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Continental construction in Central Asia and actualistic comparisons with western Pacific: Preface

1. Introduction

A huge territory of central and eastern Asia hosts the Central Asian Orogenic Belt (CAOB), the world largest accretionary orogenic belt, which evolved during more than 800 m.y. The CAOB has been a major target of Project #592 “Continental construction in the Central Asian Orogenic Belt (Altaids) compared with actualistic examples in the western Pacific” of the International Geoscience Correlation Program (IGCP) (http://www.unesco.org/new/en/natural-sciences/environment/earth-sciences/international-geoscience-programme/igcp-projects/deep-earth/project-592/; http://igcp592.igm.nsc.ru/), which is sponsored by UNESCO and International Union of Geological Sciences (IUGS). The Project started in 2012 and has been highly evaluated at the last four annual meetings of IGCP Scientific Board (2013–2016). The major scope of the Project is the understanding how continental crust forms, grows and evolves, which is a highly important issue in earth sciences. The formation of the continental crust was one of the most important events that ever happened in Earth's history. As one of the largest orogenic collages in the world, the CAOB records a long-lived accretionary orogenesis and the largest Phanerozoic continental growth. Therefore, the CAOB has been regarded as an ideal laboratory to address the mechanism of continental growth. The crust of Asia formed through either one or a combination of the following four processes: by (1) crustal growth, (2) crustal formation, (3) continental growth, and (4) continental formation. These processes have not been systematically investigated and a lot of questions remained unanswered, including the following aspects: (i) proportions of juvenile and recycled continental crust in the CAOB; (ii) whether Pacific or Himalayan styles of orogeny were dominating during the formation of the CAOB; (iii) whether magmatic arcs or Gondwana-derived terranes with Precambrian basement were accreted to the Siberian, Kazakhstan, Tarim and North China cratons; (iv) what was the balance between continental formation and tectonic erosion, and (v) what social benefits or geohazards are related to the formation of the CAOB including formation of minerals deposits and surface/environmental impact through volcanism and seismicity.

In this Special Issue we present results of our project research activities with foci to the key elements of continental construction, i.e. formation of juvenile crust at accretionary or Pacific-type convergent margins, first of all at intra-oceanic arcs, and mixed or recycled crust at Andean-type active margins, accretion of allochthonous terranes, supra-subduction and intra-plate mantle magmatism, transformation and tectonic erosion of crustal material at convergent margins and their related environmental impacts. Those papers will definitely contribute to the understanding of the formation and evolution of accretionary orogens and their related processes of magmatism, tectonics and formation of top commercial mineral deposits. We have selected 19 targeted papers written by the authors from Russia, China, Uzbekistan, Tajikistan, United Kingdom, Germany, France, Czech, South Korea, Taiwan, Australia and Poland. The geography of the Special Issue covers the whole territory of the CAOB: from Kazakhstan, Tienshan (Uzbekistan, Tajikistan and China) and Altai (Russia, China and Mongolia) orogens in the west through southern Siberia and Mongolia to Inner Mongolia (China) and Far East (Russia, South Korea) in the east (Fig. 1). The topics of the papers embrace the whole history of the CAOB: the formation of Precambrian microcontinents as important segments of the CAOB, the Neoproterozoic opening and Paleozoic evolution of the Paleo-Asian Ocean and its surrounding subduction zones and its Late Paleozoic–Early Mesozoic suturing, the subsequent collision and amalgamation of the Siberian, Kazakhstan, Tarim and North China continents, which all formed what we know now as the Central Asian Orogenic Belt. In addition, several papers addressed the questions of Late Paleozoic to Cenozoic intra-plate magmatism and rifting, which transformed the seemingly already stable continental crust of the CAOB.

