

SMP005-01

Room:201B

Time:May 23 14:15-14:30

## Dissolved noble gases in sediment pore water as proxies for fluid transport within a lake basin?

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The recent development of analytical techniques to determine routinely noble-gas concentrations in the pore water of unconsolidated sediment allows the application of the well-established concepts of noble-gas geochemistry to sediments from lakes and oceans. In particular, the accumulation of non-atmospheric noble-gas isotopes in the sediment column allows tracing the geochemical origin and transport processes of the pore fluids.

Helium (He) is known to emanate from solid earth. Therefore, the abundance of terrigenous He isotopes can reflect the residence time and transport dynamics of the pore fluids in the sediment pore space. Moreover, different geochemical He components can be distinguished by their typical <sup>3</sup>He/<sup>4</sup>He isotope ratios ( $\sim 10^{-5}$  for mantle-type He,  $\sim 10^{-8}$  for crustal He). Therefore, the <sup>3</sup>He/<sup>4</sup>He isotope ratios measured in the pore water of unconsolidated sediments allow characterization of the geochemical reservoir from where terrestrial He and simultaneously other transient fluids originate.

We present noble-gas data measured in the pore water of sediment samples collected from various sediment cores from Lake Van (eastern Anatolia, Turkey). Lake Van is one of the largest terminal lakes and the largest soda lake on Earth. The lake basin is situated in a tectonically active region and it is known to accumulate mantle fluids.

We determined the effective diffusivity in the uppermost ~2 m of the sediment column of Lake Van by tritium (<sup>3</sup>H) analysis. The effective diffusivity allows conversion of the measured He concentration profiles into He fluxes.

The geographical distribution of the He fluxes within the lake basin is discussed in the context of the available geological and seismic data. Our measurements reveal a north-south zonation of the determined He fluxes in the lake basin whereby low He fluxes are observed near the volcanic region in the north and high He fluxes are present near the intrusive and metamorphic rocks of the Bitlis massif in the south. The strongest He emission is identified at the borders of the deep main basin of Lake Van and correlates well with seismic features that suggest the presence of preferential pathways in the sediment column (probably generated by the ongoing subsidence of the basin) that may foster the release of terrigenous fluids.

The <sup>3</sup>He/<sup>4</sup>He isotope ratios in the sediment pore water identify the terrigenous He injected into Lake Van as a mixture of crustal and mantle He with a <sup>3</sup>He/<sup>4</sup>He ratio of  $(2.6-4.1) \times 10^{-6}$ . The samples from the shallow water and the deep water have distinctly different isotopic composition. This geochemical separation suggests that the terrigenous He entering the sediments of Lake Van is further enriched in radiogenic He produced in the sediment minerals during the migration in the pore space.

Our result make a strong case that noble-gases in the pore water of unconsolidated sediments have the potential to be used as proxy to characterize differences in the petrology and lithology within basins of lakes and oceans as well as the origin and the transport processes of the pore fluids.

Keywords: terrigenous He, geogenic fluids

SMP005-02

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## Supra subduction zone chemistry of intrusions into a Miocene accretionary prism, south-west Japan

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We analyzed exceptionally fresh glass from the chilled margin of a basaltic dike of Miocene Muroto gabbroic suite, within the youngest part of the Shimanto accretionary prism, Japan. The REE pattern closely resembles to the standard sample JA-1, Hakone volcano calc-alkaline andesite, and clearly differs from MORB. The-MORB-normative pattern of incompatible elements also resembles calc-alkaline andesite, except for some mobile elements. These geochemical results show that Muroto gabbroic suite that intrudes the accretionary prism has a petrogenesis similar to the Izu-Bonin immature arc. Paleogeography indicates, however, that the Muroto gabbroic suite is not related an accreted equivalent of the Izu-Bonin arc. We propose that the near-trench intrusions formed as a result of subduction of the North New Guinea-Pacific Ridge. We propose that spreading ridge failed to subduct as a result of buoyancy and a new subduction zone initiated seaward so that fluids from the subducting slab infiltrated the hot mantle beneath the stalled spreading center, resulting in supra-subduction zone magmatism that locally intruded the accretionary prism.

Keywords: Muroto gabbroic suite, basaltic dike, fresh glass, Hakone JA-1 standard sample, calc-alkaline, Izu-Bonin arc

SMP005-03

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## Variations in compositions and genetic conditions of magmas through the Izu-Ogasawara subduction zone establishment

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Ogasawara (Bonin) Archipelago comprises the Eocene submarine volcanoes that represent initial stage of the Izu-Ogasawara subduction zone to a more matured arc magmatism along the present volcanic arc. We have discussed petrogenetic processes of the volcanic rocks of the Hahajima Island Group, southern Ogasawara Archipelago (Kanayama et al., 2010JGU Meet.). This study shows secular evolutions of composition and thermal structure in the wedge mantle through the Izu-Ogasawara subduction zone establishment.

