Japan Geoscience Union Meeting 2015
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SMP09-01 Room:201A Time:May 27 09:00-09:30

Extreme metamorphism, geodynamic regimes and supercontinent cycles

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This work is part of a larger project to use the geological record of magmatism and metamorphism to develop hypotheses about geodynamics that may be tested using numerical models. Apparent thermal gradients of metamorphism, as recorded by close-to-peak mineral assemblages, retrieved from rocks equilibrated at high P, P–T or T, for which the timing is obtained from various chronometers, may be used be interrogate the rock record to assess secular change in the apparent thermal gradients of metamorphism. One-sided subduction creates asymmetry in the thermal structure of convergent plate margins, with lower dT/dP in the subduction zone and higher dT/dP in the orogenic hinterland. During collisional orogenesis these distinct thermal environments are imprinted in the rock record as contrasting types of metamorphism. Proterozoic orogens record eclogite–HP granulite (E-HPG) metamorphism, with gradients of 350–750C/GPa, and granulite–UHT metamorphism, with gradients of 750–1500C/GPa. By contrast, Phanerozoic orogens register UHP metamorphism with strikingly lower gradients of 150–350C/GPa, and UHP metamorphism is the defining feature of Phanerozoic collisional orogenesis in Eurasia. What is the change in geodynamics recorded by these data?

For contemporary conditions, geodynamic modeling of collisional orogenesis shows that slab breakoff occurs at depths $>$300 km; strong lower crust results in coupled collision with UHP metamorphism, whereas weak lower crust results in decoupled collision with only E-HPG metamorphism. Increasing the ambient mantle temperature by 80–100C leads to shallow slab breakoff ($<$200 km) and unconventional modes of collision, viz a truncated hot collision regime (strong lower crust) and a two-sided hot collision regime (weak lower crust). Inverting these data, as ambient mantle temperature declined to $<$100C warmer than the present day the change to deeper slab breakoff generated a colder environment and enabled stronger crust?mantle coupling that allowed subduction of continental rocks to mantle depths. Thus, the appearance of UHP metamorphism is inferred to be a consequence of secular decrease in ambient mantle temperature. By contrast, granulite facies and UHT metamorphism in central East Gondwana likely represents deep crust metamorphosed under a large, moderately thick orogenic plateau that formed as a result of Ediacaran collision and hinterland thickening, with radiogenic heating generating peak metamorphic temperatures in the Cambrian. It may be no coincidence that Gondwana could have been located over the African LLSVP at the dawn of the Phanerozoic or that the first UHP belts had a subduction polarity broadly towards the core of East Gondwana.

The Ediacaran–Cambrian witnessed a change in the style of continental breakup and aggregation. In a Hoffman breakup, continental lithosphere fragments, disperses and reassembles by elimination of the complementary superocean (e.g. the process by which the Gondwanan elements of Rodinia were transformed into Gondwana). By contrast, in a Wilson cycle sensu stricto, continental lithosphere simply fragments and reassembles along the same (internal) contacts, closing an internally generated ocean basin (e.g. the transformation from Pannotia to Pangea). Internally generated ocean basins were opened and closed asymmetrically by rifting of ribbon terranes from the northern margin of Gondwana and their accretion to Laurentia, Baltica and Siberia forming the Caledonides, Variscides and Altaides, as reflected in the Cambrian to Triassic record of metamorphism. The change was also registered by multiple geochemical indices, such as epsilon Hf(t) and 87Sr/86Sr, with complex temporal records characterized by short wavelength variations that reflect the overlapping opening and closure of several major oceans (Iapetus, Rheic, Paleotethys and Neotethys). This pattern is superimposed on a simpler long wavelength variation that is temporally related to the supercontinent cycle.

Keywords: ultrahigh-temperature metamorphism, eclogite–high-pressure granulite metamorphism, ultrahigh-pressure metamorphism, geodynamic regimes, supercontinent cycles, Hoffman breakups and Wilson cycles

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SMP09-02 Room:201A Time:May 27 09:30-09:45

Tectono-metamorphic evolution during Asian continental growth

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In E- and SE-Asia, there are at least six micro-continental blocks of North China, South China, Indochina, Shanthai, Sibumasu and West Burma from NE to SW. Geological Research program to realize the tectono-metamorphic processes in continental collision zones of E- and SE-Asia has been done for the last decade. During the processes, the following new evidences were identified especially in Vietnam and related areas; 1) findings of UHT (˜1000 C) pelitic granulites, UHP (˜40 kbar) Dia-bearing eclogitic rocks and HP/MT gneisses from the Kontum Massif, 2) LT eclogite and HP granulite from the Song Ma suture zone, and 3) UHT/extremely-HP aluminous metamorphic rocks from the Red River zone. Estimated P-T conditions and reaction textures from these rocks delineate a characteristic clockwise P-T-t path for each other, which generally represent a collision zone metamorphism (Osanai et al., 2004; Nakano et al., 2008, 2009, 2013).

A simultaneous collision metamorphism throughout Vietnam should have taken place during the continental collision between Indochina and South China blocks, which led to the formation of the Trans Vietnam Orogenic Belt (TVOB: Osanai et al., 2008). Northern extension of the TVOB reaches up to Cangshan Mountains in Yunnan Province, near Dali, through the Ailaoshan terrane in China and tapers off caused by the final Indian sub-continent collision and large crustal deformation during Eocene time. Permo-Triassic metamorphic and granitic rocks in SW Borneo are considered as the southern extension of the TVOB, which would be separated by the South China Sea opening during Cenozoic. Pre-collisional low-grade metamorphic and plutonic rocks of Devonian age (400˜Ma) also distribute in the TVOB as large blocks surrounded by shear zones.

The metamorphic rocks from the Nujiang-Kachin area in Yunnan Province and Myanmar, and the Inthanon-Hua Hin area in Thailand indicate low-pressure metamorphic field gradients with low-pressure clockwise P-T evolution processes, which show a different evolution process to the TVOB (Yonemura et al., 2013). They situate in the continental collision boundary between the Shanthai and Sibumasu blocks. Newly determined LA-ICP-MS dating indicates a middle Triassic (220-200 Ma) collision metamorphism for the Nujiang-Kachin and Inthanon-Hua Hin areas. The LTHP (blueschist) and amphibolite-facies metamorphic rocks from the collision zone between Indochina and Shanthai blocks, which are Cangshan-Simao area in Yunnan Province and Rayong area in Thailand, also show a Permo-Triassic metamorphic age and a clockwise P-T evolution.

The metamorphic rocks from the Mongolian Altai Mountains in the Central Asian Orogenic Belt (CAOB: Sengor et al., 1993) show Devonian to Early Permian (ca. 350 Ma and ca. 260 Ma) collision metamorphic event. On the other hand the rocks from the Lake Zone in west-central Mongolia indicate Cambrian (ca. 500 Ma) metamorphism. Therefore the multiple collision zone metamorphism and related orogen to form the Asian Continent would have taken place from N (southern margin of Siberian Craton) to S and SW, and the collided blocks in SE-Asia were finally deformed and converged in the Sanjiang region by the Indian sub-continent collision at Eocene.

