the Engyoji area, several blocks of jadeite-lawsonite–bearing high-P–type blueschist facies rocks of a few meters occur within serpentinite. The rocks appear dark blue and are either massive and compact or exhibit schistosity. Coarse bluish domains and veins of jadeite are visible in the exposures. Epidote and pumpellyite occur as secondary minerals. Samples of blueschist were collected from three exposures in the area surrounding Engyoji. The serpentinite sample was collected from the Toyodenka Mine area, where serpentinites with very coarse grained antigorite and yellowish-green chrysolite are mined. Relict rounded and ellipsoidal blocks of peridotite also occur within the serpentinite matrix. Thin veins of rodingite with pinkish hydrogrossular are also developed at many places. Blocks of diopside are also embedded within the serpentinite matrix, which survived rodingitization. The serpentinite is traversed by metasomatic veins of magnesite and aragonite, suggesting passage of CO₂-rich fluids in the mantle wedge. Representative field photographs of the various rock types are shown in Figure 4.

**ANALYTICAL TECHNIQUES**

**Petrology**

Polished thin sections were prepared at the Peking University and at Tsukuba University. Petrographic studies were carried out using polarizing microscope.
Figure 3. Schematic north-south profile of the Kurosegawa tectonic zone in the Ino district of Shikoku showing the occurrence of blueschist blocks in serpentine mélangé (after Maruyama, 1981a). The samples were collected from these blocks and the host serpentine. F—formation; G.—group.

Figure 4. Representative field photographs of the blueschists and serpentinite from Kochi, Shikoku. (A) Block of jadeite-glaucophane blueschist. (B) Exposure of glaucophane, lawsonite, and phengite-bearing blueschist. (C) Serpentinite mélangé. (D) Serpentinite from which sample was collected for zircon separation and geochronology.
Zircon Geochronology

Zircon grains were separated from crushed rock samples by gravimetric and magnetic techniques, and then purified by hand picking under a binocular microscope at the Yu’neng Geological and Mineral Separation Survey Center (Langfang City, Hebei Province, China).

Cathodoluminescence (CL) imaging at the Beijing Geoanalysis Center used a scanning electron microscope (JSM-510) equipped with a Gantan CL probe, and transmitted and reflected light images were examined by petrological microscope. Individual grains were mounted onto double-sided adhesive tape and enclosed in epoxy resin discs. The discs were polished to a certain depth and gold coated for CL imaging and U-Pb isotope analysis. Zircon morphology and internal structure were examined using a JSM-6510 scanning electron microscope equipped with a backscatter probe and Chroma CL probe. The zircon grains were also examined under transmitted and reflected light images using a petrological microscope.

Zircon U-Pb analyses were determined by laser ablation–inductively coupled plasma–mass spectrometry housed at the National Key Laboratory of Continental Dynamics of Northwest University (Xi’an, China). The detailed procedures were described by Yuan et al. (2004). The laser spot diameter and frequency were 30 μm and 10 Hz, respectively. Zircon 91500 was employed as a standard and the standard silicate glass NIST 610 as a standard and the standard silicate glass NIST 610 was used to optimize the instrument. Raw data were processed using the Glitter program (data reduction software; http://www.glitter-gemoc.com/) to calculate isotopic ratios and 206Pb/238U, 207Pb/235U, and 208Pb/232U ages. Data were corrected for common lead according to the method of Andersen (2002), and the ages were calculated using Isoplot 4.15 software (Ludwig, 2003).

RESULTS

Petroleum

The high P-T schists in the Kurosegawa zone are mostly metabasites and metacherts. Previous studies (e.g., Maruyama et al., 1978; Maruyama 1981a, 1981b) reported high-P minerals such as jadeite, glaucophane, lawsonite, and chloromelane from these rocks. The protoliths could be deciphered in some cases as pillow lava, hyaloclastite, and massive lava as one group, and green schist and amphibolite as the other. These rocks have a low P-T metamorphic origin and their protoliths may have originally formed at a mid-ocean ridge. Amphibolites in such settings formed under more medium or high P-T conditions and have been correlated with a subduction initiation setting (Wakabayashi and Dilek, 2003). The Kurosegawa schists, derived from volcanic rocks, preserve rare augite as a relic mineral, and hyaloclastic textures that can be seen under the microscope. These metacarbonates underwent high P-T metamorphism. Textural and mineralogical evidence for protolith formation as MORBs and possible coeval metamorphism under low P-T conditions, followed by high P-T metamorphism in the subduction zone, were well documented (Maruyama et al., 1978).

