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A new concept of continental construction in the Central Asian Orogenic Belt

(compared to actualistic examples from the Western Pacific)

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A new concept of continental construction based on four main terms: (1) crustal growth, (2) crustal formation, (3) continental growth and (4) continental formation is presented here. Each of these terms reflects a certain process responsible for the formation of what we call now "continental crust". This concept is applied to the Central Asian Orogenic Belt (CAOB), which is a global major accretionary orogen formed after the closure of the Paleo-Asian Ocean, and to its actualistic analogues – orogenic belts and accretionary complexes of the Western Pacific. The main focuses of the paper are the state of activities in the study of the CAOB, the theoretical basics of the new concept of continental construction, its challenges, prospects and social impacts, main methods of investigation. The main issues of the paper are what has been done in this field of geoscience, which questions remained unaddressed and which problems should be solved. The most important challenges are: (a) dominantly Phanerozoic formation of the CAOB continental crust versus its dominantly Archean growth; (b) to what extent the CAOB continental crust was juvenile or recycled; (c) whether magmatic arcs or Gondwana-derived terranes were accreted to the Siberian, Kazakhstan, Tarim and North China cratons; (d) what was the balance between continental formation and tectonic erosion based on modern examples from the Western Pacific; (e) what social benefits (mineral deposits) and geohazards (seismicity and volcanism) can

be inferred from the study of orogenic belts formed in place of former oceans.

Introduction and State-of-the-art

Understanding how continental crust forms, grows and evolves is a highly important Earth Science problem. The major significance of the newly proposed continental construction approach is linked to the fact that the formation of the continental crust was one of the most important events that ever happened in Earth history. The focus of this paper is continental crust construction in Central and East Asia, namely Central Asian Orogenic Belt (CAOB), and its comparison with Western Pacific. The great Central Asian Orogenic Belt (Jahn, 2004; Windley et al., 2007) or Altaid orogenic collage (Sengor and Natal'in, 1996) or Central Asian Orogenic Supercollage (Yakubchuk, 2004; Yakubchuk et al., 2005) extends from the Uralides in the west to the Pacific margin in the east, including orogenic areas in Russia (Altai-Sayan, Transbaikalia, Primorje), East Kazakhstan, Kyrgyzstan, Uzbekistan, China, and Mongolia (Fig. 1). It is located between the East European, Siberian, North China and Tarim cratons. It is one of the largest accretionary orogens on Earth and evolved over some 800 Ma thus representing an ideal natural laboratory to unravel geodynamic processes during voluminous Phanerozoic continental growth and to prove whether the Phanerozoic was an important period of continental crust formation or its dominantly Archean origin.

The CAOB, like other major accretionary orogens (Fig. 2) is a complex collage of ancient microcontinents and arc terranes, accretionary wedges, fragments of oceanic volcanic islands (seamounts) and, possibly, basaltic plateaus, oceanic crust (ophiolites) and successions of passive continental margins. The amalgamation of these terranes occurred at different times and was accompanied by post-accretion granitic magmatism and exhumation of HP-UHP

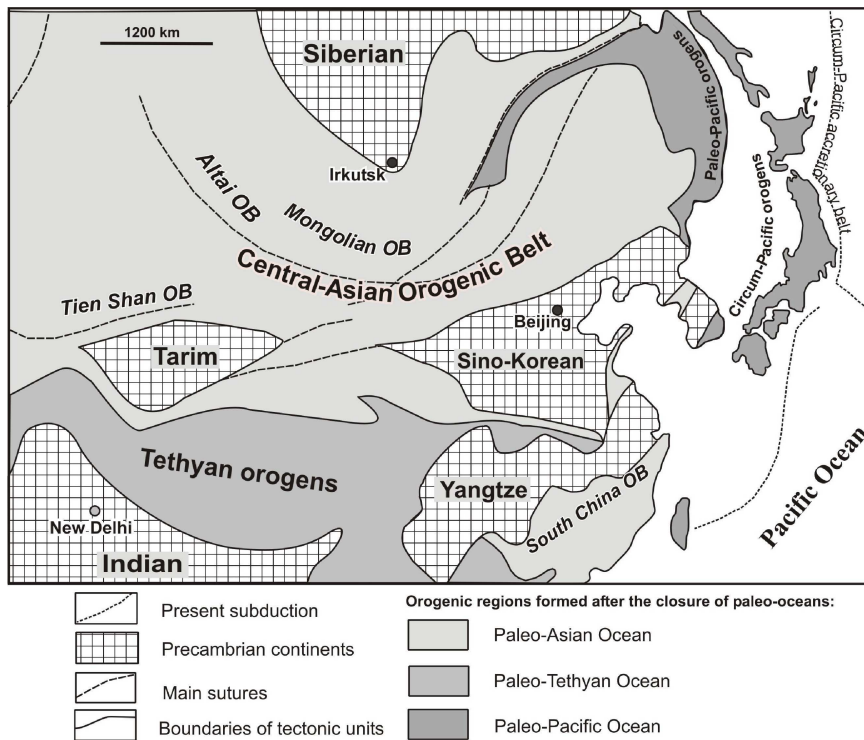


Figure 1. Simplified tectonic scheme of Central and East Asia showing the main orogens formed after the closure of paleo-oceans and approximate location of local orogenic belts - OB, (modified from Ren et al., 1999 and Li, 2006).

metamorphic rocks, post-collisional orogenic granitoid magmatic (K-rich), intraplate plume-related magmatism, large scale post-orogenic strike-slip faults and formation of post-orogenic clastic sedimentary basins; (e.g., Sengor and Natal'in, 1996; Shu et al., 1999; Kruk et al., 1999; Laurent-Charvet et al., 2002, 2003; Jahn, 2004; Kröner et al., 2007; Wang et al., 2007; Windley et al., 2007; Charvet et al., 2007; Volkova and Sklyarov, 2007; Gladkochub et al., 2008; Lin et al., 2009; Safonova et al., 2009, 2010; Sun et al., 2008; Seltmann et al., 2010).

