

SCG065-01

Room:301B

Time:May 23 14:15-14:30

## The formation and subduction of continental crust: session scope

Shinji Yamamoto<sup>1\*</sup>, Tsuyoshi Komiya<sup>2</sup>, Kenji Kawai<sup>1</sup>

<sup>1</sup>Tokyo Institute of Technology, <sup>2</sup>The University of Tokyo

Previous studies of Archean geology, geochemistry of detrital materials and comprehensive investigations of subduction zones have provided great insights into the evolution of continental crust and mantle, but simultaneously raising another questions, thus offering new perspectives. Especially, subduction of continental material into the mantle is a key to better understand the evolution of continents and mantle. Here I briefly overview continental growth and destruction models ever proposed, and introduce for the session scope.

There is a long-standing controversy when and how continents formed. Recent active studies on U-Pb and Lu-Hf systematics of detrital zircons reveal the processes of crustal evolution on a global scale from the Hadean to the present. They propose that the formation of continental crust started from 4.4 Ga and that at least 70% volume of the existing continental crust were produced from the mantle before 2.5 Ga. Moreover, considerations of thermal evolution for the Earth mantle have proposed that rapid continental growth happened in the Hadean to Archean because higher mantle temperature in the Hadean to Archean must produce extensive amounts of TTG magma and that presumably more than 100% of the present continental crust must have been formed on the ancient Earth. However, Archean crust is preserved only in small portion (~10%) of Earth surface, and vestiges of Hadean crust are only Acasta gneiss complex and Jack Hills detrital zircons. To explain little preservation of ancient crust, it is suggested that the small areal preservation of Archean crust is a result of reworking of older crust and/or long term subduction of Archean TTG into the mantle.

Subduction and recycling of differentiated material into the mantle are of considerable significance for making mantle heterogeneity. Continental crust has been returned to the mantle at subduction zones, in the styles of sediment subduction, subduction erosion, arc subduction and continental subduction. Geophysical and geological investigations at modern subduction zones document that the amount of subducting continental material versus arc produced at the subduction zone have been balanced, resulting in no volumetric growth of continental crust, probably from Archean to present. Applying Cenozoic recycling rates of continental crust into the mantle ( $2.5\text{-}3.7\text{ km}^3/\text{yr}$ ), a volume of crust equal to the standing inventory of  $7 \times 10^9\text{ km}^3$  can be removed from the surface during past 1.9-2.8 G.y. However, the above-mentioned estimates still remain unclear because the supply rate of juvenile crust from the mantle and subducted continental material into the mantle in the ancient Earth are poorly constrained.

Previous isotopic and trace element studies of OIBs have suggested the presence of long-lived recycled components related to ancient continental crust stored in the deepest mantle. However, subducted granitic material is expected to be trapped at the bottom of the upper mantle. Because, subducted granitic material is no longer buoyant over a depth of 250 km in the mantle. Thereafter, continental material will be buoyant again compared to surrounding mantle at the base of the transition zone. However, there is no geophysical observation for the accumulation of the granitic material at the mantle transition zone. There has been controversial what produces anomalous seismic-wave velocity and density changes at depths of 400 to 700 km. Recent experimental and theoretical studies suggested that the PREM velocities are higher than those of both adiabatic pyrolite and piclogite in the lower part of the mantle transition region. Subducted granitic material can produce anomalous velocity and density discrepancy in the lowermost transition zone.

Keywords: formation of continental crust, subducted continental crust, Hadean to present, fate of subducted granitic material

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Room:301B

Time:May 23 14:30-14:45

## Mineral inclusion thermobarometry in >4 Ga Jack Hills zircons provides constraints on Hadean geodynamics

Michelle Hopkins<sup>1\*</sup>, T. Mark Harrison,<sup>2</sup> Craig E. Manning<sup>2</sup>