When subduction of the Pacific plate beneath the Philippine Sea plate initiated at ~50 Ma, the eastern edge of the Philippine Sea plate was started to extend, which led to upwelling of asthenosphere and producing depleted MORB-like basalt magma without slab contribution (Stern and Bloomer, 1992; Ishizuka et al., 2006, 2009; Reagan et al., 2010). As subduction proceeds, subducted slab-derived fluids and melts changed the magma composition from depleted MORB to boninite and arc tholeiite at 48 Ma pervasively along the Izu-Ogasawara-Mariana forearc (Ishizuka et al., 2009; Reagan et al., 2010). On the Ogasawara Ridge, boninite and arc tholeiitic magmas were replaced by low-Si boninite and calc-alkalic magmas at 45 Ma in the Chichijima Island Group and at 43-42-Ma on the western escarpment of Ogasawara Ridge (Ishizuka et al., 2006; Umino and Nakano, 2007). Arc tholeiite and calc-alkaline magmas after 44 Ma generated by melting of the asthenospheric counterflow that upwelled from deeper parts of the wedge mantle. By ~35 Ma, the volcanic front shifted to the present position and formed the Eocene Izu-Ogasawara arc by arc tholeiitic and calc-alkalic magmatism with similar geochemical signatures to the Quaternary Izu-Ogasawara arc lavas. Since 35 Ma, position of the volcanic front remained unchanged during the splitting of the Kyusyu-Palau Ridge and the opening of the Shikoku-Parece Vela Basin, suggesting that the thermo-chemical structure of the wedge mantle has reached a stable condition for the first ~15 million years since the subduction initiation.

The variation of magma compositions in time and space on the Ogasawara Ridge denotes the decrease in the melting region within the wedge mantle from broad areal and depth ranges (48-46 Ma-boninite and arc tholeiite) to a limited deeper part of the mantle (44 Ma-basalt).

Source mantle composition changed from highly depleted peridotite as the boninite source to relatively fertile MORB-source peridotite as the SHIs basalt source, strongly suggesting that fertile mantle upwelled from a deeper part and replaced depleted boninite source. This indicates that circulation of wedge mantle start around 44Ma, which the time SHIs magmatism began.

The change in slab component from melt-dominant Eocene boninites through less melt-enriched SHIs basalts to fluid-dominant Quaternary front lavas can be ascribed to cooling of the wedge mantle as the result of successive plate subduction for the last 50 Ma.

**Keywords:** Ogasawara (Bonin) Islands, wedge mantle, primary magmas, genetic conditions, degrees of melting, subduction zone

SMP005-04

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## Chemical comparison between terrestrial ferropicrites and Martian shergottites and soils

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Ultramafic volcanic rock called "ferropicrite" occurs in some terrestrial large igneous provinces (LIPs) of various ages such as Pechenga (Kola Peninsula, Early Proterozoic), Siberia (Permo-Triassic), Parana-Etendeka (Early Cretaceous), and East Greenland (Early Cenozoic). Recently, we found ferropicrites and related ferrobasalts (rarely with olivine spinifex texture) from Permian greenstones occurring as basal part of a nappe in the Jurassic accretionary complex in Obama City, Fukui Prefecture (Ichiyama et al. 2006; Ichiyama et al. 2007). Filiberto (2008) pointed out close chemical resemblance between these terrestrial ferropicrites and Martian meteorites (especially shergottites), which includes ferrobasaltic, ferropicritic and ultramafic cumulate rocks. In general, terrestrial basaltic rocks and Martian shergottites plot in separate fields in the Mg/Si-Al/Si, Ca/Si-Mg/Si, and Fe-Si diagrams, but terrestrial ferropicrites plot in the same field as the Martian rocks. The ferropicrites containing 20 wt.% or more FeO cannot be produced by partial melting of ordinary terrestrial mantle rock (peridotite), but can be produced by high-pressure partial melting of Fe-rich eclogite that may be recycled material of the subducted ancient oceanic crust (Ichiyama et al. 2006). The origin in the analogous "heavily processed mantle" may be applicable to the Martian shergottites (Filiberto 2008). However, the Martian shergottites are distinctly richer in Mn and Cr than the terrestrial ferropicrites, and this characteristics is also shared by the Martian soils analyzed by "Spirit" in Gusev Crater (Gellert et al. 2006). The two elements behave contrastingly through partial melting and magmatic differentiation processes (incompatible and compatible, respectively), and the fact that the Martian rocks are rich in both elements suggests chemical uniqueness of the Martian mantle. The Martian rocks are also rich in Co but poor in Ni. This does not favor the magmatic origin in the mantle doped with metallic iron or iron sulfide. The Cr-rich and Ni-poor feature of the Martian mantle suggests that it mainly consists of pyroxene rather than olivine. The chemical resemblance between Martian soils and shergottites suggests widespread occurrence of ferropicritic rocks on Mars, contrasting to their scarcity on the Earth. It is possible that the Martian mantle is more pyroxenitic or eclogitic than the terrestrial mantle, and the Mars produced much more ferropicritic magmas. Melting temperature of iron-rich eclogite is lower than peridotite, and this may have merited the ancient, long-term, voluminous magma production that is unlikely in the rapidly cooling, small planet.