The discussion about CAOB evolution over the last 20 years resulted in two groups of hypotheses. The first group of researchers regard the southern margin of the Siberian continent a result of accretion of oceanic arcs and/or Gondwana-derived continental blocks to the Siberian, Russian, and North China cratons (e.g., Zonenshain et al., 1990; Didenko et al. 1994; Yin and Nie, 1996; Wang and Liu, 1986; Buslov et al., 2001; Laurent-Charvet et al., 2003; Xiao et al., 2010). The second type of models views the Central Asian collage to be made mainly of Paleozoic subduction-accretion materials (Sengor et al., 1993; Sengor and Natal'in, 1996; Yakubchuk, 2008), which accumulated against a few magmatic arcs of extended length. The most of recent geological, tectonic, geodynamic and metallogenic maps and reconstructions of the CAOB are based on the one or the other model.

The existence of terranes of Gondwana affinity in the CAOB is still under discussion, because the original structure of the belt was strongly broken and deformed by later tectonics and orogeny. Recent studies have shown that orogenic events in accretionary belts, in contrast to collisional orogens, are controlled by a variety of different mechanisms, including accretion of allochthonous terranes, subduction of buoyant lithosphere and oceanic ridges, plate reorganization and changing tectonic patterns and structural styles

(e.g., Buslov et al., 2004; Cawood et al., 2009; Seltmann et al., 2007; Pirajno, 2010). Different orogenic mechanisms are characterized by specific sets of tectonic features, which can more easily be recognized in the active Western Pacific orogens and applied to help interpreting older counterparts where the tectonic setting is less clear, such as in the CAOB (Buslov and Watanabe, 1996; Sengor and Natal'in, 1996; Maruyama et al., 1997; Cawood et al., 2009).

The problem of juvenile versus recycled crust formation has been discussed in several recent publications (e.g., Yuan et al., 2007; Jahn et al., 2009, 2010; Kruk et al., 2010; Safonova et al., 2010). The CAOB is considered to be the most important site of juvenile crustal formation since the Neoproterozoic, because during its amalgamation, which involved terrains of different geodynamic origin overlain by magmatic units, massive amounts of granitic magmas were generated with juvenile Nd isotopic signatures (Jahn et al., 2000; Jahn, 2004). The detrital zircon spectra obtained from modern sands of rivers draining the territory of the CAOB (Rino et al., 2008; Safonova et al., 2010) also confirmed that the Phanerozoic was the major period of granitoid magmatism in Central Asia, which was probably related to its

formation. The western part of the CAOB was formed during the Early Paleozoic collision of the Kokchetav and Altaï-Mongolian terranes with the Siberian Craton (Dobretsov and Buslov, 2007). The evolution of the central part of the CAOB included several stages of collisions between the Kazakhstan and Tarim continents and smaller continental blocks, e.g., Junggar, which resulted in formation of the Chinese Altaï and Tianshan orogenic belts (Gao et al., 1995, 1998; Li J.Y., 2003; Xiao et al., 2004; Charvet et al., 2007; Kroner et al., 2007, 2008; Lin et al., 2009; Biske and Seltmann, 2010). The eastern part of the CAOB was formed during the Middle Paleozoic collision of the Tuva-Mongolian terrane and Siberian Craton (Didenko et al., 1994) and Late Paleozoic-Early Mesozoic collision of the North China and Siberian Cratons (e.g., Meng et al., 2010). Paleozoic syn- and post-collisional and intraplate granitic intrusions (Kovalenko et al., 2001; Yarmolyuk and Kovalenko, 2003) are distributed mainly in the northern part of the CAOB (Transbaikalia). The huge Early-Middle Palaeozoic peaks in the detrital zircon spectra of Ob' and Yenisey river sands match the Altaï/CAOB crustal growth event very well (Safonova et al., 2010). However, it is not seen in several published models for crustal evolution based on zircon age peaks (Condie, 1998; Kemp et al., 2006; Hawkesworth et al., 2010). Have some researchers underestimated the amount of Phanerozoic crustal growth because they did not work in Central Asia?

The majority of continental blocks in Central Asia have crystalline basements, considered to be Precambrian in age (Fig. 2). In places, this age has been confirmed by isotopic dating, but for many others the age determination was based on lithologic/structural relationships. Employment of modern methods of isotopic dating has shown that previous age assessments of Precambrian basement are not always valid. The isotopic dating of CAOB granitoids performed during the last 10 years allowed researchers to develop a general scenario of massive juvenile crust production in the CAOB with limited influence

