Delineation and characterisation of major tectonic provinces of Dronning Maud Land (East Antarctica) and significance for Rodinia assembly

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We present a large new geochronological data set from a critical transition zone in central Dronnig Maud Land, East Antarctica, where Grenville-age rocks of the Maud Belt are juxtaposed along the juvenile Tonian Oceanic Arc Super Terrane (TOAST). Previously, central Dronning Maud Land had been interpreted as part of the Kuunga Orogen (580-500 Ma) by some researchers, because of the lack of metamorphic ages of ca. 630-600 Ma, though based on a relatively small study. However, our new study clearly highlights the significance of metamorphic ages also in the range from 670 –600 Ma in this region and shows that a subdivision into Kuunga vs. East African Orogen is not valid. Our new data rather support a long-lasting, protracted Late Neoproterozoic/Early Palaeozoic tectono-metamorphic history along the margin of Kalahari. We can trace characteristic Kalahari-type rocks until the Wohlthat massive (12˚E), to the E of which typical TOAST-related rock crop out. The boundary zone coincides largely with the Forster Magnetic Anomaly, a major aeromagnetic lineament in the region. The second part of this study includes the age analyses of glacial drift from the southern side of the Dronning Maud Land Mts.. The moraines stranded as a result of the northward flowing ice-sheet and they therefore should characterise the cryptic subice geology inboard of the Dronning Maud Land Mts. Nine moraine bulk samples from 15-25˚E resulted in ca. 1100 new U-Pb zircon spot ages that range between ca. 2000 and 500 Ma. The very few oldest Palaeoproterozoic ages come from the easternmost localities and may indicate a provenance of the Ruker Craton. All samples are dominated by a major TOAST age peak of ca. 990 –900 Ma, clearly indicating that the TOAST reaches far inland, as has also been suggested by geophysical data. In addition, however, a significant Stenian age peak of ca. 1080 Ma also occurs. Although Late Mesoproterozoic ages are common in both the Maud Province of western-central DML as well as in the Rayner Complex to the E, the Stenian moraine sample differ with respect to composition and/or isotope geochemistry. They are juvenile, with depleted mantle extraction ages around 1.3 Ga, are subduction-related, and therefore resemble an early phase of oceanic arcs that was so far unknown in this region. Thus, TOAST related rocks are produced over a protracted period of time from ca. 1080 to at least 900 Ma. There is no sign of major metamorphic overprint immediately after crust formation. Therefore, these island arcs may have formed independent or peripheral to Rodinia and may reveal major accretionary tectonics outboard of Rodinia. Much later, the TOAST underwent major tectono-metamorphic overprint at 670 –500 Ma, as a result of the extroversion of Rodinia and its subsequent incorporation into Gondwana.

Keywords: Tonian Oceanic Arc Super Terrane (TOAST), Supercontinent assembly, Dronning Maud Land, East Antarctica

Oxygen isotope evidence for growth of zircon in metacarbonate rocks from Sør Rondane Mountains, East Antarctica

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Zircons in metasedimentary rocks are extensively studied to understand the provenance and tectonic evolution of orogenic belts, since it is believed that zircon can preserve the isotopic composition of different stages of orogenesis. In this study we report SHRIMP ages and geochemical characteristics of zircons in impure metacarbonate rocks from the Sør Rondane Mountains (SRMs), East Antarctica. The SRMs, located in the Neoproterozoic to Early Cambrian East African-Antarctic collisional orogen, are composed of medium- to high-grade metasedimentary, metaigneous and intrusive rocks of diverse composition. Multidisciplinary geological studies have revealed that this region can be separated into two distinct terranes, a metasedimentary and metaigneous dominated Northeastern (NE) and a meta-tonalitic and meta-sedimentary dominated Southwestern terrane (SW), that collided at around 650-660 Ma along the Main Tectonic Boundary [1] [2]. Strontium isotope chemostratigraphy of pure metacarbonate rocks suggested late-Tonian (880-850 Ma) apparent depositional ages in the SW terrane, whereas those in the NE terrane recorded early Cryogenian ages (820-790 Ma) [3]. Furthermore, a detailed study of Nd isotopes in the metacarbonates has helped to identify the existence of an extinct East Antarctic Ocean and its peripheral oceanic island arc system that preceded the formation of the East Antarctic continent in the Neoproterozoic before the final assembly of Gondwana.

