Estimate of subduction rate of island arcs to the deep mantle

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Evolution of life on the Earth is strongly related to the oceans and the continents, both of which are unique to the Earth. Continental materials contain a large amount of incompatible and radiogenic elements, which may affect terrestrial thermal history and chemical evolution, as well as the Earth’s surface environment. Geological studies have revealed that continental materials are subducted from the Earth’s surface via the following three mechanisms (e.g. Yamamoto et al., 2009): tectonic erosion, sediment subduction, and direct subduction of immature oceanic arcs, which are found, for example, in the western Pacific. In the first two processes, the continental materials are conveyed through subduction channels of thickness of 2-3km just above the subducting slabs, and therefore considerable amount of continental materials reaches 270 km depth (Ichikawa et al., 2013, 2014), below which the continental materials are denser than the surrounding mantle materials due to coesite-stishovite transition. Here, in order to estimate the subduction rate of continental materials of oceanic arcs to the deep mantle, we have conducted numerical simulations of subduction of arcs based on the finite element method, using relevant rheology models. The results show that the subduction rate highly depends on temperature profiles of the subducting slabs and the geometry of the arcs.

Keywords: island arc, subduction, numerical simulation

Archean to Paleoproterozoic polymetamorphic history of the Salma eclogite in the Kola Peninsula, Russia

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The tectonic and thermal evolution of the Precambrian Salma eclogite in Kola Peninsula, Russia, one of the oldest eclogites of the world, is significant key for understanding the Precambrian geodynamic mechanisms. However, there has been much debate about the timing of eclogite-facies metamorphism: Archean (2.72-2.70 Ga) or Paleoproterozoic (1.91-1.88 Ga). The controversy is due to the difficulty to decide which zircon formed during the eclogite facies metamorphism owing to the absence of garnet or omphacite inclusions in zircon. In this study, we present geochronological, petrographic, and geochemical data from the Salma eclogites. The Archean metamorphic zircons (2.73-2.72 Ga) that contain inclusions of garnet + amphibole + plagioclase + quartz + rutile ± biotite are unzoned grains with dark CL, and they are relatively enriched in HREE. In contrast, the 1.89-1.88 Ga sector, patched, and cloudy zoned zircons with pale grey CL include inclusions of garnet + omphacite + calcic clinopyroxene + amphibole + quartz + rutile ±biotite, and they have the flat pattern of HREE due to the amounts of abundant garnet during the eclogite facies metamorphism. Microstructural observations, P-T analyses, zircon inclusion analyses, and U-Pb zircon dating revealed multiple metamorphic stages that the Salma eclogite had undergone. The amphibolite facies metamorphic event firstly occurred at 2.73-2.72 Ga. In the Paleoproterozoic period, the Salma eclogites underwent prograde metamorphism from the epidote-amphibolite or amphibolite facies to eclogite facies metamorphism. The eclogite facies metamorphism occurred under the P-T condition of 16-18 kbar and 740-770 °C at 1.89-1.88 Ga, with a subsequent granulite facies metamorphism during decompression stage from 18 kbar to 9-12 kbar. Finally, later amphibolite facies metamorphism occurred at 8-10 kbar and 590-610 °C during cooling. Whole rock chemistry indicates that the Salma eclogite was originally tholeiitic basalt formed at the mid-ocean ridge. Our data suggest that the oceanic basalt was first metamorphosed at 2.73-2.72 Ga, and then deeply subducted to form the eclogite at 1.89-1.88 Ga, implying that the continent-continent collision between the Kola and Karelian continents occurred during the Paleoproterozoic, rather than the Archean. This and previous studies imply that the deep subduction accompanying eclogite may have begun in the Paleoproterozoic, and that the geothermal gradient in the Precambrian subduction zones gradually decreased, as evidenced by changes from the oldest Neoarchean high pressure granulite through Paleoproterozoic eclogite, to Neoproterozoic blueschist.