<sup>1</sup>University of Colorado, <sup>2</sup>University of California

Detrital zircons from the Jack Hills of Western Australia provide an important record of terrestrial conditions during the Hadean Eon (ca. >4 Ga). Mineral inclusions captured in these ancient zircons add an extra dimension to our knowledge of Hadean Earth. The inclusion population is dominated by the presence of quartz and muscovite, most apparently primary to these igneous zircons. Several lines of evidence support this view and argue against widespread exchange between most of these inclusions and their environment: (i) lack of association with cracks; (ii) magmatic crystal forms; (iii) absence of exchange with fuchsitic (Cr-rich) micas in the host conglomerate; and (iv) the heterogeneity in Sipfu values. We report new data on Ti concentration in quartz inclusions within Hadean zircons. The factor-of-10 difference in Ti content among included quartz grains is evidence against chemical communication between the host quartzite and inclusions, since the Jack Hills quartzite contains rutile which was mobile during metamorphism at ca. 2.5 Ga. Using the recently calibrated Ti-in-quartz thermobarometer yields a narrow range of pressure (20 $\pm$ 2 kbar) for the three samples. This is in broad accord with the pressure range estimated for included muscovites with  $\sim$ 3.4 Sipfu (18 $\pm$ 9 kbar). Taken together, the Hadean zircon inclusion assemblages yield estimates of magmatic P-T conditions from 5 to ca. 20 kbar at 700 $\pm$ 40 C further supporting their formation under geotherms of  $\sim$ 60 C/km thus implying conductive near-surface heat flow of ca. 20 to 80 mW/m<sup>2</sup>. Of all formational environments that satisfy the spectrum of geochemical constraints available and the inference of melt generation under suppressed heat flow, the most plausible appears to be partial melting of both juvenile and mature continental sediment via continuous underthrusting beneath a stable upper plate. We postulate that this melting could occur two different ways: fluxed melting of underthrust sedimentary material, or fluxed melting of the upper plate due to plate dehydration or degassing of hydrous magma in the underthrust environment.

Keywords: zircon, Hadean, inclusion, thermobarometry, U/Pb age, Jack Hills

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Room:301B

Time:May 23 14:45-15:00

## No evidence of Hadean granitic crust from monazites

Tsuyoshi Iizuka<sup>1\*</sup>, Oliver Nebel<sup>1</sup>, Malcolm McCulloch<sup>1</sup>

<sup>1</sup>Australian National University

The oldest identified terrestrial materials are Hadean (>4.0 Gyr ago) detrital zircons from Mount Narryer and Jack Hills metasediments in the Narryer Gneiss Complex, Western Australia, that potentially contribute to our understanding of the evolution of the early Earth. The zircons have been documented to contain inclusions of muscovite, quartz, K-feldspar, biotite and monazite. The hydrous, peraluminous inclusion assemblage has been taken as evidence that the zircons crystallized from granitic (*sensu stricto*) melts, with implications for the existence of plate boundary interaction and sedimentary recycling in the Hadean era. However, neither monazite inclusions in the zircons nor detrital monazites from the metasediments have U-Pb ages older than 3.6 Gyr, requiring either that the inclusions are not primary origin but grew along cracks in the zircons or that Hadean igneous monazites were preferentially recrystallized during later metamorphism. Here we present micrometre-scale, *in situ* Sm-Nd isotopic ratio measurements of the detrital and metamorphic monazites from the Mount Narryer and Jack Hills metasediments. The data reveal that older monazites are source of light rare earth elements for younger metamorphic monazite formation and, therefore, that monazite could inherit its primary Sm-Nd isotopic signature during the recrystallization processes. These findings, combined with the U-Pb and Sm-Nd isotope systematics of the detrital and metamorphic monazites, indicate that no igneous monazites older than 4.0 Gyr were recrystallized to form the monazites. Our results therefore suggest that the source rocks of >4.0-Gyr-old detrital zircons contained few monazites and the inclusions are secondary origin, eliminating the evidence for Hadean granitic crust.

SCG065-04

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## Slab melting as a key to understand origins of continental crust and mantle reservoirs "EM1 and EM2"