Safonova (2017-in this issue) opens the Special Issue with a paper discussing a problem of disagreement between the evaluation of proportions of new or “juvenile” and recycled crust by geological data, whole-rock Nd isotopes and Hf-in-zircon isotopes. The author shows that in terms of geology, presence of accretionary complexes, intra-oceanic arcs, oceanic plate stratigraphy units (OPS), and MORB-OIB derived blueschist belts, and whole-rock Nd isotopes, the CAOB is a typical Pacific-type belt. However recent Hf-in-zircon isotope data reveal a big portion of recycled crust. Such a controversy is explained by the presence of accreted microcontinents and isotopically mixed igneous reservoirs, which have been previously mentioned in (Kröner et al., 2014), and by the tectonic erosion of juvenile crust (Safonova et al., 2015). The author insists that a combination of detailed geological studies with isotopic results is necessary while studying crustal growth in fossil orogenic belts, as the up-to-date high-precision isotope methods on their own may not reflect some *syn*- and post-tectonic magmatic processes.

2. Precambrian crustal growth and orogeny in the western CAOB: Kazakhstan, Kyrgyzstan, Uzbekistan, Tajikistan

Kovach et al. (2017-in this issue) present U—Pb ages and Hf isotopic compositions of detrital zircons combined with whole-rock Nd isotopic data from Neoproterozoic quartzite-schist sequences of the Kokchetav, Ishkeol'mes and Erementau-Niyaz terranes of northern Kazakhstan in

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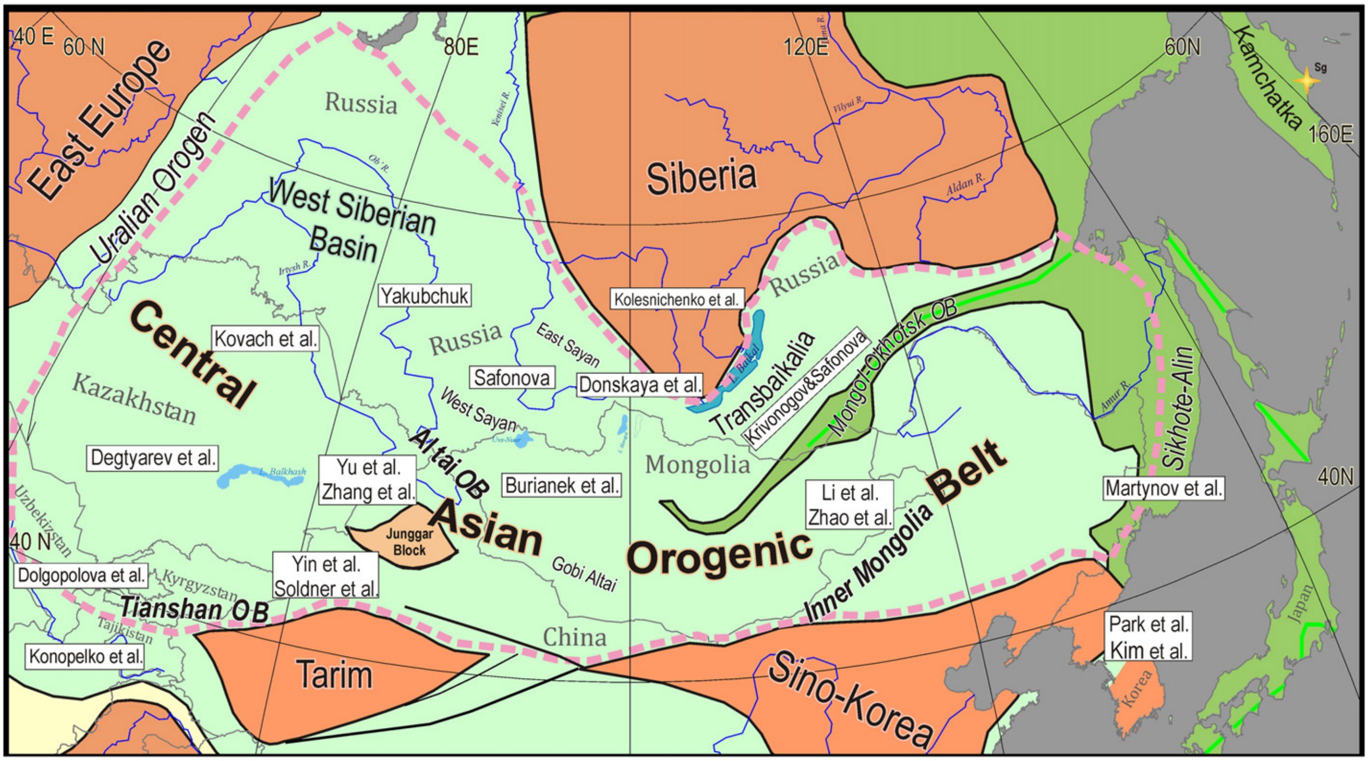

