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

SCG008-01 Room:301A Time:May 26 08:30-08:45

CHIME monazite dating as a tool to detect polymetamorphism in high-temperature metamorphic terrane

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The chemical Th-U-total Pb isochron method (CHIME) monazite dating was carried out for pelitic-psammitic migmatites and the Ao granite (one of the Younger Ryoke granites) from the Aoyama area, Ryoke metamorphic belt, SW Japan. The Ao granite gives an unequivocal age of 79.8+/-3.9 Ma. The migmatites yield ca. 100 Ma monazite grains with younger domains of ca. 80 Ma. Some grains show ca. 80 Ma overgrowths on the older core of around ca. 100 Ma, and others show patchy rejuvenation of ca. 100 Ma grains.

Recent study on the Pb diffusion in monazite (Cherniak et al., 2004) concluded that Pb diffusivity in monazite is low and thus the closure temperature of monazite is high. However, reinterpretation of Cherniak et al. (2004) data by favoring the SIMS data rather than RBS data showed that results of Cherniak et al. (2004), Suzuki et al. (1994) and Smith & Giletti (1997) can define single array that gives the diffusivity similar to Suzuki et al. (1994). If this interpretation is accepted, the closure temperature of Pb diffusion in monazite becomes low, and about 600-750 ^{o}C provided that the cooling rate is ca.30 ^{o}C/Myr.

With this closure temperature, it is possible to reset monazite in the pelitic-psammitic migmatites from the Aoyama area by the thermal effect of the Ao granite intrusion alone. The patchy nature of the distribution of rejuvenated parts within monazite grains prefers, however, the rejuvenation mechanism other than volume diffusion, such as grain boundary diffusion along the microcracks developed in the monazite grains. Some of the monazite grains with young overgrowth rim are armored in biotite, supporting the possibility of the fluid activity affecting the rejuvenation of monazite grains. Therefore, ca. 80 Ma overprinting on migmatites over the Grt-Crd zone in the Aoyama area is probably caused by the combination of a thermal effect and a fluid activity caused by the Ao granite intrusion. Partial rejuvenation of the monazite grains implies that the thermal and fluidal effects were not too strong to completely reset the monazite grains.

Although the contact metamorphism by the Ao granite is hard to be detected through the field survey and petrographic examination, possibly because the migmatite already possessed the high-temperature mineral assemblage and was immune from the contact metamorphism in terms of major metamorphic mineral assemblage, the CHIME monazite dating reveals the presence of contact metamorphism clearly. The field mapping of the CHIME monazite age can be a powerful tool for recognition of polymetamorphism in high-temperature metamorphic terrains where later thermal effects cannot be easily detected by the growth of new metamorphic minerals.

Keywords: CHIME monazite dating, polymetamorphism, Aoyama area, Ao granite, contact metamorphism, closure temperature

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

SCG008-02 Room:301A Time:May 26 08:45-09:00

Accretionary complex related to Paleo-Tethys subduction in northern Thailand

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The Paleo-Tethys, which opened in response to the Devonian separation of the North China, South China and Indochina blocks from Gondwana, occupied a large area around the equator from the Devonian to Triassic, where carbonates, chert, and basalt were deposited in a pelagic domain (e.g., Metcalfe, 1999). These Paleo-Tethyan rocks characterized by Ocean Plate Stratigraphy were subducted beneath the Indochina Block during the Permian to Triassic (Wakita and Metcalfe, 2005).

In the Inthanon Zone of northern Thailand, melanges occur in association with oceanic rocks of Paleo-Tethys origin. According to Hara et al. (2009), melange formation was characterized by hydrofracturing and cataclastic deformation, with mud injection under semi-lithified conditions followed by shear deformation and pressure solution. Illite crystallinity data suggest metamorphic temperatures below 250 degree during melange formation. The combined structural and metamorphic data indicate that during melange formation, the accretionary complex related to Paleo-Tethys subduction developed at shallow levels within an accretionary prism. Asymmetric shear fabrics in melange indicate top-to-south shear. After correction for rotation associated with collision between the Indian and Eurasian continents, the trend of the Paleo-Tethys subduction zone is estimated to have been N80E. We conclude that the Paleo-Tethys was subducted northward beneath the Indochina Block from the Permian to Triassic. Sandstones are dominant within melange, generally characterized by lithic greywacke. Based on the composition and geochemistry of sandstones collected from melange within the Inthanon Zone, provenance of sandstone is characterized by mostly continental arc, and slightly continental margin. We interpreted that the origins of sandstones are from both of continent (Indochina Block) and arc developed along the Indochina Block, which is possibly the Sukhothai Zone. Based on melange kinematics and sandstone provenance, we reconstruct island arc system by the Paleo-Tethys subduction during Permian to Triassic time.

Keywords: accretionary complex, Paleo-Tethys, melange, sandstone geochemistry, Inthanon Zone, Thailand

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

SCG008-03 Room:301A Time:May 26 09:00-09:15

Geotectonic subdivision of the Central Plain of Thailand: A perspective from Permian and Triassic successions

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In the last two decades, increasing geological evidence produced a number of substantial understandings on the geotectonic subdivision and evolution of mainland Thailand. Now, we have a consensus of opinion that the Sukhothai Zone (Permian-Triassic island arc system) to the east and the Sibumasu Block (fragment of the eastern Cimmerian continent) to the west are the two major geotectonic domains constituting Northern Thailand. However, their southward extensions to the Central Plain of Thailand are still less clear due to the poor information of basement rocks.

