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Isotope provinces, mechanisms of generation and sources of the continental crust in the Central Asian mobile belt: geological and isotopic evidence

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Abstract

The available geological, geochronological and isotopic data on the felsic magmatic and related rocks from South Siberia, Transbaikalia and Mongolia are summarized to improve our understanding of the mechanisms and processes of the Phanerozoic crustal growth in the Central Asian mobile belt (CAMB). The following isotope provinces have been recognised: 'Precambrian' ($T_{DM} = 3.3$–2.9 and 2.5–0.9 Ga) at the microcontinental blocks, 'Caledonian' ($T_{DM} = 1.1$–0.55 Ga), 'Hercynian' ($T_{DM} = 0.8$–0.5 Ma) and 'Indosinian' ($T_{DM} = 0.3$ Ga) that coincide with coeval tectonic zones and formed at 570–475, 420–320 and 310–220 Ma. Continental crust of the microcontinents is underlain by, or intermixed with, 'juvenile' crust as evidenced by its isotopic heterogeneity. The continental crust of the Caledonian, Hercynian and Indosinian provinces is isotopically homogeneous and was produced from respective juvenile sources with addition of old crustal material in the island arcs or active continental margin environments. The crustal growth in the CAMB had episodic character and important crust-forming events took place in the Phanerozoic. Formation of the CAMB was connected with break up of the Rodinia supercontinent in consequence of creation of the South-Pacific hot superplume. Intraplate magmatism preceding and accompanying permanently other magmatic activity in the CAMB was caused by influence of the long-term South-Pacific plume or the Asian plume damping since the Devonian.

Keywords: Central Asian mobile belt; Phanerozoic; Crustal growth; Isotope Provinces

1. Introduction

The formation and evolution of the terrestrial continental crust is undoubtedly one of the 'key' problems in Earth science. It is generally suggested that the growth of the continental crust has been essentially completed in the Early Precambrian (Windley, 1995; Condie, 1998). However, recently it was demonstrated based on geochronological and isotopic data that the continental crust growth in many Phanerozoic orogenic belts was also very significant (Samson et al., 1989, 1995; DePaolo et al., 1991; Kovalenko et al., 1996a,b; Jahn et al., 2000a,b; Chen and Jahn, 1998), but the mechanisms of the production of new crust is still an issue of debate.

One of the most expressive examples of such belts is the Central Asian mobile belt (CAMB) (Zonenshain, 1972), also known as Altaid Tectonic Collage (Sengor et al., 1993) or Central Asian Orogenic Belt (Hu et al., 2000; Jahn et al., 2000a,b; Wu et al., 2000). This orogenic belt contains very large volumes of granitoids and related rocks that were emplaced during the Paleozoic and Mesozoic. Until recently these granitoids, especially the granitoids in Tuva, Sayan Mts, Transbaikalia and Mongolia, have been poorly studied and many aspects of their timing and origin, as well as their significance as indicators of Phanerozoic crustal growth, were controversial. New geochemical, geochronological and isotopic data indicate that the CAMB is an important site of juvenile crustal growth during the Phanerozoic (Kovalenko et al., 1996a,b; Jahn et al., 2000a,b; Chen and Jahn, 1998; Wu et al., 2000). In order to further improve our understanding of the mechanisms and processes of such crustal generation we summarize in this paper the available

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geological, geochronological and isotopic data that were obtained during the past decade on the felsic magmatic and related rocks from South Siberia, Transbaikalia, Mongolia and adjacent terrains of the Siberian Craton. The main purposes of the paper are: (1) to document the possible sources of the Phanerozoic granitoids from the CAMB, (2) to assess the role of basement rocks and intraplate igneous activity in the genesis of Phanerozoic intrusive granites and Phanerozoic continental crust, and (3) to discuss the mechanisms and processes that could lead to generation of juvenile continental crust in Phanerozoic mobile belts.

