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7th International Symposium on Gondwana to Asia: Evolution of Asian Continent and its Continental Margins

Abstract Volume

Editors

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The Construction and Destruction of Continents and Supercontinents

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Continental growth occurs predominantly through the addition of juvenile crust by arc magmas. In the early history of the Earth, the parallel collision of intra-oceanic arcs was an important process to build embryonic continents. Recent studies from Archean terranes in different parts of the world have offered important clues for the process of amalgamation of composite arcs. A modern analogue for the Archean process is the western Pacific domain where the majority of island arcs are concentrated in the oceanic domain. Accretionary tectonics is well recognized as the hallmark of continental growth and it has long been believed that all materials in the subduction zone are accreted onto the continent. The mass flux through convergent plate margins has received considerable attention in recent studies particularly to evaluate the origin and growth of the continental crust. Recent studies suggest that the processes of subduction-erosion, sediment subduction and arc subduction play crucial roles in the destruction of continents. The zone along which two continental plates have joined, or where an oceanic lithosphere has been totally subducted, defines a suture. Sutures have been traditionally identified by the presence of ophiolites and blueschist facies rocks. However, the deep erosion in Precambrian terrenes has erased these rock records and one of the important criteria to distinguish ocean closure from surface geology comes from the concept of ocean plate stratigraphy (OPS). OPS is defined as the original composite stratigraphic succession of the ocean floor before it was incorporated in an accretionary complex and records the succession from the initiation of the oceanic plate at a mid oceanic ridge to subduction at an oceanic trench. An evaluation of the architecture of the tectosphere (subcontinental lithospheric mantle) from recent geophysical studies indicate a layered structure with contrasting velocity domains suggesting stacked layers of subducted and accreted oceanic lithosphere. Ancient cratonic roots have been variably 'eroded' through subsequent processes including subduction, asthenospheric upwelling and magmatic pulses. The 'erosional plane' can be imaged from the nature of the Lithsophere-Asthenosphere Boundary (LAB). Evidence for decratonization from a number of ancient cratons are described in this presentation as interpreted from geophysical data. The balance between creation and destruction of continental crust changes over a supercontinent cycle, with a higher crustal growth through magmatic influx during supercontinent break-up as compared to the tectonic erosion and sediment-trapped subduction in convergent margins associated with supercontinent assembly which erodes the continental crust. The periodic assembly and dispersal of supercontinents through the history of the Earth had considerable impact on mantle dynamics and surface processes. The process of formation of supercontinents and their disruption are evaluated in the light of recent studies based on numerical simulation as well as conceptual models on mantle dynamics. The process of assembly of supercontinents induces a temperature increase due to the thermal insulating effect leading to a planetary-scale reorganization of mantle flow. This results in the longest-wavelength thermal heterogeneity in the mantle; this degree-one convection is integral to the emergence of periodic supercontinent cycles. Supercontinent breakup has been correlated with a temperature increase due to upwelling plumes originating from the deeper lower mantle or Core-Mantle Boundary (CMB) as a return flow of plate subduction occurring at the margins of supercontinents. Active mantle plumes from core-mantle boundary may disrupt the periodicity of supercontinent cycles. Superplumes originating from the CMB are fuelled by recycled subducted slabs, and act as pipes connecting the Earth's core to the surface as well as the planetary space.

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High Geothermal Gradient and Low Uplifting Rate of Granulites from North China Craton: Their Implication for Early Precambrian Tectonics

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High-grade metamorphic rocks are extensively distributed in the North China Craton (NCC), and study on high-temperature and high-pressure granulites (HT-HP) and high-ultra-high temperature granulites (HT-UHT) is a key issue to understanding the tectonic evolution of the Early Precambrian Earth. The HT-HP granulites are mainly garnet-bearing mafic granulites that are metamorphosed and deformed dykes enclosed in the orthogneisses. The HT-UHT rocks are metamorphosed pelites (khondalites), and sapphirine and spinal in khondalite indicates metamorphic temperature > 900-1000 ℃. This study deals with the occurrences, distribution, metamorphic conditions and history, isotopic ages of the two granulites, and emphasizes the following aspects: ① the peak metamorphic conditions and PT paths with a relief of pressure for two granulites are similar; ② their metamorphic ages of the peak and followed decompressional stages are also similar;③ HT-HP and HT-UHT granulites probably occur in area distribution other than in linear distribution;④ Several continental collisional models have been proposed for HP granulites. However, it is still argued that these rocks have much higher geothermal gradient of ～16 ℃/km and much slower uplifting rate of 0.33-0.5 mm/yr than those in Phanerozoic orogenic belts, indicating the rigidities of the old continental crust are significantly different from those of Phanerozoic crust⑤ All these observations suggest that we should rethink geological and tectonic models for the evolution of the North China craton.

Keywords: Early Precambrian, HT-HP granulites, HT-UHT granulites, tectonic implication, North China Craton

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The >540 Ma Pacific Superplume-Related Oceanic Magmatism: Evidence from Accretionary Complexes of Central and East Asia

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Plume-related oceanic magmatism form oceanic islands, seamounts and plateaus, which are important features in geological history because they trace magmatism related to deep mantle activity of plumes and superplumes (Maruyama, 1994). Besides, accretion of oceanic seamounts to active continental margins significantly contributed to continental crust growth. Both modern and paleoseamounts commonly consist of Ti-LREE-Nb enriched plume-related basalts (OIB-type) capped with massive limestone and associated with other units of oceanic plate stratigraphy (OPS) (Isozaki et al., 1990): MORB, pelagic chert, hemipeganic siliceous shale, basalt-carbonate breccia (slope facies), carbonate “cap”, etc. Late Neoproterozoic-Mezozoic seamounts of the Paleo-Asian Ocean (PAO) and Paleo-Pacific oceans formed in relation to the Pacific Superplume are hosted by accretionary complexes (AC) from foldbelts of Central and East Asia (Safonova et al., 2009 and references therein): Altay-Sayan (Russian Altay and East Kazakhstan), NW China (Yang et al., 1999), central and northern Mongolia, southern Kyrgyz Tien Shan, Russian Far East and Japan. The intraplate magmatism was active in the PAO during Late Neoproterozoic-Permian and in the Paleo-Pacific Ocean – Carboniferous-Late Cretaceous. The intraplate basalts were accreted to active continental margins during oceanic subduction (Buslov et al., 2001).

In spite of different ages the basalts have much in common: a similar geological position in accretionary complexes of orogenic belts formed during closure of paleo-oceans and subsequent collisional processes, spatial relation to mélange zones and island arc formations, and their close association with OPS units, which are indicative of their formation on an oceanic rise: reefal limestone, Z-folded slope facies, siliceous shale, etc. The majority of OIB-type basalts from all AC’s of Central and East Asia possess geochemical affinities of typical OIB: TiO_2>1.5 wt.%, La/Sm_n>1.3, Gd/Yb_n>1.4, Nb/La_{pm}=1.2-1.9; Nb/Th_{pm} =1.02-5.6.

Of special interest was the Middle Paleozoic gap in manifestation of PAO intraplate magmatism first noted by Safonova (2009). Recently, the first geochemical data on the OIB-type basalts hosted by the Ulaanbaatar AC of Mongolia (Late Silurian-Devonian) and Atbashi-Kokshaal AC of Southern Tien Shan (Devonian) and new data on the poorly studied Char AC of East Kazakhstan (Late Devonian-Early Carboniferous) have been obtained. Those data permitted to narrow the Middle Ordovician-Middle Devonian gap of PAO plume-related magmatism (~100 Ma) to a period from the Late Ordovician to the Late Silurian (~40 Ma).

The successive character of the PAO magmatism can be more reliably proven by the careful study of the Middle Ordovician-Silurian OPS units including OIB-type basalts in NW China, Mongolia, Kyrgyzstan and central Kazakhstan. For this morel field and analytical works seem to be necessary including ICP MS trace element and isotope analyses. Obtaining such data would allow us to confirm the intra-plate origin of those lavas as parts of oceanic seamounts, to estimate their petrologic parameters and understand their mantle sources.

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Thinning of Sub-Continental Lithospheric Mantle under Eastern China: The Role of Water and Multiple Subduction

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We present a comprehensive model to explain why the Archean sub-continental lithospheric mantle (SCLM) under eastern China was thinned and delaminated so drastically in the Cretaceous. The SCLM under Eastern China has been affected by the subduction of several oceanic plates, the sites of former oceans now commonly marked by sutures: to the north the south-dipping Permo-Triassic Solonker and Jurassic Mongol-Okhotsk sutures, to the south the north-dipping Permo-Triassic Dabie Shan and Song Ma sutures, and to the east is the west-dipping Pacific oceanic plate (200-100 Ma). Water was carried down under eastern China by the hydrated Pacific plate for at least 100 Ma, by the Solonker, Dabie Shan and Song Ma plates for at least 250 Ma in the Paleozoic, and by the Mongol-Okhotsk plate for at least 200 Ma until the Jurassic. Tomographic images show that the Pacific plate has ponded along the top of the mantle transition zone under eastern China. An addition of 0.2 wt% subducted H_2O lowered the solidus temperature of hydrous mantle peridotite by 150°C, which led to extensive melting in the hydrous mantle transition zone. After formation of the Solonker and Dabie Shan sutures, post-collisional thrusting in the Jurassic led to major thickening of the crust, and the hydration caused major eclogitization of the thickened deep crust, which together triggered collapse of the hydro-weakened eclogitic crustal root. Also in the Cretaceous, the melting of the hydrated SCLM led to voluminous magmatism, accounting for abundant, well-documented, mafic, adakitic and granitic intrusions (that have brought up some eclogites), to extensive gold mineralization, and to metamorphic core complexes and sedimentary basins that formed under extensional conditions in the upper crust. Part of the root was physically delaminated, and part of the thinned SCLM was chemically transformed and replaced by upwelling fertile asthenospheric material, which later fed the rise of extensive alkali flood basalts and volcanoes in the Cenozoic. As a result of these processes eastern China, today, has high heat flow, a thin crust and lithosphere, low mantle seismic velocities, flat surface topography, and is still seismically unstable.

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Formation and Evolution of the Dabie-Sulu Orogenic Belt

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Since findings of coesite and microdiamond as inclusions in metamorphic minerals from eclogites in the Dabie-Sulu orogenic belt in east-central China, this belt has undergone extensive and intensive studies of geochronology, tectonics, petrology and geochemistry in the past two decades. It has been recognized that UHP metamorphic rocks in this orogenic belt formed by the Triassic subduction of the South China Block beneath the North China Block. While the investigation of surface outcrops reveals that this continental subduction zone is one of the largest (> 30,000 km2) and best-exposed UHP metamorphic terranes on Earth, the study of samples from the Chinese Continental Scientific Drilling (CCSD) program shows a continuous occurrence of coesite and its pseudomorph in metamorphic rocks up to depths of 5,000 m. Therefore, a huge amount of the continental crust was subducted to mantle depths and then returned back to crustal lelevs.

On the basis of field occurrence and country-rock association, three types of eclogite have been recognized in the Dabie-Sulu orogenic belt: (1) G-type, gneiss-hosted enclaves or layers; (2) M-type, interlayers with or enclaves within marble or calc-silicate rocks; (3) P-type, in association with metaultramafic rocks (peridotite and pyroxenite). The gneiss has the most extensive occurrence, and it is mainly composed of granitic orthogneiss with protolith U-Pb ages of middle Neoproterozoic (740 to 780 Ma), a minor amount of biotite paragneiss with protolith U-Pb ages of middle Paleoproterozoic to late Archean (1.9 to 2.6 Ga). The marble was metamorphosed from pure and impure limestones that were deposited in the Neoproterozoic. The peridotite and pyroxenite rocks were the ultramafic intrusions in the middle Neoproterozoic. Correspondingly, the three types of eclogite have the different ages of protoliths, but mainly in the middle Neoproterozoic. The occurrence of mid-Neoproterozoic igneous rocks is a characteristic feature of rift magmatism in South China. Therefore, all these metamorphic rocks have the tectonic affinity to the South China Blocks. Whole-rock Sm-Nd and zircon Lu-Hf isotope studies of UHP eclogites indicate that their protoliths were princiaplly derived from partial melting of the subcontinental lithospheric mantle rather than the asthenospheric mantle, excluding the possibility of the subduction of oceanic crust.

The maximum pressure estimates lie in the diamond stability field (>3.3 GPa), and the maximum temperatures vary from 730 to 850°C depending on P-T paths of the subduction/exhumation of different UHP slices during the continental collision. In terms of the differences in metamorphic P-T conditions, UHP slices are subdivided into low-T/UHP, mid-T/UHP and high-T/UHP units, respectively. The low-T/UHP unit is estimated to have a peak pressure of 3.3 GPa at about 670°C but a peak temperature of 730°C at about 1.5 GPa, whereas the mid-T/UHP and high-T/UHP units have a peak pressure of 4.0 GPa at about 700-750°C but a peak temperature of 800-850°C at about 2.0 GPa. The UHP metamorphism in the coesite stability field is determined by SIMS and LA-ICPMS in-situ U-Pb dating techniques to occur in a range of 240 to 225 Ma, with HP eclogite- or granulite-facies recrystallization at 220±5 Ma during the exhumation. While granulite-facies overprinting is remarkable at for the high-T/UHP unit, amphibolite-facies retrogression is evident for the mid-T/UHP unit. There are variable occurrences of partial melting and even migmatitization in the three units of UHP rocks, indicating the local accumulation of aqueous fluids from the decompression exsolution of structural hydroxyl and molecular water in nominally anhydrous minerals as well as from the breakdown of hydrous minerals.

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Late Oligo-Miocene Crustal Level Shearing along the Ailao Shan Red-River Shear Zone: Constraints from Structural Analysis, and Sr-Nd and Lu-Hf Geochemistry of Leucocratic Intrusions along the Shear Zone

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The over 1000 km Ailao Shan-Red River (ASRR) shear zone is one of the most important geological discontinuities in Southeast Asia. Great controversies remain on the nature of the ASRR shear zone and its role in shaping the tectonic framework of Southeast Asia.

Our observation reveals the existence of two types of Cenozoic leucocratic intrusions along the shear zone, e.g. the Paleogene high potassic alkaline rocks (>30Ma) and the late Oligocene to early Miocene calc-alkaline granitic rocks (28-21Ma). The former are concordant dykes and are generally strongly sheared into mylonitic rocks. The latter are either concordant and show weak strain fabric, or discordant and show no strain fabric. Although the two types of leucocratic rocks are not discriminable due to extensive post-magmatic, and mostly syn-shearing metasomatism, however, they have distinct REE, Sr-Nd, Hf isotope signatures and are different in mineralizing features. Whole rock REE have enriched LREE and depleted HREE without any Eu anomalies. Whole rock Sr-Nd ($^{87}Sr/^{86}Sr_{(i)}$: 0.7069 to 0.7098; εNd(t): -7.98 to -3.31) and in situ Zircon Hf isotope (-0.79 to +6.2) analyses yield a binary mixing trend between the mantle- and supracrustal-derived melts for the Paleogene mineralizing magma, and an origin from crustal melts for the late Oligocene-early Miocene barren magmatism. Here our new data suggest that most of the Paleogene magmatic rocks are either sheared high potassium alkaline rocks or deformed calc-alkaline intrusions. They are identical to and are the deformed counterparts of rocks from the two Paleogene magmatic provinces on both sides of the ASRR shear zone, i.e. the Jinping-Fan Si Pan province and the Dali-Beiya province. These two types of leucocratic rocks are formed as the result of post-collisional delamination of a thickened crust, and deformed and offset by the left lateral shearing along the ASSR shear zone. The late Oligo-Miocene calc-alkaline granitic rocks are localized within the ASRR shear zone. They are in overall concordant to the mylonitic foliation in the shear zone and preserve microstructures typical of syn- to late kinematic emplacement. They have negative Eu anomalies, variable but mostly higher Sr ratios ($^{87}Sr/^{86}Sr_{(i)}$: 0.7070 to 0.713), lowerεNd(t) (-9.27 to -6.81) and negative Hf (-10.2 to -1.1). These characteristics and the similarities of the Sr-Nd isotopes of the rocks to the gneiss country rocks suggest that the granitic melts were derived from the anataxis of crustal rocks. We conclude that shearing along the ASRR shear zone is coeval with the magmatism between 27 Ma and 21 Ma. On the other hand, the tectono-magmatic relationship also provides clues of the shearing limited to the crust level, instead of the entire lithosphere. Extrusion of the crust of the Indochina block did not occur until shearing started, subsequent to the post collisional collapse. The transformation from extension-related to extrusion related tectonic regimes contributed to the transition from localized high rates sedimentation to widespread low rates deposition in the entire South China Sea.

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Emeishan Large Igneous Province (SW China) and the Mantle Plume Up-Doming Hypothesis

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The Middle Permian (~262 Ma) Emeishan Basalt Formation of SW China is a commonly cited example of a large igneous province (LIP) that formed due to a deep-mantle plume impacting the base of the lithosphere and generating large regional-scale up-doming prior to volcanism. Recently, though, this assertion has been challenged on the grounds that some lava flows close to the centre of the LIP were erupted in a submarine setting. Here we analyze all the available biolithostratigraphical, petrological, geochemical and volcanological information and show that these support the idea that the terrain was generated by a plume that originated in the mantle. Emeishan melted from a hot mantle source with trace element contents that are similar to the source of Icelandic and intraplate ocean island basalts. However, the amount and lateral extent of updoming is significantly less than is predicted by conventional deep-mantle plume models. We conclude that large-scale doming is not a diagnostic feature of mantle plumes; surface topography can be greatly influenced by the type of lower mantle plume (thermal or thermochemical), how it transits the transition zone, and how it interacts with the lithosphere.

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Triassic Tectonics in the South-Western Margin of the South China Block and the Welding of the South China-Indochina Blocks

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It is widely accepted that the Red River Fault (RRF) is the boundary between the South China and Indochina Blocks. Although this interpretation explains well the Cenozoic to present tectonic framework of SE Asia, and particularly the left-lateral strike-slip and related phenomena along the RRF, or the oroclinal bends observed in SE Yunnan and NE Vietnam, it does not apply for older orogenic events. Ophiolites and accretionary complexes are lacking along the RRF. For pre-Cenozoic tectonics, the Song Da zone corresponds to a Permian-Triassic rift developed within the Indochina Block. The Song Ma suture is generally acknowledged as a major plate boundary active during the Triassic (e.g. Lepvrier et al., 2008). However, the Song Ma suture is located South of the RRF, it cannot be considered as the Triassic boundary between the South China Block and Indochina Block since a the Cenozoic displacement along the RRF implies that the part of Indochina located south of the Song Ma suture should be placed more to the Northwest during Triassic times.

North of the RRF, in NE Vietnam, an ophiolitic melange with blocks of serpentinized ultramafic, gabbro, mafic lava, chert, and limestone enclosed within a siliceous muddy matrix is exposed along the NW-SE striking Song Chay fault (Lepvrier et al., 2009). More to the northeast, this ophiolitic melange overthrusts a pervasively foliated and folded Cambrian to Early Triassic series. The Triassic Song Chay augen orthogneiss is an Ordovician (ca. 440 Ma) porphyritic granite that intruded Cambrian pelites and limestone, and experienced ductile shearing during the Triassic orogeny at ca 230-200 Ma (Maluski et al., 2001; Roger et al., 2000).

Farther North, the Devonian- Carboniferous marble and pelite series overthrusts, with a flat lying mylonitic contact, an intermediate Lower to Middle Triassic turbiditic Unit. This flysch unit widely develops to the North in Guangxi and Yunnan provinces where it is known as the "Nanpanjiang basin". In NE Vietnam, the Triassic flysch tectonically overlies, through a decollement layer upon an unmetamorphosed but weakly folded domain formed by a Permian to Devonian carbonate platform. Furthermore, an unconformity, already well identified in South China separate the Devonian to Triassic series form the underlying Cambrian-Ordovician pelitic series. In Guangxi, Triassic turbidite directly overlies a huge carbonate platform of several km thick that widely develops in Yunnan, Guangxi, Guizhou and Guangdong provinces. Locally in NE Vietnam and W. Guangxi, laterite and bauxite formation argue for a Permian emersion and karstification of the limestone platform.

In several places (for instance near Caobang), the Triassic turbidite includes, meter to kilometer-sized olistoliths of pillow basalts, limestone and siliceous mudstone. The mafic rocks are also well developed in Guangxi and Yunnan Provinces where they are sometimes described as "Babu ophiolites" (eg. Cai and Zhang, 2009). However, our field observations (e.g. near Baise) show that these rocks intrude Carboniferous or Permian limestone series in which they develop a thermal contact metamorphism. Most of the basalts and gabbros exhibit an alkaline geochemical signature. Thus, in addition with their lithological assemblage, quite different from that of an ophiolitic suite, we interpret these Permian mafic rocks as formed by an intraplate magmatism, probably related to the Emeishan plume.

At the scale of the entire belt, the deformation increases from the NE to the SW. In the outer zone, e.g. between Baise and Caobang, the Devonian to Early Triassic series is deformed in a thin-skin tectonic style. Km-scale parts of the carbonate platform overthrust to the N. or NE the middle Triassic turbiditic series. Conversely, in the inner zone, the architecture of the belt is a stack of ductilely deformed thrust sheets separated by mylonitic contacts. The ductile deformation related to nappe stacking is characterized by a flat-lying foliation and a N-S to NE-SW striking stretching lineation. Kinematic indicators and North-verging folds argue for a North-directed shearing. Close to the Song Chay suture, the Paleozoic metapelites experienced a MP/MT metamorphism with the development of biotite-garnet-staurolite assemblage. These micaschists yields monazite U-Th-Pb ages bracketed between 255 and 232 Ma. These dates are in agreement with previous works in NE Vietnam (e.g. Deprat, 1917; Bourret, 1922). Our field and laboratory analyses indicate that this stack of nappes was acquired prior to the unconformable deposition of the Upper Triassic terrigeneous sediments and the emplacement of Late Triassic granitoids.

The NE Vietnam-SW China nappes were transported to the N-NE and rooted in the Song Chay suture zone that represents the true Triassic boundary between the South China Block and the Indochina. The possible extensions of this suture in the Jinshanjiang belt of Yunnan province, and in SE China are discussed.

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KT-9

A Century Old Stratigraphic Controvery in Gondwana Basins of Peninsular India: An Attempt to Resolve it

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Establishing stratigraphy is a usual part of geologic investigation. What is unusual about the century-old stratigraphic controversy of the Gondwana succession in peninsular India is its persistence for more than a century. Gondwana succession ranging in age from Early Permian to Early Jurassic is best developed in the Raniganj basin of the Damodar Valley, India where it is classified into four distinctly different sedimentary packages designated as facies: Facies A, B, C, and D. All these facies bear the genetic signature of climate during Gondwana sedimentation as the global climate was changing from an icehouse state in the Early Permian to greenhouse state in the Mesozoic.

The stratigraphic controversy involves Facies C and Facies D only. Facies C is represented by a red mudstone and sandstone association. Sandstones are feldspathic with fresh feldspars. Mudstones are soft, which crumble easily. Facies C forms low land and valleys. Facies D stands out as hills, hummocks, and mounds of conglomerate, pebbly sandstone, purple colored very fine sandstone and minor amount of highly indurated purple colored siltstone that, at times, resembles porcelain. These two facies can be differentiated by lithology and their topographic expression. The stratigraphy of this succession was established nearly 150 years ago, almost by default as the moderately dipping beds and the topography displayed the order of superposition of different facies in a saucer-like structure. Since then there had been no dispute on stratigraphy in the Damodar Valley basins. However, the dispute started elsewhere. While mapping Pranhita-Godavari (King, 1881) and South-Rewa (Hughes, 1881) basins, they discovered *Glossopteris* flora in the Early Jurassic, Facies D. In the late 19th century, *Glossopteris* was thought to have become extinct by the end of Permian. Considering the incompatibility of Permian flora in Early Jurassic rock they adjusted the stratigraphic position by bringing down Facies D to merge it with the upper part of Facies B (Late Permian). This unusual move, without ascertaining the order of superposition between strata, created many stratigraphic anomalies, particularly the relation between Facies C and Facies D. Based on fossil evidence biostratigraphers concluded that Facies C overlies Facies D, while the field geologists observed Facies D overlies Facies C with an unconformity.

The problem is field-based and therefore, its solution lies in establishing the order of superposition between Facies C and Facies D in the field, collectively by geologists having opposing viewpoints. In order to break the impasse, a Field Seminar was arranged in the Pranhita-Godavari and in South-Rewa where the problem originated.

Three critical sections in each basin were selected where all members as a group examined each facies, described them and observed the order of superposition. In all six locations, three each in the Pranhita-Godavari and in the South Rewa show identical geological sections where Facies D overlies Facies C with an unconformity. Thus, the stratigraphy of these two basins is now identical to the stratigraphy of the Damodar Valley basins, the type section of peninsular Gondwana. The collective confirmation of the group should settle the century-old controversy.

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KT-10

Palaeomagnetic Evidence for Cross-Continental Megashearing in Australia during the Late Neoproterozoic Assembly of Gondwanaland: No Need for Pre-750 Ma Rodinia Breakup

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The breakup of the Neoproterozoic supercontinent Rodinia may have triggered dramatic changes in the Earth's climate and atmospheric conditions, leading to the explosion of complex life. However, there is a longstanding controversy regarding the timing of the breakup events, particularly that between Australia-East Antarctica and Laurentia. Early palaeomagnetic work demanded the breakup of the SWEAT-type reconstructions, if valid, to have occurred by ca. 750 Ma (Wingate and Giddings, 2000). However, stratigraphic record in southeast Australia indicates a rift-drift transition between the Sturtian glacial deposits (ca. 750-690 Ma) and the overlying sag-phase deposits (Powell et al., 1994; Preiss, 2000) that were recently dated at ca. 650 Ma (Kendall et al., 2006). This geologically based age estimation from Australia agrees with those from South China where the rifting finished at around the time of the Nantuo glaciation (Wang and Li, 2003), dated at between ca. 650 Ma and 635 Ma (Condon et al., 2005; Hoffman and Li, 2009; Zhang et al., 2008; Zhou et al., 2004), and for western Laurentia (Ross, 1991; Fanning and Link, 2004). There are even younger rifting ages suggested for eastern Australia (Crawford et al., 1997).

There appear to be systematic and significant differences between pre-650 Ma palaeomagnetic pole positions from the North Australian Craton and those from the South-West Australian Craton (South Australian Craton plus West Australian Craton), making tectonic interpretations and Rodinia reconstructions equivocal (Li et al., 2008; Schmidt et al., 2006; Wingate et al., 2002). However, both these differences and the discrepancy on the timing of Rodinia breakup can be reconciled by a possible trans-continental mega-shearing along the Paterson and Musgrave Orogens, manifested as a ca. 40° clockwise rotation of the South+West Australian Cratons relative to the North Australian Craton around a vertical axis north-central Australia. The timing of the mega-shearing (the shear zone termed here the Paterson-Musgrave mega shear zone) was likely active between ca. 650 Ma and ca. 550 Ma, as evidenced by the ca. 650-550 Ma Ar-Ar muscovite ages and granitic intrusions in the Rudall Complex of central Paterson Orogen (Durocher et al., 2003) and the 600-550 Ma foreland basin deposition and metamorphic/cooling ages in and around the Musgrave Block (Aitken et al., 2009; Camacho, 2002). The late Neoproterozoic dextral sense of shearing at both the Rudall and Musgrave complexes (Aitken et al., 2009; Bagas, 2004) is consistent with the hypothesised sense of rotation.

By comparing the Proterozoic palaeopole positions between Australia (after correcting for the 40° rotation) with those of Laurentia, it is suggested that Rodinia probably did not break apart until ca. 650 Ma, thus agreeing with the stratigraphically estimated rift-drift transition time. The proposed 40° rotation occurred during the breakup of Rodinia and the assembly of Gondwanaland. Two possible revised Rodinia fits are presented here. One has South China adjacent to Western Australia. In this configuration there is a gap between Australia-East Antarctica and Laurentia that needs to be filled with yet unidentified continent(s), and it neglects the geological arguments for an Australia-South China-Laurentia connection (e.g., Li et al., 2008). Our preferred reconstruction is similar to that in the "missing-link" Rodinia model (Li et al., 1995, 2008), in which South China is placed between eastern Australia and Laurentia.

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SS01-O-1

Application of the Modern Ophiolite Concept in China with Special Reference to Precambrian Ophiolites and Dongwanzi

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Much has been learned in the past 40 years about the great diversity of the internal structure and geochemical compositions of Phanerozoic ophiolites indicating that these on-land fragments of ancient oceanic lithosphere formed in distinctly different tectonic settings during their igneous evolution. Recent studies in the Archean and Proterozoic greenstone belts have shown that the Precambrian rock record may also include diverse ophiolite occurrences as part of craton development in the early history of the Earth. We review the salient features of the Precambrian ophiolite record to highlight what has been learned about Precambrian oceanic spreading systems since the original Penrose definition of ophiolites in 1972. Some of the diagnostic, characteristic, typical, and rare aspects of ophiolites of all ages are presented in a table in order to help determine if tectonically deformed and metamoprhosed sequences in ancient mountain belts may be considered as ophiolites. The results of this comparative study are important in that they enable researchers to more realistically characterize allochthonous mafic/ultramafic rock sequences as ophiolitic. This approach is more deterministic in contrast to some other arbitrary classification schemes requiring three or four of the Penrose-style ophiolitic units to be present in the Precambrian record for a specific rock sequence to be considered ophiolitic. Once these tectonic fragments are recognized as remnants of ancient oceanic lithosphere, great progress shall be made in understanding early Earth history, particularly in China. We discuss the significance and implications of the Precambrian ophiolite record to constrain the mode and nature of the plate tectonics that operated in deep time.

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SS01-O-2

Processes of Continental Decrease in a Subduction Zone and its Implications for the Mantle Dynamics

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Geologists have long believed that the granitic crust (TTG: Tonalite- Trondhjemite- Granodiorite) once formed on the surface must have survived through the whole history of the earth without any subduction because of its buoyant nature (e.g. McKenzie, 1969). The growth history of continental crust in a subduction zone shows that with its simultaneous formation in island arcs (e.g. Rudnick, 1995; Suyehiro et al., 1996) considerable amounts of continental crust have also been subducted into the deep mantle (Scholl and von Huene, 2007). Such ongoing subduction processes can be seen in the Circum-Pacific region, through tectonic erosion, sediment subduction (von Huene and Scholl, 1991) and arc subduction (Santosh et al., 2009; Yamamoto et al., 2009).

If the extensive subduction of island arcs was common in the Archean, and if one assumes twice the production of arcs compared to today due to higher mantle temperature in the Archean, huge amounts of TTG must have been present in deep mantle, presumably in the mantle transition zone and/or the D″ layer on the CMB. Recent seismological studies suggest that TTG crust can be detected near the base of the mantle transition zone (Kawai et al., 2010, in prep.). If a huge amount of the recycled TTG is stagnant in the mantle transition zone, then we must consider the potential role of recycled TTG as an obstruction for subducting slab (Kawai et al., 2010, in prep.) and as a heat source to initiate mantle plumes (Senshu et al., 2009).

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Petrology and Geochronology of Khondalite Rocks in Western Collisional Belt of the North China Craton, China

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The basement rocks of the North China craton (NCC) are divided into the Eastern and Western blocks separated by the Trans-North China orogen on the basis of lithologic associations, structures, metamorphism and isotopic ages. The Western block is represented by a khondalite-dominated supracrustal that are believed to represent the products of collision between the north Yinshan block and the south Ordos block before the final amalgamation of the NCC basement.

Aluminous gneiss, khondalites, occur in the western block, and record a clockwise metamorphic P–T history characterized by nearly isothermal decompression following peak metamorphism at ca. 1.3 GPa and 825ºC. Four metamorphic stages are recognized based on mineral assemblages. The early prograde metamorphic assemblage contains Ky + Bt + Ms + Grt + Pl + Qtz. The peak metamorphic mineral assemblage is characterized by Grt + Sil + Bt + Kfs + Pl + Qtz and the formation of cordierite after garnet, leading to a retrograde assemblage of Grt + Sil + Crd + Pl + Kfs + Qtz. Garnet retrogrades to biotite and the formation of pervasive matrix muscovite define a final metamorphic stage, inferred at ca.,0.6 GPa and 700ºC. Quantified metamorphic stages and a related clockwise P–T path derived from pseudosection analysis in the KMASH system suggest a collisional event along an east–west Palaeoproterozoic structural belt with the western block of the NCC basement.

LA-ICP-MS zircon U–Pb dating and cathodoluminescene (CL) image analysis were used to determine the protolith and metamorphic ages of khondalite rocks. The samples of Sil-Bt-Grt gneiss record the oldest ages of 2550~2480 Ma, suggesting the existence of a Paleoproterozoic provenance for the Jining Complex. Ages of 2162~2047 Ma are interpreted as metamorphic ages of supercrustal rocks of the khondalites series. The Sil-Ksp-Grt vein and granite probably record the same metamorphic event with single population ages of 1985±28 Ma and 1957±19 Ma, respectively, representing formation of the khondalite belt within the western block when collision between the north Yinshan block south Ordos block occurred. The Sil-Grt-K-Fsp mylonite also yielded a single group age of 1842±18Ma, that may date the final collision of the Eastern and Western block, leading to establishment of the NCC.

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Application of the Zr-In-Rutile Thermometry to the Ultrahigh Temperature Granulites of the Khondalite Belt, North China Craton

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The Zr-in-rutile thermometry (Ferry and Watson, 2007) was applied to the ultrahigh temperature (UHT) granulites from three outcrops involving Dongpo, Tuguishan, and Dajing/Tuguiwula of the Khondalite belt, North China craton. The Zr concentrations of analyzed rutiles display a small intra-grain variation, a large inter-grain variation, a bimodal distribution of around 1500 and 6000 ppm, respectively, and no relationship with the textural setting (matrix vs. inclusion). These characteristics may be ascribed to the post-peak diffusional resetting associated with slow cooling rates and/or the presence of fluid, as suggested by Luvizotto and Zack, (2009). The rutiles with higher calculated temperatures are less affected by the late resetting, giving near-peak metamorphic temperatures. The results of in excess of 900 ℃ from the three outcrops, even higher than 1000 ℃, reconfirm the existence of the UHT metamorphism. The grains with lower temperatures preferentially occur close to or in contact with zircon and quartz, which may be affected easily by the diffusional resetting. These temperatures are consistent with the closure temperature of Zr-in-rutile (Cherniak et al., 2007). In addition, there is a positive correlation between the contents of Zr and Hf, and between Nb and Ta of the rutiles. Our results also suggest that the Zr-in-rutile thermometry is possibly more resistant to diffusional alteration than the Ti-in-zircon one, which conflicts with the pervious results. It may be the results that the zircon is formed later than rutile during the retrogression.

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SS01-O-5

Metasedimentary Rocks of Angara-Kan Block (Yenisey Ridge) as Indicators of Paleoproterozoic Passive Margin of the Siberian Craton

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There are two main basement uplifts within the south-western margin of the Siberian Craton: Sharyzhalgay and Angara-Kan terranes. The Angara-Kan terrane is situated on the south of the Yenisey ridge and it consists of the Archaean and Paleoproterozoic high-grade metamorphic rocks. The most part of Angara-Kan block is composed of garnet-bearing, garnet-pyroxene and hypersthene-bearing gneisses with layers of two-pyroxene and hypersthene-bearing gneisses, and garnet and hypersthene gneisses with cordierite and sillimanite, these rocks are called Kan Group. The magmatic protoliths was suggested to form at ca. 2.6-2.7 Ga. The granulitic metamorphism occurred at ~1.9 Ga (Bibikova et al., 1993).

Compositionally, the metasedimentary rocks of the Kan Group span 54-74 wt. % SiO_2, and they have variable to high Al_2O_3 contents (up to 22.3% weight). Based on various classifications the protoliths of studied gneisses correspond to terrigenous sediments varying from graywacke siltstones or sandstones to pelitic mudstones and clayey rocks. Using the program MINLITH (Abbyasov, 2006) the averaged normative mineral composition of initial sedimentary rocks was determined in terms of three main components: pelitic, quartz and feldspar. The biotitic gneisses contain more than 60% of clastic components (normative quartz+feldspar) whereas the pelitic component increases (up to 50-60%) in high-aluminous ones.

The metasedimentary rocks are characterized by $T_{Nd}(DM)$ values from 2.5 to 2.8 Ga. SHRIMP U-Pb dating used to estimate a time of sedimentation. Zircon grains from dated sample are presented by 2 main morphological types: (1) prismatic zircons with smoothed edges; (2) rounded zircons. Round or irregular shape of cores in cathodoluminescence (CL) images is evidence of their detrital origin. Relicts of oscillatory zoning in cores are indicative of their initial magmatic origin. The most ancient core yields an age of 2662±10 Ga. Some cores are characterized by the age of ~2.2-2.3 Ga. The main set of zircon cores yields ages ranging between the 1.94 and 2.21 Ga. Thus, the sedimentation occurred during later Paleoproterozoic, i.e. after ca. 1.94 Ga.

The trace element distribution in zircon can help to determine their original nature more definitely. The two different groups are marked out on the basis of their REE patterns. The cores of first group with younger ages (2.0-1.9 Ga) are characterized by similar REE spectra with HREE enrichement $(Lu/Gd)_n$=18-25 and the strong positive Ce (Ce/Ce*=8-37) and negative Eu (Eu/Eu*=0.03-0.13) anomalies that is typical of magmatic zircons. They have Th/U=0.15-0.44 which is typical of magmatic zircons as well. The second group of cores have older ages (2.6-2.2 Ga) and are depleted in HREE (about 10-100 chondritic) and MREE in comparison with the first group. The REE patterns of these zircon cores are similar to metamorphic zircons. Thus, it can be concluded that there were both younger magmatic and older metamorphic rocks in source provenance of metaterrigenous rocks of the Kan Group.

The ages of detrital zircon cores indicate the lower limit of sedimentation, which is younger than 1.94 Ga. The initial sedimentary association of the Angaro-Kan terrane includes both graywackes and clayey rocks. Geochemical and isotopic data on paragneisses suggest that metasedimetrary rocks marked the later Paleoproterozoic passive margins of the Early Precambrian crustal block. Following high-grade metamorphism of sedimentary deposits was due to collision and consolidation of Siberian Craton.

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SS01-O-6

Growth of Archean Lower Continental Crust: An Arc Accretion Model

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The Meso-Neoarchean lower crust in two key regions, West Greenland and the Scourian of NW Scotland, underwent fundamentally similar modes of evolution, except that the last two were also subducted to eclogite depths. We first describe in detail the crust in West Greenland, then layered complexes in Scotland emphasizing their high-pressure assemblages, then some modern analogues, and finally discuss the implications worldwide of these findings.

West Greenland

Recent synthesis of the voluminous data on the Meso-Neoarchean crust of West Greenland has led to the following re-evaluation and model (Garde, 2007; Windley and Garde, 2009). The ca. 700 km long, Archean craton of West Greenland consists of six Meso-Neoarchean (ca. 3000–2720 Ma) shear zone - bounded crustal blocks that display similar cross-sections; from south to north Ivittuut, Kvanefjord, Bjørnesund, Sermilik, Fiskefjord, Maniitsoq. Each block has a southerly upper and a northerly lower zone, thus each faces upwards to the south. Upper zones have prograde amphibolite facies mineralogy and have never been in the granulite facies, whereas lower zones reached granulite facies and were partly retrogressed to amphibolite facies. Upper and lower zones consist predominantly of tonalite-trondhjemite-granodiorite (TTG) orthogneisses; geochemistry suggests generation by slab melting in subduction settings of active continental margins. The gneisses contain km-thick metavolcanic amphibolite layers typically bordered by km-thick layers containing anorthosite and leucogabbro. Most upper zones contain upper greenschist to amphibolite facies metavolcanic belts including volcaniclastic, andesitic rocks. The two most-prominent metavolcanic belts have supra-subduction zone island arc or proto-arc geochemical signatures (Garde, 2007; Polat et al, 2008).