We have investigated several basement rock units distributed in Uthai Thani and Nakhon Sawan provinces of the central part of the Central Plain. Quaternary deposits widely cover the major parts of these provinces, but there are a number of monadnocks consisting of older rocks. In eastern Nakhon Sawan Province, the basements are composed mostly of Permian platform-type carbonates. They are interpreted as parts of the Saraburi Limestone of the Indochina margin.

In central Nakhon Sawan and eastern Uthai Thani provinces, there are some, N-S trending monadnock ranges. Of them, we newly studied a carbonate unit composed of several limestone mountains. It consists of massive, shallow-marine limestone, and bioclastic grainstone and packstone are the major microfacies. In places, boundstone made by skeletal metazoans is observed. Late Triassic foraminifers occur from it. Based on the foraminiferal contents and lithology, it can be correlated to a limestone member of the Lampang Group in the Sukhothai Zone of Northern Thailand. In the same area, intermediate-acidic volcanic/volcaniclastic rocks of possibly Permian age are distributed. In Northern Thailand, a similar rock unit widely underlies the Sukhothai Zone.

Slightly to the east of the Late Triassic limestone, there are ranges of small mountains consisting mainly of fine-grained siliciclastics. Characteristically this unit contains chert successions in some parts; one of which distributed around Nakhon Sawan city is called the Khao Gob Chert. Permian radiolarians are found from some of the chert successions. Their lithological characters and age suggest that they can be correlated to the Permian Khanu Chert exposed to the north in the Sukhothai Zone. Moreover, granitoids in the same mountain ranges are of I-type characterizing the Eastern Granitoid Belt, which corresponds in Northern Thailand to the Sukhothai Zone.

In western Uthai Thani Province, there is a remarkable range consisting of karstified limestone, which is called the Uthai Thani Limestone. It is generally weakly metamorphosed and deformed, but Permian age is evident based on the occurrence of rare and poorly preserved fusulines from some localities. The Uthai Thani Limestone can be distinguished from the Late Triassic limestone just to the east by its distinctive NNW-SSE extension and by having different deformation and metamorphic records. It is more reasonable to correlate it with the Sai Yok and the Ratburi limestones widely distributed in the Sibumasu Block of Western and Peninsular Thailand. Moreover, granite in western Uthai Thani Province exhibits an S-type affinity of the Central Granitoid Belt, which corresponds to the eastern part of the Sibumasu Block.

All these lines of evidence suggest that central Nakhon Sawan and eastern Uthai Thani provinces belong to the southern extension of the Sukhothai Zone of Northern Thailand. In contrast, western Uthai Thani Province where the Uthai Thani Limestone and the S-Type granitoids crop out can be labeled as a part of the Sibumasu Block. Thus, we conclude that, in the Nakhon Sawan-Uthai Thani area there is a remarkable gap in terms of geotectonic properties of basement rocks between the Late Triassic limestone and the Uthai Thani Limestone. It corresponds to the southern extension of the Chiang Rai Tectonic Line in Northern Thailand, which separates the Sukhothai Zone to the east and the Sibumasu Block to the west.

Keywords: Central Thailand, geotectonic subdivision, Sukhothai Zone, Sibumasu Block, Permian, Triassic

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

SCG008-04 Room:301A Time:May 26 09:15-09:30

Evolution of Magmatism and Metallogeny along the Western Edge of the Indochina Terrane

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Igneous rocks and their associated mineral deposits form north-south trending belt with the dimension of about 1700 x 100 km2 along the edge of the Khorat Plateau from central Lao PDR to southeastern Thailand. These igneous rocks are predominantly felsic to intermediate plutonic and volcanic rocks with minority of mafic and ultramafic exposures. The latter which are usually Late Paleozoic in ages are regarded as to be temporally and spatially associated with the Loei suture which subdivided Indochina terrane from the Paleotethys Ocean. Based on U-Pb zircon, Rb-Sr whole rock, and 40Ar-39Ar dating, magmatism and associated mineralization are inferred to have a prolong history of tectonism from compression to extension and ranging in ages from Middle Paleozoic to Miocene. The first stage of tectono-magmatic episode includes calc-alkaline magmatism during Middle Paleozoic (ca. 405 ? 399 Ma) ages and associated with their mild Kuroko type mineralization of Fe, Cu, Pb, Zn, Ba and Mn minerals. They are mainly in the northern part of the belt and may have been part of Caledonian Orogeny. This igneous activity was formed as a result of calc-alkaline magmatism due to subduction of paleothethystic oceanic slab beneath the western edge of Indochina terrane. The second stage of magmatism took place within the early Indosinian Orogeny (ca. 260 ? 240 Ma). The igneous rocks are of calc-alkaline I-type affinity and thought to have been responsible for the late stage mineralization including porphyry copper, volcanogenic sulfide, skarn type, and hydrothermal Au-Ag vein styles which are mainly occurred in the northern belt. Such the strongly mineralized magmatism is believed to have formed in response to the continuous oceanic subduction beneath the Indochina terrane. Though associated unexplained Sn mineralization was reported in Lao PDR, it was virtually absent in Thailand. Associated accretionary complex and weak Cyprus type Cr and Ni mineralization may also have formed at this stage. The third stage of magmatism may have occurred in the very late stage of Indosinian Orogeny (ca. 190-210 Ma), and it was thought to have occurred in the extension environment giving rise to mainly alkaline magmatism, particularly along the suture zone. Stitching plutons with weak poly metallic vein-style mineralization may have formed due to the relaxation of the crust after intense compression. The fourth stage of magmatism may have formed in association with reactivation of major strike ? slip northwest ? trending faulting in response to early Himalaya Orogeny. Mylonitization of earlier granitoid rocks may have been occurred at this stage along with the post tectonic minor intrusions of water poor pegmatites and aplites with weak vein-style mineralization of Sb + Au-Ag hydrothermal ores. The fifth stage of magmatism is found in the central belt, and it was formed as a result of crustal relaxation during Miocene time (18-25 Ma). This rift related alkaline magmatism may have formed due to crustal thinning, and mantle upwelling by high heat flow activity may be responsible for partial melting of the lower crustal materials. Poly-metallic mineralization and Au-Ag veins of high sulfidation systems may have took place along the north-south ? trending open fractures, particularly in the central to eastern Thailand. Continental rifting event may have been continued to the last episode of magmatism during ca. 0.5 to 7 Ma along the Loei suture in response to high heat flow by upwelling mantle materials. Tectonic activity is geomorphologically and geochronologically evident to continue to the present time and gives rise to the presence of reactivated northwest ? trending active faults in the central belt. Only non-mineralized hydrothermal veins are encountered along these faults.

