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Editorial

Tectonics of the Central Asian Orogenic Belt and its Pacific analogues

The huge region of Central and East Asia has experienced a long geological history resulting in the formation of the Central Asian Orogenic Belt (CAOB) or Altaids (Şengör et al., 1993; Jahn et al., 2004), one of the world largest orogens extending from the Ural mountains in the west to the Russian and Chinese Far East (Jahn et al., 2004; Windley et al., 2007; Xiao et al., 2015) (Fig. 1). Its complicated tectonic evolution and associated processes generated numerous world-class mineral deposits, the origin, evolution, and resource potential of which have been foci of studies by many national and international research teams (Seltmann et al., 2003; Safonova et al., 2011). According to the statistics of the Web of Science and International Union of Geological Sciences (IUGS) during the last decade, the CAOB has been a research front of the international geo-community.

However, the architecture of the CAOB remains controversial, in particular, in terms of its crustal composition, deformation, metamorphism, sedimentation, and kinematics (Jahn et al., 2004; Kröner et al., 2014). Furthermore, the CAOB has experienced superimposition of different orogenic domains and has been overprinted by younger tectonism, the mechanism of which remains to be understood (Windley et al., 2007; Xiao et al., 2008).

In order to understand the development of these orogens and basins in a global tectonic framework, they need to be compared to other orogenic belts and basins, such as those in the Circum-Pacific and Tethyan domains (Fig. 1). Under a big umbrella of IGCP 592 Project "Continental construction in the Altaids (Central Asian Orogenic Belt) compared to actualistic examples from the western Pacific" (Safonova et al., 2011), we assembled papers for this special issue of the Journal of Asian Earth Sciences, which compare the geological and tectonic history of orogenic belts and basins in Central Asia with those in the Circum-Pacific and Tethyan domains (Fig. 1), utilizing geologic, geophysical, petrological, geochronological, and other data. The comparison can help not only to improve our understanding of the evolution of these different tectonic terranes, but also can help to identify which areas have excellent data in some fields, and other areas where researchers need to press funding agencies to bring the data into international standards.

1. Basic features of the CAOB

The basic composition of the CAOB can be subdivided into three collages: Mongol–Okhotsk Orocline, Kazakhstan Orocline, and Tarim–North China (Şengör et al., 1993; Xiao et al., 2015) (Fig. 1). The northernmost one is the archipelago system of the southern active margin of the Siberian Craton, composed of the Siberian Craton and its southerly distributed (present-day coordinates) Tuva–Mongol arc chain including the Altai and southern Mongolian arcs, which are linked to the evolution of the Paleo-Asian Ocean. The southern margin of the Tuva–Mongol arc chain (present-day coordinates) may have mostly interacted, before middle Triassic, with the other parts of the CAOB, including the Kazakhstan Orocline collage in the middle, and the Tarim–North China collages in the south, which may have formed the majority of the huge CAOB. The northern margin of the Tuva–Mongol arc chain (present-day coordinates) may have mostly interacted with itself through oroclinal closing the intervening Mongol–Okhotsk Ocean, which has been conventionally separated from the tectonics of the CAOB, but would have overprinted the eastern segment of the CAOB. The whole CAOB hosts dozens of accretionary complexes, with recent analogues formed in the modern circum-Pacific (Kusky and Bradley, 1999; Safonova et al., 2009).

In this special issue, we have collected 34 papers, encompassing the archipelago system of the southern active margin of the Siberian Craton, western segment, eastern segments including the western Pacific, and interactions and superimposition of geodynamic processes.

2. Archipelago system of the southern active margin of the Siberian Craton

Likhanov et al. (2015) studied three superimposed metamorphic events of pelitic gneisses and schists within the Yenisey regional shear zone (Garevka complex) at the western margin of the Siberian Craton. The first stage occurred as a result of the Grenville-age orogeny during late Meso–early Neoproterozoic (1050–850 Ma), the second stage was characterized by middle Neoproterozoic (801–793 Ma) collision-related medium-pressure metamorphism, and the final stage evolved as a syn-exhumation retrograde metamorphic event (785–776 Ma) recording uplift of the rocks to upper crustal levels in shear zones. The post-Grenville episodes of regional metamorphism are used to support the spatial proximity of the Siberia and North Atlantic cratons (Laurentia, Baltica, Svalbard) at c. 800 Ma.