The 2 km-thick (c. 2970 Ma) Fiskenæsset Complex comprises chromite-layered anorthosites (An_{75}–An_{95}), leucogabbros, gabbros (with meta-igneous amphiboles) and peridotites, and contains local roof pendants from overlying metavolcanic tholeiitic amphibolites. Trace element systematics suggest a genetic link between the Fiskenaesset Complex and the bordering basaltic rocks ranging from mid-ocean ridge basalt to island arc basalt. Overall the data suggest derivation from a hydrous magma of an oceanic island arc (Polat et al., 2009).

The style of deformation changes downwards within crustal blocks; upper zones are characterised by linear metavolcanic belts deformed by mostly one major phase of isoclinal folding, and lower zones by kilometre-scale double-triple fold interference patterns. Everywhere TTG protoliths have intruded anorthositic and volcanic rocks typically along ductile shear zones, in places so extensively that only anorthositic or amphibolitic lenses are preserved. The Meso–Neoarchean crust was thickened by a combination of thrusting, isoclinal folding and continual TTG injection. Dissimilarities in the proportions of anorthositic and metavolcanic rocks in the six blocks suggest that they evolved in several different microcontinents, but by similar processes. Confirmation of this model is provided by the presence of a 400 m-wide shear zone with mylonitic, cataclastic and augen gneisses on the proposed boundary between the bottom of the Bjørnesund block and the top of the Sermilik block; this is a late cataclastic shear on a suture zone between different types of gneisses of these two crustal blocks. The Greenland crustal blocks provide an exceptional, well-exposed example of how crustal growth took place in the Meso-Neoarchean from island arcs to continental margin arcs, and finally by collision tectonics to produce an amalgamated continent. The linear Paleoarchean Akilia-Isua block (Nutman et al., 2007) was trapped between the Sermilik and Fiskefjord blocks and thus incorporated into the Meso-Neoarchean continent.

NW Scotland

The Scourian complex on the mainland of NW Scotland consists predominantly of c. 3.0 Ga granulite facies tonalitic to granodioritic gneisses that contain many remnant layers up to several hundred metres thick of former layered gabbro-ultramafic complexes that contain peridotites, gabbros, garnet gabbros, garnet leucogabbros, garnet wehrlites, and garnet websterites (Bowes et al., 1964). O'Hara (1961) estimated a P of 17 kbar and T of 1000°C, but later PT studies of the granulite facies rocks were in the range of 8-11 kbar and 850-1000°C. In an area with best-preserved assemblages (near the village of Achiltibuie) we discovered (unpublished) a garnet-clinopyroxene association with a only a minor overprint of amphiboles. Inclusions of clinopyroxene within garnet are omphacitic (X_{Jd} up to 20.1 [Na-Fe^{3+}-2Ti]*100). The petrology, mineral chemical signatures and phase diagram results demonstrate high *P*-*T* conditions of *c*. 21-23 kbar and 1050°C. Specifically, an isochemical phase diagram calculated in the CaO-Na_2O-K_2O- FeO-MgO-TiO_2-Al_2O3-SiO_2-H_2O system for a calculated bulk chemical composition for the peak garnet+omphacite+clinopyroxene+rutile assemblage with a minor amphibole-plagioclase symplectite indicates the high-P stability of the assemblage. Precise metamorphic conditions were estimated based on the compositional isopleths of the peak mineral compositions (X_{Mg} [Mg/(Fe+Mg)] and X_{Grs} [Ca/(Fe+Mg+Ca)] isopleths for garnet and X_{Mg} and X_{Jd} [Na/(Ca+Na)] for clinopyroxene).

In summary, the makeup of the Scourian complex is similar to that of the crust in West Greenland, except that the mafic rocks of the layered complexes are garnet-rich and contain evidence of high-pressure mineralogy. We interpret the available data from Achiltibuie to indicate that the rocks were subducted to eclogite-facies c. 70-75 km depths and during exhumation were equilibrated in the granulite facies at about 3.0 Ga. In so far as the remainder of the 100 km-long Scourian complex contains abundant similar relict layered igneous complexes with similar garnet-rich assemblages that it is likely that garnets elsewhere contain omphacite inclusions and that a large area/volume of the crust was deeply subducted in the Neoarchean.

Modern Analogues

Comparable modern analogues to the rocks described above represent the plutonic core of an intra-oceanic island arc, an are in, for example, the Peruvian Andes, the Southern California batholith, Kohistan in the Himalaya of Pakistan, and Fiordland in New Zealand.

Whereas the upper crustal levels of the batholiths of the Andes and Cordillera of western America typically with diapiric granitic plutons are not comparable to the deeper crustal levels exposed in West

Greenland, the deep sections of these mountain ranges do present remarkably analogous profiles. In Patagonia and British Columbia (the Coast plutonic complex) sheets of calc-alkaline hornblende-bearing tonalite, trondhjemite, granodiorite or diorite intruded along thrusts and shear zones, became foliated to gneisses, were metamorphosed in the high amphibolite or granulite facies at 9–10 kbar, and underwent partial melting to produce migmatites. These high-grade gneissic rocks and structures developed during crustal thickening in active continental margins in association with sub-horizontal thrust-nappe tectonics in the Mesozoic or Tertiary. Confirmation of the gneissic character of the deep Andes comes from crustal xenoliths in Columbia that consist of hornblende tonalitic gneisses, granulite facies gneisses, pyroxenites, pyribolites (two pyroxene amphibolites) and pyriclasites (two pyroxene–biotite–plagioclase schists).

The Cretaceous western Peninsular Ranges batholith in southern California is made up of hundreds of mid-crustal plutons of hornblende–biotite tonalite and granodiorite, intruded into island arc-type volcanic and volcaniclastic rocks, some emplaced as foliated and gneissose sheets along ductile shear zones during synkinematic amphibolite facies metamorphism. Tonalitic gneisses and tonalites contain bodies of locally layered and graded norite, gabbro, gabbro anorthosite and anorthosite that consist of very calcic cumulate plagioclase $An_{70–96}$ and inter-cumulus magmatic hornblende; they were derived from a high-alumina basaltic magma. This western batholith formed as a root of a primitive island arc on oceanic lithosphere at a convergent plate margin. Lee et al. (2007) constructed a model for generation of the Peninsular Ranges batholith as follows: in the Triassic a fringing island arc was created off the Paleozoic continental margin of North America, in late Jurassic to early Cretaceous times the back-arc basin closed and this fringing arc was accreted onto the edge of the North American continent, and in the early Cretaceous farther eastwards subduction gave rise to new basaltic arc magmas, which gave rise to the main tonalitic–granodioritic batholiths that were emplaced into the accreted island arc on the active continental margin. They went on to suggest that this environment was applicable along the entire Cordilleran margin from Alaska to Chile, and as a general mechanism even to the Archean. One example is the Jurassic Border Ranges complex in Alaska, which is composed of ultramafic cumulates, massive and cumulate gabbronorites that overlying andesitic volcanic rocks. The gabbroic rocks contain calcic plagioclase (An75–100), iron-rich pyroxene and magnetite. These plutonic and volcanic island arc rocks were intruded by calc-alkaline plutons of tonalite, granodiorite and quartz diorite in batholithic proportions.

In the Cordillera Occidental of the Peruvian Andes late Cretaceous plutons of the tonalitic–granodioritic Coastal Batholith were emplaced into volcanic rocks of the Albian Casma Basin and their broadly coeval basic plutonic complexes. The 6 km-thick Casma volcanic pile consists of pillow-bearing basalts, hyaloclastites, basaltic andesites, dacites and rhyolites; the volcanic rocks have low Zr/Y vs. low Zr values characteristic of oceanic arcs. The basic complexes comprise anorthosite (with cumulate plagioclase up to An94) and gabbro with inter-cumulus hornblende that is secondary after clinopyroxene, but derived from a late volatile-rich residual melt. The complexes occur in layers and lenses up to 5 km wide, and 40 km long, but grouped in "clusters indicating the former presence of substantial bodies that prior to fragmentation may have approached 1000 km2 in area". The tonalitic– granodioritic plutons were emplaced into the volcanic–plutonic rocks with the result that many of the latter now occur as lenses and inclusions within the tonalites and granodiorites. Similarities in mineralogy, and major and trace element patterns suggest that the volcanic rocks represent the liquid fraction after cumulate crystallization of the basic complexes, both generated from tholeiitic magmas in the mantle. The tonalitic–granodioritic plutons include primary magmatic hornblendites, and layered gabbros with cumulate plagioclase and inter-cumulus magmatic hornblende that indicate that these complexes crystallized under a very high fluid pressure; extrusive equivalents are pyroclastic and basaltic–andesitic volcanic rocks. The Cordilleran batholiths in North and South America provide a viable modern analogue for the arc-generated crustal growth in West Greenland and NW Scotland (Windley et al., 1981).

The Cretaceous Kohistan island arc (Pakistan) consists of calc-alkaline volcanic and volcaniclastic rocks and an associated Chilas complex of layered norites and noritic gabbros that formed the root or magma chamber of the arc. The island arc was accreted to the southern margin of the Asian continent, and in consequence magmatism changed from oceanic to continental leading to emplacement of the tonalitic-granodioritic Trans-Himalayan batholith into the island arc in an Andean-type continental margin setting.

Discussion

In the modern examples quoted above, island arcs were able to accrete to margins of continents, because continents existed in the Mesozoic and Cenozoic, but in West Greenland, or anywhere else worldwide, there were no major continents in existence in the Meso to Neoarchean. However, e.g. in West Greenland there were many island arcs available to mutually accrete and amalgamate into microcontinents, around which other fringing island arcs could begin the conversion to continental arc magmatism. These speculations imply that the processes of continental growth from island arc magmatism to continental arc/ cordilleran magmatism were broadly similar throughout much of Earth history, and for this reason tectonic blocks of different ages can be found with similar crustal sections and with broadly comparable components and age relations. Both experimental work and geochemical studies have indicated that there was a change from generation of tonalite–trondhjemite- to granodiorite-dominated continental crust at the end of the Archean, as direct partial melting of the subducting slab became less feasible as the Earth became cooler. The Archean gneisses of the North Atlantic craton and the Paleoproterozoic Julianehåb batholith in South Greenland actually provide a good example of this geochemical change. However, it would seem that this transition did not have other fundamental influences on the magmatic and tectonic accretion of new continental crust over time as discussed above. The results of this study, based on West Greenland and a variety of Archean and modern analogues, suggest that continental growth through time has commonly taken place by processes dominated by arc generation.

The examples from NW Scotland demonstrate that not only were subduction processes possible in the Meso-Neoarchean in order to produce calc-alkaline island arcs and active continental margin arcs, but that they were also able to transport material to eclogite facies depths, as today. However, it is important to look for the differences as well as the similarities between ancient and modern rocks and environments. One significant difference is that, whereas in the Phanerozoic subduction has produced low-temperature eclogitic rocks, in the Meso-Neoarchean plate subduction gave rise to high-temperature eclogite facies assemblages, a difference that may readily be ascribed to changes in thermal gradients with time.

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Late Paleoproterozoic Evolution of the Central-Northern Margin of the North China Craton: Evidence from Magmatism

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There are significant Paleoproterozoic magmatism in the central-northern margin of the North China craton, represented by the Xuwujia gabbronorites (ca. 1950-1920 Ma), the Liangcheng granitoids (ca. 1930-1890 Ma) and the Halaqin volcanism (ca. 1910-1880 Ma). The Xuwujia gabbronorites comprise mainly gabbronorite, as well as some norite, olivine gabbronorite, monzonorite, quartz gabbronorite, and quartz monzonorite. They occur as dykes, sills, and small plutons intruded in Paleoproterozoic khondalites and Archaean basement, and as numerous entrained bodies and fragments of variable scales in the Liangcheng granitoids, which are aluminium-rich grano-diorite to granitic plutons with scales of tens of kilometres. The Halaqin volcano-sedimentary succession is composes of conglomerate, sandstone, pelite, carbonates and volcanics, from bottom to top. It was strongly deformed, presenting as tight folds which indicates thrusting from south to north in a present coordinates. The Xuwujia gabbronorites and Liangcheng granitoids underwent amphiolite-granulite-facies metamorphism; whereas the Halaqin volcano-sedimentary succession underwent greenschist to amphibolite-facies metamorphism. All of these associations could have metamorphosed and deformed at ~1850-1800 Ma, and thus could uplift from different crustal levels during a related geological process.

The Halaqin volcanic rocks show a trimodal distribution, with SiO_2-contents range from 45-50 wt% (basalts), 53-60 wt% (andesites), and 70-76 wt% (dacite-rhyolite). The basalt and andesite rocks are quite similar to the Xuwujia gabbronorites (mafic to intermediate); whereas the dacite-rhyolite is similar to the granitoids (felsic). The mafic to intermediate rocks can be chemically divided into two groups: a high-Mg group (6–23 wt% MgO) and a relatively low-Mg group (2-6 wt% MgO). The high-Mg group shows slight light rare earth element enrichment (La/YbN = 0.45–1.76), and small negative anomalies in high field-strength elements. The low-Mg group is enriched in light rare earth elements (La/YbN = 1.51–11.98). The majority shows negative anomalies in high field-strength elements (e.g., Th, Nb, Zr, and Ti). Initial εNd (at 1.93 Ga) values of the mafic to intermediate rocks vary from −5 to +2. The occurrence and chemical variations of the Xuwujia gabbronorites and the Halaqin volcanics can be interpreted by magma originated from the asthenosphere, contaminated by melts from the mantle wedges, and assimilated by crustal materials. The felsic rocks have strongly enriched light trace element patterns (La/YbN = 8.49-47.9) and large ion lithophile elements, but depleted high field strength elements (e.g. Nb, Zr, Ti). Initial εNdt (t=1.9 Ga) values vary from− 7 to -2. They could be derived from the crust, with contribution of magma from mantle.

The Xuwujia gabbronorites originated from a mantle region with high potential temperatures (~1550°C), and could have extremely high primary eruption temperature (up to 1400 °C). This gabbronoritic magmatism was likely the trigger of the followed magmatism and extensive crustal anatexis, and extra heat for the local ultra-high- temperature metamorphism. A ridge subduction scenario is suggested for the geological evolution of the study area and the dynamic cause of the above intrusive (Xuwujia gabbronorites and Liangcheng granitoids) and extrusive (Halaqin volcanism) magmatism. This subduction was possibly followed by the final amalgamation and cratonization of the North China craton.

Keywords: North China craton; Paleoproterozoic; Xuwujia gabbronorites; Liangcheng granitoids; Halaqin volcanics; ridge-subduction

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Tectonic Formation and Palaeozoic Evolution of the Gorny-Altai – Altai-Mongolia Suture Zones, Revealed by Zircon LA-ICP-MS U/Pb Geochronology

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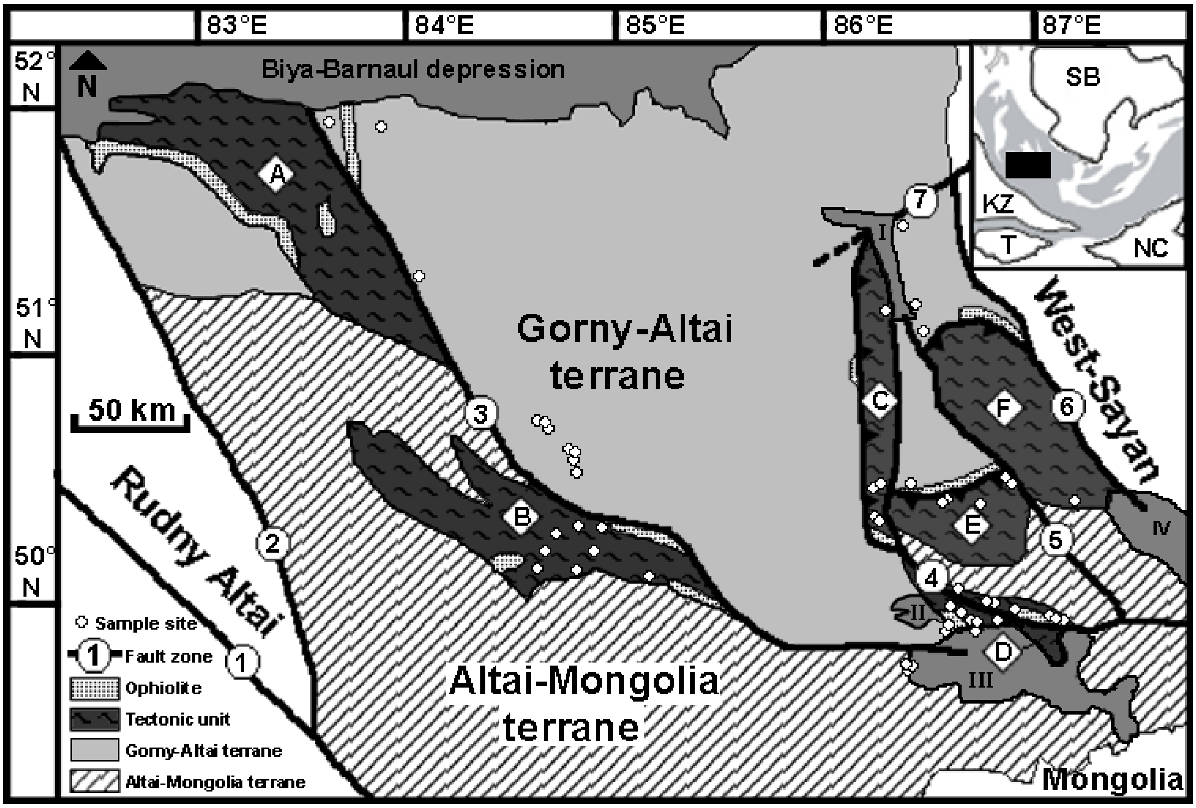
The Altai Mountain Belt (AMB) is located between Siberia and Kazakhstan and forms a complex collage of tectonic units, bounded by suture zones. During the Palaeozoic, Gondwana-derived terranes and subduction-accretion complexes collided progressively with the Siberian Craton. The Late-Palaeozoic final closure of the Ob-Zaisan and Ural-Mongolian branches of the Palaeo-Asian Ocean led to the collision of amalgamated Siberia with Kazakhstan and the final formation of Palaeo-Eurasia (Dobretsov et al., 1995; Buslov et al., 2001, 2004). This introduced Late-Palaeozoic reactivation (strike-slip) of pre-existing sutures and contributed to the complexity of the AMB (Buslov et al., 2004).

In order to understand the multi-stage evolution of the Siberian AMB, we performed a detailed geochronological study on these suture zones. More specifically, we focussed on the Charysh-Terekta (CT) and Kurai-Ulagan (KU) ophiolitic suture zones, which are subduction-accretion-collision zones that stitch the Gorny Altai terrane (GA) to the Altai-Mongolia block (AM) (figure). GA forms an accretionary complex, composed of fragments of Caledonian and Hercynian mobile belts. AM is a Gondwana-derived microcontinent, dominated by passive margin, shelf and continental slope sediments (Buslov et al., 2001, 2004; Safonova et al., 2004; Ota et al., 2007).

Zircons were analyzed from several tectonic units, situated along both sutures (figure). Syn- and post-collisional granitoid intrusives were targetted, together with the gabbroid and associated plagiogranitic sequences of the ophiolite units themselves. More than 50 zircon U/Pb ages were obtained and preliminary results point towards a Late Ediacarian – Early Cambrian formation age (550-510 Ma) of the sutures and a Late Silurian – Late Devonian age (420-360 Ma) for the syn- and post-collisional granitoids. These results corroborate well with previously reported tectonic models, which are mainly based on stratigraphy and K/Ar chronology (Buslov et al., 2001, 2004; Safonova et al., 2004; Ota et al., 2007).



Simplified tectonic map of the AMB, showing its major (Pre)-Palaeozoic tectonic units: A = Maralikha-Zasurin, B = Uymon, C = Teletsk, D = Chagan-Uzun, E = Ulagan, F = Erekta; and bounding sutures / faults: 1 = Irtysh, 2 = North-Eastern, 3 = Charysh-Terekta, 4 = Kurai-Ulagan, 5 = Teletsk-Bashkauss, 6 = Shapshal, 7 = West-Sayan. Meso-Cenozoic basins: I = Teletskoye, II = Kurai, III = Chuya, IV = Dzhulukul. Continental blocks (inset): SB = Siberia, KZ = Kazakhstan, T = Tarim, NC = North-China (after Buslov et al., 2004; Ota et al., 2007).

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Petrology and SHRIMP U-Pb Zircon Chronology of Ultrahigh-Temperature Granulite from South Altay Orogenic Belt, Northwestern China

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Diagnostic mineral assemblages, mineral compositions and zircon SHRIMP U–Pb age are reported from an ultrahigh-temperature (UHT) spinel-orthopyroxene-garnet granulite (UHT rock) from the south Altay orogenic belt of NW China. This Altay orogenic belt defines an accretionary belt between the Siberian and Kazakhstan-Junggar plates that formed during the Paleozoic. The UHT rock examined in this study preserves both peak and retrograde metamorphic assemblages and microstructures including equilibrium spinel + quartz, and intergrowth of orthopyroxene, spinel, sillimanite, and cordierite formed during decompression. Mineral chemistry shows that the spinel coexisting with quartz has low ZnO contents, and the orthopyroxene is of high alumina type with Al2O3 contents up to 9.3 wt%. The peak temperatures of metamorphism were >950°C, consistent with UHT conditions, and the rocks were exhumed along a clockwise P-T path. The zircons in this UHT rock display a zonal structure with a relict core and metamorphic rim. The cores yield bimodal ages of 499 ± 8 Ma (7 spots), and 855 Ma (2 spots), with the rounded clastic zircons having ages with 490-500 Ma. Since the granulite was metamorphosed at temperatures >900°C, exceeding the closure temperature of U-Pb system in zircon, a possible interpretation is that the 499 ± 8 Ma age obtained from the largest population of zircons in the rock marks the timing of formation of the protolith of the rock, with the zircons sourced from a c. 500 Ma magmatic provenance, in a continental margin setting. We correlate the UHT metamorphism with the northward subduction of the Paleo-Asian Ocean and associated accretion-collision tectonics of the Siberian and Kazakhstan-Junggar plates followed by rapid exhumation leading to decompression.

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Geochemistry and SHRIMP Zircon Geochronology of the Neoproterozoic Suprasubduction Zone Ophiolite at Hongseong, South Korea: Implications for the Amalgamation of East Asia during the Neoproterozoic Gondwana

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Within the Hongseong area, the Wolhyeonri Formation consists mainly of high-grade paragneisses with lens-shaped dismembered bodies of serpentinized ultramafic/mafic rocks, together with metavolcanics, quartizites and limestones; these packages are corresponding to the eugeoclinal rocks. Here, it is notable that serpentinized mafic and ultramafic complexes are occurred as dismembered bodies. For example, two serpentinized lens-shaped bodies (viz. Baekdong and Bibong) show peridotite, and serpentinite as parts of the ultramafic cumulate (lowermost parts of the ophiolite sequence) and gabbro, anorthothite, sheeted dike and pillow basalt as the mafic complex above the ultramafic complex. Both complexes are intruded by late stage plagiogranites and gabbroic-diabasic dikes and sills. Recently we have found two interesting features from the Wolhyeonri Formation: (1) At least host Wolhyeonri Formation of the ultramafic bodies that was mapped as both orthogneisses and paragneisses are turned out to be mostly paragneisses (sedimentary origin). (2) It shows various contact relationships such as fault and normal depositional contact with dismembered serpentinized bodies (where exposed). (3) Ultramafic and mafic rocks are occurred with eugeoclinal rocks. These lines of evidences indicate that dismembered ultramafic bodies could be interpreted as blocks of oceanic crust, thus ophiolites. Hereafter we called this mixture of metasediments and mafic/ultramafic bodies (ophiolite bodies) with eugeoclinal rocks as Wolhyeonri complex. The Geochemistry and SHRIMP zircon geochronology of the Baekdong ophiolite indicates the signature of a Pacific-type orogeny with a wide ocean at ca. 900 Ma followed by subduction and accretion from Neoproterozoic to Paleozoic era. The initiation of a northwardward subduction of the Gyeonggi massif and emplacement of slab-derived magmas are recorded in a wide TTG (tonalite-trondhjemite-granodiorite) belt, the magmatic zircons from which record oldest ages of ca. 850 Ma. Combined major and trace element data from the ultramafic to mafic rocks of the ophiolite complex indicate that they were formed in nascent arc to backarc spreading in suprasubduction zone setting. SHRIMP zircon U-Pb ages of high-pressure garnet granulite to eclogite reflect two Paleozoic metamorphic events (dominant Late Silurian to Early Devonian and minor Late Carboniferous), together with 1,818 inheritance zircon cores; ophiolite complex is also intruded by late-stage granitoid of ~ 740 Ma. These data together with SHRIMP ages from other dismembered ultramafic and mafic complex suggest the formation of nascent arc to backarc spreading within the range of ~740 to 810 Ma. Considering the sedimentation age of the SHRIMP detrital zircon studies from the metasediments and metavolcanics suggest that they were deposited in the range between 475 to 425 Ma. This indicates that the TTG arc was collided into the stable craton between 800 and 475 Ma along the Hongseong suture. Based on the evidences from the Baekdong suprasubduction zone ophiolite in the Hongseong area, we propose a tectonic model as the trace of a Neoproterozoic to Paleozoic subduction and accretion events marking a crustal evolution history at a convergent margin probably related to the amalgamation of Gondwana. We also envisage that the Hongseong area of the Gyeonggi massif is an accretionary belt that developed during a long-lived subduction system between Neoproterozoic and Paleozoic before the final continental collision of East Asia in the Triassic.

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Mid-Mesoproterozoic Magmatism in the Northern North China Craton: Implications for the Columbia Supercontinent

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The evolution of Columbia supercontinent is of great interest to earth scientists in recent years (e.g., Rogers and Santosh, 2002; Zhao et al., 2003; Hou et al., 2008; Santosh, 2010). Assembly of Columbia supercontinent was completed during 2.1–1.8 Ga and its final breakup occurred during 1.3–1.2 Ga (e.g., Zhao et al., 2003; Hou et al., 2008). Because of lack of reliable isotopic ages for the Mesoproterozoic (1.6–1.0 Ga) magmatism and tectonism in the NCC, whether or how the North China Craton (NCC) was involved in the Paleo-Mesoproterozoic supercontinents is still controversial (e.g., Zhai et al., 2000; Lu et al., 2008; Rogers and Santosh, 2002; Zhao et al., 2003; Li et al., 2008).

Diabase sills are are widespread within the late Paleoproterozoic-Mesoproerozoic sedimentary rocks in the northern NCC and extend for several hundreds kilometers. Recently LA-ICP-MS zircon and baddeleyite U-Pb dating results on a diabase sill sample emplaced into the Mesoproterozoic Wumishan Formation indicate their emplacement during the Mid-Mesoproterozoic around 1.35 Ga (Zhang et al., 2009), which is similar to the TIMS baddeleyite U-Pb age (1320±6 Ma) of the diabase sill emplaced into the Xiamaling Formation (Li et al., 2009). These large volumes of Mid-Mesoproterozoic mafic magmatism in northern NCC are probably related to the breakup of the Columbia supercontinent and suggested that the NCC was a member of Nena including the Laurentia (North America and Greenland), Siberia and Baltica cratons in the supercontinent (Zhang et al., 2009). Breaking of the NCC away from the Columbia supercontinent occurred from 1.35 Ga, which is also supported by the paleomagnetic results (Wu et al., 2005; Pei et al., 2006; Zhang et al., 2006; Li et al., 2008).

Except for these disbase sills, our new geological and zircon LA-ICP-MS U-Pb data show that the emplacement ages of some granitic plutons emplaced into the late Paleoproterozoic-Mesoproterozoic Bayan Obo Group in northern NCC are around 1.33–1.30 Ga. These Mid-Mesoproterozoic granitic plutons, together with the large volumes of diabase sills, constitute a typical bimodal magmatic association in northern NCC, which provides further evidence for continental rifting related to breakup of the Columbia supercontinent during the Mid-Mesoproterozoic.

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Age Constraints within the Korean Collision Belt, Hongseong, South Korea: Implications for Neoproterozoic to Mesozoic Tectonic Links between the Korean Peninsula and the Central-Eastern China

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The Hongseong area of the western Gyeonggi massif has long been considered to be a possible eastern extension of the Dabie-Sulu collision belt of China, where Paleoproterozoic, Neoproterozoic and Paleozoic rocks were regionally metamorphosed at least during the East Asian Triassic collision event (e.g., Oh et al., 2005; Kim et al., 2006, 2008; Zhai et al., 2007; Kwon et al., 2009). The southern and eastern parts of the Hongseong area are predominantly represented by late Early Proterozoic supracrustal and basement rocks. In contrast, the western part of the area consists of the Neoproterozoic Deokjeongri tonalite-trondhjemite-granodiorite (TTG) gneisses and Paleozoic Wolhyeonri complex and Taean Formation (e.g., Kim et al., 2006, 2008; Zhai et al., 2007; Kwon et al., 2009). The Paleozoic sequences might be corresponding to the continental margin assemblages, and are related to the subduction and collision before Triassic. Detailed SHRIMP zircon U-Pb ages of the various rock units reflect Neoproterozoic arc magmatism and Paleozoic to Mesozoic tectono-metamorphic evolution of this region. Especially within the Wolhyeonri complex, two Paleozoic metamorphic events (M1 and M2; dominant Late Silurian to Early Devonian and minor Late Carboniferous) are recorded in subhedral to rounded zircons that show textures indicative of high-grade metamorphism. These events were probably related to the subduction before the collision. In addition, most of the rocks preserved within the Paleozoic Wolhyeonri complex were overprinted again by Middle Triassic high-grade (M3) metamorphism. These indicate that the Wolhyeonri complex should have undergone high-grade metamorphisms in a convergent tectonic setting associated with the subduction and collision events during the accretion of the Eurasian continent. Similar geochronological features have also been identified from the Qinling, Tongbai-Xinxian and northern Dabie areas in east-central China as well as the Kurosegawa-Oeyama-Renge areas along southwestern Japan. These evidences of Paleozoic coeval subduction in China, South Korea, and Japan before the Triassic collision during the final amalgamation of Eurasia continent are consistent with regional tectonic linkage of Gondwana.

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Structural Cross-sections and Transpressional Tectonics from Gondwana- Cauvery Suture Zone, Southern India

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The development of multi-scale geologic structures in transpressional zones is dependent on the strain imposed by the boundary conditions, which implies that there may not be a simple or significant relationship between large-scale crustal deformation structures and outcrop-scale structural observations. Transpression also involves extrusion tectonics that often redistributes rheologically weak material both laterally and vertically within the shear zones. In this contribution, we analyse multi-scale structural observations and construct structural cross-sections from the Gondwana-Cauvery suture zone (CSZ) and suggest that the CSZ represents a classic example of transpressional deformation typical of modern collision zones.

The CSZ is an east-west trending, ~350 km long and ~65 km wide zone that straddles the Archean Dharwar craton in the north and the Southern Granulite Terrain (SGT) in the south. The CSZ is marked by boundary shear zones in the north and south and constitutes a network of shear zones in the interlying region. While a set of east-west trending sub-parallel shear zones are dominant in the western part, sigmoidal shear zones linking the boundary zones are the characteristic features in the eastern part. The striking presence of steep mylonitic fabrics and associated gentle as well as steeply plunging lineations not only along the same shear belt but also within the same outcrop suggest the nature of transpressional deformation. Further, the presence of widespread asymmetrical structural elements that include: domes and basins, curvilinear and hairpin bends of hinge lines, amoeboid forms, interfering fold structures and associated planar and linear fabrics associated with in the axial zone of the CSZ, indicate typical constrictive deformation in a broader transpressional tectonic regime.

The structural cross-sections across the CSZ display the nature and geometry of the shear belts, consistent dextral kinematics, contemporaneity of mylonitic fabric development favouring a crustal-scale 'flower structure' model for the CSZ. In the eastern part, the CSZ shows a map view of duplex like structures and a sectional view of imbricate thrusts and a 'flower structure'. Geophysical signatures across the CSZ exhibit oppositely dipping reflection fabrics, prominent gravimetric signatures, high conductivity and magnetic anomaly patterns, consistent with the interpretation of exhumation and extrusion of high-pressure rocks along the CSZ during the collision tectonics. The transpressional deformation is reflected in Moho upwarp and crustal uplift with major strain partitioning along the shear belts.

The CSZ shows the following variety of structural features typical of a deeply eroded transpressional orogen: (i) convergence of crustal-scale shear systems at depth reaching the lithospheric mantle, (ii) Moho upwarp of ~5km, (iii) heterogeneous strain variation, (iv) widespread melting, granite magmatism, migmatisation and retrogression, (v) significant spatial and temporal variation in the geometry of foliation trajectories and the behavior of stretching lineations, and (vi) presence of flower-like structures and associated extrusion tectonics. These regional and local-scale structures described above clearly reveal the mechanisms of accommodating three dimensional transpressive deformation in deep to mid-crustal levels that accommodated large orogen-parallel movements and shortening during possible Neoproterozoic oblique continental convergence. The deformation in the lower crust allows motion to be transferred from the lithospheric plates to upper crust. The kinds of structures described above from the CSZ are correlatable with those seen in large-scale tectonic zones such as subduction zones.

Our recent studies indicate that the CSZ is decorated with slices of dismembered ophiolite suites all over, which are associated with imbricate thrust sheets and duplex structures. These ophiolites are bound by shear zones that marked the sites of consumption of oceanic crust involving continents and island arcs that occurred in the past. The chemical characteristics of ophiolitic rocks from the CSZ indicated supra-subduction zone setting suggesting the closure of Neoproterozoic Mozambique Ocean, followed by collision and obduction during the final stage of amalgamation of the Gondwana supercontinent in the end Precambrian.

We interpret the foregoing multi-scale structural observations and cross-sections from the CSZ as indicative of two major stages of deformation: (i) Late Archaean/ Paleoproterozoic northward compression resulting in north verging-thrusts and nappes and (ii) Late Neoproterozoic dextral transpression involving high strain zones leading to significant reorganization and reworking of earlier structures. The latter event is associated with alkaline-carbonatite magmatism, the emplacement of ophiolitic rocks and granitoid plutons (800-500Ma), and widespread retrogression. In the light of the above, we infer that the CSZ must have been subjected to oblique convergent tectonic regime with variations in the angle of obliquity.

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Chromian-Spinel Compositions of the Serpentinized Ultramafic Rocks from the Bo Xinh Massif in Song Ma Suture Zone, North Vietnam – Implications on the Magma Genesis and its Tectonic Significance

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The Indochina Block is a Gondwana-derived terrane that was individualized by the opening of different branches of the Paleotethyan Ocean, and is marked by the presence of various suture zones (Tri T.V, 1979; Lepvrier et al., 2004). In Northern Vietnam, the boundary between the Yangtze part of the South China Block and the Indochina Block has been defined by the NW-trending Song Ma suture zone (Lepvrier et al., 2004). Several isolated serpentinized ultramafic bodies are occurred within the Song Ma suture zone and most of them suffered various degrees of serpentinization, deformation and metamorphism. The serpentinized ultramafic rocks consist mainly of chrysotile and lizardite serpentines with minor amounts of magnetite and relict chromian-spinels (Cr-spinels hereafter).

Cr-spinels from the Song Ma suture zone show mesh-textured pseudomorphs of olivine and rare bastite pseudomorphs of orthopyroxene. Cr-spinels occur as irregular anhedral to subhedral shapes, and grain size ranges from 0.5 to 2.0 mm. Magnetites replaced the Cr-spinels along intergranular cracks and along their rims. Chemical compositions of the Cr-spinel cores are characterized by medium Cr_2O_3 (37.03 – 39.41%), high Al_2O_3 (29.08 – 32.01%), FeO (15.08 – 17.80%), MgO (14.09 – 16.13%) and very low TiO_2 (0.00 – 0.12%). The Cr# [Cr/(Cr+Al)] and Mg# [Mg/(Mg+Fe^{2+})] have minor ranges 0.44 – 0.47 and 0.62 – 0.71, respectively. They also show low Fe3+# [Fe^{3+}/(Fe^{3+}+Al+Cr] and high Fe^{2+}/Fe^{3+} ratios of 0.018 – 0.040 and 5.52 – 11.24, respectively. These cores are rimed by Al-and/Mg-poor, Fe-rich magnetite and ferritchromite, and are characterized by extremely-high FeO (49.99 – 65.31%) and very low Cr_2O_3 (22.79 – 27.26%), MgO (0.33 – 9.34%). We have focused on these primary igneous cores and metamorphic rims of the Cr-spinels for studying the magma genesis and its tectonic significance, and the core compositions are used for the following discussions. The moderate Cr# and high Mg# are represented for Cr-spinels from harzburgite peridotites (Pober and Faupl, 1988). The high Al_2O_3 and medium Cr# represents those formed in a low-depleted mantle that is commonly characterized by the MORB affinity (Dick and Bullen, 1984). The high Al2O3 content and relatively high Fe^{2+}/Fe^{3+}, however, indicates those from the suprasubduction zone tectonic setting (Kamentsky et al., 2001) such as an arc in front of a subduction zone instead of MORB tectonic setting (Pearce, 2003). In addition, very low TiO_2 along with high Al_2O_3 contents are not characteristics of a fore-arc setting (Dick and Bullen, 1984). Above mentioned Cr-spinel compositions ranging from MORB to island arc to back-arc fields can be explained by various melting conditions in a back-arc tectonic setting (Kamenetsky et al., 2001; Rollinson, 2008). The MORB-like peridotite can also be formed in back-arc spreading centers or fore-arc basins (Dilek and Polat, 2008). Thus we, from the characteristics of Cr-spinel compositions, interpret that the Bo Xinh serpentinites might be formed in a back-arc spreading related to the subduction of the Indochina block beneath the South China block.

The back-arc interpretation provided here will give an important ramification to support the evolution of Paleotethyan oceanic lithosphere between the Indochina and South China blocks. The active northward subduction of the Paleotethyan oceanic lithosphere occurred prior to the Late Permian-Triassic in age as indicated by series of calc-alkaline magma that emplaced the Song Ma and the Red river fault zones showing geochemical characteristics of a continental volcanic arc (Trung et al., 2007). The back-arc spreading should be occurred at north of the subduction zone along southern edge of the North China block. Serial Mg-rich, Ti-poor Permian basaltic-andesitic rocks that are observed within the northern Song Ma suture zone may also have formed in the back-arc spreading zone along with the emplacement of the present-day Cr-spinel-bearing peridotites.

In summary, the Cr-spinel chemistry of the Bo Xinh serpentinites from the Song Ma suture zone, Northern Vietnam provides evidences for Paleozoic suprasubduction zone ophiolites that existed between the Indochina and South China blocks during the amalgamation of the Gondwana supercontinent. Thus, the study of Bo Xinh serpentinites will provide important clues on the possible evolution of Southeast Asia since Early Paleozoic.