Keywords: Indochina, Metallogeny, Tectonic, Magmatism, Thailand, Laos

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

SCG008-05 Room:301A Time:May 26 09:30-09:45

Renewed geology of northern Vietnam: Miocene metamorphic domes extruded the older accretionary complexes

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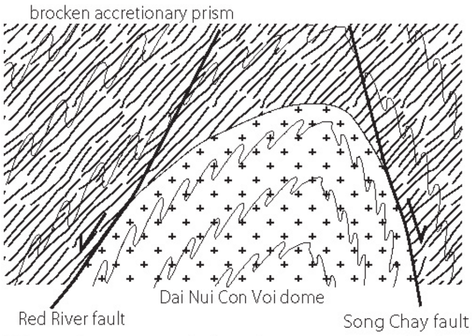
When we observe northern Vietnam geology handling Geological and Mineral Resources Map of Viet NAM 1: 200,000, published and copyright by Department of Geology and Minerals of Viet NAM, Hanoi, we notice so many NW-SE trending faults, part of which are strike-slip faults, and major, map-scale plunging-anticlines. Cores of the anticlines consist of metamorphic or granitic rocks, or partly early Paleozoic sedimentary rocks, and the other younger rocks, late Paleozoic and early Mesozoic normal sequences overlay the core complex in order of these ages surrounding the anticlinal core. We soon notice discrepancy. We could not observe clear strike-slip faults in outcrops, except for a part of the Red River and Song Chay faults. Strike-slip faulting may not play an important role for northern Vietnam structural development. The core complexes, dated and exhumed Tertiary, is overlain by the older coherent sequences, but the sequences are broken and seldom show anticlinal structure. Also for the cover sequences, these expected older Indosinian structures and younger overlapping dome structures are not distinguished. We found bedded chert, umber, and varicolored mudstone, at the first time from northern Vietnam, other than widely distributed and previously known limestone and basalt, which was previously interpreted shallow sea platform limestone and intra-continental rift products by Lepvrier et al. (2008). These rock suites constitute accretionary complex, and such cover rocks do not possess original sedimentary sequence. For example, pelitic and psammitic schist, mapped as the Devonian, is a matrix of accretionary melange, and the age of the schists may be incorrect and younger than presently considered.

As for the dome structure of the Red River shear zone, a focus of northern Vietnam geology, Leloup et al. (2001) considered the Dai Nui Con Voi dome a left-lateral ductile shear zone throughout the anticline with NW-SE axis (stretching and doming is contemporaneous in single transtensive condition), and they connected its movement with opening of the South China Sea (Tapponnier et al., 1982). Jolivet et al. (2001) follows that transtensive condition, but divided into the earlier ductile top to the NW shear and stretching restricted to the anticlinal core and the later brittle-ductile transition left-lateral shear restricted to the margins. They assume that the exhumation and doming is due to normal faulting of the Song Chay fault and scraping off the hanging wall rocks. Anczkiewicz et al. (2007) also considered left-lateral transtensive situation for doming, but shows both marginal faults have component of normal faulting, and such progressive deformations including mylonite shearing is undergone under relatively high temperature. The most recent study of Yeh et al. (2008) divided the deformations into earlier stretching phase with ductile northwestward shear and later transpressional doming phase. Brittle left-lateral faulting was followed in transtensive phase.

Our structural division is also earlier ductile and later brittle-ductile transition deformations, common to both core complexes as well as sedimentary covers extruded by core complexes. However, contrast to the all above studies, transpressional and dextral ductile shear is for the earlier deformtion, and later brittle normal faulting, following the ductile extrusion of metamorphic rocks, never major strike-slip faulting, plays an important role in northern Vietnam.

We describe the renewed geology of northern Vietnam, Miocene vertical extrusion of metamorphic core complexes into older accretionary complexes, which were further broken by the extrusion. Existence of major fault with major strike-slip component, which is a traditional Red River fault, is very doubtful, and most of such fault has normal fault sense movement.



Moetamorphic dome model

Miniture of metamophic dome

Anticlinal fold accompanies axial planar cleavages, dextral streaching lineationons, and parasitic folds

Keywords: Northern Vietnam, metamorphic dome, D1 trans pression, dextral, D2 Red River normal fault, accretionary prism origin

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

SCG008-06 Room:301A Time:May 26 09:45-10:00

Insight into the tectonic deformation patterns along eastern Taiwan from seismological observations