Zhang et al. (2015a) present a petrogenetic and geochemical study for a suite of high Ba–Sr biotite monzogranite and associated mafic microgranular enclaves (MMEs) from the Ulaan Uul batholith in the Bayankhongor area, central Mongolia. They conclude that magma mixing between felsic magma derived from sedimentary rocks and mafic magma derived from sub-continental lithospheric mantle (SCLM) may account for the formation of high Ba–Sr granitoids. They further propose that the late

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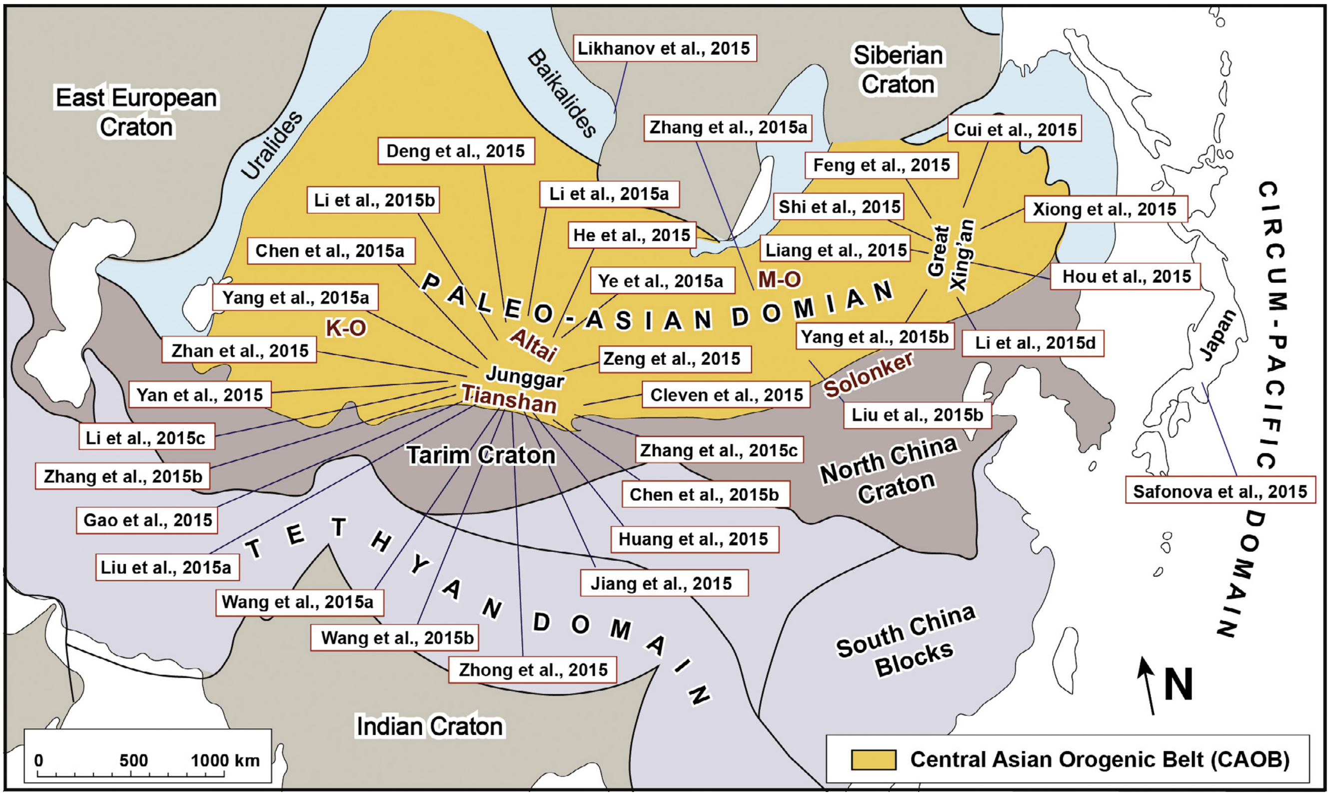

Fig. 1. Simplified tectonic map of the Central Asian Orogenic Belt or Altaids showing the Kazakhstan Orocline (K-O), Mongol–Okhotsk Orocline (M-O), and Tarim–North China collage systems (modified after Şengör et al., 1993; and Xiao et al., 2008).

Neoproterozoic to early Cambrian extensional environment in the Bayankhongor area was caused by the roll-back of subducting Bayankhongor oceanic lithosphere.