In contrast to the typical sedimentary O and C isotopic composition, low concentrations for mobile trace elements and flat REE patterns for pure metacarbonates, the impure metacarbonates have heterogeneous O and C isotopic compositions, high concentrations of mobile elements and LREE enriched patterns. These together with the presence of hydrous minerals in impure metacarbonates suggest that they have been affected extensively by fluid infiltration events. Petrographic observations revealed that zircon is abundant. Superficially the grains appear detrital, but CL imaging revealed textures consistent with metamorphic growth. SHRIMP analyses of zircons in three impure metacarbonate rocks gave well defined tight concordia U-Pb zircon ages of 545 +/- 1 Ma (n=55), 546+/- 2 Ma (n=33) and 549 +/- 2 Ma (n=58), younger than the peak metamorphism of the SRMs.

Oxygen analyses of dolomite/calcite and zircon in these rocks yielded interesting results—high $d^{18}O_{(SMOW)}$ for zircon of about 23.4‰, and 24‰ in the surrounding dolomite. Similar to the previous reports on high oxygen isotope ratios for zircons in metacarbonate rocks from Sri Lanka and Myanmar [5], the zircons in the Sør Rondane impure metacarbonate rocks have not only re-equilibrated with the U-Pb system at c.550 Ma, but also for the oxygen isotopes with the surrounding carbonate minerals. Based on the evidence from oxygen isotopes, we suggest the possibility of oxygen isotope equilibration between zircon and carbonate and total dissolution-reprecipitation of zircons in metacarbonate rocks during the last stage of fluid infiltration coeval with the granitic activity. We also discuss the possible role of alkaline Ca-bearing fluids that might have been instrumental for the recrystallization process of zircon in metacarbonate rocks.

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Keywords: zircon, oxygen isotope, Antarctica

New Ar^{40}/Ar^{39} data from western, Dronning Maud Land, Antarctica: possible implications for Gondwana amalgamation.

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Biotite and amphibole Ar^{40}/Ar^{39} data on mineral separates from gneisses from the Sverdrupfjella and Kirvanweggan areas of Maud Province of western Dronning Maud Land (DML), Antarctica are reported. The samples were collected from “basement gneisses” the crystallisation ages of which are typically ~1000 and ~1200Ma old. The data provide insights into the post-orogenic evolution of western DML recognising that the area was involved in the amalgamations of Rodinia and Gondwana at ~1000-1150 Ma and ~500-600Ma respectively .

The data from the two areas show distinct differences. Data from six samples from Sverdrupfjella show that the dates from Bt-Hbl are similar. The dates range between ~460Ma and ~550Ma except for one severely disturbed Bt sample suggesting a date of ~326Ma. In four of the six samples the dates from Hbl are older than those from Bt with differences between Hbl-Bt pairs of between ~20-40Ma whereas in a sixth sample Bt yields a ~30Ma older date than Hbl.

In contrast data from six samples from Kirwanveggan show greater variability. The dates from four of five Bt samples range between ~498Ma-~520Ma with one sample yielding a date of ~868Ma. The dates from seven Hbl samples range from ~480Ma to ~1260Ma. This latter range in age correlates very crudely spatially with the youngest dates being from northern Kirwanveggan, to the oldest from the most southerly basement exposures in Kirwanveggan at Skappelnabben.

Immediately south of Skappelnabben, virtually undeformed quartz arenites and grits of the Urfjell Formation with ages of ~530Ma (from whole-rock Rb-Sr data), ~566Ma (SHRIMP U/Pb minimum detrital zircon age) and ~579Ma (Ar-Ar detrital muscovite age) are reported. The ages of detrital zircons suggest a provenance area similar to northern Mozambique and/or central to eastern Dronning Maud Land.

The data from Sverdrupfjella suggest a relatively short lived thermal pulse between ~460Ma and ~550Ma with the narrow range between older Hbl and younger Bt pairs being consistent with rapid cooling. In Sverdrupfjella and more broadly, DML, this age range is coincidant with widespread granitoid intrusion, inferred to provide an advective heat source during this period. In contrast, in Kirwanveggan, where younger granites are absent, the range in ages for Hbl are consistent with a crustal gradient between N. Kirwanveggan (~5-6kb) and near surface at south central Kirwanveggan at Skappelnabben. The data are consistent with deposition at surface of the Urfjell quartz arenites approximately ~550Ma ago.

The crustal gradient is consistent with post- orogenic erosional uplift of Sverdrupfjella and northern Kirwanveggan with Sverdrupfjella having experienced thermal input from granitoid intrusions and is consistent with the post -orogenic evolution of a mega-nappe collisional model for Gondwana amalgamation proposed by Grantham et al. (2008) in which granitoid genesis is related to anatexis in the footwall of the mega-nappe complex. The crustal gradient described above is consistant with thinning of the nappe complex southwards and termination north of the Urfjell area of Kirwanveggan.

