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Interplay of magmatism, sedimentation, and collision processes in the Siberian craton and the flanking orogens

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Abstract

The interplay of geodynamic and sedimentation processes in the Central Asian orogen and the Siberian craton is discussed in several aspects: (i) general tectonics of the Central Asian orogen, (ii) correlation of deposition and collision events, (iii) deposition history and sediment sources on the northern and eastern margins of the Siberian craton, compared, and (iv) history of the Central Asian orogen (Altaids) and formation of Early Mesozoic sedimentary basins.

Chemical and isotope compositions and geochronology of Neoproterozoic–Paleozoic sedimentary sequences indicate deposition synchronicity in basins of different types, within both the craton and the orogen. Thus geodynamic models of deposition in separate basins provide reliable evidence of the history of orogens flanking the Siberian craton.

The study has confirmed the existence of the Vendian–Early Paleozoic Charysh–Terekta–Ulagan–Sayan–Olkhon strike-slip suture between the continental-margin complexes of Siberia and Kazakhstan, with the crust of juvenile and mixed types, respectively. Late Paleozoic large-scale strike-slip faulting deformed the previous tectonic framework and caused tectonic mixing of the older structures on different margins. This superposed deformation makes it difficult to decipher the paleogeography, paleotectonics, and paleogeodynamics of the Central Asian orogen.

Keywords: microcontinents; island arcs; tectonics; geodynamics; orogens; sedimentary basins; accretionary-collisional zones; Central Asian orogen; Siberian craton; Kazakhstan–Baikal continent

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Introduction

The papers in this Special Issue of *Russian Geology & Geophysics* report important results presented in 2012 at workshops in Ust'-Kamenogorsk, Novosibirsk, and Irkutsk, which all base upon isotope dating of zircons from igneous and metamorphic rocks, as well as detrital zircons from sediments. The broad use of the geochronological approach has become possible due to joint international efforts and development of isotope dating centers at VSEGEI (St. Petersburg) and Institute of Geochemistry (Irkutsk). The workshops in Ust'-Kamenogorsk (13–20 June) and Novosibirsk (27–28 August) were held as part of integration projects run by the Siberian and Ural branches of the Russian Academy of Sciences and the Ministry of Science and Education of Kazakhstan (*Correlation of Altaids and Uralids: Magmatism, Metamorphism, Stratigraphy, Geochronology, and Metallogeny*).

Many talks at the jubilee tenth workshop *Geodynamic Evolution of the Central Asian Orogen: from Ocean to Continent* of October 17–20, 2012, hosted by the Institute of the Earth's Crust in Irkutsk, concerned new stimulating results in key issues of geology, tectonics, and metallogeny of the Central Asian orogen (CAO), one of the world largest mobile foldbelts. CAO is remarkable for its long-active tectonism spanning over 700 Myr. The orogenic processes began in the Neoproterozoic, about 1000 or 950 Ma (Kuzmichev and Larionov, 2011, 2013), but the activity still continues within some CAO areas. Reconstructing the early history of the orogen and key collisional and accretionary events in its evolution are of top priority for deciphering the history of

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continental growth in Eurasia, which has been widely discussed in Russia and abroad. Other presentations at the Irkutsk workshop of October 2012 addressed the geodynamic evolution of sedimentary sequences in the Siberian craton. The main focus at the three workshops was on several issues, which are considered to more or less detail in the present collection of papers, namely:

– global and regional geodynamics;

– petrology, geochronology, and metallogeny of igneous complexes in cratonic and orogenic areas;

– Olkhon geodynamic test ground: global and regional tectonics and metamorphism;

– stratigraphy and compositions of sedimentary rocks with wide using of the detrital zircons;

– deep structure, paleomagnetism, and seismicity.

Global problems of tectonics and geodynamics in the Central Asian orogen

The interplay of magmatic, sedimentary, and collisional processes in the Siberian craton and its flanking orogens, studied with reference to new data and published evidence, has been a subject of many papers in this volume (Buslov et al., 2013; Dmitrieva et al., 2013; Gladkochub et al., 2013; Letnikova et al., 2013; Prokopiev et al., 2013). Of special importance are isotope constraints on Neoproterozoic–Paleozoic sedimentary sequences, including U–Pb dating of detrital zircons and the Sr, C, and O isotope compositions of carbonates, which provide clues to tectonic environments of deposition and sediment sources (of juvenile and recycled material), as well as to the time of deposition events within the adjacent Siberian craton and Central Asian orogen.

New crust forms in zones of subduction, in spreading and plume-active settings, and is recycled in continental margins and zones of collision. The composition of subducted slabs preserved in fragments within collision zones has some implications for the crust type. Estimating the shares of juvenile and recycled crust requires analyzing the isotope composition and ages of granitic and metamorphic sedimentary rocks and, respectively, igneous and detrital zircons in them. In this respect, combining data on isotope ratios of Hf in zircons and Nd in rocks, which correlate with the distribution of tectonic zones in CAO, is a highly effective tool for understanding the origin of granitoids and the relative percentages of new and recycled crust in the orogen.

The isotope analysis of rocks, including Hf ratios in zircons and their U–Pb ages, are more so important because suprasubduction tracers in many CAO granites record actually the compositions of the magma source rather than the magma itself, and thus are unfit for geodynamic reconstructions. According to Hf isotope compositions of zircons and their trace-element chemistry, the amount of juvenile crust in CAO is less than it was assumed before (Condie et al., 2009; Kovach et al., 2013).

The Central Asian belt is a large accretionary-collisional orogen (Berzin et al., 1994; Kröner et al., 2007; Mossakovsky et al., 1993; Sengör et al., 1993; Windley et al., 2007) that had a long geological history from the Late Riphean through the Mesozoic, with several events of juvenile crust production (Jahn et al., 2000; Kovalenko et al., 1996, 2003, 2004; Rudnev, 2013). The CAO eastern part comprises fold zones produced by Neoproterozoic (Baikalian), Vendian–Early Paleozoic ("Caledonian"), and Middle–Late Paleozoic ("Hercynian") orogenies and Precambrian composite microcontinents sutured by igneous complexes of different ages, compositions, and tectonic settings (Berzin et al., 1994; Didenko et al., 1994; Kovalenko et al., 2004; Mossakovsky et al., 1993; Zonenshain et al., 1990; etc.). There has been some controversy in tectonic division of the area. The models suggested in (Buslov, 2011; Dobretsov and Buslov, 2007, 2011) distinguish four major tectonic units within the orogen (Fig. 1):

1. Vendian–Paleozoic continental-margin complexes in western Siberia that enclose structures of the Vendian–Cambrian Kuznetsk–Altai island arc, as well as complexes of the Ordovician–Early Devonian passive margin and the Devonian–Early Carboniferous active margin in the northern Altai–Sayan folded area and in the basement of the eastern West Siberian plate. The Kuznetsk–Altai island arc extends for more than 1000 km within the western Altai–Sayan folded area but only fragments of oceanic crust exist in its accretionary prisms (Buslov et al., 2013), while Sr–Nd isotope data along with trace-element compositions of plagiogranites indicate predominant juvenile basaltic sources of their parent magma (Rudnev et al., 2013a,b).

2. The Kazakhstan–Baikal composite continent with its Vendian–Cambrian basement formed as the Paleoasian oceanic plate, with enclosed pre-Cambrian Gondwanan microcontinents and terranes, subducted beneath the Kazakhstan–Tuva–Mongolia island arc system bordering Siberia in the southeast (in the present frame of reference). The subduction and the ensuing collision of the microcontinents and terranes with the island arc led to crust growth and formed the basement of the composite continent. The latter occupies a vast territory according to estimation of M.M. Buslov and N.L. Dobretsov covering the Baikal region, the southern Altai–Sayan folded area, Tuva, Mongolia, Kazakhstan, and Tien Shan, and its crust consists of both juvenile and recycled material (Kovach et al., 2013). In the Early–Middle Paleozoic, the continent was separated from Siberia by the Ob'–Zaisan ocean.

3. The Vendian–Early Paleozoic Charysh–Terekta–Ulagan–Sayan–Olkhon strike-slip suture between the Siberian margin complexes and Kazakhstan–Baikal continents. In the Altai–Sayan region, the suture zone comprises fragments of the Late Vendian–Early Ordovician oceanic crust of the Ob'–Zaisan basin, Ordovician blueschists and Cambrian–Ordovician turbidites, Ordovician–Silurian collisional granites and metamorphic rocks of shear zones. In its eastern segment, in the Tuva and Baikal regions, the suture consists of high-grade rocks of the Sangilen and Olkhon shear zones and strongly deformed oceanic crust.