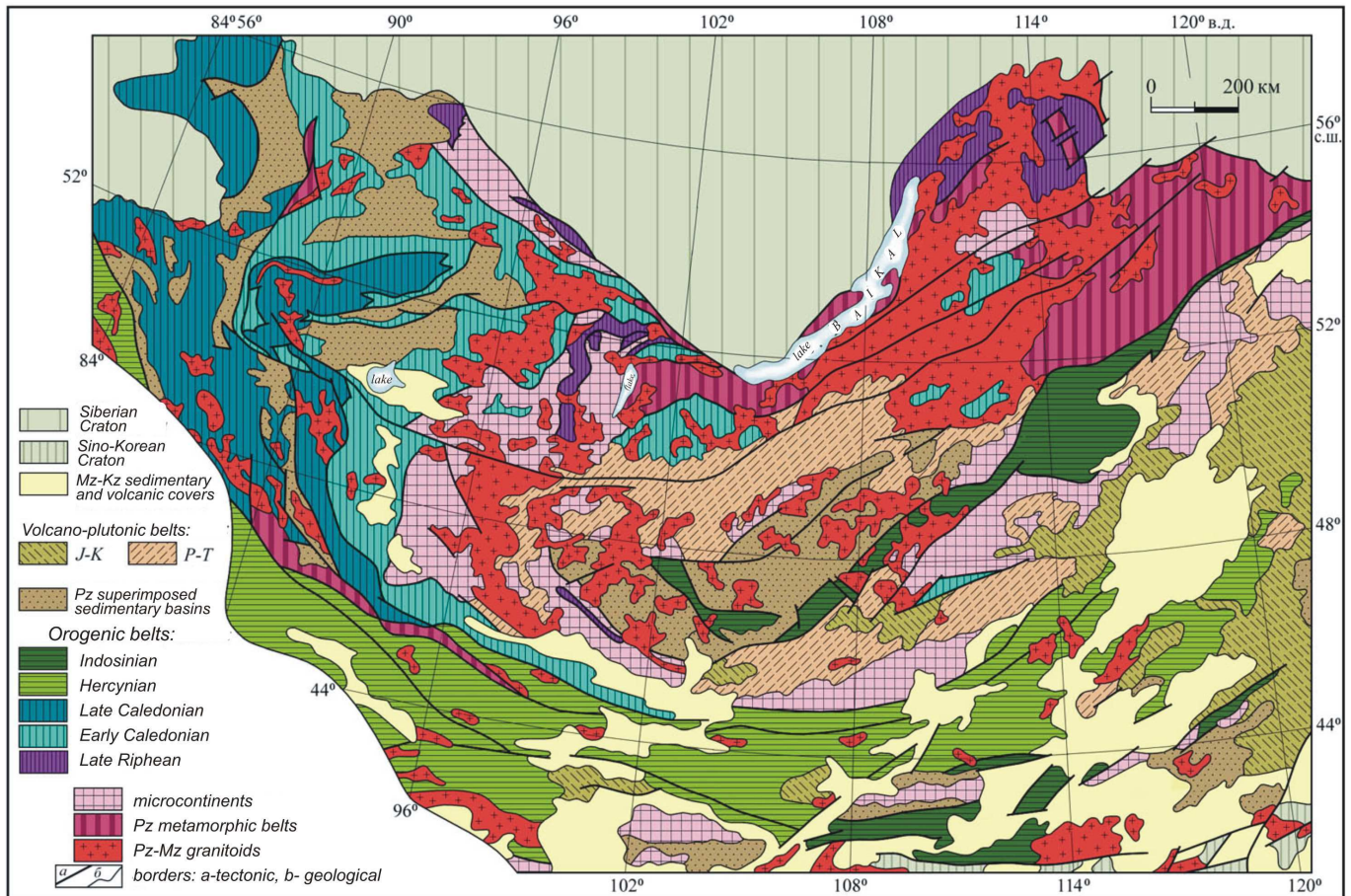


Figure 2. Geological scheme for the eastern segment of the Central Asian Orogenic Belt (from Yarmolyuk et al., 2011).

of old microcontinents in the genesis of Phanerozoic granitoids (e.g., Sengör et al., 1993; Kovalenko et al., 2004; Jahn et al., 2004). In places, Precambrian gneisses have turned out to be Mesozoic in age or even younger (Webb et al., 1999; Salnikova et al., 2001; Wilde and Wu, 2001; Gladkochub et al., 2008). However, the recently obtained detrital zircon age spectra for the CAOB showed prominent peaks at 1.8-2.0 and 2.5-2.7 Ga, which confirmed also an important role for older crust in the orogen's evolution (e.g., Rino et al., 2008; Safonova et al., 2010).

The original paleogeographic position of the continental blocks in the CAOB is also a subject of intense debate. Most researchers argue for the Gondwana affinity of many allochthonous terranes in the CAOB (e.g., Berzin et al., 1994; Kheraskova et al., 1995; Fedorovsky et al., 1995; Gladkochub et al., 2008; Buslov et al., 2001; Dobretsov and Buslov, 2007). Others consider multiple accretion of magmatic arcs (e.g., Sengör and Natal'in, 1996; Yakubchuk, 2008) or infer exclusively a Siberian origin for the same blocks (e.g., Kuzmichev et al., 2001).

Many different research groups from Russia, Kazakhstan, Uzbekistan, Kyrgyzstan, China, Japan, UK, Germany, Belgium, etc. (for review go to <http://www.iagod.org/igcp>) have been involved in the study of the CAOB. However, a lot of questions remained unanswered, including three major problems: (1) Archean versus Phanerozoic crustal growth or to what extent the CAOB continental crust was juvenile or recycled; (2) whether magmatic arcs or Gondwana-derived terranes were accreted to the Siberian, Kazakhstan, Tarim and North China cratons; (3) what was the balance between

continental formation and tectonic erosion. To solve many of related problems we propose a new concept of continental construction, which was first presented in the IGCP Proposal no. 592 submitted to UNESCO in October, 2010 (<http://www.iagod.org/igcp>).

The new concept: Rationale

The ongoing controversial discussion requires us to prove whether the CAOB formed as result of an important period of continental crustal growth in the Phanerozoic (Jahn et al., 2004) versus an opposite idea that most of juvenile crust was formed in the Archean (Condie, 1998; Kemp et al., 2006; Hawkesworth et al., 2010). We argue that the study of the continental construction in the CAOB should be performed in the context of global geodynamic events of plate tectonics (horizontal tectonics) and plume tectonics (vertical core-mantle-crust geodynamics), e.g., birth/death of oceans, assembly/breakup of supercontinents and their relation to bursts of superplumes, and correlated with recent geological processes recorded at ocean-continent convergent margins of the Western Pacific. One solution is to compare the data obtained in the CAOB with those available on relatively well studied accretionary complexes and island-arc-active margin units of the Western Pacific: Russian Far East, Japan, Korea, and East China. To undertake such a study we propose a new concept of continental construction.