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Keywords: Ar40/Ar39 ages, Western Dronning Maud Land, Gondwana

Timing of UHT metamorphism in eastern Gondwana.

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The east Gondwana reconstruction is extensively done based on the geochronological and structural studies. In this study we attempt to bring out a precise correlation using the timing of UHT metamorphism and representative mineral assemblages from Antarctica, Sri Lanka, and southern India. East Gondwana continental fragments including Trivandrum Block and Madurai Block southern India, Highland Complex Sri Lanka, southern Madagascar and East Antarctica consist of several occurrences of metapelitic rocks, orthogneiss and charnockite. This study focuses on sapphirine-quartz bearing ultrahigh-temperature metapelites from Rajapalayam, Madurai Block, southern India,Gampola, Highland Complex, Sri Lanka and Rundvågshetta, Lützow-Holm Complex, East Antarctica.
Samples of Cordierite-rich metapelites with sapphirine-quartz assemblage within garnets porphyroblastswere selected for U-Pb geochronology, Ti-in-zircon thermometry and REE analysis by Sensitive High Resolution Ion Microprobe (SHRIMP) from each location. Zircons wereanalysed both as separated grains and in-situ in thin-sections. Monazite grains separated from the same sample were analysed for U-Pb geochronology. The zircons were classified according to their morphology and REE patterns in the respective zones.
The cathodoluminescence images of zircons from Rajapalayam, Madurai block, showed distinct core with grey mantle and dark rims. On the basis of the chondrite-normalisedYb-Tb ratio, the REE patterns were catagorized as ‘high’ (4.7-6.6) and ‘flat’ (0.8-1.5). The cores gave a ‘high’ REE pattern while the grey and dark zones outside the cores gave ‘flat’ pattern. The Ti in zircon thermometry yielded a range of temperatures between 756˚C and 794˚C. The cores gave discordant ages as expected from detrital zircons and the oldest age observed was 2.8 Ga. The grey mantle region gave a weighted mean $^{206}Pb/^{238}U$ age of 528.6 ±4.5 Ma and the dark rims gave 522.5 ±3.7 Ma (95% c.l.). Monazite also gave $^{206}Pb/^{238}U$ age 554.6 ±7.2 while the $^{208}Pb/^{232}Th$ age was 544.7 ±7.2 (95% c.l.). Metamorphic monazite crystallized before metamorphic zircon.
The zircons from Highland Complex, Sri Lanka has detrital cores with pale or grey outer zone. On the basis of the chondrite-normalisedYb-Tb ratio the cores gave ‘high’ (7.5-23) REE pattern and the outer zone gave ‘flat’ (0.2-1.4) REE pattern. The Ti in zircon thermometry produced a temperature range from 682˚C to 914˚C from the separated and in-situ zircon grains. The core ages plots at ca. 900 Ma. The outer regions gave two groups of higher (n=38) and lower (n=42) weighted mean $^{206}Pb/^{238}U$ age at 560.4 ±4.4 Ma and 554.0 ±4.2 Ma respectively.
The Rundvågshetta zircons in CL showed cores, black inner zone and differentiated inner and outer zones. The cores and the black inner zones gave ‘high’ (8.1-14.8) REE patterns on the basis of chondrite-normalisedYb-Tb ratio and the inner and outer regions gave ‘low’ (0.2-0.6) REE pattern. The Ti in zircon thermometry yielded 735˚C to 858˚C. The cores gave dispersed $^{206}Pb/^{238}U$ age between 2.5-2.4 Ga. The black inner zone gave a weighted mean $^{206}Pb/^{238}U$ age of 596 ±11 Ma (n=6). The inner zone formed two groups to produce an older age of 556.3 ±7 Ma (n=5) and a younger age of 532.0 ±4.5 Ma (n=14). The outer zone also formed an older group at 549.0 ±5.8 Ma (n=12) and a younger group at 533.3 ±5 Ma (n=15). Monazite also gave $^{206}Pb/^{238}U$ age 586.1 ±5.5 Ma while the $^{208}Pb/^{232}Th$ age was 580.1 ±6.7 Ma (95% c.l.). Monazite also gave $^{206}Pb/^{238}U$ age 554.6 ±7.2 while the $^{208}Pb/^{232}Th$ age was

544.7 ±7.2 (95% c.l.). Metamorphic monazite crystallized after metamorphic zircon. The above results enable us to understand the linkage between high temperature lower crust of eastern Gondwana.We compare and contrast the UHT conditions in each terrain and present a model of Gondwana correlation