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To decipher the siesmotectonic structures in the Taiwan region, we have obtained more than 1,900 centroid moment tensor (CMT) solutions by inverting the broadband waveforms recorded at the BATS network. This dataset reveals the characteristics of faulting types along the eastern coast of Taiwan that is associated with the interaction between the continental margin and the NW moving Philippine Sea plate (PSP). In general, to the south of Hoping (24.3^{o}N), the faulting type is dominated by thrusting and the sigma-1 direction is almost perpendicular to the strike of Costal Range. However, between Hopin and Lanyang river, the strike-slip faulting type is prevailing along some EW trending geological boundaries in the crust with sigma-1 directed in NW-SE. Some low-angle dip-slip events at depth around 20 km were observed in the vicinity of Hopin. We infer that they may correspond to the interface earthquakes, where the underneath subducted slab moves westward. To the north of Lanyang river, the crust is dominated by normal faulting, which is believed to be caused by the spreading of the Okinawa Trough. On the other hand, for those intermediate depth earthquakes occurred beneath Ilan plain, the determined focal mechanisms show thrusting pattern with sigma-1 sub-parallel to the trench. Therefore, Kao and Jian(2001) suggested that the subducted PSP slab is colliding with the mantle lithosphere of EUP. Chou et al.(2006) also discovered the folding at the western edge of slab. Based on seismicity and 3-D velocity structures, Wu et al.(2009) proposed that the intersection of the Ryukyu Trench with Taiwan is placed at the latitude of 23.7^{o}N, placing the northern part of the Costal Range on EUP. This is consistent with the uplifting rate along the Costal Range and the modeled deformation pattern. According to these observations, we concluded that the PSP starts subducting at 23.7^{o}N and the upper plate boundary approaches the bottom of the brittle seismogenic layer at about 24.3^{o}N, where very low-angle dip-slip events may occur. Once the slab subducts completely underneath the seismogenic layer, the faulting type in the crust would be dominated by pre-existed boundaries subjected to a torque that may be imposed by the trench retreat and the opening of back-arc basin. Behind the Lanyang river, the Okinawa Trough plays an important role for the occurrence of shallow normal faulting events.

Keywords: CMT, Focal Mechanism, Seismotectonics, Stress Tensor, Collision, Subduction

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

SCG008-07 Room:301A Time:May 26 10:00-10:15

Petrology of eclogites from the Orobashy area, Aktyuz region, northern Kyrgyz Tien-Shan

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The Aktyuz region is located in the Zaili Range of the Northern Kyrgyz Tien-Shan. Here, eclogites have been reported from two areas, i.e. Aktyuz area and Orobashy area (Orozbaev et al., 2010). Lens-shaped serpentinite bodies of varying size occur in the Orobashy area along NNE-SSW trending faults located within Kapchygai and Kokbulak migmatites. The largest serpentinite body contains 20 cm to 30 m across blocks of eclogites, garnet amphibolites, garnetitites and gneisses. Eclogite, garnetitite and garnet amphibolite blocks are massive, and range from 40 cm to 10 m in diameter. The marginal parts of the eclogite and garnetitite blocks are amphibolitized. Both blocks and serpentinite matrix are intruded by granitic dykes.

Eclogites consist mainly of garnet, clinopyroxene, amphibole, clinozoisite and rutile with minor plagioclase, epidote, quartz, chlorite, biotite, paragonite, phengite, ilmenite, titanite, apatite and zircon. Garnets and clinopyroxene show coexisting texture and thus define the peak metamorphic assemblage. Garnets contain inclusions of amphibole (tschermakite, pargasite), quartz, epidote, rutile, ilmenite, apatite, plagioclase, biotite and rare paragonite and phengite. Garnets show a prograde zoning and they have compositions of 36.1-61.3 mol% of almandine, 13.3-21.9 mol% of grossular, 10.8-43.4 mol% of pyrope and 0.1-4.9 mol% of spessartine. Clinopyroxenes are Na-rich diopside in composition and their jadeite content varies from 0 to 19 mol%. The symplectite of Amp+Qtz and/or Amp+Pl is developed after clinopyroxene suggesting decompresssional decomposition. Amphiboles occur as inclusions in garnet and clinopyroxene, and also in the matrix. Amphibole in the matrix is Mg-hornblende and contains inclusions of garnet, clinopyroxene (Jd9-12), rutile and quartz. Amphiboles in garnets are tschermakite and pargasite, whereas those in clinopyroxene are Mg-hornblende. Amphiboles in symplectites and in the veins are also classified as Mg-hornblende. Clinopyroxene, garnet and amphibole are cross cut by veins. Feldspars in the eclogites are plagioclase (An4-50) and K-feldspar. Paragonite occurs only as inclusions in garnets. Phengite occurs in the matrix and as rare inclusions in garnet. Epidote occurs as inclusions in garnets, clinopyroxenes and in the veins. Occasionally, clinozoisite develops in the matrix of some eclogites. Veins are mainly composed of plagioclase, epidote, amphibole and apatite.

The texture and the mineral chemistry of the Orobashy eclogites suggest three metamorphic stages i.e., prograde, peak and decompression stages. The mineral inclusions in garnet such as amphibole (tschermakite and pargasite), quartz, plagioclase (An13-50), epidote, biotite, paragonite, phengite, rutile, ilmenite and apatite may suggest mineral assemblage of the amphibolite facies conditions for the prograde stage. The coexistence of garnet and Na-rich diopside together with rutile and quartz in the matrix suggests the peak metamorphic assemblage. The garnet-clinopyroxene geothermometer of Ravna (2000) and Nakamura (2009) yielded T = 590-710 C at 13 kb, minimum pressure based on Jd=19 content in clinopyroxene. The symplecite of Amp+Qtz and Amp+Pl suggest decompression stage for the eclogites. Hbl-Pl geothermometer (Holland & Blundy, 1994) yielded 610-670 oC for this stage, and the minimum Jd content (>5) may suggest about 5 kbar for pressure conditions.