Gen Shimoda<sup>1\*</sup>

<sup>1</sup>Geological Survey of Japan, AIST

It has been widely accepted that at least three enriched geochemical reservoirs must exist in the mantle to explain the isotopic diversity of ocean island basalts (OIBs). These reservoirs are known as enriched mantle 1 (EM1), enriched mantle 2 (EM2) and high-u (HIMU;  $u = 238\text{U}/204\text{Pb}$ ) (e.g., White, 1985; Zindler and Hart, 1986). Understanding the origins of these reservoirs is essential for understanding Earth's chemical evolution and thus many studies have been conducted. Proposed origins for HIMU (and FOZO) is recycling of oceanic crust, namely, single process has been widely accepted. Origins of EM1 and EM2, on the other hand, are still divergent: (1) recycling of oceanic crust with variable amounts of continental crustal materials via sediment subduction or tectonic erosion, (2) delamination of continental crust, or (3) recycling of metasomatized oceanic lithosphere (e.g., McKenzie and O Nions, 1983; Weaver, 1991; Chauvel et al., 1992; Hofmann, 1997; Stracke et al. 2003, 2005; Workman et al., 2004; Willbold and Stracke, 2006). Recent studies of the origin of EM1 and EM2 suggest that the source materials of these magmas have variable chemical and isotopic compositions, suggesting that continental crustal material recycling via tectonic erosion can be a suitable origin of these magmas, because chemical variations of continental crust are much greater than those of oceanic crust (Willbold and Stracke, 2006). Although the proposed models successfully explain the origin of EM1 and EM2 reservoirs, a study that examines the relationship between ancient subduction zones, production of continental crust, and isotopic variations between EM1 and EM2 reservoirs could yield significant information. Geochemical modeling of the origin of EM1 and EM2 is, therefore, conducted from the perspective of slab melting, i.e., adakite production. For the model, the average composition of adakites is estimated from literature data for 18 trace elements. The estimated adakite composition can be explained by melting of oceanic crust without sediment contribution. The compiled data further suggest that the mantle-slab melt reaction would play a major role in the production of basic adakites. In addition, crystal fractionation in the magma chamber should produce additional chemical variations in adakites, in particular for acidic adakites. To test the effect of chemical variations on the isotopic composition of recycled adakites, correlations between trace elements and  $\text{SiO}_2$  concentrations, and the MELTS program are employed. The results suggest that recycling of a basic adakite ( $\text{SiO}_2 = 55\%$ ) can account for EM1 isotopic signatures with age of about 2.0 Gyr. The isotopic compositions of less-basic adakites and their evolved magmas shift towards EM2 values with increasing  $\text{SiO}_2$  concentrations. In particular, evolved acidic adakite can yield EM2 isotopic signatures. These lines of evidence suggest that the recycling of adakites at various stages of evolution can conceivably produce the entire isotopic range between EM1 and EM2 reservoirs. Consequently, adakite recycling via sediment subduction or subduction erosion can account for the origins of EM1 and EM2 reservoirs. In this context, residual garnet under high pressure and plagioclase fractionation at low pressure might play an essential role in producing the chemical variations among adakites that ultimately govern the isotopic compositions of these geochemical reservoirs.

Keywords: slab melting, adakite, EM1, EM2, continental crust

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## Crystal differentiation trend of TTG rocks

Yoshiaki Kon<sup>1\*</sup>, Tsuyoshi Komiya<sup>2</sup>

<sup>1</sup>Geological survey of Japan, AIST, <sup>2</sup>University of Tokyo

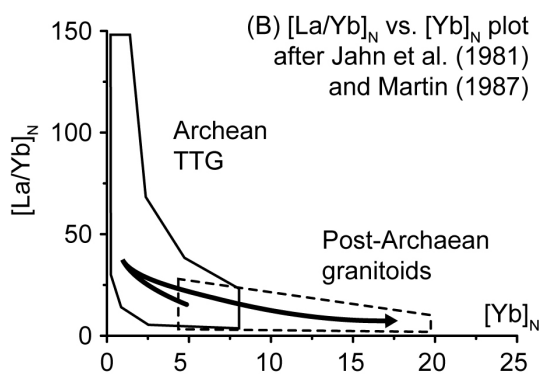
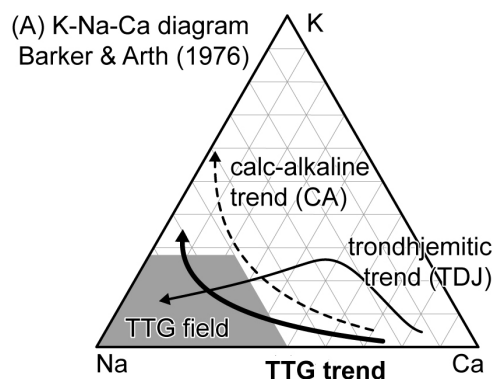
Continental crust is the key and unique system of the Earth, thus its formation and growth strongly affect not only dynamics and evolution of the solid Earth but also climate and biological evolution on the surface. TTG (tonalite, trondhjemite, granodiorite) has an important role for continental growth of early earth, and its origin has been investigated. It is essential to estimate chemical compositions of the primitive magma that to understand the compositional changing along fractional crystallization and crustal assimilation. In this presentation, chemical compositions of TTG are compiled, and we make a revisional study for its fractional crystallization trends.