Keywords: UHT metamorphism, Gondwana, Spr-Qtz

Regional age zonation and multiple tectonic pulses of Neoproterozoic-Cambrian age from the western boundary of Eastern Ghats Belt, India: A comprehensive tectonic model for final amalgamation

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Eastern Ghats Belt (EGB), India is a Proterozoic orogenic belt characterised by the UHT-HT metamorphism. The status of EGB evolving in between the proto-India and its Precambrian neighbours (e.g., East Antarctica) is important and intriguing in terms of the Proterozoic “supercontinent” cyclicity. Although, the precise timing of cratonisation of northern EGB with Proto-India is still unclear. The timing of final thrusting of EGB on adjacent Proto-India (Bastar Craton=BC) is intuitively correlated at ~500-550 Ma (Upadhyay et al., 2008 among others). This cratonisation history is obscured as the tectonic model of cratonisation, tightly constrained by high-precision geological time, is absent from the marginal rocks. To delineate the exact age and tectonic model of cratonisation of EGB with respect to Proto-India, a detailed study of microtextural evolution coupled with high precision dating techniques (U-Pb SHRIMP zircon and U-Th-total Pb EPMA monazite dating) were carried out on the rocks along an east-west transect at the western boundary between EGB and BC.

At the eastern side of the western boundary, zircon and monazite grains of charnockite yield ~950 Ma age, which roughly coincides with the granulite metamorphism of Eastern Ghats Province of EGB. The youngest date recorded from the zircon and monazite grains of the charnockite is ~775-850 Ma. On the western side, the monazite grains closely associated with garnet grains in the sillimanite-bearing pelitic granulite exhibiting ~800 Ma ages from the Y-rich portion. The Y-enrichment in monazite grains and development of symplectite texture around garnet grains in mafic granulite is possibly in the response of garnet breakdown during an early phase of exhumation at ~800 Ma (Chatterjee et al., 2017). The appearance of late-hornblende in mafic granulite and the presence of fibrolite inclusion within ~500-550 Ma zircon grains in pelitic granulite suggest retrogression from granulite facies to granulite-amphibolite transitional facies occurred during ~500-550 Ma. However, this age of retrogression was exclusively confined near the western boundary due to the presence of adjacent shallow and cold craton. Thus, a spatially high-resolution geochronological data from the systematically sampled rocks exhibits a domainal age zonation across the western boundary of EGB for the first time. Eventually, textural evolution combined with geochronological data facilitate to construct a *P-T-t* path of the granulites.

Zircon dating of migmatitic hornblende gneiss of BC suggests that the rock formed at ~2400 Ma, which later suffered a younger thermal event at ~550 Ma due to thrusting of deep crustal EGB rocks on shallow crustal BC rocks during cratonisation (“hot” on “cold” thrusting, Gupta, 2012). On the other hand, detrital zircon and monazite of foliated quartz breccia (parallel to the local shear fabric) near the thrust contact exhibit a wide age span with multiple age peaks in between ~3100 and ~500 Ma. Since the quartz breccia preserves the thrust-related foliation, it is inferred that the quartz breccia deposited contemporaneously with the thrusting in an incipient basin adjacent to thrust front. The youngest detrital monazite grain record ~495 Ma age, which imply that thrusting was continued overstepping the Precambrian-Cambrian boundary. Finally, collating all the textural and geochronological results from the marginal rocks of EGB and BC, a comprehensive tectonic model of deep to shallow crust related to the cratonisation of EGB with Proto-India is offered.

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Keywords: SHRIMP dating, Tectonic model, Cratonisation history of EGB

Garnet granulites from the Palghat-Cauvery suture zone, southern India: indications of high-temperature Gondwana suture