4. Late Paleozoic zones of thrust and strike-slip faulting, which make up an orogenic collage of terranes produced by

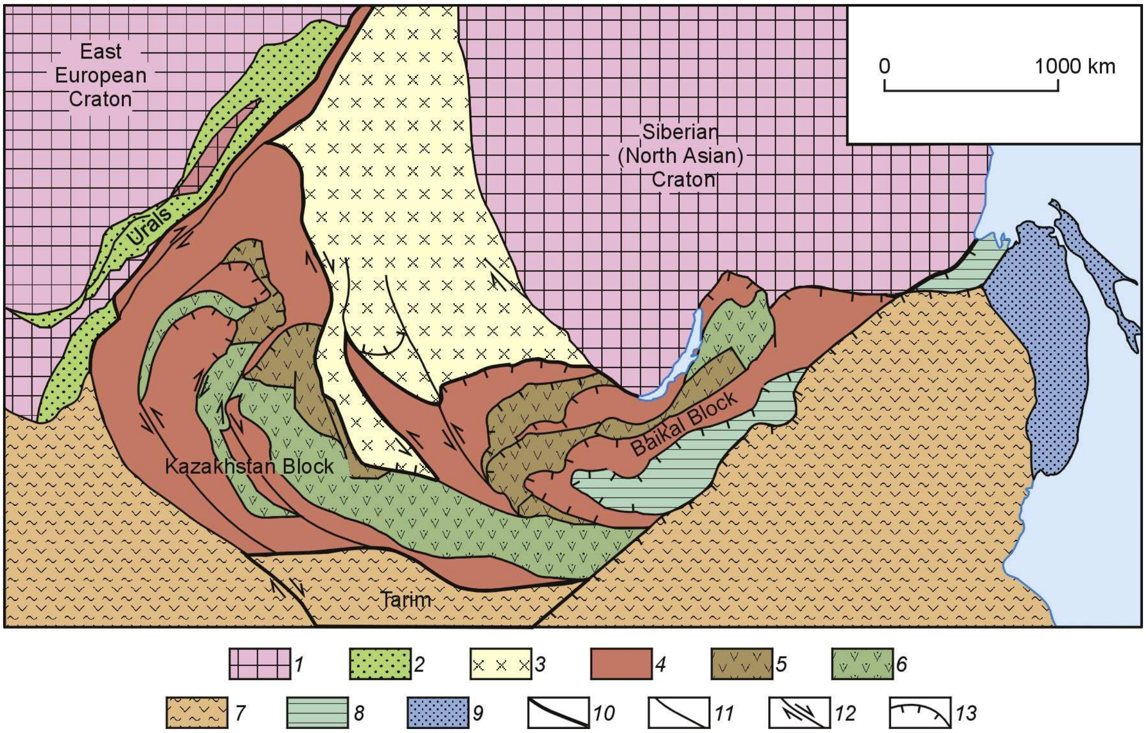

Fig. 1. Simplified tectonic framework of the Central Asian orogen, after (Buslov, 2011). *1*, Precambrian cratons; *2*, Paleozoic rocks of East European craton passive margin; *3*, Vendian–Paleozoic continental-margin rocks of Siberian (North Asian) craton; *4–7*, Kazakhstan–Baikal composite continent: accretionary-collisional zones with enclosed Gondwanan Precambrian microcontinents (*4*), Vendian–Early Cambrian Kazakhstan–Tuva–Mongolia island arc, mostly igneous (*5*) and sedimentary rocks of accretionary prisms and fore-arc basins (*6*), and Early Mesozoic accretionary-collisional belt with enclosed Gondwanan microcontinents and continents (*7*); *8*, Early Mesozoic Mongol-Okhotsk strike-slip suture zone; *9*, Late Mesozoic accretionary-collisional belt; 10, limits of Kazakhstan–Baikal composite continent; *11*, Late Paleozoic faults, undifferentiated; *12*, Late Paleozoic and Early Mesozoic strike-slip faults (arrows indicate the direction of motion); *13*, Late Paleozoic and Early Mesozoic thrust faults.

two collision events. They were (i) the Late Devonian–Early Carboniferous transform accretion and the subsequent Kazakhstan–Baikal–Siberia collision that gave rise to the North Asian continent and (ii) the Late Carboniferous–Permian collision of North Asian continent with East European continent.

Unlike the earlier models, this tectonic division includes the Vendian–Early Paleozoic Charysh–Terekta–Ulagan–Sayan–Olkhon suture between the continental margins of Siberia and Kazakhstan with juvenile and mixed crust types, respectively; the Olkhon segment of the zone has been discussed in detail in (Donskaya et al., 2013; Mekhonoshin et al., 2013). The Precambrian–Early Paleozoic tectonic framework became deformed by large-scale Late Paleozoic strike-slip faulting, which caused tectonic mixing of the older structures in different margins making it difficult to decipher the paleogeography, paleotectonics, and paleogeodynamics of the Central Asian orogen.

The Mesozoic and Cenozoic activity produced intracontinental orogens within the CAO structure. The activity was associated with propagation of collision-induced deformation inward the continent (Buslov, 2012; Buslov et al., 2007, 2008; De Grave et al., 2004, 2006, 2007; Dobretsov et al., 1996). Specifically, distant effects from the Eocene India–Eurasia collision was responsible for the neotectonic mountains growth in Central Asia and formation of related sedimentary basins, strike-slip and thrust zones, and rifts.

The structures produced by Cenozoic deformation and the older tectonic elements are recognizable in the satellite map of free air gravity anomalies (Fig. 2), which is an objective and unified basis of the DNSC-08 world database (Andersen et al., 2010). The tectonic implications of the gravity field can be used to identify the types of deformation patterns (Dobretsov et al., 2013) resulting from events of different ages, which makes this analysis an important part of studies. See, for instance, a zone of Cenozoic deformation in Fig. 2 extending from Lake Baikal (B in Fig. 1) and the Baikal rift system as far as the basins of Junggar (J) and Tarim (T) and the basins on the flanks and in the interior of the Tien Shan (T). This zone, expressed in the surface topography as a system of basins and ranges, results from the Miocene–Pleistocene propagation of deformation (younger than 23 Ma) induced by the India–Eurasia collision: the successive uplift of Tibet and subsidence of Tarim; the uplift of the Tien Shan and the subsidence of Junggar; the uplift of the Altai and the East Sayan ranges and the mountains around Lake Baikal and the formation of pull-apart basins between them (Buslov, 2012; Buslov et al., 2008; De Grave et al., 2007; Dobretsov et al., 1995, 1996; Glorie et al., 2012). The uplifts and the origin of basins in this system are typically rhombic structures, both along the borders and in the interior. The gravity lows and