**Major element :** Although TTG is a part of *sensu lato* calc-alkaline series, it is distinguished from *sensu strict* calc-alkaline series (Nockolds and Allen, 1953) by its high Na-content (Fig. A). Generally, *sensu lato* calc-alkaline series shows positive correlation between Ca content and K/Na ratio. This trend was determined using Ca-Na-K composition of andesitic to granitic rocks (Nockolds and Allen, 1953; Barker and Arth, 1976). On the other hand, a trondhjemite-trend has negative correlation between Ca content and K/Na ratio (TDJ trend: Barker and Arth, 1976). However, this trend was determined using Archean bimodal trondhjemite-basalt suite, and there was no typical correlation among granitic rocks. Therefore, Martin (1994) proposed a trondhjemite (TDH)-field which Na-rich granitoids were classified (Fig. A). However, TDJ trend was still used as a fractional crystallization trend of TTG rocks, to distinguish from *sensu lato* calc-alkaline trend.

However, each TTG suits have also positive correlation between Ca content and K/Na ratio (e.g. Kleinmanns et al., 2003). It suggests that TTG rocks has a fractional crystallization trend, and it changes along *sensu lato* calc-alkaline trend (Fig. A).

**REE :** Adakite are and/or Achaean TTG are well known as a HREE-depleted rocks, and its origins are considered as a partial-melting of hydrated basalts under garnet-stability field (e.g. Arth and Hanson, 1972). To discriminate these rocks,  $[La/Yb]_N$ - $[Yb]_N$  plot has been used (Fig. B: Jahn et al., 1981). Although, these rocks have high  $[La/Yb]_N$  ratio (5-150) and low  $[Yb]_N$  value ( $<8.5$ ) (Martin, 1987), most samples have relatively low  $[La/Yb]_N$  ratio ( $<50$ ). For some adakite,  $[La/Yb]_N$  has positive correlation to  $SiO_2$  content while  $SiO_2$  content was low, and it has negative correlation to  $SiO_2$  content while  $SiO_2$  content was high (e.g. Richards and Kerrich, 2007). It was well explained by fractional crystallization of hornblende and plagioclase. It means that HREE-depleted granitoids can also made by fractional crystallization.

**References** Arth and Hanson (1972) *Contrib. Min. Pet.*, **37**, 161-174., Barker and Arth (1976) *Geology*, **4**, 596-600., Jahn et al (1981) *Geochim. Cosmochim. Acta*, **45**, 1633-1652., Kleinmanns et al (2003) *Contrib. Min. Pet.*, **145**, 377-389., Martin (1987) *Precam. Res.*, **35**, 257-276., Martin (1994) *Archean Crustal Evolution*, 205-259., Nockolds and Allen (1953) *Geochim. Cosmochim. Acta*, **4**, 105-142., Martin (1994) *Archean Crustal Evolution*, 205-259., Richards and Kerrich (2007) *Economic Geol.*, **102**, 537-576.



Keywords: granite, TTG, calc alkaline, REE

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Room:301B

Time:May 23 15:30-15:45

## Age of the arc lower crust from mafic enclaves in the Tanzawa tonalites, Izu Arc, Japan

Kazue Suzuki<sup>1\*</sup>, Shinji Yamamoto<sup>1</sup>, Yibing Li<sup>1</sup>, Takafumi Hirata<sup>2</sup>, Yoshiaki Kon<sup>3</sup>, Soichi Omori<sup>1</sup>, Shigenori Maruyama<sup>1</sup>

<sup>1</sup>Tokyo Institute of Technology, <sup>2</sup>Kyoto University, <sup>3</sup>AIST

The continental lower crust comprises approximately half of the bulk continental crust and plays a significant role in making the continents. According to seismic observations and studies of crustal xenoliths, the continental lower crust is thought to consist of amphibolites and/or granulite (Christensen and Moony, 1995). However, petrology and chronology of the continental lower crust still remain open questions because it is usually not exposed on the surface of the continent.

To obtain the relevance and age constraints of the continental lower crust from common occurrence of granitic rocks, we propose a new method of U-Pb zircon dating from mafic enclaves in granites with LA-ICP-MS. Zircons can survive and retain their crystallization ages even in the metamorphic overprints and magmatic modifications. In this study we collected the mafic enclaves in Tanzawa tonalites (4-5 Ma by SHRIMP: Tani et al., 2010), in the Izu collision zone, Japan. The Tanzawa tonalites are intrusive to gabbro (5-6 Ma: Tani et al., 2010) and Tanzawa group (basalt detritus in 3-17 Ma: Aoike, 1997). The mafic enclaves show textures, which suggest mixing with the surrounding tonalite. SiO<sub>2</sub> content in mafic enclaves varies from 46.99 to 58.26 wt%. The enclaves are considered to have two or more origins because of their various lithologies from amphibolite to doleritic basalt. We separated 355 zircon grains from nine mafic enclaves and 46 grains from the host tonalite and analysed them using LA-ICP-MS at Kyoto University and Advanced Industrial Science and Technology.