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The *P-T-t* evolution and significance of garnet-bearing granulites from the Palghat-Cauvery Shear Zone is considered as a trace of the Gondwana suture in southern India. The garnet-kyanite rock preserves inclusions of gedrite, spinel and quartz within garnet. Further, the inclusions of sapphirine with spinel in garnet mark the prograde formation of garnet from a low-pressure hydrous condition to higher pressure. The formation of garnet-rim around gedrite, supports the garnet forming reaction after gedrite. The garnet-corundum-stauorlite-kyanite assemblage stable at higher pressures probably represents the peak metamorphic stage. Garnet core with inclusions preserves a Fe-rich composition while the rims are Mg-rich and poor in inclusions. The variations in rare earth element chemistry of garnet-core and rim are consistent with the major element variation reaction textures. The rare earth element chemistry of garnet is compared to that in zircons. Most of the staurolite in the studied samples show moderate to high Mg-content. The thermodynamic modeling results assessed the *P-T* peak of this unusual granulite to be around 14-15 kbar at temperature around 900˚C. Textural features, petrogenetic and phase diagram consideration delineate a tight *hairpin*-type anticlockwise *P-T* path for this granulite. The U-Pb zircon geochronological results correlate the timing of near-peak metamorphism in the Palghat-Cauvery Shear Zone to the Late Neoprotrozoic (537± 5.1 Ma), probably linked to the East African Orogen and the closure of Mozambique Ocean. This age data are broadly consistent with the zircon SHRIMP ages reported in Collins et al. (2007), as well as the larger database of EPMA ages from monazite and zircons in several ultrahigh-temperature granulite localities in the Madurai Block as well as from the Plaghat-Cauvery Shear Zone (Santosh et al., 2006). The extreme crustal metamorphism recorded from the Palghat-Cauvery Shear Zone mark this region as the thermal front between the Proterozoic granulite terranes in the south and the Archean terrane in the north in southern India. The presence of dunite and chromite-bearing lithologies in this belt further confirms the probability of this zone being an oceanic suture. Collins et al. (2007) also considered this zone as a probable trace of the Gondwana suture. The inherited zircon ages recorded in our study indicate that the sediments were derived from an Archean igneous province, similar to the Betsimisaraka suture in eastern Madagascar.

Keywords: Gondwana suture , southern India, UHT metamorphism

Petrogenesis and Tectonic evolution of Madras Block, southern India

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Madras Block, one of the least studied crustal domain in southern India, has an important role in palaeo geographic reconstruction because of its geographical position. The block lies towards the south-eastern part of Archean Dharwar Craton and north-eastern margin of Archean to Proterozoic Southern Granulite Terrain, separated from the Namakkal Block by Salem - Attur Shear Zone (SASZ) in the south, and from Shevaroy Block by Nallamali Shear Zone (NMSZ)in the west. Its eastern part is covered with younger sediments. Extensive studies have been made on adjacent regions such as north eastern Dharwar Craton and Palghat Cauvery Shear Zone correlating them with Napier complex and Lützow-Holm complex (in Enderby Land, Antarctica), whereas there have been no significant studies of the Madras Block so far. A detailed petrological, geochemical, geochronological, and isotopical study ofthe Madras block will help us to understand the crustal evolution of thisregionand also give us an idea about the connections with Rayner Complex, East Antarctica.

The Madras Block consists mainly of a massif charnockite. Few locations have been examined so far regarding its geochemical and geochronological signatures (Howie, 1955; Subramanian, 1959; Sen, and Sahu, 1970; Sen, 1970; Sen, et al., 1970, Glorie et.al., 2014). From a recent field survey carried out in this region, it is observed that the east to central part of the block mainly consist charnockite exposures. Other than charnockite, this region also has significant exposures of Hbl–Bt gneiss/Quartzofeldspathic gneiss/Bt-gneiss/TTG, Ep–Hbl Gneiss, 2–Px granulite, Amphibolite and Metagabbro intruded by younger dolerite dykes and granites. These ortho-gneiss are also associated with meta-pelites, Grt–Bt Gneiss, and calc-silicates. The northern side of the region consists mainly of amphibolites. The west and southern side consists mainly of Hb-Bt gneiss and granitic plutons. Pink granitic plutons can be found along the centre of the block, intruded into the charnockite.2-Px granulites co-exist with charnockite. Contact zones between charnockite - granite, charnockite –TTG, and TTG- amphibolites are very evident.

From this block, we can see three types of charnockite: high-grade Opx bearing granulite (Charnockite), Cpx and Opx bearing granulite (Cpx Charnockite), and Grt–Opx bearing granulite (Grt charnockite). Grt bearing charnockite are observed around Palar river and NSZ region, Cpx-rich charnockite is also exposed along the northern side of the block. The presence of hemo-ilmenite in these samples indicates these rocks are highly oxidized. The charnockite is present along the east to central part of the block. Charnockite from the type area (St. Thomas Mount -Pallavaram) are Cpx-bearing charnockite and are gabbroic in nature. Po, Ccp and Py are common in all the charnockite samples. These sulfides have been remobilized along the Plg grain boundary. Ilm and Mag are also present in these samples. Samples from the shear zone show a linear orientation and gneissic texture rich in Bt and Amph. The shear zone rocks are well hydrated such Opx is rehydrated back to odel for the genesis and evolution of Madras blockof precise radiometric dating techniques.graph Bt.

