Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SMP08-01 Room:A05 Time:May 26 10:00-10:15

The January 2013 and May 2014 North Aegean Earthquakes Sequence: Their Role in the Aegean Region

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Abstract

The North Aegean Sea is one of the most seismically active and deforming region between the Eurasia and Anatolia tectonic plates. This area is dominated by dextral strike-slip faulting and is characterized by frequent strong earthquakes.

On 8th January 2013 at 14:16 UTC a moderate earthquake (Mw= 5.7) occurred between the south of Gokceada and southwest of Bozcaada Islands. The earthquake was felt at a wide area. The area is defined as the continuation of the branch of North Anatolian Fault (NAF) inside the Aegean Sea. Fault plane solution determined by this study shows that the earthquake occurred on NE-SW oriented strike slip fault segment. The aftershocks distribution also supported the rupture of the NE-SW oriented fault.

Approximately 17 months later, another big earthquake occurred in the same area. On 24th May 2014, at 09:25 UTC, a powerful Ml=6.7 (Mw=6.8) earthquake hit Greece and Turkey, 87 km west of Canakkale, and totally 350 people injured in Greece and Turkey. The main-shock occurred on a fault with a NE-SW strike, where the largest portion of the energy was released towards these directions. Therefore the earthquake was felt strongly in Canakkale, Istanbul and Marmara region. In this study, we calculated CMT solutions for main-shock and important aftershocks ($M>4.0$). CMT analyses were done for more than 50 important earthquakes. Moment tensor solutions show generally strike-slip faulting. The fault which caused earthquakes, is thought to be a branch of North Anatolian Fault Zone in the North Aegean Sea. Generally, the location of the earthquakes and orientation of the NE-SW nodal planes are consistent with right-lateral faulting within the North Aegean Trough (NAT). The Aegean Sea is characterized by dextral strike-slip faulting along NE-SW striking faults, along fault zones formed parallel to the North Aegean Trough (NAT). Strike slip faulting is changing to oblique, with significant component of extension, as one goes from the Aegean to the coastal area of NW and Western Turkey.

The sources region of the North Aegean earthquakes is influenced by both the Aegean extensional regime and the strike-slip regime in the western part of the North Anatolin Fault Zone.

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Keywords: North Anatolian Fault, North Aegean Sea, aftershock, strike-slip regime, Moment tensor solution

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Deciphering the Variscan orogeny: HP metamorphism at different temperatures and HT metamorphism at different pressures.

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The European Variscan belt is well known for its voluminous granites and widespread migmatite complexes. However, the same short orogenic episode also resulted in the formation of blueschists and numerous bodies of eclogite. The picture is further complicated by large bodies of felsic granulite (including the type locality for granulite), pods and lenses of mantle-derived garnet peridotite and, since the beginning of the 20th century, also ultra-high pressure coesite and/or microdiamond-bearing rocks. How can all these apparently different rocks be created in a single orogen and be exposed so soon after the tectonometamorphic events (as revealed from post-orogenic conglomerates and sedimentary sequences) in such close proximity? The answer lies in deciphering critical rock types through microanalysis of major and trace elements as well as isotopes. The garnet peridotites, sometimes enclosing mantle-type eclogite lenses, occur together with the felsic granulites. Detailed investigation has revealed that these K-feldspar+quartz- rich rocks with minor garnet, kyanite and rutile formed at eclogite facies conditions. Recent studies have confirmed microdiamond and coesite in such so-called granulites thus confirming UHP conditions i.e. the crustal rocks have been subducted to mantle depths and trapped slices of mantle during their exhumation. Geochronological and diffusion studies have determined a rapid exhumation of these units. These are not the only HP rocks, however. An earlier phase of subduction and exhumation produced eclogites that were in a hanging wall position before exhumation of the hot granulite-peridotite units. Further away from the final subduction zone the exhuming hot granulite-peridotite bodies flowed to underplate the crust. Locally, these hot complexes domed upwards and became caught-up and flattened-out in mid- to upper-crustal shear zones. Where such complexes are exposed today they are bounded by units representing middle and lower crust, locally containing a 3rd type of eclogite in places together with spinel peridotite. Eclogites in this situation can show a pyroxene-hornfels overprint (olivine-bearing textures) despite preserving omphacite (from the eclogite facies stage) as well as granulite and amphibolite facies breakdown textures. With the realisation that the eclogites are from different stages of the subduction-collision history, as deduced by detailed investigation of suitable key samples by multiple microanalytical methods, it is now possible to piece together this most enigmatic orogenic belt. Is this type of relamination of upper crustal material to the lower crust an example of what is happening in the Himalaya today?