Fig. 1. General outline of the Central Asian Orogenic Belt showing the geographical coverage of the Special Issue. Modified from Safonova and Santosh (2014).

the north-western CAOB. The authors discuss possible provenances and position of these terranes in Mesoproterozoic time. Their data indicate that Mesoproterozoic (1.13–1.46 Ga), Paleoproterozoic (1.65–1.78 and 1.86–1.92 Ga), and Neoarchean rocks were the sources of those metasediments. Based on the Hf-in-zircon and whole-rock Nd data the authors suggest that the Mesoproterozoic and latest Paleoproterozoic rock complexes formed in a subduction-related oceanic or continental arc setting or were derived from mafic underplating. However, Paleoproterozoic and Neoarchean rocks have been unknown in the western CAOB. The authors argue that the crustal basement of northern Kazakhstan is similar to that of the Chinese Central Tian Shan terrane and different from the Archean basement of the Tarim Craton. The major peaks of the detrital zircon age patterns of the Neoproterozoic quartzite-schist sequences fit the formation and breakup of the Columbia/Nuna supercontinent and assembly of the Rodinia supercontinent or another large continental domain.

Degtyarev et al. (2017-in this issue) demonstrate that in contrast to the previous beliefs on widespread presence of the Paleoproterozoic and even Archean metamorphic crust, the new data showed dominance of Meso- to Neoproterozoic sedimentary, magmatic and metamorphic assemblages, with insignificant Paleoproterozoic rocks. Archean material was confirmed exclusively in detrital and xenocrystic zircons in younger strata. Nevertheless, the isotopic data indicated that Meso- to Neoproterozoic felsic magmatic rocks were mostly sourced from reworked Neoarchean and Paleoproterozoic continental crust, with potentially wider presence at deeper crustal levels. Most Meso- to Neoproterozoic assemblages are of intraplate origin, with limited extent of supra-subduction assemblages.

Dolgopolova et al. (2017-in this issue) discuss the geodynamic evolution of the Tienshan in Uzbekistan based on new Sr–Nd–Pb–Hf isotope and U—Pb zircon age data from four major terranes: 1) the Sultan-Uvais, 2) Kyzylkum-Nurata, 3) Gissar, and 4) Chatkal-Kurama. The Sr—Nd isotopes show a wide range of εNd_t (−5 to +7) and $(^{87}Sr/^{86}Sr)_t$ of 0.704–0.707, indicating involvement of both mantle-derived material and older crustal sources. A wide range of Hf-isotope compositions could be due to recycling of older crustal protolith(s). In the Southern Tien Shan (Kyzylkum-Nurata and Gissar terranes) strongly juvenile εHf_t values (up to +16), suggest involvement of subducted oceanic crust. New age data confirmed: 1) old age of the Turkestan Ocean (505 Ma), 2) Silurian–Early Devonian and Carboniferous episodes of subduction, and 3) a significant volume of subduction-related and post-collisional granitoids (ca. 320–290 Ma). The authors conclude that the western Tien Shan is characterized by multiple subduction-accretion processes responsible for 300 m.y. of evolution and crustal growth followed by the Permian post-collisional magmatism.