Keywords: ferropicrite, LIP, oceanic plateau, mantle, Mars meteorite, shergottite

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SMP005-05

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## The Pacific-type orogeny and exhumation model of regional metamorphic belt

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Pacific-type orogeny model has been proposed by Dewey and Bird (1970) right after the establishment of plate tectonics. Since then, critical data have been accumulated mainly in Japan Islands and the revised model was proposed by Maruyama (1997). By these models, Pacific-type orogen has been considered to have grown continuously oceanward through time, ca. 100km per 100 m.y. Yet, a new concept of tectonic erosion was proposed along the active continental margin (von Hunene and Scholl, 2002), and it occurred more extensively in the past, and close relationship with the formation and exhumation of regional metamorphic belt seems to be present. Here, I propose a revised model of the Pacific-type orogeny, based mainly on geology of Japan islands and modern analogs over the world.

SMP005-06

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## Geochronology of the Sanbagawa belt in SW Japan

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The Sanbagawa belt was one of the classical high P/T metamorphic belts that trends roughly E-W over 800 km in central to SW Japan. However, recent U-Pb analyses of detrital zircon revealed that the belt consists of two metamorphic belts; Sanbagawa and Shimanto. The Sanbagawa schists consist mainly of metabasites, and pelitic and psammitic schists, with subordinate amounts of siliceous and calcareous schists. The protoliths of the psammitic and pelitic schists are of continental affinity. The protoliths of the metabasites, and siliceous and calcareous schists are oceanic in origin. The protoliths (Triassic to early Cretaceous) were accumulated and mixed at an ancient trench between 142-120 Ma and buried into the subduction zone to be metamorphosed at the conditions from the pumpellyite-actinolite through blueschist to epidote-amphibolite facies and up to eclogite facies.

Timing of peak metamorphism has been estimated by Rb-Sr whole rock isochron method using pelitic schists in the oligoclase-biotite zone (122 $\pm$ 12 Ma), zircon U-Pb method of Iratsu eclogite (110-120 Ma) and Lu-Hf method of garnet-omphacite pair in Seba and Kotsu eclogites (88-89 Ma). Multichronology of Iratsu eclogites concluded the peak age is 115-120 Ma. The oligoclase-biotite zone schists that once reached eclogite facies have the mineral paragenesis (P=7-11 kbar, T= 460-510°C) formed at 85.6 $\pm$ 3.0 Ma with an extensive hydration during exhumation. The Iratsu eclogites also record the overprinting of epidote amphibolite facies at 109 Ma. These evidences suggest the overprinting has a long duration (23 mys) and depends on permeability of rocks controlling the timing of overprinting with hydration; less permeable eclogites being restricted in the hydration.

The Sanbagawa and the Shimanto metamorphic belts overlap in phengite argon age though both belts are completely different in their peak ages. This is due to mainly significant argon depletion from phengite in the Sanbagawa schists that have experienced severe ductile deformation for the duration longer than 31 my during exhumation in comparison with the Shimanto schists that have experienced the deformation shorter than 13 my to reset the phengite K-Ar system. This significantly different duration of deformation during exhumation result in the two contrasting age-temperature-structure relationships of the Sanbagawa and Shimanto metamorphic sequences. The former has the thermal structure that the highest-grade rocks occur in the middle part of the apparent stratigraphy and a positive correlation in age-temperature relationship that the ages get progressively older with increasing metamorphic temperature. The later where the thermal structure for the higher-grade zone is in the lower part of the apparent stratigraphic succession, displays a negative correlation that younger ages are in the higher-grade metamorphic rocks. This contrasting relationship is also observed in the Ishigaki and the Nishiki metamorphic sequences of the Triassic Suo belt. The different natures of subducted oceanic plate boundary may control the different exhumation processes of Pacific type of high P/T metamorphic belts.

Keywords: Sanbagawa HP belt, Shimanto HP-belt, phengite K-Ar ages, zircon U-Pb ages, Sm-Nd ages, Rb-Sr ages

SMP005-07

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## Partial melting of deeply subducted metasediment -discovery of the melting textures from the quartz bearing eclogite in