Keywords: Variscan, HP granulite, Garnet peridotite, Eclogite, pyroxene-hornfels

SMP08-03 Room:A05 Time:May 26 10:30-10:45

Combined geochronology and P-T pseudosection constrains protracted garnet growth in high-pressure eclogite

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Understanding convergent margin processes requires determination of the onset of subduction, the number and polarity of subduction zones, and the duration of subduction zone metamorphism. Garnet growth and intracrystalline zonation can be used to constrain the timing, duration, and kinetics of tectonometamorphic processes. An eclogite from the Huwan shear zone in the Hong'an orogen was investigated with combined pseudosection analysis and multiple geochronology. The pseudosection analysis illustrates that garnet growth is continuous and along an early near isothermal trajectory followed by a near isobaric heating path from 1.9 GPa/500 ℃ to 2.4 GPa/575 ℃. $^{40}Ar/^{39}Ar$ dating of amphibole inclusion in garnet from the eclogite yielded age of 310 $\pm$ 5 Ma, which is consistent with the U-Pb age of 302 $\pm$ 6 Ma for the metamorphic zircons within uncertainty. Garnet from the sample was crushed to obtain separate core and rim material that produced Lu-Hf ages of 296.9 $\pm$ 3.8 Ma and 256.9 $\pm$ 3.9 Ma, the latter is consistent with its Sm-Nd age of 254.3 $\pm$ 4.6 Ma for the same aliquots. Similarly limited zircon U-Pb ages of *c*. 257 Ma were obtained in zircon rims with garnet inclusion. These ages were interpreted to bracket the period of garnet growth and the difference of up to ~40 Myr is best explained by protracted garnet growth. We propose that the rocks became detached from the downgoing slab and remained in the subduction zone for a long time without much change in P-T conditions until the entry of the continental crust in the subduction zone, which incorporated the rocks into the following subducted and exhumed at some time later than *c*. 254 Ma. The increasing observations of protracted garnet growth and long-lived subduction in various orogens worldwide demand more sophisticated geodynamic models.

Keywords: Lu-Hf, garnet, protracted metamorphism

SMP08-04 Room:A05 Time:May 26 11:00-11:15

Lawsonite-blueschist in the Hakoishi sub-unit, Kurosegawa belt, Kyushu, Japan, as Water Carrier Into the mantle.

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Lawsonite blueschist (LBS) is considered to have formed in the past cold subduction system and to be one of the most hydrated metabasites in the relevant area, with more than 5 wt% of H2O (e.g., Hacker et al., 2003). In these rocks, lawsonite, pumpellyite and chlorite are major H2O carriers. The dehydration reaction owing to the breakdown of such hydrous minerals is considered to play the important role as the trigger of arc magmatism, deep intraslab earthquake and trace element recycling in the cold subduction system.

LBS, almost free from chemical and textural modifications during the exhumation stage, occurs in the Hakoishi sub-unit of the Kurosegawa belt, Kyushu, in the outer belt of Southwest Japan. The main constituents of the Hakoishi sub-unit, extending in east-west trending narrow horst like area of ca. 10 x 1 x at least 1 km3, are metabasites and metachert along with minor amount of metagabbro and metapelite. Our filed mapping cannot detect the significant discontinuity or tectonic contact within the unit, suggesting that the LBS facies metamorphic rocks in Hakoishi sub-unit form a coherent block up to 10 km length originated from the upper part of subducting oceanic crust in Paleozoic time.

Following main high-pressure metamorphic minerals are well developed in all types of protoliths in the sub-unit, such as lawsonite (Lws), pumpellyite (Pmp), Na-pyroxene (Napx), Na-amphibole (Namp), chlorite (Chl), albite (Ab) and quartz (Qz). The following westward progressive mineral assemblage change is identified even in 10 km horizontal distance in the sub-unit;

Pmp + Namp (Zone1),
Lws + Pmp + Namp (Zone2)
Lws + Napx + Namp (Zone3)
with excess Chl, Qz and Ab.

Jadeite component (XJd) of Napx gradually increases from Zone1 (XJd=0.15) to Zone3 (XJd=0.50). Glaucophane (Gln) component [YAl = Al/(Al + Fe3+)] of Namp also increases from Zone1 (YAl=0.15) to Zone3 (YAl=0.80).