Keywords: Asian continent, micro-continent collision, collision metamorphism, extreme metamorphism, zircon U-Pb age

SMP09-03 Room:201A Time:May 27 09:45-10:00

Metamorphosed bauxites from the Red River Shear zone, northern Vietnam: inferences and geological significance

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Aluminous metamorphic rocks from the Red River Shear zone in northern Vietnam were investigated in this study. The shear zone has abundant pelitic rocks that have been formed under sillimanite-grade metamorphic condition at the Paleogene period. The aluminous rocks are mainly divided into high-grade (garnet-sillimanite-corundum, garnet-sillimanite-spinel, garnet-corundum-spinel rocks) and low-grade (kyanite-corundum-hematite-phengite rock) rocks and both types show similar whole rock chemical composition with basaltic to andesitic bauxites. Detailed petrographical observations, the high-grade metamorphosed bauxites have experienced prograde stage more than 2.0 GPa at 800 C (based on the assemblage of staurolite + kyanite + rutile + siderite in garnet). The low-grade bauxite preserves the peak condition at 500 C and pressure more than 1.2 GPa (based on the assemblage of hematite + corundum + rutile + phengite + allanite + chloritoid + kyanite in the matrix). Because bauxite commonly formed at the surface on the continent, such high-pressure metamorphic conditions from the metamorphosed bauxites suggest continent-continent collision and its subduction.

Zircon grains in garnet-sillimanite-corundum rock show several U-Pb ages from 265 Ma to 36 Ma may due to the loss of Pb during shearing and/or thermal event at the Paleogene time. However, dark luminescent zircon cores show concordia age of 257 +/- 8 Ma. The zircon cores contain CO_2 rich fluid inclusions and the density is similar to other CO_2 rich fluid inclusions trapped in garnet, corundum, and staurolite. Therefore, we conclude that the high-pressure metamorphism has occurred at the Late Permian that should have strong relation to continental collision between the Indochina and South China cratons.

Keywords: metamorphosed bauxite, continental collision, Red River Shear zone, Vietnam

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SMP09-04 Room:201A Time:May 27 10:00-10:15

Duration of low-P/T type metamorphism and zircon/garnet REE partitioning in migmatites, Ryoke metamorphic belt, Japan

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Duration of low-pressure/high-temperature type, upper amphibolite to granulite facies Ryoke metamorphism is estimated by SHRIMP zircon U-Pb dating. Zircon in migmatites (up to ca. 800^{o}C, ca. 0.5 GPa) has inherited core and metamorphic rim, and between them is a dark-cathodoluminescence (dark-CL) annulus with melt (glass) inclusions (Kawakami et al., 2013). The rim shows variation in age from ca. 95.5 Ma to 88.7 Ma, suggesting the duration of hypersolidus high-temperature condition for ca. 7 Myr. Zircon rims with old ages tend to show steeply positive HREE patterns whereas the young zircon rims tend to show less steeply positive HREE patterns. Ti content in zircon rims are low, ranging from 1.23 to 2.25 ppm. This small variation in Ti content may imply narrow temperature range of zircon rim formation.

Garnet in the same sample has zoning in trace elements, and REE and Y contents are high in the core and lower towards the rim, suggesting prograde growth of this garnet. Garnet shows steeply positive HREE patterns at the core whereas it becomes less steep at the rim. Zircon grains with dark-CL annulus with um-sized inclusions are also included in the garnet, and judging from the mixed analysis of thin zircon rim and core, these inclusion zircon also has rims with steeply positive HREE patterns. This suggests that the inclusion zircons also have the rim that grew during the prograde, melt-present stage of the Ryoke metamorphism, but has the steeply positive HREE patterns even though they likely grew simultaneously with garnet in the presence of melt.

Systematic change of REE patterns in garnet and in zircon rim described above suggests that availability of HREE decreased as zircon grew, because of the simultaneous growth of garnet. In spite of this, D_{REE}(garnet/zircon) does not show flat pattern nor approach unity for HREE (e.g., Rubatto, 2002), showing different trend from the cases in the UHT rocks. Possible controlling factors of D_{REE}(garnet/zircon) include (i) difference in pressure and temperature conditions, (ii) difference in garnet composition, especially in grossular content (Taylor et al., 2014), (iii) effect of self-diffusion of garnet trace element compositional profiles under UHT conditions (Buick et al. 2006), and (iv) different timing of zircon and garnet growth (Buick et al. 2006). Among the possible controlling factors of the difference of D_{REE}(zircon/garnet) from UHT examples discussed above, (ii) can be neglected because garnet in this study has low grossular content (0.02-0.03) but showing the steep HREE pattern. Factor (iii) is not likely because our garnet preserves zoning in trace elements and even the high-Y annulus is preserved. Factor (iv) is also not likely from the above-mentioned observations that support simultaneous growth of zircon and garnet. Therefore, the temperature condition could be the most likely factor to control D_{REE}(garnet/zircon), although an example of Whitehouse and Platt (2003) who reported the flat D_{REE}(garnet/zircon) pattern near unity does not fit this interpretation. Our example suggests that it can be misleading to judge timing of 'normal' granulite facies metamorphism solely from the D_{REE}(garnet/zircon) pattern on the assumption that D_{REE}(garnet/zircon) becomes unity when garnet and zircon coexisted.

Keywords: high temperature metamorphism, partial melting, zircon, garnet, rare earth elements

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SMP09-05 Room:201A Time:May 27 11:00-11:30

East Antarctica and supercontinent configuration: the Dronning Maud Land perspective

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The geology of East Antarctica and its correlation in major supercontinents is highly speculative, since only a very small part of it is exposed. Therefore a better connection between geology and geophysics is needed in order to correlate exposed regions with ice-covered, geophysically-defined, blocks. In Dronning Maud Land (DML), two distinct late Mesoproterozoic/early Neoproterozoic tectono-metamorphic provinces appear, separated by the major, NE-trending Forster Magnetic Anomaly and South Orvin Shear Zone. To the west of this lineament, the Maud Belt has clear affinities with Grenville-age continent-continent mobile belts. East of the Forster Magnetic Anomaly, juvenile rocks with early Neoproterozoic age (Rayner-age) and an accretionary character crop out. The international GEA-II expedition (2012) targeted a white spot on the geological map immediately to the E of the Forster Magnetic Anomaly. This area allows the characterization and ground-truthing of a large and mostly ice-covered region, the SE DML Province that had previously been interpreted as an older cratonic block. However, new SHRIMP/SIMS zircon analyses and their geochemistry indicates that the exposed basement consists of a ca. 1000-900 Ma juvenile terrane that is very similar to rocks in Sor Rondane. It lacks significant metamorphic overprint at the end of crust formation, but it shows medium to high-grade overprinting between ca. 630-520 Ma, associated with significant felsic melt production, including A-type granitoid magmatism. Therefore, the aeromagnetically distinct SE DML province does neither represent the foreland of a Late Neoproterozoic/EarlyPaleozoic mobile belt, nor a craton, as has previously been speculated. It more likely represents the more juvenile, westward continuation of Rayner-age crust (1000-900 Ma). To the west it abuts along the NE-trending Forster Magnetic Anomaly. The latter is interpreted as a suture, which separates typical Grenville-age crust of the Maud Belt (ca. 1200-1030 Ma) to the W from Rayner-age crust to the E. Therefore the larger eastern part of DML has clearly Indian affinities. Its juvenile character with a lack of metamorphic overprint at the end of crust formation points to an accretionary history along this part of the Indian segment of Rodinia, immediately following final Rodinia assembly.