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Study of dehydration process of the subducting crust is important to understand the Island arc magmatism and recycling water to deep mantle. We have systematically done UHP experiments, petrology and geochemistry on natural UHP eclogites from the Kokchetav and Dabie-Sule UHP belts (Okamoto and Maruyama, 1999, 2004; Okamoto et al., 2000, 2006). The results have suggested that decomposition of phengite would produce melt (or super critical fluid) in coesite and diamond stability depths. That is, migration of K-rich melt might be rather dominant in overlying mantle wedge in deep mantle. Quartz bearing eclogite from the Sanbagawa belt has been considered as subducted metasedimentary rocks down to upper mantle (e.g. Okamoto et al., 2004; Utsunomiya et al., 2011). Recently we have discovered partial melting texture from the quartz bearing eclogite body in central Shikoku, Japan. The outcrop reveals that plagioclase-quartz rich veins in the eclogite. The veins contain large garnet overgrown with Fe-rich, red coloured rims. The sample was carefully collected and observed under microscope, SEM-EDS at Saitama Univ. and EPMA at Waseda Univ. Under BSE image, the eclogite exhibit well equilibrated texture consisted of garnet, clinopyroxene, phengite and quartz. Garnet has inclusion free core and rims. Ca content is high in the core, however, there is no chemical zonation in Fe, Mg and Fe/Mg ratio. Garnet from the melt portion suffered extensive brittle fractures and shows obvious zonal textures. In the core of the garnet, clinopyroxene, epidote, rutile and quartz are included. In the mantle, phengite is included and matrix quartz is included in the rims. There is no Ca variation from core to rims although there is an increase of Fe and Ti from core to rims. From these lines of evidence, we conclude that melt were produced due to decomposition of phengite with clinopyroxene and quartz. P-T estimates using phengite-garnet-clinopyroxene geothermobarometer give that P, T exceed 2.5 GPa, and 750 °C.

Keywords: Deep subduction zone, Metapelite, Eclogite, Partial melting

SMP005-08

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## Significance of metacarbonate rocks in understanding the supercontinental evolution

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Extensive metasedimentary supracrustal sequences exposed in the crustal fragments of the East Gondwana supercontinent, especially in East Antarctica, Sri Lanka, peninsular India, Madagascar and Mozambique, provide us with an opportunity to understand the geodynamic evolution of supercontinent assembly and breakup, as well as to extract key information on the depositional environments of paleo-oceans that separated the proto-continents. The closure of the Neoproterozoic Mozambique Ocean is considered to be a consequence of supercontinental assembly of East Gondwana and West Gondwana during a protracted Pan-African Orogeny that spatially extended from the Arabian-Nubian Shield to the East Antarctic shield, through East Africa, Madagascar, peninsular India and Sri Lanka. The difficulty in constraining the characteristics of the Mozambique Ocean is mainly due to the high-grade metamorphism and tectonic reworking of the sediments during the regional Pan-African Orogeny. However, metacarbonate rocks potentially provide valuable information on the paleo-ocean geochemistry and depositional environments. Here we present a comprehensive geochemical/isotopic evaluation of metacarbonate rocks from East Antarctica, Sri Lanka, peninsular India, Madagascar and Mozambique to constrain the age of deposition of carbonate in the Mozambique Ocean. An extensive data set of C, O and Sr isotope geochemistry combined with trace and rare earth element geochemistry of the high-grade metamorphosed dolomitic and calcitic marbles shows that most underwent post-depositional geochemical alteration. In particular, Sr and O isotope alterations are extensive, with  $^{87}\text{Sr}/^{86}\text{Sr}_{(550\text{Ma})}$  ratios as high as 0.758 and oxygen isotope values as low as -5 parts per thousand. For this evaluation we carefully screened out samples affected by diagenetic and metamorphic alterations based on the carbon, oxygen and strontium isotope results in comparison with reported geochemical parameters of non-metamorphic Meso- to Neo-proterozoic carbonate sediments. Some of the metacarbonate layers preserve pre-metamorphic geochemical characteristics, such as low Sr isotope ratios, high oxygen and carbon isotopic values and well-equilibrated, unaltered trace and rare earth element patterns. Consistently low  $^{87}\text{Sr}/^{86}\text{Sr}_{(550\text{Ma})}$  ratios of 0.705 with high carbon and oxygen isotopic compositions suggest an apparent age of deposition in the Neoproterozoic (ca. 700-850 Ma), with rare exceptions of 0.704 that indicate a Mesoproterozoic age. These apparent depositional ages are consistent with ages obtained from detrital zircons in metapelitic rocks associated with the metacarbonates. Our study thus provides important constraints on the age of carbonate deposition in the Mozambique Ocean that separated East and West Gondwana.

**Keywords:** metacarbonate geochemistry, strontium isotopes, carbon and oxygen isotopes, gondwana, chemostratigraphy

SMP005-09

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## Chromitite as a possible tracer of mantle dynamics

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Podiform chromitites are frequently found from the Moho transition zone to upper mantle section of ophiolites, and interpreted as a kind of cumulates formed by melt/harzburgite interaction and related magma mixing within the shallowest part of the upper mantle. They have been traditionally classified into two types, concordant and discordant ones: the former and the latter are concordant and discordant, respectively, to foliation of surrounding harzburgite. The two types of chromitites are completely different in petrography and chemistry as Ahmed and Arai (2002) described. I would like to propose that some of the concordant chromitites have experienced ultra-high pressure (UPH) conditions and are possibly of deep recycling origin. The diamond-bearing chromitite from the Luobosa ophiolite, Tibet, is a typical example. Our preliminary data on the two types of podiform chromitites from the Oman ophiolite are consistent with this interpretation.