Petrogenetic grid in NCMASH system reveals that the observed mineral assemblages are stable from 0.45 GPa and <300 C for Zone1 to 0.80 GPa and <300 C for Zone3 and that the following mineral reactions are inferred to define each zone boundary in NCF3+MASH system;

(1) 3.4 Pmp + 2.9 Chl + 12 Ab + 10 Qz + 2.2 hematite (Hem) + 9.5 H2O = 13.5 Lws + 6 Namp

(2) 3.3 Namp + Lws + 0.8 Hem + 2.2 Ab + 1.9 H2O = 9.7 Napx + 1.8 Chl + 10 Qz

These data suggest that the studied rocks were formed under extremely low geothermal gradient (ca. 5-10 C/km).

The above mentioned all metamorphic reac-tions are hydration type. Actually H2O content stored in hydrous minerals in studied blueschists (BS) increases from 2.4-4.2 wt % in Lws-free BS in Zone1 to 5.0-7.0 wt % in Lws-bearing BS in Zone2 and Zone3. These data verifies that the LBS in the Hakoishi sub-unit make clear the hydration mechanism in the cold subduction system.

Estimated P-T condition of the Hakoishi sub-unit well fits to a thermal modeling of the Philippine sea plate subducting beneath the Kii Peninsula (Peacock, 2009). Extensive seismic studies were also carried out beneath the Kii Peninsula. For example, Kato et al. (2014) found low velocity areas in three places, inside the arc crust between 5-20km depth, in the mantle wedge just overlying the Philippine sea plate between 35-50 km depth, and at the wedge shaped part between the tip of the mantle wedge and the Philippine sea plate. They ascribed the reason of low-velocity to deep fluid activities. In the latter two areas, H2O-rich fluid released by dehydration reactions are considered to be supplied from the subducting Philippine sea plate through the eclogitization of hydrated metabasite at the depth greater than 50 km (Kato et al., 2014).

Our data suggests that LBS forming reaction should have taken place in the layer 1 and 2 of Philippine sea plate at the depth of 15-25 km beneath the Kii Peninsula. We suppose the LBS would carry high water content of 5.0-7.0 wt% to the incipient depth of the eclogitization at the depth of 30-60 km.

Keywords: Lawsonite, blueschist, cold subduction

SMP08-05 Room:A05 Time:May 26 11:15-11:30

Seismic anisotropy from crust to core: a mineral and rock physics perspective

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Since the early work of Hess and co-works for mantle in the 1960s and Poupinet et al. in 1980s for the inner core, we know that seismic anisotropy is a global phenomenon. Progress in seismology has led to a much more complete image of the Earth's interior in terms of heterogeneity and anisotropy. The interpretation of the seismic anisotropy requires a multidisciplinary effort to unravel the geodynamic scenario recorded in today's seismological snapshot. Progress in mineral physics on the experimental measurement of elastic properties at extreme conditions are now completed by *ab initio* atomic modelling for the full range of temperatures and pressures of the Earth's interior. The new data on the elastic constants of wider range minerals enables more realistic petrology for seismic anisotropy models. Experimental plastic deformation of polycrystalline samples at deep Earth conditions allows the direct study of crystal preferred orientation (CPO) and these studies are completed by *ab initio* atomic modelling of dislocations and other defects that control plasticity. Finally, polycrystalline plasticity codes allow the simulation of CPO reported by experimentalists and the modelling of more complex strain paths required for geodynamic models. The CPO of crustal and mantle rocks from the Earth's surface or recovered as xenoliths, provides a geological verification of the CPOs present in the Earth. The systematic use of CPO measured by U-stage for field studies all over the world for last 40 years has now been intensified in last 15 years by the use of electron back-scattered diffraction (EBSD) to study of CPO and the associated digital microstructure. It is an appropriate time to analysis CPO databases of olivine and other minerals, which represents the work of our group, both present and former members, as well as collaborating colleagues. It is also interesting to compare the natural record as illustrated by our databases in the light of recent experimental results. Information on CPO together with single crystal elastic constants and the equation of state allow the modelling of seismic anisotropy due to plasticity at any PT condition, and the connection with geodynamic processes related to large-scale flow in the deep Earth.

Keywords: seismic anisotropy, upper mantle, inner core, plastic deformation, crystal preferred orientation

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Rheology in subduction channel inferred from P-T paths in tectonic blocks from serpentinite melange

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The Kamuikotan metamorphic rocks distributed around the Asahikawa-city have been known as typical high-P/T type metamorphic rocks. Serpentinite melange occupies the stratigraphically highest position of these metamorphic rocks, in which amphibolites tectonic blocks occur (e.g. Ishizuka et al., 1983). These blocks experienced medium to low pressure metamorphism followed by high pressure metamorphism, while blueschist blocks which did not experience polyphase metamorphism also occur, as explained below. There are three types of compositional zoning in amphibole constituting these tectonic blocks (Okamoto et al., 2013, Annual Meeting of Geological Society of Japan): Type I, actinolite overgrown by glaucophane; Type II, magnesio-hornblende overgrown by actinolite, which is further rimmed by glaucophane; Type III, tschermakite or pargasite overgrown by glaucophane or magnesio-riebeckite. While type I zoning occurs in amphiboles from blueschists, type II zoning occur in ones from amphibolites. It is clearly inferred from type II zoning that the rocks were once cooled before they experienced high-P/T type metamorphism. Amphiboles with type III zoning occur in a garnet-amphibolite sample, for which higher pressure and temperature for formation are inferred from the mineral assemblage than the amphibolites and cooling are also inferred to have occurred from the compositional zoning of garnet (Okamoto et al., 2013).

