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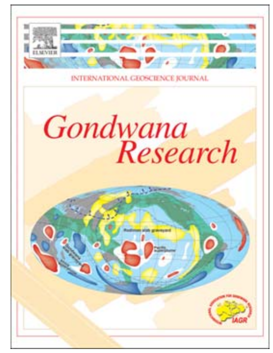

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Editorial

A tribute to Akiho Miyashiro: Introduction

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Akiho Miyashiro (Fig. 1) was born in Okayama, SW Japan in the year 1921. He graduated from the Geology Department of University of Tokyo in 1941, and subsequently obtained MS and Ph.D. degrees. His PhD research was on metamorphic petrology of the low-pressure Cretaceous regional metamorphism in Abukuma plateau, central Honshu, Japan. Thereafter Miyashiro devoted his attention to the investigation of regional metamorphism to establish a theoretical framework of metamorphic petrology.

Although glaucophane-schist facies was known from late 1920s, and debates surrounded on their origin through Na-metasomatism, Miyashiro and his group including Y. Seki and S. Banno carried out detailed field mapping of the isograds including glaucophane. In both the regions of their investigation in Japan, one in the Kanto Mountain and the other in the Hida marginal belt, Miyashiro and team confirmed the lower and upper metamorphic facies and thus delineated the boundary reactions dividing the blueschist facies rocks.

In the 1950s and 60s, metamorphic facies series was solely ascribed to Barrovian-type. Miyashiro proposed three metamorphic facies series using Al2SiO5 polymorphism, i.e., andalusite-sillimanite type, kyanite-sillimanite type and jadeite-glaucophane type together with two intermediates types.

In the Japan arcs, the low-P/T regional metamorphic belt runs parallel to the high-P/T regional metamorphic belts on the ocean-side. Miyashiro listed up three pairs of examples and speculated their origin by oblique mantle convection to yield low geothermal gradient on the ocean side and high-geothermal gradient on the volcanic front. Although his original definition of paired metamorphic belts in Japan had to be revised extensively (see Brown, 2010-this issue), his concept remains valid and his idea immensely contributed to develop our understanding of consuming plate boundary processes when plate tectonics was proposed.

In 1965, Miyashiro moved to USA at the Columbia University and initiated petrological investigations on the ocean-floor metamorphic rocks dredged and collected by Lamont-Doherty of Oceanographic Laboratory. Miyashiro and F. Shido described metamorphic minerals and established the hydrothermally altered nature and facies series at lowest P/T condition. Later, they proposed a petrologic model of mid-Atlantic Ridge, combined with seismogenic characters with M. Ewing.

Following the work on mid-oceanic ridge metamorphism, Miyashiro and group proceeded to describe the magmatic nature of ocean-floor rocks from bulk chemical analysis. They classified mid-oceanic ridge basalt (MORB) into Pl- and Ol- tholeiites with rare pigeonite-tholeiites based on the phenocryst assemblages. Combining experimental works of basalt tetrahedron at different pressures, they formulated the conditions of petrogenesis of MORB magma under mid-oceanic ridge, the major conclusions from which are still valid.

Miyashiro then attempted to differentiate volcanic rocks by employing new discrimination diagrams such as SiO2-FeO/MgO for calc-alkaline and tholeiitic rock series. Moreover, sub-classification of alkaline rocks was also proposed, a work that has been often referred to (see Kushiro, 2010-this issue).

Applying his discrimination diagrams, Miyashiro questioned the mid-oceanic ridge origin for the Cyprus Ophiolite, and instead, proposed an arc origin. This led to an intense and heated debate not only in the case of Cyprus ophiolite (see Pearce and Robinson, 2010- this issue) but also in general as to whether or not ophiolites indicate mid-oceanic origin, which was at that time a great shock for the proponents of plate tectonics theory. Although a number of publications opposing Miyashiro's view came out, the application of immobile or less mobile trace element chemistry provided results that supported Miyashiro's theory. In the meantime, bronzite phenocrysts were also reported in some calk-alkaline rocks in Oman. Finally, the stratigraphic horizon of calc-alkaline rocks above the MORB rocks was confirmed suggesting a change of tectonic environment from MOR to subduction zone. Recently it was also found that the structurally lowest unit is the blueschist-eclogite facies regional metamorphic unit (see Isozaki et al., 2010-this issue), clearly indicating the tectonic environment of subduction zone when calc-alkaline rock series activity prevailed.

Late in Miyashiro's academic career, he proposed a new concept of hot region, similar to hot spot, but in this case the size is far bigger. He proposed that hot regions triggered the opening of Atlantic Ocean, the Tasman Sea and related small ocean basins to the east of Australia since Cretaceous time. The final active ones were concentrated in the Western Pacific, where a series of hot regions formed ocean basins in East Asia. The origin of back-arc basins was one of the major topics of debate, and geophysicists interpreted as either trench-retreat or anchored-slab.

Miyashiro, on the other hand, speculated the presence of hot rising plume from deep mantle, unrelated or related to subduction. In the later years, when detailed seismic tomographic data became available (see Isozaki et al., 2010-this issue for a review), plumes, probably hydrous plumes, were clearly identified under Asia and western Pacific.