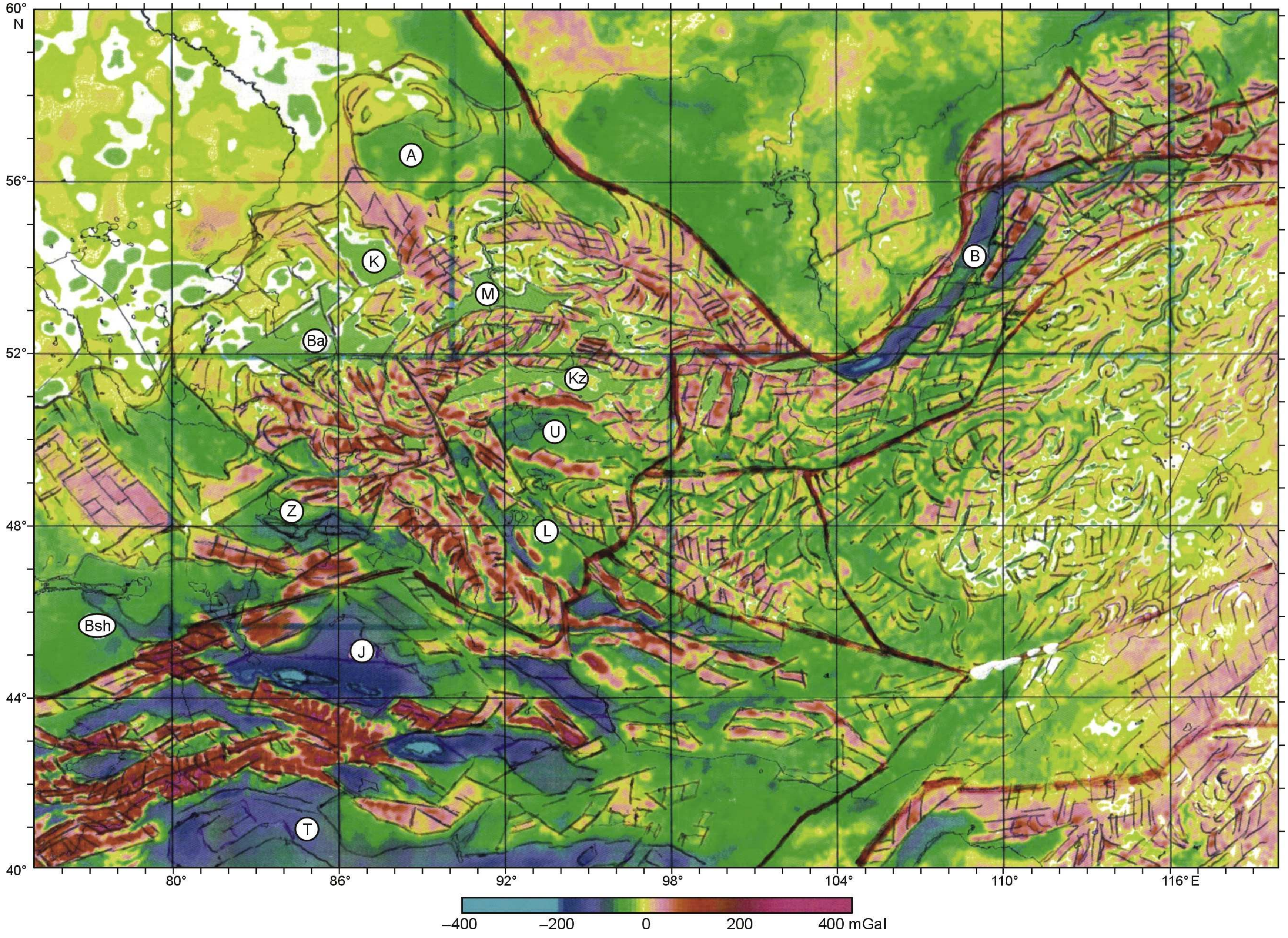

Fig. 2. Map of free-air gravity anomalies, a fragment. Southern Siberia, Tien Shan, and Mongolia (Andersen et al., 2010). Structural elements are distinguished by Dobretsov. See text for explanation. Letters stand for names of basins: T = Tarim, J = Junggar, Bsh = Balkhash, Z = Zaisan, L = Lake zone, U = Uvs Nuur, Kz = Kyzyl, Ba = Barnaul, K = Kuznetsk, M = Minusa, A = Achinsk, B = Baikal.

highs have the largest contrasts from –300 to +300 mGal in the Tien Shan and its surroundings, and from –250 to +200 mGal around Lake Baikal (Fig. 2). The orogen outside the zone of Cenozoic deformation shows oval-shaped and tortuous patterns produced by thrusting and later strike-slip faulting, which are especially prominent in eastern and northwestern Mongolia, as well as in Tuva and in the West and East Sayans (Buslov et al., 2013; Rudnev et al., 2013b). Its gravity field consists of moderate lows (–50 to –60 mGal) in the Achinsk (A), Kuznetsk (K), Minusa (M), Barnaul (BA), and Kyzyl (Kz) basins of the Altai–Sayan area and larger negative anomalies of –100 to –120 mGal in the Uvs Nuur (U), Zaisan (Z), and Balkhash (Bkh) basins, which are located, respectively, northwest and southwest of the Cenozoic deformation zone (Fig. 2).

The gravity pattern of the Siberian craton and the sediments on the West Siberian plain (Fig. 2) is diffuse and roughly corresponds to the features of basement uplift and subsidence.

The areas of Cenozoic deformation have been studied in terms of deposition history correlated with the events of collisional mountain growth (Buslov, 2012; Buslov et al., 2008; De Grave et al., 2007; Glorie et al., 2012; Novikov, 2013), and the results are expected to become a subject of future special issue of *Russian Geology and Geophysics*.

Lately geophysical data collected on long transects have been used extensively in Russia and abroad to investigate the lithospheric structure, metallogeny and exploration criteria for magmatism-related mineral deposits, as well as seismic risks. Specifically, Didenko et al. (2013) apply this approach to study the junction between the eastern Central Asian orogen and the Siberian craton along the profile 3-DV (52–60º N and 122–129º E) from Skovorodino to Tommot, where several deep faults separate the orogen from the Aldan–Stanovoi shield. Seismic, density, and resistivity data acquired along the transect have allowed more rigorous constraints on tectonic boundaries within the crust. The crust appears to consist of several large blocks bounded by translithospheric faults and has different layered sections in the shield and orogenic areas.

Paleomagnetic reconstructions for the Mesozoic period (Didenko et al., 2010, 2013) reveal the Stanovoi fold and thrust belt, no less than 1000 km long, in the zone of Aldan–Stanovoi junction, with its history controlled by collisional events of the Selenga–Stanovoi and Mongol-Okhotsk microcontinent and orogen blocks with the Siberian craton lying in the north. The Mongol-Okhotsk orogen was thrust in the Mesozoic under the shield along the Dzheltulak and North Tukuringra faults in the collisional suture zone. As a result of pressure from the downgoing plate, tectonic sheets from the middle and lower crust became detached and drawn to the upper crust level in the Stanovoi fault zone. Thereby the sheets of high-grade metamorphic rocks became thrust over Jurassic terrigenous sediments filling the South Aldan basin and over the metamorphics of the Aldan block. Thus, the tectonic units along the transect differ in the structure of crust and lithospheric mantle, and the faults are divided, correspondingly, into those originated at crustal and subcrustal depths.

The deformation (collisional) processes in the crust of the present eastern flank of the Mongol-Okhotsk orogen lasted as long as the earliest Eocene being driven by the rotation component of motion of Siberia (Didenko et al., 2010), unlike the western part of the CAO–Siberia junction where the effect of the India–Eurasia collision remains still active (Fig. 2).

Deposition history and events of accretion and collision

In this section we correlate the deposition events on the Siberian craton with events of accretion and collision on the craton periphery over a long time span from the earliest Neoproterozoic (1000 Ma) to the latest Paleozoic (250 Ma).

The correlation between the deposition history on the craton and the geodynamic events in the flanking orogens is made using ages of detrital zircons (Fig. 3) from different stratigraphic levels of Vendian (Ediacaran) craton sediments (Gladkochub et al., 2013; Letnikova et al., 2013) compared with those of zircons from Neoproterozoic and Early Paleozoic orogens lying south and southwest of the craton. The orogens may have been sources of clastics input into the Vendian–Neoproterozoic and Paleozoic sequences of the craton (Fig. 3). The Neoproterozoic sediment transport was from the periphery of the Gargan block in the East Sayan mountains, the Tuva-Mongolian massif in northwestern Mongolia, and the Yenisei Ridge (Kuzmichev and Larionov, 2011, 2013; Rojas-Agramonte et al., 2011; Romanova et al., 2012); in the Paleozoic, clastic material likewise came from the East Sayan mountains and northwestern Mongolia, as well as from the Olkhon zone (Dobretsov, 2011; Nozhkin et al., 2011; Rudnev, 2013; Rudnev et al., 2013a; Volkova et al., 2010).

The Archean and Paleoproterozoic rocks (ages from 1800 to 3200 Ma in Fig. 3) of the Siberian craton basement, which remain preserved, in different amounts, in all basement inliers (the Aldan and Anabar shields and the Sharyzhalgai inlier in the southwest) were the source of sedimentary material in Neoproterozoic–Early Paleozoic sequences in the craton interior and on its periphery. Archean dates, ever more obtained recently, record relic crust growth events followed by crust recycling in the Paleoproterozoic (Turkina et al., 2011, 2013). The Paleoproterozoic evolution cycle ended with ultramafic-mafic intrusions (Chinei, Medvedev, and other complexes) at about 1800–1700 Ma.

In the latest Paleoproterozoic, Siberia collided with North America, to form the Columbia supercontinent, according to the model of Didenko et al. (2013) based on paleomagnetic data. The continental blocks accreted along the southern margins of Siberia (Angara–Anabar and Aldan–Stanovoi provinces) and the northern margin of the Canadian shield (both in the present frame of reference). That collision event may have been responsible for the formation of late Paleoproterozoic (Karelian and Baltic) igneous and metamorphic rocks which bear 2100–1850 Ma zircons widespread in sediments of the southern Siberian craton (Fig. 3).

Mesoproterozoic (Grenvillian or Laxfordian, 1450–1100 Ma) sediment sources that represent orogenic events