The zircon age population from tonalite show relatively narrow range distribution around 5 Ma, resulting in mean age of  $4.7 \pm 1.5$  Ma, which corresponds to the U-Pb zircon ages previously determined by SHRIMP (Tani et al., 2010). While the zircon age population from mafic enclaves in tonalite show wide range distribution from 5 to 43 Ma, most of zircons yielded around 5 Ma. This result implies that the mafic enclaves were affected and/or mixed with the tonalitic magma at when the mafic enclaves were incorporated. Zircons of ages older than 5 Ma in the mafic enclaves would be originated from rocks surrounding the Tanzawa tonalites. Because the Tanzawa group (3-17Ma) and the gabbro suite (5-6Ma) are intruded by the Tanzawa tonalites, they are probably the origin of the zircons which yielded around 6-20Ma. On the other hand, the zircons showing older than 20Ma have to be originated except from the Tanzawa group and the gabbro suite. Because Tanzawa group is the juvenile arc basalt on the Philippine Sea Plate plate, there is nothing except the arc lower crust beneath Tanzawa tonalitic pluton which is older than Tanzawa group. Thus, the zircons which yielded 20-43Ma must be originated from the arc lower crust. The oldest zircon age ( $42.9 \pm 8.6$ Ma) implies that the arc lower crust formed by at least  $42.9 \pm 8.6$ Ma. It is correspond to the estimate that proto-Izu-Bonin arc had initiated subduction by 48Ma (Seno and Maruyama, 1984). Our result from this study implies that the zircon U-Pb dating for mafic enclave in continental crust can provide a new data for age distribution of the continental lower crust.

Keywords: continental lower crust, mafic enclave, zircon, U-Pb dating, LA-ICP-MS, granite



# Japan Geoscience Union Meeting 2011

(May 22-27 2011 at Makuhari, Chiba, Japan)

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Time:May 23 15:45-16:15

## Arc-generated blocks with crustal sections in the West Greenland: Crustal growth in the Archean with modern analogues

Brian Windley<sup>1\*</sup>

<sup>1</sup>University of Leister

The ca. 700 km long, Archean craton of West Greenland consists of six Meso-Neoproterozoic (ca. 3000 - 2720 Ma) shear zone - bounded crustal blocks that display similar cross-sections; from south to north Ivittuut, Kvanefjord, Bjornesund, Sermilik, Fiskefjord, Maniitsoq. Each block has a southerly upper and a northerly lower zone, thus each faces upwards to the south. Upper zones have prograde amphibolite facies mineralogy and have never been in the granulite facies, whereas lower zones reached granulite facies and were partly retrogressed to amphibolite facies. Upper and lower zones consist predominantly of tonalite - trondhjemite - granodiorite (TTG) orthogneisses; geochemistry suggests generation by slab melting in subduction settings of island arcs and active continental margins. These crustal blocks provide an exceptional example of how continents evolved in the Meso - Neoproterozoic. Comparable Archean examples in Kapuskasing and Pikwitonei (Canada) and modern analogues in Fiordland (New Zealand), Kohistan (Himalayas), Southern California batholith, Peruvian Andes, and Hidaka (Japan) demonstrate that processes of continental growth from island arc to continental arc magmatism (and by implication to continental collision) were broadly similar throughout most of Earth history.

Keywords: crustal block, amphibolite, anorthosite, TTG, island arc, Archean

SCG065-08

Room:301B

Time:May 23 16:30-16:45

## True Continental growth

Tsuyoshi Komiya<sup>1\*</sup>

<sup>1</sup>Komaba, University of Tokyo

Continental crust is very important for evolution of life because most bioessential elements are supplied from continent to ocean. In addition, the distribution of continent affects climate because continents have much higher albedo than ocean, equivalent to cloud. Conventional views suggest that continental crust is gradually growing through the geologic time and that most continental crust was formed in the Phanerozoic and late Proterozoic. However, the thermal evolution of the earth implies that much amounts of continental crust should be formed in the early Earth. This is Continental crust paradox.