Complex assemblages formed by high P-T metamorphism were described from the metabasite, including (1) lawsonite + glaucophane + jadeitic pyroxene, (2) lawsonite + pumpellyite + glaucophane + jadeitic pyroxene, and (3) lawsonite + pumpellyite + crossite ± chloromelane ± stipnomelane. Some metabasites do not contain quartz. Albite is rare. Accessory phases are phengite, titanite, apatite, calcite (aragonite), epidote, and opaque minerals including pyrite, chalcopyrite, and sphalerite. Metamorphosed cherts are dominated by quartz (>80%), and contain minor high P-T minerals such as lawsonite, glaucophane, crossite, graphite, quartz, and albite. Metamorphic pyroxenes are dominated by impure jadeite. Minor salite and chloromelane were also identified.

Representative photomicrographs of the samples analyzed in this study are shown in Figure 5.

All of these mineral assemblages have been interpreted to indicate the metamorphic facies as being of jadeite-glaucophane type formed at P-T conditions of 300–350 °C and 10–12 kbar (Maruyama et al., 1978). Potassium-argon dating of phengitic micas separated from typical lawsonite-glaucophane-jadeitic pyroxene schists yielded ages of 240–208 Ma, constraining the timing of metamorphism (Maruyama et al., 1978).

Zircon Geochronology

Representative CL images of the zircon grains from the different rocks analyzed in this study are shown in Figures 6 and 7. The U-Pb analytical data are given in Supplemental Data Table 1, and the data are plotted in concordia diagrams together with their combined age data histograms and probability curves in Figure 8. A brief description of the zircon characteristics and age results from individual samples is given in the following.

1GSA Data Repository Item 2016165, Supplemental Data Table 1, Zircon U-Pb age data from blueschist and associated rock in Kochi, Japan, is available at www.geosociety.org/pubs/ft2016.htm, or on request from editing@geosociety.org.

KBS-1—Blueschist

Zircon grains from this rock are colorless or slightly brownish, and show well-developed prismatic to stumpy morphology with clear and sharp grain margins. The grains show a size range of 60–120 μm × 50–100 μm and aspect ratios of 2.5:1–1:1. In CL images, the zircons display euhedral to subhedral grain contours with faint oscillatory zoning or clear patch zoning. Some grains occasionally have tiny, dark structureless cores (Fig. 6A). We analyzed 30 zircon grains from this sample. Their Pb, Th, and U contents are low and are in the ranges 14–56 ppm, 15–48 ppm, and 39–155 ppm, respectively (Supplemental Data Table 1). Their Th/U ratios (0.29–0.52) are >0.1, suggesting a magmatic origin. All the analyzed spots are highly concordant (cordance > 95%; see Fig. 8A; Supplemental Data Table 1). The data yield a 206Pb/238U mean age of 505 ± 3 Ma (mean square of weighted deviates, MSWD = 0.64, N = 30) (Fig. 8A).

KBS-2—Blueschist

Zircon grains from this sample are colorless or light brown. They all show well-developed prismatic to stumpy or negative crystal morphology. The grains are mostly euhedral with sharp grain contours, and show a size range of 80–160 μm × 70–160 μm with aspect ratios of 2.5:1–1:1. In CL images, all the zircon grains display clear oscillatory zoning (Fig. 6B). We analyzed 30 zircon grains from this sample; they show low Pb, Th, and U contents in the ranges 12–47 ppm, 10–51 ppm, and 32–122 ppm, respectively (Supplemental Data Table 1). Their Th/U ratios are in the range 0.30–0.57, suggesting a magmatic origin. All the analyzed spots are highly concordant (cordance > 95%; see Fig. 8B; Supplemental Data Table 1). The data yield a 206Pb/238U mean age of 503 ± 3 Ma (MSWD = 0.40, N = 30) (Fig. 8B).