Takeshita et al. (2013, Annual Meeting of Geological Society of Japan) reported quartz c-axis fabric patterns from three metachert layers intercalated with blueschists. Although all of these show monoclinic symmetry, indicating shear-dominant flow, the shear direction relative to geographical orientations is unknown because of the occurrence as tectonic blocks. Further, these quartz c-axis fabric patterns are significantly different, which are characterized by (1) asymmetrical small circle girdles with the half-opening angle less than 30o, (2) asymmetrical type I crossed girdles, and (3) a pattern close to asymmetrical type II crossed girdles with a Y-maximum. The patterns (1), (2) and (3) indicate that basal$<$a$>$, basal$<$a$>$+rhomb$<$a$>$, and basal$<$a$>$+prism$<$a$>$are dominant slip systems in quartz, respectively, and the temperatures for formation are inferred to have increased from (1) to (3), ranging between 300 to 500 oC.

Those P-T paths inferred from compositional zoning in amphiboles, and different temperature conditions for deformation inferred from quartz c-axis fabric patterns could indicate that these rocks with different P-T paths could have been juxtaposed in the ancient subduction channel, and were cooled with time. These results are in accord with the previous studies that the subduction responsible for the formation of Kamuikotan metamorphic rocks was initiated at c. 140 Ma by the jump of trench (Kiminami and Kontani, 1983), which was followed by the steady state subduction leading to the cooling of subduction channel and resultant formation of high-P/T type metamorphic rocks. Further, the juxtaposition of tectonic blocks in subduction channel could have resulted from the weak rheology of serpentinite, as simulated by Gerya et al. (2002). In the present talk, we will demonstrate that the weak rheology in subduction channel could have been also contributed by dissolution-precipitation creep assisted by fracturing in amphibolites and blueschists in addition to the well-known weak serpentinite rheology.

Keywords: Kamuikotan metamorphic rocks, P-T paths, quartz c-axis fabric, dissolution-precipitation creep, compositional zoning in amphibole, blueschist

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EBSD-measured crystal preferred orientations of Sanbagawa eclogites

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Electron backscattered diffraction maps and crystal preferred orientations of the two types of eclogites in the subduction-related high-pressure/low-temperature type Sanbagawa metamorphic belt, central Shikoku, Japan have been reported. Type 1 eclogite (garnet: 43%, omphacite: 35%, secondary actinolite: 7% and hornblende: 5% with minor quartz, muscovite and rutile), garnet-rich and dark green, have strong crystal preferred orientations in omphacite and rutile, weak but complex fabric pattern in garnet suggesting their deformation during peak eclogite facies stage. Type 2 eclogite (omphacite: 41%, garnet: 39%, retrograde hornblende: 11% with minor quartz, epidote/zoisite, rutile and titanite), omphacite-rich and light green, also show identical fabric to that of type I. Crystal preferred orientations (CPOs) of minerals in both types show that omphacite has the strongest CPO along [001]-axes and {011}-poles, suggesting intracrystaline flow along [001]{110} and [001](100) slip systems representing subduction-related deformation rheology at mantle depth. Fabric preserved in rutile (stable at eclogite facies) is identical to omphacite with maxima along [001]-axes also indicate same deformation mechanism. Amphibolite facies minerals (e.g., hornblende and actinolite) exhibit similar CPOs to that of omphacite, indicating homotaxial crystal growth/recrystallization after the replacement of omphacite during late-stage retrogression. In both type eclogites the deformation was mainly accommodated in omphacite which developed L-type fabric, representing a constrictive stress regime. Based on jadeite content (>0.35 in type 1 and <0.3 in type 2) in the omphacite in both type eclogites there is no clear correlation for the development of L-type fabric in relation to the cation ordered-disordered structure despite of slightly different equilibration temperatures. Garnet, behaving as rigid body, exhibit complex CPO and do not show any clear plastic deformation.

Keywords: EBSD, Eclogites, crystal preferred orientations, Sanbagawa