Konopelko et al. (2017-in this issue) introduce a refined model of tectonic evolution of the Tajik Tien Shan. The authors present first LA-ICP-MS U—Pb zircon ages as well as geochemical and Sr–Nd–Pb isotope data from the Chatkal-Kurama and Gissar terranes in Tajikistan. Two subduction episodes during Silurian–Early Devonian and Carboniferous were documented in the Chatkal-Kurama terrane at the northern margin of the Turkestan Ocean. At the same time, in the Early Carboniferous, rifting of the southern passive margin of the Turkestan Ocean formed the short-lived Gissar Basin, separated from the Turkestan Ocean by the Gissar micro-continent. In the latest Carboniferous, the Turkestan Ocean and the Gissar Basin were closed. The Early Permian post-collisional intrusions of the Gissar microcontinent have intraplate geochemical affinities and isotopic compositions in the northern Gissar terrane and inherited subduction-related features in the Chatkal-Kurama terrane.

3. Granitoid magmatism and metamorphism in the Altai and Tienshan orogens of NW China

Yu et al. (2017-in this issue) discuss the tectonic setting of the Chinese Altai in the Early Paleozoic as a result of decoupling between whole-rock Nd and zircon Hf isotopes in the Early Paleozoic granite. Whole-rock Nd and Hf isotopic data of the Early Paleozoic granite illustrates that Nd—Hf isotopic decoupling is prevailed in the crust of the Chinese Altai during the Early Paleozoic, which was inherited from the lithospheric mantle metasomatized by melt from the subducted sediments. Therefore, new data support that the Chinese Altai was a magmatic arc composed of mainly juvenile materials in the Early Paleozoic and ancient basement may not exist.

Zhang et al. (2017-in this issue) propose oceanic sediment recycled into the arc crust to have been an important component of the source magmas for the granites in the Chinese Altai. In this process, a significant amount of ^{177}Hf was retained by residual zircons in the subducting slab, elevating the ^{176}Hf/^{177}Hf ratio of the melt and decoupling it from the ^{143}Nd/^{144}Nd ratio. Approximately 40% of exposed rock in the Altai Orogenic Belt is granite, which suggests that over 40% of continental growth in the orogenic belt is attributable to felsic arc magmatism. This demonstrates that oceanic sediment recycling was an important process in the continental growth of the Chinese Altai, an aspect that has been often overlooked in previous studies.

Soldner et al. (2017-in this issue) present new petrological, geochronological and microstructural data from (ultra)high-pressure (UHP) metabasites (eclogites and blueschists) enclosed in metapelites to discuss structural and polymetamorphic evolution of the South Tianshan orogen (North-Western China). The eclogite and blueschist yielded peak and retrograde P–T conditions of 25–26 kbar and 425–500 °C and 10–13 kbar and 500–550 °C respectively, and the eclogite yielded Lu–Hf and Sm–Nd isochron ages of 326.0 ± 2.9 Ma and 318.4 ± 3.9 Ma. respectively, for the prograde metamorphism. The authors conclude about a significant mechanical coupling with the upper plate concomitant with oroclinal bending of the Kazakh orocline and following horizontal shortening of South Tianshan accretionary wedge.

Yin et al. (2017-in this issue) report new geochemical data, in situ zircon U—Pb ages, and zircon Hf isotopic data for representative granitic intrusions of the Central Tianshan orogenic belt. LA-ICP-MS zircon dating results show that the Central Tianshan monzogranites and granodiorites formed at ca. 362 Ma and ca. 354 Ma, respectively. The two types of granitoids show similar Hf-in-zircon isotopic compositions and positive εHf(t) values suggesting that they were likely derived from partial melting of the Mesoproterozoic metamorphic basement of Central Tianshan orogenic belt accompanied by significant input of juvenile material. The authors propose a slab roll-back model to account the Early Carboniferous magmatism in the Central Tianshan.