Keywords: chromitite, origin, ultrahigh-pressure minerals, mantle dynamics

SMP005-10

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## Missing link between ultra-high pressure (UHP) and ultra-high temperature metamorphism (UHT): A case study in the Bohemi

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The Gföhl unit in the Bohemian Massif is a unique metamorphic belt, as both ultra-high pressure (UHP) and ultra-high temperature (UHT) metamorphic rocks are exposed together. The maximum P-T conditions of the Ky-bearing Gföhl granulite are estimated as  $\sim 1000^\circ\text{C}$  and 1.5–2.0 GPa (e.g., Carswell & O'Brien, 1993), equivalent to UHT conditions (Harley, 2004) or high-P granulite-facies conditions (O'Brien & Roetzel, 2003), while the most of UHP conditions ( $> 3.0$  GPa) have been identified from lenticular bodies in the country rock with felsic compositions, i.e., Grt-peridotite and associated eclogitic rocks. Thus, a significant pressure gap is apparently existed between UHP lenses and surrounding (U)HT host. However, recent petrologic studies succeeded to identify the UHP conditions from some peculiar rocks/minerals mostly derived from crustal materials, such as Cpx with K-feldspar lamellae (Becker & Altherr, 1992), pyrope/Opx-bearing quartzite (Kotkova et al., 1997), and garnet with minor but significant amounts of Na<sub>2</sub>O (=0.18wt%) and TiO<sub>2</sub> (=0.5 wt%) in migmatitic gneiss of the Gföhl unit (Vrána & Fryda, 2003). These geological and petrologic lines remain the issue to be solved, how and where the UHP and (U)HT rocks were mixed with both together? What is the predominant mechanism to bring up these rocks from upper mantle to the earth surface?

This paper briefly introduces the present state of our research.

Re-evaluation of peak P-T conditions of a Ky-eclogite associated with Grt-peridotite hosted by migmatitic gneiss at Nove Dvory gave  $1050\pm 1150^\circ\text{C}$  and 4.5–4.9 GPa (Nakamura et al., 2004), which are well concordant to those of the host peridotites (Medaris et al., 1990). Some garnet porphyroblasts in the Ky-eclogite remain a chemical zoning suggesting P-increase during the garnet growth, which infers that the host peridotite and the associated eclogite experienced the subduction to  $\sim 150$  km depth. Any signs of UHP conditions had not been found from the country migmatitic gneiss at Nove Dvory. However, Raman spectra for SiO<sub>2</sub> phases indicating the transformation from coesite to quartz were found from the migmatitic gneiss at relevant area (Kobayashi et al., 2008). These results suggest that at least a part of the Gföhl migmatitic gneiss has been subducted to UHP depths and its P-T history is more complicated rather than the traditional idea of moderate-T/Low-P origin of the gneiss (Linner, 1994). The rareness of UHP evidence in the Bohemian Massif may owe to the higher-T overprinting of post-UHP metamorphism than those in the Dabie-Sulu belt, China.

Peak P-T conditions of a Grt-rich granulite at Rohy were estimated as  $\sim 2.2$  GPa and  $1000^\circ\text{C}$  based on the association of omphacitic Cpx inclusions (X<sub>Jd</sub>=30 and X<sub>Tsch</sub>=15), Pl inclusions (X<sub>An</sub>=30) and the host Grt (Prp<sub>18</sub>–27Alm<sub>38</sub>–41Grs<sub>34</sub>–40). Similar peak-P values can be inferred from using GASP barometer for the composition of grossular-rich Grt core (Grs<sub>20</sub>) in the Ky-bearing granulite at Plesovice. However, Grt-peridotite hosted by the Ky-bearing granulite at Plesovice records UHP conditions ( $850\pm 1030^\circ\text{C}$  and 2.3–3.5 GPa; Naemura et al., 2009) for Variscan HP metamorphism. An apparent peak-P gap among mantle- and crust-derived rocks still remains. The Plesovice Grt-peridotite records post-peak decompression conditions, represented by the development of kelyphites around UHP garnet, as  $730\pm 770^\circ\text{C}$  and 0.5–1.5 GPa (Naemura et al., 2009). Although partial melting textures are also common but their P-T conditions is not well constrained in the at Plesovice, P-T values of the post-peak decompression stage for Grt-peridotite are almost overlap to those of partial melting in the nearby area, at Ktis (Kobayashi et al., 2010). These facts may infer the partial melting can give a buoyant force for the mixture of mantle materials and crustal rocks from lower crustal depth to the earth's surface, but the exhumation mechanism from upper mantle to the lower crust for the UHP rocks is still under the veil.