He et al. (2015) studied a suite of igneous rocks, including high-Mg dacite of the Kangbutiebao Formation and the associated gneissic granodiorites, and conclude that they were possibly generated in the same tectono-magmatic event, their precursor magmas were probably mainly derived from the Habahe sediments, suggesting a possible ridge subduction regime in the early Devonian tectonic evolution of the Chinese Altai.

Ye et al. (2015) carried out an integrated study of the Devonian (ca. 400 Ma) Alaskan-type ultramafic–mafic complexes widely distributed along the southern Altai orogen. Geochemical data indicate that these mafic intrusions crystallized from evolved mafic magmas and compositions of the clinopyroxene and hornblende and show typical arc affinities. It is inferred that the underplating of mafic crust beneath the Altai orogenic belt significantly contributed to the Phanerozoic vertical continental crust growth in that region.

Deng et al. (2015) investigated the magma evolution processes and the sulfide saturation history of the Ural-Alaskan type Tuerkubantao mafic–ultramafic intrusion in southern Altai orogen. Igneous zircons from a gabbro in the intrusion yielded a LA-ICP-MS U–Pb age of 370.3 ± 4.8 Ma, indicating that the intrusion was emplaced in the Late Devonian. The geochemical features show that the primary magma was generated from partial melting of metasomatized lithospheric mantle triggered by the upwelling of asthenosphere at the Altai active continental margin.

Li et al. (2015a) present new $^{40}Ar/^{39}Ar$ dating results for granitic gneisses and amphibolites exposed in the Qiongkuer Domain in two areas (Alahake and Fuyun) of the southern Chinese Altai. The $^{40}Ar/^{39}Ar$ plateau ages of amphiboles and biotites from both Aalaheke and Fuyun areas are younger than the Permian high temperature metamorphism in the Qiongkuer Domain, which may have been associated with the development of the sinistral Erqis Shear Zone during the collision between the Chinese Altai and the East Junggar. The subsequent exhumation processes were variable in different areas of the Qiongkuer Domain.

Zeng et al. (2015) studied the Zhaheba albitites (498.0 ± 5.8 Ma) and albite granites (494.6 ± 6.9 Ma) of the Zhaheba ophiolite, one of the two ophiolites in East Junggar, that were roughly coeval and with distinct petrographic textures. Geochemical data indicate that the rocks were likely derived from the anatexis of amphibolites, which were related to hydrothermal alteration of gabbros in intra-oceanic backarc basin.

3. Western segment of the CAOB

Li et al. (2015b) investigated the Zaysan–Jimunai Basin located in the area from eastern Kazakhstan to the southern Altai, focusing on the Carboniferous–Early Permian tectonostratigraphic evolution and the Mesozoic–Cenozoic structural patterns of the Zaysan–Jimunai Basin using 2D and 3D seismic reflection profiles. They proposed that a bi-vergent subduction existed for the Irtysh–Zaysan Ocean from eastern Kazakhstan to the southern Altai, which experienced episodic modifications related to transpressional events from the Mesozoic to the Paleogene.

Chen et al. (2015a) report new geochronological and geochemical results for the Late Silurian–Middle Devonian plutons in the Xiemisitai–Saier Mountains, northern West Junggar, including undeformed peralkaline granite, alkali feldspar granite, monzogranite, quartz syenite, syenite, monzodiorite, diorite, and hornblende gabbro. Geochemical data enable the authors to state that these A-type granites and associated mafic to felsic intrusions may occur in a post-collisional extension setting since the end-Silurian, after the initial amalgamation of the West Junggar terrane during the Middle–Late Silurian. They further point out that on-going lithospheric extension during the Early–Middle Devonian would give rise to the mantle-derived magmatism in the northern and southern West Junggar and juvenile oceanic crust in central West Junggar.

Yang et al. (2015a) report their recent field study on the imbricate thrusts, duplexes, "web" structures, pinch-and-swell structures, tilted structures in pillow metabasalts, and shear band cleavages widely developed in the Karamay ophiolitic mélange of West Junggar. U–Pb analyses of zircon grains from basalt suggests a Middle Devonian age of the Karamay ophiolitic mélange. Geochemical results suggest that all the alkaline basalts were derived from a mantle plume-related source in an intra-oceanic setting, which can be correlated to a Middle Devonian mantle plume-related magmatism within the Paleo-Asian Ocean.