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Sedimentary Records of Mesoproterozoic Transition from Rifting to Drifting of the Northern North China Craton

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Extensive continental rifting occurred in the peripheral regions of the North China craton in Mesoproterozoic time. This study presents a stratigraphic and sedimentary investigation of early Mesoproterozoic succession, the Changcheng and Nankou Groups, of the northern margin of the North China craton, and tries to reconstruct its tectono-sedimentary history. It is shown that the northern North China craton experienced a two-stage evolution in the early Mesoproterozoic. The early-stage or synrift subsidence and sedimentation were controlled by normal faulting and accompanied by volcanism, as recorded by the Changcheng Group. In contrast, late or postrift stage saw a period of broad subsidence over a vast area and was characterized by widespread occurrence of shallow-marine clastic and carbonate rocks. The Nankou Group represents the early-phase deposition of postrift succession. The bulk of subsequent postrift sequence, however, was made up of the Jixian Gr, which was thought to have developed in a passive-margin tectono-sedimentary setting. A diachronous transgressive unconformity is identified, and together with its time-equivalent conformity, it separates the synrift and postrift sequences. This transgressive unconformity is actually a breakup unconformity in consideration of its genetic linkage with the breakup of continents and creation of oceanic crust. The ages of the Dahongyu and Gaoyuzhuang Groups overlying the breakup uniformity are thus used to infer the timing of the seafloor spreading and the resulted drifting of the North China craton, which are in general from 1630 to 1600 Ma. This time estimate of the dispersal of the North China craton from adjacent continents is comparable with the timing for the breakup of Columbia.

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Platinum-Group Element Geochemistry of Basalts from the Tarim Large Igneous Province in NW China: Implication for a Mixing Process during Magma Chamber Replenishment

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Tarim Permian continental flood basalts (CFB), widely distributed in the western and central parts of Tarim Basin, were regarded as an product of the Tarim large igneous province, which can be comparable to the Siberian Traps in Russia and Emeishan large igneous province in SW China. The systematic study in Platinum-group elements (PGE) characterization for the Tarim Permian basalts from the typical Yingan section shows that they contain relatively low PGE abundances, with the Os, Ir, Ru, Rh, Pt and Pd contents of 0.014-0.106, 0.007-0.067, 0.035-0.253, 0.011-0.078, 0.043-0.149 and 0.026-0.124 ppb, respectively. The basalts show generally depletion in Pt and Pd contents and a distinctive bell-shaped pattern, being different from other typical CFBs in the world (e.g. Emeishan large igneous province and East Greenland CFB) on the primitive mantle-normalized diagram. The samples analyzed in this study have strongly increase in Cu/Pd ratios (ca. 400,000-1,760,000) with relatively lower and constant Pd/Ir ratios, suggesting that the basalts may experience sulfur saturation and the PGE may be removed during sulfide segregation. Comparison of the PGE concentrations, trace and rare earth elements and Sr-Nd isotopes from the base to the top lavas, we propose a multi-stage mixing process between the relatively primitive injecting magma and the more evolved resident magma during magma chamber replenishment, which may be responsible for the sulfur saturation of the basaltic magma. In addition, crustal contamination during magma emplacement may also contribute to the sulfur saturation at the early stage. PGE depletion of the Tarim CFB provides a useful indicator of mineralization of Cu-Ni-PGE deposit associated with the layered mafic-ultramafic intrusions in the Tarim large igneous province, and an exploration potential was argued.

Key words: platinum-group elements; trace and isotopic geochemistry; sulfur saturation; magma replenishment; Tarim large igneous province

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SS02-O-8

Tectonic Evolution of the Qinling-Tongbai Orogenic Belt

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The Qinling-Tongbai-Dabie-Sulu orogenic belt marks the suture between the North and South China Blocks in Central China, forming one of the most important orogens in the eastern Asia. There are hot controversies about the location and number of sutures and the timing of arc-continent and continent-continent collisions during the convergence between the North and South China Blocks. The Dabie-Sulu orogenic belt is characterized by the occurrence of Triassic UHP eclogite-facies metamorphic rocks due to the Triassic continental deep subduction. Thus, the Triassic continent-continent collision is evident in east-central China. On the other hand, there are Paleozoic events of arc-continent collision in the Qinling-Tongbai orogenic belt that were overprinted by the Triassic process of continental collision. This has caused much complexity on the time and location of arc-continent and continent-continent collisions between the North and South China Blocks. We present an integrated study of regional geology, geochemistry and geochronology for the Qinling-Tongbai orogenic belt in order to formulate a framework of its tectonic evolution .

A Qinling microcontinent is defined for the Precambrian basement in the Qinling-Tongbai orogenic. It has the tectonic affinity to the South China Block as indicated by occurrences of ca. 1.0-0.9 Ga U-Pb ages for magmatic or detrital zircons, suggesting its formation during assembly of supercontinent Rodinia. It was then rifted from the South China Block at ca. 0.83-0.74 Ga due to breakup of Rodinia. During the Cambrian convergence between the North and South China Block, the Erlangping arc would develop between the Qinling microcontinent and the North China Block. UHP metamorphism of the Qinling microcontinent occurred at ca. 500-480 Ma, possible due to its northward subduction beneath the Erlangping arc. As a consequence, the Erlangping arc was thrusted over the Kuanping unit along the southern edge of the North China Block at ca. 490–480 Ma. This is the first episode of arc-continent collision, leading to accretion of the Qinling microcontinent to the North China Block. Progressive convergence of the South China Block toward the North China Block during the Early Paleozoic would generate the Shangdan arc and backarc basin between the Qinling microcontinent and the the South China Block. At ca. 400-430 Ma, the Shandan backarc basin became closed to cause the northward subduction of oceanic crust beneath the Qinling microcontinent, resulting in the granulite-facies metamorphism and magmatism. This is the second episode of arc-continent collision, leading to not only accretion of the Shandan arc to the North China Block but also reworking of the Erlangping arc rocks.

With the progressive convergence between the South and North China Blocks during the Late Paleozoic, the subduction zone of oceanic crust would have retreated to the southern margin of the Shandan arc. There would be the Mianlue sea of the Late Paleozoic between the Shandan arc and the South China Block, forming the intercontinental basin. The Liuling unit, corresponding to the the Xinyang Group in the Tongbai region and the Foziling unit in the Dabie region, is the Paleozoic flysch unit that developed over the Mianlue seacrust terrestrial sediments from the South China Block. Northward subduction of the seacrust beneath the Shandan arc resulted in the closure of the Mianlue sea, the third episode of arc-continent collsion and thus the ca. 310 Ma HP eclogite-facies metamorphism in the Huwan shear zone.

So far there is no report of Paleozoic arc volcanism and the three episodes of arc-continent collision in the Dabie-Sulu orogenic belt. This indicates that the continental collision in the Qinling-Tongbai orogenic belt is accomplished by a series of Paleozoic arc-continent collsion but in the Dabie-Sulu orogenc belt by a single Triassic continent-continent collision. This is consistent with paleomagnetic studies that suggested a clockwise rotation of the South China Block after its collision with the North China Block in its northwast corner.

Subduction of the South China Block beneath the North China Block may start in the Late Permian, but coesite-phase UHP eclogite-facies metamorphic event is bracketed between 240 and 225 Ma. There are also HP eclogite-facies recrystallization at 215-225 Ma and amphibolite-facies retrogression at 205-215 Ma. Extensive occurrences of the Triassic isotopic ages for HP-UHP metamorphic rocks in the Qinling-Tongbai-Dabie-Sulu orogenic belt are a manifestation of the Triassic continent-continent collision, a crucial tectonic event that led to the final coalescence of the South and North China Blocks and thus assembly of supercontinent Pangea. Taken together, the amalgamation of the two continental blocks along the Qinling-Tongbai-Dabie-Sulu orogenic belt is a multistage process that spans about 300 Ma.

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Structural Geometry of an Exhumed UHP Terrane in Yangkou Bay, the Eastern Sulu Orogen, China: Implications for Continental Collisional Processes

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High-precision 1:200-1:1,000 mapping of Yangkou Bay, eastern Sulu orogen, defines the structural geometry and history of one of the world's most significant UHP (ultrahigh-pressure) belts. At least four stages of folds are recognized in UHP eclogites and associated quartzo-feldspathic gneiss. UHP-eclogite facies rootless F1 and isoclinal F2 folds are preserved locally in coesite-eclogite. Mylonitic to ultramylonitic quartzo-feldpsthic and coesite-eclogite shear zones separate small-scale 5-10-meter-thick nappes of ultramafic-mafic UHP rocks from banded quartzo-feldspathic gneiss. These shear zones are folded, and progressively overprinted by amphibolite-greenschist facies shear zones. The prograde to retrograde D_1-D_5 deformation sequence is explained by deep subduction of offscraped thrust slices of lower continental or oceanic crust from the down-going plate, caught between the colliding North and South China cratons in the Mesozoic. After these slices were structurally isolated along the plate interface, they were rolled in the subduction channel during exhumation and structural juxtaposition with quartzo-feldspathic gneisses, forming several generations of folds, sequentially lower-grade foliations and lineations, and intruded by in situ and exotically derived melts. Shear zones formed during different deformation generations are wider with lower grades, suggesting that deep-crustal/upper mantle deformation operates more efficiently, perhaps with more active crystallographic slip systems, than deformation at mid-upper crustal levels.

Keywords: Yangkou, UHP metamorphism, structural mapping, Sulu orogen, superimposed folding

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Structural Pattern and Evolution of Qikou Sag in Bohai Bay Basin

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Qikou sag situated in the Northeastern Huanghua depression,Bohai Bay Basin is a Cenozoic faulted basin of a rhombus in shape. It is surrounded by Cangxian uplift to the west, Chengning uplift and Kongdian swell to the south and Shaleitian uplift to the east. The subsiding center of the Qikou sag is locate on western offshore of the Bohai Bay with Tertiary sedimentary rocks of more than 10,000 meters in thickness, an intensively extensional region in Northern China Craton where its crustal thickness is less than 28 kilometers.

Currently, the Qikou Sag is characterized by a dish-like shape without central dome and parallel-aligned grabens (or half-grabens), which is different from those of the other sags in the Bohai Bay Basin. Around the center of the sag, there are various structural slopes to be developed due to active basement-involved faulting. On the slope break of the sag, sags are formed and controlled by NE-trending faults. The boundary faults of the Qikou sag are mostly listric faults, separating the rifting domains from peripheral structural highs. To the west,the sag has the NE-trending Cangdong fault., the NEE-trending Zhaobei fault system is its south border. To the north, there is the Hangu fault. The eastern of the sag is NW-trending Shaxi fault.

The Qikou Sag is separated into four unique extensional blocks by three important transfer-zone or basement-involved faults, called the coast-line transfer fault, the Haihe fault and Qidong fault, respectively. The four extensional blocks are named the Beitang-Xingang, Banqiao-Binhai, Chenghai and Depocenter, respectively.

The Beitang-Xingang block located in the Northern part of the Qikou sag, delimited by the Haihe fault to the south, is controlled by the Hangu extension fault system, being characterized by the NE-trending grabens and structural highs. In western extensional block, the Banqiao-Binhai block, the NE-trending half-graben and horsts are developed by block tilting along the Cangdong listric fault system. In the Chenghai block, the Zhaobei fault system is dominated by the north-dipping domino-type faults, controlling local structural pattern. Structures in the subsiding center of the Qikou sag are not dominantly basement-involved structures in sedimentary cover. In summary, different blocks show different structural styles with different strikes.

Along the basement-involved and transfer faults, the faulting appears apparently intensive, resulting in the development of more second-order faults and even volcanic activity. Some en echelon fault pattern and negative flower-like structures developped along coastline transfer fault, implying that dextral strike-slipping may occur during rifting.

In the Qikou sag, various structural styles are controlled by pre-Paleogene structures in the basin basement, especially Mesozoic structures resulting from the destruction of the North China Craton. The negative inversion of Mesozoic thrust faults and folds intensely influenced the Tertiary rabens in the Qikou Sag. The basement-involved faulting controls sedimentation in the grabens.

The post-Paleocene structural evolution of the Qikou Sag is mainly divided into two structural stages: Early Oligocene and Late Oligocene to Early Miocene. In early Oligocene, major NW-directed extensional event resulted in a series of NE-trending faults. During Late Oligocene to Early Miocene, extensional direction is changed to slightly North-South-directed in order to geenrate the EW-trending structures in the Qikou Sag. At the same time, the coastline fault is a strike-slip fault, differentiating the western and eastern structural patterns.

Keywords: Qikou Sag, Paleogene, faulting, structural evolution, Bohai Bay Basin

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Early Archean Crustal Components in the Indochina Block: Evidence from U-Pb Ages and Hf Isotope of Detrital Zircons from the Central Vietnam

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Southeast (SE) Asia consists of allochthonous continental blocks disintegrated from the northern margin of Gondwana. These include the South China, Indochina, Sibumasu, Qiangtang, West Burma and Lhasa blocks, which amalgamated to form the SE Asian continent during Paleozoic to Mesozoic periods (Metcalfe, 1996). There is no crust forming event older than 2.5 Ga in SE Asia continent, based on U-Pb age and Hf isotope data of zircons from four large rivers (Red, Mekong, Salween, and Irrawaddy, Bodet and Schärer, 2000). However, zircons of eastern part of the Indochina block are lacking in the study of Bodet and Schärer (2000). Here we performed U-Pb dating and Hf isotope analysis of detrital zircons from rivers of central Vietnam in order to characterize continental crust of the Indochina block. The in-situ U-Pb zircon dating results indicate the older zircons (Archean to Cambrian) show four major clusters: 2.5, 1.6, 1.0-0.9 and 0.65-0.5 Ga with two oldest Mesoarchean zircons. The younger zircons show three major clusters in 0.45, 0.25, and 0.03 Ga. In the epsilon Hf diagram, Mesoarchean zircons (3.1 and 3.2 Ga) are plotted between depleted mantle (DM) and Chondritic Uniform Reservoir (CHUR) lines and slightly lower than the CHUR, respectively. This is the evidence for >3.0 Ga juvenile crustal formation in the Indochina block. Each cluster of the older zircons (2.5 Ga, 1.6 Ga, 1.0-0.9 Ga and 0.65-0.5 Ga) have a large range of epsilon Hf, plotted either between the CHUR and DM lines or far below the CHUR line (+11.1 to -34.4). These data indicate the presence of juvenile crustal growth and extensive reworking of Hadean to Mesoproterozoic crust occurred episodically through Archean to Cambrian. Such Hadean to Msoarchean crustal components have not been detected from zircons from four large rivers in SE-Asian continent (Bodet and Schärer, 2000). Epsilon Hf value of 0.45 and 0.25 Ga zircons are plotted in a range from near DM to lower than CHUR, suggesting significant mantle magmatism with recycling of Proterozoic crust. Compared to the older zircons, epsilon Hf values of these younger zircons are less negative and are comparable with that they were formed by recycling of mainly Proterozoic crust. Epsilon Hf values of 0.03 Ga zircons are plotted from CHUR to lower value, suggesting crust melting is dominant in Oligocene event in this region. The range of Hf model ages for the younger zircons is consistent with those from four large rives in SE-Asia (Bodet and Schärer, 2000) and also Sm-Nd isotope data of basement rocks from the Kontum massif, where yielding Proterozoic crustal formation (Lan et al., 2003).

Our results suggest that the Indochina block has long crustal evolution history and could involve significant amount of Archean continental crustal components, especially >3.0 Ga age, in addition to Proterozoic crustal components.

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Early Paleozoic Granitic Magmatisms in the Zhangguangcai Range, NE China: Constraints on Timing of Amalgamation of the Songnen–Zhangguangcai Range and the Jiamusi Massifs

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The Zhangguangcai Range, NE China, is located in the eastern section of the Central Asian Orogenic Belt (CAOB). The Paleozoic tectonic evolution of NE China is characterized by the amalgamation of microcontinental massifs (including the Erguna, Xing'an, Songnen–Zhangguangcai Range, and Jiamusi massifs from west to east) (Sengör et al., 1993; Sengör and Natal'in, 1996). However, the timing of the amalgamation of microcontinental massifs has been a controversial. The early Paleozoic magmatisms in the Zhangguangcai Range provide insights to determine the Paleozoic tectonic evolution between the Songnen–Zhangguangcai Range and Jiamusi massifs. LA-ICP-MS zircon U-Pb daing results indicate that the early Paleozoic magmatisms can be subdivided into three stages, i.e., the late Cambrian-early Ordovician (484~492 Ma), the late Ordovician (443~461 Ma), and the middle Silurian (424~425 Ma).

The late Cambrian-early Ordovician granitic magmatism occurs in the Xiao Hinggan (Liu et al., 2008) and Zhangguangcai Range Mountains, and is composed mainly of granodiorite, monzogranite, and syenogranite. Chemically, they belong to high-K calk-alkaline series and are classified to a post-colliosional I-type granite. Taken together with the early-middle Ordovician calc-alkaline volcanic rocks (basalt-andesite- dacite- rhyolite association) in the study area, we propose that they could have formed under an active continental margin tectonic setting.

The late Ordovician granitic magmatism, ocuurred in the Zhangguangcai Range and the Xiao Hinggan Mountains, consists chiefly of tonalite and rhyolites. The tonalites (443~450 Ma), collected from the Zhangguangcai Range adjacent to the Mudanjiang fault, are chemically a calc-alkaline series similar to I-type granite, implying that they could have formed under the tectonic setting of an active continental margin. However, the rhyolites (451 Ma), collected from the Xiao Hinggan Mountains far away from the Mudanjiang fault, are chemically similar to A_2-type rhyolite, suggesting an extensional environment.

The middle Silurian granitic magmatism, occurred in the Zhangguangcai Range, consists of monzogranite. Compared with the late Ordovician intermediate-acidic igneous rocks, they have relatively high SiO_2 (73.51%~75.69%) and total alkali contents (Na_2O+K_2O= 7.18%~8.35%) as well as low MgO (0.17%~0.27%). In the K_2O vs. Na_2O diagram, most samples belong to I-type granites, but some samples belong to A2-type granites, suggesting an extensional environment following collision of the the Songnen-Zhangguangcai Range and the Jiamusi massifs.

The above findings, combined with geochronological data of detrital zircons from the late Paleozoic sedimentary rocks in eastern Heilongjiang province (Meng et al., 2010), we propose that a westward subduction of an oceanic plate beneath the Zhangguangcai Range could happen during the early-late Ordovician, and that the amalgamation and collision between the Jiamusi and the Songnen-Zhangguangcai Range massifs could take place in the middle Silurian. This research was financially supported by the Geological Survey of China (Grant 1212010070301).

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Zirconological Constraints on Formation and Evolution of Precambrian Continental Lithosphere in South China

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The continental lithosphere consists of continental crust and lithospheric mantle. Because the juvenile crust is extracted by partial melting of the asthenospheric mantle and the residual peridotite forms the subcontinental lithospheric mantle, generation of the continental crust and lithospheric mantle is generally coupled in time and mechanism. Previous Re-Os isotope studies have demonstrated that the oldest Re-depleted age for the lithospheric mantle of South China is the middle Paleoproterozoic and there is a decrease in Re-depleted age from the north (Dabie-Sulu and North Yangtze) to the south (Cathysia). Here we present an integrated study of zirconology, particularly zircon U-Pb ages and Lu-Hf isotopes, on the formation and evolution of the Precambrian crustal and mantle lithospheres in South China.

Crustal materails of Archean ages occur differently in the Yangtze and Cathysia Blocks. In the Yangtze Block, the Archean U-Pb ages have been identified from Archean rocks, xenocrystic zircons in volcanic rocks, residued zircon cores in igneous or metamorphic rocks and detrital zircons in sedimentary rocks. The Archean rocks of the Yangtze Block mainly outcrop in the Kongling complex in the Yangtze Gorge, including TTG gneiss and migmatite. Zircon U-Pb dating reveals that major TTG magmatism occurred at 2.9-2.95 Ga and minor at 3.2 Ga. Residued zircons with U-Pb ages around 3.2 Ga are abundant. These zircons have negative $\varepsilon_{Hf}(t)$ values and Hf model ages about 3.5 Ga, implying that the earliest crustal materials in the Yangtze Block might have been extracted from the mantle in the Paleoarchean. Plenty of Archean zircons with two U-Pb age populations at 2.9-2.8 Ga and 2.6-2.5 Ga are also found in some lamproite diatremes in the Yangtze Block. This could either suggest a possible presence of Archean basement beneath the South China continenal upper crust, or just provide a record of recycled detrital materials in subduction zones. For the Cathysia Block, Archean U-Pb ages are mainly recorded in residued zircon cores and detrital zircons.

Paleoproterozoic ages are frequently found in South China and many localities mentioned with Archean ages also record the Paleoproterozoic information. Igneous and metamorphic rocks with the middle Paleoproterozoic ages have been reported in the Northern Yangtze. We have found some migmatites, metasedimentary gneisses and amphibolites in the Kongling complex with zircon U-Pb ages of 1.9-2.0 Ga and negative $\varepsilon_{Hf}(t)$ values, suggesting reworking of Archean crust. Granite and dolerite dyke with U-Pb ages around 1.85 Ga and negative $\varepsilon_{Hf}(t)$ values have been reported also in the Northern Yangtze. These suggest that the middle Paleoproterozoic event mainly occurred as reworking of the ancient Archean crust. However, residued zircons with consistent U-Pb ages and Hf model ages at 2.15 Ga and 1.82 Ga were reported in the Dabie-Sulu orogenic belt, suggesting a possible growth of juvenile Paleoproterozoic crust. For the Cathysia Block, some high-grade metamorphic rocks outcrop in southwestern Zhejiang Province and northwestern Fujian Province, mainly including the Badu and the Mayuan Formations. Zirconological studies in the southwestern Zhejiang showed that mafic rocks and granites have consistent U-Pb ages of ca. 1.85 Ga but different $\varepsilon_{Hf}(t)$ values of −7 to −3 and −15.6 to −10.0, respectively. They are also reworked products of ancient Archean crust.

A characteristic feature of South China is widespread occurrence of the Neoproterozoic ages of igneous rocks, particularly in the period of 820-740 Ma. Our studies on the Dabie-Sulu metaigneous rocks showed that their protolith ages mainly cluster at 740-780 Ma. Their $\varepsilon_{Hf}(t)$ values can be subdivided into two groups, one from 12.9±0.7 to 5.9±0.9 and the other from 2.3±0.3 to −2.7±0.6, which correspond to the Neoproterozoic juvenile crust and reworked Paleoproterozoic crust, respectively. As for the Northern Yangtze, our studies on the Huangling batholith and Xiaofeng dykes in the Yangtze Gorge showed that they have U-Pb ages of 800-820 Ma, extremely negative $\varepsilon_{Hf}(t)$ values and Archean Hf model ages. This suggests that the continental lithosphere of the North Yangtze is ancient in the Neoproterozoic and the lithospheric mantle is isotopically enriched one. Zircon studies on the Neoproterozoic igneous rocks of the eastern Jiangnan Orogen yield small positive $\varepsilon_{Hf}(t)$ values and Hf model ages of late Meoproterozoic to early Neoproterozoic. Thus the Neoproterozoic continental crust in this area is mainly juvenile crust and its reworked product. Studies on the western Jiangnan Orogen show that zircons from Neoproterozoic igneous rocks have $\varepsilon_{Hf}(t)$ values around 0 or slightly negative and their Hf model ages are mainly Paleoproterozoic and rarely Meoproterozoic. This means that the Neoproterozoic crust here are mainly reworked ancient crust and the lithosphere here might formed in the Paleoproterozoic. Studies on the western margin of the Yangtze Block yields zircon U-Pb ages of 750-780 Ma, positive $\varepsilon_{Hf}(t)$ values and Hf model ages of Early Neoproterozoic to Late Mesoproterozoic, reflecting growth of juvenile crust in the continental rifting zone. Thus, not only the growth and reworking of juvenile crust but also the reworking of ancient Archean and Paleoproterozoic crust took place in the Neoproterozoic during assembly and breakup of supercontinent Rodinia. And the growth of juvenile crust occurred both in arc-continental collision and rifting zones. Correspondingly, the continental lithosphere of South China in the Neoproterozoic is composed of both ancient and juvenile ones.

In conclusion, the growth of juvenile crust in South China was dominated at the early stage of its accretion (i.e. Archean). With the evolution of the lithosphere, more juvenile crust was added to the Yangtze Block and more ancient crust was available for reworking in the Middle Neoproterozoic.

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New Paleomagnetic Data Support a Middle Permian Age for the NE India Abor Volcanics: Significance for Gondwana- Related Break-Up Models

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Confusion exists as to the age of the Abor Volcanics of NE India. Some consider this primarily mafic unit to have been emplaced in the Early to mid-Permian, whereas others assign it an Early Eocene age, a difference well in excess of 200 million years. The divergence in opinion is significant because fundamentally different models explaining the geotectonic evolution of India depend on the age designation of the unit. Paleomagnetic data reported here indicate that steep dipping magnetizations (mean of 71.7 ±5.3°, which equates to a paleo-latitude of ~56.5°) are recorded in the formation, which is only consistent with the unit being of Permian age, (possibly Artinskian based on a magnetostratigraphic argument). At this time, the sub-continent was located >50°S (in the Early Eocene it would have been just north of the equator). The mean declination is counter-clockwise rotated by (~95°), around half of which can be related to the motion of Indian block; the remainder is due to local tectonics, most likely Himalayan-age thrusting in the Eastern Syntaxis. Several workers have proposed correlating the Abor Volcanics with broadly coeval mafic volcanic suites in Oman, NE Pakistan-NW India southern Tibet-Nepal, which were generated in response to the Cimmerian continental block peeling off eastern Gondwana in the Early-Middle Permian. Instead we suggest that that the Abor basalts relate to India-Antarctica/India-Australia extension that was happening at about the same time. Such an explanation more easily accommodates the relevant stratigraphical and structural data (present-day position within the Himalayan thrust stack), as well as the plate tectonic model for Permian eastern Gondwana.

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SS03-O-5

Evidence for Palaeo-Tethyan Oceanic Subduction within Central Qiangtang, Northern Tibet

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The mechanism of formation of blueschist-eclogite belts and their space-time distribution are important in understanding the tectonics associated with convergent plate boundaries. Here we investigate the garnet-bearing blueschists from Rongma area of central Qiangtang in northern Tibet. The mineral assemblage in these rocks is characterized by porphyroblastic garnet set within a matrix of fine-grained amphibole, white mica, epidote, chlorite, albite and quartz with accessory rutile, titanite and apatite. The Mn content of the garnet porphyroblasts decreases from core to rim, whereas the Fe and Mg contents show an increasing trend respectively. Fine-grained rhomb-shaped inclusions of paragonite and epidote in association with quartz occurring within the core of the garnet porphyroblasts are interpreted as pseudomorphs after lawsonite. Large grains of epidote with inclusions of Na amphibole, rutile and quartz occur in the matrix in contact with the rims of the garnet grains. In the matrix, we identify two stages of Na amphibole rimmed by Na-Ca amphibole and albite. Retrograde chlorite is rimmed by fine-grained biotite. Based on microstructural observations and pseudosection modelling, we trace the P-T path for the Rongma garnet blueschist from about 2.1 GPa and 480°C (lawsonite- stability field) to about 1.7 GPa and 560 oC (epidote eclogite field), marking an initial increase in temperature. This stage is followed by a decrease of pressure through the blueschist facies down to P-T conditions of about 0.8 GPa and 540°C. In combination with previous work including the available isotopic age data, the P-T path obtained in the present study suggests deep subduction of palaeo-Tethyan oceanic crust between southern and northern Qiangtang blocks, supporting the model that the blueschist belt defines the location of the palaeo-Tethyan suture zone within northern Tibet. Since the transformation of lawsonite to epidote is known to release water along the subduction channel, our results also provide clues to a better understanding of the subduction-related late Permian to early Triassic andesitic magmas in northern Tibet.

Keywords: garnet blueschist, petrology, metamorphic history, tectonics, cold slab subduction, Tethys, northern Tibet

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SS03-O-6

Uplifting of the Jiamusi Block in the Eastern Central Asian Orogenic Belt, NE China: Evidence from Basin Provenance and Geochronology

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The main part of Jiamusi Block, named as Huanan-Uplift, is located in the northeastern Heilongjiang, China. The Huanan-Uplift is surrounded by many relatively small Mesozoic-Cenozoic basins, e.g. Sanjiang Basin, Hulin Basin, Boli Basin, Jixi Basin, Shuangyashan Basin and Shuanghua Basin. However previous research works were mainly focused on stratigraphy and palaeontology of the basins, therefore, the coupling relation between the uplift and the surrounding basins have not been clear. Based on the field investigations, conglomerate provenance studies of the Houshigou Formation in Boli Basin, geochronology of the Huanan-Uplift basement, we have been studied the relationships between Huanan-Uplift and the surrounding basins.

The regional stratigraphic correlations indicates that the isolated basins in the area experienced the same evolution during the period of the Chengzihe and the Muling Formations (the Early Cretaceous). The paleogeography reconstructions suggest that the area had been a large-scale basin as a whole during the Early Cretaceous. The Huanan-Uplift did not exist.

The paleocurrent directions, sandstone and conglomerate provenance analyses show that the Huanan-Uplift started to be the source area of the surrounding basins during the period of Houshigou Formation (early Late Cretaceous), therefore, it suggests that the Jiamusi Block commenced uplift in the early Late Cretaceous.

The granitic gneisses in Huanan-Uplift give 494-415 Ma monazite U-Th-total Pb ages, 262-259 Ma biotite and 246-241 Ma K-feldspar $^{40}Ar/^{39}Ar$ ages. The cooling rates of 1-2℃/Ma from 500-260 Ma and 10-11℃/Ma from 260-240 Ma have been calculated based on the ages. This suggests that the Jiamusi Block had a rapid exhumation during late Permian, which should be related to the closure of the Paleo-Asian Ocean between the Siberian and North China continents.

It is concluded that during the late Paleozoic the Jiamusi Block was stable with a very slow uplifting. With the closure of the Paleo-Asian Ocean the Jiamusi Block underwent a very rapid exhumation in the late Permian. In the early Mesozoic the area went into a basin developing stage and formed a large basin as a whole during the Early Cretaceous. In the Late Cretaceous the Jiamusi Block started uplifting and the basin was broken into isolated small basins.

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Geology Of The Migmatite and Gneissic Granite in the Wenquan Group (NW Tianshan): Implication for Neoproterozoic Crustal Thickening and Partial Melting

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Various microcontinents or continental fragments were involved in the Central Asian Orogenic Belt (CAOB), the origin of these continental blocks is important not only for the understanding of the accretion-collisional processes of the CAOB, but also for deciphering the relationship between these blocks and global supercontinents. The metamorphic rocks of the Wenquan Group in the North Chinese Tianshan have been regarded as Paleoproterozoic basement of the Yili Block that is one of the constituent parts of the CAOB. The Wenquan Group is mainly composed of pre-Neoproterozoic meta-volcanic and meta-sedimentary rocks, including amphibolite, micaschist, quartz schist, biotite gneiss and marble; and Neoproterozoic migmatite and orthogneiss. Migmatization occurs in the amphibolite, paragneiss and micaschist, associated with intruding of gneissic granite. Migmatites show typical schlieren and ptygmatic textures. Leucosomes and mesosomes are often foliated showing gneissic structure. Orthogneiss occur as several-hundred meters to few-kilometers wide dykes. Enclaves of amphibolite are locally observed showing a consistent foliation with that in the host orthogneiss.

SHRIMP U-Pb dating on zircons from two gneissic granite samples yielded consistent ages of 908 ± 11 Ma and 905 ± 7 Ma, with inherited zircons of 1070-1160 Ma. An older age of 926 ± 12 Ma was obtained from the leucosome of one migmatite sample. These ages are consistent within errors and close to those of Neoproterozoic granitoids occurring in the Chinese Tianshan. Whole rock geochemical data indicate that the orthogneiss belong to aluminous or peraluminous calc-alkaline series, they have $\varepsilon Nd(910)$ values of between -1.8 and -3.2. These features of orthogneiss and migmatite indicate an origin of partial melting of continental crust, and the occurrences of synchronous migmatite support a thickening and partial melting of continental crust. This event is extensively recognized in the Gondwana-originated continental blocks of Central Asia, more specifically in Yili, Kazakhstan and Central Tianshan blocks. It is therefore considered that the thickened crust was partially melted during Neoproterozoic (930-900 Ma) in northern Yili following a Grenville-stage orogeny, which could be correlated with the assemblage of the Rodinia supercontinent.

Keywords: North Chinese Tianshan; Wenquan Group; migmatite; Neoproterozoic; crustal thickening and partial melting

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Foliation Genesis and Tectonic Implication of the Neoproterozoic Deokjeongri Tonalite- Trondhjemite- Granodiorite in the Hongseong Area, Korea

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The Neoproterozoic Deokjeongri TTG (tonalite-trondhjemite-granodiorite) arc in the Hongseong area consists of metamorphosed tonalite, amphibole-biotite granodiorite and leucocratic granite (Kim et al., 2008). Tonalite gneiss is rich in the northwestern part of the arc. The overall content of mafic minerals increases toward the south. Several lens-shaped masses of ultramafic rock, amphibolite and marble occur as xenoliths in the Deojkeongri TTG. Available SHRIMP U-Pb zircon ages from the Deokjeongri TTG indicate that they were intruded at ca. 850–820 Ma and metamorphosed at ca. 235–223 Ma (Kim et al., 2008). Most of the bodies in the Hongseong area show overall NNE-SSW orientation, whereas the Deokjeongri TTG trends NNW–SSE. The overall NNW–SSE strike of the foliated Deokjeongri TTG changes drastically into E–W direction, where it contacts with meta-volcanic and meta-sedimentary rocks (viz. the Weolhyunri complex) at the southern part of the Deokjeongri TTG. Foliation intensity also increases toward the southern part. Tonalite gneiss was experienced deformation associated with the intrusion of granodiorite. Previously the Deokjeongri TTG was considered to be granitic gneiss because of strongly developed foliation and banded layering due to Middle Triassic tectonic activity (Oh et al., 2004). Outcrop-scale deformation structures such as foliations, minor shear zones and folds are pervasively developed through the granodiorite, while ductile deformation fabrics are lack in microstructure. Foliations are defined by strong preferred orientation of biotite and hornblende, but quartz and feldspar are free of plastic deformation microstructures such as elongated minerals and recrystallization. Except the preferred orientation of biotites and hornblendes, granodiorite shows typical equi-granular micro-texture without the evidence of plastic deformation. Uncommonly plagioclase has oscillatory compositional zoning and laths of plagioclase make a weak preferred alignment. The contacts between mafic enclaves and the host granodiorite are gradational and appear a bleached zone with poor mafic minerals in granodiorite. Mafic enclave includes macro-scale ductile deformation structure as isoclinal folds, sigmoidal-shaped boundins and grain tail complexes closely associated with the foliation generation observed in the granodiorite. Although mafic minerals show dimensional preferred orientations, internal structures of deformed mafic enclaves are also lack of evidences related to the solid-state plastic deformation. Local gneissic banding in granodiorite shows high temperature deformation microstructures such as grain-boundary migration recrystallization of quartz. These lines of evidence indicate that foliations within the granodiorite resulted in the magmatic flow during the Neoproterozoic. Both magmatic foliation and the solid state foliation that are preserved within the Deokjeongri TTG suggests that they might have formed during the Neoproterozoic, which gives some clues on the tectonic evolution of the Hongseong area before the final amalgamation of East Asia during Triassic.

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Age and Origin of Suzhou A-type Granites in South China: In Situ Zircon U-Pb Age and Hf-O Isotopic Constrains

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A-type granites are a distinct group of granites that can occur in both continental and oceanic crusts. While volumetrically insignificant, the origin and genesis of the A-type granites are still controversial. We carried out in this study a systematic analysis of in situ zircon U-Pb age and Hf-O isotopes for the Suzhou A-type granites from South China, with aims of shedding new light on their origin.

The Suzhou granite pluton is a small high level anorogenic composite body in eastern South China Block. Three phases of granite intrusions are recognized, which are previously dated at 145-110 Ma by Rb-Sr and Ar/Ar methods. The granites are characteristically high in SiO_2 (>70%), total alkaline ($K_2O+Na_2O>8.3\%$), high-field-strength elements, K_2O/Na_2O, Fe/Mg, and Ga/Al ratios, but generally low in CaO, Al_2O_3 and Sr, typical of A-type granites. Previous Sr, Nd and O isotopic studies suggested that the Suzhou A-type granites are products generated by crustal re-melting, and the mantle-derived melts may or may not be involved in the granites. Our SIMS zircon U-Pb dating results yield a consistent age of 126.5±0.8 Ma for all three phases of granites, indicating the Suzhou granites were formed in a single magmatic episode. All the analyzed zircons are characterized by homogeneous oxygen isotope compositions, with ^{18}O values mostly between 4.7 and 5.8‰ falling into the range of normal “mantle zircons” (^{18}O = 5.3±0.3‰). Thus, zircon oxygen isotopic data suggest that the granites are derived from either a dominant mantle origin, or re-melting of mafic to intermediate igneous rocks, with little, if any, involvement of supracrustal materials. In contrast to the homogeneous oxygen isotopes, these zircons have highly variable Hf isotopes, with Hf(t) = –10 to +13, suggesting involvement of at least two end-member sources in their genesis. One end-member should be the deplete-mantle source in terms of the highly positive Hf(t) values, while the other could be either the enriched mantle or ancient mafic-intermediate igneous rocks at crust levels characterized by highly negative Hf(t) values. If the granites are generated by extreme fractionation of hybrid basaltic magma derived from depleted and enriched mantle sources, a large volume of mafic rocks would be invoked. However, there are little co-existing mafic rocks found in the region, thus, contribution from the enriched mantle source is unlikely. We prefer the second interpretation that the ancient igneous rocks are more likely the other major source accounting for the highly negative Hf(t) values, although the origin of enriched-mantle source cannot be totally ruled out. We conclude that the Suzhou A-type granites are the products generated by re-melting of ancient mafic-intermediate igneous rocks triggered by underplating or intrusion of the depleted mantle-derived magmas that provided not only the heat source but also part of masses for the formation of Suzhou A-type granites.

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SS04-O-1

Heterogeneous Thermal State and Structure of the Lithosphere beneath Eastern China: Xenolith Constraints

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Application of reliable thermo- barometers on garnet-bearing peridotite and pyroxenite xenoliths and granulite xenoliths entrained by Cenozoic basalts in eastern China reveals two main types of geotherm. The first type, as exemplified by Hannuoba, Mingxi and probably NE China, is characterized by a constant slope of data in the pressure-temperatures space, corresponding to ~70 mW/m^2. The second type, as exemplified by the high geotherms (corresponding to ~80 mW/m^2) of Nushan and probably Xinchang, is characterized by variable slopes, with the samples with pressure < 20 kbar defining a gentle slope, whereas the samples with pressure > 20 kbar define a virtually vertical slope. The different slopes in the second geotherm may correspond to different heat transfer mechanism, with conductive transfer for the shallow upper mantle and advective transfer for the deep lithospheric mantle. This observed transition in thermal transfer is consistent with theoretical modeling. The two types of geotherm are not mutually exclusive, because the second type may characterize the thermal state of whole lithospheric section including both mechanical boundary layer (MBL) and thermal boundary layer (TBL), while the first type may only depict the MBL. Nevertheless, the occurrence of variable geotherms for different regions is significant, and can be reflective of a heterogeneous lithospheric structure in eastern China: (a) Eastern North China craton (NCC) is characterized by a second-type geotherm, corresponding to a thin lithosphere (~70 km). Comparison of the equilibrium temperatures of spinel peridotites with this geotherm constrains the depth to Moho in this area to be 30 km. In contrast, western NCC possesses a relatively low thermal gradient, indicative of a thick lithosphere (> 90-100 km) and a thick crust-mantle transition zone (28-42 km). The dramatic change in crustal and mantle structure across the Daxing'anling-Taihangshan is consistent with recent seismic studies. (b) There is a decrease in thermal gradient and in lithospheric thickness from coast to inland in South China (from ~ 80 km to > 90 km), which is collaborated with westward variation in basalt geochemistry. (c) The weak convex-upward pattern of the geotherm in Qilin and Leizhou peninsula is peculiar, probably reflecting a transitional feature between conductive and advective heat transfer. It may have resulted from impregnation of mantle plume on the base of the lithosphere and/or magmatic underplating related to South China Sea spreading. These new results not only provide a basic framework for the ongoing 4-D lithosphere mapping project in eastern China, but also yield important implications for deep processes that operated over the past.