Keywords: Paleoproterozoic eclogite, Kola Peninsula, P-T-t path, polymetamorphism, subduction, geothermal gradient

Petrotectonic indicators for distinctive modern-style subduction zone

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Understanding how and when plate tectonics began on Earth and what came before is paramount for understanding the evolution of the solid Earth as well as its climate and biology. These questions are unresolved, with estimated beginnings that range from >4 Gya to <1 Gya. We were thus very interested to read a recent paper by Palin & White (2016) [Nature Geosciences] who argued that blueschist –metamorphic rocks formed during subduction– did not form on Earth until about 0.8 Gya because oceanic basalts were too Mg-rich prior to that time. We agree with their foundation assessment that the oldest blueschists are of Neoproterozoic age. We further agree: 1) presence of blueschists (or glaucophane-bearing rocks) indicate formation by modern-style subduction-driven plate tectonics; 2) importance of understand why these are missing from the first ~3.8 Gyr of Earth history; 3) absence is not a preservation artifact; and 4) that the thermal structure of subduction zones has not changed greatly since plate tectonics began. We question their conclusion that a change in oceanic crust composition was primarily responsible. Our refutation is based on the global inventory of other subduction-related indicators unlikely to be controlled by oceanic crust compositions. These include coesite- or diamond-bearing regional ultrahigh-pressure (UHP) metamorphic rocks, lawsonite-bearing rocks, jadeitites, and specific HP mineral (or mineral assemblage) in aluminous metasediments and metachert/quartzite, such as carpholite all of which first appear in the geologic record about the same time that blueschists occur. UHPs require subduction of continental crust to depths of at least 100 km and return to the surface. The initiation of UHP metamorphism near the Precambrian–Cambrian boundary could attest to an abrupt change in the subduction zone geothermal gradient due to large amounts of heat loss from the Earth’s interior (Maruyama & Liou 1998), but like the slightly earlier appearance of blueschists could indicate the beginning of subduction and plate tectonics in Neoproterozoic time. Lawsonite formation requires high-P/T metamorphic conditions, typically blueschist and low-T eclogite facies; lawsonite can also be found in very-low-grade pumpellyite–actinolite facies metabasalts but not in the prehnite–pumpellyite facies metamorphic rocks that dominate Archean greenstone belts. The oldest lawsonite-bearing rocks are latest Neoproterozoic in age, implying that sufficiently cold subduction-zone thermal structures for lawsonite formation had to wait until Late Neoproterozoic time to exist (Tsujimori & Ernst 2014); lawsonite is stable even in a MgO-rich basaltic composition. Jadeitite formation requires the direct hydrous fluid precipitation or the interaction of such fluid and subduction zone metamorphic rocks at a high-P/T condition within forearc mantle wedge. There are no know occurrences of the historically important and economically valuable rock jadeitite for the first ~4 Gyr of Earth history (Harlow et al. 2015), which is easily explained if subduction did not begin until Neoproterozoic time. The oldest aluminous metasediments and metachert/quartzite are Archean in age. However, the oldest Fe–Mg carpholite and/or talc+phengite, as indicative of blueschist-facies condition, in those rocks are Late Paleozoic in age. In addition to the aforementioned metamorphic assemblages, we also point out the ophiolite record; ophiolites are indirect indicators of subduction because many of these form during the formation of new subduction zones; the rest are backarc basins and normal oceanic crust (Stern et al. 2012). Although a few ophiolites are ~1.9 Gya, nearly all ophiolites are Neoproterozoic or younger. Taken together, the absence of blueschists and the other subduction indicators compels the conclusion that subduction –and modern-style plate tectonics– did not occur until Neoproterozoic time.