Continental crust comprises granitoid, accretionary complex, sedimentary and metamorphic rocks. The latter three components originate from erosion of continental crust because the accretionary and metamorphic complexes mainly consist of clastic materials with minor basaltic oceanic crust. Granitoid has two components: juvenile component through slab-melting and recycling component by remelting of continental materials. Namely, only the juvenile component of granitoids contributes to net continental growth. The remains originate from recycling of continental crust. The estimate of continental growth is highly varied. Thermal history implied the rapid growth in the early Earth, whereas their present distribution suggests the slow growth. Mantle composition suggests the moderate increase in the Proterozoic to Phanerozoic. The former regards continental recycling as important whereas the latter regarded as insignificant. Continental recycling has three components: intracrustal recycling, crustal reworking, and crust-mantle recycling.

We calculate true continental growth including continental formation and recycling. We changed a recycling rate, and find an answer to satisfy five conditions: its present distribution (no continental recycling), geochronology of zircons (intra-continental recycling, redistribution of continental materials or formation of accretionary complex), Hf isotope ratios of zircons (remelting of continental materials), isotope evolution of upper mantle (return of continental materials to the mantle) and secular change of mantle temperature.

Subduction geotherm depends on the mantle temperature because thickness, size and life-span of oceanic plates are controlled by mantle temperature. Increase of mantle temperature leads to their short life-spans due to the smaller sizes, and results in hot subduction geotherm; thus, hotter mantle temperature allows more granitoid formation through subduction of thicker and younger oceanic crusts. The amounts of intra-continental recycling, redistribution of continental materials and deposition of clastic sediments in trenches depends on amounts of continental crusts. Especially, amounts of continental crusts and lengths of subduction zones control amounts of clastic sediments. More continental crusts lead to more sediment. Longer subduction zone leads to more sediments in trenches. Because the length of subduction zone depends on mantle temperature, high mantle temperature results in high crustal formation and deconstruction. We changed erosion rate of continental crust and calculated secular changes of continental formation and destruction to fit the five types of estimates of continental growth curves. The calculation shows the following. (1) The distribution of continental crust 2.7 Ga is equivalent to the modern amounts. (2) Especially, the distribution of continental crust from 2.7 to 1.6 Ga is much larger than at present, and the size around 2.4 Ga became maximum and decreases since then. More continental crusts were formed during the high mantle temperature at 2.7, 1.9 and 0.8 Ga, and more amounts were destructed after then. As a result, 2.4 Ga continental crust apparently became minor, and few Archean continental crust remained. The timing of large distribution of continental crust corresponds to the timing of icehouse, namely 2.4, 1.6 and 0.8 Ga in Precambrian.

Keywords: Continental growth, evolution of Earth's surface, continental recycle, Archean, early Earth, mantle overturn



SCG065-09

Room:301B

Time:May 23 16:45-17:00

## Tectonic erosion and geotectonic evolution of the Japanese Islands

Yukio Isozaki<sup>1\*</sup>, Shigenori Maruyama<sup>2</sup>, Shinji Yamamoto<sup>2</sup>

<sup>1</sup>Univ. Tokyo, <sup>2</sup>Tokyo Inst. Technology

The ca. 700 million year-long geotectonic history of the Japanese Islands comprises three distinct intervals; i.e., 1) the age of a passive continental margin off the South China continental margin (ca. 700-520 Ma), 2) the age of an active margin characterized by an arc-trench system (ca. 520-20 Ma), and 3) the age of an island arc off East Asia (20 Ma to the present). These three intervals are chronologically separated by two major boundaries with significant tectonic episodes; i.e., the ca. 520 Ma tectonic inversion from a passive to an active margin by the initiation of subduction from the Pacific side, and the ca. 20 Ma tectonic isolation of the modern island arc system from the Asian margin by the back-arc basin (Japan Sea) opening. Here, the evolutionary history of the Japanese Islands is revised significantly on the basis of new lines of information that derived from a new dating technique of detrital zircon in sandstone. Particularly noteworthy is the recognition of the Early Paleozoic to Middle Mesozoic arc batholiths that were exposed extensively in the past but not at all at present because the pre-Cretaceous granites merely occur as kilometer-size blocks in the modern Japanese Islands. As to these older granites, the remarkable disagreement between the current distribution and the predominance of their clastic grains in younger sandstones suggests the effectiveness of past tectonic erosion processes in the fore-arc domains. The newly documented historical change in sandstone provenance suggests that proto-Japan has experienced not only accretionary growth but also large-scale tectonic erosion in multiple stages. During the ca. 500 million-year history of the Japanese Islands, a large amount of juvenile arc (continental) crust was formed several times, however, most has already disappeared from the surface. In short, the orogenic growth of Japan, even in a long-lasting active continental margin setting, is explained as the intermittent repetition of ocean-ward continental growth and continent-ward contraction of an active arc-trench system.