Keywords: Geotherm; thermo-barometry; garnet-bearing peridotite and pyroxenite; granulite; xenolith, lithosphere; eastern China

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Lithospheric Mantle Boundary between North China and Yangtze Carton in the Eastern Segment: Constraint from Lead Isotopes of Cenozoic Basalts

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Cenozoic intraplate basalts in eastern China show variations of lead isotope ratios that essentially correspond to major lithospheric domains. The basalts from North China exhibit the depleted characteristics of radiogenic lead isotopes, but the basalts from Yangtze and South China have enriched radiogenic lead isotopes (e.g. Chung, 1999). This study reports new lead isotope data for Cenozoic basanites occurring in Sulu UHP belt, the eastern boundary between North China and Yangtze craton. The results show that, the $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios are in range of 17.975 ~ 18.108, 15.509 ~ 15.521 and 38.109 ~ 38.213, respectively. These values are very similar to those of late Cretaceous basalts within Dabie orogenic belt, which are 17.936 ~ 17.995, 15.500 ~ 15.563 and 38.399 ~ 38.496 for $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios, respectively. This fact implies that the lead isotopes of lithospheric mantle beneath Sulu belt are identical to those of Dabie belt. The lithospheric mantle lead isotope characteristics of Sulu belt is closer to that of Yangtze craton, which $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios are higher than those of North China craton (Chung, 1999). For example, the $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios are 18.103, 15.467 and 38.058 respectively in Fangshan basalt of Jintan County, and 18.150, 15.574, 38.469 respectively in Fushan basanite of Dangtu County (Peng et al., 1986). Both locations are within Lower Yangtze massif. On the contrary, North China craton exhibit much lower lead isotope values. For instance, the Dashushan basalt of Hefei City has $^{206}Pb/^{204}Pb$ ratio of 17.596, $^{207}Pb/^{204}Pb$ ratio of 15.389 and $^{208}Pb/^{204}Pb$ ratio of 37.844; and the basalts in Mingguang City have $^{206}Pb/^{204}Pb$ ratios of 17.009 ~ 17.771, $^{207}Pb/^{204}Pb$ ratios of 15.370 ~ 15.437 and $^{208}Pb/^{204}Pb$ ratios of 37.642 ~ 37.782 (Peng et al., 1986). Accordingly, there exists significant difference of lead isotope characteristics between the Cenozoic basanites in Sulu UHP belt and the intraplate basalts in North China craton.

Our new obtained lead isotopes of basalts in Sulu UHP belt do not support the crustal detachment collision model proposed by Li (1994), which suggests a subsurface suture between North China and Yangtze craton running in the lower crust through Nanjing City, about 500 km south of Sulu belt. Although Chung's (1999) work on the basalt geochemistry favours Li's model, the only sample located in the southern bank of Yangtze River reported by Chung (1999) occurs actually in Sulu belt! Accordingly, we suggest that the lithospheric mantle boundary between North China and Yangtze craton runs through Sulu UHP belt, and there does not exist a northward detachment of Yangtze upper crustal in the eastern side of Tanlu fault as argued by Li (1994) and Chung (1999).

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SS04-O-3

Remelting of Subducted Continental Lithopshere: Geochronological and Geochemical Evidence from Mesozoic Igneous Rocks in the Dabie-Sulu Orogenic Belt

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The Dabie-Sulu orogenic belt is located between between the South China Block and the North China Block. It contains various compopsitions of ultrahigh-pressure (UHP) metamorphic rocks as identified by in-situ occurrences of coesite and microdiamond in metamorphic parageneses. This demonstrates the subduction of the continental crust to mantle depths of over 120 km and then return back to crustal levels. A large number of geochronology, tectonics, petrology and geochemistry has been devoted to the UHP rocks, demonstrating that their formation is due to the Triassic subduction of the South China Block beneath the North China Block. This provides us an excellent natural laboratory to stuty recycling of subducted continental lithosphere in continental collision zones.

There is numerous exposures of Mesozoic mgmatic rocks along the Dabie-Sulu orogenic belt, with emplacement ages mainly at Late Triassic, Late Jurassic and Early Cretaceous, respectively. The Late Triassic alkaline rocks and the Late Jurassic granitoids only crop out in the eastern part of the Sulu orogen, whereas the Early Cretaceous magmatic rocks occur as massive granitoids, sporadic intermediate-mafic intrusive and volcanic rocks throughout this orogenic belt. Despite the different ages for their emplacement, the Mesozoic magmatic rocks are all characterized not only by enrichment of LREE and LILE but depletion of HFSE, but also by high initial Sr isotope ratios, low $\varepsilon_{Nd}(t)$ values and low radiogenic Pb isotope compositions. Some zircons from the granitoids contain inherited magmatic cores with Neoprotozoic and Triassic U-Pb ages, respectively. The Neoproterozoic ages also have been found in some inherited zircon cores from the Cretaceous mafic rocks. Most of the mafic roks have zircon $\delta^{18}O$ values either lower or higher, and whole-rock $\delta^{13}C$ values lower, than those for the normal mantle.

A systematic comparison with adjacent UHP metaigneous rocks shows that the Mesozoic granitoids and mafic rocks have elemental and isotopic features similar to the UHP metagranite and metabasite, respectively. This indicates that these magmatic and metamorphic rocks share the diagnostic features of continental lithospheric source that has a tectonic affinity to the northern margin of the South China Block. Their precursors were derived from reworking of arc-type crust that formed by arc-continent collision in the middle Paleoproterozoic and the early Neoproterzooic, respectively. They underwent the UHP metamorphism and the post-collisional anatexis at different times and depths, respectively. Therefore, the Mesozoic magmatic rocks were derived from anatexis of the subducted continental lithosphere itself beneath the collision-thickened orogen. The geodynamic mechanism of post-collisional magmatisms is tectonic collapse of the orogenic roots in response to lithospheric extension. We advocate that reworking of the orogenic lithospheric mantle and crust is a basic process for petrogenesis of continental igneous rocks in preexisting continental collision orogens.

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Geochemstry of Adakites in Gangdise Magmatic Arc: Evidence of the Remaining Slab Melting

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The Gangdise Magmatic zone is located in the north of the Yarlung-Zangbo suture zone, it records the entire process of the Neo-Tethys Ocean subduction, collision of the Eurasian and Indian Continents, so it can reflect the relationship of the organic belt's evolution and the uplift of Qinghai-Tibet Plateau more directly. The Zaxi rock mass this article reported is in Gangdese magmatic arc, located in the Namulin Ditch, approximately 5 km south to Yarlung Zangbo River. The rock mass is the Biotite Quartz-diorite, the essential minerals are the plagioclase feldspar, the potash feldspar, the amphibole and the quartz, including few of the biotite. Initially, we speculated that the rock's formation time is the Oligocene, according to the relationship observed in the wild and the lithological characteristics. The rock is of the acidic component, the SiO_2 content is relatively low, which changes between 59.5-60.2wt%, the MgO content is high, is 3.14-3.38wt%, the K_2O content is low, is situated between 2.25-2.71 wt%, K_2O / Na2O =0.61-0.71; The Sr content of this group of rocks is relatively low, is 773-790×10^{-6}, Y and the Yb content is relatively high, 7.89-10.1×10^{-6} and 1.11-1.12×10^{-6} respectively; Eu(Eu/Eu*)= 0.97-1.27 which has positive anomaly, or weak negative anomaly; The rock has a low Sr isotopic ratio and a relatively higher Nd isotopic ratio. $^{87}Sr/^{86}Sr$= 0.70398-0.70410, $^{143}Nd/^{144}Nd$= 0.512812-0.512830. According to the Sr/Y-Y and $(La/Yb)_N$-Yb picture, the samples are cast in the area of adakite.

In the diagram of MgO-SiO_2, Sr-SiO_2, the samples from Zaxi rock mass are all cast in the lagging plate subduction caused adakite area. In Sr-Nd isotopic figure, Zaxi diorite is similar with the Shigatse Ophiolite in isotopes, which showed that the rock mass originates from the partial melting of the subduction plate. The adakite produced by the plate melting has a higher $^{143}Nd/^{144}Nd$ isotope ratio and less K_2O and lower in the ratios of K_2O and $^{87}Sr/^{86}Sr$. What's more, for the plate reacts with the mantle as it ascends, melts often have a higher MgO content, similar to the low Silicon adakite defined by Martin.

In the regional, Gangdese zone of magma located in the north of the Yarlung zangbo suture zone. The rock band developed a magmatic arc as the Neo-Tethys Ocean subducteded to the North in the early Cretaceous period; the subduction process lasted until the Neo-Tethys Ocean closed in the Paleocene (around 65Ma). The approximate age of the formation of the Zaxi rock mass is about 30 Ma , it is not likely that it is produced by the melting of the young hot melt oceanic crust. Actually, in recent years, the study found that not only the partial melt of the hot young oceanic crust may form the adakite, but also some old oceanic crust left in the oceanic crust and upper mantle can form adakite. This low Silicon adakite is probably originated from partial melting of subducted oceanic crust stayed at the top of the upper mantle. This conclusion also shows that the slab remained in the upper mantle in a fairly long period, rather than as people speculated that the Neo-Tethys Ocean separated from the orogen and sank into the lower mantle in the Eocene.

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SS04-O-5

Structural Controls on and Contributions to Syenite-hosted Gold Mineralization in the Cadillac–Larder Lake Deformation Zone, Southern Abitibi Greenstone Belt: An Example from the Matachewan Area

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The structural controls of gold deposits in the Cadillac-Larder Lake Deformation Zone (CLLDZ) in general are established. However, the syenite-hosted gold deposits in this region remain poorly constrained. The Matachewan area is located on the western extension of the CLLDZ, characterized by polyphase deformation, pervasive alteration and syenite-hosted gold mineralization. Detailed structural studies were undertaken to establish the relationships between the deformation and mineralization and to further define the tectonic evolution of the CLLDZ.

Three stages of deformation (D_1 to D_3) were identified based on overprinting relationships. The sinistral D_1 deformation resulted from an early NE-SW-orientated compression. F_1 folds are rarely preserved because of the intense overprinting by the subsequent D_2 deformation. S_1 foliation strikes NW-SE, overprinting S0 bedding at a small angle. D_2 occurred under a N-S-orientated transpression, characterized by top-to-the-NW oblique thrusting and E-W-orientated strike-slip dextral shearing. F_2 folds plunge steeply to the SW or S. S_2 foliation dominantly strikes NE-SW to nearly E-W and dips steeply to the south, which is consistent with the major structures of the CLLDZ. D_3 was characterized by a sinistral ductile to brittle deformation and generated NW-SE-trending subvertical kink bands, indicating a lower temperature condition than that of the D_1 and D_2.

The Matachewan syenite-hosted gold deposit is associated with the development of the CLLDZ. Three main stages of veining occur in the syenite. The earliest stage of veining (V_1) is characterized by sheared and boudinaged quartz-ankerite veins, dipping to the south at moderate to high angles. The second stage (V_2) is represented by folded quartz-pyrite veinlets and disseminated sulfide, dipping to the NNE at shallow to moderate angles. The third stage (V_3) is of similar feature with V_2 and is comprised of en echelon or planar quartz-carbonate veins with sulfide minerals, dipping to the NE at moderate angles. Petrological studies reveal that the major phase of gold mineralization is associated with V_2 veins, and partially with V_3 veins. Structural overprinting relationships indicate that V_2 and V_3 veins developed during D_2 and late D_2, respectively, involving sub-horizontal NW-SE compressional stress under high fluid pressure. The attitude of these auriferous veins essentially controls that of the mineralization.

In general, the structural features of the Matachewan area can be well correlated with those of other areas of the CLLDZ. The intimate relationship between the deformation and the geometry of auriferous veins can help to examine other syenite-hosted gold deposits of the CLLDZ and guide gold exploration.

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From Mantle Peridotite to Olivine-Bearing Websterite: Transfornation of Nature of the Mesozoic Lithospheric Mantle in the Eastern North China Craton

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The mechanism of the destruction of the North China Craton (NCC) has been a controversial due to the lack of direct evidence from the nature of the Mesozoic lithospheric mantle. However, the olivine-bearing websterite xenolith discovered in the Feixian basalts from western Shandong, except for the previously reported olivine xenocrysts with high forsterite (Pei et al., 2004; Gao et al., 2008), provides insights into the nature of the lithospheric mantle underlying the eastern NCC during the Mesozoic. The previously discovered olivine xenocrysts in the Feixian basalts, together with the spinel harzburgite xenoliths with Archean Re-depletion model ages in the early Cretaceous high-Mg diorites from western Shandong (2.60 - 2.68Ga; Xu et al., 2008), suggest the existence of the Archean lithospheric mantle in the early Cretaceous (Pei et al., 2004). However, the olivines from olivine-bearing websterite xenolith are chemically different from those from of the Archean cratonic lithospheric mantle. The former have relatively low Mg#'s (average 86.4) and Ni contents (2187 – 2468 ppm) and high Ca (983 – 1134 ppm), Cr (159 – 217 ppm), and Ti (58 – 76 ppm) concentrations, similar to those of olivines from dunite xenoliths entrained by the early Cretaceous high-Mg diorites (Xu et al., 2010). Additionally, the orthopyroxenes from the olivine-bearing websterite xenolith have higher Ni, Co and lower Cr concentrations (average Ni = 1273 ppm, Co = 73 ppm, Cr = 1656 ppm, n = 5) than those (average Ni = 804 ppm, Co = 61 ppm, Cr = 3019 ppm, n = 5) of orthopyroxenes from the lherzolite xenoliths in the Cenozoic basalts of eastern China. Meanwhile, comparing with the clinopyroxenes (average Ni = 382 ppm, Co = 23 ppm, Cr = 5805 ppm, n = 3) from the spinel - lherzolite xenoliths in the Cenozoic basalts of eastern China, the clinopyroxenes from the olivine - bearing websterite xenolith have much high Ni, Co and low Cr concentrations (average Ni = 676 ppm, Co = 35 ppm, Cr = 3225 ppm, n = 5). These features suggest that the olivine - bearing websterite were produced through interaction between the Archean lithospheric mantle and siliceous - and calc - rich melts. The δ18O values of residual olivines from olivine - bearing websterite xenolith range from 7.10 ‰ to 8.40 ‰, obviously different from typical mantle olivine values (5.20 - 5.50 ‰, Valley et al., 1998), further implying that the olivine-bearing websterite was formed by the delaminated continental crust-derived melt – peridotite reaction. The replacement of olivine-bearing websterite to the mantle peridotites such as harzburgite and lherzolite with the Archean Re-depletion model ages implies the transformation of the nature of the Mesozoic lithospheric mantle, i.e., delamination and subsequently delaminated continental crust-derived melt — peridotite reaction being major mechanisms for the destruction of the NCC.

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SS04-O-7

Isotopic Thermometry in High to Ultra-High Temperature Terrains: An Empirical Calibration of Graphite-Calcite Thermometry

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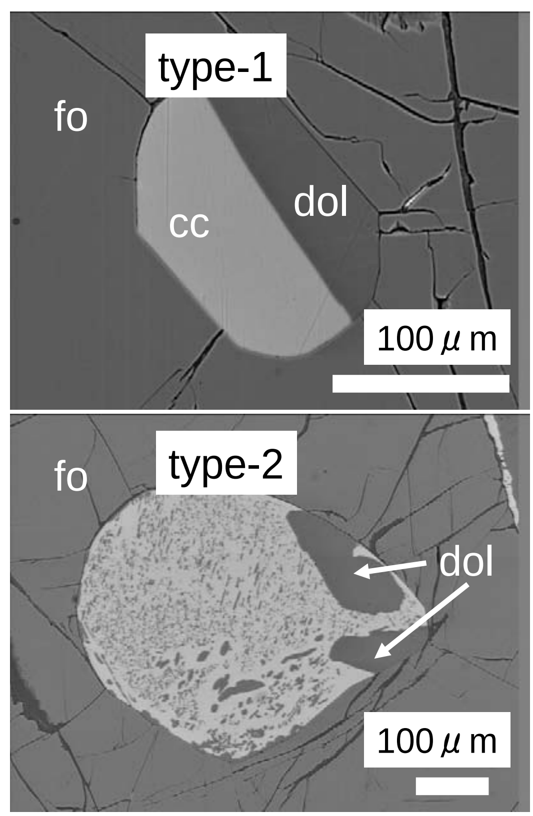
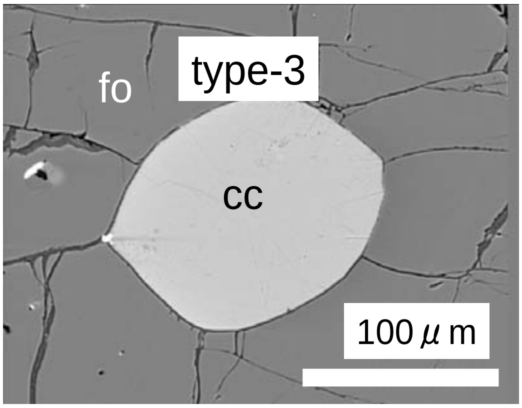
Isotopic thermometry is an important tool for unraveling the thermal history of metamorphic events, because it is independence of pressure. When applying this thermometer to high to ultra-high temperature ranges, the re-equilibration of isotopic exchange reaction during its cooling history will give the re-equilibrium temperature but not the peak temperature attained. Carbon isotope thermometry between calcite and graphite is the most suitable thermometry to estimate the peak metamorphic temperature in high-grade terrains with crystalline limestone. This is because calcite is an abundant phase with relatively high carbon diffusivity, whereas minor graphite with a very slow rate of diffusion is an inert mineral for isotopic exchange reactions. The temperature dependence of calcitegraphite fractionations determined by various methods, i.e. theoretical, experimental and empirical calibrations show a wide variation, still in the range of high to ultra high temperatures. Carbon isotopic fractionation within the system of calcite-dolomite-graphite system is marbles from Highland complex in Sri Lanka and from Skallevikshalsen, East Antarctica contained calcite-dolomite-

graphite assemblage, where the rocks have been metamorphosed under high to ultra-high temperatures. We used these ultra-high temperature assemblages to calibrate calcite-dolomite solvus temperature for carbon isotopic geothermometry.

Solid inclusions of magnesian calcite in forsterite and spinel in marbles show mineralogically a close system in and represent a possible ultra-high temperature chemical equilibrium. Then these solvus temperatures give us the best opportunity of preservation of the maximum temperatures attained. These solvus temperatures gave us a high-temperature region of 770-890 ℃. We obtained a consistent relationship between the empirical carbon isotopic signature (calcite-graphite, dolomite-graphite) and the solvus temperatures of the inclusion.





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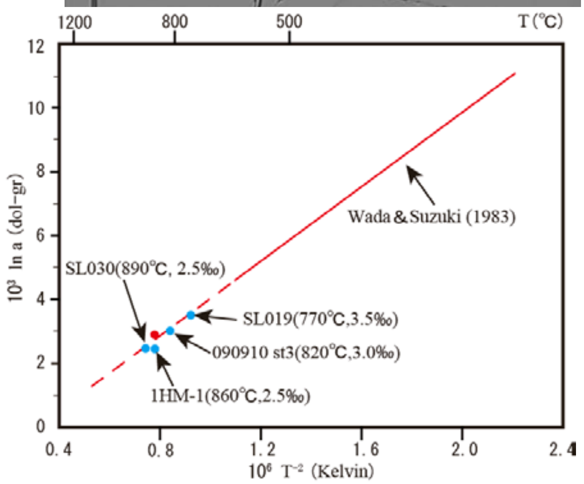
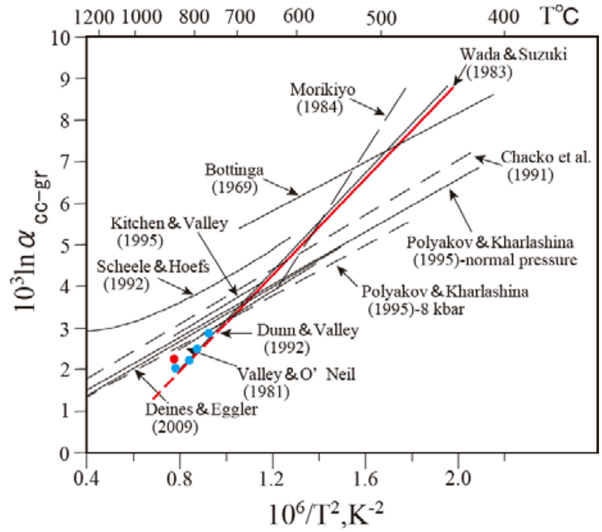


1200
800
500
T (°C)
10³ ln a (dol−gr)
Wada & Suzuki (1983)
SL030(890°C, 2.5‰)
SL019(770°C,3.5‰)
090910 st3(820°C,3.0‰)
1HM-1(860°C,2.5‰)
10⁶ T⁻² (Kelvin)



1200 1000 800 700 600 500 400 T°C
10³ln α cc−gr
Wada & Suzuki (1983)
Morikiyo (1984)
Bottinga (1969)
Chacko et al. (1991)
Kitchen & Valley (1995)
Scheele & Hoefs (1992)
Polyakov & Kharlashina (1995)-normal pressure
Polyakov & Kharlashina (1995)-8 kbar
Dunn & Valley (1992)
Valley & O' Neil (1981)
Deines & Eggler (2009)
10⁶/T²,K⁻²

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SS04-O-8

The Fluids Evolution and Metallogenesis of the Tiemurt Lead-Zinc-Copper Deposit, Xinjiang.*

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The Tiemurt lead-zinc-copper deposit occurs in Devonian volcanic-sedimentary basin of the Altay orogenic belt. The metamorphic hydrothermal ore-forming process can be divided into early, middle and late stages. Four types of fluid inclusions include aqueous water (W-type), pure CO_2 (PC-type), CO_2-H_2O (C-type) and daughter mineral-bearing (S-type). The homogenization temperature of the primary C-type and W-type fluid inclusions in the early stage quartz ranges from 330 to 370°C and their salinities range from 2 to 6 wt.% NaCl eqv.. The middle-stage quartz trapped W-type, PC type, C-type and S-type fluid inclusions with the lower temperature (270 ~ 330°C) and higher salinity (2 ~ 6 wt.% NaCl eqv.). Gases in fluid inclusions are CO_2, CH_4 and N_2. The late-stage quartz veins contain only aqueous fluid inclusions with homogenization temperature between 118 and 205°C. The low salinity and high CO_2 content indicate that the ore fluids were metamorphic in origin. In the middle stage, coexistence and similar homogenization temperature of C-type, W-type and S-type fluid inclusions imply that metal precipitation resulted from fluid boiling, CO_2-escape and transient oversaturation. The trapping pressure of fluid inclusions range from 80 to 260 MPa, suggesting an alternating hydrostatic-lithostatic fluid-system, controlled by fault-valve at the depth of 8 ~ 10 km. Therefore, the Tiemurt Pb-Zn-Cu deposit could be taken as an example of orogenic deposit formed during Late Carboniferous arc-continental collision, although it possibly overprinted on or stem from a VMS/Sedex system.

Keywords: Fluid inclusion; CO_2-rich fluid; Tiemurt Pb-Zn-Cu deposit; orogenic-type Pb-Zn deposit; Altay orogenic belt.

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SS04-O-9

Pressure-Temperature Evolution and Shrimp Geochronology of Neoproterozoic Ultrahigh-Temperature Metamorphic Rocks from Rajapalaiyam in the Madurai Block, Southern India

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1. Introduction

The southern granulite terrane (SGT), India, comprises several large granulite blocks that underwent high- to ultrahigh-temperature (UHT) metamorphism during the assembly of the Gondwana Supercontinent (e.g., Santosh et al., 2009). Previous petrological studies on granulites from the Madurai Block, the largest crustal block in this region, suggest the peak metamorphic conditions of the block as >900 °C and 8–12 kbar, which is consistent with the occurrence of diagnostic UHT mineral assemblages such as sapphirine + quartz, orthopyroxene + sillimanite + quartz, spinel + quartz, and high-Al2O3 orthopyroxene (e.g., Tsunogae and Santosh, 2010). The Rajapalaiyam area in the southern part of the Madurai Block, where sapphirine + quartz was first reported from the SGT by Tateishi et al. (2004), is composed of UHT pelitic granulites with various mineral assemblages. Although several petrological studies have been carried out on the locality, the peak pressure condition and style of exhumation path (either clockwise or counterclockwise) have not yet been determined. In this study we adopted pseudosection analysis for the first time on granulites from Rajapalaiyam to understand the P-T evolution of the Madurai Block. We further performed SHRIMP U-Pb analysis of zircons in the sapphirine + quartz-bearing granulites to determine the time of UHT metamorphism. In a previous study Braun et al. (2007) reported U-Pb monazite age for Rajapalaiyam rocks and inferred the timing of peak UHT metamorphism as 800-900 Ma, which is older than the peak metamorphic ages from other localities in the SGT (e.g., Santosh et al., 2006).

2. Mineral equilibria modeling and zircon geochronology

P-T pseudosections were calculated using THERMOCALC 3.33 (Powell and Holland, 1988) with an updated version of the internally consistent data set of Holland and Powell (1998; data set tcds55s). Calculations were undertaken in the system Na_2O-CaO-K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O-TiO_2-Fe_2O_3 (NCKFMASHTO) (White et al., 2007). Bulk-rock compositions for UHT granulites were determined by X-ray fluorescence analysis. The P-T pseudosections constrain the peak metamorphic condition of Rajapalaiyam at 8.5-10 kbar, 900-1000 °C, which corresponds to the stability of garnet + orthopyroxene + plagioclase + ilmenite + sillimanite + quartz + liquid assemblage. The peak event was followed by cordierite-forming lower-pressure stage probably along a clockwise P-T trajectory. SHRIMP analysis of metamorphic zircons, selected after careful examination of cathodoluminescence images, yielded Neoproterozoic ages of ca. 560 Ma.

3. Discussion

The pseudosection analysis of sapphirine + quartz-bearing UHT granulite from Rajapalaiyam yielded peak metamorphic conditions of 8.5-10 kbar and 900-1000 °C, which is nearly consistent with previous estimates based on P-T grid and geothermobarometry (e.g., Tsunogae and Santosh, 2010). However, it is interesting to note that our pseudosection analysis suggests sapphirine + quartz is not a possible stable phase at the peak condition. This is probably due to prograde partial melting of protolith metasediments and subsequent melt extraction during peak stage, which could have modified the original bulk-rock chemistry. The clockwise P-T path inferred from this study is consistent with the paths from other UHT localities in the Madurai Block (e.g., Tsunogae et al., 2008). SHRIMP analysis of zircons from the UHT granulite gave U-Pb ages of ca. 560 Ma, which is consistent with the Neoproterozoic metamorphic ages reported from other areas in the Madurai Block (e.g., Santosh et al., 2006; Collins et al., 2007). The T ~1000 °C UHT metamorphism and subsequent decompression along a clockwise path in Rajapalaiyam probably associated with the Neoproterozoic subduction and following continent-continent collision attending the final amalgamation of the Gondwana supercontinent (Santosh et al., 2009).

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Chemical Characteristics of Garnet and Biotite, and Metamorphic P-T Path of Ultrahigh-Temperature Granulite from Altay Orogenic Belt, NW China

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The Altay ultrahigh-temperature granulite, located in Fuyun Wuqiagou of North Xinjiang, NW China, has two mineral assemblages: garnet + orthopyroxene + spinel + biotite + cordierite + plagioclase, and sillimanite + cordierite + spinel. Chemically, garnet is mainly almandine with X_{Mg} values of 0.25-0.46, and Mn- and Ca-poor with. It, coexisting with biotite or orthopyroxene, has lower X_{Mg}, and occurring as porphyroblast, has higher X_{Mg}. Some garnet as porphyroblast has zonal structure, showing MgO decreasing and FeO increasing from the core to the rim. Biotite has higher MgO and TiO_2, and lower F and Cl contents with X_{Mg} of 0.55-0.80. Biotite, contacting with garnet and orthopyroxene, has relatively higher X_{Mg}, and occurring in matrix, has lower X_{Mg}, which the latter indicates Fe-Mg exchange between garnet and biotite during the retrograde metamorphic process. According to garnet and biotite pair, and garnet-cordierite pair thermometers, and some evidence of high Al_2O_3 content in orthopyroxene as well as spinel-quartz paragenesis, indicating peak temperature condition of 900°C, and retrograde biotite arriving at temperature of 800°C of granulite-facies condition. A clockwise metamorphic P-T path for an evolutional process of the Altay ultrahigh-temperature granulite can be deduced, which underwent a metamorphic process from an isothermal decompression to isobaric cooling, and then to rapidly uplifting. Combined with the previous study, the formation of the Altay ultrahigh-temperature granulite should genetic link with collisional and orogenic process, and a rapidly uplifting due to post-tectonic movement.

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SS05-O-1

Mesozoic Subduction over the South China Sea

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A Mesozoic mega-subduction zone of the west Pacific has been proposed by many workers to be existed from Russia, through Japan, Taiwan to North Palawan with evidences of Mesozoic orogeny, magmatism, accretionary complexs and/or metamorphic rock belt. It has also been assumed to extend southwestward through the South China Sea to the east margin of Vietnam based on widespread occurrences of granite rocks. Direct evidences for the SW continuation of the Mesozoic subduction belt have long been rare due to present marine environment. In recent years, dredge, drill, and seismic survey have been carried out across the South China Sea from which new lines might be found to define the Mesozoic subduction.

At first, granite rocks were dredged from the northwest slope of the Nansha Islands and dated as 158 Ma, 153 Ma and 127 Ma, respectively, contemporary with Early Yanshanian granites in South China and Vietnam. Secondary, seismic profiles over the Liyue Bank in northeast Nansha Waters show apparent double layer tectonic-layer structure, in which the upper layer of Neogene sequences shows continuous and strong reflections while the lower layer of Mesozoic sequence appeared as dipping reflections. Correlation of drilling data have proved that a major unconformity and sedimentary hiatus of Paleogene occurred between the Mesozoic and the overlying Neogene layers over Liyue Bank, similar to the case of Dongsha Waters in the conjugated northern margin of the South China Sea. The contemporaneity of magmatism and similarity of sedimentary hiatus implies that the Nansha Block and the South China along with its margin belongs to a united active setting at that time. Thirdly, moderate to tight folds with west-dipping detachment fault underneath in the underlying Mesozoic sedimentary sequences were interpreted from seismic profiles in the hinterland of Nansha Islands. Trended in NE-direction, they were covered by undeformed marine Neogene sediments, dissimilar to the NW Sabah and Sarawak where Cenozoic subduction and collision had deformed gently to tightly the thick younger sequences and consumed the proto-South China Sea. The proto-South China Sea had separated the Nansha Block from the NW Sabah and Sarawak before their later convergence. Therefore, the Mesozoic folds and the bottom detachment fault occurred in the Nansha Waters can be determined as the traces of the Mesozoic subduction.

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SS05-O-2

Tectonic History of South Delhi Fold Belt, A Resemblance with South Granulite Terrane and East African Orogen.

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Granulitic terranes occur in various tectonic settings and geological period and have been used for continental correlation within Supercontinental models. In that context, the granulites of the Delhi Fold Belt (DFB) in NW India, which is less known for correlation point view, is very significant. The granulites include pelitic, calcareous and basic granulites, and show multiple phase of folding and shearing. The F_1 and F_2 folds are coaxial in NE-SW axis; the F_3 folds are along NW-SE direction and have produced various type of interference pattern on superposition with earlier folds (Biswal et al, 1998). The exhumation of the granulites has taken place during syn to post F2 folding. The SHRIMP U-Pb dating of zircon from pelitic granulites and synkinematically emplaced granites indicate that the sedimentary succession of the granulites was deposited around ca. 1.2 Ga to 0.8 Ga, folding and granulite metamorphism have taken place ca. 0.8 Ga followed by exhumation and juxtaposition of granulites with low grade rocks through thrusting and the last phase of granitic activity occurred at ca. 0.7 Ga. This shows for the first time, that the DFB granulites are much younger than many Indian granulites. The major occurrences of granulites close in age to the DFB granulites have been identified in the Southern Granulite Terrane of India and East African Orogen (EAO). The granulitic rocks in South India are divided into two blocks namely Northern Granulite Terrane (NGT) and Southern Granulite Terrane (SGT) separated by the combined Salem-Attur-Palghat-Cauveri shear zone. The NGT is of Archaean age. The SGT has been further sub divided into two blocks namely the Madurai block and the Trivandrum block, separated by the Achankovil shear zone. The Madurai block dominated by charnockites and associated quartzites show UHT metamorphism that has been dated at 508 ± 9 Ma. The Trivandrum block dominated by metasediments that shows UHT metamorphism at ca. 560-528 Ma. The EAO includes Arabian-Nubian Shield (ANS), adjoining terranes of Egypt and Ethiopia and Madagascar. The Archaean - Palaeoproterozoic (2840 Ma) as well as Mesoproterozoic crust (1029 Ma) components has been reported from the Arabian-Nubian Shield (ANS). The ANS rocks show greenschist to amphibolite facies metamorphism, whereas the charnockites and enderbites are found in the southern part of EAO suggesting increase in the grade of metamorphism. The adjoining terranes of Egypt have been reported with Neoproterozoic to Cambrian volcanism e.g. large scale intrusion of ca. 750 Ma volcanic rocks. 550 to 530 Ma old post-orogenic granites are reported from Ethiopia. Madagascar consists of a collage of terranes showing a diverse tectonic history and shows granulite facies metamorphism and isothermal decompression at around 550 and 510 Ma. From the above discussion it is apparent that the DFB granulites and Southern Granulite Terrane of India are close in age as well as structural style and metamorphic events with the various granulite belts of the EAO. The extension of the combined Salem-

Attur-Palghat-Cauveri Shear Zone into Madagascar, and East African Orogen to the west and Sri Lanka and Antarctica to the east has been proposed to suggest the presence of the Mozambique Ocean (Santosh et al, 2009). We suggest that the South Delhi Basin probably marks a trace of the proto-Mozambique Ocean in NW India that closed when the combined Marwar Craton and Arabian-Nubian shield collided with the Aravalli-Bundelkhand Protocontinent at ca. 0.7 Ga.

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Thrust Tectonics as the Mechanism for the Exhumation of the Granulites, an Example from the Podiform Granulitic Terrane of the South Delhi Fold Belt, Rajasthan and its Implication on Gondwana Assembly

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Granulites represent lower crustal rocks that have been exhumed to the upper crust by various tectonic processes which may or may not be related to the formation of the granulite. In fact, formation and exhumation of the granulites may be separated in time by several hundreds of millions of years. The formation of granulites can occur in compressional setting as well as in extensional setting. Exhumation can occur through several processes including the formation of nappes in a collisional orogen, decompression on the overlying crust, underplating by other crustal blocks and oblique shearing along multiple retrograde shear zones in a transpressional setting.

Here we deal with the podiform granulitic terrane of the Neoproterozoic Delhi Supergroup of the Aravalli Mobile Belt (AMB) of NW India. This has been referred as Balaram-Kui-Surpagla-Kengora (BKSK) granulite terrane which has been demarcated by Surpagla-Kengora Shear Zone (SKSZ) in the east and Kui-Chitraseni Shear Zone (KCSZ) in the west from the low grade terranes. The granulite terrane comprises pelitic granulites, calc granulites, gabbro-norite-basic-granulite (GNBG) and several suits of granites. These rocks have undergone three phases of folding (F1, F2 and F3)(Biswal et al, 1998).The granulite facies metamorphism is synkinematic with F1 folding. From the spinel, biotite, cordierite and garnet assemblages in the pelitic granulites the peak metamorphic condition has been deduced at Tmax ≥ 850°C and pressure condition 5.5 - 6.8 kbar. The development of the shear zones is synkinematic with F2 stages of folding. From several shear sense indicators preserved in the mylonites, it has been deduced that the KCSZ defining the western margin of the granulites show a NW sense of thrusting while the SKSZ marking the eastern margin show normal slip. From these sense of shearing, it has been interpreted that the granulite terrane has been uplifted along these two boundary shear zones. Further the shear zones occurring within the granulite terrane show thrust slip character suggesting that the granulite block has been exhumed by thrusting of descrete blocks. The thrusting was syn-to post-kinematic to F2 folding. SHRIMP dating of zircon recovered from the pelitic granulites and various phases of granites has produced ages that indicate the age of deposition between ca. 1240 Ma and ca 860 Ma. The deformation and granulite facies metamorphism is between 860 and 800 Ma. This was followed by uplift of the granulites by thrusting and the F3 folding.

From the above discussion, the Neoproterozoic age of the BKSK granulites is evident. The granulites are produced in a compressional setting as the granulite facies indicating minerals define the S1 fabric in the rock. Further, the granulites have been exhumed by thrusting as indicated by the granulite terrane bounding shear zones and intra-terranal thrusts. The formation of the granulites and exhumation history speak regarding the tectonics of the Gondwana assembly. Juxtaposition of continents to form the supercontinent has occurred by collision of different crustal blocks. The NW India collided with Marwar-Arabian-Nubian shield during this assembly. Though it is not very clear about different crustal blocks of the NW part of the India those were involved in such assembly, the Delhi fold belt definitely participated in such crust building process. This is quite evident in the deformational events of the BKSK granulites.

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The Tectonic Evolution of East China Sea Shelf Basin in Meso-Cenozoic

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The East China Sea shelf basin，located in South China block in southeast margin of the Eurasian plate, is a part of tectonic system of the west Pacific oceanic margin. The occurrence, development and evolution of the East China Sea shelf basin has been controlled by the co-action of the collision, subduction and back-arc spreading between the Eurasian plate and the Pacific plate and long-distance effect of the convergence, collision and extrusion between the Indian plate and the Eurasian plate. The tectonic evolution of the East China Sea shelf basin so far from the late Jurassic can be roughly divided into four stages: (1) late Jurassic-early Cretaceous hot dome and igneous activity stage: fast and flat subduction occurred between the Pacific plate and the Eurasian plate from late Jurassic to early Cretaceous, which made the mantle plume and asthenosphere upwell, resulted the uplift, magma intrusion and volcanic eruption of the East China Sea shelf basin, and laid the tectonic evolution basis of the East China Sea shelf basin.(2) late Cretaceous-Eocene Syn-rift stage: since the late Cretaceous, the Indian plate and the Eurasian plate collided and the East China continent creeped eastward in large scale. At the same time, the subduction between the the Eurasian plate and the Pacific plate induced back-arc convection and intensive tension. From then on, the East China Sea shelf basin began to form and to accept deposits. (3) Oligocene-Miocene tectonic inversion stage: since the Oligocene, the direction of the movement of the Pacific plate relative to the Eurasian plate changed from NNW to NWW, and the eastward regional creeping of the margin of the Eurasian plate slowed or terminated. The stress field of the East China Sea shelf basin changed from tensile stress into compressive stress. (4) Pliocene-now regional sagging stage: since the Pliocene, as the subduction plate backed off toward east, the back-arc spreading zone had followed. The Okinawa Trough was constantly pulled into present-day back-arc basin. The global sea-level rise appeared to accelerate the relative sea level rise, and resulted in the formation of the East China Sea continental shelf in Pleistocene. At this point, the East China Sea shelf basin accepted the connectivity with other open marine sedimentary basin.