KBS-2—Blueschist

Zircon grains from sample KBS-2-2 are colorless to brownish, and show prismatic to stumpy morphology. The grains are mostly euhedral with sharp grain contours and have a size range of 50–100 μm × 40–70 μm with aspect ratios of 2.5:1–1:1. In CL images, the zircons mostly display clear or faint oscillatory zoning (Fig. 7A). We analyzed 30 zircon grains from this sample, and the data show low Pb, Th, and U contents in the ranges 10–59 ppm, 10–80 ppm, and 27–164 ppm, respectively (Supplemental Data Table 1). Their Th/U ratios (0.29–0.61) are >0.1, suggesting a magmatic origin. The data show high cordance (>95%; Fig. 8C; Supplemental Data Table 1), and yield a 206Pb/238U mean age of 504 ± 3 Ma (MSWD = 0.65, N = 30).
We analyzed 21 zircon grains from this sample, and the data show >95% concordance (see Figs. 8D, 8E; Supplemental Data Table 1). Among these, 17 analyses with low Pb (6–43 ppm), and relatively high Th (40–262 ppm) and U (47–383 ppm) give a $^{206}\text{Pb}/^{238}\text{U}$ mean age of 152 ± 3 Ma (MSWD = 3.0, N = 17) (Fig. 8E). Two spots with low Pb (26–31 ppm), a Th content of 167–243 ppm, and a U content of 196–286 ppm yield slightly older $^{206}\text{Pb}/^{238}\text{U}$ ages of 172 ± 4 Ma and 189 ± 3 Ma, respectively. The remaining 2 analyses give $^{206}\text{Pb}/^{238}\text{U}$ ages of 500 ± 6 Ma and 561 ± 5 Ma, similar to those in the three blueschist samples (KBS-1, KBS-2-1, and KBS-2-2). Their Pb, Th, and U contents are higher than those in the other zircons from this sample and are in the ranges 136–160 ppm, 225–312 ppm, and 322–386 ppm, respectively (Supplemental Data Table 1). All the data show Th/U ratios of 0.38–1.64 (higher than those from other samples in this study), suggesting a magmatic origin. The magmatic zircons in the serpentinite are presumably of xenocrystic origin, trapped during sediment subduction and/or extrusion of mantle diapirs along faults, as is also inferred from the occurrence of several exotic blocks, together with features typical of extrusion along the Benioff thrust. The ca. 150 Ma age probably marks the timing of serpentinite extrusion along the forearc thrust.

Combined age data histograms of all the above data display a $^{206}\text{Pb}/^{238}\text{U}$ age peak at 504 ± 1.6 Ma (MSWD = 0.56, N = 91) with a subpeak at 152 ± 3 Ma (MSWD = 3.0, N = 17) (Fig. 8F).

**DISCUSSION**

**Age Data and Implications**

This is the first study to report magmatic zircons from blueschist facies regional metamorphic rocks in southwest Japan. The presence of magmatic zircons may indicate that the source rocks were SiO$_2$-oversaturated rocks such as MORB, and not oceanic island alkali basalts. The presence of magmatic zircons also suggests the formation of the rocks at a mid-ocean ridge. An alternative explanation would be an arc origin for the blocks in mélange; this would be consistent with a subduction-erosion scenario in which an arc-trench gap is partially or entirely removed by subduction erosion. Subduction erosion is thought to increase the inner trench slope angle, favoring the development of submarine landslides that would transport blocks of arc material from the upper plate to the subduction zone. In some cases these olistoliths were subducted along
with the matrix and were metamorphosed to produce blueschist facies assemblages (e.g., Wakabayashi, 2012). In this case, the metavolcanic rocks were considered to be volcaniclastic. An example, described by Utsunomiya et al. (2011), is the quartz eclogite from the border of the Iratsu eclogite mass in the Japanese Sanbagawa belt with its volcanic-rich turbidite protolith.