The whole rock chemistry of the charnockite gives: SiO_2: 62.75; TiO_2: 0.89; Al_2O_3: 14.68; Fe_2O_3: 7.97; MnO: 0.10; MgO: 2.42; CaO: 4.46; Na_2O: 3.78; K_2O: 2.04; P_2O_5: 0.28.From the Harker Variation Diagrams, MgO, CaO, TiO_2, and Fe2O3 indicates a negative trend with SiO_2 whereas K_2O shows a positive trend. Na_2O and Al_2O_3 show only scatter. Based on the EPMA analysis of the charnockite, Opx has the X_{Mg} of 0.306, Cpx have X_{Mg} of 0.43, and the Grt is Fe rich. From the petrography and geochemistry, there are clear indications for a metamorphic grade zoning in Madras Block.

Keywords: MADRAS BLOCK, SOUTHERN INDIA, CHARNOCKITE, ORTHOPYROXENE

Petrology and geochemistry of post-tectonic dykes in Tiptur area, Western Dharwar craton, Southern India

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Mafic dyke swarms are one of the major geologic features that represents crustal extension episodes during which basaltic material from the mantle is transferred to the continental crust. The study of these dykes will help to understand the nature and composition of the mantle source. The emplacement of dykes is regarded as one of the final stages of cratonization and hence the study of these dykes throws light into the accretionary history of the craton. In the Dharwar craton of Southern Peninsular India, mafic dykes are densely spread like other Precambrian terranes of the world. Although dykes are well distributed in Dharwar craton, only those of Eastern part of the craton have been extensively studied and less attention has been given to the detailed petrologic, geochemical and geochronological studies of the dykes in the Werstern Dharwar Craton (WDC). Studying the mafic dykes in the WDC will help to understand the activity of the craton during Late Archean to early Proterozoic and this will help to obtain a complete picture of the tectonic evolution of Dharwar craton.
One of the major dyke swarms in the WDC is Tiptur dyke swarm, where NE-SW as well as NW-SE dykes are densely distributed. Preliminary petrological studies were carried out to understand the nature and composition of this dyke swarm and the studied dykes falls into two distinct groups. The NW-SE trending dykes were unaltered, composed predominantly of plagioclase and pyroxenes with minor opaque minerals. The NE-SW trending dykes showed high degree of alteration with the preservation of only 50% or less remnant ophitic textures as well as original mineralogy. The bulk rock geochemical analysis using XRF has been conducted. Loss on ignition were found to be less than 1% for all the samples. In the wt% of major oxides, SiO_2, CaO, Fe_2O_3 and alkalies shows smaller variations whereas MgO and Al_2O_3 show large differences. The overall chemical composition of the dykes indicate sub-alkaline tholeiitic nature with the NE-SW dykes falling into basalt field and NW-SE dykes in basaltic andesite fields. In the trace element geochemical characteristics, an overall enriched pattern is observed. Primitive mantle-normalized multi-element diagram of NW-SE dyke samples showed an LILE enriched pattern. Significant negative Nb and Ta anomaly along with a negative correlation between Zr and Sr is observed which may indicate the interaction of continental/ oceanic materials through subduction process. NE-SW dykes shows a slight LILE enrichment. Chondrite-normalized REE diagram shows that the NW-SE dykes have an LREE enrichment and flat HREE pattern whereas a relatively flat pattern for both LREE and HREE for NE-SW dykes. The $(La/Lu)_N$ ratio for NW-SE dykes is >2, which indicate derivation from a more enriched source and for NE-SW dykes is <2 indicative of a depleted mantle source. Immobile incompatible element (Th-Yb-Nb) distribution also indicate an enriched mantle source for NW-SE dykes and a depleted or more primitive mantle source for NE-SW dykes.
Preliminary assessment of petrologic and geochemical features suggest that NW-SE dykes and NE-SW dykes may not be co-genetic, they might have formed from different mantle sources and might have emplaced in two different episodes. The NW-SE dykes of the present study is comparable to the dyke swarms in the eastern Dharwar craton which is linked to the global mafic magmatism at around 2.2 Ga that led to intracontinental rifting and related breakup of Archean continents. Based on mineralogy and alteration index the NE-SW dykes can be thought to be a part of an older event. WDC being older than the EDC, the NE-SW dykes might be older than the NW-SE dykes and might have emplaced prior to the amalgamation of the current eastern and western part of the craton, and carry important information on mantle dynamics in the Archean and Paleoproterozoic, although age dating of the dykes is essential to

confirm their temporal and spatial relations.