Keywords: the East China Sea shelf basin; Meso-Cenozoic; Pacific plate; Eurasian plate; Indian Plate; tectonic evolution

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Preliminary Division to Units of "Blocking Tectonics" in China and Adjacent Regions

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Based on Profs. Xia Zhu and Guangding Liu's idea on tectonics of China, and facing to the problems in the course of mapping and edition of "a series of Geological - geophysical maps in China seas and adjacent regions", a new theory called "Blocking Tectonics" has been established gradually. The theory is on global tectonics, whose nature is mobilism. The tectonic evolution of China is divided into 5 stages in the theory. It is emphasized in structural analysis that regional structures control local structures, and deep structural processes control shallow structural processes. Its methodology is summarized as "one theory of mobilisim; two elements of property and models; three principles of combination between geology and geophysics and geochemistry, between quantitative and qualitive anaysis, and between forward modeling and inversion; and many feedbacks of the mentioned-above study".

Under the guidance of "Blocking Tectonics", taking tectonic evolution in China and adjacent regions as an example, and referring to their results of block division, and using the latest gravity data result, the Chinese land-seas and adjacent regions were subdivided structurally into 3 tectonic domains or more than 30 blocks by many active tectonic units – junction or suture zones, and these blocks was classified.

The first-order tectonic units are plates which are Eurasian Plate, Indo-Australian Plate and Philippine Sea Plate in the study regions. In the regions of Eurasian Plate, uniform China continental block formed after the closing of Paleo-Asian Ocean across Lake Zaysan - Arguna - Irtysh suture during Hercynian period, and the following closing of Tethys during Indosinian period. The present plate tectonic famework formed after Indosinian period. The junction zone of Helan Mountain - Longmen Mountain - Red River, is an important tectonic border. In the west of the border, the blocks are compressed affected by the collision of Indian continent to Tibetian continent, and the junctions between the blocks are characterized by little blocks involved in the junction. In the east of the border, the blocks are stretched and activated affected by the subduction of the Pacific plate. The Cenozoic Sea Basins near the Eastern China, such as Banda Sea, Sulawesi Sea, Sulu Sea, South China Sea and Japan Sea, formed younger and younger form south to north.

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Accretionary Orogen and Evolution of the Japanese Islands - Implications from a Sr-Nd isotopic study of the Phanerozoic Granitoids from SW Japan

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The Japanese Islands represent a segment of a 450 Ma old subduction-related orogen developed along the western Pacific convergent margin, and most tectonic units are composed of late Paleozoic to Cenozoic accretionary complexes and their high P/T metamorphic equivalents (e.g., Isozaki et al., 2010). The formation of the Japanese Islands has been taken as the standard model for an accretionary orogeny. According to Maruyama (1997), the most important cause of the orogeny is the subduction of an oceanic ridge, by which the continental mass increases through the transfer of granitic melt from the subducting oceanic crust to the orogenic belt. Sengor and Natal'in (1996) named the orogenic complex the "Nipponides", consisting predominantly of Permian to Recent subduction-accretion complexes with very few fragments of older continental crust. These authors pointed out the resemblance in orogenic style between Japan and the Central Asian Orogenic Belt (CAOB). The present work uses new and literature Sr-Nd isotopic data to test the statements made by these authors. A large proportion of the granitoids from SW Japan have high initial $^{87}Sr/^{86}Sr$ ratios, negative εNd(T) values and Proterozoic Sm-Nd model ages. The Japanese isotopic data are in strong contrast with those of two celebrated accretionary orogens, the Central Asian Orogenic Belt and Arabian-Nubian Shield, but are quite comparable with those observed in SE China and Taiwan, or in classical collisional orogens in the European Hercynides and Caledonides. This raises questions about the bulk composition of the continental crust in SW Japan, or the type of material accreted in accretionary complexes, and negates the hypothesis that the Nipponides contains very few fragments of older continental crust. The subduction-accretion complexes in Japan are composed mainly of recycled continental crust, probably of Proterozoic age. This study, however, supports the idea that the proto-Japan was initially developed along the southeastern margin of the South China Block.

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Timing of Mylonitization in the Nihonkoku Mylonite Zone of North Central Japan: Implications for Cretaceous Sinistral Ductile Deformation throughout the Japanese Islands

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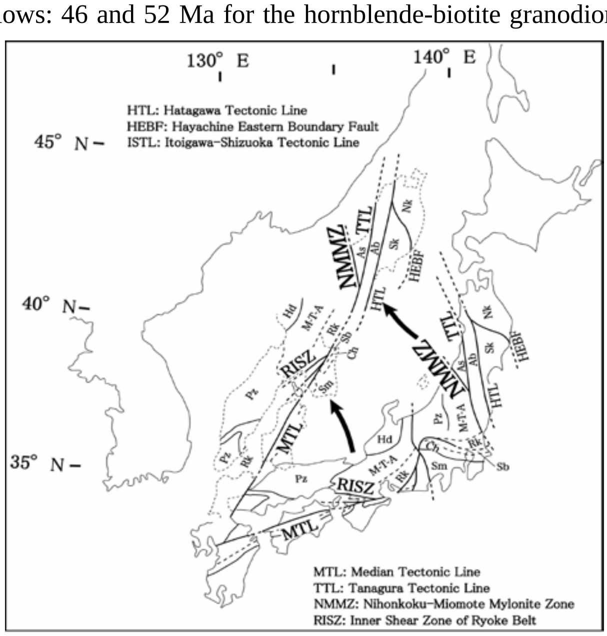
The Japanese Islands are regarded to have been located on the eastern margin of the Asian Continent, before opening of the Sea of Japan. Therefore, geotectonic study of the Japanese Islands is important to understand the tectonics of East Asia. In the Japanese Islands, Cretaceous sinistral ductile shear zones appear along and around the Median Tectonic Line (MTL), the Tanagura Tectonic Line (TTL), the Hatakawa Tectonic Line (HTL) and so on.

The Nihonkoku Mylonite Zone (Takahashi, 1998) is one of the Cretaceous sinistral ductile shear zones in the Japanese Islands. The Nihonkoku Mylonites are composed mainly of hornblende-biotite granodiorite mylonite, biotite granodiorite mylonite, and biotite granite mylonite, derived from Cretaceous granitic rocks in the Ashio Belt. SHRIMP U-Pb analyses of zircon from the Nihonkoku Mylonites yield ages of 67 Ma for the hornblende-biotite granodiorite mylonite, 64 and 63 Ma for the biotite granodiorite mylonite, and 67 Ma for the biotite granite mylonite. K-Ar ages obtained for biotite are as follows: 46 and 52 Ma for the hornblende-biotite granodiorite mylonite; 49 and 47 Ma for the biotite granodiorite mylonite; and 51 Ma for the biotite granite mylonite. The SHRIMP U-Pb ages of zircon indicate the age of intrusion of the granitic magma, whereas the K-Ar ages indicate the cooling of granitic magma. Mylonitization occurred under conditions of the upper greenschist to amphibolite facies. Based on these results, the magmas of the parent rocks of the Nihonkoku Mylonites were intruded at around 65 Ma, and mylonitization occurred at around 55–60 Ma.



The TTL is recognized as a major pre-Tertiary tectonic line within the Japanese Islands. However, its northern extension has not yet identified, mainly because pre-Tertiary basement rocks are covered by Tertiary and Quaternary systems, although the TTL is exposed at the southwestern margin of the Abukuma Mountains. The Nihonkoku–Miomote Mylonite Zone (Takahashi, 1999), is regarded as a possible northern extension of the TTL. The timing of mylonitization along the TTL is regarded to pre-date 107 Ma, followed by phyllitization prior to 60–70 Ma and subsequent low-temperature sinistral deformation that produced fault breccia and gouge after 60–70 Ma (Koshiya, 1986). This period of low-temperature deformation coincides with the timing of mylonitization within the Nihonkoku Mylonite Zone. Two stages of sinistral deformation are recognized along the MTL: high-temperature deformation that produced a foliation within the older Ryoke granite at ~90 Ma, and subsequent low-temperature deformation that produced the Kashio Mylonites at around 65–70 Ma (Takagi, 1997). The final phase of ductile flow within the MTL is thought to have occurred at 62–63 Ma, based on Ar-Ar whole-rock plateau ages obtained for protomylonite along the MTL (Dallmeyer and Takasu, 1991). Therefore, we correlate the main mylonitization within the Nihonkoku

Mylonite Zone with (1) low-temperature deformation that occurred following the main mylonitization along the TTL, and (2) the final phase of ductile flow along the MTL.

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SHRIMP U-Pb Zircon Ages of the Hida Metamorphic Rocks, Japanese Island, and their Tectonic Implications

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The Hida belt is a pre-Cretaceous continental terrane among the Japanese island arc system consisting of predominated oceanic terranes. Understanding tectonic evolution history of the Hida belt is thus critical to correlate it with major East Asian cratons and to reconstruct configuration of the Permo-Triassic continental collisions in the easternmost side of the Eurasian continental margin before build-up of the Japanese island arc system.

We report here SHRIMP U-Pb zircon ages obtained from two metamorphic sedimentary rocks from the northeastern part of the Hida belt. Samples include garnet-biotite schist (TY0504) and garnet-biotite gneiss (TY142), both of which belong to the Hida metamorphic rocks, originally formed in a continental shelf or rift environments.

Most of zircon grains in the samples have newly recrystallized rims, yielding the Permo-Triassic metamorphic ages of 236 Ma (TY142) and 251 Ma (TY302). Inherited cores of zircons from garnet-biotite schist and gneiss samples show oscillatory zoning patterns and have higher Th/U ratio, suggesting magmatic origin. Total 71 age spots of inherited zircon cores of the garnet-biotite schist are grouped as 272 Ma (n=3), 301 Ma (n=37), 329 Ma (n=6), 422 Ma (n=4), 1840 Ma (n=10) with older ages dated up to 2639 Ma (n=3). Total 74 age spots of inherited zircon cores of the biotite-garnet gneiss are grouped as 276 Ma (n=2), 332 Ma (n=7), 1026 Ma (n=2), 1859 Ma (n=52) with sporadically older ages dated up to 2654 Ma (n=3).

The age spectra obtained here from two of the Hida metamorphic rocks are well corroborated with previously reported tectonotermal events in the Hida belt. However, the first finding of the late Carboniferous inherited zircons suggests additional tectonothermal event, not recongnized yet in the Hida belt. The depositional ages of the Hida schist and gneiss are constrained by the most probable youngest age group obtained from inherited zircon cores and are considered to occur between early Permian and late Permian, which is younger than previous consideration. The age spectra obtained from two of Hida metamorphic rocks are well comparable with the Carboniferous-Permian Pyeongan Supergroup in the eastern Ogcheon belt of Korea. The prominent age peak of ca 1.8-1.9 Ga and absence of Neoproterozoic ages from the Hida metamorphic rocks suggest its crustal correlation with the North China Block rather than South China block. Taking into account the paleogeographic reconstruction before the Miocene opening of East Sea (Japan Sea), it may be argued that the Hida belt possibly formed at the margin of the North China Block (Sino-Korean craton), and later evolved as a Permo-Triassic mobile belt as suggested by Arakawa et al. (2000).

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Pre-Jurassic Tectonics of the Volcanic Rocks in Thailand and Nearby Region: Evidence from Geological, Petrochemical and Geochronological Analyses

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Based upon our results on volcanic stratigraphy, regional geology, petrochemistry, and geochronology, volcanic rocks of pre- Jurassic ages in Thailand can be subdivided into 5 belts. They are totally about 900 km in length and 500 km in width. The volcanic belts are mainly located in northern portion of the country and trend roughly in the north-south direction. They are from the west to the east as Chiang Mai, Lampang, Nan, Phetchabun, and Sra Kaeo Belts. Several kinds of polymetallic mineral deposits have been recognized in individual belts. Our regional survey reveals that the Chiang Mai Belt belongs to the western part of the Lampang-Chiang Rai tectonic block and commences from Chiang Mai City and extends northward to Chiang Rai and ends at the Thai-Myanmar border. Volcanic rocks are mainly pillow basalts to amphibolite and metavolcanic mafic rocks of Late Paleozoic age and are always associated with gabbroic to ultramafic rocks. Geochemical data reveals that the Chiang Mai Belt belongs to within – plate and seamount – type affinity and represents subduction-related accretionary blocks formed not too far from the Shan-Thai block. To the east of this belt is the Lampang Belt of Permo-Triassic age which largely exposed in Tak, Lampang, Phrae, Nan, and Chiang Khong areas in the north and Nakhon Sawan to Chantaburi areas in the south. The belt extends northwards to easternmost Myanmar and southern Yunan. This belt can be correlated with volcanic belts of Yunan located between Channing-Menglian and Lanchangjiang zone. They are mainly calc-alkaline andesite with minority of basalt and rhyolite and display geochemical characteristics of subduction-related arc –type magmatism. This belt belongs to Sukho Thai zone of the eastern Lampang-Chiang Rai block. The Nan Belt which trends in the northeast – southwest direction is composed of basalts, mafic and ultramafic breccias which have been metamorphosed to low – grade green schist. The volcanic rocks are associated with metagraywacke and metachert. The belt extends to the Luang Prabang and Dien Bien Phu areas in Laos. The belt is regarded as an accretionary complex (or mélange) of off-scrapped Paleotethys oceanic crust with east-dipping subduction beneath the Nakhon Thai terrane. The Phetchabun Belt commenced from Loei through Phetchabun in the north and extends to Prachinburi and Srakaeo Chantaburi and Ko Chang in the south. The rocks are mainly Permo-Triassic andesite with minority of basalt and rhyolite. Results from geochemistry show that the rocks belong to calc-alkaline series and occur as a result of east-dipping subduction beneath the Indochina block. The Sra Kaeo Belt is composed largely of pillow basalt with serpentinite and ultramafic rocks and chert-clastic unit. This belt can be correlated with the Nan Belt and is interpreted as an accretionary complex which has been formed as remnants of oceanic islands and seamounts and remnants of ocean floor basalt.

Keywords: Volcanic, Thailand, pre-Jurassic, tectonic, subduction, oceanic crust

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Structural Development of the Sanjiang Basin, Ne China and its Tectonic Implication for the Mesozoic-Cenozoic Evolution of the West Pacific Continental Margin*

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The Sanjiang basin is a Mesozoic-Cenozoic superimposed basin in the eastern Heilongjiang Province, NE China, and constitutes an integrated basin with the Middle Amur basin in the Far East of Russia. It almost overlies the Bureya Precambrian terrain with Paleozoic and Mesozoic folding and its multi-stage records of sedimentation and deformation may play a significant role in unraveling the complex tectonic evolution of the West Pacific continental margin. Despite the many studies conducted in the past ten years, the origin and evolution of the Sanjiang basin still remains controversial. Various attitudes about the basin origin have been proposed, such as rift basin, foreland basin, rift-sag basin, rift-sag-rift basin, etc. The complex evolutionary history, widespread Cenozoic deposits, and limited exploration are three main limiting factors in the testing of these hypotheses, which in turn restricts understanding of the tectonic evolution and further resources survey in this region. Based on the 2D seismic reflection profiles and drilling-hole data, this study analyzes the stratigraphic sequences and deformation behavior, and structural development of the Sanjiang basin. Four main basin-prototypes have been identified as Middle-Late Jurassic sag with shallow marine facies, Early Cretaceous rift and sag with terrestrial facies, Late Cretaceous foreland basin with molasse fillings and Cenozoic rift and sag with terrestrial facies. An alternative structural development model is established and corresponding tectonic setting is also discussed as following: (1) The basin was initiated as a shallow passive margin depression of the southern Mongol-Okhotsk Ocean since the Middle Jurassic and terminated between the end Jurassic and the beginning of Early Cretaceous due to the orogeny of the Mongol-Okhotsk suture. (2) The basin appears to have experienced periods of volcanism, rifting and widespread sag during the Early Cretaceous resulted from large scale upwelling of the asthenosphere and intensive lithospheric thinning, which was probably associated with the fast and oblique subduction of the paleo-Pacific plate along the West Pacific continental margin. (3) An Andes-type active continent margin occurred during the Late Cretaceous, since the subduction direction of the paleo-Pacific plate changed from NWN to EW. The Sanjiang basin and other Mesozoic basins underwent intense compression, uplift and a series of thrust and fold belt formed. With the further development of the orogeny along the eastern continental margin, a short-lived and local extended foreland basin also formed in the eastern Sanjiang basin. However, this foreland basin suffered compression and damage again along with other former Mesozoic sedimentary basins until the Eocene rift took place. (4) Several NE- and NEN-trending half grabens were developed in the eastern Sanjiang basin, and the extension ceased with mild contraction and then the basin thermally subsided and deposited with thin sediment layer during the Miocene and Quaternary. The Cenozoic evolution of the Sanjiang basin was attributed to far-field effect of extension caused by the slab rollback of the Pacific plate and the backarc rifting along the West Pacific continental margin.

Keywords: Structural development; Sanjiang basin; Mesozoic-Cenozoic; West Pacific continental margin

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When Did Plate Tectonics Begin on the North China Craton? - A Metamorphic Perspective

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Understanding when and why plate tectonics began on Earth is one of the most important unresolved problems in earth sciences. As a final result of plate tectonics, continental collisional orogens are regarded as a milestone in recognizing the operation of plate tectonics in Earth's history. Metamorphism of collisional belts is generally characterized by clockwise P-T paths involving isothermal decompression following the peak metamorphism. Therefore, clockwise P-T paths involving isothermal decompression are considered as a hallmark of plate tectonics, especially in the early history of the earth. As one of the oldest continental blocks in the world, the North China Craton is considered as a promising area for applying the large-scale synthesis approach of metamorphic P–T paths to understand tectonic settings or processes. Tectonically, the North China Craton composes three small continental blocks (Eastern Block, Yinshan Block and Ordos Block) and three Paleoproterozoic tectonic belts (Trans-North China Orogen, Khondalite Belt and Jiao-Liao-Ji Belt). Metamorphism of late Archean basement rocks in the Eastern and Yinshan Blocks is characterized by anticlockwise P-T paths, mostly involving isobaric cooling, reflecting the underplating or intrusion of large volumes of mantle-derived magmas, possibly related to the uprising of mantle plumes. Metamorphism of the basement rocks in the Khondalite Belt and the Trans-North China Orogen is both characterized by clockwise P-T paths involving isothermal decompression, suggesting that the two orogens underwent initial crustal thickening followed by rapid exhumation/uplift tectonic processes. Such tectonic processes are typical indicators of collisional orogens that accommodate plate tectonics. The Paleoproterozoic Jiao-Liao-Ji Belt can be divided into the southern and northern zones, of which the former is characterized by anticlockwise P-T paths, whereas the latter is characterized by clockwise P-T paths, constituting paired metamorphic belts, which also indicate a regime of plate tectonics. The time of the initiation of plate tectonics in the North China Craton can be approximated by the age of the earliest juvenile crustal components in the three Paleoproterozoic tectonic belts. So far, the convincing oldest, subduction-related, juvenile crustal component in the North China Craton is the 2.56 Ga Wutai granitoids in the Trans-North China Orogen, which can be used to approximate the timing of the onset of plate tectonics in the North China Craton.

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Geochronologic, Geochemical and Sr-Nd Isotopic Constraints on the Genesis of the Lailisigao'er and Kekesai Intrusions, Xingjiang, NW China: Implication for the Tectonic Evolution of Western Tianshan from Subduction to Collision

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This paper presents and discusses new zircon U-Pb chronology, major, trace element and Sr-Nd isotope data for the Lailisigao'er and Kekesai intrusions in the western Chinese Tianshan. The intrusive rocks in the Lailisigao'er area are composed of granodiorite porphyry and monzogranite porphyry of high-K calc-alkaline series, with a zircon SHRIMP U-Pb age of 373.5±3.6 Ma. The Kekesai intrusion consists mainly of high-K calc-alkaline granodiorite porphyry, with a zircon LA-MC-ICP-MS U-Pb age of 299.9±0.61 Ma. Two intrusions are characterized by their high ASI (1.0–1.52), high K/Na ratios (K_2O/Na_2O: 0.85–2.2) and low MgO contents (MgO: 0.47%–1.26%). They are enriched in LREE (Lailisigao'er: $(La/Yb)_N$=5.25–10.57; Kekesai: $(La/Yb)_N$=14.56–23.69) with similar LREE patterns but different HREE patterns. The Kekesai intrusion shows stronger fractionated HREE patterns ($(Gd/Lu)_N$=1.16–3.21) than the Lailisigao'er intrusion ($(Gd/Lu)_N$=0.82–1.47). Moreover, the Lailisigao'er intrusion displays mildly negative Eu anomalies (Eu/Eu*: 0.55–0.92), while the Kekesai intrusion shows weak negative-, or positive-Eu anomalies (Eu/Eu*: 0.85–1.21). Both intrusions are enriched in LILE, such as Rb, Th, U, K and LREE, but depleted in HFSE (e.g. Nb, Ta, P, Ti and HREE). The Lailisigao'er intrusion possesses strong depletion of Nb, Ta than the Kekesai intrusion in trace element spidergrams. Most of the Lailisigao'er rocks belong to low-Sr and high-Yb type with low Sr contents (122–356 ppm) and high Yb contents (1.84–2.57 ppm). The Kekesai rocks show low Yb contents (Yb: 0.6–0.87 ppm) and weak enrichment to depletion in Sr (Sr: 146–577 ppm), and can be divided into two types, i.e. high-Sr and low-Yb type (Adakite) and low-Sr and -Yb type (Himalaya-type). The initial Sr-Nd isotopic compositions for the Lailisigao'er rocks are I_{Nd}=0.512284–0.512359 and I_{Sr}=0.707847–0.709644, respectively, with $\varepsilon_{Nd}(t)$ values of -2.79–-1.46. And its Nd model ages vary from 1.20 to 1.28 Ga. Compared with the Lailisigao'er intrusion, the Kekesai rocks show lower I_{Sr} (0.705091–0.705578) and younger Nd-model age (0.73–0.78 Ga), but higher I_{Nd} (0.512589–0.512654) and $\varepsilon_{Nd}(t)$ values (2.80–3.55),. Element and isotope data demonstrate that the Lailisigao'er intrusion likely derived from the partial melting of the Meso-Proterozoic crust due to the subduction of the Balkhash-Junggar remnant ocean basin toward south beneath the Yili-Central Tianshan block in the Late Devonian, whilst the Kekesai intrusion was associated with intercollision process between Yili-Central Tianshan and Junggar blocks, and the magma was possibly produced by the melting of thickened lower crust. In conclusion, the western Tianshan was in epicontinental arc setting in the Late Devonian (~373 Ma) and in continent-continent collision setting at the end of Late Carboniferous (~300 Ma). This indicates the tectonic evolution process of Western Tianshan from subduction to collision.

Keywords: Lailisigao'er intrusion; Kekesai intrusion; Geochemistry; Zircon U-Pb dating; Western Tianshan

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Mid-Paleozoic opposite Orogenic Belt in Inner Mongolia of China and its Significance for Central Asian Orogenic Belt

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In the eastern segment of the Central Asian Orogenic Belt (CAOB) between the Tuva-Mongolian microcontinent (TMM) in the north and the North China craton (NCC) in the south, the most important debate has been that when, where and how did the Paleoasian Ocean close. Several models have been suggested including the early-middle Paleozoic opposite subduction and collision (Xu et al., 1993), the Permian accretion leading to collision (Xiao et al., 2003) or the Permian subduction, collision and slab break-off of an intraoceanic arc-trench system (Jian et al., 2010) along so-called “Solonker suture”.

We repeat our model and present some new data in this abstract. Three main tectonic units (south margin of the TMM, early Paleozoic ocean crust and north continental margin of the NCC) and two middle Paleozoic southward and northward subductional orogenic belts, respectively, have been recognized in Inner Mongolia of China. The southward orogenic belt (SOB) consists of forearc mélange, arc, and back-arc foreland basin from north to south and results from a southward subduction of the early Paleozoic ocean crust under the NCC. Its forearc mélange is characterized by ultramafic and basaltic blocks and politic rocks with southward-dipping foliations, extending from Guerbanwulan in the west, to Solonker, Gangnaobao, and Tulinkai in the east. The arc diorites and volcanic rocks can be traced along the south of the mélange, with the ages between 455-425Ma (in the west segment, this study), 452-417Ma (in the middle segment, Bater area, Jian et al., 2008) and 472-425Ma (in the east segment, Tulinkai area,Jian et al., 2008). The foreland basin consists of the folded upper Silurian flysch with southward-dipping axial-plane cleavages and the lower Devonian red molasses.

The northward orogenic belt (NOB) includes arc, forearc mélange, peripheral foreland basin and foreland fold belt from north to south, caused by a northward pre-later Devnian subduction of the early Paleozoic ocean crust under the TMM. The arc rocks outcrop in Sonidzuoqi area, with the age of 498-421Ma (Jian, et al., 2008). The forearc mélange extends from Xilinhaote, Honggeer, Wuletu to Ailigemiao from east to west, containing ultramafic rock, blueschist with Ar/Ar age of 386Ma, quarzite and dolomite blocks. The peripheral foreland basin is characterized by the upper Devonian red molassses and there is an unconformity between the molasses and mélange. The foreland fold belt consists of the Ondor Sum group with the age of 460Ma (this study). The northward-dipping foliations occur in both the mélange and fold belt.

The recognition of the NOB and SOB and their multidisciplinary evidences in stratigraphy, deformation, chronology and sedimentation suggest that the CAOB had been closed before the later Devonian by an earlier southward and later northward subductions, respectively, along a wider area in the Inner Mongolia, north China.

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Origin of the Late-Triassic Granitoids from the Dongjiangkou Area, Qinling Orogen, Central China: Implication for Continent Subduction in the Qinling Orogen

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Research of high-Mg adakitic granitoids in collisional orogen can provide important information about the nature of orogenic lower crust and upper mantle during active orogenic process. This paper presented new data of petrology, geochemistry, zircon U-Pb age, Sr-Nd-Pb and zircon Lu-Hf isotopic composition for a suit of Late-Triassic granitoids and mafic enclaves from the Dongjiangkou area in the Qinling orogenic belt, central China, and proposed these high Mg# adakitic granitoids may be derived from subducted continental crust and undergone subsequent interaction with overriding mantle wedge. The host granitoids have zircon LA-ICP MS U-Pb ages of 214 ± 2 Ma to 222 ± 2 Ma, synchronous with the exhumation age of the Triassic UHP metamorphic rocks in the Dabie orogenic belt. They display some adakitic affinity, e.g., high Sr, Ba contents, high La/Yb and Sr/Y ratios, low Y and Yb contents, no significant Eu anomalies, low Yb/Lu and Dy/Yb ratios, suggesting amphibole + garnet and plagioclase-absent residue in their source region. Their evolved Sr-Nd-Pb isotopic compositions [$(^{87}Sr/^{86}Sr)_i$ = 0.7050 to 0.7055, and $\varepsilon_{Nd}(t)$ = –6.6 to –3.3; $(^{206}Pb/^{204}Pb)_i$ = 17.599 to 17.799, $(^{207}Pb/^{204}Pb)_i$ = 15.507 to 15.526, $(^{208}Pb/^{204}Pb)_i$ = 37.775 to 37.795] and high K_2O and Rb contents, as well as large variation in zircon Hf isotopic composition($\varepsilon_{Hf}(t)$ = -9.8 to +5.0), suggesting they were derived from reworking of ancient lower continental crust. In the Harker diagrams, Mg#, CaO, P_2O_5, K_2O/Na_2O, Cr, Ni, Nb/Ta, Rb/Sr and Y display outward increasing trend, while the Sr/Y and Eu/Eu* display decreasing trend with increasing MgO contents from the Meizhuang tonalite to the Yingpan granodiorite, these evolutionary trends indicate the interaction of primitive adakitic melts with the overlaying mantle peridotite. Mafic microgranular enclaves and mafic dykes from the Dongjiangkou area display identical zircon U-Pb ages of 220Ma, they are characterized by lower SiO_2, high TiO_2, Mg# and similar evolved Sr-Nd-Pb isotopic composition. Zircons from the mafic microgranular enclaves (MME) and mafic dykes show large variation in Hf isotopic composition with $\varepsilon_{Hf}(t)$ values of -11.3 to +11.3. It can be inferred that they may be formed by partial melting of enriched mantle and assimilated some host adakitic granitoids during their ascent.

In combination with regional geology, we therefore propose that the high-Mg# adakitic granitoids in the Dongjiangkou area may be resulted from interaction between subducted Yangtze continental crust and overriding mantle wedge: Triassic continental collision caused the Yangtze continental lithosphere subducted beneath the North China block, slab break-off at ca. 220Ma caused asthenosphere upwelling and exhumation of continental crust, the Triassic clock-wise rotation of the Yangtze block cause extension setting in the Dabie area and led to the rapid exhumation of subducted continental lithosphere, while compressive setting in the Qinling area and partial melting of subducted continental crust at high pressure (amphibole ± garnet stable field) would produce adakitic granitic magma, magma bodies extensively react with ambient peridotite to form the Mg-rich hybrid magmas.

Keywords: Qinling orogenic belt; Late-Triassic; adakitic granitoids; zircon Lu-Hf isotope; continental subduction

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Newly Discovered Triassic Eclogites from Central Qiangtang, Northern Tibet: U-Pb Zircon Age Determination, Petrologic-Geochemical Characterization and Implication for the Closure of the Paleo-Tethys Ocean

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High-pressure and low-temperature (HP/LT) metamorphic rocks (eclogite and blueschist) are generally regarded as an indicator of subduction-zone metamorphism. A ~500 km-long HP/LT metamorphic belt, including eclogite and blueschist, were recently documented in the middle of the Qiangtang Block, northern Tibet. Here we report our results of petrological, mineralogical, geochemical and geochronological investigations of these rocks. The Qiangtang eclogite occurs as blocks and lenses in Grt-Phn schist and marble, and is composed of garnet, omphacite, phengite and rutile. Eclogitic garnet contains numerous inclusions, such as glaucophane and phengite in the core, and omphacite in the mantle or inner rim. In strongly retrograded eclogite, the omphacite is replaced by glaucophane, barroisite and albite. Four stages of metamorphic evolution can be determined: (1) blueschist facies; (2) peak eclogite facies; (3) decompression blueschist facies and (4) retrograded greenschist facies. Grt-Omp-Phn geothermobarometer yielded a peak eclogite facies metamorphic condition of T ~450°C and P ~2.2 GPa. Whole-rock geochemistry for eclogite and blueschist show that these rocks have the similar characteristics to those of E-MORB and OIB. Positive $\varepsilon_{Nd}(T)$ values for all samples suggest that their protoliths were originated from depleted mantle source. These data indicate that protoliths of the Qiangtang eclogite and blueschist could be derived from enriched middle oceanic ridge and oceanic island. Zircon U-Pb dating gave ages of 230 ± 3 Ma and 237 ± 4 Ma for two eclogite samples. The ages are interpreted as the time of eclogite facies metamorphism. Moreover, 40Ar/39Ar dating of phengite from the eclogite and Grt-Phn schist yielded ~220 Ma, which are probably indicative of the time of exhumation to the middle crust.

In conclusion, we suggest that a Paleozoic ocean should present in the central Qiangtang area, and this ocean may be the western extension of Changning-Menglian Paleo-Tethys Ocean in the eastern margin of Tibetan plateau. The HP/LT metamorphic rocks were formed by northward subduction of this Paleo-Tethys Ocean and they marked a Triassic suture zone between Gondwana-derived block and Laurasia.

Keywords: Tibet; Qiangtang; eclogite; P-T path; geochemistry; zircon U-Pb and 40Ar/39Ar dating; oceanic subduction

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The Early Mesozoic Thrust and Fold Sheet Structure along the Southern Margin of Yangtze Block and its Geodynamic Significance

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The Early Mesozoic tectonic and geodynamic evolutions of the South China block (SCB) are still debated questions. Along the southern margin of the SCB, the Yunkai and Song Chay massifs are key regions to address these questions. In both of these massifs, an Early Mesozoic ductile deformation with thrust and folds structures have been observed. In the Yunkai massif, a flat-lying to moderately dipping foliation with a clear NE-SW stretching and mineral lineation is indicated by amphibolite and greenschist facies metamorphic minerals. Along this lineation, top-to-the-NE ductile shearing is indicated by sigma type K-feldspar porphyroclast systems, sigmoidal quartz veins, and it has been considered as the main ductile deformation in this area (Lin et al., 2008). In the north of the Yunkai massif, foliated granite and gneiss overthrust strongly sheared and folded Late Paleozoic strata by Carboniferous. Geochronological works indicate the time of deformation around 220 Ma (Wang et al., 2007). In North Vietnam, the Song Chay massif presents quite similar lithological and structural features with the Yunkai massif. It is formed by augen orthogneiss, the protolith of which is an Early Paleozoic porphyritic granite that intruded a Cambrian pelite and limestone series. Alike for the Yunkai massif, in the Song Chay massif, the flat lying foliation, a NE-SW mineral and stretching lineation, and top-to-the-NE ductile deformation are the main structures. . These features are interpreted in terms of nappe stacking (Deprat,1917; Lepvrier et al.,2009). To the north of the Song Chay massif, the weakly metamorphosed but strongly deformed Paleozoic sedimentary series overthrusts Lower to Middle Triassic turbidite. The age of the deformation ranges from Late Triassic to Early Jurassic (Roger et al. 2000; Maluski et al., 2001).

The geodynamic significance of this Early Mesozoic deformation in the Yunkai and Song Chay massifs are not settled yet. A link with the tectonics of Indochina appears likely. The closure age of the oceanic domain, which separated Indochina from South China and the subsequent collision of the two blocks, remains controversial (Carter and Clift, 2008 and reference therein). Detailed structural investigations and geochronological dating, along the Song Ma zone, show that the major collisional event occurred during the Late Permian-Early Triassic (Lepvrier et al., 2008). However, as the Song Ma suture is located south of the Red River fault, it cannot be considered as the Triassic boundary between the South China Block and Indochina Block due to several hundred of kilometers of Cenozoic displacement along the Red River fault. Furthermore, the newly discovered Song Chay ophiolitic suture might account for the Triassic plate boundary in the southern margin of SCB in North of Vietnam (cf Faure et al., this meeting). The Yunkai and Song Chay massifs, that both belong to the southern margin of SCB, are involved in this Indosinian orogenic belt that probably extends in NW China along the Jinshajiang.

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Mesozoic Intracontinental Tectonic Evolution of the Xuefengshan Belt, South China

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The structural style, tectonic evolution, and geodynamic significance of the Xuefengshan Belt, which is located in the center of the South China Block in Hunan Province, are still on debate. Recent studies have proposed that this intracontinental belt was formed by large-scale over-thrust developed in the Late Mesozoic (Yan et al., 2003) or by Triassic transpressional tectonics (Wang et al., 2005). An Early Mesozoic flat slab subduction to the NW is also suggested (Li and Li, 2007).

Detailed field observation indicate that the Xuefengshan Belt can be divided into 3 tectonic zones:

(1) The Outer Box-Fold Zone of the Wulingshan Mountain is characterized by a conspicuous box-fold structure with gravity collapse folds, and normal faults developed in the both limbs when strata are turn to the vertical.

(2) The Central Xuefengshan Zone is separated from the Outer Zone by a Main Thrust that also corresponds to the cleavage front. Folds coeval with a pervasive slaty cleavage dominate the structure of this zone. A NW-SE trending mineral and stretching lineation commonly develops on the cleavage surfaces. From west to east, the dip of the cleavage surface exhibits a fan-like pattern. To the West, the SE-dipping slaty cleavage is associated with NW-verging folds, whereas to the East, the syn-schistose folds are verging to the SE. The deepest rocks are exposed around Triassic plutons. These rocks exhibit ductile structures coeval with a greenschist facies metamorphism.

(3) The Eastern Zone consists of post-Middle Devonian to Early Triassic sedimentary series deformed mainly by NW-directed folds and thrusts. However, SE-verging folds and collapse folds are also observed.

The bulk architecture of the whole belt results of a polyphase deformation. Our structural analysis allows us to separate three events: the first one (D1), characterized by a top to the NW ductile shearing, represents the main structure of the Xuefengshan Belt. The second one (D2) corresponds to the back-folding and back-thrusting stage with NW-dipping cleavages or foliations. The last phase (D3) is a NW-SE or W-E shortening event associated with upright folds with vertical axial plane cleavages.

The Xuesfengshan Belt is interpreted as an Early Mesozoic intracontinental orogen, which is originated by continental subduction, directed towards the SE.

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SS06-O-8

Development and Genetic Mechanism of the "Kongtongshan Conglomerate"

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Kongtongshan conglomerate（TK）is a suit of the coarse clastic progradational alluvial fan glutenite，which is situated at the corner of the Qinling-Qilian arc Orogenic Belt, and structural confluence area of EW belt and SN belt in China. Because of the special structural position, TK must be clarified in order to understand the Mesozoic strata, sediment, and structure (e.g., Liu Huaqing et al. 2006).For about half a century, many geological scientific institution and the personal researchers have obtained much results on TK from some sides, such as regional distribution (e.g.,Bureau of Geology and Mineral Resources of Gansu.,1989,1997), sedimentary characteristics(e.g., Ke Baojia et al. 1991;Chen Anning et al.2002;Han Yonglin et al.2005;He Zixin et al. 2005；Fu Jinghua et al.2005), formation age(e.g., Liu Shao-long,1986;Chen Gang et al.2007), provenance (e.g., Liu Huaqing et al.2006;Zhao Wenzhi et al.2006), dynamic environment(e.g., Chen Gang, 1999;Liu Hepu et al.2000；Liu Chiyang et al.2005;Tang Hua et al.2006;Zhao Hongge et al.2007). So some research results will make contribution to the further understanding of TK. However, different researchers have different opinions about formation age and dynamic environment of TK, especially in the dynamic environment. It can be divided into three main opinion on forming environment of Tk: (1)the foreland basin environment controlled by paleo-uplift of western margin of the Ordos Basin (e.g., Chen Gang, 1999; Wang Hongjiang,2001); (2) the foreland basin environment controlled by the Qinling-Qilian Orogenic Belt of southern margin of the Ordos Basin (e.g., Liu Hepu,2001;Liu Chiyang,2005; Zhao Hongge et al. 2007); (3)the piedmont-facies sedimentary environment controlled by Tethys Ocean in the Qinling-Qilian Orogenic Belt (Tang Hua et al. 2006; Bai Yunlai et al.2006;Liu Huaqing,2006).

To make sure the dynamic environment of Kongtongshan Conglomerate is the key to recognize prototype basin , tectonic attribute, tectonic evolution and breakage of northwestern china Craton. By means of sedimentary, structure, fission trace, the regional background, the dynamic mechanism of Kongtongshan conglomerate can be comprehensively analyzed on southwestern margin of the Ordos Basin. The Kongtongshan conglomerate developed under dextral strike slip environment in late Triassic, which resulted from gradually closing of the Paleo-Tethys Ocean from east to west. Under the regional dynamic environment of strike slip, the ancient Qingtongxia-guyuan fracture reactivated, which controled the formation of Kongtongshan Conglomerate. It can be divided into three stages, which are respectively corresponding with the rapid increase of temperature, slow-lowering of temperature and rapid lowering of temperature from thermal history of fission track. The early stage was transtensional fault-sedimentary from 231Ma to 218Ma,the late stage was transpressional depression-sedimentary from 218Ma to 205Ma ,and the last stage was denudation from 205 Ma to 195 Ma. Buried warming time of TK, regional dynamic background and dynamic evolution mechanism of TK show Kongtongshan Conglomerate developed in late Triassic(Fig.1).