4. Precambrian crust, Paleozoic mantle magmatism and Meso-Cenozoic rifting in southern Siberia – Mongolia

Buriánek et al. (2017-in this issue) present new geological, geochemical and geochronological data to propose a geodynamic scenario for the early stages of the CAOB evolution. The history of the southern Baydrag continental margin in Mongolia could be interpreted as a result of two successive oceanic subductions of the Mirovoi Ocean from 1 to 0.75 Ga and subsequently to a newly formed oceanic subduction zone starting from 570 Ma. The Zamtyn Nuruu Grenvillean arc is interpreted as a result of Mirovoi Ocean subduction beneath Rodinian margin, while the Early Cambrian diorites and gabbros testify initiation of supra-subduction magmatism of the Palaeo-Pacific plate beneath a continental fragment of Gondwanan, most likely Tarim affinity. These two events were separated by the development of a Neoproterozoic passive margin probably associated with Rodinia fragmentation.

Donskaya et al. (2017, in this issue) focus on the pre-collisional history of the Olkhon terrane of the northern Central Asian Orogenic Belt (CAOB). Based on new data on zircon ages and chemistry of rocks from several complexes of the Olkhon terrane the authors show that the terrane is a collage of numerous chaotically mixed tectonic units composed of sedimentary, volcanic and plutonic complexes of different ages originated in different tectonic settings. The Olkhon terrane formed during an Ordovician collision by amalgamation of fragments of island arcs, back-arc basins, oceanic islands, and other tectonic elements. Donskaya and co-workers conclude that all pre-collisional complexes in the Olkhon terrane have their analogues among the rocks formed during main events in the northern CAOB history. Moreover, the reconstructed milestones in the Olkhon terrane history appear to be an echo of events in the CAOB northern segment.

Kolesnichenko et al. (2017-in this issue) provide new results suggesting heterogeneous distribution of water in the mantle beneath the central Siberian Craton. This study is based on new petrographic, major element and Fourier transform infrared (FTIR) spectroscopy data and PT-estimates of whole-rock samples and minerals of peridotite xenoliths. The authors have described samples of non-deformed, medium-deformed and highly deformed lherzolites, harzburgite and dunite. The results show that the amount of water in the mantle xenoliths is well correlated with the deformation degree. The high water contents in studied deformed peridotites could be evidence for metasomatism of relatively dry diamondiferous cratonic roots by hydrous and carbonatitic fluids/melts supplied from subduction zones beneath the Siberian continent in Neoproterozoic-Cambrian time.

Krivonogov and Safonova (2017-in this issue) review sedimentological, geomorphological, lithological, geochronological and geophysical data from major, minor and satellite basins of the Baikal Rift Zone (BRZ) in Transbaikalia, an important segment of the central CAOB. They discuss various aspects of its evolution with foci to structural and facial features of BRZ sedimentary sequences to understand better their sedimentation environments, tectono-sedimentation stages, neotectonic features and volcanism in the region. The authors consider key questions of BRZ evolution from in terms of sedimentology, in particular, correlation of Mesozoic and Cenozoic basins, bilateral growth of the Baikal rift, Miocene sedimentation environment, the Miocene/Pliocene boundary events, Pliocene and Pleistocene tectonic deformations and sedimentation rates and links between major tectonic and volcanic stages.

5. Crustal growth, orogeny and rifting in the eastern CAOB

The Late Mesoproterozoic, Neoproterozoic and Paleozoic magmatic suites in the Korean Peninsula provide important insights into the crustal evolution histories of Gondwana in the East Asian continents, including the Central Asian Orogenic Belt (CAOB) between the Tarim-North China and Siberian blocks, and the Central China Orogenic Belt (CCOB) along the North and South China blocks in China.