There are three different types of metamorphic events for the HP rocks of the Aktyuz Formation. Here, for the Orobashy eclogites single metamorphic event is recognized, which is HT metamorphism from amphibolite facies up to eclogite facies conditions and then decompression again to amphibolite facies conditions. Exhumation of the Orobashy eclogites to relatively shallow crustal levels was accompanied by re-equilibration under HT amphibolite faices conditions, probably during a period of continental collision, correlative to the third metamorphic event in the Aktyuz area.

Keywords: Orobashy, Aktyuz, eclogite, Tien-Shan, Kyrgyzstan

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

SCG008-08 Room:301A Time:May 26 10:15-10:30

Permian peri-glacial deposits in the Harahorin area, north-central Mongolia

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INTRODUCTION The Harhorin area of north-central Mongolia is located in the Khangai-Khentei Belt of the Central Asian Orogenic Belt. The area consists mostly of early Carboniferous Khangai-Khentei accretionary complex (Kurihara et al., 2009) with some cover sequences and younger igneous rocks. One of the cover sequences, Urmegtei Formation, contains dropstone-bearing peri-glacial deposit. Here we show the result of geological and chronological studies of the peri-glacial deposit and discuss the implications.

GEOLOGIC SETTING The study area consists mainly of the following geologic units.

The Yashil Formation is the local formation name of the Khangai-Khentei accretionary complex.

The Urmegtei Formation is an upward-fining cover sequence, which consists, in ascending order, of conglomerates, sandstones, and varved sandstone and mudstone beds with granite dropstones. The formation has been sheared with NW-striking and SW-dipping structural foliation and N-trending stretching lineation showing downward increasing strain. From shear-sense indicators we interpret that the top-up-to-the-north (dextral) oblique thrusting formed these structural elements.

Felsic dikes cut the Urmegtei Formation and have been sheared with the formation.

Undeformed porphyritic granite batholith cuts all the above sheared rocks.

AGE DATING We measured U-Pb zircon ages of the following three samples using LA-ICP-MS equipped in the Hirata Laboratory of Kyoto University and in the Earthquake Research Institute of the University of Tokyo.

1. *A granite dropstone in the Urmegtei Formation* contains zircons with many inclusions and microcracks. We chose 3 clear zircon grains for analysis and calculated $^{206}Pb/^{238}U$ weighted mean age of 273.0+/-4.9 Ma from analytical data, suggesting that the dropstone was supplied from an Early Permian (Kungurian) granite body (ICS, 2009).
2. 17 zircons from *a sheared felsic dike* have $^{206}Pb/^{238}U$ weighted mean age of 246.5+/-4.0 Ma.
3. 10 zircons from *the undeformed granite batholith* have $^{206}Pb/^{238}U$ weighted mean age of 217.5+/-8.7 Ma.

DISCUSSION

Brief geologic history: The age of sedimentation of the Urmegtei Formation is constrained between 278 Ma (Artinskian of Early Permian) and 242 Ma (Anisian of Middle Triassic), because the Formation contains a dropstone of 273.0+/-4.9 Ma and was cut by a felsic dike of 246.5+/-4.0 Ma. The dated felsic dike was sheared with the Urmegtei Formation and was cut by the undeformed granite batholith of 217.5+/-8.7 Ma, suggesting that the shearing of the Urmegtei Formation was terminated between 251 Ma (Induan of Early Triassic) and 208 Ma (Norian of Late Triassic).

Implications of the peri-glacial deposit: The Earth in Late Carboniferous age was in an icehouse mode and a global warming trend took place from Sakmarian of Early Permian. In the Northern Hemisphere, 278-242 Ma glacier-related deposits were detected only in the Wordian (Middle Permian) to Wuchiapingian (Upper Permian) of the Verkhoyansk, Kolyma and Omoron areas of northeastern Siberia (Ustritskiy, 1973). From the circumstantial evidence and our present study, we propose the following tectonic history. (1) The Khangai-Khentei accretionary complex, probably covered by the Urmegtei Formation, must have formed in a subduction zone that was connected to the continental-margin or island-arc terrane in the present-day northeastern Siberia, i.e. the Verkhoyansk, Kolyma and Omolon areas. (2) In Wordian to Wuchiapingian ages, the accretionary complex was in an arctic area near the northern end of the Angara block (present-day northeastern Siberia), where the Urmegtei Formation was deposited. (3) The Khangai-Khentei accretionary complex, approximately 2,000 km apart from northeastern Siberia at present, must have dextrally displaced to the present position. If the dextral oblique thrust shearing in the Urmegtei Formation and the 246-Ma felsic dike is a consequence of the dextral displacement, the displacement must have been terminated by 208 Ma.

Keywords: Permian, peri-glacial deposit, U-Pb age, tectonics, Khangai-Khentei belt, Mongolia

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

SCG008-09 Room:301A Time:May 26 10:45-11:00

Significance of metacarbonate rocks in unraveling the formation of Central Asian Orogenic Belt

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Metacarbonate rocks are key rock units in orogenic belts because they represent possible remnants of oceanic sediments. Furthermore, they provide important information regarding the fluid-rock history during metamorphism. Central Asian Orogenic Belt (CAOB) consists of several subduction-accretion complexes formed between 1000 Ma and 250 Ma. Metamorphic rocks in this region are important not only in understanding the tectonic evolution of the CAOB, but also can give important clues in understanding the formation of Asian continent. During the Japan-Mongolia Joint Geological Research we have collected several key rock units from the western and northwestern regions of Mongolia. Here we present carbon and oxygen stable isotope characteristics of metacarbonate rocks from the several localities of Central Asian Orogenic Belt of Mongolia. Metacarbonate rocks are common in the CAOB and occur as comparatively thin layers intercalated with pelitic and psammitic gneisses.