2. General geologic setting and magmatic evolution of the CAMB

The 1000–2000 km wide CAMB is situated between two major Precambrian cratons of Central Asia (Siberian Craton in the north and Tarim and North China Cratons in the south) and extends across central Asia for about 5000 km (Fig. 1). The tectonic architecture of the CAMB is defined by a combination of the microcontinental 'composite' blocks and sublinear mobile belts of different ages (Neoproterozoic–Cambrian–Early Ordovician (Caledonian), Ordovician–Early Carboniferous (Hercynian) and Carboniferous–Permian (Indosinian)) extending for hundreds and even thousands of kilometres (Fig. 1). It is necessary to note that Russian geologist traditionally use the term 'Caledonian structures' for CAMB since first half of the XIX century (Yanshin, 1966). As in other regions (Read and Watson, 1975), evolution of the Caledonian fold belts of the CAMB started at the end of Neoproterozoic and finished to the end of Silurian–Early Devonian time when deposition of molassa began (Mossakovsky, 1975). The Caledonia structures of the CAMB are characterised by several pulses of orogeny in various regions, f.e., Early Ordovician (Lake Zone), Late Ordovician (Sangilen block), Silurian (Mongolian and Gobi Altay).

The microcontinental 'composite' blocks containing high-grade rocks constitute a significant proportion of the continental crust of the CAMB. The largest of them have been named the Dzabkhan, Khangai, Tuvino–Mongolian, Barguzin and Altai (Fig. 1). The tectonic position of these microcontinental blocks in the Neoproterozoic is the subject of considerable discussion. Some authors (Mossakovsky et al., 1994; Didenko et al., 1994) proposed that they were derived from East Gondwana, whereas others (Belichenko et al., 1994; Berzin et al., 1994) considered them fragments