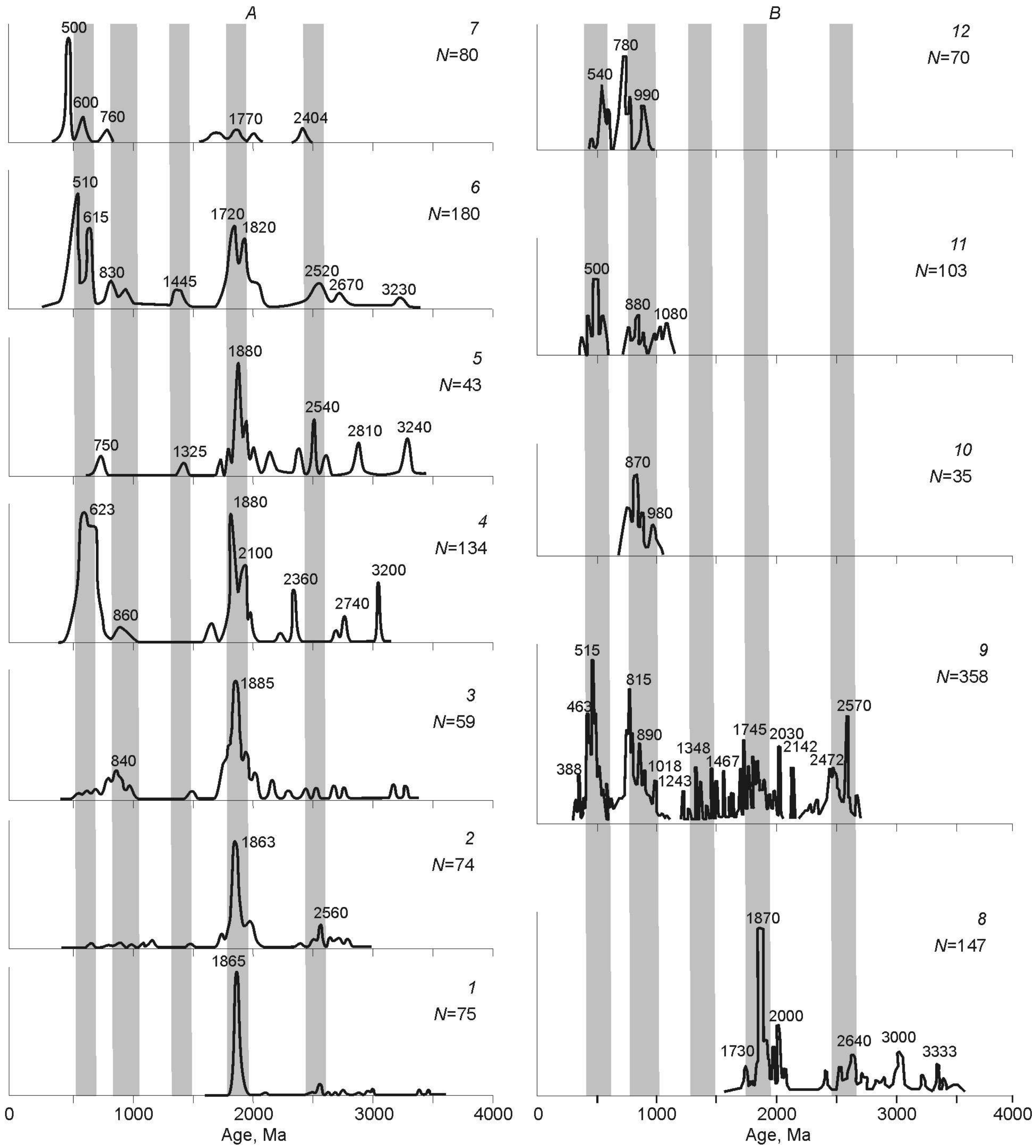

Fig. 3. Histograms and cumulative U–Pb age probability plots for detrital zircons from sedimentary rocks in southern Siberian craton (*A*, *1–7*) and igneous and metamorphic rocks on the craton periphery (*B*, *8–12*). Vendian deposits: *1*, Goloustnaya Fm; *2*, Uluntui Fm; *3*, Kachergat Fm; *4*, Ushakovka Fm (Gladkochub et al., 2013; Letnikova et al., 2013); *5*, Cambrian deposits, Oselok Fm, area of Solenoe Village (new data obtained at Honkong University, Honkong); *6*, *7*, Early Ordovician (*6*) and Middle Devonian (*7*) deposits in the Biriusa catchment, area of Shelekhovo and Pokrovka Villages (new data obtained at Ghent University, Belgium); *8*, southern Siberia (craton basement) (Rojas-Agramonte et al., 2011); *9*, Mongolia (Rojas-Agramonte et al., 2011); *10*, East Sayan (Gargan block of Tuva–Mongolia microcontinent) (Kuzmichev and Larionov, 2012, 2013); *11*, Tuva, northwestern Mongolia (Tuva–Mongolia microcontinent) (Kuzmichev and Larionov, 2012, 2013); *12*, Yenisei Ridge (Nozhkin et al., 2013; Vernikovsky et al., 2012). *N* is number of dates.

associated with the assembly of Gondwana are of sporadic occurrence. The fold-thrust belts and sediments of the Yenisei Ridge located in the southwestern Siberian craton are commonly attributed to the Grenevillian orogeny. This interpretation stems from Paleoproterozoic Nd model ages (2.1–2.3 Ga) obtained for sediments of the Sukhoi Pit and other formations and from few (mainly old) dates for the Rybnaya–Panimba belt (1300–1400 Ma) which underwent metamorphism at 1043–1051 Ma, in the beginning of the following cycle (Popov et al., 2010). Finally, the Grenvillian belt has been suggested to lie under the Verkhoyansk Group of sediments (Parfenov et al., 2003; Rozen et al., 2006).

The Neoproterozoic evolution of the fold-thrust belts of the Yenisei Ridge included two key events, at 1050–800 and 780–620 Ma (Nozhkin et al., 2011). The earlier event produced granite-gneiss domes related to the late Grenvillian orogeny 1100–950 Ma, such as the best studied Teya dome which underwent the main orogenic phase at 1100–950 Ma and two later events about 880–850 Ma and 700–670 Ma (Nozhkin et al., 2011). Magmatic activity during the 880–850 Ma event consisted in emplacement of the Teya granite and the Middle Tyrada granodiorite dated at 857 ± 9.5 Ma (Nozhkin et al., 2011; Vernikovsky et al., 2011). Finally, the rocks were subjected to kyanite–sillimanite metamorphism at 850–830 Ma (Likhanov et al., 2009). The later interval (780–620 Ma) was the time of bimodal volcanism (780–750 Ma) and sublakaline plutonism (Ayakhta complex, 760–750 Ma). The postcollisional stage was marked by formation of basins filled with molasse and trachybasalt–trachyte volcanics of 730–700 Ma (Nozhkin et al., 2011) and intrusion of the Glushikha granitoids of 750–720 Ma (Vernikovsky et al., 2011). Eruptions of alkali-picritic lavas (670–650 Ma) and intrusion of the Middle Vorogovo alkali–granite–syenite complex (630–620 Ma), including the Tatar subalkaline granites (630 Ma), constituted the final event of magmatism.

Events corresponding to the time of Late Grenvillian orogeny left imprint in the East Sayan mountains (Kuzmichev and Larionov, 2013) and in the surroundings of the Kara pluton (Vernikovsky et al., 2013). The time span of magmatic activity in the Dunzhugur arc of the East Sayan has been constrained by the ages of 1034 to 900 Ma. In the beginning of its history 1034–1000 Ma ago, the arc experienced boninite magmatism recorded in the 1020–1010 Ma Dunzhugur ophiolite (Khain et al., 2002). After the collision of the Tuva–Mongolia microcontinent (Gargan block) with the Dunzhugur arc and related emplacement of 785–790 Ma Sumsunuur granitoids, there appeared the Sarkhoi active margin with felsic volcanism dated at 800–770 Ma (Kuzmichev and Larionov, 2011). The Shishkhid oceanic island arc, the third element in the system, underwent two magmatic events at 830–800 Ma and 775 ± 8 Ma, as constrained by zircon ages (Kuzmichev and Larionov, 2013), and a collision event, presumably about 650 Ma.

The U–Pb ages (LA-ICP-MS method) of detrital zircons from Late Precambrian terrigenous sediments of the Baikal Group and the Ushakovka Formation in the western Baikal region (southern Siberian craton) reported by Gladkochub et al. (2013) show the abundance of Neoproterozoic zircon in sandstones from the upper horizons of the Baikal Group and the Ushakovka Formation might be due to the shrinkage of the ocean basin as a result of the convergence of the craton with the microcontinents and island arcs within the Paleoasian ocean. The U–Pb ages of detrital zircons constrain the Late Precambrian deposition in the western Baikal region (Baikal Group and the Ushakovka Formation) within the Late Vendian (Ediacaran). The absence of Mesoproterozoic detrital zircons from the analyzed samples of cratonic Ediacaran sediments supports the hypothesis of a very long (about 1 Byr) global lull in magmatism within the southern craton part (Gladkochub et al., 2013).

Unlike the age spectra of the rocks below (Goloustnaya Fm) and above (Kachergat Fm), Mesoproterozoic ages appear in zircons from the Uluntui formation of the Baikal Group (Gladkochub et al., 2013), which may have come from the Tuva–Mongolia and Dzavhan microcontinents. The Late Vendian Ushakovka sandstones bear abundant Neoproterozoic zircons, possibly because the oceanic space had reduced by that time as a result of convergence between Siberia and the microcontinents and island arcs in the Paleoasian basin. The ocean closure within that segment gave rise to an Early Paleozoic collision zone (Donskaya et al., 2000, 2013; Gladkochub et al., 2008), a part of the large Charysh–Terekta–Ulagan–Sayan–Olkhon shear zone (Fig. 1) (Buslov, 2011; Dobretsov and Buslov, 2007, 2011).

A first-cycle origin and similarity to island arc clastics in major- and trace-element compositions were inferred from chemical and isotope data for Late Precambrian sediments in the Anamakit–Muya zone of the Baikal–Muya belt southeast of the craton (Ust‘-Kelyana and Tuluya sequences), including preliminary U–Pb LA-ICP-MS ages of detrital zircons and Sm–Nd data for the Tuluya rocks (Dmitrieva et al., 2013). Very low Th, Rb, Zr, Hf, LREE and relatively high Co, Ni, Sc, V, Cr, Fe_2O_3 contents in the Ust'-Kelyana sandstones make them similar to oceanic arc sediments, while notable Zr, LREE, Th, Rb, and Nb enrichment of the Tuluya rocks is evidence of deposition within a continental island arc or an active continental margin. According to isotope geochronology evidence, the detrital material produced by erosion of Neoproterozoic 625–700 Ma island arc igneous complexes, similar to those in the Karalon–Mamakan zone (Yakor' and Karalon formations), is mixed in the Tuluya sequence with older (812–824 Ma) rocks like those of the Kelyana and/or Dzhaltuk Groups. The lower age bound of deposition corresponds to 600 Ma, judging by the youngest ages of detrital zircons (Dmitrieva et al., 2013).