Keywords: Dronning Maud Land, Forster Magnetic Anomaly, supercontinents, juvenile crust, early Neoproterozoic, suture zone

SMP09-06 Room:201A Time:May 27 11:30-11:45

Insights from zircon chronology and chemistry constraints into Neoproterozoic orogens at Sor Rondane, East Antarctica

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Zircon chronology combined with its mineral chemistry is key tools for evaluating the temporal evolution of metamorphic processes. Assembly of Gondwana supercontinent has been argued in numerous studies. Generally the reported ages of Gondwana collision zones are in the range of 750-500 Ma (e.g., Meert, 2003; Jacobs et al., 2003; Grantham et al., 2003). From East Antarctica, a number of Neoproterozoic to Cambrian high-grade metamorphic terranes are distributed, and pervasive 550-500 Ma metamorphic ages have been reported from most of these terranes (e.g., Fitzsimons, 2000; Harley, 2003; Shiraishi et al., 2003) with minor >600-550 Ma ages (Shiraishi et al., 2008; Dunkley et al., 2014; Hokada and Motoyoshi, 2006).

Sor Rondane Mountains is one such area where older c.640-600 Ma high-grade metamorphic rocks along with pervasive 550-500 Ma age events have been reported (e.g., Shiraishi et al., 2008; Osanai et al., 2013; Adachi et al., 2013; Hokada et al., 2013). Hokada et al. (2013) discussed based on the zircon and monazite U-Th-Pb and REE analyses by using ion microprobe and electron microprobe applying to garnet-biotite-sillimanite gneiss and associated multiple generations of leucocratic veins in the central part of Sor Rondane Mountains, and suggested multiple (at least three stages of) metamorphic and fluid (intrusion of leucocratic vein) events at >700 Ma, 640-630 Ma and 550-520 Ma with main granulite-facies event at c.637+/-6 Ma. Combined with the other available and newly obtained age data, temporal processes of possible geologic events recorded in Sor Rondane Mountains and their implications for supercontinent evolution of Gondwana during c.700-550 Ma will be discussed.

Keywords: Gondwana supercontinent, zircon U-Pb age, rare earth elements, high-grade metamorphism, East Antarctica, Sor Rondane Mountains

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SMP09-07 Room:201A Time:May 27 11:45-12:00

Sr and Nd isotopes in metacarbonate rocks as proxies for paleo-tectonic reconstruction prior to supercontinent assembly

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Chemically precipitated carbonate sediments directly record seawater composition that helps us to decode the Earths paleo-environment, existence of paleo-oceans and provide valuable clues on paleo-tectonic position of continents in the Earths history. In addition, the geochemical and isotopic composition of carbonate rocks also have a strong dependence on the depositional tectonic setting and surrounding source rock composition especially in the Precambrian era, during which biological activity were less prominent and vegetation was virtually absent. Here we present evidence for the existence of an Oceanic Island arc system and peripheral Oceans before the formation of Gondwana supercontinent in the Neoproterozoic. Applying a multi-element isotope geochemical approach on chemostratigraphically well-constrained metacarbonate rocks collected from several supracrustal terrains in Gondwana, including the remote Sor Rondane Mountains in East Antarctica, we model carbonate deposition surrounding an island arc system, mid-ocean volcanic islands and shallow marine continental shelf of a yet unidentified interior Antarctic continent, all of which accreted and amalgamated in the late Neoproterozoic to early Paleozoic to form the Gondwana supercontinent.

We also compare the metacarbonate data with basement rocks from various neighboring Gondwana continents, wherein some regional affinities could be established. Nd model ages of cratonic basements from East Africa (Kalahari) and India (Dharwar) is obviously different from Balchen carbonate rocks from Sor Rondane in East Antarctica, and the possible existence of a cratonic nucleus within the East Antractic continent is speculated, surrounding which the carbonate rocks of the Balchen region might have deposited. Thus, the Sr and Nd isotopic compositions provide important information about depositional setting of sedimentary rocks and relationship with surrounding basement and continents. Geochemical proxies, such as Nd and Sr isotopes of metacarbonate rocks, can yield key information not only of paleo-oceans but also about the surrounding rocks of oceanic crust (basement) and continental crust during the time of deposition, which can lead us to a better understanding of paleo-tectonic setting of crustal fragments that assemble to form supercontinents.

Keywords: Metacarbonate rocks, Gondwana, Sr isotopes, Nd isotopes, tectonic setting

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SMP09-08 Room:201A Time:May 27 12:00-12:15

Comparison of Sr-Nd isotope data from N. Mozambique and Dronning Maud Land and Sor Rondane, Antarctica.

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A recently proposed mega-nappe model for the Neoproterozoic?Cambrian-age Kuunga Orogeny involves collision between N. and S. Gondwana. S.Gondwana is inferred to have comprised southern Africa (consisting of the Kalahari Craton and parts of adjacent metamorphic belts including the Barue and Nampula complexes of the Mozambique Belt), western Dronning Maud Land (WDML), Antarctica (consisting of the Grunehogna Craton and the Maud Belt) and Sri Lanka (consisting of the Vijayan Complex). N. Gondwana is inferred to have comprised parts of south central Africa, Sri Lanka, Madagascar and India (consisting of the Tanzanian Craton and parts of adjacent metamorphic belts including the Xixano Complex of Cabo Degado Complex, the Highlands and Wanni Complexes, the Central Dronning Maud Land and Sor Rondane areas and Lutzo Holm Bukta areas.

Differences in published geochronological data from the metamorphic belts of the various areas are fundamental to defining the various components of the mega-nappe model. Comparison of published and unpublished Sr and Nd radiogenic isotope data, calculated at 500Ma from the metamorphic belt basement gneisses of the mega-nappe component areas, show broad differences between the different areas from N and S Gondwana.

Neoproterozoic to Cambrian-age granitoids which intrude the various areas mostly mirror their host country rocks suggesting localised anatexis without significant juvenile input. Sr and Nd isotope data from some of these intrusions suggest that they were sourced in the footwall but intrude the hanging wall components of the mega-nappe. The Sr-Nd data from the N Gondwana correlated areas dominantly show marginally negative, less evolved ϵNd characteristics but similar, positive, wide ranged ϵSr characteristics compared to the S. Gondwana correlated areas.

Comparison of the Sr-Nd isotopic provinces show broad similarities with various geophysical domains defined by recently published aeromagnetic and gravity data sets from Antarctica.

The data are evaluated in terms of their implications for the meg-nappe model for the Kuunga Orogeny.