Keywords: Mafic dyke swarms, Precambrian, Dharwar craton

Paleozoic multiple thermal events in the Altai Range, Mongolia

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Altai Mountains are mainly situated in western Mongolia and northwestern China where correspond to heart of the Central Asian Orogenic Belt. The orogenic belt is the largest and longest-lived accretionary and collisional orogen on Earth, from the Ediacaran to the Permian. Therefore, study of Altai Mountains may provide some constraints on the growth of continent during the Paleozoic period.
The Altai Mountains are composed mainly of Paleozoic sedimentary and metamorphic rocks that were intruded by voluminous granitic intrusions. The metamorphic rocks that are focused in this study are in thrust contact with surrounding sedimentary rocks. Two metamorphic age clusters have been identified by our widespread monazite U-Th-Pb EMP dating; c. 350 Ma and 260 Ma. Samples containing normal-zoned garnet yield an age of c. 350 Ma or 260 Ma. However, samples containing garnet that shows discontinuous zoning in Ca have two monazite ages (i.e. c. 350 Ma and 260 Ma). The younger monazite grains are observed in the matrix and in garnet rim. Therefore, based on the metamorphic ages, there are three rock types; 1) rocks metamorphosed at 350 Ma, 2) at 260 Ma, and 3) both at 350 Ma and 260 Ma. Detrital zircon U-Pb ages from all three rock types show similar features each other, which are also consistent with the zircon ages in surrounding accretionary prism.
The 350 Ma metamorphic event that is well-preserved in the rocks from the western Altai Range, has been considered to be related with arc setting and burial of accretionary prism. The metamorphic pressure-temperature gradient and prograde metamorphic trajectory are various may due to the effect of ridge subduction during this period. The 260 Ma metamorphism mostly observed in rocks from the eastern Altai Range is characterized by hairpin-shaped anticlockwise pressure-temperature path. Considering the metamorphic age (c. 260 Ma) and the youngest age of the surrounding accretionary prism (Carboniferous), the event is final activation event in the Central Asian Orogenic Belt that may relate with closure of ocean and continental collision tectonics. During the presentation, we will discuss on the metamorphism and the ages.

Keywords: metamorphic rocks, Altai Range, Mongolia

Metamorphic *P–T* evolution and U–Pb dating of the high-grade metapelitic rocks from the Khondalite Belt, North China Craton

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The Wulashan-Daqingshan Complex and the Jining Complex in the Khondalite Belt, the North China Craton yield high-grade sillimanite-cordierite-garnet metapelitic rocks with representative metamorphic assemblages and microstructures. In combination with petrological observation and *P–T* pseudosections, a clockwise *P–T* path involving periods of near-peak, post-peak near-isothermal decompression and decompressional cooling is therefore inferred. For the garnet-cordierite-sillimanite metapelitic rocks of the Wulashan-Daqingshan Complex, the peak assemblage is garnet + biotite + K-feldspar + plagioclase + sillimanite + quartz + ilmenite + magnetite + liquid with *P–T* conditions of 830–860 ˚C and 9.5–11 kbar. The following near-isothermal decompression assemblage is garnet + biotite + cordierite + K-feldspar + plagioclase + quartz + magnetite + ilmenite + liquid at 840–880 ˚C and 6.0–7.5 kbar, characterized by matrix cordierite isolated from garnet by biotite decompressional dehydration melting reaction of Bt + Sil + Qz ±Pl →Crd + Kfs ±Ilm + Melt. Subsequent decompressional cooling processes resulted in cordierite and biotite + plagioclase symplectites surrounding garnet due to the following reactions of Grt + Sil + Melt →Crd + Bt + Fe-oxide and Grt + Melt →Bt + Qz ±Pl. The sillimanite-cordierite-garnet metapelitic rocks of the Jining Complex have preserved polyphase mineral assemblages and microstructural evidence of anataxis, resulting from biotite dehydration melting. Petrological observations revealed that these rocks contain three metamorphic assemblages: a peak assemblage of garnet porphyroblast and matrix biotite + sillimanite + K-feldspar + plagioclase + quartz + ilmenite + magnetite, a post-peak near-isothermal decompressional assemblage of garnet + cordierite + biotite + sillimanite + K-feldspar + plagioclase + quartz + ilmenite + magnetite, and a decompressional cooling assemblage of garnet + biotite + cordierite +K-feldspar + plagioclase + quartz + ilmenite + magnetite. A clockwise *P–T* path was defined involving the inferred peak stage followed by post-peak near-isothermal decompression and decompressional cooling stages, with *P–T* conditions of 790–825˚C and 9–10 kbar, 810–890˚C and 6.0–6.5 kbar, and 780–810 ˚C and 4.0–5.5 kbar, respectively. Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) U–Pb analyses of the sillimanite-cordierite-garnet metapelitic rocks on detrital zircons yield yielded a protolith age of ~2.0 Ga. Moreover, metamorphic zircons yielded the late Paleoproterozoic metamorphic age of 1850 ~ 1950 Ma with age groups of ~1950 Ma, ~1900 Ma, and ~1850 Ma. The clockwise *P–T* paths and new zircon data reveal that the Paleoproterozoic Khondalite Belt involved in continent–continent subduction and collision followed by exhumation and cooling between the Yinshan and Ordos Blocks in the Western Block of the North China Craton, and experienced the Paleoproterozoic granulite-facies metamorphism.