The terms of continent/continental/crust/crustal growth or formation have been used during the last decades by many scientists, in different senses though. We propose a new conceptual approach of

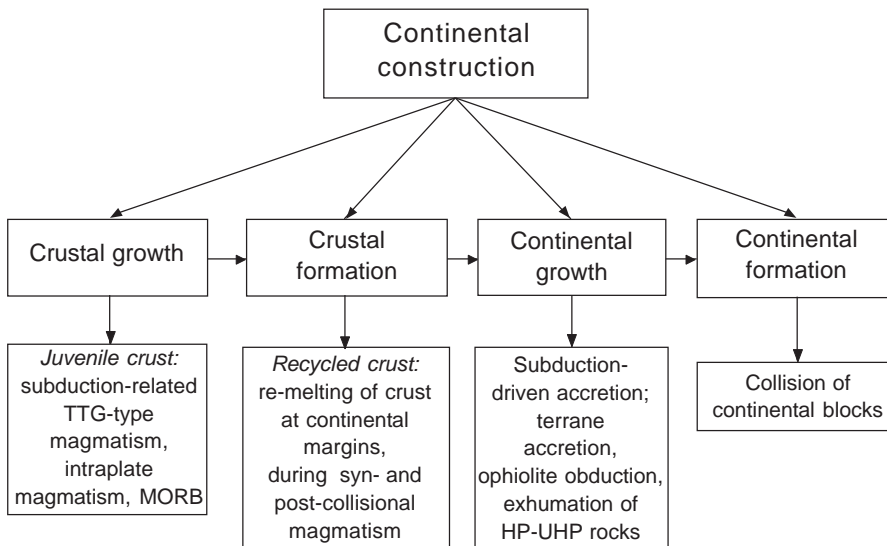


Figure 3. A scheme of the new conceptual approach for continental construction.

continental construction which is based on four terms: crustal growth, crustal formation, continental growth and continental formation (Fig. 3). Each term has a certain meaning.

1. *Crustal growth* implies generation of juvenile crust, which takes place at mid-oceanic ridges, in island arcs, back arcs and fore-arcs and Pacific-type active continental margins (mantle-derived mafic to andesitic magmas), and continental/oceanic intraplate magmatism, i.e. direct eruption of basaltic magma to the surface forming Large Igneous Provinces, namely, continental flood basalts and oceanic basaltic plateaus. Fragments of oceanic crust formed in mid-oceanic ridges, oceanic plateaus can be accreted to continental margins during subduction (Fig. 4).
2. For *crustal formation* we understand generation of continental crust containing recycled material at continental margins and during syn/post-collisional magmatism through evolution of juvenile basaltic to andesitic magma into granitic rocks by

remelting of old continental crust. Those processes are common at Andean-type active continental margins and during collision of continental blocks, which induce the heating of continental crust material and its related granitoid magmatism. Post collisional or anorogenic granites may form due to crustal reheating and reworking (Jahn, 2004; Jahn et al., 2009; Kovalevko et al., 2004; Fig. 4).

3. The subduction-induced accretion of allochthonous terranes (oceanic islands/plateaus, oceanic arcs, passive margins, continental blocks of variable size) containing both juvenile and recycled crustal material is *continental growth* (Fig. 4). Those processes of accretion are accompanied by intensive tectonic deformation, thrusting, sometimes obduction of oceanic crust, exhumation of ultra-

high-pressure and high-pressure rocks from mantle depths, etc.

4. Final collision of continental blocks, which results in formation of new continents and supercontinents, is *continental formation*. Collision of continents results in closure of oceanic basins and is accompanied by intensive orogeny, i.e. mountain growth, which is marked by formation of suture-shear zone and peaks of granitoid magmatic activity.

All these processes of crustal growth, crustal formation, continental growth and continental formation are main components of continental construction in both petrological and geodynamic senses. In our view all these stages, each corresponding to a specific group of geological processes, are to be considered in mutual relationship. The new approach is aimed to the following:

1. To evaluate the generation of juvenile crust through contribution of a) subduction-related TTG-type magmatism, b) intraplate plume-related magmatism leading to formation of Large Igneous