Thermal history and heat source of the southern part of Hidaka metamorphic belt

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The Hidaka metamorphic belt is an exposed collision zone of island arcs, in which the metamorphic grade increases from the east to the west reaching granulite facies in the western end. Shimura et al. (2015) measured zircon U-Pb ages of the Hidaka metamorphic belt and obtained ~37Ma for the eastern lower-grade zone and ~19Ma for the western higher-grade zone. On the basis of this systematic age zonation, they argued that the Hidaka metamorphic belt was formed through piling up of older and younger crustal sections. However, the heat source of metamorphism and magmatism has not revealed yet.
Peridotite bodies representing mantle materials are distributed along the west margin of the Hidaka metamorphic belt. The largest body, Horoman Peridotite complex, underwent heating and partial melting at the depth of >1GPa, followed by exhumation with cooling, particularly rapid cooling at the depth of <0.7GPa (Ozawa, 2004; Takahashi, 2001). Recent seismic studies in the southern part of the Hidaka metamorphic belt revealed a seismic structure characterized by an eastward-dipping wedge of mantle material extending towards the Hidaka main thrust (Kita et al., 2012). These mantle-side observations suggest that peridotite complex with high temperature played a role as a heat source for the Hidaka metamorphism and magmatism. We examined P-T-t path of metamorphic rocks exposed in the southern end of the Hidaka metamorphic belt, which is characterized by the densest distribution of peridotite bodies, and obtained U-Pb zircon age of the rim of grains from metamorphic rocks and tonalite in order to clarify heating mechanism of the Hidaka metamorphic belt.
There are a few small peridotite bodies along Nikanbetsu and Abeyaki rivers in southern end of the Hidaka metamorphic belt, around which pelitic and mafic metamorphic rocks belonging to granulite to hornblende facies and garnet-bearing tonalite are distributed. The pelitic gneiss consists mainly of Pl+Qz+Bt±Grt±Opx±Crd±Kfd and the mafic rock mainly of Pl+Qz+Hbl+Cpx, in which leucocratic veins consisting of Pl+Qz±Bt±Grt±Opx occur. Garnet-bearing metamorphic rocks and tonalite are distrubuted within the distance of 300m from Nikanbetsu and Abeyaki peridotite complexes, suggesting a temperature gradient toward the peridotite bodies. Metamorphic rocks distribute outside of the areas consists of of pelitic gneiss and mylonite characterized by Pl+Qz+Bt±Ms mineral assemblage and absence of leucocratic veins. The metamorphic rocks are bounded in the east by a large tonalite body with a thrust dipping toward the east., because the garnet-bearing zone is dependent on the spatial distribution of the peridotite mass. We investigated the chemical composition of minerals in the garnet-bearing zone. The. chemical compositions and zoning pattern of garnet and plagioclase grains show systematic spatial variations, suggesting a short-distance thermal gradient in the southern end of the Hidaka belt.
The large tonalite body distributed in the east give 36~39Ma U-Pb zircon ages, which is concordant with Shimura et al. (2015). The tonalite and metamorphic rocks distributed in the west yield 19~22Ma, This age is in accordance with or a alightly younger than the Rb-Sr isochron age of 23±1.2Ma obtained from phlogopite veins of the Horoman peridotite complex, which are thought to have formed during exhumation of the Horoman complex (Yoshikawa et al., 1993). These ages suggest that a hot mantle material acted as a heat source for metamorphism and magmatism in the Nikanbetsu and Abeyaki region. The thermal history of mantle material and subsequent cooling during uplift is recorded in the metamorphic rocks.

Keywords: Hidaka metamorphic belt, thermal history, heat source, garnet, zircon U-Pb age

Zircon SHRIMP U-Pb dating from the Horoman perdiotite –age constraint for tectonic juxtaposition of peridotite body into granulite in Arc-Arc collision zone-