Park et al. (2017-in this issue) report the results of field mapping, SHRIMP U—Pb and geochemical analyses from Late Mesoproterozoic and Early Neoproterozoic magmatic rocks in the Hongseong area, central-western Korean Peninsula. Based on all available data, the authors define a Neoproterozoic magmatic chain in the western Gyeonggi massif, southern Korean Peninsula, preserving arc-related orogenic (ca. 900–770 Ma) and rift-related post-orogenic (ca. 762–730 Ma) igneous activities that can be attributed to the Rodinia supercontinent. This implies that the area might be located along the margin of the Rodinia supercontinent. Kim et al. (2017-in this issue) present reliable petrological, geochemical and SHRIMP zircon U—Pb analyses for the Early to Middle Paleozoic migmatized gneisses from the Hongseong area in the central-western Korean Peninsula. The migmatized paragneiss underwent partial melting, migmatized at ca. 9.2–12.0 kbar and 770–870 °C during 432 Ma to 403 Ma in age. Together with their arc-related geochemical signatures, these geochronological data provide possible tectonic correlations from subduction to collision tectonics along East Asian continental margin.

Li et al. (2017, in this issue) present geochemical, petrologic and U-Pb-Hf zircon data from quartz-feldspathic rocks of the Xilingol complex in Inner Mongolia, China to discuss the tectonic evolution of the eastern CAOB. The rocks are in the upper amphibolite facies and their protoliths are wackes and litharenites representing a fore-arc sedimentary sequence with an age of diagenesis of ca. 387 and 340 Ma. The fore-arc formed at an active continental margin of the South Mongolian microcontinent. The northward subduction of the Paleo-Asian oceanic crust underneath the microcontinent induced accretionary wedge-continent collage in the Xilinhot area, and the prograde biotites from the paragneisses with an age of ca. 312–301 Ma formed in the beginning of the collage, which could continue until ca. 282 Ma as recorded by the retrograde biotites. Detrital materials from the South Mongolian microcontinent and the Baolidao arc instead of the North China craton were deposited in a fore-arc basin indicating the presence of the Solonker zone separating the northern subduction zone from the southern subduction zone in the CAOB. The microcontinents of the eastern CAOB could be derived from Tarim rather than from Siberia, North China or Gondwana.

Zhao et al. (2017-in this issue) present new sedimentological analysis, detrital zircon dating and geochemical studies on the Late Carboniferous–Early Permian terrigenous strata and accompanying volcanic rocks from northern Inner Mongolia (China). The authors combined the literature data from northern Inner Mongolia and South Mongolia and concluded that a unified continent existed in northern Inner Mongolia and South Mongolia before the Late Carboniferous. A Late Carboniferous–Early Permian rift system was developed in this unified continent and induced synchronous magmatism and deposition of non-marine sediments.

Martynov et al. (2017-in this issue) provide a comprehensive review on the geotectonic framework and the evolutionary history of the East Sikhote-Alin area. According to the current and widely accepted tectonic model, this area was formed as a subduction system from the Late Cretaceous to the Late Tertiary. Using field relationships, whole-rock and isotope geochemistry, the authors show that: (1) only the Late Cretaceous andesitic and silicic volcanics, i.e., enriched in LILE and depleted in HFSE can be interpreted as typical subduction complexes; (2) the Paleogene change of the Pacific plate – eastern Eurasian convergence pattern terminated the Late Cretaceous subduction and induced slab tearing and injection of Pacific MORB-type oceanic asthenosphere into the subcontinental lithosphere; (3) the effect of the oceanic asthenosphere on the continental margin ended in the Late Miocene after the Sea of Japan had opened and a new subduction zone initiated east of the Japan Islands; (4) EMI signature of the Late Miocene–Pliocene within-plate basalts support the eastward asthenospheric mantle flow beneath Asia possibly related to mantle plumes.