Miyashiro's works listed above are some of his representative and epoch-making contributions and reflect his excellent comprehension and in depth knowledge in various branches of geosciences covering geology, geophysics, geochemistry, and paleontology. His ability for systematization is unparalleled as clearly vouched by his famous books and publications (see Kushiro, 2010-this issue).

After his retirement at Albany, New York State University, Miyashiro wrote a book entitled "What is Science Revolution?" in Japanese. In this, Miyashiro tried to evaluate the theories that have appeared in geology and broadly in the fields of Earth Science on the viewpoint of Science History with a philosophical outlook which include his disagreement on plate tectonics as a paradigm shift. Unfortunately could not translate this book into English before he passed away in 2008.

This special issue of *Gondwana Research* is a tribute to Akiho Miyashiro and compiles a set of 15 contributions. The issue opens with a note by I. Kushiro on the contributions of Miyashiro where the author outlines the major works of Miyashiro which brought about significant advancements in several fields of earth sciences. Miyashiro's most important work is the proposal of 'metamorphic facies series' with three different baric types and 'paired metamorphic belts' in the circum-Pacific (subduction) zones. In addition to his significant work on abyssal tholeiites and island arc volcanic rocks, Miyashiro also devoted his attention to meteorites.

W.G. Ernst (2010-this issue) in his article also emphasizes, Akiho Miyashiro's seminal paper on regional metamorphism and his concept of paired metamorphic belts. More recent studies have clarified two main types of convergent plate margins: Pacific underflow of thousands of km of oceanic lithosphere, and Alpine closure of an intervening oceanic basin leading to continental collision. The Pacific-type underflow of basaltic crust-capped plates produces new and recycled continental crust, whereas the Alpine-type convergence reshuffles collided terranes, albeit does not generate juvenile sialic crust.

S. Karato (2010-this issue) reviews the historical development of our understanding of rheological properties of the Earth's mantle that control most of the important geological processes such as the style of mantle convection and the nature of thermal evolution. Through the integration of a broad range of observations, a gross picture of rheological stratification of the Earth's mantle was proposed in the middle of the 19th century. Major developments in the first half of the 20th century provided a basis for scaling analyses that are critical to the applications of laboratory results to the Earth's interior. New experimental techniques to study the rheological properties in Earth's deep interior were developed during the last a few years which now allow a quantitatively study of the rheological properties of Earth materials down to the lower mantle condition.

M. Brown (2010-this issue) in his article on 'Paired metamorphic belts revisited' observes that the duality of thermal environments in modern plate tectonic regime is the hallmark of one-sided (asymmetric) subduction, which generates two contrasting types of broadly contemporaneous metamorphic belt, one of high d*T*/d*P* type and the other low d*T*/d*P* type. Brown proposes that the broadly contemporaneous occurrence of granulite and ultrahigh-temperature metamorphism with eclogite–high-pressure granulite metamorphism in the geological record since the Neoarchean Era is evidence of dual thermal environments and indicates that subduction has operated on Earth since that time. He refers to the classic paired metamorphic belt concept of Miyashiro and suggests that this concept may be generalized and extended more widely to subduction-to-collision orogenic systems in addition to accretionary orogenic systems.

J.A. Pearce and P.T. Robinson (2010-this issue) address the famous debate initiated by Miyashiro on the tectonic setting of ophiolite complexes by proposing that 'the Troodos ophiolitic complex was probably formed in an island arc'. They evaluate and update Miyashiro's work and conclude that the Troodos Massif is made up of oceanic crust built from a high-Si, moderate-Fe tholeiitic magma, overlain by boninites. The geochemical characteristics and geological setting support models in which the Troodos Massif formed by slab roll-back following subduction initiation, probably near a slab edge.

Y. Isozaki and colleagues (2010-this issue) provide a revised geotectonic framework and updated evolutionary history of the Japanese islands based on new data gathered from seismic tomography, vibroseis/ground-breaking seismic experiments, and detrital zircon chronology. Their synthesis shows that proto-Japan experienced large-scale tectonic erosion in multiple stages, and the corresponding large amounts of continental crust materials were subducted. They explain the orogenic growth of Japan during the last ca. 500 million years based on recent concepts of tectonic erosion coupled with continental contraction, as well as the oceanward accretionary growth.

S. Maruyama and colleagues (2010-this issue) present a new concept on metamorphism and metamorphism belts. They address various issues including (1) progressive and retrogressive metamorphism recorded on surface exposures of regional metamorphic belts, (2) geochronological constraints on dating the timing of metamorphism; (3) origin of metamorphic textures, (4) P-T-t path, (5) metamorphic facies series, (6) exhumation models, and (7) role of fluids during regional metamorphism. Based mainly on their recent studies on the Kokchetav, Dabie Shan, Indonesia, and the Franciscan and Sanbagawa belts, Maruyama and colleagues propose several revolutionary models, these offering new challenges to the geological community.