Keywords: metapelitic rocks, partial melting, phase equilibria modeling, P–T path, Khondalite Belt

The growth, reworking and evolution of early Precambrian crust in the Jiaobei terrane, the North China Craton: Constraints from U-Th-Pb and Lu-Hf isotopes, and REE concentrations of zircon from granitoid gneisses

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The early Precambrian crustal growth and reworking of the North China Craton (NCC), its tectonic subdivision and amalgamation, and its major magmatic and metamorphic events are important issues of considerable controversy. The high-grade metamorphic Jiaobei terrane located at southeastern NCC, mainly composed of Archean and Paleoproterozoic granitoid gneiss and metamorphic supracrustal rocks, is generally considered to be the southern extension of the Jiao-Liao-Ji belt which has commonly been regarded as a Paleoproterozoic active belt on the eastern margin of the NCC.
To better understand the growth, reworking, metamorphism and tectonic evolution of the Jiaobei terrane, Jiao-Liao-Ji belt as well as NCC, we have conducted a coupled LA-ICP-MS U-Th-Pb dating, trace element and in situ Hf isotopic study of zircons from Archean and Paleoproterozoic granitoid gneisses which mainly comprise Archean TTGs (tonalite-trondhjemite-granodiorite) and Paleoproterozoic deformed monzogranitic gneisses, undeformed syenogranites and pegmatitic granites. A comprehensive dataset of CL-images, Th/U ratios, REE (rare earth element) concentrations, $^{176}Lu/^{177}Hf$ and $^{176}Hf/^{177}Hf$ ratios of distinct zircon domains from the early Precambrian granitoid gneisses is presented. The results defined three stages of Archean continental crustal growth by TTGs magmatisms at ~2.9, 2.7 and 2.5 Ga, respectively. The TTGs have positive zircon $\varepsilon_{Hf(t)}$ values, and two-stage Hf model ages clustering at ca. 3.3-2.7 Ga. We also defined multi-stage Paleoproterozoic granitic magmatisms by remelting of continental crust during 2.2-2.0 and 1.8 Ga. The Paleoproterozoic granitoids show negative $\varepsilon_{Hf(t)}$ values, and two-stage Hf model ages mainly ranging from 3.2-2.7 Ga. We also obtained two groups of metamorphic ages of ~2.5 and ~1.86. The ~2.5 Ga metamorphic event which is widely occurrences in the NCC is thought to be linked to underplating of large amounts of mantle-derived magma, and the 1.86 Ga metamorphic event which is occurrences in western Khondalite belt, Trans-North China Orogen and Jiao-Liao-Ji belt is thought to be linked to arc (continent) –continent collision responding to assembly of supercontinent Columbia.
Based on our new results, combined with the previous researches, we summarized that the growth and evolutional history of early Precambrian continental crust in the Jiaobei terrane is following: 1) >~2.9 Ga, the Jiabei terrane were dominated by basic crust (oceanic crust) with limited early Archean continental crust which had been denuded; 2) At ~2.9 Ga, 2.7 Ga and 2.5 Ga, the ~3.3-2.7 Ga juvenile thickened basaltic lower crust experienced episodic partial melting companied with remelting of continental crust triggered by upwelling of mantle plume, and formed the Archean continental crust consisting of plenty of TTGs and minor continental crust-remelted (high K) granites; 3) During ~2.2-2.0 Ga, the continental crust took place rifting and thinning caused by upwelling of mantle materials, resulting in formation of ~2.2-2.0 Ga granitoids by remelting of the continental crust; 4) During ~1.95-1.85 Ga, the Jiaobei terrane underwent granulite to high amphibolite facies metamorphism caused by collision-related tectonic processes and closing of the rift; 5) At ~1.8 Ga, the continental crust underwent extension and thinning again caused by upwelling of mantle materials, which resulted in formation of ~1.8 Ga granites by remelting of the continental crust.

Keywords: The Jiaobei Terrane, Early Precambrian geology, Continental crustal growth, Archean TTGs gneisss, North China Craton