Keywords: Kongtongshan conglomerate; Formation Age; Dynamic mechanism; Late Triassic

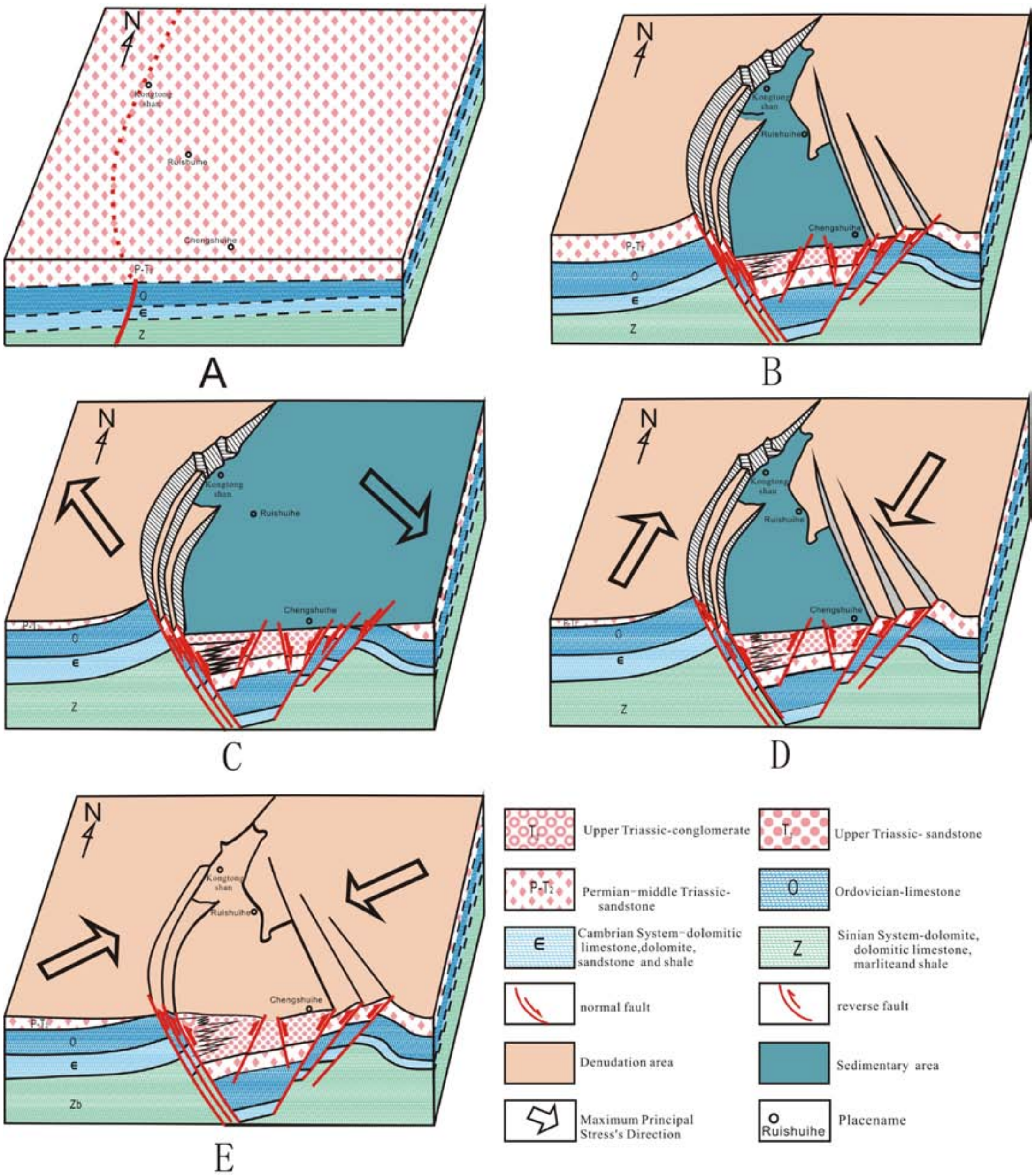

Fig.1 Dynamic enviroment on evolution of kongtongshan conglomerate in Late Triassic

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SS06-O-9

Mesozoic Magmatism Dynamics in South China-Revelation from the Correlation with Adjacent Areas

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The present paper has been discussed mainly the spatial-temporal distributional characteristics of the Permian, Triassic, Jurassic and Crataceous granitoids in the South China, Hainan Island, Vietnam, South Korea and Japan.

There are no Permian granitoids in South China, but are widespread in Hainan Island and Vietnam, which could be classified into two stages: 299-282Ma and 278-260Ma. The granites of first stage are impressed by metaluminous I-type granites of island arc–active continental margin. The later granites are strongly peraluminous with strong deformation features, which may belong to syn-collisional magmatism on the continental collision zone between the Sibumasu and Indosinian-South China Blocks.

The early-middle Trassic granitoids are distributed in Vietnam, Hainan Island , WS of South China, South Korea and Japan, which may resulted from the collision of Sibumasu and Indosinian-South China Blocks, North China and Yangtze Block, Siberian Block movement toward South, i.e Indosinian, Akiyoshi and Songrim orogeny respectively. The late-Triassic A-type granites and syenites occur in Hainan Island (243-221Ma) and South Korea (220–219 Ma).

The Jurassic (especially middle-Jurassic: 170-155Ma in China) granites are mostly exposed in South China and South Korea, which can be considered as the amalgamation of microcontinental massifs in the South China and the North China Blocks, named the plate convergence in East Asia, i.e Early Yanshan and Daebo orogeny respectively.

The middle Jurassic granites are seldom exposed whether in Japan or in Vietnam and Hainan Island. There are about 50Ma gap (158-110Ma) in South Korea, and about 45Ma gap (170-125Ma) in Japan, which might be resulted from the shallow angle northward (oblique) subduction of the Pacific Plate associated with high convergence rate (30.0cm/y; Hee Sagong et al, 2005). The start (150Ma) of the large scale Mesozoic volcanic-intrusive activity in the southeastern China is no straight relation with subduction of the Pacific Plate, which is distinct with Japan.

The Cretaceous granites(～125Ma) with contemporary and same origin are all developed in South China, Hainan Island, Vietnam, South Korea and Japan, which are accompanied by extensive volcanic activities during the same period. The volcano-intrusive belt accompanying with rhyolites was significantly affected by subduction of the Paleo-Pacific ocean, and can be considered as one of the most important evens of the eastern Asian active continental margin during the Late Mesozoic.

Summarizing above mentioned, considering the Indosinian orogeny expressed strongly both in Vietnam and Hainan Island, authors can attribute them into the Indochina Block, and South China and South Korea into the East China Continental Block. The north and south parts of the Korean Peninsula bounded by Honam Shear Zone are correlated with the North China and Yangtze Blocks respectively. Japan and Taiwan belong to the eastern Asian island arc belt. Before opening of the Japan Sea as the back-arc basin in the Miocene (15Ma), Japan was once belonged to the part of Central Asian Orogenic Belt. The widespread development of Jurassic to Cretaceous accretionary complexes and juvenile crustal formation along Asian continental margin support such an interpretation.

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Numerical Simulation of the Dynamical Mechanisms of the 2008 Wenchuan Earthquake (Ms=8.0) in China: Implications for Earthquake Prediction

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The sudden and unexpected Wenchuan earthquake (Ms=8.0) occurred on the Longmen Shan Fault, causing a large number of casualties and huge property loss. Almost no definite precursors were reported prior to this event by Chinese scientists, who made a successful prediction of the 1975 Haicheng earthquake (M=7.3) in China. Does the unsuccessful prediction of the Wenchuan earthquake mean earthquake prediction is inherently impossible?

In order to answer this question, I simulated co-seismic deformation and stress change, and recurrence of major earthquakes associated with the listric reverse fault by means of viscoelastic finite element method. Our modeling shows that changes of co-seismic equivalent stress mainly occurs in the vicinity of the seismogenic fault, especially hanging wall of the fault in the depth range above 12 km. Modeled co-seismic slip distribution and modeled average recurrent interval corroborate with geological, geodetic and seismological observations. At the same time, the result suggests the larger slips on the gently dipping fault occur simultaneously with slips on the steeply dipping fault, and might have triggered slips on the steeply dipping fault to form great events such as the 2008 Wenchuan earthquake. Also, the model displays the slip history on the Longmen Shan thrust fault, showing that the average earthquake recurrence time on the Longmen Shan fault is very long, 3,298 years, which is in agreement with the observed by paleoseismological investigations and estimations by other methods. Moreover, the model results indicate that the future earthquake on the Longmen Shan fault could be evaluated based on numerical computation, rather than on precursors or on statistics. Numerical earthquake prediction (NEP) seems to be a promising avenue to successful prediction, which will play an important part in natural hazard mitigation. NEP is difficult but possible, which needs well funding.

Keywords: Wenchuan earthquake; dynamic mechanisms; Longmen Shan fault; finite element; numerical earthquake prediction.

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Fluids in High- to Ultrahigh- Temperature Metamorphism along Collisional Sutures: Evidence from Fluid Inclusions

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1. Introduction

Characterization of the role of fluids associated with high-grade metamorphism has received considerable importance in current petrological research, particularly in understanding the stability of mineral assemblages, fluid-rock interaction processes, and degree of partial melting. Fluid inclusions trapped in various metamorphic minerals provide potential tools in obtaining direct information on the nature, composition, and density of fluids at various stages of metamorphism. Recent works on the characterization of fluids associated with high- to ultrahigh-temperature metamorphism along collisional suture zones have provided valuable information on P-T evolution and exhumation history of hot orogens along collisional sutures (e.g., Tsunogae et al., 2008a, b; Santosh et al., 2010). However, there has been no attempt so far to integrate these results in understanding the processes and evolution of fluids in Precambrian suture zones. In this study we synthesize the information on the composition and density of fluid inclusions trapped in various granulite minerals from three UHT metamorphic terranes (Cambrian Palghat-Cauvery Suture Zone (Southern India), Neoarchean Limpopo Complex (Southern Africa), and Neoarchean Napier Complex (Antarctica)), and compare the nature of the trapped fluids.

2. Palghat-Cauvery Suture Zone, Southern India

The southern granulite terrane in India comprises several crustal blocks which were welded together during the Late Neoproterozoic to Early Cambrian collisional orogeny related to the final amalgamation of the Gondwana supercontinent (e.g., Santosh et al., 2009). The Palghat-Cauvery Suture Zone (PCSZ) is regarded as the trace of the Gondwana suture zone in southern India (Santosh et al., 2009), dissecting the Archean Dharwar Craton to the north and the granulite terrane to the south. Previous petrological studies on this region presented evidences for a prograde HP event and subsequent UHT metamorphism along a clockwise path (e.g., Shimpo et al., 2006; Nishimiya et al., 2010). Available fluid inclusion studies of hot orogens within the PCSZ demonstrated the occurrence of abundant CO_2-rich inclusions in Mg-Al rich rocks and retrogressed eclogites (e.g., Ohyama et al., 2008; Santosh et al., 2010). Most of the inclusions are pseudosecondary and low density (0.59 to 0.95 g/cm^3), while primary high-density (>1.1 g/cm3) inclusions have been found only in garnet within mafic granulites (Santosh et al., 2010).

3. Limpopo Complex, Southern Africa

The Limpopo Complex is a classic example of the Neoarchean granulite-facies orogeny formed by continent-continent collision of Kaapvaal and Zimbabwe Cratons. The Central Zone of the complex is composed of various metasedimentary and metavolcanic rocks that records peak metamorphic conditions at UHT. Tsunogae et al. (2010) reported Mg-rich staurolite inclusions within garnet in garnet-orthopyroxene granulite and its replacement by sapphirine + quartz, suggesting prograde HP metamorphism and peak UHT metamorphism along a clockwise P-T path. Fluid inclusions trapped in garnet and plagioclase in the granulite are pseudosecondary in origin. The trapped fluids are all CO2-rich with relatively low density (0.72 to 0.87 g/cm^3) (Tsunogae et al., 2007).

4. Napier Complex, Antarctica

Although the tectonic evolution of the Napier Complex is not clearly known, the widespread occurrence of UHT metamorphic rocks in this region suggests its formation related to an orogeny possibly associated with continent-continent collision during Neoarchean. Previous investigations on sapphirine-bearing UHT granulites from Tonagh Island in the complex suggest counterclockwise P-T evolution of the rocks (Tsunogae et al., 2002). Fluid inclusions are present as a primary phase in garnet, sapphirine, orthopyroxene, and quartz. They are high-density (~1.07 g/cm^3) CO_2-rich fluids probably trapped during peak UHT metamorphism (Tsunogae et al., 2002). Some late-stage fluids are also CO_2-rich and high density (~1.02 g/cm^3).

5. Discussion

Available petrographic and microthermometric studies of fluid inclusions trapped in high-grade minerals from the three regions demonstrate that CO_2 was the dominant metamorphic fluid present during high-grade metamorphism of the areas. Although CH_4, N_2, and H_2O were detected by laser Raman spectroscopy analyses of some inclusions, they are minor components (e.g., Tsunogae et al., 2008a, b). The abundance of dry CO_2-rich fluids is consistent with the occurrence of some diagnostic mineral assemblages of UHT metamorphism such as sapphirine + quartz, spinel + quartz, and orthopyroxene + sillimanite + quartz, that could have been stabilized at low H_2O-activity. However, there is a significance difference in fluid density between granulites with clockwise (PCSZ and Limpopo) and counterclockwise (Napier) paths. Isochores based on CO_2 density of most fluid inclusions from the PCSZ and Limpopo Complex yield a significantly lower pressure estimate than those predicted from peak metamorphic conditions by geothermobarometry. This is probably due to the significant effect of density decrease of this category of fluid inclusions due to rapid decompression along clockwise P-T trajectory, which could have given rise to partial or complete decrepitation of the inclusions. In contrast, estimated isochores for primary inclusions in sapphirine granulites from the Napier Complex are consistent with the stability field of sapphirine + quartz (1000-1100^{o}C at 9 kbar), suggesting that most of the Napier fluid inclusions did not undergo significant effect of decrepitation and density decrease probably because the uplifting P-T trajectory of Tonagh Island is nearly parallel to the isochore of high-density inclusions (Tsunogae et al., 2002). Our results therefore suggest the preservation or absence of primary high-density fluid inclusions is controlled by the style of post-peak P-T path.

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High-Pressure Mafic Granulites from Perundurai and Kanja Malai in the Palghat-Cauvery Suture Zone, Southern India

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Introduction

The southern granulite terrane in India comprises several crustal blocks which were welded together during the Late Neoproterozoic to Early Cambrian collisional orogeny related to the final amalgamation of the Gondwana supercontinent (e.g., Santosh et al., 2009). The Palghat-Cauvery Suture Zone (PCSZ) is regarded as the trace of the Gondwana suture zone in southern India (Santosh et al., 2009), dissecting the Archean Dharwar Craton to the north and the granulite terrane to the south. Available petrological investigations of high-grade metamorphic rocks in the central part of the PCSZ around Namakkal and Karur districts provided evidence for a prograde high-pressure (HP, P >12 kbar) metamorphism and subsequent peak ultrahigh-temperature (UHT) event along a clockwise P-T path of this region (e.g., Shimpo et al., 2006; Santosh et al., 2010; Nishimiya et al., 2010). However, the HP-UHT granulites were mostly reported so far from the central part of the PCSZ, and it is not known whether such HP-UHT event is a unique feature of the central part of the PCSZ or a common feature throughout the PCSZ. We thus attempted to evaluate P-T evolution of the western part of the PCSZ in the Perundurai region where garnet-bearing mafic granulites occur. We also examined the granulites from Kanja Malai region along the northern margin of the PCSZ.

Perundurai region

The dominant minerals in mafic granulite from Perundurai are subidioblastic garnet and clinopyroxene which are separated by fine-grained (0.05-0.1 mm) symplectic intergrowth of orthopyroxene and plagioclase. The texture suggests the progress of the reaction; Grt + Cpx + Qtz => Opx + Pl, indicating that garnet + clinopyroxene + quartz was a possible peak assemblage. Peak metamorphic conditions of Perundurai mafic granulite was estimated to be >12 kbar and 800-900°C on the basis of geothermobarometry and experimental study of Green and Ringwood (1967). The peak stage was probably followed by near isothermal decompression from HP stage along clockwise P-T trajectory. The P-T path is almost equivalent to those of previous studies from the PCSZ (e.g., Shimpo et al., 2006).

Kanja Malai region

Mafic granulite form Kanja Malai region is characterized by coarse-grained (up to several cm) and poikiloblastic garnet in contact with subidioblastic to xenoblastic clinopyroxene, quartz, and plagioclase. The equilibrium assemblage of this sample during the peak stage is therefore inferred to be garnet + clinopyroxene + plagioclase + quartz. Peak metamorphic conditions of the rocks were calculated as 790-800°C and 10-12 kbar. The preservation of equilibrium garnet + clinopyroxene + quartz assemblage in some mafic granulites (e.g., sample MD29-2C2) indicates that the prograde pressure of the rocks is above the Pl-out curve of Green and Ringwood (1967), which corresponds to P >12 kbar at 800°C. Stable occurrence of garnet + clinopyroxene + orthopyroxene + plagioclase + quartz in some samples possibly suggests gradual P-T decrease by decompressional cooling nearly parallel to the Pl-out curve. Such a P-T trajectory has not so far been reported from the PCSZ.

Discussion

The high-temperature metamorphic conditions of T = 800-900°C and P >12 kbar, followed by near isothermal decompression, obtained from the garnet-clinopyroxene assemblage in mafic granulites from Perundurai, are consistent with the previous *P-T* estimates from the PCSZ (e.g., Santosh et al., 2010). The results suggest regional HP (P ~12 kbar) metamorphism and subsequent UHT event throughout the PCSZ. In contrast, mafic granulites from Kanja Malai suggest gradual *P-T* decrease by decompressional cooling nearly parallel to the Pl-out curve. The contrasting *P-T* paths obtained from the two localities suggest that whereas Perundurai is a part of the metamorphic orogens developed within the PCSZ during Gondwana assembly, the high pressure granulites of Kanja Malai might belong to a different orogenic regime. We thus performed preliminary SHRIMP U-Pb dating of zircon grains in HP charnockite from Kanja Malai region and obtained mean $^{207}Pb/^{206}Pb$ age of 2477.6±1.8 Ma as the time of peak metamorphism. As Kanja Malai is located at the northern margin of the PCSZ against the Archean Dharwar Craton, we regard the cooling path with slow exhumation and *ca*. 2.5 Ga U-Pb zircon SHRIMP ages from Kanja Malai samples to indicate a Neoarchean to Paleoproterozoic thermal event related to the crustal evolution at the margin of the Dharwar Craton. This event is distinct from the HP-UHT peak metamorphism followed by rapid decompression of the metamorphic orogen associated with the Late Neoproterozoic-Cambrian Gondwana assembly.

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Pressure-Temperature Evolution and SHRIMP Geochronology of Neoproterozoic Ultrahigh-Temperature Metamorphic Rocks from Rajapalaiyam in the Madurai Block, Southern India

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1. Introduction

The southern granulite terrane (SGT), India, comprises several large granulite blocks that underwent high- to ultrahigh-temperature (UHT) metamorphism during the assembly of the Gondwana Supercontinent (e.g., Santosh et al., 2009). Previous petrological studies on granulites from the Madurai Block, the largest crustal block in this region, suggest the peak metamorphic conditions of the block as >900 °C and 8–12 kbar, which is consistent with the occurrence of diagnostic UHT mineral assemblages such as sapphirine + quartz, orthopyroxene + sillimanite + quartz, spinel + quartz, and high-Al_2O_3 orthopyroxene (e.g., Tsunogae and Santosh, 2010). The Rajapalaiyam area in the southern part of the Madurai Block, where sapphirine + quartz was first reported from the SGT by Tateishi et al. (2004), is composed of UHT pelitic granulites with various mineral assemblages. Although several petrological studies have been carried out on the locality, the peak pressure condition and style of exhumation path (either clockwise or counterclockwise) have not yet been determined. In this study we adopted pseudosection analysis for the first time on granulites from Rajapalaiyam to understand the *P-T* evolution of the Madurai Block. We further performed SHRIMP U-Pb analysis of zircons in the sapphirine + quartz-bearing granulites to determine the time of UHT metamorphism. In a previous study Braun et al. (2007) reported U-Pb monazite age for Rajapalaiyam rocks and inferred the timing of peak UHT metamorphism as 800-900 Ma, which is older than the peak metamorphic ages from other localities in the SGT (e.g., Santosh et al., 2006).

2. Mineral equilibria modeling and zircon geochronology

P-T pseudosections were calculated using THERMOCALC 3.33 (Powell and Holland, 1988) with an updated version of the internally consistent data set of Holland and Powell (1998; data set tcds55s). Calculations were undertaken in the system Na_2O-CaO-K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O-TiO_2-Fe_2O_3 (NCKFMASHTO) (White et al., 2007). Bulk-rock compositions for UHT granulites were determined by X-ray fluorescence analysis. The *P-T* pseudosections constrain the peak metamorphic condition of Rajapalaiyam at 8.5-10 kbar, 900-1000 °C, which corresponds to the stability of garnet + orthopyroxene + plagioclase + ilmenite + sillimanite + quartz + liquid assemblage. The peak event was followed by cordierite-forming lower-pressure stage probably along a clockwise *P-T* trajectory. SHRIMP analysis of metamorphic zircons, selected after careful examination of cathodoluminescence images, yielded Neoproterozoic ages of *ca*. 560 Ma.

3. Discussion

The pseudosection analysis of sapphirine + quartz-bearing UHT granulite from Rajapalaiyam yielded peak metamorphic conditions of 8.5-10 kbar and 900-1000 °C, which is nearly consistent with previous estimates based on *P*-*T* grid and geothermobarometry (e.g., Tsunogae and Santosh, 2010). However, it is interesting to note that our pseudosection analysis suggests sapphirine + quartz is not a possible stable phase at the peak condition. This is probably due to prograde partial melting of protolith metasediments and subsequent melt extraction during peak stage, which could have modified the original bulk-rock chemistry. The clockwise *P*-*T* path inferred from this study is consistent with the paths from other UHT localities in the Madurai Block (e.g., Tsunogae et al., 2008). SHRIMP analysis of zircons from the UHT granulite gave U-Pb ages of *ca*. 560 Ma, which is consistent with the Neoproterozoic metamorphic ages reported from other areas in the Madurai Block (e.g., Santosh et al., 2006; Collins et al., 2007). The *T* ~1000 °C UHT metamorphism and subsequent decompression along a clockwise path in Rajapalaiyam probably associated with the Neoproterozoic subduction and following continent-continent collision attending the final amalgamation of the Gondwana supercontinent (Santosh et al., 2009).

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Magmatic Stages in Viet Nam

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On the basic of detailed study on structural geology, substantial composition (mineralogical, petrological, geochemical) origin anh geodynamic enviroments, magmatic fomations in Viet Nam have been divided into 32 magmatic associations belonging to 9 different tectonic settings: mid-oceanic ridge (MOR), volcanic arc (VA), back-arc basin (BAB), syn-collision (syn-COLL), post-collision (post-COLL), continental rift (CR), continental flood basalt (CFB), anorogeny (AOR) and shear-zone related (SHZ). They include 7 stages of magmatic activity as below.

1.The Archean stage (AR)

Meso-Neoarchean basalt and trondhjemite-tonalite-granodiorite association.

2. The Paleo-Mesoproterozic stage (PP-MP)

a. Paleoproterozoic basalt and gabbro-alkaline feldspar granite association.

b. Mesoproterozoic basalt-andesite and gabbro-pyroxenite association.

3. The Neoprotezoic-Early Cambrian stage (NP-Є1):

a. Early Neoproterozoic gabbro-diabase association

b. Early Neoproterozoic basalt and ophiolite association

c. Middle Neoproterozoic diorite-granodiorite-granite association.

d. Late Neoproterozoic volcanite and ophiolite association.

e. Early Cambrian gneisogranite-migmatite association.

4. Early-Middle Paleozoic stage (PZ1-2)

a. Early Paleozoic microcline granite association.

b. Early Paleozoic basalt and ophiolite association

c. Middle Ordovician-Early Silurian basalt-andesite-ryodacite and gabbro-diorte-granodiorite association.

d. Silurian diorite-granodiorite-granite association.

e. Late Silurian-Early Devonnian gneisogranite-biotite granite-two mica granite association.

f. Early Deronia rhyolite-trachyrhyolite and granite association.

g. Midde Paleozoic alkaline syenite-nepheline syenite association.

5. Late Paleozoic-Early Mesozoic stage (PZ3-MZ1).

a. Late Carboniferous-Permian basalt-andesite-rhyolite and gabbrodiorite-granodiorite-granite association.

b. Late Carboniferous-Permian komatiite-basalt-trachyte and peirdotite-gabbro-granosyenite association.

c. Late Permian-Early Triassic biotite granite-two mica granite association.

f. Late Permian-Early Triassic basalt-rhyolite and peridotite-gabbro-granite association.

g. Middle Triassic dacite-rhyodacite-rhyolite and porphyric granite-granophyre association.

h. Middle-Late Triassic syenite-lamproite association.

6. Late Mesozoic-Early Cenozoic stage (MZ3-KZ1)

a. Jurassic-Cretaceous rhyodacite-rhyolite and granite-granophyre association.

b. Late Jurassic-Cretaceous andesitobasalt-andesite-rhyolite and gabbrodiorite-granodiorite-granite association.

c. Late Jurassic-Cretaceous basalt-trachyrhyolite-rhyolite and gabbro granosyenite-alkaline granie association.

d. Late Cretaceous biotite granite-two mica granite association.

e. Paleogene trachyte-leucitophyre and syenite-lamproite association.

7. Late Cenozoic stage (KZ3)

a. Oligocene peridotite-gabbro and granite-leucogranite-pegmatite association.

b. Middle Miocene-Early Pleistocene tholeiitic basalt and gabbro dolerite association.

c. Quatern alkaline basalt association

Basically, these magmatic activity stages might raleted to the opening-closing of oceans and amalgamation of terranes and cratons through, Grenville, Pan-African, Caledonian, Indosinian, Yanshanian and Himalayan orogenic events

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Paleoproterozoic Crustal Melting Granites in the Hengshan Complex, Central Zone of the North China Craton: Evidences from Zircon U-Pb Ages and Nd Isotopies

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In the Central Zone of the North China Craton, there is a Hengshan complex which is mainly composed of ca. 2.5Ga TTG gneisses with some inherited 2.7 Ga crustal material and experienced 1.85Ga high-pressure granulite facies metamorphism during continental collision of final assembly of the craton. Here, we study a suit of potassic granites, which are widely distributed in the Hengshan complex as highly deformed small intrusions, sheets and dykes, and are called Lingyunkou granites by local geological survey because of the typical occurrence around that village. Amphibolite-granites and biotite-granite can be identified from thin section. Both granites have high SiO_2 contents of 70.98 –74.65 *wt*%, and high K_2O + Na_2O contents of 8.85 –10.41 *wt*%, but still belong to the metaluminous, calc-alkaline series indicated by A/CNK and A/NK parameters.

In order to investigate their formation ages, we carried out in situ zircon U–Pb age dating by LA-ICP-MS and SIMS (Cameca 1280) respectively. Zircons from the amphibolite-granite sample No. 09LYK06 give out U-Pb ages of 2046±16 Ma (MSWD=0.41) by LA-ICP-MS and 2084.4±4.2 Ma (MSWD=2.1) by SIMS, while we obtained zircon U-Pb ages of 2060±18 Ma (MSWD=0.65) by LA-ICP-MS and 2083±15 Ma (MSWD=0.18) by SIMS for the biotite-granite sample No. 09LYK13. These are considered as crystallization ages of the granites.

Sm-Nd isotopic compositions of 7 whole rock samples are analysed using isotope dilution + TIMS method on MAT 262 mass-spectrometer. All samples have negative $\varepsilon Nd_{(t)}$ values of -1.4 to -3.3, and very old two-stage depleted mantle model age T_{DM2} ranging from 2.66 to 2.81 Ga, indicating that the Lingyunkou potassic granites were most likely derived from partial melting of a pre-exsting ancient crustal source. Combining with field occurence, major and trace element composition, we suggest that the source of the Lingyunkou potassic granites were the 2.5 Ga Tuling TTG gneisses and metasedimentary slabs within the gneisses

The formation ages of the Lingyunkou potassic granites from Hengshan complex are identical with that of the Nanying granitic gneisses (~2.08 Ga) from Fuping complex, which was suggested as the product of Paleoproterozoic magmatism in the Central Zone of the North China Craton. The 2.08 Ga Lingyunkou potassic granites confirmed the Paleoproterozoic crustal melting event, and further extended the spreading area of the event. It is probably a major tectono-thermal event prior to the final collision of the North China Craton at ~1.85 Ga.

Keywords: Potassic granite, zircon U-Pb ages, Nd isotopic geochemistry, crustal melting event, Paleoproterozoic, Hengshan complex, North China Craton.

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New Zircon U-Pb Ages and Hf Isotopes from the Helanshan Complex in the North China Craton: Implication for the Khondalite Series Deposited in A Back-Arc Basin?

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The Khondalite Belt in the Western Block of North China Craton trends northwesterly and extends 600 km long, consisting of, from east to west, the Daqingshan, Ulashan, Qianlishan and Helanshan Complexes. It was generally considered as a collisional belt formed at ca.1.95 Ga between the Yinshan block to the north and the Ordos Block to the south. Granulite facies metasedimentary rocks and S-type granites dominate this belt. The supercrustal metasedimentary sequences, referred as the Khondalite series in literature, are commonly considered to be deposited at a stable continental margin and are used to infer the direction of subduction between the involved two blocks.

We present in this study U-Pb ages and Hf isotopes of zircons from the metasedimentary rocks of the Helanshan Complex and the S-type granites intrusive into the metasedimentary rocks. These S-type granites were thought to be the products generated by anatectic melting of the Helanshan metasedimentary rocks (Hu et al., 1993). SIMS U-Pb zircon results indicate that the two-mica granite and porphyritic K-feldspar granite were formed at 1956 ± 19 Ma and 1947 ± 6 Ma，respectively. Seventy-five detrital zircons from a garnet-cordierite gneiss were analyzed by in situ U-Pb dating and Hf isotope. Five analyses have ages older than 2.4 Ga, while the remaining 70 analyses yield ages between 2.2 and 2.0 Ga. All the analyzed zircons have εHf(t) values ranging from +8.8 to -3.0, corresponding TDMC model ages between 2.9 and 2.1 Ga, with two major peaks at 2.6 and 2.3 Ga.

The SIMS U-Pb ages for zircons from the metasedimentary rocks and S-type granites from the Helanshan Complex place the depositional age of the metasedimentary rocks between ca. 2.0 Ga and ca. 1.95 Ga. This deposition age is just slightly younger than the zircon Hf TDMC model ages of ca. 2.3 Ga for these metasedimentary rocks with positive εHf(t) values, suggesting their derivation form dominant juvenile source with short crustal residence time. Soon after deposition, these sedimentary rocks were experienced high-grade metamorphism and anatectic melting at ca. 1.95 Ga. These features imply that the protoliths of Khondalite series are most likely sourced from a magmatic arc and deposited in a back-arc basin setting, rather than a passive continental margin as previously thought (Condie et al., 1992). The Khondalite series in the Daqingshan, Ulashan and Qianlishan show similar evolutionary history with the Helanshan Khondalite series (e.g., Wan et al., 2009), suggesting the whole Khondalite Belt likely formed in a back-arc setting. This interpretation is coincidence with the subduction polarity based on the interpretation of seismic data (Santosh et al., 2010).

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Early Precambrian Continental Growth of Southwestern Siberian Craton

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The Siberian Craton is the largest craton in Asia and records multistage crustal evolution through the Early Precambrian. The final assemblage of the Siberian craton resulted from amalgamation of Archaean superterranes at 2.0-1.85 Ga. We analyzed new geological and geochronological data on the southwestern Siberian Craton and constrained the Precambrian crustal evolution from 3.4 to 1.85 Ga. The Early Precambrian crust of the southwestern Siberian Craton is exposed within the Sharyzhalgay uplift which includes the Bulun and Onot granite-greenstone terranes and the Irkut and Kitoy granulite terranes. The Paleoarchaean TTG complexes represent the oldest crust of the granite-greenstone terranes. TTGs formed during two discrete magmatic events at 3.4 and 3.3-3.25 Ga, and their metamorphism and migmatization took place at ca. 3.2 Ga. The TTG's T_{Nd}(DM) values of 3.3-3.6 Ga suggest contribution of even older crustal material in their genesis. The metasedimentary-volcanic rocks of the greenstone belts formed at ca. 2.9 Ga. Formation of bimodal volcanic rocks and carbonate-terrigenous sediments of the Onot belt was related to the rifting of the Paleoarchean continental crust whereas the basalts and siliceous-argillaceous sediments of the Urik belt formed in an oceanic setting and were thrust on the continental margin. The basalts of both greenstone belts were derived from depleted mantle that is confirmed by positive ε_{Nd} ranging from +4.7 to +3.0 unlike the felsic volcanics with ε_{Nd} of -3.6 to -0.6, which originated from an older crustal source. Rare relicts of Paleoarchaean felsic granulites in the Irkut and Kitoy terranes formed at ca. 3.4 Ga and were metamorphosed at ca. 3.0 Ga (Poller et al., 2005). Within those terranes most magmatic protoliths of the mafic and felsic granulites formed at ca. 2.7-2.6 Ga as a subduction-related volcanic sequence at an active margin of an ancient continental block. The input of older crust material is confirmed by the ε_{Nd} values of the felsic granulites ranging from -4.8 to +1.2. The Neoarchaean evolution of the Irkut and Kitoy terrane was finished by collisional high-grade metamorphism and granite magmatism at 2.57-2.54 Ga. Minor mafic dikes intruded in the late Paleoproterozoic, i.e. at 1.96 Ga. The granite-greenstone and granulite terranes developed independently during the Archean and amalgamated during a Paleoproterozoic collisional event. The coeval high and low grade metamorphism and the emplacement of granite and enderbite occurred at 1.85-1.88 Ga in all terranes of the Sharyzhalgay uplift (Poller at al., Sal'nikova et al., 2007). The Paleoproterozoic granitoids have ε_{Nd} values from -5.7 to -13.4 indicating that they are derived largely from older continental crust with variable mantle input.

Based on the negative ε_{Nd} and T_{Nd}(DM) of 2.6-3.6 Ga we conclude that the Paleoarchaean crust significantly contributed to younger magmatic rocks, i.e. the Precambrian evolution of the southwestern Siberian Craton occurred through recycling of older continental crust. At the same time the younger felsic magmatic rocks have more radiogenic Nd isotope composition than the Paleoarchaean crust, therefore the intracrustal melting was accompanied by contribution of mantle material. From 2.9 to 1.96 Ga the mafic magmatism also contributed to continental crustal growth by providing an input of mantle material. Thus, during the Early Precambrian, the multiple processes of crustal recycling played an important role in the evolution of the southwestern Siberian Craton.

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SS02-P-1

Petrogenesis and Tectonic Implication of Permian High Ti/Y Basalts from the Eastern Part of the Emeishan Large Igneous Province (LIP), Southwestern China

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Permian high Ti/Y basalts are widespread in the Emeishan large igneous province (LIP), their petrogenesis and source region can promote our understanding of the mantle plume theory in the Yangtze Block. This paper reported high Ti/Y basalts from the eastern margin of the Emeishan LIP. The Guangxi basalts have zircon U-Pb age of 257 Ma, which is consistent with the eruption age of the Emeishan mantle plume. Both the Guangxi and Guizhou basalts display evolved Sr-Nd isotopic composition and Dupal Pb isotopic composition, $(^{87}Sr/^{86}Sr)_i$ = 0.705231 to 0.706147, positive to slightly negative εNd(t) values of −0.13 to + 0.68, Δ7 = 5 to 11, Δ8 = 70 to 84. The Guangxi basalts display low SiO_2 (44.82 to 49.71 wt. %), TiO_2 (2.29 to 3.54 wt.%) contents, they are enriched in LREE and LILEs with (La/Sm)N values of 2.2 to 2.6, high Ce/Yb ratios of 19.6 to 30.0 and slightly negative anomalies in Nb and Ta. The Guizhou basalts display higher SiO_2 (47.49 to 50.27 wt. %), TiO_2 (3.93 to 4.92 wt. %), Zr, Nb and La contents, higher Ce/Yb (30.2 to 37.8) and Sm/Yb (3.56 to 4.19) ratios than those of the Guangxi basalts, they display no negative Nb, Ta anomalies. The distinct differences between the Guangxi and Guizhou basalts can not be explained by fractional crystallization of a common parental magma. We proposed that the Guizhou basalts were originated from partial melting of metasomatized veins in the Yangtze continental lithosphere when they heated by the upwelling Emeishan plume, and the Guangxi basalts may resulted from mixing between metasomatized veins melts and continental materials.

Keywords: mantle plume; high-Ti basalts; metasomatized veins; Emeishan flood basalts; partial melting

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SS02-P-2

Assembly of Eurasia, Late Carboniferous to Present

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The continent of Eurasia comprises several major plates and secondary terranes, separated by multiple orogenic belts of various Phanerozoic ages. The present land-mass of Eurasia is a collage of once separated blocks. Assembly of Eurasia was completed through long-term and complicated tectonic evolution from the Paleozoic to the Cenozoic. Ten maps showing the motions of the major plates in Eurasia following the assembly and break-up of Pangea from Pennsylvanian to present day are presented.

The Pennsylvanian - Early Permian maps show the former dismemberment of Eurasia. Siberia, Baltica and Kazakhstan amalgamated all by clockwise rotation and converge in a large-scale sinistral system (a "oroclinal bending of an originally straighter arc" model; Abrajevitch et al., 2007). Paleomagnetic evidence indicates that the Mongol - Okhotsk Ocean was still not completely closed during the Middle - Late Jurassic interval. The final ocean closure and collisional orogeny took place in the Early Cretaceous (Fig. 1). All these complicated tectonic processes make many present-day basins, such as Tarim Basin and Junggar Basin in Central Asia, become typical superimposed sedimentary basins. Paleomagnetic results from smaller crustal fragments (Kunlun, Qaidam for example) are reviewed and the evidence for collision and orogenies between plates are mainly based on predecessors' achievements and some published paleomagnetic results. The results indicate that most orogenies are to some degree collisional in nature.

The first purpose of our reconstruction is to describe the relative motions of the major plates in Eurasia relative to each other and to the paleogeographic poles from the Late Carboniferous to the present. The second is to describe the influence of tectonic evolution on basin type. Maps showing the motions of the major plates in Eurasia have been prepared by first rotating each block into its correct paleolatitudinal and paleoazimuthal position for successive time intervals, using the paleomagnetic poles (virtual geomagnetic pole, VGP). The plates were then assembled into their paleolongitudinal position using evidence from sea-floor spreading based mainly on the work of Irving (1983), Müller et al. (1993, 1997), Torsvik et al. (1996, 1999, 2001, 2008) and van der Meer et al. (2010). Motions of the smaller crustal fragments relative to the major plates are shown by comparing the paleomagnetic evidence from the smaller crustal fragments with that from the plates to which they are now attached. Analysis and diagrams were created with GMAP (Torsvik and Smethurst, 1999) and a prototype of GPlates (GPlates 0.9.9.1; Müller et al., 2003).