Moving over to the theme of advancements in metamorphic petrology, M. Tirone and J. Ganguly (2010-this issue) evaluate garnet compositions as recorders of P-T history of metamorphic rocks. To retrieve the thermal history of metapelites, these authors developed a finite difference scheme for modeling multicomponent diffusion profiles in garnet, incorporating provisions for continuous nucleation and growth. They developed a numerical code which they apply to retrieve the *T–t* history of the low pressure–high temperature Ryoke metamorphic belt, Japan, by modeling the concentration profiles of Fe, Mn, Mg and Ca of garnets of different sizes that have been inferred to have developed by a process of continuous nucleation and growth.

M. Beltrando and colleagues (2010- this issue) evaluate the pressure-temperature-time-deformation evolution of the high- to ultra-high pressure metamorphic units in the Western Alps. The Western Alps represent the amalgamation of a Cretaceous and an Eocene orogen, which developed at the expense of the Adriatic and European rifted margins, respectively. To a first order, the orogen grew through the progressive episodic accretion of units located towards north-westerly positions. Accretion of subducting units at the front of the orogen was coeval with kinematic reworking of tectonic contacts in the hanging wall units, locally resulting in renewed deformation/metamorphism.

In the next contribution, T. Ota and Y. Kaneko (2010- this issue) present a review of Late Miocene blueschist and eclogite belts, offer new insights on the tectonic evolution of high- and ultrahigh-pressure metamorphic rocks. From a synthesis of the geology, metamorphism and chronology of these rocks, the authors evaluate the formation and exhumation processes of these rocks as well as their significance on the tectonics at convergent plate boundaries.

A. Kadarusman et al. (2010) address the world's youngest blueschist belt from the Leti Island in Eastern Indonesia which crops out as an 'A'-type high-pressure metamorphic belt with different stage of evolution. Whereas an advanced domal uplift stage is seen in Timor Island, the high pressure metamorphic belt is still in the first stage of tectonic extrusion on this eastern island. The metamorphic rocks in Leti are tectonically juxtaposed against overlying ultramafic rocks and underlying unmetamorphosed continental shelf sediments, bound by normal and reverse faults, respectively. Based on detailed estimates of the P-T conditions, the burial depth is estimated at 30-35 km at the peak metamorphic stage, which the authors relate to the main stage of the collisional event. Slab-breakoff at depth in the collision zone facilitated rapid uplift by wedge extrusion and active erosion during the exhumation stage.

H. Masago et al. (2010-this issue) compute the volume of aqueous fluids which infiltrated into the high- ultra-high pressure metamorphic rocks during exhumation of the Kokchetav massif, Kazakhstan. Based on the change in water content and the spatial coverage of the lithological units, the volume of aqueous fluids was calculated as 0.1% of the total mass of the massif. Their results suggest that the fluid infiltration at the exhumation stage is tectonically common, and that even a small amount of water infiltration enhances the retrograde recrystallisation in permeable lithologies such as pelitic and felsic schists/gneisses.

In the next paper, Shibuya et al. (2010-this issue) investigate the secondary mineral assemblages and compositions of the basaltic rocks of the Fortescue and Hamersley Groups in Western Australia to reveal the metamorphic conditions. The metamorphic grade increases northward, which is opposite to the general southward increase of the regional metamorphic grade. The authors identify a strong correlation between the change of metamorphic grade and stratigraphy. They suggest that the metamorphism in this region was caused by continental rifting at around 2.2 Ga.

R. Mason et al. (2010-this issue) presents a petrological description of the chiastolite variety of andalusite with a case study of the Zhoukoudian aureole, Beijing, China. Chiastolite porphyroblasts here grew alongside garnet porphyroblasts and the rotation of crystals during growth accompanied by deformation gave rise to curved quartz rods. The chiastolite had a multi-stage growth history during deformation and removal of large volumes of Si in solution from the matrix.

In the final contribution in this special issue, Y. Eyuboglu and colleagues (2010-this issue) describe the structural characteristics and geochemical features of an Alaskan-type mafic-ultramafic complex from NE Turkey. The main lithological units of this complex include plagioclase peridotite, melagabbronorite, banded gabbro and anorthosite (Phase-I), gabbro-pegmatite dikes (Phase-II), unmetamorphosed banded gabbro (Phase-III), cumulate olivine gabbronorite (Phase-IV), and non-cumulate gabbroic dikes and stocks (Phase-V). The study reveals that the various units formed from high-Al hydrous basaltic magmas, which were derived from partial melting of a subduction-metasomatized subcontinental-lithospheric mantle. These magmas underwent crystal fractionation and mineral concentration processes in small magma chamber(s) at shallow crustal levels.

The 15 papers assembled in this issue cover some of the important fields in which Miyashiro made pioneering contributions. We thank all the contributors to this volume for their patronage and support. We also thank all the referees who spared valuable time and efforts to offer scholarly reviews within limited time. We dedicate this special issue to the memory

of Akiho Miyashiro and hope that these works would further enthuse investigations in the various topics on which Akiho Miyashiro made lasting impressions.

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Figure caption

Fig. 1. Akiho Miyashiro (30-10-1920 – 22-7-2008). Photo taken in December 1974.


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