The synthesized dates of detrital zircons from the Vendian, Early Cambrian, Early Ordovician, and Early Devonian sediments from the Biryusa basin in the southern Siberian craton (unpublished data by J. De Grave) are compared in Fig. 3 with the ages of zircons from igneous and metamorphic rocks of the southern craton basement, the Kazakhstan–Baikal composite continent, the Tuva–Mongolia island arc and the microcontinent of the same name, East Sayan (Gargan block of the Tuva–Mongolia microcontinent), Tuva and northwestern Mongolia (Tuva–Mongolia microcontinent), and collisional complexes of the Yenisei Ridge in the southeastern craton part. Gray bars correspond to magmatic events in the history of the Siberian and Kazakhstan–Baikal continents. The two continents share the events of 2480–2780, 1730–1950, and 700–465 Ma; the 1260–1450 Ma (Grenville) and 1100–780 Ma (Baikalian and Late Grenvillian) events show up in the Kazakhstan–Baikal continent only, while the record of the 824–625 Ma (Delian) cycle appears in Kazakhstan–Baikal as well as in the Baikal–Muya belt (Dmitrieva et al., 2013) and the Yenisei Ridge (Nozhkin et al., 2011).

Grenvillian detrital zircons are rare in the sedimentary cover of the Siberian craton, except the Uluntui Formation. Minor amounts of these zircons, with their ages corresponding to the Baikalian, Delian, and Grenvillian orogenies, exist in Vendian, Early Ordovician, and Early Devonian sediments. They may have come from the Baikal–Muya belt (824–625 Ma igneous complexes) and Yenisei Ridge sources (Fig. 3).

The igneous and metamorphic zircons apparently were transported to the Vendian–Early Devonian basins on the craton from some constant source that lasted for ~ 200 Ma. That was possibly the Sayan–Baikal–Muya collisional belt flanking the craton in the south. The belt originated between 850 and 650 Ma in the place of the active continental margin, which was extended by accretion of the Muya and Barguzin microcontinents and a later island arc accreted to Siberia between 650 and 490 Ma (Zhmodik et al., 2006). The models suggested in (Buslov, 2011; Dobretsov and Buslov, 2007, 2011) predict the continental growth and the formation of the composite continent basement in the Siberian southeastern margin as a result of Vendian–Cambrian subduction and subsequent collision of Gondwanan microcontinents and terranes with the Kazakhstan–Tuva–Mongolia island arc; the later Early Ordovician continental collision gave rise to the Olkhon strike-slip zone.

Clues to many controversial issues may be obtained from chemical and isotope compositions of sediments studied in addition to dating detrital zircons (Letnikova et al., 2013). Data obtained by today's advanced methods of isotope geochemistry have implications for (i) the compositions and ages of the source areas of clastics, (ii) deposition environments, (iii) key events in the basin history, and (iv) correlation between sediments deposited within the craton and in the surrounding orogens, using isotope age constraints on deposition cycles. The contents of major, trace, and rare-earth elements in sediments of the Late Precambrian Baikal and Oselok Groups of the Siberian craton, as well as the Sm–Nd and Rb–Sr systematics in terrigenous and carbonate samples and U–Pb (LA-ICP-MS) ages of detrital zircons from the Oselok rocks, allow a number of important inferences (Letnikova et al., 2013). The lithology and types of sediments depend on their deposition environment (facies). On the other hand, the analyzed rocks share the same geochemistry and isotope features, namely the Eu negative anomaly, Th/U and La/Th ratios, and Zr and Hf abundances, which may result from mechanic sorting and mixing of sediments and their transport in shallow-marine environments. The compositional similarity of the sediment sources leaves no doubt of deposition synchronicity within the Siberian shelf under a passive tectonic regime. Note that only mafic tuffite material found in the upper sections of the Baikal and Oselok Groups indicates the onset of subduction in the craton surroundings.

New structural and chemical data for granitoids of the Tutai and South Olkhon complexes in the Olkhon terrane of CAO (Donskaya et al., 2013) evidence of their synorogenic and synmetamorphic origin. The reported 488.6 ± 8.0 Ma U–Pb zircon ages of the Tutai granites almost coincide with those obtained earlier for the South Olkhon quartz syenites (495 ± 6 Ma), which both have the same position in the regional framework. The granitoids underwent the final stages of deformation and metamorphism at 464 ± 11 Ma. The Tutai pluton consists of moderately potassic granite and the South Olkhon one is composed of quartz syenite and granite. The trace-element compositions of the granitoids (low Y and Yb, fractionated REE spectra, and high Sr/Y ratios) indicate their formation under conditions of garnet crystallization in deep crustal restite. The higher Y and Yb contents of the South Olkhon quartz syenites as compared with those of the granites suggest the lack of equilibrium between the quartz syenite magmas and garnet paragenesis during their formation or evolution. The Tutai and South Olkhon granites were derived from quartz–feldspar crustal rocks, whereas South Olkhon quartz syenites might have originated from a mixed (crustal–mantle) source. It is presumed that the granitoids formed within accretion-thickened crust. Early accretion, which has been first identified in the region, affected not only the Pribrezhnaya zone (the zone of the Tutai and South Olkhon plutons) but also the entire Anga–Satyurty megazone of the Olkhon terrane. The accretion event ended with the convergence and oblique collision of the Olkhon terrane and Siberian continent, when strike-slip faulting became spread over the whole region (Donskaya et al., 2013).

The Early Paleozoic rocks of the Olkhon region in the folded periphery of the craton make an exceptional geological test ground where to study the mantle–crust interaction deep in the crust (Mekhonoshin et al., 2013). Namely, mantle-residue ultramafic bodies and boudines along faults (blastomylonite sutures) and syndeformation amphibolite-facies granites may represent oceanic crust in the collisional system of Early Paleozoids of Western Pribaikalia which became drawn to the surface as a result of tectonic movements. This inference stems from the chemistry and mineralogy of the rocks, as well as their U–Pb and Ar–Ar ages, and the respective reconstructed thermal history (Mekhonoshin et al., 2013).

Deposition history and sediment sources in the northern and eastern surroundings of the Siberian craton: compared

Detrital zircons from sediments on the northern and eastern periphery of the Siberian craton have been studied in the Verkhoyansk Group and its stratigraphic equivalents in the New Siberian Islands and around the Laptev Sea. The Verkhoyansk Group is one of the world thickest terrigenous sequences deposited along the eastern craton border (northern circum-Pacific margin) after the Devonian rifting and the formation of the Vilyui rift (Dobretsov et al., 2013). The deposition lasted from the Early Carboniferous through the Early Jurassic and produced a 15 km thick layer of sediments (Miller et al., 2013; Prokopiev et al., 2008, 2013). The clastics were transported mainly from the Baikalian and Altai–Sayan mountains by the paleo-Lena river system; some amount of