Carbon and oxygen isotope studies on metacarbonate rocks shows a large spread in isotope values among different belts within the CAOB. However, the coupled C-O isotope trend can be broadly grouped into two categories. (1) Metacarbonate rocks that preserve pre-metamorphic stable isotope signatures, and (2) those affected by fluid ? rock interaction processes during metamorphism. In the first case, we were able to obtain carbon and oxygen isotopic composition that might be representative of sedimentary signatures, although isotopic shifts caused by the exchange of carbon isotopes with graphite derived from organic material is present in some samples. The equilibrium between calcite and graphite in such samples were used to understand the temperature of metamorphism in such samples. In the second case, we have got large coupled carbon and oxygen isotope shifts which are indicative of fluid-rock interaction during metamorphism. Such samples helped to understand the role of fluids during subduction-accretion processes during the formation of CAOB.

Keywords: metacarbonate rocks, carbon isotopes, oxygen isotopes, Central Asian Orogenic Belt, Mongolia

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

SCG008-10 Room:301A Time:May 26 11:00-11:15

Geodynamics and ore mineralization in Bayankhongor metallogenic belt, Central Mongolia

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ayankhongor metallogenic belt is one of the main gold producing area in Mongolia. In the regional geotectonic setting the Bayankhongor metallogenic belt is north-west trending tectonic zone, which consists of several tectonic units as Archean Baidrag terrane, Burd metamorphic unit, Bayankhongor ophiolite belt, Zag metamorphic belt and southern part of Hangai intra-continental basin. The tectonic zones of Bayankhongor belt has several episodes magmatic activity starting from Proterozoic continuing to Cambrian, Early Paleozoic, Late Paleozoic, and Mesozoic.

The Bayankhongor belt is known by its gold mineralization since ancient time, and there are remnants of old mining activity at the several places. Ore mineralization is closely associated with long history of geodynamic setting of the belt starting from old oceanic crust through accretion, collision and obduction as well as intra-continental magmatic activity.

Results of various stage geological stud, indicate that there are many deposits and occurrences of gold, copper, tungsten, iron, nickel and PGE etc. Copper, nickel and PGE mineralization thought to be related with mafic and ultramafic units of ophiolite belt, and formed during oceanic setting. Gold bearing quartz vein zones, and cold copper bearing scarn deposits, which must be primary source of placer deposits, are mainly distributed along the south and south west part of the belt.

Placer deposits mainly found along the along the mountain Jargalant, which is obducted ophiolite zone, and Burd passive continental margin terrane and Bombogor Proterozoic metamorph terrane. Age of placer deposits ranges from Mesozoic to Recent.

We study age and geochemistry of magmatic rocks which are distributed in and around the ore mineralization occurrences, in order to make clear its genetic relation and as well as reconstruction of tectonic evolution of Bayankhongor metallogenic belt. Result petrochemistry and of age dating analyses will be discussed and presented.

Keywords: Bayankhongor, ophiolite, gold, placer, PGE, magmatic rocks

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

SCG008-11 Room:301A Time:May 26 11:15-11:30

Formation of continental crust at the Izu-Honshu collision zone

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The tectonic setting of arc-arc collision and arc accretion in the Izu-collision zone is similar to that of Archean orogenic belts (e.g. Taira et al., 1992). Understanding the petrological processes of granite formation in the Izu-collision zone, where the geodynamic information is not modified by polyphase deformation and metamorphism, may contribute to understanding ancient orogenic belts, especially those related to collisional settings. The Pacific plate began subducting beneath the Philippine Sea plate about 50 million years ago to produce the currently active Izu-Bonin-Mariana (IBM) arc. The collision between the northern IBM arc system and the Honshu arc of the Eurasia plate has been occurring since the middle Miocene (c. 15 Ma) as a consequence of the northwestward migration of the Philippine Sea plate. The collision has led to the accretion of IBM arc crust to the Honshu arc, associated with a southward migration of the plate boundary and trench system. Neogene granite plutons are widely exhumed by tectonic uplift associated with arc collision. Tamura et al. (2010) integrated new geochemical results with recent geophysical imaging of the arc and concluded that Miocene plutonic rocks in the Izu collision zone were derived from the Eocene-Oligocene middle crust, which was partially melted, remobilized and rejuvenated during the collision. Similar rejuvenating processes may have operated in other collision zones. Moreover, (1) the mafic arc lower crust is missing at the collision zone (Kitamura et al., 2003) and (2) the aseismic Philippine Sea plate, which is subductiong to depths of 130-140 km without evidence of a tear or other gap, has been detected even beneath areas 120 km NW of the collision zone (Nakajima et al., 2009). Thus, collisional coalescence accompanies delamination of arc mafic lower crust. Both processes are inevitable at the collision and necessary to yield continental crust.

Keywords: granites, middle crust, crustal structure, arc magmas, andesite

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

SCG008-12 Room:301A Time:May 26 11:30-11:45

Chronology, Petrology and Numerical Simulation for Cretaceous to Paleogene Granitic Rocks, SW Japan

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Granitoid is one of the main components of the continental upper crust, and is thought to provide key information on evolution of the continental crust yet the origin of granitoid remains enigmatic. In order to address this important and unresolved problem, we have studied the origin of the Cretaceous to Paleogene granitic rocks in SW Japan. We especially focus on (1) spatial-temporal variation of granitoid, (2) temporal variation of petrological signature of granitoid, and (3) tectonic and dynamic setting that caused the observed spatial-temporal variation and provided heat for the melt generation, based on the U-Pb zircon age, whole rock chemistry, and numerical simulation for the thermal field of subduction zone. As a result, systematic spatial-temporal variations of magmatism and the spatial variations of petrological signatures in SW Japan have been observed. Numerical modeling suggests that ridge subduction model can explain spatio-temporal variation of granitic rocks in SW Japan. Based on these results, we discuss the origin of these variations.