In the present case, the prominent oscillatory zoning in the zircon grains under CL and the lack of overgrowth around the magmatic core clearly suggest a lack of zircon recrystallization during the relatively low temperature blueschist facies metamorphism. Investigations on the timing of blueschist facies regional metamorphism have traditionally relied on K-Ar age dating of phengitic micas; Maruyama et al. (1978) applied this technique and reported ages of 240–208 Ma from the rocks we investigated in this study. These ages correspond to those of Sangun blueschist facies metamorphism (Isozaki et al., 2010), and constrain the timing of arrival of the oceanic lithosphere at the trench that marked the subduction margin along East Asia. If this interpretation is correct, blueschist facies rocks can be potentially used to date not only the birth of the protolith, but also the arrival time at a subduction zone. In the present case, the 500 Ma age from magmatic zircons dates the birth of the plate at the mid-oceanic ridge, and the K-Ar age of ca. 240 Ma from phengitic micas dates the subduction zone metamorphism.

Previous studies have classified the geotectonic history of Japan into two parts that were separated by the onset of oceanic subduction in the Cambrian (e.g., Maruyama et al., 1997; Isozaki et al., 2010). The first part is represented by a passive continental margin, whereas the second is characterized by an active margin. The evolution of proto-Japan is considered to have occurred along the passive continental margin of south China, particularly along the Cathaysian margin (e.g., Isozaki and Kase, 2014; Aoki et al., 2015). The ca. 500 Ma age obtained from zircons in the blueschists can also be used to demonstrate the site in the mid-Pacific Ocean. Figure 9A shows a reconstruction of the paleo-Pacific Ocean ca. 500 Ma and Figure 9B shows a schematic plate tectonic model. It is believed that the Neoproterozoic supercontinent Rodinia rifted and fragmented ca. 700–600 Ma (Hoffman, 1991; Maruyama et al., 2007), opening the Pacific Ocean. The records of this event have been well documented within the circum-Pacific orogenic belt; the oldest Pacific orogenic belt shares the same structural architecture of orogenic components. The structural top is occupied by so-called ophiolites, underlain by 500–450 Ma blueschist facies rocks that are, in turn, underlain by younger accretionary complexes intercalated with blueschist facies rocks every 100 m.y. down to the actively descending slab (Maruyama et al., 2009). Based on these records and geomagnetic configurations from polar wander paths for major continents (e.g., Maruyama et al., 1997; Isozaki et al., 2010), the site of the 250 Ma blueschist facies rocks can be speculated as having a mid-ocean ridge origin.

Figure 6. Cathodoluminescence images of zircons in blueschist samples KBS-1 and KBS-2–1.
Figure 7. Cathodoluminescence images of zircons in blueschist sample KBS-2–2 and serpentinite sample KBS-5C.

Figure 8. Age data concordia plots. (A) Blueschist sample KBS-1. (B) Blueschist sample KBS-2–1. (C) Blueschist sample KBS-2–2. (D, E) Serpentinite sample KBS-5C. (F) Histograms showing combined age data from all the samples. MSWD—mean square of weighted deviates.
Tectonic Scenario of the Kurosegawa Zone, Southwest Japan

The Kurosegawa zone is characterized by the ubiquitous occurrence of serpentinite over ~800 km along the zonally distributed orogenic belts in the southwest Japan arc (Fig. 1). The Kurosegawa zone is tectonically located on the top of the accretionary complexes that have grown downward since 600–500 Ma (Maruyama et al., 1978; Isozaki, 1997; Isozaki et al., 2010). The current Benioff plane is traced from the trench axis of the Kurosegawa zone (Maruyama et al., 1984). How- ever, recent discoveries have radically changed the general concept of subduction zone geology, particularly the identification of tectonic erosion and sediment subduction into the deep mantle (Fig. 10A), or even partial underplating beneath a volcanic front (von Huene and Scholl, 1993; Yamamoto et al., 2009). Subduction zones act as major pathways of material flux into the deep mantle, transporting substantial volumes of trench sediments and arc crust through sediment subduction and tectonic erosion (Santosh, 2010). Due to buoyancy, the subducted TTG material is stacked in the mid-mantle region and may not sink to deeper levels (Kawai et al., 2013). Another important finding from on-land geology concerns the ongoing processes along the Benioff thrust (Isozaki et al., 2010).