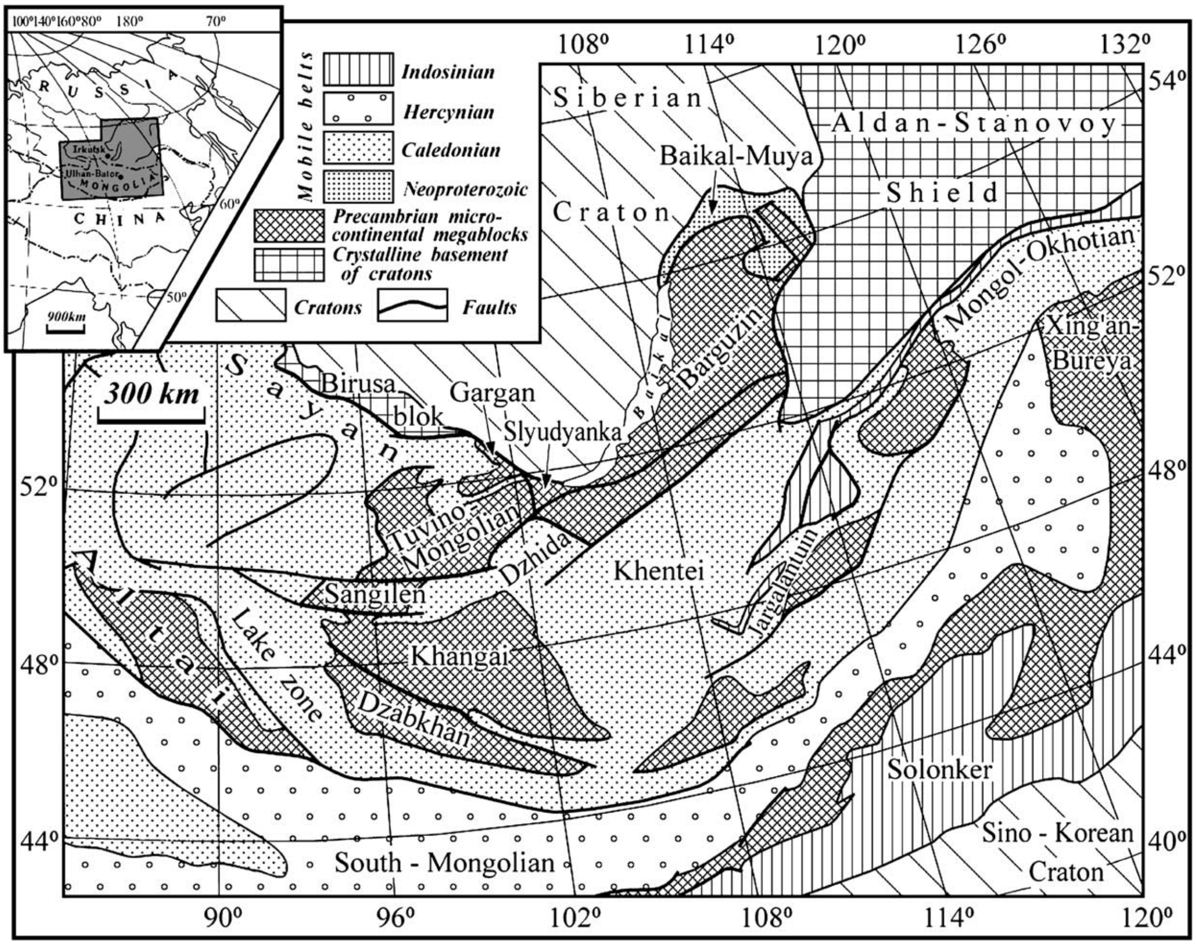

Fig. 1. Simplified tectonic division of the Central Asia after (Yanshin, 1980) with additions of authors.

rifted off the Siberian Craton. We suggest that microcontinents of the CAMB were derived from a single supercontinent Rodinia that included as East Gondwana as Siberia.

The magmatic evolution of the CAMB was described in detail in many publications (Yanshin, 1980, 1989; Zanvilevich et al., 1985; Gordienko, 1987; Kovalenko and Yarmolyuk, 1990; Yarmolyuk and Kovalenko, 1991; Neymark et al., 1993, 1998; Berzin et al., 1994; Dobretsov and Kidryashkin, 1994; Ruzhentsev and Mossakovsky, 1995; Pusharovsky, 1997; Kovalenko et al., 1999b; Dergunov et al., 2001; Khain, 2001) and was recently summarized by Kovalenko et al. (1995, 1999b), Yarmolyuk et al. (2000) and Dergunov et al. (2001). According to Kovalenko et al. (1995, 199b)) and (Yarmolyuk et al., 2000), orogenic and intraplate igneous activity in Central Asia continued throughout the entire Phanerozoic (from the Late Neoproterozoic to present time) without any significant interruption. The correlation and sequence of tectonic and magmatic events as well as the spatial–temporal relationships of the Phanerozoic within-plate and orogenic magmatism in the CAMB are given in Table 1 and Fig. 2, that are compiled on the base of available geological and geochronological data (Kovalenko and Yarmolyuk, 1990; Yarmolyuk and Kovalenko, 1991; Kozakov, 1993; Khain et al., 1995a,b, 2002; Kotov et al., 1995a; Kogarko et al., 1995; Kovalenko et al., 1995, 1996a,b,c; Yarmolyuk et al., 1995, 1996, 1997a,b, 1998, 1999a,b; Gusev and Peskov, 1996; Vladimirov et al., 1999; Kozakov et al., 1999a,b, 2001a,b, 2002a; Reznitskii et al., 2000; Dergunov et al., 2001; Salnikova et al., 2001; Kuzmichev et al., 2001; and references in these publications).