Keywords: N. and S. Gondwana, Sr and Nd isotopes, mega-nappe model, Kuunga Orogeny

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SMP09-09 Room:201A Time:May 27 12:15-12:30

Mesoproterozoic suture between India and Madagascar

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The understanding of position of southern India in various supercontinent assemblies, its amalgamation and rifting with various continental fragments have significant implication in understanding the tectonic processes through geological time-scale. The southern India is a mosaic of various crustal domains, which are divided by shear/suture zones, but several controversies exist regarding the tectonic framework, shear zones and crustal blocks of southern India. The detailed structural lineament mapping of southern India along with new and compiled of geological and geochronological datasets help in delineating new shear zones and redefining the Precambrian crustal blocks of southern India. Especially, in a Madagascar- India correlation point of view, recent studies have reconstructed plate margins of India and Madagascar based on flexural isostasy along the Western Continental Margin of India (WCMI) and the Eastern Continental Margin of Madagascar. In this context, the newly proposed Mesoproterozoic Kumta and Mercara suture zones (1400-1000 Ma) welding Archean crustal blocks in western India offer critical insights into Precambrian continental juxtapositions and the crustal evolution of Gondwana. The textural evidences, mineral chemistry and thermodynamic modeling of quartz-phengite schist, garnet-biotite schist from the Kumta suture suggest peak metamorphic P-T conditions of c. 18 kbar, 550^{o}C and c. 11 kbar, 790^{o}C respectively and garnet-biotite-kyanite-gedrite-cordierite gneiss from the Mercara suture suggests peak metamorphic P-T conditions of c. 12.5 kbar, 825^{o}C. The calc-silicate granulite and mafic granulite were re-equilibrated under high-pressure conditions of 15-20 kbar at a temperature of 800-900^{o} C. The Bondla-ultramafic complex in the northwest of Kumta suture contains shale, basalt, dolerite, gabbro, chromite bearing serpentinite, chromitite and peridotite. The chromite chemistry from ultramafics suggests the evolution in a supra-subduction zone arc setting. Towards the east of the Kumta suture, the Sirsi shelf contains weakly deformed sedimentary rocks (limestone, shale, banded iron formations, greywacke, sandstone and quartzite) unconformable on high-grade ca.2571 Ma gneisses of the Dharwar craton. The Karwar block to the west of the Kumta suture is mainly composed of weakly deformed tonalite-trondhjemite-granodiorite (TTG) with enclaves of amphibolite. Whole-rock major and trace element data suggest that the TTGs (Type I, low K2O, high Na2O, Sr) were derived from a volcanic arc, and that the TTGs (Type II, high K_2O, low Na_2O, Sr) have within-plate signatures. Amphibolites have a chemical composition comparable to basalts to basaltic andesites with MORB signatures. The Karwar block TTGs (Type I) are ca. 3200 Ma with ?Hf range of -0.7 to 4.4. The whole-rock ?Nd ranges from -2.4-2.1 representing juvenile crustal origin. The Coorg block, about 100 km south of Karwar block mainly consists of highly metamorphosed lower-crustal rocks yielding 3200 Ma age with positive to negative ?Hf spread (3.3. to -3.2) indicating their source as mixture of juvenile and recycled crustal materials. Metasedimentary rocks from the Kumta suture have ?Hf (t) values that range from -9.2-5.6, and TDM ages that range from 2747-3546 Ma; comparable values in metasedimentary rocks from the Mercara suture range are from -18.9-4.2 and from 3214-3647 Ma respectively. Synthesis of the above results suggests that the Kumta and Mercara suture zones incorporate sediments, which range in age from Paleoarchean to Mesoproterozoic, and were subjected to high-pressure metamorphism in the late Mesoproterozoic. The protolith sediments were mainly derived from juvenile crust that was mixed with products of recycled older continental crust. Integration of the results indicates the Mesoproterozoic Kumta-Mercara suture in western Peninsular India interpreted as eastern extension of the Betsimisaraka suture of Madagascar.

Keywords: Gondwana Supercontinent, Continental Correlation, Crustal evolution, Mesoproterozoic suture

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A comprehensive study on India-Madagascar paleo-fit in the Gondwana Supercontinent

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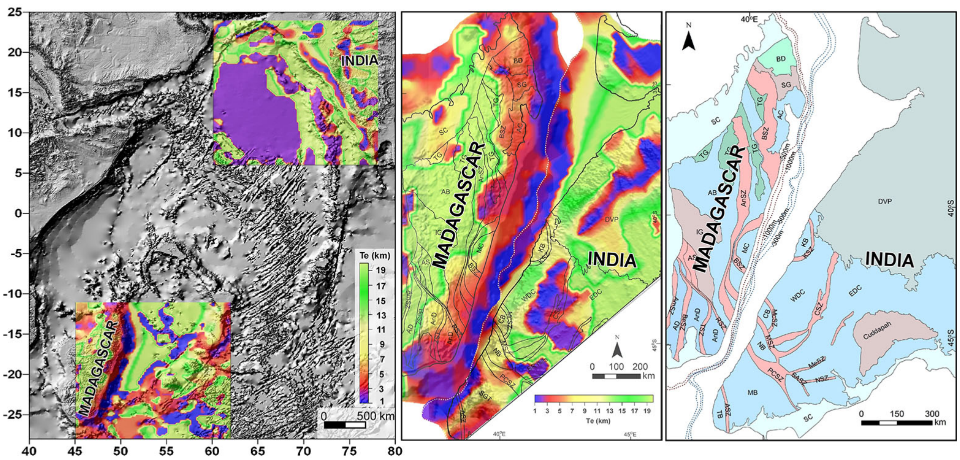
This study addresses one of the most disputed problems in the history of the earth science, which is on the paleo-fit of India and Madagascar continents in the Gondwana Super Continent Assembly. The study contributes new constraints on, and definitions of, the reconstructed plate margins of India and Madagascar based on flexural isostasy along the western continental margin of India (WCMI) and the eastern continental margin of Madagascar (ECMM). We have estimated the nature of isostasy and crustal geometry along the two margins, and have examined their possible conjugate structure. Here we utilize elastic thickness (Te) and Moho depth data as the primary basis for the correlation of these passive margins. We employ the flexure inversion technique that operates in spatial domain in order to estimate the spatial variation of effective elastic thickness. Gravity inversion and flexure inversion techniques are used to estimate the configuration of the Moho/Crust-Mantle Interface that reveals regional correlations with the Te variations. These results correlate well with the continental and oceanic segments of the Indian and African plates. The present study has found a linear zone (~1680 km) of anomalously low-Te (1-5 km) along the WCMI, which correlates well with the low-Te patterns obtained all along the ECMM. We suggest that the low-Te zones along the WCMI and ECMM represent paleo-welding zones of lithosphere thermally and mechanically weakened by the combined effects of the Marion hotspot and lithospheric extension due to rifting. Based on the present Te results, we have produced a precise India-Madagascar assembly during the time of their rifting (see Figure below), which is confirmed by the Moho geometry and the bathymetry of the conjugate shelf margins, and by the matching of tectonic lineaments, lithologies and geochronological belts between India and Madagascar.

Figure Caption: Elastic thickness structure of the western margin of India and eastern margin of Madagascar (left), correlation of similar Te zones of India-Madagascar conjugate margins (centre), and the paleo-fit of India and Madagascar deduced from the Te correlations justified by the fit of shear zones (Ratheesh Kumar et al., Gondwana Research, 2014).

Keywords: Gondwana, Paleo-fit, elastic thickness



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Late Proterozoic syenite magmatism in the Sor Rondane Mountains, East Antarctica

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Syenites and related intrusive rocks are important to understand the process of collision zone magmatism in Dronning Maud Land (DML), East Antarctica, because DML is situated within the continental collision orogen between the West and East Gondwana. The Sor Rondane Mountains (SRM) is located in the eastern part of DML. According to the previous results, the timing of continental collision is regarded as the late Proterozoic (650 to 600 Ma) on SRM. Post-collisional intrusive rocks, granite stocks, a syenite complex, lamprophyres and dolerites, intrude the metamorphic rocks during the extensional stages in the region of SRM. In this paper, we address the geochronological and geochemical studies of the syenite complex and lamprophyres, and then discuss the timing of intrusion and the origin and formation of syenite magma.