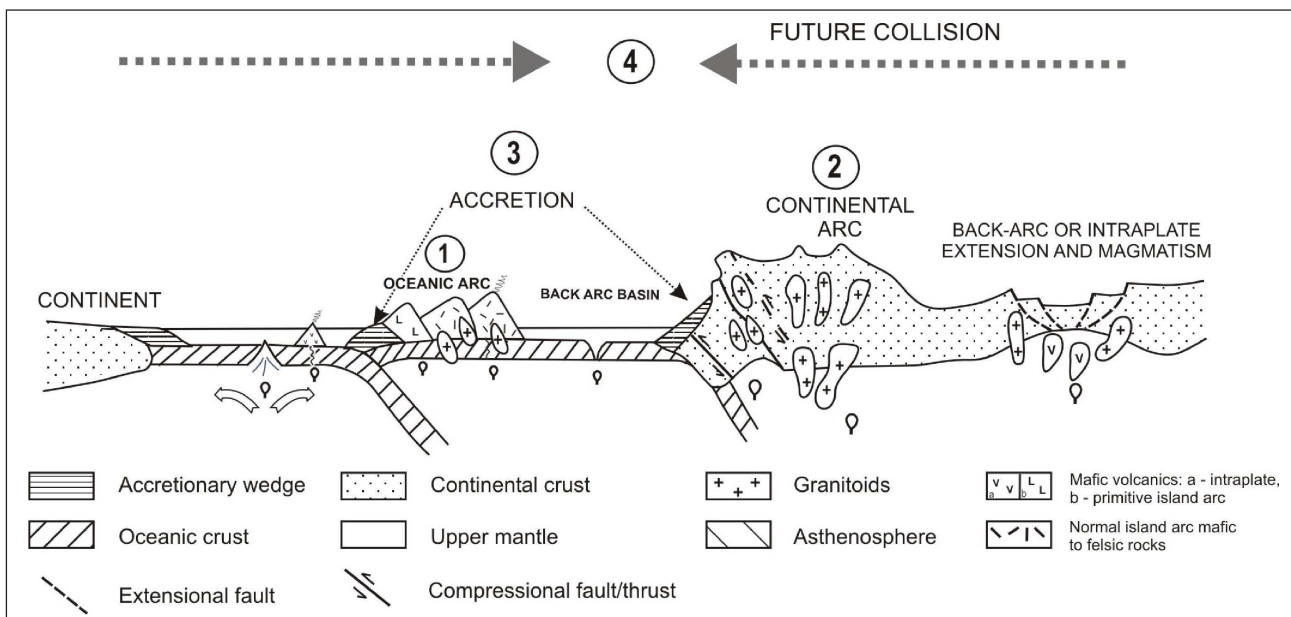


Figure 4. A schematic profile illustrating three stages of continental construction: 1 – crustal growth, 2 – crustal formation, 3 – continental growth (numbers in circles). For more details see Fig. 3.

Provinces: oceanic plateaus/islands and continental flood basalts, etc.; c) crust formed at mid-oceanic ridges, i.e., crustal growth of Stage no. 1. The objects to be studied are a) orogens dominated by island-arc assemblages with attached accretionary complexes hosting oceanic plate stratigraphy (OPS) units, e.g. in Russian-Chinese-Mongolian Altai compared with accretionary orogens in Russian Far East, Japan, Korea, Alaska; b) intraplate rift/plume-related basaltic traps and volcanoes, e.g., Kuznetsk and Minusa Basins in southern Siberia, volcanic fields in southern Transbaikalia-northern Mongolia.

2. To evaluate the contribution of re-melting of crust by an unspecified heat source producing redistribution of crustal layers (residue and intrusions) to the generation of continental crust containing recycled material, i.e., crustal formation of Stage no. 2 (Fig. 4). The proposed objects of study should be intermediate to felsic magmatic complexes and terrigenous rocks in terranes built on older crust, like active continental margin and syn- and post-collisional granitoids. Of special importance is U-Pb dating of zircons and Nd isotope composition of those rocks, which would allow us to estimate the portion of juvenile versus recycled crust and define main periods of granitoid magmatism.
3. To study tectonic processes recorded in accretionary complexes consisting of various sedimentary, terrigenous and magmatic units to evaluate volume of accreted terranes, compensated by sediment subduction and subduction erosion (Scholl and von Huene, 2009) and subduction/accretion related deformation and metamorphism, i.e., continental growth of Stage no. 3. The proposed objects of study are tectonic patterns, structural styles and deformation-metamorphism-related minerals in accretionary complexes with metamorphic units (including those with high-pressure and ultra-high-pressure rocks, HP-UHP), which occur in suture-shear zones formed after the closure of the Paleo-Asian Ocean (Fig. 1).
4. To study tectonic processes related to collision and including crustal thickening, mechanical underplating, structural re-adjustment of individual blocks, strike-slipping, i.e., continental formation of Stage no. 4. The proposed objects of study are collisional zones with thick terrigenous units, collisional granitoids, accretionary complexes, island-arc and back-arc terranes, ophiolites, metamorphic HP-UHP units, microcontinents, etc. Figure 5 shows several illustrated example of continental construction processes.
5. To evaluate social impacts of geological processes related to the formation of orogenic belts in place of former oceans like the CAOB, which are social benefits and geohazards. The social benefits are numerous and voluminous metallic- and non-metallic mineral deposits of accretionary orogens. The geohazards are surface impacts/consequences of volcanic eruptions, earthquakes and their triggered tsunamis and land-slides (Fig. 6). The beneficial objects to be studied are metal-rich magmatic and metamorphic complexes, ore-bearing strike-slip fault zones and sulfide-metal rich volcanic rocks. The geohazard study should be focused on petrologic and geochemical-isotope study of volcanic and sedimentary rocks, which record volcanism-related climate changes, and tectonic and geophysical study of seismicity.

This approach implies careful reconstruction of each stage/process within each individual orogenic belt of the CAOB: Altai-Sayan and Transbaikalia (Russia), Eastern and Central Kazakhstan, Kyrgyz

Tianshan, Chinese Altai and Tianshan, Mongolian Altai, and their comparison with accretionary orogens in Russian Far East (Kamchatka, Primorje), Alaska, Japan, Korea, and, possibly, Indonesia.

The inferred processes, events and mechanisms of continental construction are to be carefully compared in relative aspects (geochronological isotopic ages, geochemistry, structural styles, tectonic patterns, lithology, etc.) with the present-day or recent/Quaternary examples from the Western Pacific (north to south: Japan, Korea, East China). These regions have been better studied than the Central Asian Orogenic Belt and represent good actualistic examples for comparison. All this would allow reconstructing a whole evolutionary pattern of this huge orogenic system. Such kind of holistic view can only be realized with the help of an interdisciplinary approach including U-Pb and Ar-Ar isotope geochronology, igneous and metamorphic petrology, isotope (Hf-Nd-Os-O) and major/trace element geochemistry, lithology, sedimentology, micropalaeontology, tectonics, structural analysis, palaeomagnetism, geophysics, metallogeny and environmental geology.