U-Pb zircon age determinations using LA-ICPMS was performed on total 91 rock samples. The obtained age range from 95 Ma to 30 Ma, with a possible temporal gap between 60 Ma and 50 Ma. During 95-60 Ma, the systematic migration of granitoid magmatism from the south to the north occurred. Temporal variation of petrological signatures is also observed: with time, (1) initial ratio of Sr isotopes (87Sr/86Sr) decreased from enriched characters (0.7090-0.7065) to depleted ones (0.7065-0.7050), and (2) rock types of granitoid changed from ilmenite-series to magnetite-series.

In order to investigate the mechanism of temporal changes observed, ridge subduction model has been tested with numerical simulation, especially in terms of thermal impact of the subducted ridge as a function of subduction velocity and angle with or without slab window. The numerical results suggest the following points: (1) thermal impact of ridge subduction is potentially large especially when subduction velocity changes from high to low (i.e., the leading plate subducts faster), creating a slab window, (2) after the ridge subduction, melting region, mainly of slab melting, shrinks from the trench side to the rear arc side, and (3) subduction angle together with subduction velocity is important to control the overall duration and spatial range of magmatism, required to explain the observed wide horizontal range of the magmatism.

Finally, the numerical results have been compared with the observed spatio-temporal variation of the granitoid magmatism in SW Japan. The comparison suggests that the observed features (e.g., long duration (greater than 35 m.y.), a wide across-arc distance (~150 km) of the magmatism, and northward (toward backarc side) migration of the magmatism) require a shallow subduction angle (~10 degrees) with velocity change of the plates from high to low is required. With these specific conditions, it is inferred that the ridge subduction could have been the primary cause of Cretaceous to Paleogene granitoid magmatism in SW Japan.

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

SCG008-13 Room:301A Time:May 26 11:45-12:00

Correlations of the blueschist facies metamorphism from the Heilongjiang Complex, NE China and the Suo belt, SW Japan

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The Jurassic accretionary terranes, which are characterized by high-P/T blueschist facies metamorphism, have been documented from the eastern margin of the Asian continent. Such high-P/T metamorphic evidence occurs from northeastern Russia via northeastern China to southwestern Japanese islands (Sengor et al., 1993; Isozaki, 1997; Taira, 2001; Wu et al., 2007).

High-P/T blueschists of the Heilongjiang Complex are exposed in northeastern China, and they consist mainly of epidote-glaucophane schists with minor amounts of garnet-barroisite schists and glaucophane aegirine-augite schists. The peak metamorphic conditions obtained for the Heilongjiang high-P/T metamorphic rocks vary from the epidote blueschist facies (320-550 C, 6-15 kbar; e.g. Bai et al., 1988; Zhou et al., 2009; Li et al., 2010a) to the epidote amphibolite facies (500-540 C, 10-12 kbar; Li et al., 2010b). U-Pb ages of 190-255 Ma for detrital zircons suggest that the protoliths of the Heilongjiang Complex are the early Mesozoic granitic batholiths (e.g. Zhou et al., 2009; Li et al., 2010c). Furthermore, the high-P/T Heilongjiang metamorphic rocks were developed by the subduction and collision of the Jiamusi Massif to the eastern border of Central Asian Orogenic Belt at the time of Jurassic period (145-190 Ma; Wu et al., 2007; Li et al., 2010c).

In the Japanese islands, Jurassic accretionary terranes occur as large-scale nappes that are tectonically sandwiched between overlying pre-Jurassic and underlying post-Jurassic sequences (e.g. Isozaki, 1997). The Suo metamorphic belt in southwestern Japan is characterized by blueschist facies metamorphism of 160-230 Ma in metamorphic age (Nishimura, 1998). The blueschists are predominantly made up of epidote-glaucophane schists with subordinate epidote-barroisite schists and sodic clinopyroxene-bearing phengite-epidote schists in the Suo belt, especially in the Gotsu and Masuda areas (e.g. Sengan, 1985). The peak metamorphic conditions preserved in the epidote-glaucophane schists are defined by the crystallization of porphyroblastic epidote, Na-amphibole (glaucophane and Mg-riebeckite), phengite (Si = 6.6-7.0 pfu), chlorite, hematite and titanites, suggesting the epidote-blueschist facies metamorphic conditions (430-530 C, 12-15.5 kbar). Additionally, the metamorphic facies series of the Suo schists of pumpellyite-actinolite facies through glaucophane schist facies to epidote amphibolite facies has been described by previous studies (e.g. Nishimura et al., 1998).

These facts suggest the similarities of both high-P/T blueschists from the Heilongjiang Complex, NE China and the Suo metamorphic belt, SW Japan, not only in the timing of metamorphism, but also in the metamorphic conditions. In this study, we therefore propose that the Heilongjiang high-P/T metamorphic rocks continued to the south, and the Suo metamorphic belt in southwest Japan is thus possible southern extension of the Heilongjiang Complex. The results reported here will contribute toward a better understanding of the Mesozoic tectono-metamorphic development of the eastern margin of the Eurasian continent.

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Keywords: high-P/T, blueschist, Heilongjiang Complex, Suo metamorphic belt, NE China, SW Japan

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

SCG008-14 Room:301A Time:May 26 12:00-12:15

Multiple collision metamorphism during Asian continental growth with relation to the formation of Kurosegawa tectonic zo

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In E- and SE-Asia, there are at least seven micro-continental blocks of Mongolia, North China, South China, Indochina, Shanthai, Sibumasu and West Burma from N-NE to SW. Geological Research program to realize the tectono-metamorphic processes during continental collision orogen of E- and SE-Asia has been done for the last decade.