Zhan et al. (2015) conducted a systematical investigation of the Early to Middle Permian NW trending calc-alkaline dykes and the Late Permian NE trending tholeiitic dykes. Trace element and isotopic data may indicate that the NW trending dykes were generated by partial melting of a recently metasomatized subducted cold lithospheric mantle (SCLM) coupled with variable assimilation of juvenile crustal materials, whereas the NE trending dykes were derived from the partial melting of a similar SCLM with a lower degree of metasomatism than the NW trending dykes which were subsequently subjected to magma modification by the fractional crystallization of olivine, pyroxene and/or plagioclase. The mafic dyke swarms in this region are the products of Phanerozoic continental growth in North Xinjiang with widespread lithospheric extension.

Gao et al. (2015) investigated the Huoshaoqiao (903.5 ± 2.2 Ma) and Wulasutanwutuaiken (933.6 ± 1.2 Ma) gneissic granitoid plutons showing geochemical characteristics of Andean arc granites with a Late Paleoproterozoic crustal source with limited input of juvenile materials. They also studied the Wuwamen bimodal intrusive complex (meta-gabbro, 733 ± 5 Ma; granitic dyke, 730 ± 5 Ma) characterized by the protolithic mafic magma being originated from a sub-continental fertilized lithospheric mantle source and the acidic magma being originated from lower crustal melting. They conclude that the ~900 Ma plutons originated from remelting of older crust in an Andean-type active continental arc setting associated with the assembly of Rodinia, whereas the development of the ~730 Ma bimodal intrusive magmatism is interpreted as a result of the Rodinia breakup.

Yan et al. (2015) report petrogenetic and geochemical results from the Wuling (poikilitic) hornblende gabbro from the Awulale Mountains, western Tianshan. They conclude that the Wuling hornblende gabbro was emplaced during the late Carboniferous in a subduction-related setting fluxed by fluids released by the down-going slab. They propose that an arc–nascent back-arc system had been developed between the Nalati Mountains and the Awulale Mountains during the late Carboniferous, where the magma derived from decompression melting of MORB-like mantle caused by the slab roll-back and flux-induced melting of mantle wedge were both contributed to their generation.

Liu et al. (2015a) studied texturally well-preserved lahars exposed in the Latest Paleozoic Arbasay Formation, Northern Tian Shan. The lahars consist primarily of two lithofacies: massive, poorly lithified diamictites and stratified, moderately lithified gravelly sandstones. The characteristics of the Arbasay Formation lahars, together with the geochemical characters of the co-existing volcanic rocks, clearly prove that they were deposited in a post-collisional extensional regime. They further conclude that the North Tian Shan Ocean must have closed before 314 Ma.

Early Neoproterozoic granitic gneisses from the Central Tianshan Arc were studied by Huang et al. (2015), suggesting that the protoliths of these granitic gneisses formed during a relatively short time period between ca. 970 and 915 Ma, mainly clustering at ca. 940 Ma, and their protoliths were derived by the recycling of older continental crust. The authors further conclude that the early Neoproterozoic granitic rocks in the Chinese Eastern Tianshan were formed along an active continental margin and the Central Tianshan Arc was located at the periphery of Rodinia, separated from the Tarim Craton in the early Neoproterozoic.

Jiang et al. (2015) conducted a systematic investigation of plagiogranites exposed as exotic blocks in the South Central Tianshan ophiolitic mélange with U–Pb zircon ages of 775 ± 11 Ma and 416 ± 4 Ma, respectively. They conclude that the 775 Ma Wuwamen plagiogranites originated during the breakup of Rodinia, whereas the 416 Ma Guluogou plagiogranites were generated in an Andean-type active continental margin environment related to the northward subduction of the South Tianshan Ocean.

Wang et al. (2015a) conducted geochemical and geochronological analyses on granitoids exposed extensively in the Central Tianshan arc. A mylonitic granodiorite intruding the Central Tianshan basement has a zircon U–Pb age of ca. 496 Ma and shows geochemical affinity to adakite, which can be attributed to the subduction of the Paleo-Tianshan Ocean. The closure time of the Paleo-Tianshan Ocean was dated at ca. 430 Ma. Two other granitic samples (granodiorite, ~330 Ma; monzodiorite, ~319 Ma) display the chemical characters of I-type granites, indicating another turn of magmatic arc setting mostly related to the subduction of the North Tianshan Ocean.

The South Tianshan records the final amalgamation process of the Yili-Tianshan arc with the Tarim Craton, but the subduction polarity and collisional timing are controversial. Li et al. (2015c) identified two episodes of Late Paleozoic A-type magmatism in Qunjisayi, western Tianshan. The Late Carboniferous rhyolites (306 ± 2 Ma) and Early Permian granites (296 ± 3 Ma) have geochemical features similar to those of typical A2-type granitoids. They conclude that the Late Paleozoic Qunjisayi A-type magmatism was genetically linked to the geodynamic transformation from late subduction to collision.