**Keywords:** UHP metamorphism, UHT metasomatism, continental collision, Bohemian Massif

SMP005-11

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## Metamorphic history of Grt-rich gneiss in Lhenice shear zone, Bohemian Massif inferred from inclusions and zoning of Grt

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Multiple equilibrium stages were identified from peraluminous garnet (Grt)-rich gneiss at Ktis in the Lhenice shear zone, located between Blansky les and Prachatic granulate massifs in the southern Bohemian Massif, Czech Republic (e.g. Rajlich et al., 1986). The matrix of the rock mainly comprises cordierite (Crd), sillimanite (Sil), biotite (Bt), Grt, quartz (Qtz), K-feldspar (Kfs) and plagioclase (Pl) along with accessory minerals such as spinel (Spl), apatite (Ap), monazite (Mnz) and zircon (Zrn). Bt, Sil, kyanite (Ky) and Pl occur as inclusion phases in Grt. Crd occurs only in the matrix both as isolated grains and as reaction coronas developed around Grt. Spl is closely correlated with the Crd corona. Some coarse-grained ( $> 3$  mm) Grts show chemical heterogeneity both in major and trace elements. Grossular (Grs)-content is homogeneous and high ( $X_{\text{Grs}} = 0.27$ ) in a center of the grain and smoothly decreases towards the grain margin ( $X_{\text{Grs}} = 0.02$ ). However, pyrope (Prp)-content shows an inverse pattern against Grs-content; i.e., Prp-content is low and constant ( $X_{\text{Prp}} = 0.03$ ) in the center of the grain and gradually increases towards the margin (up to  $X_{\text{Prp}} = 0.28$ ). The contours of Grs and Prp contents show symmetrical hexagonal shapes. The distribution pattern of phosphorus, however, shows a striking contrast against Grs-content. The core of the grain is characterized by low-phosphorus content almost below the detection limit of the EPMA analysis but it is armored by the high-phosphorus rim accompanying with local development of phosphorus-poor outermost rim. Phosphates, such as Ap and Mnz, with large amounts of  $\text{CO}_2$ - $\text{N}_2$  fluid inclusions are abundant in the phosphorus-poor core but are lacking in the phosphorus-rich rim. The outline of phosphorus-poor core shows a hexagonal shape, which is symmetrical to those of Grs and Prp content contours, but it is located outside of higher  $X_{\text{Grs}}$  ( $=0.27$ )- and lower  $X_{\text{Prp}}$  ( $= 0.03$ )-content contours. These observations suggest that the outline of phosphorus-poor core should indicate the original shape of Grs-rich garnet developed during an early stage of the metamorphism. The zoning pattern of major/trace elements in garnet and the mode of occurrence of constituent minerals suggest that the studied rock experienced three equilibrium stages represented by following mineral assemblages with excess of Bt, Pl, Qtz and Kfs:

Stage 1:  $X_{\text{Grs}}$ -rich ( $= 0.27$ ) and phosphorus-poor Grt core + Ky + Ap + Mnz +  $\text{CO}_2$ - $\text{N}_2$  fluid

Stage 2:  $X_{\text{Grs}}$ -poor ( $= \text{ca. } 0.05$ ) and phosphorus-rich Grt rim + Ky/Sil

Stage 3:  $X_{\text{Grs}}$ -poor ( $= 0.02$ ) and phosphorus-poor Grt outermost rim + Sil + Crd +/- Spl + Mnz

The geothermobarometry gives following P-T conditions for each stage: 1.5-2.3 GPa at 700-900 °C for Stage 1, 730-830 °C and 1.0-1.3 GPa for Stage 2, and 740-850 °C and 0.6-0.8 GPa for Stage 3. The P-T conditions for the Stage 2 are slightly higher than the peak P-T conditions for gneisses of the Varied /Monotonous Units in the literatures and the P-conditions for the Stage 1 are similar to those of HP-granulite in the Gfoehl Unit. The inferred P-T conditions both by a model petrogenetic grid and a pseudosection analysis suggest that the studied rock experienced the isothermal decompression at least from the Grt rim stage (Stage 2, 1.0-1.3 GPa) to the matrix stage (Stage 3, 0.6-0.8 GPa). This decompression path would overstep following dehydration melting reactions at different depths:  $\text{Ms} + \text{Qtz} = \text{Grt} + \text{Bt} + \text{Sil} + \text{Kfs} + \text{Liq}$  at 1.0-1.2 GPa and  $\text{Bt} + \text{Sil} + \text{Qtz} = \text{Grt} + \text{Crd} + \text{Kfs} + \text{Liq}$  at 0.3-0.6 GPa. Furthermore, phosphorus-poor core includes Ap and Mnz, but the phosphorus-richest rim is free of them. This kind of zoning of phosphorus in Grt was probably formed related to the partial melting reaction including phosphate minerals. The high-phosphorus Grt rim should be formed through these reactions, in other words, higher-phosphorus content of Grt can be used as an indicator of partial melting of the host rock.