The syenite complex occurring in the Lunckeryggen, the central part of the Sor Rondane Mountains, consists of a layered syenite, melanosyenite dikes and quartz syenite dikes. The syenite complex and the Lunckeryggen granite that is K-feldspar-rich alkaline granite are coeval intrusive rocks. The boundary between them is not clear and shows mingling structure. The lamprophyre locally intrudes the granite as a syn-plutonic dike. The U-Pb zircon dating used for the SHRIMP-II installed at NIPR gives ages of 559.4 +/- 1.6 Ma, 550.0 +/- 1.7 Ma, 548.8 +/- 3.4 Ma for the layered syenite, the granite and the melanosyenite dike, respectively. The recalculated Pb-Pb age of the lamprophyre shows 557.5 +/- 4.8 Ma. Considering the field relationships and the zircon SHRIMP dating, the syenite complex, granite and lamprophyre would, therefore, intrude into this suture zone during the same magmatic stage. The dolerite dikes also intrude the same stage as the previously described intrusive rocks because of their mode of occurrence although the dolerite dikes have not been dated yet.

The syenite complex and the lamprophyre have significant character with high-K ($K2O/Na2O>3$), high-LREE/HREE ratios and relatively enriched Sr-Nd isotopic compositions. The chondrite-normalized REE patterns of clinopyroxenes from the melanocratic part of layered syenite and lamprophyre show the concaved upward between LREE and MREE with HREE depletion. Considering petrography, mineralogy and geochemistry, the syenite complex has been derived from the lamprophyre magma, and fractional crystallization and accumulation played an important role of formation of the layered structure. The dolerite shows geochemical features similar to those of the within plate basalts in terms of some discrimination diagrams. Moreover, the Sr-Nd isotopic compositions of the dolerites are slightly depleted rather than the lamprophyres.

The lamprophyre possessing primitive compositions includes phenocrysts of Mg- and Cr-rich phlogopite. The P-T conditions of the lamprophyre magma are estimated by the biotite-liquid equilibrium relations. The calculated P-T conditions for the formation of lamprophyre magma are up to 1150 ?C and 1.6 GPa that is equivalent to 60 km depth that corresponds to the spinel lherzorite facies. On the other hand, the dolerite would be produced by the partial melting of a garnet lherzolite because of its geochemical signatures such as Ce/Sm and Sm/Yb ratios. The dolerite magma would, therefore, be derived from a source mantle deeper than that of the lamprophyre magma. The geochemical studies including Sr-Nd isotopic compositions reveal that the lamprophyre magma is derived from the enriched mantle; probably is formed by interaction between the dolerite magma derived from athenospher mantle and the enriched lithospheric mantle.

Keywords: East Antarctica, Sor Rondane Mountains, Collision zone, Syenite, Lamprophyre, Dolerite

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Crustal assembly of the Masora and Antananarivo domains, central-eastern Madagascar

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In reconstructions of the Gondwana supercontinent, correlations of Archean domains between Madagascar and India remain debated (e.g., Key et al., 2011; Ishwar-Kumar et al., 2013; Brandt et al., 2014; Collins et al., 2014; Plavsa et al., 2014; Rekha et al., 2014; Tucker et al., 2014). In this study, we aim to establish correlations among these Archean domains using whole-rock geochemistry and U-Pb zircon geochronology of meta-granitoids from the Masora and the Antananarivo domains, central-eastern Madagascar.

A meta-granitoid from the central part of Masora domain is dated at 3277 Ma and shows strongly fractionated REE pattern with high La/Yb ratio, which is a typical Archean tonalite-trondhjemite-granodiorite composition. A tonalitic gneiss from the southeastern part of the Antananarivo domain is dated at 2744 Ma and shows a positive Eu anomaly and relatively fractionated REE pattern with high La/Yb ratios. The major and trace element abundance of the tonalitic gneiss is consistent with the melt-depleted facies i.e., restitic rocks out of which some melt has been extracted (e.g., Barberton granitoids, south Africa; Moyen et al., 2007), different from that of the ca. 2500 Ma granitoid of the northwestern part of Antananarivo domain (e.g. Kroner et al., 2000; Macey et al., 2009). In addition, the major and trace element compositions of the ca. 760 Ma granitic gneisses are consistent with volcanic-arc origin for the protoliths.

Based on the geochemical and geochronological results, along with existing data, we identified three episodes of granitic magmatism at ca. 3300 Ma, 2700 Ma, and 2500 Ma in central-eastern Madagascar. Three diachronous magmatism events are consistent with those reported for the Dharwar Craton in India (Jayananda et al., 2013; Peucat et al., 2013), suggesting that the Archean Masora and Antananarivo domains in Madagascar were part of the Dharwar Craton at the end of Neoarchean (Tucker et al., 2011, 2014). The 700-800 Ma volcanic arc granitoids identified in central Madagascar (e.g. Handke et al., 1999; Kroner et al., 2000) have not been reported from the Dharwar Craton in India. Therefore, the subduction of the oceanic plate that led to the formation of these granitoids likely took place at the western margin of the Dharwar Craton, which included part of central-eastern Madagascar.

Keywords: Madagascar, Masora domain, Antananarivo domain, Archean, whole-rock geochemistry, U-Pb zircon geochronology

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LA-ICP-MS Zircon U-Pb ages from metamorphic rocks in the southwestern part of Highland Complex, Sri Lanka

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Sri Lanka has been considered to locate inside the collision zone during amalgamation of the Gondwana supercontinent in Neoproterozoic to Early Cambrian (e.g. Meert, 2003). Therefore, Sri Lanka plays an important role to elucidate the process of amalgamation of the Gondwana supercontinent. Based on rock type, metamorphic grade and Nd model ages, the metamorphic rocks in Sri Lanka are subdivided into three major crustal units (Cooray, 1994; Kehelpannala, 1997; Kr?ner et al., 2003), which are Wanni Complex, Highland Complex (HC) and Vijayan Complex. The HC is composed of interlayered predominantly granulite-facies partly attaining to ultrahigh temperature (e.g. Osanai et al., 2006), granitic (charnockitic to enderbitic) gneiss and supraclastic metasediments with Nd model ages of ca. 2.0-3.0 Ga. However, Because of the shortage of zircon U-Pb isotope data by spot analysis and these geochronological data reported mostly from the central part of HC, the geochronological framework of HC is still unclear. In order to understand the geological process in HC, it's necessary to conduct the geological, petrological, geochemical and geochronological work by the unified method on the whole area of HC. This study provides the first report of LA-ICP-MS zircon U-Pb ages from metamorphic rocks in the southwestern part of HC.