Methods, challenges and prospects

This section presents brief descriptions of methods and techniques to be used while performing study of large accretionary belts, like the CAOB, their related challenges and future prospects

1. New methods of *field work* based on combined field teams including regional geologists, lithologists, structural geologists, petrologists, geochemists and geophysicists in order to provide a multi-disciplinary approach and comprehensive study of geological localities. This would allow reduction of field work expenses and would guarantee high-quality and efficient field work performance. An important issue is application of GIS technologies during field works and for more efficient processing and interpretation of geological and geomorphological data on basis of existing and to be developed in future GIS platforms.
2. *Regional geological* studies should be focused on clearing up geological relationships between lithological units of different geodynamic origins, preparation of geological sections, stratigraphic columns, maps and schemes, which are necessary for tectonic and geodynamics reconstructions. It would be essential to produce in a unified way lithotectonic logs allowing precise definition of passive margins, oceanic plate stratigraphy, and accretionary complex, to reconstruct oceanic realms in time and to identify location and age of spreading centers and suture zones across the whole CAOB.
3. Detailed *structural analysis* based on satellite imagery and structural transects seems to be necessary to get information about kinematics of principal movements and variations in major plate configurations in time. This would contribute to our understanding of (1) what are critical rheological and mechanical parameters controlling continent construction, e.g., highly anisotropic crust oriented parallel to tectonic stress or thermal weakening associated with activity of magmatic arcs; (2) how rapidly did the Central Asian Orogenic Belt grow in terms of plate tectonics in general and accretionary tectonics in particular ("horizontal" processes).
4. The main basis for the continental construction approach is *geochronological U-Pb zircon and Ar/Ar mineral isotope dating*. The events of juvenile crust generation must be supported by the

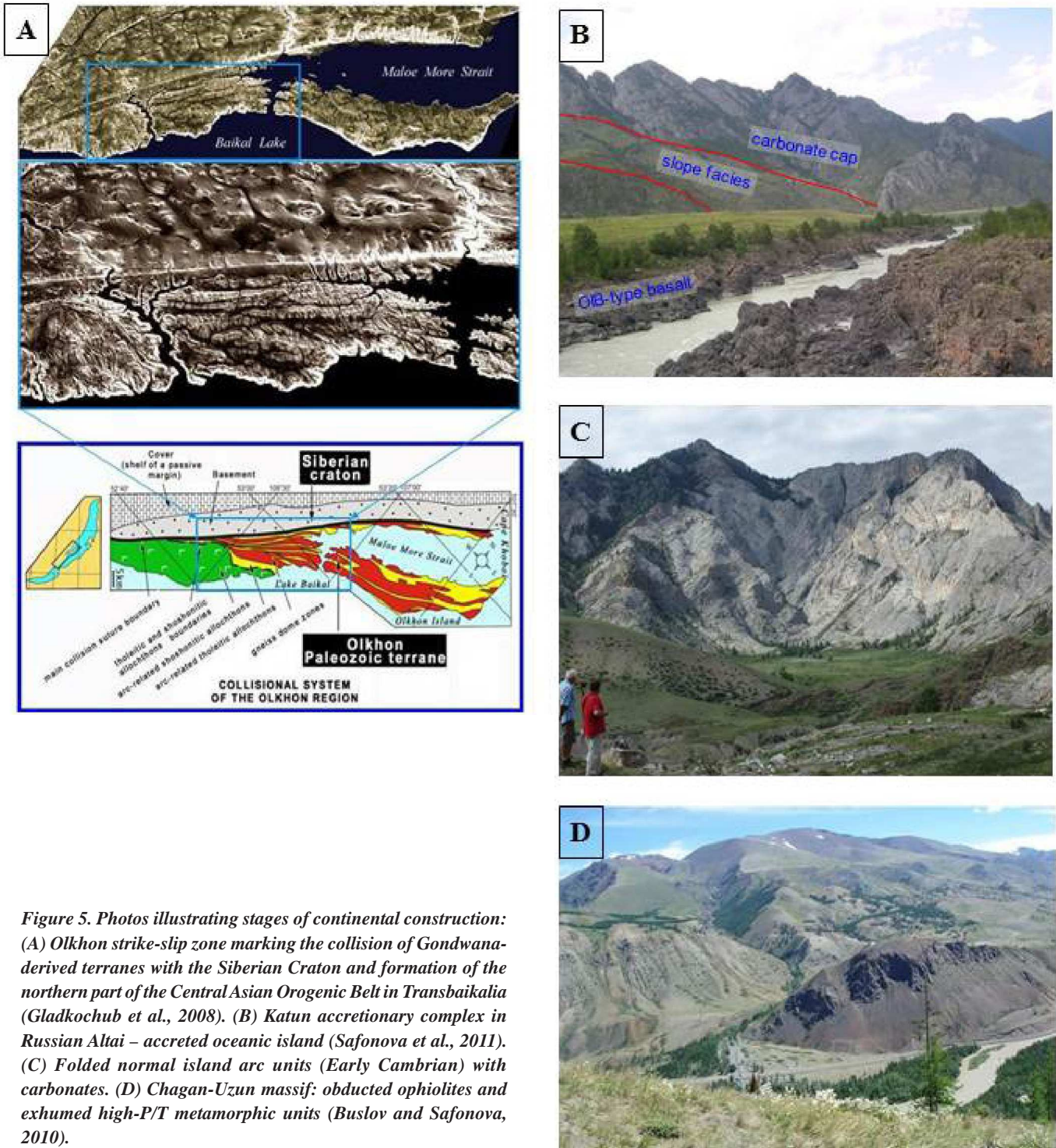


Figure 5. Photos illustrating stages of continental construction: (A) Olkhon strike-slip zone marking the collision of Gondwana-derived terranes with the Siberian Craton and formation of the northern part of the Central Asian Orogenic Belt in Transbaikalia (Gladkochub et al., 2008). (B) Katun accretionary complex in Russian Altai – accreted oceanic island (Safonova et al., 2011). (C) Folded normal island arc units (Early Cambrian) with carbonates. (D) Chagan-Uzun massif: obducted ophiolites and exhumed high-P/T metamorphic units (Buslov and Safonova, 2010).

dating of island/back/fore-arc units, mid-oceanic ridge basalts and oceanic island/plateau basalts from individual accretionary complexes of CAO and Japan (Fig. 1). The recycled crust will be evidenced by the dating of metasedimentary and metamorphic units of terranes/orogens built on older crust and intermediate to felsic volcanic and intrusive complexes. The dating of minerals from metamorphic and magmatic rocks in suture-shear zones is necessary to define the time intervals of faulting, shearing, and metamorphism and the types and scale of deformation and to evaluate volume of accreted terranes versus tectonic erosion.