**Keywords:** Bohemian Massif, Lhenice shear zone, Partial melting, Phosphate, Phosphorus, Fluid inclusion

SMP005-12

Room:201B

Time:May 23 17:40-17:55

## Petrology of chromian spinel-bearing serpentinites in the Ise area, Hida Marginal Belt characteristics of their protolith

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The Ise area is located in the western part of the Hida Marginal Tectonic Belt (central Japan), which includes several sporadic exposures of ultramafic rocks sometimes forming serpentinite melange of Paleozoic age. Ultramafic rocks in the Ise area, enveloped by Paleozoic-Mesozoic sedimentary rocks, are completely serpentinitized; however, the abundance of bastite after orthopyroxene suggests harzburgite protoliths. The bastite- and mesh-textural serpentinites after orthopyroxene and olivine, respectively, are distinguished from each other in  $\text{Al}_2\text{O}_3$ ,  $\text{Cr}_2\text{O}_3$  and  $\text{NiO}$  contents. The bastite-textured serpentinite is high in  $\text{Al}_2\text{O}_3$  (up to 4.0 wt%) and  $\text{Cr}_2\text{O}_3$  (up to 1.2 wt%), but low in  $\text{NiO}$  (<0.3 wt%) relative to mesh-textured one. Relic chromian spinel is vermicular in shape and sometimes enclosed in orthopyroxene (bastites). It shows an intra-grain chemical homogeneity, and is sometimes altered to ferritchromite at the margin. It has an average composition of 32.0 wt%  $\text{Al}_2\text{O}_3$ , 14.0 wt%  $\text{MgO}$ , 36.0 wt%  $\text{Cr}_2\text{O}_3$ , 17.0 wt%  $\text{FeO}^*$  (total iron) and 0.03 wt%  $\text{TiO}_2$ . The chromian spinel has a narrow range of  $\text{Cr\#}$  [=  $\text{Cr}/(\text{Cr} + \text{Al})$  atomic ratio] from 0.38 to 0.51 (0.43 on average) and low  $\text{Fe}^{3+}$  [( $\text{Fe}^{3+}/(\text{Cr} + \text{Al} + \text{Fe}^{3+})$  atomic ratio, <0.03)], similar to chromian spinel in lherzolite-harzburgite from Kotaki and Oeyama ultramafic blocks. It is also similar in chemistry to spinels in forearc peridotite in supra subduction zone setting (SSZ). We found siegenite ((Ni, Co) $_3\text{S}_4$ ), millerite (NiS), violarite ( $\text{Fe}_2\text{Ni}_2\text{S}_4$ ) and Cobalt gersdorffite Co-(NiAsS). The degree of melting using  $\text{Cr\#}$  of chromian spinel is around 15-17% partial melting, which is slightly lower than the degree (around 18-25%) estimated by using  $\text{Cr\#}$  versus  $\text{TiO}_2$  model. This is consistent with the petrographical observation (harz. protoliths). The harzburgite protoliths were possibly serpentinitized by slab-derived fluids in SSZ during the exhumation process. The slab-derived fluids causing serpentinitization, which contained fluid-mobile elements (e.g., As), are responsible for formation of the Ni-Co-sulfides and arsenides.

Keywords: chromian spinel, sulfides, serpentinite, Ise, Hida Marginal Belt, Japan

SMP005-13

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Time:May 23 17:55-18:15

## Kohistan of Pakistan is a collage of island arc, back-arc & continental margin settings: mafic dykes are the indicators