Zhong et al. (2015) present a systematic study of mafic, intermediate and felsic intrusive rocks in the Baluntai area, Central Tianshan, and suggest variable degrees of involvement of the Proterozoic crustal basement and the juvenile mantle components during the early Paleozoic magmatic generation. The early Paleozoic arc-type magmatic rocks within the Chinese Central Tianshan likely resulted from the southward subduction of an oceanic basin located to the north.

Based on geochronological and geochemical studies for three highly deformed granitic plutons (monzonitic granites, biotite K-feldspar granites and two-mica granites) exposed in the Kumishi area of the South Tianshan, Chen et al. (2015b) conclude that these felsic magmatic rocks were formed in an arc-related tectonic setting, and suggest a northward subduction of the South Tianshan Ocean in the early Paleozoic. A single northward subduction and a divergent bi-directional subduction are further proposed to interpret the formation of the western and eastern South Tianshan Belt, respectively.

Cleven et al. (2015) conducted a systematic study on the Hongliuhe ophiolite in the Eastern Tianshan and its comparison with the Yueyashan–Xichangjing ophiolite in the Beishan. The entire analysis paints a picture of subduction rollback-related extension affecting the margin of an emerging or mature arc just prior to a known magmatic cycle that ended with a collision in the Devonian, at the latest.

The Zhibo and Chagangnuoer iron ore deposits which occur at the same volcanic edifice and are situated along the eastern segment of the Awulale Iron Metallogenic Belt in the Western Tianshan were studied by Zhang et al. (2015b). Systematic data indicate a magmatic source for the iron oxide mineralization, and the volcanic rocks, the granitoids and the iron ore bodies were formed in a continental arc setting during the Early Carboniferous. The ore-hosting volcanic rocks probably originated from melting of a mantle wedge that was metasomatized during subduction. Subsequently, the volcanic host rocks and the iron ore bodies were variably hydrothermally altered during subduction (ca. 319–313 Ma).

Zhang et al. (2015c) investigated the Baishan molybdenum deposit located in the eastern section of the Jueluotage tectonic belt, Eastern Tianshan. They defined a calc-alkaline and peraluminous granite porphyry intrusion beneath the Baishan Mo ore bodies and the Cu–Mo minerals are widely distributed in the porphyry. The granite porphyry intrusion was intruded in a Triassic compressional background. They further propose that there is probably a porphyry Cu deposit beneath the Baishan high-Re Mo deposit.

4. Eastern segment of the CAOB

Cui et al. (2015) studied the geochronology, petrology, and geochemistry of the metamorphic rocks of the Jiageda and Woduhe formations in the central Great Xing' an (Hing'an) Range, and found that these metamorphic rocks were formed during the late Silurian–early Devonian and middle–late Silurian, respectively. Both formations were formed in an island-arc active-continental-margin environment, and they propose that that the Xing'an terrane was located in an active continental margin related to the subduction of the Paleo-Asian Ocean during the middle Silurian–early Devonian.

Feng et al. (2015) present new age and geochemical data, suggesting that the Carboniferous rocks were likely derived from partial melting of a mantle source with minor spinel metasomatized by slab-derived fluids. They further conclude that the Carboniferous intrusive rocks formed through the partial melting of a metasomatized subcontinental lithospheric mantle in a subduction to post-collisional extensional setting triggered by the upwelling of the asthenosphere generated by slab break-off of the subducted oceanic crust between Erguna–Xing'an and Songnen block.

Li et al. (2015d) present zircon U–Pb chronological and geochemical research on the volcanic rocks of the Tamulangou Formation in the Zhalantun area, middle part of the Great Xing'an Range. The volcanic rocks spanned the Middle–Late Jurassic, formed in an extensional environment. Spatial variations in petrological, geochronological, and geochemical features of the volcanic rocks of the Tamulangou Formation indicate subduction to the southeast following orogenesis and closure of the Mongol–Okhotsk Ocean.