Multiple collision boundaries in Asian continent are identified and they are subdivided into following six;

1) Siberian craton/Mongolian: 480 ? 500 Ma,
2) Mongolian/North China: 280 ? 300 Ma (so called Central Asian Orogenic Belt),
3) North China/South China: 240 ? 250 Ma,
4) South China/Indochina: 230 ? 250 Ma (Trans Vietnam Orogenic Belt),
5) Indochina-Shanthai/Sibumasu: ca. 210 Ma,
6) Sibumasu-West Burma/Indian subcontinent: ca. 45 Ma.

Characteristics of constituent rock types and metamorphic processes in each collision boundary were reported by many detailed works (e.g. Osanai et al., 2004, 2008; Nakano et al., 2008, 2009, 2010).

Especially in the collision boundary between the North and the South China blocks (e.g. north Dabie terrane, Imjingang belt), various kinds of Permo-Triassic collision zone metamorphic rocks are identified. The Higo metamorphic complex as well as the Hida-Oki terrane in Japan would also have belonged to this type of collision zone and which experienced a top-to-the-south displacement under extrusion tectonics with forming a regional nappe structure before the Cretaceous granitic activities. The basal portion of this regional nappe extrusion would be considered as a serpentinite diaper derived from relatively ductile mantle beneath the North China craton. The diaper intruded along the collision boundary and included various kinds of metamorphic rocks of HT granulite and amphibolite from the lower crustal portion of obducted North China craton and HP blueschist and eclogite from the shallower portion of subducted South China craton. The Kurosegawa tectonic zone as the serpentinite melange corresponds with this diapir.

In the presentation, we will make a detailed talk on this tectono-metamorphic evolution in eastern Asia.

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

SCG008-15 Room:301A Time:May 26 12:15-12:30

Permian sequences and faunas in the peri-Gondwanan region and their palaeogeographical and tectonic implications

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The rifting and drifting of different tectonic blocks in the peri-Gondwanan region has long been one of the most hotly-discussed issues among geoscientists. Extensive investigations during the past decade indicate that numerous sections with carbonate and clastic deposits containing abundant Permian faunas are distributed in the Himalayan region and the Indus-Tsangbo Suture Zone in southern Tibet. A detailed comparison of faunal affinities among different tectonic blocks in different stages in the Permian Period suggests that nearly all blocks in the peri-Gondwanan region including the Qiangtang, Baoshan, Tengchong, Lasha and the Himalaya Tethys Zone are characterized by containing diamictites and typical cold-water faunas in the pre-Artinskian time, therefore were probably in a relatively high-latitude area and attached to the northern margin of Gondwanaland. By the end of late Sakmarian or early Artinskian time, warm-water faunas first occur in the Baoshan and Tengchong blocks in western Yunnan, which probably implies that those blocks began to drift away from the peri-Gondwanan margin and they moved to a relatively warm temperate zone in the Late Guadalupian (Middle Permian), as indicated by widespread distribution of warm-water faunas and carbonate deposits. The earliest warm-water faunas occurred in the Midian in the Lasha Block, which suggest a slightly later rifting and/or climatic amerioration than the Tengchong and Baoshan blocks. Numerous exotic blocks between the Lhasa Block and the Himalaya Tethys Zone containing abundant Middle Permian fusuline faunas and compound rugose corals also indicate a different palaeontological contents and palaeobiogeographical affinities between the Lhasa Block in the north and the Himalaya Tethys Zone in the south. By the Late Permian (Lopingian) time, these palaeontological and palaeobiogeographical disparities became more evident, therefore strongly suggest that the Lhasa Block probably rifted away from the peri-Gondwanan region in the early Middle Permian, a much earlier open time of the Neotethys, not Triassic as previously suggested.

Keywords: Permian, tectonic blocks, peri-Gondwanan region, faunas, rifting, drfiting

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

SCG008-16 Room:301A Time:May 26 12:30-12:45

East Asia: Seismotectonics, Volcanism and Mantle Dynamics

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We introduce the significant recent results of geophysical studies and discuss their implications on seismotectonics, magmatism, and mantle dynamics in East Asia. High-resolution geophysical imaging revealed structural heterogeneities in the source areas of large crustal earthquakes, which may reflect magma and fluids that affected the rupture nucleation of large earthquakes. In subduction zone regions, the crustal fluids originate from the dehydration of the subducting slab. Magmatism in arc and back-arc areas is caused by the corner flow in the mantle wedge and dehydration of the subducting slab. The intraplate magmatism has different origins. The continental volcanoes in Northeast Asia (such as Changbai and Wudalianchi) seem to be caused by the corner flow in the big mantle wedge (BMW) above the stagnant slab in the mantle transition zone and the deep dehydration of the stagnant slab as well. The Tengchong volcano in Southwest China is possibly caused by a similar process in BMW above the subducting Burma microplate (or Indian plate). The Hainan volcano in southernmost China seems to be a hotspot fed by a lower-mantle plume associated with the Pacific and Philippine Sea slabs' deep subduction in the east and the Indian slab's deep subduction in the west down to the lower mantle. The occurrence of deep earthquakes under the Japan Sea and the East Asia margin may be related to a metastable olivine wedge in the subducting Pacific slab. The stagnant slab finally collapses down to the bottom of the mantle, which may trigger upwelling of hot mantle materials from the lower mantle to the shallow mantle beneath the subducting slabs and cause the slab-plume interactions. Some of these issues, such as the origin of intraplate magmatism, are still controversial, and so further detailed studies are needed from now.

Keywords: East Asia, seismotectonics, intraplate volcanism, mantle dynamics, subducting slab