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Hidaka metamorphic belt, Hokkaido, Japan is known as youngest arc-arc collision in the world. It is composed of medium pressure type metamorphic rocks and felsic to mafice intrusions. It also includes the youngest granulite and the Horoman peridotite complex in the highest grade zone. Age of these rocks have been determined by various methods (K-Ar, U-Pb, Rb-Sr). However, the age of Horoman peridotite complex has not been determined yet. Only Yoshikawa et al 1993) reported the cooling age of the complex as 23 Ma according to whole rock Rb-Sr isochron. This study has performed U-Pb dating of zircons from the Horoman peridotite, and from the paragneiss surrounding the peridotite xcomplex in order to determine the intrusive age of the Horoman peridotite complex into the lower crustal conditions. Several zircon grains were separated from the peridotite. All zircons are homogeneous exhibiting different age group; 267–278 Ma, 33-40 Ma and 18-20 Ma. As a result of this measurement, rims of the zircons from the gneisses show that ^{238}U-^{206}Pb ages are 20 Ma and detrital cores are rangin from 580-510 Ma, 60-50 Ma, 46-40 Ma and 27 Ma. The rim ages are from the gneiss suffered amphibolite facies and granulite faices, and there is a consistancy with zircon rim ages (19 Ma) from the granulite (Kemp et al 2007, Usuki et al 2006 and so on). That is, granulite faices metamorphism was coeval to regional metamorphism in the lower crust at 20 Ma. The zircon ages from the peridotite was probably related to local hydration related to precipitation of phlogopite at 20 Ma, I type magma infiltration at 40 Ma and lithosphere formation at 270 Ma. It is considered that the Horoman peridotite complex was part of the lithosphere at 270 Ma, and the joined as subarc mantle prior to I type magma activity at 40 Ma, aud suffered local hydration and regional metamorphism at 20 Ma.

Keywords: Horoman peridotite, zircon , multiple history of melt infiltration and hydration

Brucite as an important phase in the mantle wedge: evidence from the Sanbagawa belt, SW Japan

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Large parts of the shallow mantle wedge are thought to be hydrated due to release of fluids from the subducting slab and serpentinization of the overlying mantle rocks. If serpentinization proceeds under low SiO_2 activity, brucite can be a major phase in the low temperature (<450°C) part of the serpentinized mantle wedge, but only very few natural examples have been documented. Combined petrological, geochemical and field-based studies show that brucite is widely distributed in the wedge mantle-derived Shiraga metaserpentinite body in the Sanbagawa metamorphic belt of SW Japan. Thermodynamic modeling combined with bulk rock composition and point counting indicates the original fully hydrated shallow parts of the Sanbagawa wedge mantle contained ~10-15 vol.% brucite before the onset of exhumation of the Shiraga body and before peak metamorphic conditions. A distinct zone of brucite-free essentially monomineralic antigorite serpentinite occurs limited to a 100-m thick marginal zone of the body. This supports the idea of a limited degree of Si-metasomatism by slab-derived fluids in the shallow mantle wedge. The presence of brucite may strongly affect the H_2O budget and mechanical properties of serpentinite, these should be taken into consideration when examining the behavior of the shallow wedge mantle.

Keywords: wedge mantle , brucite, Sanbagawa metamorphism

Transportation of an organic carbon related to Jurassic ridge-hydrothermal biosphere into deep mantle: evidence from the Sanbagawa eclogite, Japan

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In order to know the fate of an organic carbon in deep subduction zone, we have observed the Sanbagawa eclogite (Tonaru eclogite) accompanying cupper-iron sulfides (so called Besshi mine type Cu-Fe sulfides). The sulfides are considered as precipitates related to the Jurassic ridge-hydrothermal alteration. In the eclogite, Cu-Fe sulfides contain silicate with graphite along cracks. The rims of the sulfides are replaces as Fe-Cu oxides. It is considered that the graphites were on the sulfide and along the interstitial domain such as cracks then rim of the oxides were overgrown. The graphite crystallization temperature calibrated using laser Raman peak shift, is estimated lower than 300 ^{o}C. It is obviously lower than that of the metamorphic temperature of the eclogite 550-600 ^{o}C. It clearly suggests that graphite was probably from the micro-bacteria with Cu-Fe sulfides in the hydrothermal zone in the Mid-oceanic ridge system. It is well known that the Cu-Fe oxides were formed in high P/T Sanbagawa metamorphism. Therefore overgrowth of the oxides on the studied sulfide-graphite association were in deep subduction zone. In summary, the Jurassic ridge-hydrothermal alteration provides bacteria cluster, and subsequently the organic carbon would be recycled down deep in the mantle via subduction zone.

Keywords: Jurassic ridge-hydrothermal biosphere, Subduction of organic carbon , Sanbagawa eclogite