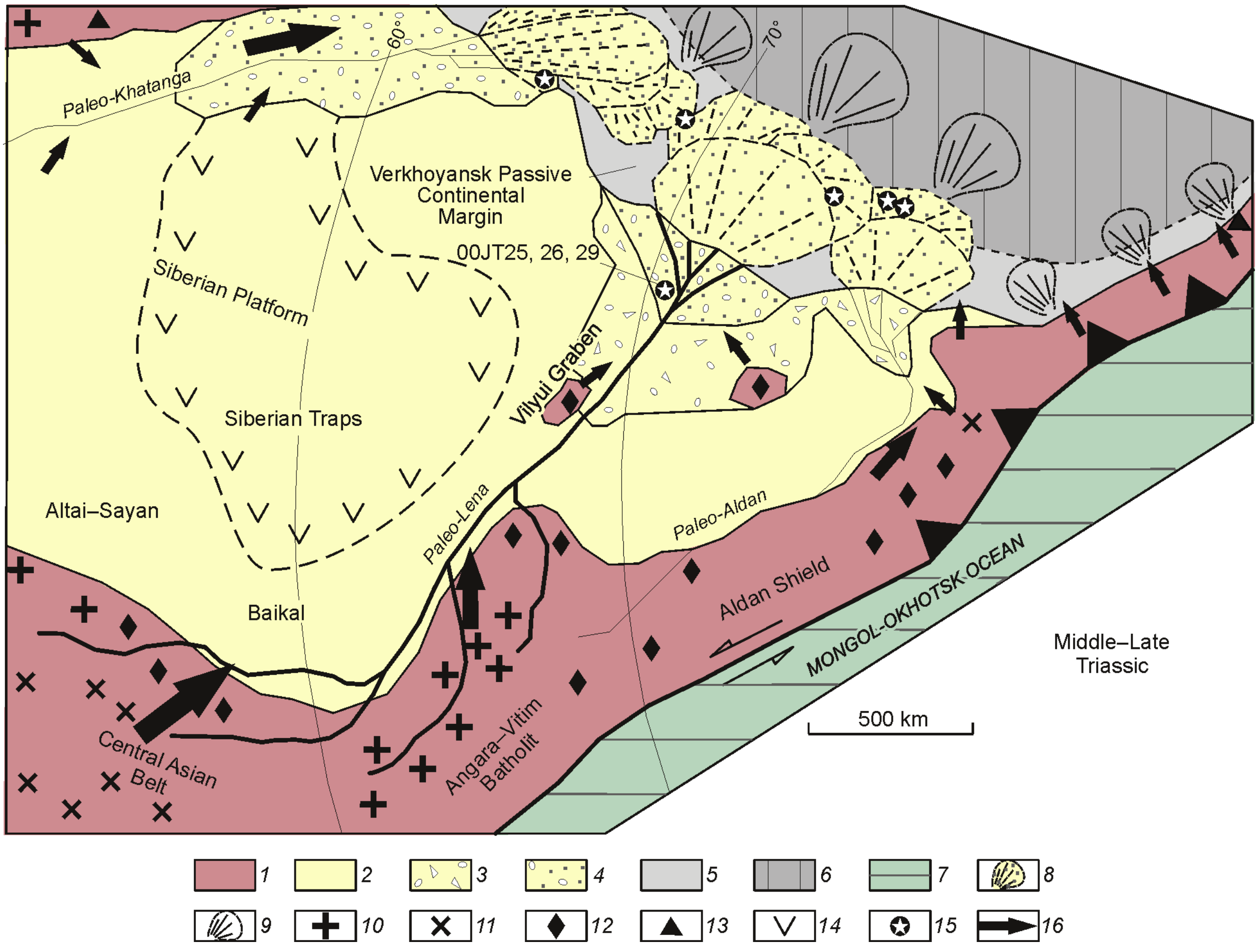

Fig. 4. Paleogeographic model of Verkhoyansk margin of Siberia (Miller et al., 2013). *1*, high mountains; *2*, low mountains; *3*, coastal plain; *4*, gulfs; 5, inner shelf; *6*, outer shelf; *7*, oceanic crust; *8*, deltas; *9*, submerged fans; *10*, Late Paleozoic granites; *11*, Early Paleozoic granites; *12*, Paleoproterozoic granites and volcanics; *13*, Permian–Triassic granites and volcanics; *14*, basalts (Siberian traps); *15*, sampling sites; *16*, current directions.

sedimentary material was carried by the paleo-Khatanga system from the Ural and Taimyr mountains (Fig. 4).

Data on detrital zircons (Miller et al., 2013) from Triassic sediments in the northern and northeastern craton surroundings, which fill the Yenisei–Khatanga and Verkhoyansk basins (paleo-Khatanga, paleo-Lena, New Siberian Islands), are compared in Fig. 5 with the zircon ages for the Chukchi Peninsula (Chukotka), Wrangel Island, and remote Arctic areas of Trans-Laurentia and Crocker Land (Sverdrup basin). All plots (Fig. 5) show the same age ranges 400–700 Ma and 700–1000 Ma, with multiple peaks within them, like in Fig. 3. Additionally, a Late Paleozoic–Early Mesozoic interval (200–400 Ma) can be distinguished in the paleo-Khatanga, paleo-Lena, New Siberian Islands, Chukotka, and Wrangel Island data, with peaks at 350, 300, and 250–260 Ma in most of the diagrams. Many curves peak at 410, 460–470, 500–520, and 560 Ma, with less prominent maximums of 620 and 680 Ma, within the late Neoproterozoic–Early Paleozoic range of 400–700 Ma. The peaks are spaced at every 55–60 Ma.

Neoproterozoic (700–1000 Ma) peaks are poorly pronounced and appear about 720 and 780 Ma (Crocker Land, Chukchi Peninsula), and 870, 920, 980 Ma. The ages older than 1 Ga in the paleo-Lena, Trans-Laurentia, and Alaska sediments cluster in three ranges of 1100–1400, 1650–2100, and 2500–2700 Ma. Unlike the diagrams of Fig. 3, there are almost no reliable Archean dates (older than 2600–2700 Ma).

The zircons that belong to the paleo-Lena system are either Early Paleozoic or Late Paleozoic–Triassic (from the Verkhoyansk area), but zircons with ages between 550–1800 Ma are few to absent. The zircons of the paleo-Khatanga system, sourced from the Ural area (Figs. 4, 5), are mostly of Late Paleozoic–Early Mesozoic ages. However, zircons of these ages are absent among the samples from Trans-Laurentia and Crocker Land (Sverdrup basin), which rather show many Grenvillian dates (1.1 to 1.5 Ga) and peak (in the Crocker Land) at 530 and 580 Ma (Miller et al., 2013).

The zircon ages of samples from the New Siberian Islands are similar to those for the Chukchi Peninsula and Wrangel Island (Fig. 5) but differ from the Alaska and paleo-Lena data. Unlike the interpretation of Miller et al. (2006, 2013), we suggest that Chukotka, Wrangel Island, and the New Siberian Islands were assembled in a single block in Permian and Triassic time, possibly joint with the Mendeleev Ridge rather than with Siberia (Koulakov et al., 2013).

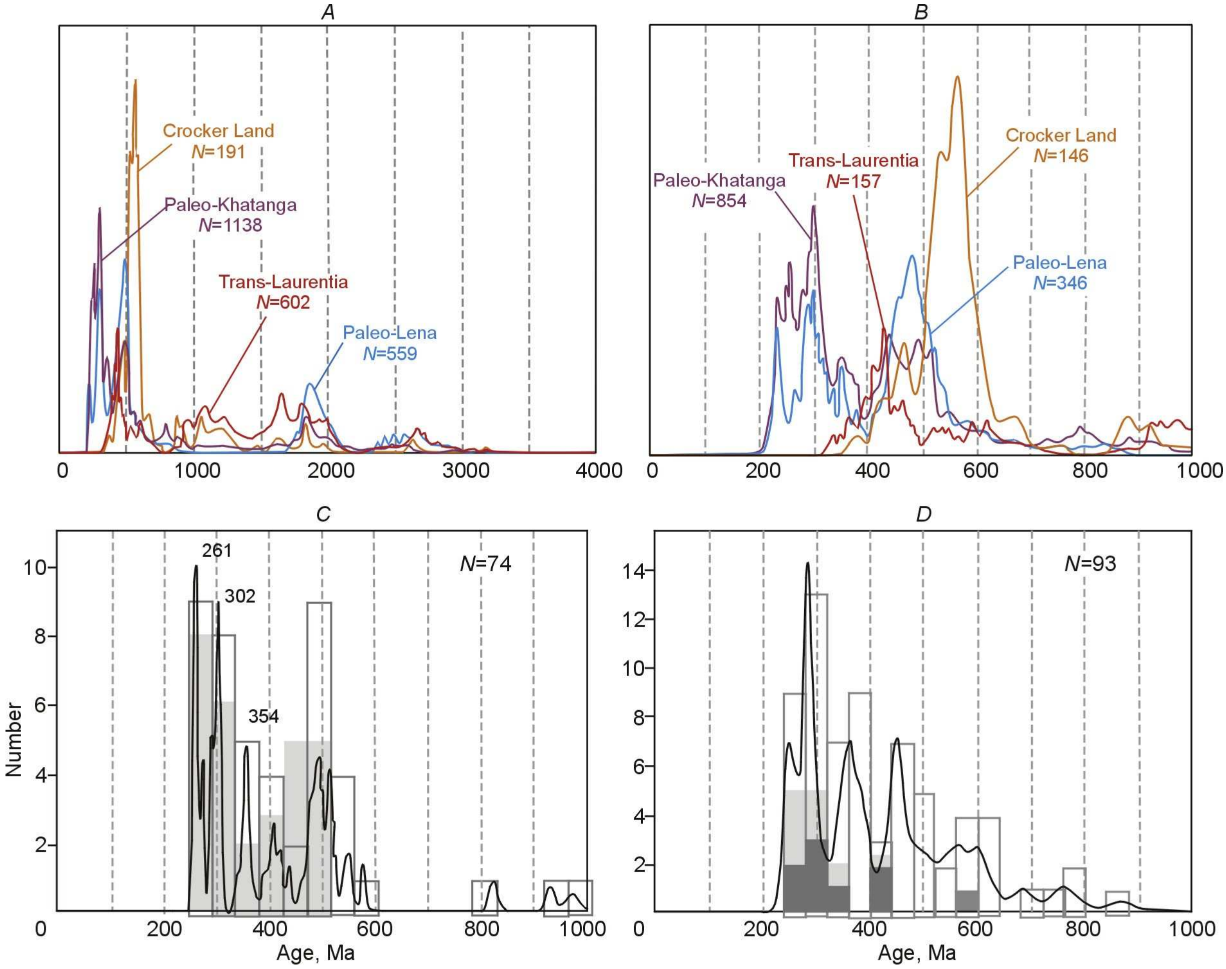

Fig. 5. Ages of detrital zircons from Triassic sediments in northern and northeastern flanks of Siberian craton, compared (Miller et al., 2013; Prokopiev et al., 2013). *A*, Yenisei–Khatanga basin; *B*, Verkhoyansk basin; *C*, New Siberian Islands; *D*, Chukchi Peninsula and Wrangel Island.