We carried out LA-ICP-MS zircon U-Pb dating for ten samples corrected from five localities (2101: South of Horana, 2510: Southwest of Ratnapura, 2704: West of Morawaka, 2201: Southwest of Rakwana, 2803: Northwest of Embiliptiya). In 2101, zircons in Grt-Opx-Bt gneiss (2101D1) show 2560-670 Ma from inherited domain and 640-470 Ma from overgrown domain. Grt-Opx-Bt granulite (2101D2) has similar ages to 2101D1, which are 2500-710 Ma from inherited domain and 640-470 Ma from overgrown domain. In 2510, zircons in felsic Grt gneiss (2510A) show 1840 Ma from inherited domain and 630-490 Ma from overgrown domain. Although zircons in Two Px granulite (2510L) have inherited domain and overgrown domain, we could obtain the ages only from overgrown domain (620-490 Ma). In 2704, zircons in Spl bg. Grt-Sil-Crd gneiss (2704G) show 2040-730 Ma and 620-470 Ma from inherited domain and overgrown domain, respectively. In respect to Grt-Opx granulite (2704C), inherited domain and overgrown domain of zircons are recognized of ages of 620-530 Ma and 590-490 Ma, respectively. In 2201, Grt-Bt gneiss (2201B) is resulted in zircon U-Pb ages of 1860-1450 Ma from inherited domain and 620-530 Ma from overgrown domain, and zircons in Grt charnockite (2201A1) show the concordant age of ca. 1820 Ma from inherited domain and 610-510 Ma from overgrown domain. In 2803, zircons in felsic Grt-Hbl-Bt gneiss (2803B) show 1980-690 Ma from inherited domain and 640-550 Ma from overgrown domain, and those in Grt-Hbl-Bt gneiss (2803C) show two concordia ages of ca. 1890 and 1770 Ma from inherited domain and 580-520 Ma from overgrown domain.

Samples in 2101, 2510 and 2704 show broad age cluster of 550-510 Ma from both CL bright and dark overgrown domain, and Neoproterozoic ages (ca. 1000-700 Ma) with the small amount of Paleoproterozoic to Archean ages (ca. 2700-1600 Ma) from inherited domain. On the other hand, samples in 2201 and 2803 show mainly 590-580 Ma from CL dark overgrown domains and Mesoproterozoic to Paleoproterozoic ages (ca. 2000-1500 Ma) with the small amount of Neoproterozoic ages (ca. 700 Ma), which is the similar characteristics in the central part of HC. 2101, 2510 and 2704 are located at less quartzite or marble distributed area, while 2201 and 2803 are mostly located at quartzite or marble distributed area in the southwestern part of HC. On the basis of the relation between the internal texture of zircons and ages, the distribution of ages from inherited domain and overgrown domain of zircons, and constituent rocks, the southwestern part of HC can be divided into two areas such as Southwestern Group and Highland Group previously recognized.

Keywords: Gondwana, Sri Lanka, Highland Complex, LA-ICP-MS, zircon

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A revised tectonostratigraphy for Late Archean supracrustal rocks in the Chitradruga schist belt, Dharwar craton, India

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In order to understand late Archean tectonic and climatic systems prior to the great oxidation event, we studied volcano-sedimentary sequence of the Dharwar Supergroup, distributed in the Chitradurga Schist Belt, Western Dharwar craton. The Chitradurga schist belt consists of >3.0 Ga greenstones (Sargur Group) and overlying 2.9-2.6 Ga volcano-sedimentary sequence (Dharwar Supergroup), which are surrounded by 3.2~3.0 Ga TTG (tonalitic-trondhjemitic-granodioritic) gneiss (Chadwick et al., 2000; Jayananda et al., 2006). The Supergroup is classified into two major groups (lower Bababudan Group and upper Chitradurga Group). Preliminary studies on metamorphic conditions and geochronology of the Chitradurga Schist Belt have shown that this subdivision has to be reconsidered (Hokada et al., 2013). Therefore, we carried out a detailed lithostratigraphy, geochronology, metamorphism and tectonic evolution of the Chitradurga Schist Belt. Furthermore, it is important to compare the geological record with the other cratons for discussing any global events occurring in the late Archean. Our new field mapping and detrital zircon U-Pb dating allows us to reconstruct detailed lithostratigraphy of the Dharwar Supergroup. The lower unit consists of basal conglomerate, stromatolitic carbonate, silici-clastics with diamictite (Talya conglomerate), chert/BIFs and pillowed basalt in assending order, indicating that rift margin environment predominated at this time. The upper unit unconformably overlies the pillow lava, and consists of conglomerate/sandstone with ~2536 Ma detrital zircons, mafic lava, BIFs and silici-clastic sequence with mafic volcanics. The provenance analysis by detrital zircons allow us to divide the Dharwar Supergroup into the lower and upper groups. Especially, the maxima in the age distribution in the upper group (Hiriyur Formation) shows a peak at around 2.55 Ga, suggesting the source from the Eastern Dharwar Craton. Three metamorphic zones are identified in the Ingaldhal basalts. The metamorphic grade increases from lower greenschist facies to sub amphibolite facies. The boundaries between three metamorphic zones are subparallel to the bedding of interbedded BIF and tectonic contact between the lower group and upper group. On the other hand, the Hiriyur metabasalts are characterized by extensive carbonatization, whereas most samples from the lower group do not contain carbonate minerals. These differences in metamorphic grade and carbonatization of the greenstone indicate that the two groups of the Dhawrar Supergroup might preserve key information about amalgamation and/or breakup of the Dharwar protocontinent in the late Arcehan.

Keywords: Late Archean, Soth India, Metamorphism, Geochronology, zircon, Supercontinent

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Nd isotope geochemistry of Archaean BIFs in the Chitradurga Schist Belt, Dharwar Craton, Southern India

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Banded Iron Formations (BIFs) are successive layers of fine grade quartz and iron minerals which consist mainly of hematite, magnetite, and siderite. They are chemically precipitated in the sea and formed mostly in the Archaean and early Paleoproterozoic, and therefore record the information of the ancient oceans. It is believed that the iron was supplied by hydrothermal vents (Bekker et al., 2010), whereas silica was either sourced from hydrothermal vents (Steinhofel et al., 2010) or continental weathering (Hamade et al., 2003). In addition to the origin of BIF, the oxidation-reduction state of the seawater can be constrained by the characteristics of trace element, rare earth element and isotope geochemistry. We have studied the geochemical characteristics, in particular the Nd isotopes of BIFs in the Chitradurga Schist Belt, western Dharwar craton, Southern India.

The Chitradurga Schist Belt belongs to the Dharwar Supergroup that overlies the basement Peninsular Gneiss (˜3.0 Ga) with enclaves of Sargur Group (3.3˜3.1 Ga). The Dharwar Supergroup is subdivided into two groups, the Bababudan Group and the Chitradurga Group. Hokada et al., (2013) suggested that the oldest depositional age of Bababudan Group and lower unit of Chitradurga group is around 3.14 Ga and 3.22?2.92 Ga and the youngest depositional age of upper unit of Chitradurga group is between 2.68 Ga and 2.63 Ga. The lower Chitradurga unit is metamorphosed to the biotite-muscovite grade whereas the upper unit is chlorite-muscovite grade. Three major BIF layers occur in the Chitradurga Schist Belt, which belongs to the Bababudan Group, lower Chitradurga unit and upper Chitradurga unit. We compare the geochemical features of these three layers in this presentation.