In contrast to these arc batholiths, the terrigenous flux from the neighboring two major continental blocks (South and North China) was less significant than previously imagined, except for the Jurassic to Early Cretaceous time when the collisional suture between North and South China blocks was selectively eroded to produce abundant terrigenous clastics. It is also significant that the eastern extension of this collisional suture was recognized in Japan as a chain of fragmentary remnants of the Triassic medium-pressure metamorphic belt. On the basis of these new lines of information, the South China-related origin of the main part of Japan is confirmed, whereas the Hida and Oki belts along the Japan Sea are identified as detached fragments of North China block. Summarizing all of these results, a series of paleogeographic maps of Japan from the Late Neoproterozoic to the Miocene is revised and illustrated.

Keywords: Japanese Islands, accretion, granite batholith, detrital zircon dating, tectonic erosion, arc crust

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SCG065-10

Room:301B

Time:May 23 17:00-17:15

## Supply rate of subducting continental crust to the deep mantle

Hiroki Ichikawa<sup>1\*</sup>, Kenji Kawai<sup>2</sup>, Masanori Kameyama<sup>1</sup>, Taku Tsuchiya<sup>1</sup>

<sup>1</sup>GRC, Ehime University, <sup>2</sup>Tokyo Institute of Technology

Subductions of granitic materials by tectonic erosion, sediment-trapped subduction, and direct subduction of immature oceanic arcs are indicated by recent geological and geophysical surveys. Geological studies have estimated the volume of subducted tonalite-trondhjemite-granodiorite (TTG) materials is 7 times larger than the volume of the present continental crust. Such a huge volume of subducted granitic materials have a large influence on the chemical evolution of the Earth, and therefore their destination in the mantle has long been debated.

A recent study indicates the TTG materials are gravitationally stable in the mantle transition zone. Capacity of this layer is large enough to reserve subducted continental crust, which might control the mantle convection to some extent. However, it is unclear how and how much they subduct dynamically through the mantle under the lithosphere.

In this study, we conducted a numerical and an analytical approach on an entanglement of a granitic layer by a slab. Sustainable thickness of the subduction channel and supply rate of the granitic materials to the deep mantle are estimated.

Keywords: Continental crust, slab

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SCG065-11

Room:301B

Time:May 23 17:15-17:30

## Seismic structure of the mantle transition zone

Daisuke Suetsugu<sup>1\*</sup>

<sup>1</sup>IFREE/JAMSTEC

The two main global discontinuities in the mantle are located at depths of around 410 and 660km (called the 410 and 660 in this paper), though their depths vary slightly in different tectonic zones (e.g., Flanagan and Shearer, 1998). The 410 and 660 are considered to be due to the olivine to wadsleyite and postspinel phase transformations, respectively (e.g., Ito and Takahashi, 1989). The pressure of both transformations is thermally controlled because the olivine to wadsleyite and post-spinel phase transformations are exothermic (positive Clapeyron slope) and endothermic (negative Clapeyron slope) reactions, respectively (e.g., Bina and Helffrich, 1994). In a cold (hot) environment such as a subduction zone, the 410 and 660 should be elevated (depressed) and depressed (elevated), respectively, which should generate temperature-related topography in the mantle transition zone (MTZ).

However, recent mineralogical studies suggest that phase transformations related to garnet, the other major component of the mantle, are involved, in addition to the olivine-related post-spinel transformation, at depths from 600 to 750km (e.g., Vacher et al., 1998), and should therefore appear as multiple seismic discontinuities in that depth range. Recent seismological studies have detected such multiple discontinuities (Simmons and Gurrola, 2000; Deuss et al., 2006; Tibi et al., 2007; Schmerr and Garnero, 2007; Andrews and Deuss, 2008). For subduction zones in particular, the relationship between subducted slabs and multiple phase transformations has been investigated in order to understand the fate of subducted slabs. In the session, I will review recent seismic results mainly on the 660.

Keywords: Mantle transition zone, the 660-km discontinuity

SCG065-12

Room:301B

Time:May 23 17:30-17:45

## Origin of small-scale heterogeneity at the shallowest lower mantle

Satoshi Kaneshima<sup>1\*</sup>

<sup>1</sup>Kyushu Univ.