5. The *micropaleontological* analysis of oceanic sedimentary units based mainly on occurrences of radiolarians and conodonts and their environment, but not only, is extremely important. It provides actually the only reliable way to define the age of OPS units, because oceanic basalts are almost impossible to be dated by isotopic methods: they are usually altered to greenstones due to their eruption in hydrothermally aggressive sea-floor conditions and subsequent post-magmatic secondary alteration and metamorphism and most mafic rocks contain few zircons.
6. *Geochemical data* including major and trace-element data and

Sm-Nd isotopes of whole rocks, composition of rock-forming minerals, Lu-Hf isotopes of zircons are still of primary importance for (i) evaluation of processes of crustal contamination, fractional crystallization and partial melting, (ii) determination of petrological parameters of rocks (temperature, pressure) and their mantle sources (EM, HIMU, DMM), mantle depth (spinel/garnet facies) and (iii) reconstruction of their geodynamic origin. Sm-Nd isotopes of mafic rocks and Lu-Hf isotopes of zircons from both magmatic felsic and sedimentary rocks will be necessary to contribute to evaluation of juvenile versus recycled crust material involvement. Adjusting up-to-date analytical technologies seems to be necessary for solving many geological problems with a special focus to new materials and types of specimens, for example, adjusting LA-ICP-MS dating techniques to analysis of “young” zircons and titanite, and developing techniques of recalculation of isotope and trace element data in order to perform better control over analytical errors and provide more reliable analytical results.

7. *Geophysical* airborne magnetic surveys would provide excellent maps allowing precisely follow trends of magmatic arcs and of accretionary “ophiolite” complexes. The gravity maps will be used to model the deep structure of crust along selected profiles allowing better reconstruction of structure of juvenile thick crust of the CAOB. Bouguer anomaly and aeromagnetic data will be used to produce 3D crustal model of critical continental and oceanic segments (anomalously thick oceanic crust). This analysis will precise the identification of regions of continental crust affected by important arc magmatism (gravity lows), oceanic crust of anomalous thickness (gravity highs) and large accumulations of highly magnetic and highly dense accreted oceanic material.
8. Better understanding of the history of *mineral deposits* in accretionary orogens would come from a careful study of diverse structural/tectonic styles and timing of mineralization, which reflect different lithosphere-asthenosphere processes during the evolution of accretionary orogens. There, the differences in arc architecture affect metallogeny, thus development of a catalogue of criteria to utilize specific mineralization processes (VMS, porphyry, granite-related, etc.) with respect to sources, nature, stages and maturity of crustal construction seems to be of vital importance. Supergiant mineral deposits appear to be controlled by interconnected lithospheric and asthenospheric processes as well as plate and plume tectonics. Addressing these relationships requires integrating geochemical, isotopic, and geophysical data with the tectono-magmatic history in order to understand the geodynamic control of major mineral deposits. State-driven (Soviet-time) exploration focused over past few decades on selected commodities and deposit types. Some exploration concepts successfully applied in global scale were neglected in the CAOB by local surveys. Meanwhile, the international mining industry considers large parts of CAOB as underexplored with good potential for new discoveries, especially if modern geophysical and geochemical methods will be applied.

9. *Seismic tomography* provides images of the lithosphere structure and behavior

beneath collision belts, which are important for reconstructing tectonic and metallogenic processes and understanding what was the main mechanism of the lithosphere recycling in continent-to-continent collision areas: delamination and/or subduction. New tomographic algorithms and implementation of anisotropic tomographic inversions for regional data would allow estimation of the flow orientations in the upper mantle and providing new constraints on the mantle dynamics underneath the CAOB.

10. Very prospective ways of reconstructing *paleoenvironments* is petrologic study of melt micro-inclusions and geochemical study (trace elements and isotopes) of carbonates capping paleoseamounts. Composition of mineral-hosted melt inclusions would allow us to estimate the amount of carbon dioxide released during volcanic eruptions. The isotope composition of carbonates record changes of seawater composition. All this would allow us to know how paleoenvironments changed after intense volcanic events (like voluminous eruption of flood basalts) or may be volcanism did not significantly affect it at all? Those results would contribute to the problem of mass extinctions and its possible relation to volcanism.

Those multi-disciplinary and multi-team research activities should be related to solution of the three main problems: to which extent the CAOB continental crust was juvenile or recycled and whether arcs or Gondwana-derived terranes were accreted to the Siberian, Kazakhstan, Tarim and North China cratons, and what was the balance between accretion (continental growth) and subduction erosion.

Of special importance is creation of unique datasets of geochronological, geochemical, and geophysical data, which is sometimes difficult due to geographical, political and informative barriers between scientists. The actualistic approach through comparison of reconstructed ancient geological events, processes and mechanisms with the recent and modern ones recorded at ocean-continent convergent margins of the Western Pacific is necessary to develop a trustworthy and reliable model for the continental construction in the CAOB.

Social impacts

The study of continental construction in the CAOB has a social importance through evaluating the surface impacts of geological processes related to formation of orogenic belts in place of former oceans. The social impacts related to the study of the CAOB can be divided into social benefits (mineral deposits) and geohazards (seismicity and volcanism; Fig. 6).