The U–Pb ages of detrital zircons from Lower Carboniferous sandstones in the frontal part of the northern Verkhoyansk fold and thrust belt show strongly different spectra in the Lower Visean (Krestyakh Formation) and Upper Visean–Serpukhovian (Tiksi Formation) stages (Prokopiev et al., 2013). Precambrian ages were obtained for 95% of detrital zircons from the Early Visean sandstones but only for 55% in Late Visean–Serpukhovian sediments. The Precambrian zircons have similar ages and distribution patterns indicating that the sediments deposited in Late Visean–Serpukhovian time comprised quite a large amount of the eroded Krestyakh clastics or material coming from the same sources that predominated in Early Visean time (craton basement, eroded Meso- and Neoproterozoic sediments, and igneous rocks of the Central Taimyr). The detrital zircons from the Tiksi sediments are Paleozoic (45%) or Early Paleozoic, with prevailing Cambrian–Ordovician ages (24%). The sediments may be fed from provinces with abundant igneous rocks of these ages, and from orogens (Taimyr–Severnaya Zemlya or CAO) extending along the northern, western, or southwestern periphery of the Siberian craton. The presence of Middle–Late Devonian zircons may result from erosion of granitoids in the Yenisei Ridge and the Altai–Sayan area. Early Carboniferous detrital zircons may arrive from igneous rocks of the Taimyr–Severnaya Zemlya orogen, thus confirming that the Kara terrane had collided by that time with the northern margin of Siberia. The Early Visean deposition occurred in small fans, possibly, at the foot of a steep escarpment which formed during the final phase of Middle Paleozoic rifting. The clastic transport was by relatively small streams which eroded the sediments nearby. In Late Visean–Serpukhovian time, clastic material became especially abundant and detrital zircons came from new sources: orogens flanking the craton in the north and southeast. At that time, there already existed a large river system which could carry the clastic material to long distances and deposit it in submerged fans of the northern Verkhoyansk passive margin (Fig. 4).

History of the Central Asian orogen (Altaids) and formation of Mesozoic sedimentary basins

Uralids in the Ural–Mongolian belt differ in their early and final phases (Puchkov, 2003, 2010) and do not belong to the framework of Altaids involving most of structures formed in the place of the Paleoasian ocean (Sengör et al., 1993). Timanids, the precursors to Uralids, differ from Baikalids in the Siberian craton flanks being rather similar to the European Kadomids (Puchkov, 2003). The Paleo-Ural ocean opening in the Ordovician broke the original relationship of Timanids with both Kadomids and Baikalids. The Ordovician–Devonian history of the Ural is similar to that of the Southern Tien Shan, Junggar–Zaisan, and South Gobi arms of the Late Paleozoic–Early Mesozoic Paleoasian ocean (Dobretsov, 2003). Island arcs in the Uralids originated in the latest Ordovician and lasted as long as the middle Carboniferous, or locally till the latest Permian. The Paleozoic sections of the Southern Urals, Southern Tien Shan, and Junggar–Zaisan areas demonstrate synchronicity in key events in the Devonian, major tectonic events in the middle Carboniferous, and continuing magmatic activity in the Permian–Early Triassic in areas that bordered the Paleo-Tethys (Southern Mongolia and Southern Tien Shan) or remained connected to it (Polar Urals).

As mentioned above, intense tectonic activity in the middle Carboniferous led to the closure of the Ob'–Zaisan segment of the Paleoasian ocean and the related collision of the Kazakhstan–Baikal composite continent with Siberia (the craton and continental-margin complexes on its periphery). The available age data for the Ural–Mongolian belt (Dobretsov, 2003; Puchkov, 2010) and the Altai–Sayan area (Buslov, 2013) confirm their marked difference at the early (Neoproterozoic) and late (Late Paleozoic–Early Mesozoic) stages of evolution.

In the Mesozoic, the convergence of Gondwanan terranes with the active margin of Eurasia gave rise to large accretionary-subduction belts produced by the Kimmeridgian and Mongol-Okhotsk orogenies, which reactivated the Paleozoic structures and allowed propagation of deformation inward Eurasia (Buslov, 2012; Buslov et al., 2008; De Grave et al., 2007).

The India–Eurasia convergence in the Cenozoic was similar to the Paleozoic and Mesozoic growth and deformation of the Eurasian lithosphere by interaction with Gondwanan terranes. The collisional stress propagated thousands of kilometers northward as far as the southern and eastern Siberia and induced the formation of a large mountain system (Buslov, 2012; Buslov et al., 2008; Dobretsov et al., 1995, 1996; De Grave et al., 2007; Glorie et al., 2012; Zonenshain et al., 1990).

Late Paleozoic thrusts associated with coeval large strike-slip faults are widespread over the Altai–Sayan folded area (Buslov et al., 2013). Late Paleozoic allochthone and autochthone structures enclose fragments of early orogenic phases. The beginning of the Kazakhstan–Baikal collision with Siberia is recorded in Vendian–Early Paleozoic thrust and strike-slip faults and related metamorphic complexes and granites. They exist in the Altai–Sayan and Baikal areas (Charysh–Terekta zone of Gorny Altai; Kurtushiba zone of the West Sayan; Sangilen upland; East Sayan; western Baikal region) and are deformed by Late Paleozoic thrusting and strike-slip faulting. Specifically, Late Paleozoic thrusts in Gorny Altai contour an autochthonous structure comprising a fragment of the Vendian–Cambrian Kuznetsk–Altai island arc with accretionary prisms of the Biya–Katun' and Kurai zones, where thrusting and folding acted in the Late Precambrian–Early Cambrian, i.e., correspond to the Salair orogeny. The Salair orogenic structure, in its turn, lies under an up to 15 km thick stratified rocks of the Anui–Chuya zone, which are Middle Cambrian–Early Ordovician fore-arc basin sediments and Ordovician–Early Devonian passive-margin terrigenous and carbonate rocks discordantly overlain by a Devonian active-margin volcanic-sedimentary complex. The upper section consists of Fammenian–Visean molasse lying transgressively over the Devonian rocks. The molasse and an unconformity at its base record a Late Paleozoic orogeny which shows up as deformation along the margins of the Anui–Chuya zone, as well as in the Biya–Katun' and Kurai zones and in the Kaim, Charysh–Terekta, and Teletsk–Kurai thrust-fold belts on their borders, with the related zones of Late Carboniferous coaliferous molasse. Judging by their Late Cambrian through Carboniferous ages, most of igneous zircons from different stratigraphic levels of the Anui–Chuya zone came from Late Precambrian–Early Ordovician igneous rocks of the Kuznetsk–Altai island arc. There are also some zircons from Middle Ordovician plume complexes of the Kuznetsk–Bateni field (northern Altai–Sayan area) and a minor amount of Paleoproterozoic zircons possibly carried from the Siberian craton.

The zircon populations from Late Carboniferous molasse of the southeastern Altai differ from the others as they include zircons from eroded Middle Devonian–Early Carboniferous and Cambrian–Early Ordovician igneous rocks of the northern Gorny Altai, as well as zircons roughly coeval with igneous rocks of the Kazakhstan–Baikal continent and the Vendian–Early Paleozoic strike-slip suture in its northern periphery.

These results support the idea that the orogens flanking the Siberian craton in the south comprise the Salair collisional structures (Buslov, 2011; Dobretsov and Buslov, 2007, 2011). The latter represent the evolution of the Kuznetsk–Altai and Tuva island arcs, and specifically the phases associated with accretion of the Kazakhstan–Baikal continent and some other terranes (including the Tuva–Mongolia microcontinent) to Siberia. The older structures are superposed with Late Devonian–Early Carboniferous and Late Carboniferous–Permian deformation coeval with the early Late Paleozoic–Early Mesozoic and Early Mesozoic orogenic phases. This deformation controls the intracontinental orogens that formed in the course of the multistage collision of Eastern Europe, Siberia, and Kazakhstan–Baikal.

In Vendian–Early Cambrian time, the Altai–Sayan area and the Lake zone of western Mongolia experienced island arc plagiogranite magmatism, which acted between 563 ± 2 and 514 ± 8 Ma and culminated at 535 ± 6 to 518 ± 2 Ma with emplacement of large plutons (Rudnev et al., 2013a).

The plagiogranites belong to tholeiite and calc-alakine series and are either low- or high-aluminous varieties according to their Al_2O_3 and REE contents, this difference being a record of different formation depths (3–8 kbar and ≥15 kbar) and magma sources.