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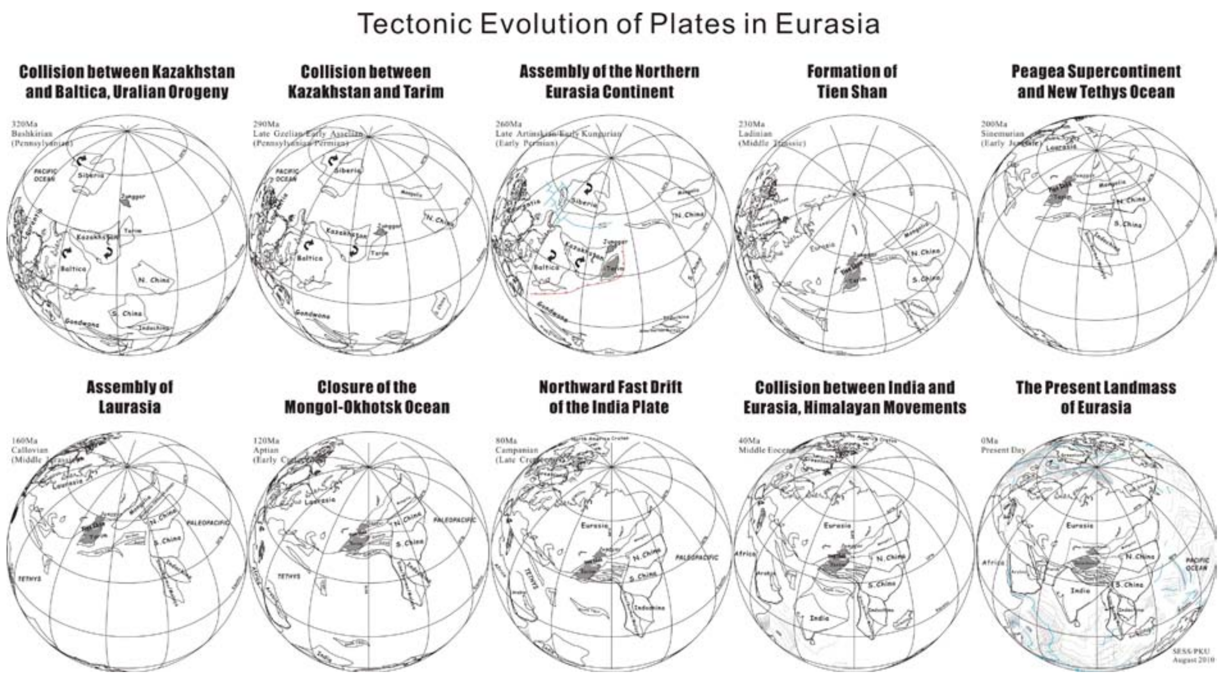

Fig. 1. Orthographic projections of Eurasia from Pennsylvanian to present day

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SS03-P-1

Mineral Assemblage and Origin of Manganese Deposits Distributed in the Accretionary Complexes of Shikoku, Southwest Japan

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1. Introduction

Many bedded manganese and iron-manganese ore deposits occur in the accretionary complexes such as Sanbagawa, Mikabu, Northern Chichibu, Southern Chichibu and Northern Shimanto belts of the Shikoku Island, Southwest Japan (Fig. 1). The ores were mined extensively during 1880-1970. Many workers studied the ore deposits mainly in the 1950s-1960s and considered that these deposits are of hydrothermal origin associated with basic volcanism (comprehensive reviews in Yoshimura, 1952, 1969; Watanabe et al., 1973). In a recent study, we proposed a new concept for the genesis of these ore deposits based on a model involving the prolonged subduction-accretion process in Japan (Nakagawa et al., 2009). In this paper, we re-examine the ore deposits based on our new field and laboratory investigations.

2. Occurrence and age of manganese deposits

In Shikoku, the manganese deposits occur mostly in bedded chert and quartz schist. Most of the deposits occur as small conformable, lenticular or irregular platy units. Some of the ores show layer structure. In the Chichibu belts, the microfossil ages of olistolith chert distributed around the deposits are Permian to Triassic, whereas the ages of the clastic matrix of olistostrome are Jurassic. In the Northern Shimanto belt, the ages of the chert are Late Jurassic to Late Cretaceous, whereas those of the matrix sediments are Late Cretaceous.

3. Constituent minerals of manganese deposits

We classify the manganese deposits in Shikoku into ten types (Types A-J) based on their mineralogy as revealed by XRD and EPMA analyses. Piemontite-quartz schist is distributed in the Sanbagawa metamorphic belt. In the mines of Nos. 1-3, braunite-piemontite-quartz ore (Type A) occurs in the schist. On the other hand, in the mines of Nos. 4-5, manganese ores (Type B) consisting mainly of piemontite, braunite, rhodonite, and rhodochrosite occur in the schist. In the Mikabu belt, manganese ores (Type C) consisting mainly of rhodochrosite, rhodonite, spessartine and ganophyllite occur in quartz schist in the mines of Nos. 6-10. In the Northern Chichibu belt, many manganese deposits occur in bedded chert, whereas iron-manganese deposits and some manganese deposits occur between greenstone and red chert. The manganese ores (Type D) embedded between greenstone and chert in the mines of Nos. 11-13 contain caryopilite, rhodochrosite, strontiopiemontite, manganaxinite, ganophyllite, calcite, barite, K-feldspar. The manganese ores (Type E) embedded within chert in the mines of Nos. 14-19 consist mainly of rhodochrosite, caryopilite (or bementite), rhodonite, braunite, chlorite and quartz. In the mines of Nos. 20-22, iron-manganese ore (Type F) consisting of hematite, magnetite, caryopilite-greenalite, calcite occur between greenstone and chert. In the Southern Chichibu belt, many small manganese deposits occur in bedded chert. The manganese dioxide ore (Type I) is abundant in this belt. The ore consists of quartz, todorokite, cryptomelane, nsutite and pyrolusite in the mines of Nos. 32-37. Manganese carbonate ore (Type H) consisting mainly of fine-grained rhodochrosite also occur in the mines of Nos. 28-31 in this belt. In the Northern Shimanto belt, small deposits of manganiferous iron ore (Type J) occur in red chert. The ore consists mainly of quartz, hematite and calcite with accessories of todorokite and birnessite in the mines of Nos. 38-40.

On the other hand, manganese and ferromanganese nodules and crusts are known to occur on modern ocean floor and are considered to have formed by hydrogenetic precipitation from cold seawater (Hein et al., 1997). They are generally composed of hydrous manganese oxide minerals such as vernadite, birnessite, todorokite and X-ray amorphous Mn-bearing ferric oxyhydroxides.

4. Genesis of the manganese and iron-manganese deposits in Shikoku

Many manganese deposits occur within chert or quartz schist. Iron-manganese deposits (Type F) and some manganese deposits (Type D) occur directly over basalt. The former group is equivalent to Mn-Fe nodules and crusts on the ocean floor. The latter minor group is equivalent to the hydrothermal precipitates associated with the mid-oceanic ridge or oceanic island volcanism. Both groups were accreted onto the proto-Japanese Island. Through subduction-accretion process, these Mn-Fe-bearing siliceous sediments on the ocean floor are considered to have been metamorphosed and converted to the manganese and iron-manganese deposits in Shikoku.

The mineral assemblages of the manganese deposits show a progressive change that can be correlated with the metamorphic grade of the accretionary complexes in Shikoku. The manganese dioxide minerals occur in the low-grade metamorphic zones. The manganese silicate minerals such as braunite, caryopilite and rhodonite occur in the higher-grade metamorphic zones. The manganese alumino-silicate minerals such as piemontite and spessartine occurr in the still higher grade metamorphic zone. These manganese silicates and alumino-silicates are considered to have formed by the reactions of manganese nodules or crusts, siliceous sediments and pelagic clays.

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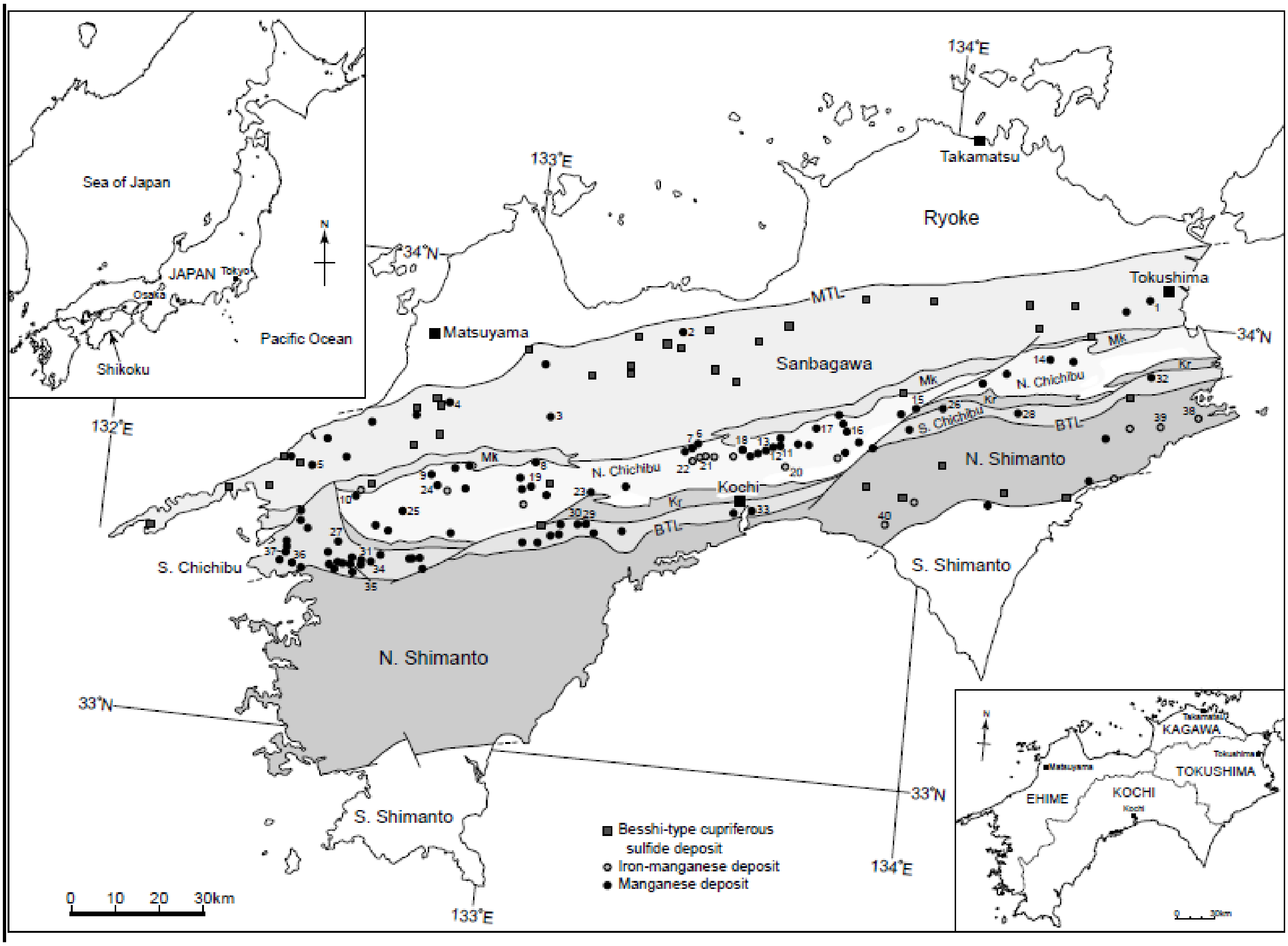

Fig. 1. Distribution of manganese, iron-manganese and Besshi-type cupriferous deposits shown within the generalized geological framework of Shikoku, SW Japan. MTL: Median Tectonic Line. BTL: Butsuzo Tectonic Line. Ryoke: Ryoke belt. Sanbagawa: Sanbagawa belt. Mk: Mikabu greenstone. N. Chichibu: Northern Chichibu belt. Kr: Kurosegawa belt. S. Chichibu: Southern Chichibu belt. N. Shimanto: Northern Shimanto belt. S. Shimanto: Southern Shimanto belt

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SS03-P-2

Evolution of Basins in Eurasia: Evidence from E-W Intra-Continent Profile

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Since most of the studies of Eurasia see from the angle of of plates' boundaries, the relationships between intrabasins are not clear. An 11,000-km-long Eurasia east-west trending intra-continent profile was made to reveals the structure of the most upper crust (less than 12 km depth) related to the regional tectonics and the basin-and-range pattern in the Eurasia continent. The most important effect of the profile is that it associates plate boundaries with the insides of basins since it leads to the possibility of contrasting different basins' evolutions.

The profile sourced by many short profiles from previous studies traverses nearly the entire territory of Eurasia from North Sea to North Okhotsk basin and extends across a variety of continental structures of northern Eurasia (along N55 °-N60 °): the Caledonides, the ancient East European platform, Uralian orogen, the West Siberian Basin with thick and gently Mesozoic-Cenozoic sedimentary cover, the Siberian Craton, and the Verkhoyansk-Kolyma Mesozoic fold belt.

Different from the southern part, except for some locally uplifts, northern Eurasia has been a nearly stable plate since the Mesozoic with weak deformation, flat strata and rare faults developing. The profile shows the records of Hercynian orogeny, the reconstruction of Paleotethys and the extensions of Pacific and Atlantic inside the basins in Eurasia. From the profile, we can also surmise some characteristics of the mantle plumes under the continent, such as it shows that the large igneous province (LIP) was formed when plates were aggregating.

Keywords: Eurasia; inter-continent profile; basin-and-range pattern

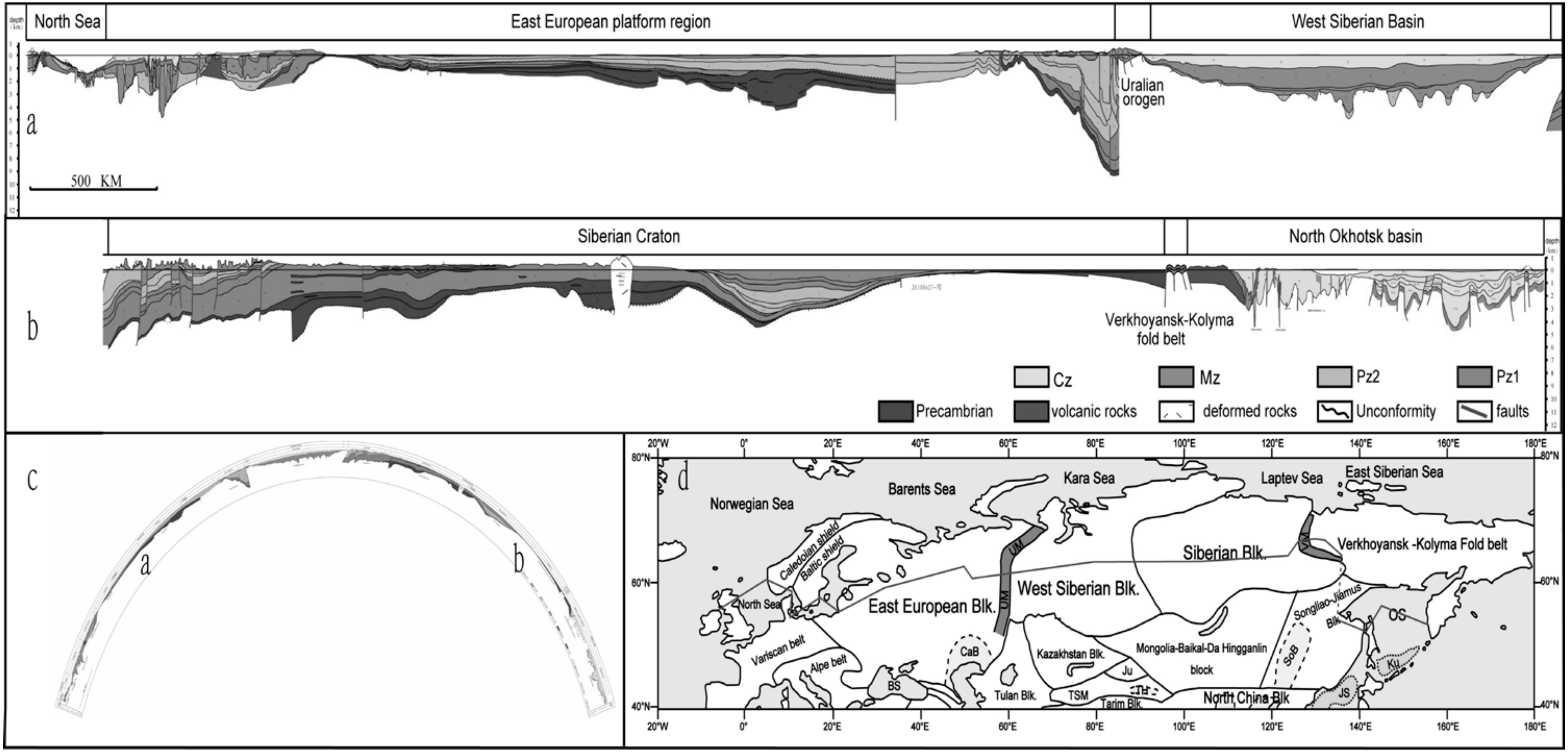

Fig. The 11,000-km-long Eurasia continent E-W profile.
a and b- the two segments of the profile; c- the whole form of the profile; position see d

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Early Permian Tectonic Evolution of Eastern Heilongjiang Province, NE China: Constraints from Zircon U-Pb-Hf Isotope and Geochemical Evidence

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The eastern Heilongjiang province, NE China, is situated in the eastern segment of the Central Asian Orogenic Belt (CAOB). belonging to the Paleo-Asiatic tectonic domain and consisting of the Songnen–Zhangguangcai Range and Jiamusi massifs (SZ and JM). Its early Paleozoic tectonic evolution was characterized by the amalgamation of microcontinental massifs (Sengör et al., 1993; Meng et al., 2010), whereas the tectonic evolution of its late Paleozoic, especially Permian tectonic evolution has been a controversal issue (Li, 2006; Meng et al., 2008). Fortunately, voluminous late Paleozoic volcanic rocks provide insights to constrain the Permian tectonic evolution in the region.

LA-ICP-MS zircon U-Pb dating results show that voluminous volcanic rocks, widely distributed in the study area, can be divided into two stages, i.e., the early Permian (~290 Ma) and middle Permian (268 Ma).

The early Permian volcanic rocks widely occurred in the SZ and JM. These volcanic rocks in the SZ, consist mainly of the basalt, basaltic-andesite, rhyolite and minor dacite. Chemically, they display a typical bimodal volcanism. The mafic rocks with SiO_2 = 50.13-53.80 %, K_2O=0.98-2.28 wt.%, Mg#= 51-71, Cr= 144-541 ppm, Ni = 74-261 ppm, $(87Sr/86Sr)_i$= 0.7044, and ε_{Nd} (t)= +4.28, as well as significant LILEs and LREEs enrichment and HFSEs depletion, suggest that the mafic magma could be derived from partial melting of the lithospheric mantle modified by the subducted slab-derived fluid. The felsic rocks with SiO_2 = 69.12-77.98 %, K_2O= 3.09-5.33 %, $(^{87}Sr/^{86}Sr)_i$= 0.7032, and ε_{Nd} (t) = +4.32, as well as depletion in Nb, Ta, Sr, P, Ti, enrichment in Th, U, K, and large negative Eu anomalies (0.28-0.95), imply a newly accretionary crustal source. Besides, the early Permian volcanic rocks from the JM consist mainly of basalt, basaltic andesite, andesite and minor dacite. They show low SiO_2, high Mg# (0.40-0.59), enrichment in Na and LREEs, depletion in HREEs and HFSEs, indicating that they could be derived from the lithosphere mantle modified by the subducted slab-derived fluid/melt. The early Permian volcanic rocks in the study area together with the existences of the magmatic-thermal events in southern JM (Li et al., 1998, 2006) and in Inner Mongolian (Wu et al., 2002; Zhang et al., 2008), suggest that: (1) an active continental margin could exist in the eastern margin of the JM, (2) the SZ could be under a back-arc setting, i.e., an extensional environment, and (3) the early Permian volcanic rocks could be related to the subduction of the Paleo-Asian oceanic plate beneath the SZ and JM.

The middle Permian volcanic rocks consists mainly of rhyolite and minor dacite with high SiO_2 (77.23-77.52 %), low MgO (0.11-0.14 %), enrichment in K2O (Na_2O/K_2O ratios < 0.80) and Rb, Th, U and depletion in Eu, Sr, P and Ti, implying a crust-derived origin. Combination with the existence of 270-254 Ma I-type granites in the JM, it is proposed that the middle Permian volcanic rocks could have formed under the collision of the Jiamusi and the Khanka Massifs. Meanwhile, it is also suggested that the tectonic evolution between the Jiamusi-Khanka massifs and the North China Craton began after the middle Permian, which is also supported by the early-middle Triassic final collision between the Siberia and the North China Cratons (Jia et al., 2004; Li, 2006; Wu et al., 2007). This study was financially supported by the Natural Science Foundation of China (Grant: 40739905 and 40672038).

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Structural Contrast and Tectonic Evolution of the Central Asian-Middle East Basin Group

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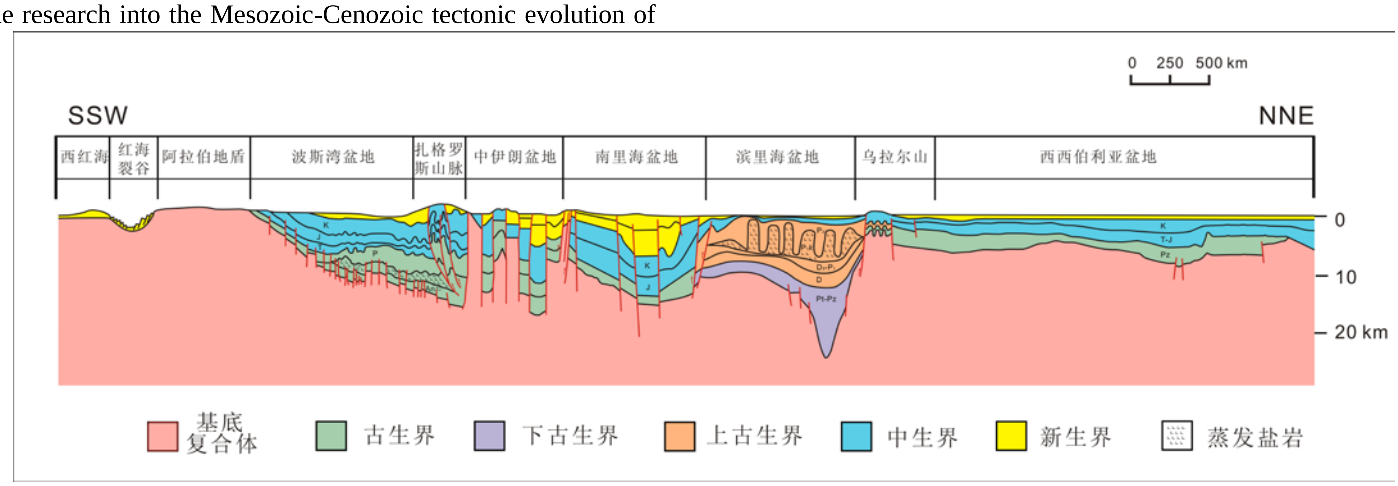
The global plate tectonic framework and activities control the formation and evolution of the sedimentary basins and also affect their characteristics and hydrocarbon resources. With an eye on the evolution of the tectonic setting, the Section, which extends thousands of kilometers from northeast fringe of the African Plate to Kara Sea, was drawn to combine the macroscale plate movements and mesoscale basin evolution analysis in order to predict the hydrocarbon resources potential. The SSW-NNE trending Section, crossing four giant oil and gas basins, including Persian Gulf Basin, South Caspian Basin, Precaspian Basin and West Siberian Basin, gives contribute to the research into the Mesozoic-Cenozoic tectonic evolution of Central Asian-Middle East area. The path of the Section involves three plates and two kinds of boundaries, which may clearly reveal the space-time overlay relations of multiple tectonic units. On this basis, through the analysis of subsidence and evolution history of the basins, it has been found that evolution sequences of basin groups encompass almost all basin types in the Wilson cycle. Considering most basins have good or even excellent prospects for oil and gas and differential hydrocarbon accumulation factors, it is believed that rigidly apply the type of a discovered rich oil or gas basin to future exploration may not be universal.



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Genesis of the Chang'an Gold Ore Deposit, in Western Yunnan and Regional Metallogenic Implication: Constraints from Ore Deposit Geology, Fluid Inclusions and Stable Isotopes

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The Ailaoshan metallogenic belt is an important polymetallic mineralization province, located in southwestern Yunnan where the Indian-Eurasian plate interaction has intensive effects. During the post-collisional extension, many high potassium alkaline intrusions were formed in the Ailaoshan area. Related to the event, there occurred intensive mineralization, forming numerous ore deposits. This paper focuses on an epithermal-porphyry-skarn type Cu-Mo-Au mineralization system, located at the Tongchang area, Jingping, in the southern segment of the Ailaoshan metallogenic belt. In this mineralization system, the ore bodies of Chang'an gold ore deposit are preserved in fractured Ordovician sedimentary clastic rocks. The gold-bearing minerals occur dominantly in sulfide-quartz veins. Fluid inclusion analysis shows that the Chang'an gold ore deposit is characterized by epithermal gold mineralization at temperatures between 200 and 280℃ at shallow crustal level. The mineralizing fluids had intermediate to low salinity (6~18%) and low densities (0.72~1.27g/cm^3). The ore minerals have $\delta^{34}S$ in the range of -13‰~3.57‰, concentrated at -2.06‰~3.57‰ with an average of 1.55‰. The $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and 208Pb/204Pb are 18.9977~19.5748, 15.7093~15.784, 39.3814~40.2004 respectively. These isotope data suggest that the ore-forming elements were mainly derived from mixed crustal and mantle sources. The Tongchang deposit is a typical porphyry-skarn Cu-Mo deposit, which constitutes part of an epithermal-porphyry-skarn type Cu-Mo-Au mineralization system with the Chang'an gold ore deposit in Tongchang-Chang'an area.
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The Tongchang-Chang'an mineralization system is genetically related to the Cenozoic high-K alkaline magmatism, which shows similar characteristics to those from the Machangqing Cu-Mo-Au mineralization province along the Ailaoshan-Red River shear zone. Based on comparative studies, the two ore-forming systems were suggested to be formed in the same mineralization province, and are transformed to form separate mineralization provinces by left-lateral strike-slipping along the Ailaoshan ductile shear zone since ca. 28 Ma.

Keywords: Chang'an gold ore deposit, Ailaoshan metallogenic belt, high potassic alkaline magmatism, Cu-Mo-Au mineralization system, Western Yunnan

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SS03-P-6

Numerical Sandbox Modeling of an Orogenic Wedge Evolution Using Distinct Element Method: Exploring New Possibilities

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Orogenic belts are relatively narrow zones on earth's crust that preserve evidences for major parts of crustal deformation. Since Chapple (1978) and Davis et al. (1983), large scale dynamic evolution of orogenic belts has broadly been explained by Critical taper theory. Especially analog experiments such as sandbox experiments (e.g. Davis et al., 1983; Marshak and Wilkerson, 1992; Mandal et al., 1997) have further provided mechanism of large-scale evolution of orogenic belts. However, these analog experiments are hard to provide quantitative information such as stress field that is vital for mechanical interpretations during evolution of an orogenic wedge.

We have used distinct element method (DEM; Itasca, 1999) for the simulation of sandbox, thus numerical sandbox, for explaining (1) the effect of pre-deformational basal slope on the evolution of orogenic belts, and (2) the effect of mechanical stratigraphy for the development of different structural styles (Fault Bend Fold vs. Fault Propagation Fold). DEM is a method for solving mechanical problems of discontinuum. It consists of particulate data structures and boundary-condition elements. Stored energy in elastically compressed particles with Hookean or Hertzian force-displacement relation is a driving force for motions of particles. The biggest advantages of numerical sandbox experiments over physical sandbox experiments are that mechanical information such as force and/or stress can be numerically measured. The measured mechanical information can be combined with kinematic observations for the 'full' interpretation of orogenic belt evolution.

From the experiments related to the effects of basal slope during the orogenic wedge evolution, it is found that the sum of topographic slope and decollement dip (critical taper angle) remains constant while decollement dip varies from 0 to 10 degrees as suggested by Mohr-Coulomb wedge model of Davis et al. (1983). However, a slight rate-dependence of the summed angle is observed as we change the velocity of backstop, and we are currently testing the material properties of the wedge. From the experiments related to the effect of mechanical stratigraphy, we found that relatively stronger wedges consisting of stronger contact bonds between the balls shows fault bend fold style structural development, while weaker wedges are evolved by fault propagation folding, and both of them are commonly observed in many orogenic belts (e.g. Sevier fold-thrust belt of western US).

We believe that quantitative information on the kinematics and mechanics of orogenic wedge evolution from the numerical sandbox experiments will be exciting as the former findings from physical sandbox experiments are later recognized to be directly applicable for the interpretation of natural fold-thrust belts evolution.

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SS03-P-7

Salt Tectonics and its Deformation Mechanism in Kuqa Fold Thrust Belt, Tarim Basin, Northwest China

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Salt tectonics is one of the most important aspects in structural geology, and plays a great role on hydrocarbon exploration. Many giant oil and gas fields in the world are located in salt basins. Kuqa Foreland Thrust Belt (KFTB) is abundant oil and gas bearing structure units in Tarim Basin and several giant gas fields including KL2 and DN2 were discovered under the salt. It is of great significance for oil and gas exploration to research salt tectonics in KFTB. Although many geoscientists have done a lot of works on it, the pattern of salt tectonics is still unclear due to poor seismic quality.

Two layers of salt were developed in the Kuqa Fold Thrust Belt: Paleogene Kumugeliemu Group (K G.) in the west and Neocene Jidike Formation (J F.) in the east. And K. G. salt is thicker and more extensive than J. F. salt. Based on field investigation and seismic interpretations, salt sheet, salt diapir, salt wall, salt nappe and salt anticline, have been recognized in The KFTB. Salt anticlines are located undersurface, while salt sheets, salt diapirs, salt wall and salt nappe are exposure. Salt anticlines are the most widespread salt structure, and they are developed in both K. G. and J. F. salt. The other salt structures are restricted distributed and only developed in the west part of KFTB within K. G. salt. Most of salt diapirs are developed along Kalayuergun Strike-slip fault. The salt wall and salt nappe are developed accompanying thrust fault.

There are three forces driving salt flowing in KFTB: differentia loading, compress stress and Strike-slip stress. In KFTB Cenozoic sedimentary is inhomogeneity, therefore differentia loading is common during the development of salt structures. The most important driving force for salt structures development in KFTB is the N-S compress stress. The salt anticlines and nappe were formed by it. The effect of strike-slip stress is limited and it only affects the areas nearby Kalayuergun Strike-slip Fault. The tensile stress associated with strike-slip fault creates the diapirs of Dongawate and Baozidong salt diapirs.

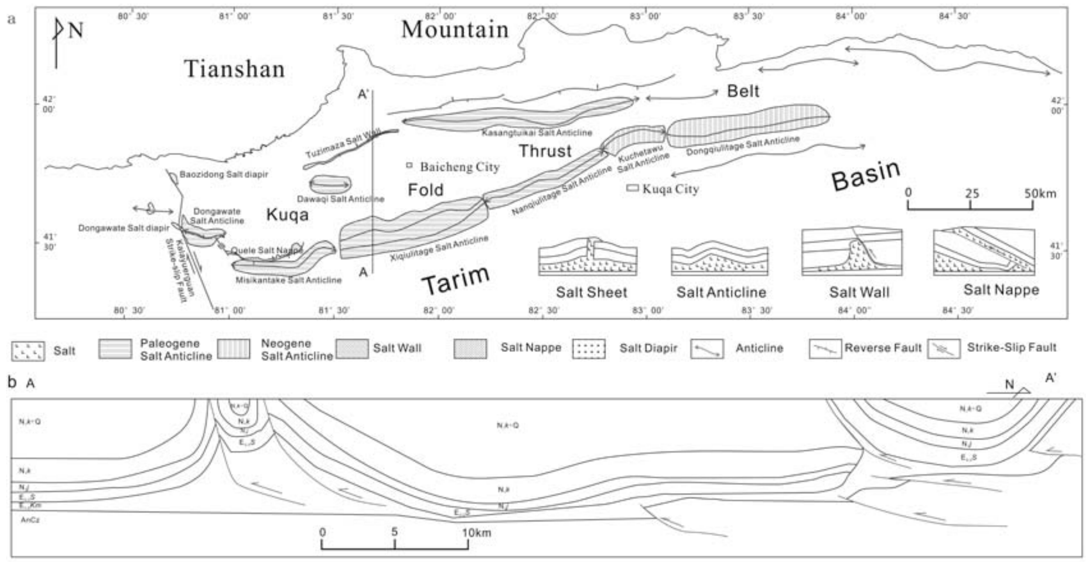

Fig. a. Distribution of different type of salt tectonics in the Kuqa Fold Thrust Belt
b. Cross section of the Kuqa Fold Thrust Belt

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SS03-P-8

The Characteristics and the Formation of Typical Salt Tectonics on the Surface in Kuqa Depression, Tarim Basin

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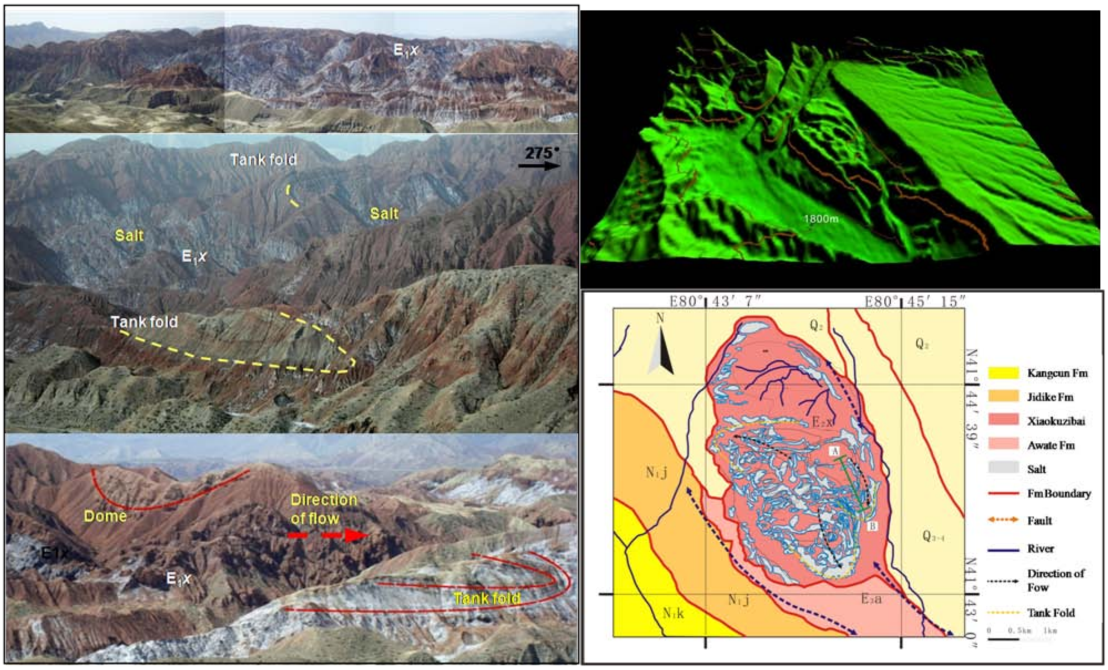
The salt tectonics in Kuqa Depression is one of the most typical salt structures in the world. It developed in a dry environment at the edge of Taklimakan Desert in central Asia, less affected by rainfall, so salt related landscape on the surface has been preserved a complete record of the movement of salt from the end of diapirism to the surface. Salt exposes in the area, with good conditions for field observations. Salt tectonics on the surface is recognized as the window to understand the formation of salt structures underground developing to salt tectonics on the surface and development of the whole process of the salt tectonics. And it can be a guide on the seismic profiles interpretation.Through the observation in the field and the interpretation of remote sensing image, we systematicly study the formation of salt flow structures in the area. In the west of Kuqa depression, we have found 2 salt sheet: Bozidun sheet and Dongawate sheet. Tank fold is a typical salt tectonics on the surface in the area. Initially, salt diapires from underground to the surface, then the salt under the action of gravity, flows from the height to the lower; in the process flow stream due to salt away, making the load of the top of salt diapirism decrease, thus contributing to salt upward extrusion, which provide an endless source of material to make salt flow to the lower . With the upward out of salt from underground, the early flow constantly is covered by late flow, then from the source to the lower layer makes up a salt-foot structure. Ultimately, it forms a large-scale salt sheet on the surface. The shape of salt sheet can be different due to the landscapes. Restrictions on the movement of salt, there are two main factors: the strength of cover and the friction of the edge of salt sheet.

Keywords: Kuqa Depression; Salt tectonics; Formation mechanism; Tank fold; Salt diapirism



Bozidun sheet and tank fold

Tank fold in Xiqiu Structure belt

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SS04-P-1

Sa Kaeo – Chanthaburi Accretionary Complex, Eastern Thailand

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Southeast Asia is an assembly of many continental blocks bounded by suture zones. The suture zone between Sibumasu (Shan-Thai) and Indochina blocks in Thailand is separated into two segments, Nan–Uttaradit to the north and Sa Kaeo–Chanthaburi to the south. Here we confine our study mainly to the southern segment area. The Sa Kaeo–Chanthaburi Accretionary Complex (SKCB-AC) constitutes the southeastern margin of Thailand and is extended from the southern part of Sa Kaeo province to the northern part of Chanthaburi province near the border line between Thailand and Cambodia. The SKCB-AC consists mainly two kinds of rock assemblages, mélange of oceanic plate material and covering sediment of turbiditic sequence. The mélange is traceable for a hundred of kilometers along the strike with up to tens of kilometer wide and contains a diverse rock blocks of various sizes set in a chaotically mixed pelitic matrix. Limestone blocks show typical karst topography and are generally fossiliferous. The fusulinacean fossils from limestones of different localities indicate Lower to Upper Permian age (Hada et al., 1999). Chert blocks vary from reddish brown, grey to green color. Radiolarians are abundant in cherts and are reported as Early to Late Permian age (Hada et al., 1999).

We have undertaken reconnaissance study of rocks (serpentinite, basalt, granite) in the mélange. The **serpentinites** compose mainly of serpentine pseudomorphed after pyroxene and minor pyroxene, chlorite and dolomite. Chromite and magnetite are the major opaques. Chondrite-normalized REE patterns vary from LREE-depleted (with La of 0.06x to 0.1x Chondrite) to LREE-enriched (with La of 0.2x to 0.8x Chondrite), reflecting some overprinting by secondary process. Such feature, together with the absence of chromian spinel and the presence of ferritchromite suggests the studied ultramafic rocks have not preserved their original characteristics even if they have been formed in the mantle. The **basalts** are porphyritic with plagioclase and clinopyroxene phenocrysts set in a fine-grained matrix of plagioclase, pyroxene and opaques. Major elements contents of SiO_2 are 46.8 – 50.6 wt% and total alkalis 3.6 – 4.8 wt% with $Na_2O > K_2O$. They belong to alkali basalts and have LREE-enriched REE pattern. The present epsilon Nd value is +4.5 – +5.9. The TiO_2-MnO-P_2O_5 tectonic discrimination diagram of Mullen (1983), together with the spider diagram showing the peaks at Nb and Ta and trough at K, indicates that the basalts represent oceanic island alkali basalt. The **granite** contains quartz, orthoclase, plagioclase, brown biotite and greenish brown amphibole. It is metaluminous (A/CNK = 0.95) and shows LREE-enriched REE pattern with negative Eu anomaly. The present epsilon Nd value is +0.5. In the primitive-mantle normalized spidergram, the granite displays enrichment in LILE (e.g. Rb, Th, U, K) and prominent negative Ba, Nb, Ta, Sr, P and Ti anomalies. In the Rb vs. (Y+Nb) diagram of Pearce et al. (1984), the granite plots in the VAG field. Thus, this granite represents subduction-related volcanic arc granite. All the information suggests rocks from SKCB-AC represent offscraped blocks from subducted oceanic crust and the remnant of subduction magmatism.