The Chitradurga BIFs are mostly composed of quartz, magnetite and hematite and rarely contain siderite, pyrite, and carbonate minerals. Bulk rock geochemistry results revealed that the BIFs contain only very less amount of Al2O3 or other oxides than SiO2 and Fe2O3. The majority of lower Chitradurga unit BIFs have low REE contents, LREE<HREE and positive Eu and Y anomaly. These characteristics are similar to Archaean BIFs from South Africa, North America and Greenland except that they lack positive La and Y anomalies. The large positive Eu anomalies in BIFs attribute to high temperature hydrothermal fluid fluxes (Bau and Moller., 1993). Therefore the environment of deposition of BIFs was related to hydrothermal flux, probably relating to a rift environment. Sr isotopic ratios show large variations caused by post depositional alterations and/or metamorphism, whereas Nd isotope ratios have only small variations. Nd is an immobile element that represents primary values. Most of the BIFs have epsilon Nd values (estimated at 2.8Ga) which is considered as the age of sedimentation after (Hokada et al., 2013) between -2 to +2 and TDM model ages between 3.0Ga to 3.3Ga. The sedimentation ages and model ages are not equivalent. The epsilon Nd(2.8Ga) of depleted mantle is about +4, and metabasalts associated with the BIFs range are between -4 and +4 , the negative values may represent the effect of later stage alterations. Within the same stratigraphic section their epsilon Nd(2.8Ga) values show both positive and negative signatures. Although the causes are not clear yet, it might possibly due to the variations in sedimentary environment affected by hydrothermal flux. The geochemical data of BIFs suggest that they were not affected by continental source and REY pattern probably show effect of high-T hydrothermal fluid fluxes in the rift environment, where they have been deposited.

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Keywords: BIF, Archaean, Dharwar Craton

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Geochemistry of Paleoarchean TTGs and Neoarchean high-K granites around Chitradurga, western Dharwar Craton, India

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The western Dharwar Craton (WDC) mainly comprises TTG-type peninsular gneiss, greenstone belts, and high-potassium granites (e.g. Chadwick et al., 2000; Jayananda et al., 2013). The TTGs are widely distributed in the WDC as 3.4?3.2 Ga basement rock and occasionally contain more elder sediments and volcanics (i.e. the Sargur Group) (e.g., Peucat et al., 1993). The greenstone belts, named the Bababudan and the Chitradurga Group, unconformably overlies the TTGs as 2.9?2.6 Ga sedimentary covers (Hokada et al., 2013), consisting mainly of conglomerate/quartzite, BIFs, and mafic to felsic volcanics (e.g. Chadwick et al., 1981). The high-potassium granites crop out as several isolated intrusions in both the TTGs and the greenstone belts. The intrusive ages of the granites are mostly around 2.61 Ga (e.g. Jayananda et al., 2006). The aim of this paper is to make clear the petrographic and geochemical characteristics of the Paleoarchean TTGs and the Neoarchean high-potassium granites around Chitradurga in the WDC, southern India.

The TTGs are largely grouped into two types; K-feldspar (Kfs)-poor meta-trondhjemite and K-feldspar-rich meta-granite. The Kfs-poor meta-trondhjemite has petrographic and geochemical features of slab-derived TTGs. On the other hand, the Kfs-rich meta-granite contains abundant K-feldspar, a mineral phase that is not common in the TTGs. Additionally, the meta-granite shows different geochemical characteristics than that of TTGs. In particular, their Al2O3 and Sr contents are not enriched, and their K2O/Na2O ratios are higher, which look like continental type of TTGs. These features of rocks suggest that the Kfs-poor meta-trondhjemite are derived from oceanic crust melting, whereas the Kfs-rich meta-granite are derived from the re-melting of crustal materials. In Paleoarchean western Dharwar Craton, many slab-derived TTGs had intruded in to the crust. In addition, it is probable that the crustal recycling has already started.

The Neoarchean high-potassium granites around Chitradurga area are divided into three intrusions; Chitradurga granite, Hosdurga granite, and Jampalnaikankote granite (Jayananda et al., 2006). We revealed that they have different petrographic and geochemical features each other. The Chitradurga granite is a massive and coarse-grained. The Hosdurga granite is characterized by mylonitic foliation and consists of pinkish medium-grained rocks. The Jampalnaikankote granite is essentially including hornblende and is locally associated with gabbroic rocks. Chitradurga and Hosdurga granites can be geochemically classified into within-plate type granites, whereas the Jampalnaikankote granite is possibly of volcanic-arc origin. This suggests that the high-potassium granites are derived from different sources implying that the Neoarchean western Dharwar crust maybe composed of heterogeneous materials including volcanic arcs and matured continents. Based on detailed geochemical, we discuss the magmatic evolution and origin of the Paleo- to Neoarchean plutonic activity in the western Dharwar Craton.

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Keywords: TTG, High-K granite, Dharwar Craton, India

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Depositional ages and provenance of Paleoproterozoic sequence of Lesser Himalaya in Nepal based on U-Pb zircon dating

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Proterozoic Lesser Himalayan sediments (PLHS) is a thick sequence attaining 10,000 m deposited on a passive continental margin of the Supercontinent Columbia, which started its rifting at around 2.0 Ga. The PLHS could be correlated to the Chancheng Group on the North China craton and the Coronation Supergroup on the Slave craton in Northwestern Territory of Canada (Sakai et al., 2013), therefore the PLHS is important to understand tectonics and sedimentation in the rifting process of the supercontinent Columbia. In addition, it has also important key to solve the exhumation process of the Himalayan metamorphic belt, so called the Higher Himalayan Crystallines (HHC), which thrusts onto the PLHS and caused inverted metamorphism. However, age data of the PLHS are very limited except the lower group and granitic intrusives (augen gneiss) into the lowest Kuncha Formation. Then, we performed detrital zircon U-Pb dating of the three groups comprising the PLHS and granitic rocks intruded into the Kuncha. As the results, depositional age of the Lower Group was estimated from 1.9 to 1.75 Ga, and those of the Middle and the Upper Group are from 1.75 to 1.7 Ga and from 1.7 to about 1.6 Ga, respectively. Furthermore, we recognized two peaks of granitic activity at around 1.85 and 1.75 Ga. In this paper, we report the results of dating and discuss on the depositional age, provenance and tectonic meaning of unconformity between the groups.

The PLHS is divided into three groups: the Lower Group, the Middle Group, and the Upper Group. The Middle and Upper Group are separated by an unconformity. The uppermost part of the Kuncha Formation of the lowest unit of the PLHS yielded the youngest detrital zircon age of 1869 $\pm$ 24 Ma. The basal part and the uppermost part of the Naudanda Quartzite of the Lower Group yielded the youngest detrital zircon U-Pb ages of 1773 $\pm$ 55 Ma and 1755 $\pm$ 45 Ma, respectively. Then, the depositional age of the Lower Group is estimated to range 1870-1750 Ma. The youngest detrital zircon of the Nourpul Formation of the Middle Group yielded U-Pb age of 1650 $\pm$ 43 Ma. The youngest detrital zircon of the Benighat Slates of the lower part of the Upper Group yielded U-Pb age of 1586 $\pm$ 53 Ma. The Riri Limestone of the Upper Group yielded Pb-Pb age of 1683 $\pm$ 68 Ma (Watanabe, 2001MS). Then, the depositional age of the Middle Group is estimated to range 1750-1640 Ma, and that of the basal part of the Kerabari Formation at the uppermost stratigraphic unit of the PLHS is estimated to range 1640-1610 Ma. The Dunga Quartzite in the Robang Formation of the uppermost unit of the Nawakot Complex yielded the youngest detrital zircon age of 1800 $\pm$ 63 Ma, which is assigned to the age of the Lower Group. Thus, it is no doubt that this overturning of age was caused by thurusting of the Kuncha nappe over the Malekhu Limestone of the Upper Group.