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Kohistan island arc of Pakistan is squeezed as lensoidal mass between the Indian continent to the south and Karakoram micro-continent to the north. The delineating contacts are the suture zones known as the Main Mantle Thrust or Indus suture and the Main Karakoram Thrust or Shyok suture. The arc contains four major magmatic complexes: from bottom to top the mafic-ultramafic Jijal complex, mafic-ultramafic Sapat complex, mafic and ultramafic Chilas complex at the base, and the Kohistan batholith in the middle part. Back-arc basin rock assemblages, the Jaglot group, occur as septum within the Kohistan batholith. Mafic dykes are found to intrude the ultramafic and mafic rocks of the Chilas complex and the granitoids of the Kohistan batholith. Mafic dykes both basaltic and dolerites, intrude the slate, quartzite and gabbros of the Jaglot group. Petrographic and geochemical studies reveal variations in mafic dykes. Mafic dykes of the Chilas complex are primitive and range from picrobasalt to basalt, tholeiitic and subalkaline. These dykes are mainly amphibolites. Mafic dykes of the Kohistan batholith are tholeiitic and calc-alkaline to alkaline and basaltic-andesite to trachy-andesite, which preserved trachytic-type texture. Mafic dykes of the Jaglot group are tholeiitic basalt and basaltic andesite, which preserved ophitic to subophitic texture. Mafic dykes of the Chilas complex are high in Al<sub>2</sub>O<sub>3</sub>, MgO, CaO, and low in Na<sub>2</sub>O, K<sub>2</sub>O, P<sub>2</sub>O<sub>5</sub>, Zr, Rb, Sr, Ba and Nb. Mafic dykes of the Kohistan batholith contain comparatively high Al<sub>2</sub>O<sub>3</sub> and low TiO<sub>2</sub>, Zr, Rb, Sr, Ba and Nb. The calc-alkaline/alkali basaltic mafic dykes are distinctly high in Na<sub>2</sub>O, K<sub>2</sub>O and P<sub>2</sub>O<sub>5</sub>, Rb, Sr, Ba, Nb and low in MgO, CaO, Fe<sub>2</sub>O<sub>3</sub> and Y. Mafic dykes of the Jaglot group are distinct to contain high TiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, Na<sub>2</sub>O, Y, Zr and low Al<sub>2</sub>O<sub>3</sub>, K<sub>2</sub>O, Rb, Sr and Ba. These dykes show flat pattern with slightly high HFSE/LILE ratios whereas the other dykes show sloping pattern with marked Nb depletion and Sr enrichment, when compared with N-MORB and primitive mantle values. Mafic dykes of the Jaglot group show enriched MORB-type affinity of back-arc basin origin whereas mafic dykes of the Chilas complex and the tholeiitic dykes of the Kohistan batholith give island arc type signatures. Calc-alkaline/alkali basaltic dykes give continental margin origin. All mafic dykes of the area are derived by the partial melting of depleted, heterogeneous mantle and enriched mantle sources during island arc, back-arc and continental margin tectonic settings.

**Keywords:** Kohistan, Island arc, Continental margin, Back-arc, Mafic dykes, Geochemistry

SMP005-14

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Time:May 23 18:15-18:30

## Geochemistry of subduction-related volcanic rocks from south Ardestan, central UDMA, Iran

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Urumieh-Dokhtar Magmatic Arc (UDMA) is formed by the subduction of the Neotethyan oceanic slab beneath central Iran. The magmatic activity in the south Ardestan, central UDMA, has been classified into Eocene, upper Miocene and Plio-Quaternary sequences. The Eocene sequence comprises volcano-sedimentary strata, which are interlayered with the basaltic and andesitic lavas. It is noted that the last Eocene magmatic event occurred as basaltic dyke that cut through the Eocene sequence and as tabular basaltic lavas on the top of Eocene sequence. The basaltic rocks in the upper and lower Eocene sequence have porphyritic texture with phenocrysts of plagioclase, clinopyroxene and olivine, in decrease order. Their major element compositions indicate high alumina characteristic ( $\text{SiO}_2=48-53$  wt%,  $\text{Al}_2\text{O}_3>17.5$  wt%,  $\text{CaO}>8.5$  wt%,  $\text{MgO}<9$  wt%); MORB-normalized trace element patterns exhibit a typical continental arc signature with characteristic enrichment in LILE and depletion in HFSE. LILE show temporal variations from lower to upper Eocene, for example Rb and Th decrease from 56 to 8 ppm and 1.95 to 0.50 ppm respectively. Similarly, the rare earth element (REE) patterns of the basalts become progressively less fractionated toward upper Eocene. The temporal variation in trace elements appears to reflect decrease in subduction components in their source mantle at the end of the subduction period. The Miocene volcanic rocks occur as basaltic andesite to andesite lava flows. Most basaltic andesites contain phenocrysts of plagioclase, olivine, pyroxene and magnetite. The andesite lavas contain plagioclase, orthopyroxene, clinopyroxene, and opaque minerals. The Pliocene dacitic lava domes intruded Miocene lavas, and they belong to the last volcanic activity in this region. They are composed of plagioclase, orthopyroxene, amphibole, quartz, and opaque minerals. Miocene basaltic andesites have a high Mg composition ( $\text{SiO}_2=54.39$  wt %,  $\text{Al}_2\text{O}_3=16.2$  wt %,  $\text{MgO}=6.79$  wt %,  $\text{Mg\#}=61$ ,  $\text{Ni}=121$  ppm,  $\text{Cr}=256$  ppm). In contrast, the Pliocene dacites have adakitic signature with low  $\text{Mg\#}$  (47.7- 45.4), high Sr/Y (88-71;  $\text{Sr}=558-816$  ppm,  $\text{Y}=7-9$  ppm) and low HREE concentrations. Such adakitic signatures suggest that they were generated by partial melting of basaltic protoliths. Based on geochemical variations of south Ardestan volcanic rocks, we infer that subduction of the Neotethyan oceanic plate beneath central Iran was ceased at upper Eocene and volcanism has resumed at Miocene under the post collision environment. The co-existence of Miocene high Mg andesite and Pliocene adakite can be accounted for by the model of delamination of lower continental crust.

**Keywords:** Urumieh-Dokhtar Magmatic Arc, Iran, calc-alkaline, adakite, high Mg andesite