Data from short-period seismic network reveal anomalous later phases for deep and intermediate-depth earthquakes in circum-Pacific subduction zones (Kaneshima, 2003, 2009). The anomalous phases are best interpreted as S-to-P scattered waves (wavelengths of ~10 km) from heterogeneities in the shallow lower mantle (depths <950 km). Several S-to-P scatterers where elastic properties of the rocks must substantially change within several kilometers are detected in the shallowest 300 km of the lower mantle beneath the circum-Pacific region. Around most of the observed scatterers the seismic tomography models have delineated high seismic velocity anomalies which are associated with recently subducted slabs. The majority of the scatterers are located near the bottom boundaries of the slabs (Kaneshima, 2009). The most likely origin of the scatterers would be basalt which used to form the oceanic crust, but the existence of the oceanic crust associated with the most recent slab subduction at the scattering sites is unlikely. Alternative explanations include: the presence of ancient basaltic rocks, phase transformation of garnet, localized dehydration of hydrous minerals, or a sharp boundary between different rock fabrics such as isotropic and anisotropic lower mantle rocks associated with mantle flow dragged by the slab subduction. Elastic properties of mantle minerals under the lower mantle conditions obtained by recent development of high pressure laboratory experiments, combined with the improved knowledge of rheology of mantle rocks, and numerical simulations of slab subduction should be essential for understanding the origin of the small scale heterogeneities.

### References:

Kaneshima, S., Small-scale heterogeneity at the top of the lower mantle around the Mariana slab, *Earth Planet. Sci. Lett.*, 209, 85-101, 2003.

Kaneshima, S., Seismic scatterers at the shallowest lower mantle beneath subducted slab., *Earth Planet. Sci. Lett.*, 286, 304-315, 2009

Keywords: shallowest lower mantle, seismic scatterer, base of slab, compositional heterogeneity

# Japan Geoscience Union Meeting 2011

(May 22-27 2011 at Makuhari, Chiba, Japan)

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SCG065-13

Room:301B

Time:May 23 17:45-18:00

## The Second Continent

Kenji Kawai<sup>1\*</sup>, Shinji Yamamoto<sup>1</sup>, Taku Tsuchiya<sup>2</sup>, Shigenori Maruyama<sup>1</sup>

<sup>1</sup>Tokyo Institute of Technology, <sup>2</sup>Geodynamics Research Center, Ehime Unive

Recent progress in our understanding of the consuming plate boundary indicates the ubiquitous occurrence of tectonic erosion of the hanging wall of the continental margin, sediment-trapped subduction, and direct subduction of immature oceanic arcs into deep mantle. Geological studies have estimated the volume of subducted tonalite?trondhjemite?granodiorite (TTG) materials to about seven times the surface total volume of continental crust. To reveal the fate of subducted crusts and how they recycle within the Earth, we studied high-pressure densities and elastic properties of TTG by means of the first principles computation method and compared them to those of peridotite. We found that TTG is gravitationally stable and its seismic velocities are remarkably faster than peridotite in the depth range from 300 to 800 km, especially from 300 to 670 km. We, therefore, propose SiO<sub>2</sub>-rich second continents in the mantle transition zone, which used to form the TTG crust on the Earth's surface. Our proposed model may provide reasonable explanations of seismological observations such as the splitting of the 670 km discontinuity and seismic scatterers in the uppermost part of the lower mantle. The difference in seismic velocities between PREM model and experimental results in the lower part of the transition zone can be explained by 25 volumetric% of TTG, which would correspond to about six times the present volume of the continental crust. Formation and dynamics of those second continents would have controlled the Earth's thermal history over geologic time.

Keywords: granite, subduction, second continent, tectonic erosion, first-principle calculation

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SCG065-14

Room:301B

Time:May 23 18:00-18:30

## The 300 Ma mantle convection history is interpreted by the surface geology

Shigenori Maruyama<sup>1\*</sup>

<sup>1</sup>Tokyo Institute of Technology

Traditionally mantle convection has been considered to be the process of internal heat loss from the Earth's interior. Recently the presence of second continents 10 times bigger than the surface total continental mass is proposed to be present on the bottom of the upper mantle (Kawai et al., 2009; Senshu et al., 2009). If this is correct, mantle convection can be predicted by the surface geology which records the subduction and tectonic erosion history to transport the TTG materials into mantle through time back to 300Ma. By the paleogeographic reconstruction of continents, past subduction zones and sites of tectonic erosion, the history of mantle convection was reconstructed to suggest the second continents controlled the past mantle convection.