A mylonitic granite intruded into the sediments of the MCT zone, which is the uppermost part of the Kuncha nappe, was dated as 1769 $\pm$ 15 Ma, and an augen gneiss intruded into the basal part of the MCT zone was dated as 1730.4 $\pm$ 9.7 Ma. They show younger ages than previously reported ages of granites intruding into the Kuncha Formation (1.9-1.8 Ga). It suggests that igneous activity occurred intermittently within the sedimentary basin of the PLHS. Age distribution histogram of detrital zircons from the Lower Group commonly have two peaks at around ˜1850 Ma and ˜2450 Ma. On the other hand, age distributions of detrital zircons from the Upper and Middle Group have an unique peak around ˜1750 Ma. This indicates that tectonic event occurred in between the Lower and Middle Group, and caused a change of the provenance of detritus.

Keywords: Lesser Himalaya

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Geochronology, geochemistry and petrology of Bashisuogong intrusions: Implications for magmatic evolution of Tarim LIP

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The alkali granitic intrusions are exposed in the Bashisuogong region, which is located in the northwest margin of Tarim Block, NW China. Recent research suggested that the coeval basalt lavas, mafic-ultramafic intrusions, as well as the mafic dikes and syenitic and granitic intrusions in Tarim, composed an Early Permian Tarim large igneous province (Tarim LIP).

Zircon U-Pb dating, whole-rock major and trace element and isotopic data are presented for the granitic intrusions in Bashisuogong region. Compared to the previous study on the coeval mafic-ultramafic and granitic intrusions in Piqiang and Halajun area of Tarim Block, the new SHIRMP U-Pb age for Bashisuogong intrusion reveals that all the igneous rocks in the northweat region of Tarim Block are coeval (ca. 275 Ma). Geochemically, the granitic intrusions show high contents of SiO_2, K_2O, total alkalis, HFSE and Ga/Al, $FeO_t/(FeO_t + MgO)$ and Nb/Y ratios, which favor an A-type affinity for the granitic intrusions.

These geochronology and geochemistry data of Bashisuogong intrusions will be integrated with published data for the other intrusive rocks within Tarim Block to provide a more complete interpretation of the magmatic source(s) and evolutionary history of this important intrusion of the Tarim LIP and with implications for the Tarim LIP as a whole.

Keywords: Tarim LIP, magmatic evolution, granitic intrusion, geochronology, geochemistry

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Tectono-metamorphic evolution of the upper sequence of Hidaka Metamorphic rocks in Satsunai-gawa River, Hokkaido, Japan

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Hidaka Metamorphic Belt (HMB) is one of the youngest *HT-LP* metamorphic belts, that provide an opportunity to investigate the low-grade metamorphism in the upper to lower cross-section of magmatic arc. The previous studies have mainly considered the lower sequence of metamorphic rocks from the various viewpoints of magmatism, metamorphism and deformation (e.g. Osanai et al. 1991; Toyoshima et al. 1994). Most of such studies on metamorphic and structural evolution of HMB are based on the data from high-grade metamorphic rocks and associated igneous rocks. Here, we propose new constraints on the tectono-metamorphic evolution of upper sequence of Hidaka Metamorphic rocks based on a comprehensive field mapping and structural analysis of upper sequence of HMB in the upper reach of Satsunai-gawa River, Hokkaido, Japan combined with Raman Spectra of Carbonaceous Material (RSCM) thermometry and Illite Crystallinity.

The study area is mainly grouped into two metamorphic zones, which are composed of muscovite-chlorite (Zone I), muscovite-biotite+/-chlorite assemblages and muscovite-biotite (Zone II), respectively. The muscovite-chlorite metasediments are metamorphosed at the peak condition of 200-400 degree C based on the RSCM thermometry and IC data, and the muscovite-biotite metasediments, schist and gneiss are metamorphosed at about 400 to 650 degree C. Peak metamorphic pattern and mineral assemblages are progressively changed from the eastern to the western area, suggesting the geothermal gradient of 39-47 degree C / km (R2 = 0.8 to 0.9). In addition to the understanding of thermal gradients, we also attempted a detailed structural analysis of metasedimentary rocks based on the data of Koyasu et al. (2007). In the study area, the structural evolution can be mainly grouped into three tectonic events; Stage I to Stage III. Stage I is characterized by the tectonic thickening of fore arc sediments (D0 stage), shearing (D1 stage), large-scale folding (B2) and sinistral and normal sense of shear (D2 stage), and layer-normal shortening of D3 quartz veins and metamorphic rocks (D4 stage) during prograde metamorphism. After these deformations, S-type tonalites intruded in these metamorphic rocks during stage II. The biotite-muscovite gneisses are mainly deformed by dextral and normal sense of shear before (D5 stage) and after the intrusion of D6 tonalites (D7 stage). Some metasedimentary layers were deformed by the sinistral and normal sense of shear (D8 stage) during retrograde metamorphism. Finally, brittle deformations are observed within the metasediments and tonalites during stage III. That D9 deformation involved the N-S to NW-SE shearing and cut the regional schistosities, B2 folding and peak metamorphic pattern (M1 thermal gradient).

At the B2 axial area, the S1 schistosity is cut by the S2 schistosity at high angle, and the syn- or post-D2 cordierite porphyroblasts are observed along to the S2 schistosity. In addition, the peak metamorphic pattern based on RSCM thermometry shows slightly oblique to the regional S1 schistosity, D0 bedding plane, and map-scale folding. These data suggest that the peak metamorphic event (M1) involved between B2 folding and the intrusion of the tonalities, and these events in the upper sequence contradict with the tectonic, metamorphic and geochronological evolutions of lower sequence. Detailed relationship between peak metamorphism and tectonic evolution of upper sequence of HMB is going to discuss in poster session.

Reference: Osanai et al., 1991. J. Metamorph. Geol. 9, 111-124. Toyoshima et al., 1994. Isl. Arc 3, 182-198. Koyasu et al. 2007. JPGU meeting, abstract.

Keywords: RSCM thermometry, Illite crystallinity, graphite, Structural evolution

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Spatial U-Pb age distributions of plutonic rocks in the central Abukuma Plateau, north-eastern Japan Arc

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Intrusive ages of the Abukuma plutonic rocks, a major Cretaceous granitic suite in the Japan Arc, were determined using zircon U?Pb age method. The U?Pb ages of the ‘Hbl-Bt granitoids’ distributed in the western to central part of the Abukuma Plateau were 113-99 Ma, whereas five ‘east leucocratic granitoids’ intruded within a short time range of 112-106 Ma. The U?Pb ages of a gabbro from the Mt. Katasone and of the ‘western leucocratic granitoid’ were115.2 $\pm$ 1.1 Ma and 96.7 $\pm$ 1.0 Ma, respectively. The above age distribution combined with geochemical results suggests that. Based on these zircon U?Pb age, significant difference of the intrusive age between ‘east-’ and ‘west leucocratic granitoids’ was indicated.

Keywords: Abukuma, granite, zircon, U-Pb, LA-ICP-MS