The main benefits for the society lie in better prospecting and

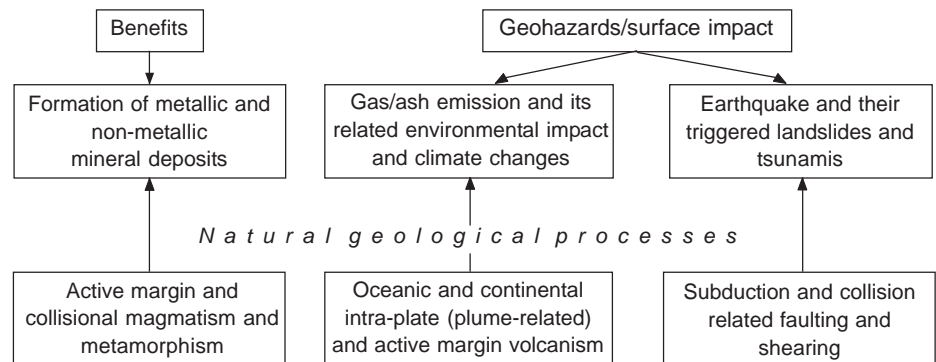


Figure 6. Social consequences of orogeny-related geological processes: benefits and geohazards.

exploration of mineral deposits, which can be provided by better understanding of their formation and evolution in relation to continental construction processes. Understanding the crustal architecture, its thickness, deformation, composition and age, role of crust-mantle interaction, all that is pivotal for the right exploration concept. Fertilisation of subcrustal lithospheric mantle, metasomatism of lower crust or lithospheric mantle, dehydration of subducted slabs etc. controls the metallogenic fertility of crustal domains. Therefore, realization of the new concept of continental construction in the CAOB, both in theory and practice, would provide additional approaches in studying mineral deposits, which will be used in developing new technological solutions in their exploration.

The mineral richness of the Altaids is legendary. The fabulous wealth of the Demidoff family in Czarist Russia derived mostly from platinum, gold and silver mines of the Urals and Altai. Since then many other mineral localities have been found and explored. These mines are located in certain tectonic niches and are mostly structurally controlled (Seltmann and Porter, 2005; Pirajno et al., 2009). Dilational jogs or pull-apart basins (formed above trans-crustal shear zones or due to arc rifting) are just two examples that control mineral trends like Sukhoj Log, Muruntau, Bakyrchik (orogenic gold deposits) or Oyu Tolgoi, Taldybulak, Kalmakyr-Dalnee (porphyry deposits). An improved understanding of the structure and tectonic evolution of the Altaids will lead to improved exploration concepts.

An important issue is that some of the world's richest hydrocarbon reserves are found in basins that resulted from the Altaid evolution. The West Siberian Basin, the Junggar and the Tarim are the largest of these. An improved understanding of their structure and tectonic evolution will naturally lead to better exploration policies.

Despite the fact that the CAOB hosts major base- and precious-metal deposits over a 5000 km interval (e.g., Yakubchuk et al., 2005; Seltmann and Porter, 2005; Seltmann et al., 2010 and literature cited therein) and has been studied during more than 20 years by many research teams, the complex evolution of the belt remains one of the least well understood. This is mostly because of its very complicated structure and poor road infrastructure in most regions of Siberia and Mongolia, which makes access difficult, as well as facing the political and language barriers. Overcoming this obstacle is important to the development of mineral exploration models across the CAOB, and understanding the current neotectonic and geodynamic processes occurring in the vicinity of the CAOB. Such work has applications to other regions currently undergoing similar geodynamic processes, e.g., the SW Pacific, Japan and Alaska.

On the other hand, studying tectonic processes related to continental construction will benefit to earthquake hazard assessment because many modern zones of increased seismicity are reactivated old suture-shear and strike-slip fault zones, which develop during accretion and collision. The correlative study of past and modern fault/seismic zones would contribute to our understanding of earthquakes and their triggered landslides and tsunamis. In relation to this seismic tomography seems to be one of the most prospective tools.

More benefits will be provided by estimation of carbon dioxide emitted during volcanic eruptions (petrologic studies of melt microinclusions), and changes of seawater composition (carbonate geochemistry and isotopes). The amount of carbon dioxide released by erupting lava and its effect on carbonate sedimentation is important

for our understanding of man-made versus natural causes of climatic changes.

All these will be correlated with modern processes/hazards currently active in the Western Pacific (volcanism and seismicity) and will allow improvement of criteria for predicting those hazardous geological events and decreasing their harmful consequences.

Conclusions

1. This concept of the study of continental construction in the Central Asian Orogenic Belt (CAOB), a world largest accretionary orogen formed after the closure of the Paleo-Asian Ocean, is based on four terms reflecting four processes of formation of what we call know "continental crust": 1) crustal growth, 2) crustal formation, 3) continental growth and 4) continental formation.
2. *Crustal growth* implies generation of juvenile crust in mid-oceanic ridges and magmatic arcs and intraplate magmatism; *crustal formation* is generation of continental crust containing recycled material at continental margins and collisional magmatism; *continental growth* is accretion of various allochthonous terranes containing both juvenile and recycled crustal material; *continental formation* implies collision/amalgamation of continental crust. All these processes are main contributors to continental construction in both petrological and geodynamic senses.
3. The most prospective questions to be addressed in future studies are (a) dominantly Phanerozoic versus Archean formation of the CAOB continental crust; (b) to which extent the CAOB continental crust was juvenile or recycled; (c) whether magmatic arcs or Gondwana-derived terranes were accreted to the Siberian, Kazakhstan, Tarim and North China cratons; (d) what was the balance between continental formation and tectonic erosion; (e) which social benefits (mineral deposits) and geohazards (seismicity and volcanism) can be inferred from the study of orogenic belts formed in place of former oceans.
4. The multi-disciplinary and comprehensive study of the Central Asian Orogenic belt must be based on the actualistic comparison of its composing tectono-lithostratigraphic units with those of the present-day Western Pacific, i.e. located in Russian and Chinese Far East regions, Japan, Korea and Indonesia.

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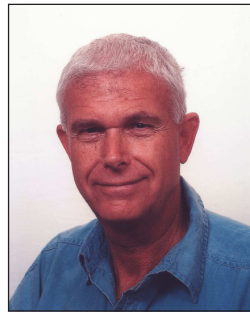
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