6. A general view on the CAOB evolution

The finale is the paper by Yakubchuk (2017-in this issue) presenting a provocative review of the history of the Central Asian Supercollage (CAOS) between the breakup of Rodinia and assembly of Pangea. The author shows that its internal pattern cannot be explained via a split of metamorphic terranes from and formation of juvenile magmatic arcs near the East European and Siberian cratons or by breakup of multiple cratonic terranes and associated magmatic arcs from Gondwana and their drift across the Paleo-Asian Ocean towards Siberia. The author suggests that the CAOS evolution can be explained by multiple regroupings of old and juvenile crust in eastern Rodinia in response to: 1) 1000–740 Ma propagation of the Paleo-Asian oceanic spreading centers towards Tarim and North China; 2) 665–540 Ma opening and expansion of the Mongol-Okhotsk Ocean; 3) 520–450 Ma propagation of the Turkestan oceanic spreading centers and arrangement of all CAOS terranes into a present layout; and 4) Middle to Late Paleozoic expansion of the Paleo-Tethys Ocean and collision of the North China and Siberian cratons to form North Asian continent prior to its collision with the East European craton along the Urals to form Laurasia.

Thus, a big progress has been achieved during the last five years by the research performed in the frame of IGCP #592. The participants and authors addressed the following big questions: 1) evaluation of juvenile to recycled crust in the CAOB based on isotope geochronology and geochemistry; 2) geology, tectonics and magmatism in different segments of the CAOB; 3) assessment of accretion as part of continental construction; 4) metallogeny and formation of mineral deposits; 5) correlations between the CAOB and WP based on new project results; 6) contribution of deep-mantle processes to continental growth; 7) correlations between recent tectonics and volcanism. Combination of U—Pb zircon ages with Nd and Hf isotopes helped to identify juvenile crust domains in the western (Kazakhstan, Altai, Junggar, Tienshan), southern (NW China and Mongolia) and eastern (Inner Mongolia) CAOB and both juvenile and recycled domains in the Kyrgyz Tianshan and southern Transbaikalia-northern Mongolia (Degtyarev et al., 2017-in this issue; Donskaya et al., 2017; Konopelko et al., 2017-in this issue; Kovach et al., 2017-in this issue). The timing of granitoid and mafic magmatism show peaks in the Late Neoproterozoic (mafic), Cambrian-Ordovician, Devonian and Triassic (granitoid) and suggested a Late Permian closure of the PAO (Buriánek et al., 2017-in this issue; Li et al., 2017; Soldner et al., 2017-in this issue; Zhang et al., 2017-in this issue; Yin et al., 2017-in this issue; Yu et al., 2017-in this issue). Deep mantle dynamics greatly contributed to the continental construction in the CAOB through Meso-Cenozoic intra-plate continental volcanism (Junggar, Transbaikalia, Mongolia, East China) related to mantle plumes (Kolesnichenko et al., 2017-in this issue; Krivonogov and Safonova, 2017-in this issue; Zhao et al., 2017-in this issue). The data on the formation ages and genesis of mineral deposits contributed to the understanding of metallogenesis and evolution of the whole CAOB (Dolgopolova et al., 2017-in this issue). Geologic and lithostratigraphic comparisons of CAOB and WP showed both P- and C-type orogenic belts in the CAOB and the domination of P-type orogenic belts as it hosts numerous localities of granitoids with juvenile isotope characteristics, blueschists derived from MORB and OIB protoliths, accreted carbonate-capped OIBs and other OPS units, huge granitoid batholiths and boninites (Kim et al., 2017-in this issue; Martynov et al., 2017-in this issue; Park et al., 2017-in this issue; Safonova, 2017-in this issue; Yakubchuk, 2017-in this issue). The project highlighted that the formation of CAOB continental crust and its related huge mineral deposits mostly benefited from supra-subduction and intra-plate juvenile granitoid and mafic magmatism.

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