Shi et al. (2015) compiled and analyzed U–Pb zircon ages and divide granitic rocks of the Chaihe–Moguqi region of central Great Xing'an Range into eight stages, varying from Early Devonian to Early Cretaceous. Paleozoic granites were associated with oceanic subduction and the amalgamation of crustal blocks. The Late Triassic granites were related to the change from the Paleo-Asian Ocean tectonic regime to the circum-Pacific tectonic regime. Early–Middle Jurassic granites resulted from either subduction of the Paleo-Pacific Plate or subduction during the amalgamation of the Jiamusi Massif and the Songliao terrane, whereas the Late Jurassic–Early Cretaceous granites were associated with both the subduction of the Paleo-Pacific Plate and the closure of the Mongol–Okhotsk Ocean.

Yang et al. (2015b) report zircon U–Pb geochronology defining an Early Cretaceous major volcanic event in the southern Great Xing'an Range, and propose that the intermediate and felsic shoshonitic magma was plausibly derived from partial melting of the subduction-modified lithospheric mantle and thickened lower crust, respectively, induced by the changes of tectonic regimes from the previous Mongol–Okhotsk subduction to the succeeding paleo-Pacific subduction during Late Mesozoic.

In order to study the lithospheric structure and survey deep resources of the Great Xing'an Range area, Liang et al. (2015) conducted a magnetotelluric sounding profile across the central Great Xing'an Range. An electrical structure model of the crust and the upper mantle was finally obtained after data processing, qualitative analysis and 2D inversion of the observed data.

A crustal seismic reflection profile across the Great Xing'an Ranges was recorded by Hou et al. (2015) to reveal features of crustal structure and deformation at the eastern CAOB. The authors identify lots of curved reflection phases from volcanic rock and opposite Moho reflection events, suggesting multi-times tectonic transformation from contraction to extension, which reflects the comprehensive dynamic action of the Mongolia–Okhotsk tectonic system and the Circum-Pacific tectonic system.

Deep seismic reflection profiles, seismic refraction/wide-angle reflection profiles, and magnetotelluric surveys, were used by (Xiong et al. (2015) to establish the lithosphere structure and geodynamic framework of the Great Xing'an Range and adjacent basins. New results show a "crocodile" style assembly fabric of the Songnen and Xing'an blocks. They further conclude that the building of the Great Xing'an Range could have evolved an earlier crustal shortening resulted from the compression between the Songnen and Xing'an blocks in late Devonian to early Carboniferous, and a later vertical building by upwelling and underplating of the magmas in Mesozoic and Cenozoic.

5. Interactions and superimposition of geodynamic processes

Liu et al. (2015b) conducted a detailed comparative study based on the Pb isotope data from ophiolites in the CAOB from the Paleo-Asian Domain and those in the Tethyan Domain, which defines an isotopic boundary between the different mantle domains and tectonic properties of the CAOB and Tethyan Domain. They further point out that the Neoproterozoic to Paleozoic evolution of the accretionary margins of the CAOB mimics the circum-Pacific type accretionary orogen, while the closure of the Tethys oceans mostly produce evolving collisional orogens.

The CAOB may have been overprinted by Mesozoic–Cenozoic geodynamic processes in Eurasia. Wang et al. (2015b) carried out LA-ICPMS U–Pb dating on detrital zircons and electron microprobe analysis on detrital heavy minerals from the Triassic to Middle Jurassic sediments along the Kuqa River section in the northern Tarim Basin and in two intermountain basins. Their results show that different features of detrital zircon ages and heavy mineral chemical compositions in individual samples reflect provenance changes due to continuous denudation and pediplanation of the Chinese West Tianshan orogen in an extensional setting during Triassic to Middle Jurassic.

Safonova et al. (2015) present the results of a detailed geochemical study of Carboniferous to Miocene oceanic island basalts (OIBs) of the Akiyoshi, Mino–Tamba, Chichibu and Shimanto accretionary complexes of Japan, which are associated with Carboniferous–Cretaceous sediments of Ocean Plate Stratigraphy (OPS). They were probably derived by low degree melting of spinel and garnet peridotite and their lavas probably erupted in an intra-oceanic setting suggesting a 250 Ma period of intra-plate magmatism probably related to mantle plume activity. The OIBs were incorporated into accretionary complexes in the western Pacific during the subduction of the Paleo-Pacific Ocean. The Late Paleozoic–Cenozoic accretionary complexes of Japan are type localities of Ocean Plate Stratigraphy and actualistic analogues of Neoproterozoic–Paleozoic accretionary complexes of the CAOB, one of the world's largest Pacific-type orogens. Studying their structurally complicated OPS units, both sedimentary and magmatic, is a key for reconstructing accretionary processes in Central and East Asia.

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