The mode of occurrence of rock components in the Kurosegawa zone with calc-alkaline volcanic-plutonic formations associated with deep-seated subduction zone complexes (blueschist) of the same age, paired at 450 Ma and 240 Ma, would suggest strong horizontal and vertical shortening occurring together (Maruyama et al., 1984). The time gaps between the formation of the accretionary complexes also suggest a sharp break, strengthening the case for tectonic erosion.

Paleogeographic Reconstruction of the Paleo–Pacific Ocean to 500 Ma

The U-Pb data from magmatic zircons in the blueschist samples presented in this study suggest (1) protolith formation ca. 500 Ma within the Pacific domain (Fig. 9B), (2) their travel to the convergent margin and arrival at the trench ca. 240 Ma, (3) their subduction accretion to the hanging wall, followed by (4) their extrusion and return to the surface by 150 Ma through the protrusion of serpentinitized mantle wedge.

The serpentinite protrusion aided in the exhumation of the blueschist facies rocks to the surface (Fig. 10B), probably along a thrust that developed within the trench-slope break at the forearc basement high. A modern analog for this is the nonvolcanic second arc between the Java trench and Sunda arc (Kadarusman et al., 2010).

Here a long, narrow serpentinite belt containing blocks of amphibolite and blueschist has developed along the forearc region, in addition to a regional blueschist belt, that represents one of the world’s youngest exhumation events along a subduction channel.

Paired Metamorphic Belts and Tectonic Erosion

Two paired metamorphic belts, now disrupted and fragmented, have been recognized in southwest Japan (Isozaki et al., 2010). The first is dated as 40–350 Ma and represents high P-T metamorphic rocks paired with ca. 400 Ma mylonitized granite together with garnet amphibolite, garnet amphibolite, paragneiss, and high-P granulites. The second and younger paired belt is represented by schist of the jadeite-glaucophane-type facies series in association with ca. 250 Ma so-called TTG granites.

All of these units were tectonically mixed and intruded by serpentinite defining the mélangé belt that extends for more than 1000 km from the Kanto Mountains near Tokyo to the central western end of Kyushu. The basal conglomerates in the belt contain serpentinite gravels, suggesting that the final tectonic adjustments of the...
two paired metamorphic belts were completed by the Early Cretaceous (ca. 120 Ma). Paired metamorphic belts do not form within the same domain, but represent two independent metamorphic units within the same arc-trench system (Isozaki et al., 2010). One forms under the volcanic front and the other along the Benioff thrust plane below the forearc basin. The 2 belts are separated by ~50 km laterally, and by ~30 km in depth. To tectonically juxtapose the paired belts strong horizontal movement is necessary, and a potential mechanism to achieve this is tectonic erosion. The Kurosegawa zone includes the two paired metamorphic belts, one ca. 400 Ma and the other 250 Ma. We therefore propose that erosion resulting in the complete destruction of mature arc crust into the deep mantle may have occurred in this region.

**CONCLUSIONS**

This study reports for the first time magmatic zircons in blueschist facies rocks from Shikoku, southwest Japan, that yield 206Pb/238U mean ages of 505 ± 3 Ma to 503 ± 3 Ma. These zircons are interpreted to have crystallized at a mid-ocean ridge within basaltic rocks, which migrated to the continental margin of paleo-Asia. The blueschist facies metamorphism probably occurred at 250 Ma when the oceanic lithosphere was subducted into the mantle depths of ~40 km, generating jadeite-glaucophane assemblages. These high-P rocks were exhumed through tectonic erosion enclosed within serpentinite.

Zircons separated from the serpentinite yielded a 206Pb/238U mean age of 152 ± 3 Ma, marking the timing of serpentine protrusion to the surface.

The serpentinite mélangé belt of Kurosegawa zone extends parallel to the active trench, and we consider this belt to be a marker of extensive tectonic erosion along a convergent plate boundary that led to the destruction of continental crust.

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**Figure 10.** (A) The process of tectonic erosion and sediment subduction (modified after the compilation in Santosh, 2010). (B) Schematic plate tectonic framework of subduction zone (modified after Maruyama et al., 2009) showing the zone of blueschist formation and its extrusion as blocks within serpentinites. HP—high pressure.
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