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SS05-P-1

Division and Distribution Characteristics of Neogene Seismic Strata Sequence, Northern East China Sea Shelf Basin

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Based on a comprehensive analysis of some new single-track seismic profiles and logging data, the Neogene seismic strata sequences of the northern East China Sea Shelf Basin are divided using the conception of sequence. In the study area, fourteen interfaces, including T_0, T_1^1, T_1^2, T_1^3, T_1^4, T_1^5, T_1^6, T_1^7, T_1^8, T_1^9, T_1, T_2^1, T_2, T_g, can be classified on the seismic profile. T_0 is the sea floor boundary. T_1^1-T_1^9 are internal boundaries in Quaternary. T_1 is the bottom boundary of Quaternary and T_2^1 is an internal boundary in Pliocene. T_2 and T_g are respectively the bottom boundaries of Pliocene and Miocene. T_1, T_2 and T_g are third-order sequence boundaries. Accordingly, the strata can be subdivided into 3 third-order sequences (Ⅰ, Ⅱ, Ⅲ) and 12 parasequences.

Sequence Ⅰ, between T_0 and T1, is composed of Quaternary, interbeded with marine facies and terrestrial facies, 2 to 600m in thickness, which enlarges from northwest to southeast. Sequence Ⅱ, between T_1 and T_2, is composed of Pliocene ranging from 8 to 940m in thickness, which become thicker and thicker from west to east. Sequence Ⅲ, between T_2 and T_g, is composed of Miocene, 6 to 1400m in thickness, which is controlled by growth faults, enlarged from east to west. The research indicates that the sedimentation centers shift from west to east since Miocene.

Keywords: seismic sequence; Neogene; Quaternary; East China Sea Shelf Basin

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SS05-P-2

Gravity and Magnetic Fields and Deep Structure of the Lile Basin, South China Sea

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Lile Basin is an important area at the Nansha and its adjacent area because of its special structural style and preferable potential of oil-gas resources. There are few documents on the basin, and the research on the deep structures is also rare because of the shortage of the marine geological survey data. This paper has collected the new data of $1' \times 1'$ satellite altimeter gravity anomaly and magnetic anomaly, analyzing the characters of the geophysical fields of the Lile Basin. We obtain various information on the deep structure by means of analytical continuation, target field extraction, discrete wavelet transform processing, inverted the buried depth of the top-surface magnetic basement and the Moho depth. The L1 line seismic profile across the Lile Basin is to establish the initial model and to perform 2.5D gravity-magnetic-seismic-coupled inversion, iterative fitting, and to finally obtain the geophysical parameters of various modules and their distribution. Based on these processing, the character of the deep structure is revealed. All the research is an essential foundation for the further research on the deep structures of the Lile Basin.

Keywords: Lile Basin; gravity and magnetic fields; deep structure; Gravity-magnetic-seismic inversion

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SS05-P-3

Role of the Nansha Micro-Plate in the Process of Gondwana's Disintegration and Asian Accretion

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Nansha Micro-plate, located in the southern South China Sea, is a small Cenozoic lithospheric plate with pre-Mesozoic basements and Meso-Cenozoic marine sedimentary cover-strata. It is buildup by bloks as following: Cenozoic oceanic lithosphere block of the South China Sea, south of Changlong-Huangyan seamount clain, in north; Nansha (Zengmu-Zhenghe-Liyue-Palawan) pre-Cenozoic thinned continentalcrust blolk，in mid; and pre-Cenozoic paleo-South China Sea lithospheric block southward subducting along the Nansha trough, in south. The Red River-East Vietnam-Wan'na strike-slip fault zone and the Manila trench-Panay over-crustal compressive sinistral strike-slip fault zone are the westren and eastern boundaries of the Nansha Micro-plate, respectively.

The core part of the Nansha Micro-plate, Zhenghe-Andu-Liyue-North Palawan-Mindoro continental block, as the southern part of the Qiongnan Block, was located on the southern margin of the Paleo-Tethys, i.e., the northern part of the Gondwana continent, in the Late Paleozoic Era. At the beginning of the Late Permian, the whole of the Qiongnan Block began to split from northmargin of Australia on the northern part of the Gandwana continent; accompanied by a series of tectonic events such as: the Meso-Tethys developped gradually between the Qiongnan Block and the Australia of the Gandwana; the Qiongnan Block northwards drifted due to the North-South spreading of the paleo-Tethys; the Qiongnan Basin, the eastern section of the Paleo-Tethyan major oceanic basin, unceasingly northwards subducted under margin of South China Continent and caused the Qiongnan Block was progressively closed to the South China Continent. Up until the end of the Mid-Triassic, with the terminal subduction of the Qiongnan Basin, which had sostenuto been for 150 Ma, the Qiongnan Block began to collide and suture with the Qiongzhong Block, and as the result, "the Qiongnan suture zone" was formed and represented by the E-W Jiusuo-Lingshui fault zone. A N-S "Proto-Zhongnan Tranform Fault" which maybe developped in the Meso-Tethys, divided the Nansha Micro-plate into eastern and western parts, called the western part as "Zhenghe-Andu Block" ("Zhenghe" for short) which still connected with the Sanya- Xisha-Zhongsha Block in the north, and the eastern part as "Liyue-North Balawan-Mindoro Block"("Liyue" for short). The part of the Paleo-Tethys Basin on the north of the Liyue Block had not subducted completely in the end of the Mid-Triassic and became a relic basin of the Paleo-Tethys (called as "North Liyue Proto-Meso-Tethyal Subbasin") which continuously received the marine sediments of the Meso-Tethyan period, as the same as that on the Liyue Block. Up to the beginning of the Yanshan movement in the Mid-Jurassic, the Meso-Tethys on the south of the Liyue Block continuously northwards spreaded and caused the North Liyue Proto-Meso-Tethyal Subbasin northwards subducted again and finished the subduction at the end of the Yanshan Movment in the Early Cretaceous. Then, the Liyue Block collided with the South China Continent, and became a accreted block of the soueastern margin of Asian Continent. Thus, in this region, the subduction-collision compressive tectonic regime since the Late Paleozoic was over, and was replaced by the extension-rifting-spreading tectonic regime of the South China continental margin since the Late Cretaceous. The Zhenghe-Liyue block gradually southwards abrupted away from the South China margin and brought on the contemporary South China Sea floor to start spreading in the north of the Zhenghe-Liyue block in the Late Oligocene; and the Nansha Micro-plate came into being. With the southwards spreading of the South China Sea, the Nansha Micro-plate continuously southwards drifted, and on the south, compelled the Meso-Tethys (Paleo-South China Sea) oceanic crust southwards subducted under Kalimantan Island. Echo for this from afar in the southern margin of the Meso-Tethys, the Australia Plate northwards drifted due to the driving of the N-S-trend spreading of the Southeast Indian oceanic floor, and the N-S-trend spread of the Meso-Tethyan oceanic floor in the north of Australia Plate constinued until 32 Ma ago and stopped the spread at that time. Then, the Meso-Neo- Tethyan oceanic crust in the north of the Australia Plate northwards subducted along the Java-Banda Trench. The opposite-diretion subduction of the southern and northern margins of the Southeast Asian Meso-Neo-Tethys oceanic floor have lasted by this time. It can be foretold that with the continuous spread of the Southeast Indian Ocean, the Australia Plate will continuously northwards drift; the Meso-Neo-Tethys of Souteast Asian Oceanic crust will certainly be entirely disappead; the Australia Plate also will entirly collide with the southeastern Asian Continent; the South China Sea will be closed; and the Nansha Micro-plate will again be put together with the southern margin of South China, eastern Asia.

This study was jointly funded by the State Fund for Natural Science of China (No.40976029) and the National Basic Research Program of China (973) (2009CB2194 and 2007CB411700).

Keywords: Nansha micro-plate; Gondwana’s disintegration；Asia’s accretion；North Liyue Paleo-Meso-Tethyan subbasin；Proto-South China Sea of eastern Meso-Tethyan major-basin；Proto-Zhongnan tranform fault.

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SS06-P-1

A Preliminary Report on the Yunxi-Suizhou Ophiolitic MÉLange in Hubei Province, Southern China

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The Yunxi- Suizhou belt, which is composed of low- grade meta- sedimentary and mafic-ultramafic magmatic rocks, occurs in a NWW trend with ~390 km length and 40 ~ 100 km width in the southern flank of Qinling-Dabie orogenic belt. There exists several hundreds blocks of mafic or ultramafic rocks. Traditionally, these rocks are interpreted as intrusive plutons and represent the rifting event along the southern margin of Qinling belt in late Proterozoic. However, Wang and Liu (2010) recognized that the mafic and ultramafic rocks in Yunxi-Suizhou belt does not exhibit intrusive occurrence, but they are exotic blocks occurred in flysch deposits by structural process. They interpret the Yunxi-Suizhou belt as mélange. Our reconnaissance survey in the belt support Wang and Liu's (2010) opinion. The field observations show that: (1) there are not chilled margins around the mafic blocks and not thermal contact metamorphic zone in the host rocks; (2) there are some plagioclase-granite veins injected mafic rocks, but these veins do not intrude into the host metasedimentary rocks; (3) the host rock do not been captured by mafic or ultramafic rocks; (4) both of the mafic and host rocks experienced strong shearing deformation. The preliminary investigation on the geochemistry of the mafic rocks in Yunxi-Suizhou belt shows tholeiitic basalt affinity and relative low REE abundance. The REE normalized curves of gabbros exhibit concave shape. Some basalts have flat REE curves, but another mafic rocks exhibit arc signature in spider diagram. The $\varepsilon_{\rm Nd}(t)$ values of mafic rocks are in range of -4 ~ +3. We interpret the mafic rocks in Yunxi-Suizhou belt as the dismembered ophiolite. The ultramafic rocks belong to the mantle part of ophiolite sequence, the gabbros are the cumulate complex. The ophiolitic suite is generated in SSZ environment as suggested by their geochemistry. The host metasedimentary rocks, which are formly named as Wudangshan Group and Suixian Group, are not stratigraphic sequences but mélange. Accordingly, the Yunxi-Suizhou belt is an accretionary wedge located between the southern margin of Qinling-Dabie orogenic belt and northern margin of Yangtze craton. The age of emplacement of Yunxi-Suizhou ophiolitic mélange is still unclear, but maybe occurred in late Paleozoic to early Mesozoic during the northward subduction of Tethys oceanic plate beneath North China craton.

This study is supported by the Fundamental Research Funds for the Central Universities (No. 2010ZY23 and 2010ZD15) and NSFC (No.90814006, 40572128, 40376013, 40104003).

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SS06-O-2

The Time Constraints, Tectonic Setting of Dalabute Ophiolitic Complex and its Significance for Late Paleozoic Tectonic Evolution in West Junggar

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Yegezikala granite situated near Saertuohai, one typical stitching pluton, intruded into Dalabute ophiolitic complex. The SHRIMP zircon U-Pb dating results of Yegezikala granite yield an age of 308±3Ma (MSWD＝0.83), which indicates the emplacement of Dalabute Ophiolite might be before 308Ma. Due to the formation age of gabbros (Sm-Nd isochron age 395Ma, LA-ICP-MS zircon U-Pb age 391Ma) in Dalabute ophiolite, the formation age of Dalabute ophiolite is well constrained. Both sides of Dalabute Ophiolite are Lower Carboniferous Volcanic-sedimentary strata with continuous strata sequences and comparatively distinct rock associations, so Dalabute ophiolite is not a suture zone(Fig. 1). Integrating the previously proposed tectonic models such as slab window and accretionary wedge, we infer that late Paleozoic tectonic evolution in West Junggar is dominated by the passive basin filling in the residual paleo-oceanic basin and the Paleozoic accretion accompanied by subduction of paleo-oceanic crust in West Junggar ceased before Late Carboniferous determined by the stitching granites and diorite dykes.

Keywords: West Junggar; Dalabute ophiolitic complex; Stitching pluton; Late Paleozoic; tectonic evolution

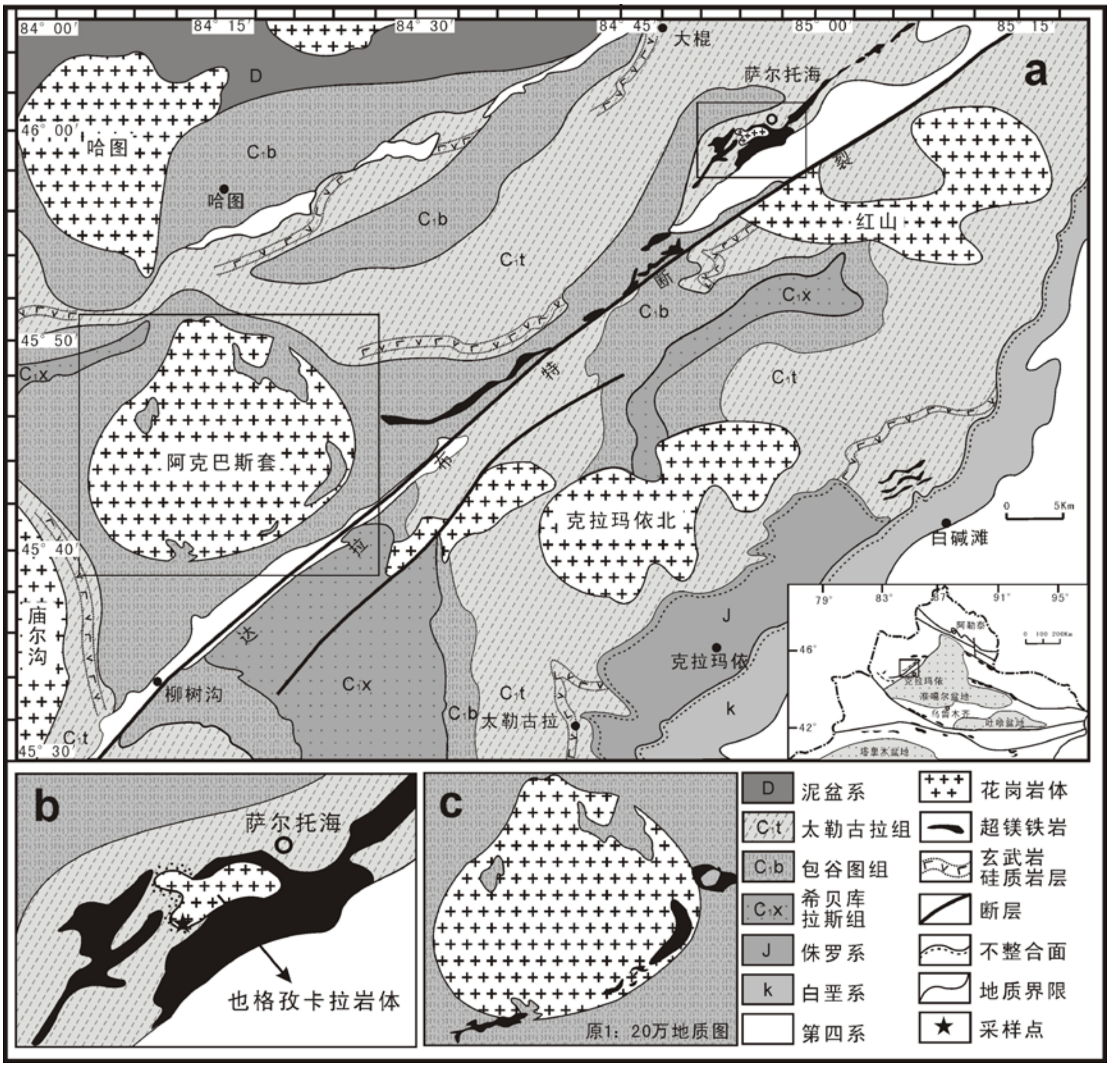

Fig.1 Tectonic and geological sketch map of West Junggar

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Timing of the Basement Rocks of the Argun Massif in Northern Great Hinggan Range and its Tectonic Implications: Evidence from Zircon SHRIMP U-Pb Ages

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The Argun massif (also spelled as the Erguna massif in Chinese literature), located in the northern Great Hinggan Range, is one of the key tectonic units in the Central Asian Orogenic Belt. The formation age of the basement rocks of the Argun massif is still an issue of hot debates. This paper presents zircon SHRIMP U-Pb ages obtained for four samples from the basement rocks of the Argun massif, and discusses their tectonic implications.

Samples HP28 and HPB3-6 from the Xinghuadukou Group are two-mica quartz schist and biotite plagiogneiss, respectively. The protolith of the former is terrestrial clastic sediment. A total of 15 analyses were conducted for the sample. Among them, twelve analyses yield $^{207}Pb/^{206}Pb$ ages from 854±34 to 1204±62 Ma; two zircons yield $^{207}Pb/^{206}Pb$ ages of 2367±12 and 2519±11 Ma, respectively; and one yields a $^{206}Pb/^{238}U$ age of 249±13 Ma. The protolith of the latter is likely a pelitic-sandy sedimentary rock. A total of 18 zircons were analyzed for the sample. Among them, fourteen analyses define $^{207}Pb/^{206}Pb$ ages ranging from 825±15 to 1099±38 Ma; three zircons yield $^{207}Pb/^{206}Pb$ ages from 1942±12 to 2263±29 Ma; and one gives a $^{207}Pb/^{206}Pb$ age of 1324±87 Ma. We interpret these ages to be overall detrital zircon age. The majority of ages range from 854±34 to 1204±62 Ma for the sample HP28, and from 825±15 to 1099±38 Ma for the sample HPB3-6, respectively, implying that the metamorphosed sediments were mainly eroded from a lithologic source with ages between 825 and 1204 Ma. Five oldest zircons with ages from 1942±12 to 2519±11 Ma might come from a pre-1.94 Ga continental crust, or from granitoids of 825 – 1204 Ma in which a few of zircons inherited from a pre-1.94 Ga continental crust. The youngest age of 249±13 Ma is interpreted as a consequence of disturbance by the Late Variscan magmatic-thermal event. Samples ML7 and ML14 are quartz diorite and monzogranite from the basement rocks of the Argun massif, respectively. Ten zircon analyses for sample ML-7 yield $^{206}Pb/^{238}U$ ages from 503 to 527 Ma, with a weighted mean age of 517±9 Ma. Twelve zircon analyses for sample ML-14 give $^{206}Pb/^{238}U$ ages ranging from 492 to 518 Ma, with a weighted mean age of 504±8Ma. The ages of 517±9 and 504±8 Ma are considered as the crystallization time of the quartz diorite and monzogranite, respectively.

The geochronological data introduced above provide important constraints on the timing of the basement rocks of the Argun massif, and lead us to draw the following conclusions: (1) the Xinghuadukou Group was deposited in middle-late Neoproterozoic (at least < 825 Ma), rather than Paleoproterozoic time as previously thought, and mainly sourced from a granitic provenance with ages mainly of 825 – 1204 Ma; (2) these granitoids of 504 – 517 Ma discovered in studied area imply that the Argun massif had accreted to south margin of the Siberian craton by Salair orogeny; (3) the Xinghuadukou Group volcano- sedimentary sequences formed in a passive continental margin setting. Therefore, the Argun massif essentially belongs to part of the Salair orogen, rather than an ancient massif with Early Precambrian crystalline basement.

Keywords: Xinghuadukou Group; Early Paleozoic granitoids; Zircon SHRIMP U-Pb dating; Argun massif; NE China

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SS06-P-4

Late Paleozoic Tectonic Evolution of the Eastern Section of the Northern Margin of the North China Craton: Constraints from the Permian Volcanism in the Middle Jilin Province, NE China

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The middle Jilin province, NE China, is located in the eastern section of the northern margin of the North China Craton (NCC), i.e., the southern margin of the Xing-Meng (Xing'an Ranges and Mongolia) Orogenic Belt (XMOB) (Sengör et al., 1993). For a long time, the late Paleozoic tectonic evolution of the eastern section of the northern margin of the NCC has been a controversial issue. However, the Permian volcanism in the middle Jilin province provides insights into the late Paleozoic tectonic evolution of the eastern section of the northern margin of the NCC.

The late Paleozoic volcanic rocks in the middle Jilin province occur in the Daheshen Formation and consist mainly of andesite and rhyolite association. LA-ICP-MS zircon U-Pb dating results from the rhyolite indicate that the rhyolite was formed in the Early Permian (279Ma), which is consistent with the age of the paleontologic of the Daheshen Formation (Mi Jiarong and Liu Maoqiang, 1985).

Andesites in the Daheshen Formation have SiO_2 = 55.72% ~ 55.83%, MgO = 4.30% ~ 4.33%, Mg# [Mg# = 100Mg/ (Mg+ Fe_{tot}^{2+})] = 50, Na_2O = 3.98% ~ 4.02%, K_2O = 2.32% ~ 2.34%, and their Na_2O/K_2O values range from 1.70 to 1.73. Compared with the andesites, the rhyolites are characterized by high SiO_2 (71.94% ~ 75.38%) and K_2O contents (4.42% ~ 4.60%), low MgO contents (0.81% ~ 0.95%) and Na_2O/K_2O values (0.55 ~ 0.59). Chemically, the volcanic rocks (andesites and rhyolites) in the Daheshen Formation belong to subalkalic high-K calc-alkaline series.

On the chondrite-normalized rare earth element (REE) and the primitive mantle-normalized spider diagrams, andesites and rhyolites display enrichment in light rare earth elements (LREEs) and large ion lithophile elements (LILEs; e.g., Rb, Ba, Th, U and K), depletion in heavy rare earth elements (HREEs) and high field strength elements (HFSEs; e.g., Nb, Ta and Ti) and P, and have weak negative Eu anomalies, which are similar to the volcanic rocks from an active continental margin setting (Kelemen et al., 2003).

Based on the geochronological, rock association, and geochemical characteristics of the volcanic rocks in the Daheshen Formation in the middle Jilin province, and combining with regional tectonic setting, we propose that the subduction of the Paleo-Asian oceanic plate beneath the the eastern section of the northern margin of the NCC happened in the Early Permian and resulted in the formation of the Late Paleozoic accretion belt in the northern continental margin of the NCC.

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SS06-P-5

The Timing and Origin of the Retrograde Partial Melting in the Sulu UHP Metamorphic Terrane, China

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During the subduction of oceanic crusts, abundant aqueous fluids can be liberated from hydrated oceanic crust and rise into the overlying mantle wedge. This process can be applied to explain the partial melting of the mantle wedge, which generates arc magmatism. In contrast to the situation of the oceanic crusts, the continental crusts are rather dry and buoyant. During the subduction of continental crust, volatile and water are commonly constrained within hydrous and nominally anhydrous minerals, which could remain stable at very high pressure, and are carried into the mantle. The widespread occurrence of coesite in the UHP metamorphic rocks in the Sulu terrane suggests a rapid exhumation process and a "dry" condition. However, at present, the exhumation process of deep subducted continental crust is not yet well disclosed. In Sulu UHP terrane, occurrence of leuogranite veins, migmatites and zoisite-kyanite-paragonite quartz veins has been documented in the recent years. Here we present field observations, P-T path, U-Pb dating and Sr-Nd-Hf isotopic analyses of these veins or migmatites, to inquire into the timing, origin and geological significance of possible partial melting process during the early stage of exhumation of the deep subducted continental crust.

In the Qinglongshan area, some zoisite-kyanite-paragonite quartz veins occur in epidote-bearing eclogite. Petrographic and Nd isotopic studies suggest these should be products of dehydration of former lawsonite in eclogite. Zircons from the vein give a SHRIMP U-Pb age of 219 ± 9Ma. The cores and rims of the zircons from the country gneiss of the epidote-bearing eclogite show irregular patch structures and oscillatory zonings, respectively. Although they show different Hf isotopic characters, the different domains of these zircons give a conformable age of 218 ± 5 Ma. This implies that an aqueous fluid activity occur at 218-219Ma.

In the Weihai area, the UHP metamorphic rocks suffered granulite facies metamorphism during the exhumation process and were dominated by the regional widespread migmatization in the later stage. A pegmatite vein within gneiss from the Weihai area gives two zircon SHRIMP U-Pb ages of 221± 7Ma and 199± 3Ma. The rims of zircons from the country gneiss yield age of 195 ± 4 Ma. Conformable zircon Hf isotopic values in the pegmatite and the country gneiss indicate a genetic relationship. We interpret the age of 221 Ma as the time of pegmatite crystallization and 199 Ma as the timing of partial melting of the country gneiss intruded by the pegmatite.

In the Rongcheng area, both dark gneiss and pale gneiss in a migmatite domain have protolith ages of ca 780Ma. The mantle and rim domains of zircon from the pale gneisses show CL features of metamorphism and partial melting origin, respectively. Their ages of 242 ± 9 Ma and 220 ± 4 Ma can be regarded as the time of peak metamorphism and partial melting of the pale gneiss.

In conclusion, low degree of partial melting of granitic gneiss after the UHP metamorphism was observed in the Sulu UHP terrane, especially in the northern Sulu terrane. This is induced by the fluid/melt activities related to the deep subduction of the continental materials and might help to explain the fast exhumation of the UHP metamorphic rocks.

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Tectonic Setting of the South China Block in the Early Paleozoic: Resolving Intracontinental and Ocean Closure Models from Detritalzircon U-Pb Geochronology

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Zircon U-Pb geochronological data on over 900 zircon grains for Cambrian to Silurian sandstone samples from the South China Block constrain the pre-Devonian tectonic setting of, and the interrelationships between, the constituent Cathaysian and Yangtze Blocks. Zircons range in age from 3335 Ma to 465 Ma. Analyses from the Cathaysian sandstone samples yield major age clusters at ~2560 Ma, ~1850 Ma, ~1000 Ma and 890-760 Ma. Zircons from the eastern and central Yangtze sandstone samples show a similar age distribution with clusters at ~2550 Ma, ~1860 Ma, ~1100 Ma and ~860-780 Ma. A minor peak at around 1450 Ma is also observed in the Cathaysian and central Yangtze age-spectra, and a peak at ~490 Ma represents magmatic zircons from Middle Ordovician sandstone in the eastern Yangtze and Cathaysian Blocks. The Cambrian and Ordovician strata show a transition from a carbonate-dominated succession in the central Yangtze Block, to an interstratified carbonate-siliciclastic succession in the eastern Yangtze Block, to a neritic siliciclastic succession in the Cathaysia Block. Paleocurrent data across this succession consistently indicate directions toward the W-NNW, from the Cathaysian Block to the Yangtze Block. Our data, together with other geological constraints, suggest that the Cathaysian Block constitutes a fragment on the northern margin of East Gondwana and both Cathaysian and East Gondwana constituted the source for the analyzed early Paleozoic samples. The similar age spectra for the Cambrian to Silurian sandstone samples from the Yangtze and Cathaysian Blocks argue against the independent development and spatial separation of these blocks in the early Paleozoic, but rather suggest that the sandstone units accumulated in an intracontinental basin that spanned both Blocks. Subsequent basin inversion and Kwangsian orogenesis at 400-460 Ma also occurred in an intracontinental setting probably in response to the interaction of the South China Block with the Australian-Indian margin of east Gondwana.

Keywords: zircon U-Pb geochronology; early Paleozoic sandstone; provenance supply, South China Block, east Gondwanaland.

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Petrogenesis of Late Triassic Post-Collisional Basaltic Rocks of the Lancangjiang Tectonic Zone, Southwest China, and Tectonic Implications for the Evolution of the Eastern Paleotethys: Geochronological and Geochemical Constraints

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The Xiaodingxi and Manghuihe volcanic sequences represent the key components of the Lancangjiang igneous zone in southwest China. Their petrogenesis can provide an important constraint on the tectonic evolution of the eastern Paleotethys ocean. The basaltic rocks from the Xiaodingxi and Manghuihe sequences yielded the SHRIMP zircon U-Pb weighted mean ages of 214±7 Ma and 210±22 Ma, respectively, which is 15-20 Ma young than the ages of the syn-collisional granite magmatism (230-241 Ma). Samples from the volcanic sequences are dominated by alkaline basalts and basaltic andesites, and can be geochemically classified into two groups. Group 1 samples, mainly from the Xiaodingxi sequence and the lower part of the Manghuihe sequence, are characterized by low MgO (1.49-7.50 %) and Zr/Nb (9.4-15.3), and high Al_2O_3 (15.95-18.39 %). They are enriched in LILE and LREE contents and depleted in HFSE, and have $^{87}Sr/^{86}Sr(t)$ ratios of 0.705473-0.706972, $\varepsilon_{Nd}(t)$ of -1.47-0.75, and similar Pb isotopic compositions to the global average composition of pelagic sediments. In contrast, Group 2 samples from the middle-upper parts of the Manghuihe sequence have similar Al_2O_3 (16.62-18.23%) but higher MgO (8.08-11.74 %) and Zr/Nb (15.9-23.9) than those of Group 1 samples. They exhibit relatively flat REE patterns, significantly negative Nb-Ta and Th-U anomalies and positive Sr anomalies. In comparison with Group 1, Group 2 samples show higher Cr, Ni contents and $\varepsilon_{Nd}(t)$ values (1.17-5.02), and lower $^{87}Sr/^{86}Sr(t)$ and Pb isotopic ratios ($\Delta 8/4$= 43.2-59.8 and $\Delta 7/4$=11.8-19.8). The geochemical data suggest that Group 1 samples might be the differentiated product of primitive high MgO and low Al_2O_3 melts originating from a refractory modified mantle with the involvement of 5-10% recycled pelagic sediments. The parental magma for Group 2 samples may have been derived from a plagioclase-rich, garnet-free source constituted by 80-85% fluid-metasomatized and 15-20 % asthenospheric components. Based on all available data, a tectonic model involving eastward subduction in the Permian and collision in the Triassic can be proposed for the evolution of the eastern Paleotethys ocean. During the late Triassic, the progressive uprising of asthenospheric mantle shortly after slab detachment may have led to the melting of the metasomatized mantle wedge, and then producing the post-collisional magmas represented by the Group 1 and 2 samples.

Keywords: Elemental and isotopic geochemistry; Zircon U-Pb geochronology; Late Triassic post-collisional magmatism; Lancangjiang tectonic zone; Eastern Paleotethys, Southwestern China

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Triassic High-Strain Shear Zones in Hainan Island (South China) and their Implications on the Amalgamation of the Indochina and South China Blocks: Kinematic and 40Ar/39Ar Geochronological Constraints

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A kinematic and geochronological study has been carried out on the Triassic high-strain shear zones in Hainan Island (southern South China). Our structural mapping indicates that there occurred the WNW- and NE-trending high-strain shear zones with high greenshist- to low amphibolite-facies metamorphism. Kinematic indicators suggest a top-to-the-NNE thrusting with a dextral component for the WNW-trending high-strain zones and a top-to-the-SE thrust with sinistral component for the NE-trending shear zones. The quartz c-axis orientations of mylonitic rocks exhibit a monoclinic point-maximum asymmetry most likely under the <a> basal gliding conditions. The timing of shearing for these shear zones has been constrained to be the middle Triassic (242-248 Ma) and late Triassic-early Jurassic (190-229 Ma) for the WNW- and NE-trending shear zones, respectively, based on $^{40}Ar/^{39}Ar$ geochronology and other geological observations. A synthesis of these kinematic and theromo-chronological data points to a two-stage tectonic model for Hainan Island with the 241-250 Ma top-to-the-NNE thrusting followed by the 190-229 Ma top-to-the- NE/E thrusting. In combination with the available data from the southern South China and Indochina Blocks, it is inferred an affinity to the Indochina for South Hainan and to the South China Block for North China, which were separated along the WNW-trending Changjiang-Qionghai tectonic zone linking to the Song Ma zone. The Triassic structural pattern of Hainan Island is spatially and temporal compatible with those of the southern South China and Indochina Blocks and might be a derivation from the amalgamation of the Indochina with the South China Blocks in response to the closure of the Paleotethys Main Ocean and subsequently northward convergence.

Keywords: Kinematics, Ar-Ar thermogeochronology, Triassic amalgamation, Hainan Island, South China Block, Indochina Block

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Intracontinental Deformation: A Case Study from Yanshanian Structures in Xuefengshan Tectonic System, South China

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Guizhou Province is located at the center of the South China Block, far away the continental margin up to 1600 Km. The main Mesozoic deformation in the Guizhou Province is also intraplate or intracontinental deformation happened during Yanshanian (Jurassic to Cretaceous) Period. Three-stage folds of various strikes are identified based on their latest deformation-involved strata in these folds and their superposional relationship, respectively. The earliest one is nearly E-W-striking folds, and the second is NE-striking folds, followed by the N-S-striking folds. The folds formed between Late Jurassic and Late Cretaceous. Secondly, the thrust fault system consists of top-to-northwest or top-to-west, N-S-striking thrust faults coeval to the N-S-striking folds approximately. To the west of west margin of the Xuefengshan Precambrian Basement, the thrust belt can be divided into three zones, including the root zone, the middle zone and the frontal zone from east to west. The root zone underwent two-stage thrusting. However, there was only one-stage thrusting in the other two zones. Thirdly, three-stage different-trending strike-slip faults parallel, spatially, to axes of three folds, came into being temporally later than the related folding. E-W-striking strike-slip faults showed dextral and transpressional characteristics. However, NE-striking strike-slip faults is characteristic of sinistral transtension. According to field relationship of intersection and confinement between these faults, it is obvious that E-W-striking strike-slip faults occurred at the earliest stage, followed by N-S- and NE-striking strike-slip faults in sequence. At last, a possible tectonic model about intracontinental deformation in the Guizhou Province is discussed.

Keywords: Xuefengshan intracontinental tectonic System, Yanshanian, Folds, Thrust faults, Deformation

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Field Guidebook Series on the Himalayan Geology and Natural Hazards

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The Himalaya is the highest and one of the largest and still growing mountain ranges on our planet. It exhibits a distinct zonal arrangement of geology, geomorphology, climate, fauna and flora; and hence is an excellent laboratory to study nature and natural science of mountain ranges. However, there are almost no appropriate guidebooks for common people in the world market to introduce geology and natural hazards in the Himalaya. We are endeavoring to publish a series of such guidebooks along different transects of the Himalaya to bring out the much-admired fantastic geology and geomorphology, and natural hazards.

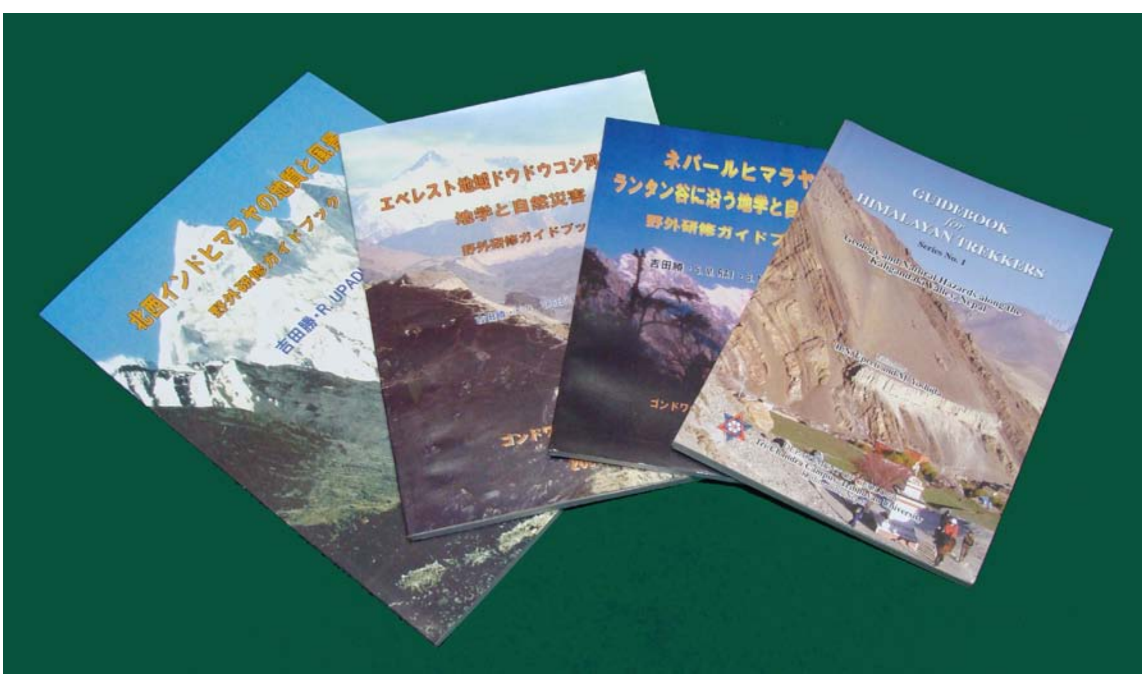

Fig. 1. Guidebook (3 Japanese and 1 English) so far published since 2005

The first guide book in this series- Guidebook for Himalayan Trekkers, Series No. 1: Geology and Natural Hazards along the Kaligandaki Valley, Nepal was published in 2005 (Upreti and Yoshida, 2005, http://www.geocities.jp/gondwanainst/Yoshida/guidebookadv.pdf), and has been widely used worldwide by individuals and groups. The guide book Series No. 2, on the Everest area in the Khumbu region, No. 3 along the Langtang Valley of Nepal and No. 4 on the NW Indian Himalaya are under progress. Also, the provisional Japanese version of these guidebooks were published in 2007, 2008 and 2009 as Miscellaneous Publications No. 18, 19 and 20 of the Gondwana Research Group/Gondwana Institute for Geology and Environment (Yoshida et al., 2007, 2008a; Yoshida and Upadhyay, 2009, http://www.geocities.jp/gondwanainst/gige/gige_publications/gigepublist.htm) and have been used by several Japanese groups in respective areas. In the presentation, details of these guidebooks, along with field excursions of some of these areas by Japanese groups will be given.

It is expected that the incredible nature of Himalayan geology and environment described in these guidebooks will facilitate to promote a wide spectrum of people worldwide to visit and study the Himalaya which will also bring economic benefit to the local people. It will also help the people living in this beautiful mountain range feel proud of their natural heritage.

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3-D Modeling of the Activity along the Longmenshan Fault Zone Driven by the Indentation of the India Plate

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The effect of the continuous northward indentation of the India Plate along the Longmenshan fault zone and its surrounding areas is modeled using finite element analysis. Comparing the simulation result with GPS surveys, seismological data and geological analysis, we quantitatively analyze the slip rate and the distribution characteristics of major principal stress of the Longmenshan fault zone. And then, the triggering mechanics of the Wenchuan earthquake is discussed accordingly. The model consists of an elastic upper lithosphere and a vicoelastic lower lithosphere. The upper lithosphere includes the Tibetan Plateau, the Sichuan Basin, the South China Block, and the Indochina Block. The faults in the block are introduced as Coulomb-type frictional zones in the modeling. The results are as followed: (1) by adjusting the faults friction, we find out that with friction coefficient increasing, the slip rate of fault zone tends to decrease. When the friction coefficient touches 0.95, the slip rate is close to the result of GPS survey. Therefore, we assume that the Longmenshan fault zone should be under the condition with intensive friction. (2) Compared with other regional of Songpan-Garzê block, the Longmenshan fault zone is in a strong friction and low stress environment, which favors significant energy accumulation enough to trigger great earthquake. (3)According to the distribution characteristics of major principal stress, we can divide the Longmenshan fault zone into four short segments from SW to NE as followed: the Luding-Dayi segment, the Dayi-Maoxian segment, the Maoxian-Bei-chu-an segment and the Beichuan-Qingchuan segment, respectively, and the maximum differentia of principal stress(σ_1) between hangingwalls and footwalls of faults appears in the Dayi-Beichuan segment, and the minimum differentia of principal stress(σ_1) appears in the Luding-Dayi segment. In the Maoxian-Beichuan segment, the principal stress(σ_1) of hanging walls of fault is almost equal to footwalls of fault. Such distribution of major principal stress is similar to the spatial distribution of the Wenchuan earthquake and its aftershock.

Keywords: Longmenshan fault zone, FEM simulation, Slip rate, The distribution characteristics of stress(σ1)

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