The high-aluminous plagiogranites are of limited occurrence and exist as small intrusions or less often as large plutons. They typically have low REE (mainly HREE) abundances and high La_N/Yb_N (most often 9 to 35, or occasionally 4–8) and Sr/Y (60–287) ratios, with prominent Sr peaks common to high-Al TTG complexes. Their parent magmas presumably formed by partial melting of metamorphic basalt compositionally similar to N-MORB, at $P \geq 15$ kbar, in equilibrium with garnet-bearing residue, during subduction of oceanic crust. This formation mechanism is consistent with similarity between high-Al plagiogranites and high-Si adakites from different regions worldwide, as well as with high positive $\varepsilon_{Nd}(T)$ values close to depleted mantle.

Unlike the high-Al varieties, the low-Al plagiogranites of the tholeiitic and calc-alkaline series show higher REE abundances but lower La_N/Yb_N (0.4–9) and Sr/Y (3–47) ratios and lack of the Sr maximum. They most likely result from melting of metamorphic basalts in the lower crust or at the base of island arc systems at pressures from 3 to 8 kbar in equilibrium with plagioclase- and amphibole-bearing mantle residue, which is evidence of shallower origin depths of the parent magma.

The Sr–Nd isotope compositions of Vendian–Early Cambrian island arc plagiogranitoids in the Altai–Sayan folded area and the Mongolian Lake zone (Rudnev et al., 2013a) show high positive $\varepsilon_{Nd}(T)$ from +9.0 to +4.7, Nd model ages T_{Nd}(DM) from 0.50 to 0.85 Ga and low initial $(^{87}Sr/^{86}Sr)_i$ ratios of 0.7034–0.7053. The high-Al plagiogranites have the highest $\varepsilon_{Nd}(T)$ = +9.0 to +7.4 indicating a basaltic (N-MORB-type) magma source. The low-Al plagiogranites in the lower and basal parts of island arc systems have low $\varepsilon_{Nd}(T)$ (+7.6 to +4.7), this being evidence of a crustal component in the parent melt.

Mesoabyssal plagiogranites in Rudny Altai were previously timed at Early–Middle Devonian but rather turned out to be Middle Carboniferous, with U–Pb zircon and Ar–Ar amphibole and biotite ages of 322–318 Ma (Kuibida et al., 2013). According to structural data, they emplaced when the stress regime changed from frontal compression to left-lateral shear. Thus they were inferred to have formed during the culmination of collision between Siberia and Kazakhstan–Baikal (Buslov, 2011; Dobretsov and Buslov, 2007, 2011). Judging by their chemistry and isotope compositions, most of the analyzed plagiogranites are high-aluminous varieties produced by melting at ~15 kbar of metabasaltic material of N-MORB affinity (Kuibida et al., 2013). On the other hand, the presence of low-Al plagiogranites in the postgranite dike series indicates melting at different depths of the collisionally thickened heterogeneous crust of Rudny Altai.

In the Fammenian–Early Carboniferous (Korobkin and Buslov, 2011), subduction of oceanic crust occurred on all margins of the Kazakhstan part of the composite continent and gave rise to the Valerianovka island arc and the Balkhash–Ili volcanoplutonic belt, as well as to volcanic arcs in the Junggar–Balkhash ocean (Bogdoshan arc) and in the Tien Shan–Pamir ocean (North Pamir arc formed coevally with the South Ghissar marginal sea). The single shelf basin, with terrigenous-carbonate deposition, which existed over a large part of the continent in Fammenian–Early Carboniferous time, gave way to three (Teniz, Dzhezkazgan, and Karaganda) separate basins in the second part of the Early Carboniferous. The two former basins accumulated Cu- and salt-bearing complexes, while thick coalbeds of the Karaganda, Ekibasstuz, and other fields were deposited in the eastern basin. The basin sediments contain green- and gray-color beds, as well as more or less abundant redbeds.

The Middle–Late Carboniferous was the time of active processes on all continental margins of the Kazakhstan–Baikal continent, closure of its flanking oceans, and convergence between East Europe and Siberia (Buslov, 2011).

Plume magmatism of the Tarim large igneous province acted between 295 and 270 Ma within the Tarim and Junggar–Balkhash region (Dobretsov, 2010) and produced bimodal, alkali-basaltic, and tholeiitic volcanics. In the Permian, East Europe was moving northward and active faulting occurred on the Chelyabinsk, Main Karatau, Jalair-Naiman, and other right-lateral strike-slip zones. The Early Permian activity consisted in mountain growth and formation of remnant half-closed deepwater basins (e.g., Junggar) with deposition of thick flysch sediments with oil shales. In the greatest part of regions, sediments, including red molasse, locally with volcanics, were deposited in intermontane and submontane basins.

The Tarim and Siberian plume activity is recorded in gabbro-picritic rocks of the Late Paleozoic–Early Mesozoic Altai collisional system in Eastern Kazakhstan (Khromykh et al., 2013). The gabbroic and picritic rocks formed after the collision, in two events (~ 293 and 280 Ma), the mafic rocks after the felsic ones. This reverse sequence of magmatism may be due to interaction of thermochemical plumes with the lithosphere. The earlier phase of activity, which produced the subalkaline gabbro, corresponded to the first contact of the rising plume with the lithosphere when the sublithospheric material had relatively small melting degrees. Then the plume head spread beneath the lithosphere, heated up the lithospheric base, and facilitated intrusion of mantle-derived melts. Thus there formed Cu–Ni–PGE gabbro-picritic intrusions within the Altai collisional system and Northwestern China.

The collage of CAO strike-slip structures had completed its formation in the Permian–Triassic. Eurasia had an active margin with the Paleo-Tethys and continued moving northward (Buslov et al., 2004). This caused strike-slip faulting and rifting in the Tarim, Ustyurt, Mangyshlak, and Tien Shan regions. The Karpinsky Ridge and the Ural orogen became thrust over the Caspian basin and Ustyurt where thick terrigenous and salt-bearing continental sediments were deposited. Deposition of red molasse occurred also in some basins of Kazakhstan and China (Chu–Sarysu, Teniz, Junggar, and Tarim).

Conclusions

In recent decades, the orogens in Central Asia lying between the East European, Siberian, Tarim, and North China cratons have been interpreted as accretionary-collisional structures consisting of oceanic crust fragments, island arc belts, and microcontinents that belonged to the Paleoasian ocean. There have been attempts to distinguish marker tectonic units (island arcs, ophiolite sutures, high-pressure metamorphic belts) as clues to paleotectonic division of the Central Asian collage of terranes. Using these markers, the geodynamic history of cratons and orogens on their borders, considered as their marginal geodynamic complexes, can be reconstructed proceeding from analogy with the present oceanic and continental convergent boundaries and fold belts extending for thousands of kilometers. Many models (Berzin and Dobretsov, 1993; Berzin et al., 1994; Didenko et al., 1994; Windley et al., 2007; Xiao et al., 2009; Yakobchuk, 2004; Zonenshain et al., 1990) show several accretionary-collisional zones of different ages that formed in Vendian–Early Carboniferous time by successive accretion of island arcs, microcontinents, and oceanic rises to Siberia. According to the model of Sengör et al. (1993), there was a single Vendian–Early Paleozoic subduction zone in the history of the Paleoasian ocean, and the related Kipchak and Tuva–Mongolian suprasubduction arcs formed on the periphery of East Europe and Siberia, respectively. The arcs underwent deformation (flexure and large strike-slip faulting) in the Middle–Late Paleozoic as a result of motion and rotation of the two continents.

This paper and the special issue as a whole present a synthesis of chemical and isotope data on Neoproterozoic–Paleozoic sedimentary sequences undertaken for the first time in terms of correlation between geodynamic and deposition processes in the Central Asian orogen and the Siberian craton. Thus reliable evidence has been obtained on the history of orogenic areas flanking the Siberian craton based on geodynamic models of deposition in separate basins. The model suggested earlier in (Buslov, 2011; Dobretsov and Buslov, 2007, 2011) appears to be universal and appropriate for untangling the tectonic framework of the Central Asian orogen. It agrees with the cited inferences on the tectonic division of the area and additionally distinguishes the Late Precambrian–Early Paleozoic Charysh–Terekta–Ulagan–Sayan–Olkhon strike-slip suture between the continental-margin complexes of Siberia and Kazakhstan, with the crust of juvenile and mixed types, respectively. Late Paleozoic large strike-slip faulting deformed the previous tectonic framework and caused tectonic mixing of the older structures in different margins. This superposed deformation makes it difficult to decipher the paleogeography, paleotectonics, and paleogeodynamics of the region.

Correlation between sedimentary sequences and events of accretion and collision, including the dating of detrital zircons, has been just in the beginning, and many issues remain yet unknown. There is no systematic data on sedimentary sequences which deposited in the time of collisional events, especially in the Cambrian–Devonian span, both on the Siberian craton and in its folded surroundings and in the Kazakhstan and Tien Shan territory. The comprehensive approach to investigation of sedimentary rocks, with reference to Hf composition of zircons and Sr and Sm–Nd isotope systematics, has not come into broad use. More evidence can be obtained from integrate analysis of satellite databases like the one shown in Fig. 2.

At the same time, new geochronological, isotope, and chemical data on sedimentary and igneous rocks reported in the papers of this volume obviously make a step forward and allow better understading the prospects of future studies.

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