During the formation of the CAMB very large volumes of orogenic and intraplate granitic rocks of Paleozoic to Mesozoic age were emplaced (Kovalenko et al., 1995, 1999b). Paleozoic granitic intrusions are distributed mainly in the northern part of the CAMB. They include (1) numerous plutons of the calc-alkaline series (granodiorite–granite) that were intruded (500–440 Ma) during and after collision of Precambrian microcontinental blocks and ensimatic island arcs of the Caledonian paleoocean; (2) Late Ordovician–Devonian (440–360 Ma) granodiorite–granite, granite, basalt–andesite and andesite–dacite–rhyolite associations of the Altai active continental margin; (3) Carboniferous and Permian granitoids of calc-alkaline series, represented by the vast Barguzin batholith (330–290 Ma) in northern Mongolia and Transbaikalia and the Hangai batholith (270–250 Ma) in west-central Mongolia (Table 1, Fig. 1). Mesozoic magmatic activity in the CAMB was mainly connected with accretionary processes up to collision of the North Asia (Siberian Craton, Caledonian and Hercynian mobile belts of the CAMB) and Sino-Korean continents and with intensive intraplate activity. During this period within the CAMB the Early Mesozoic Khentei (220–200 Ma) and Late Mesozoic Uda-Stanovoy (150–120 Ma) batholiths were emplaced (Table 1).

The intraplate magmatic activity in the CAMB and adjacent terrains of the Siberian Craton continued since the Neoproterozoic up to Cenozoic (Kovalenko et al., 1999b; Yarmolyuk et al., 2000). The earliest impulses of the intraplate magmatism (ultrabasic-carbonatite type) occurred along of southern margin of the Aldan shield (720–690 Ma) and along of the Eastern Sayan margin of the Siberian Craton (725–650 Ma) (see Table 1 and Fig. 2). At the 675–660 Ma time interval the alkaline intraplate magmatism was initiated within Enisey Ridge and continued virtually to 480 Ma (Kogarko et al., 1995; Yarmolyuk and Kovalenko, 2001). From 490 Ma to Early-Middle Devonian the system of grabens (the Minusinskaya, the Agulskaya, the Northern Mongolian etc.) were formed at the back zone of the Silurian–Early Devonian Altai marginal belt (Vorontsov et al., 1997; Yarmolyuk and Kovalenko, 1991). The alkaline and subalkaline volcanics and plutonic rocks of intraplate magmatic features characterize these grabens. Intraplate alkaline magmatism was also widespread within the Late Paleozoic Central Asian rift system. The formation of this system started at geodynamic setting when the continental margin override the spreading centre or mantle plume. Then at the Mesozoic time this setting has changed by the Mongolo–Okhotsk type of tectonic scenario with simultaneous continental collision and rifting processes. These tectonic environments prevailed during Early Mesozoic time and resulted in the generation of within-plate bimodal and alkaline basic magmatic associations in Western and Eastern Transbaikalia, Khangai, Mongolian Altai, Sayan and Kuznetsky trough (Yarmolyuk et al., 2000, 2001). During the Late Mesozoic and Cenozoic the magmatism of the CAMB has an intraplate nature only (Yarmolyuk et al., 1995, 1996, 2000).

Thus, intraplate magmatic activity occurred persistently since the Neoproterozoic until the Holocene with several peaks: at Early–Middle Paleozoic, Late Paleozoic–Early Mesozoic and Late Early-Early Cenozoic. There is correlation of within-plate and active continental margin magmatic activity, which fixes the gradual closure of the Central-Asia paleoocean (Table 1). For example, the Early–Middle Paleozoic period of the CAMB within-plate magmatism temporally relates with the formation of the Caledonides and Devonian active margin along of the Altai border of the Caledonian microcontinent. The Late Paleozoic intraplate activity was coeval with the closure of the Hercynian oceanic basin and active continental margin magmatism. The Early Mesozoic intraplate magmatic event is well correlated with the closure of the Indosinian basins and respective island arc and collision processes.

3. Methods of the study

Continental crust is a result of relatively complex magmatic processes of chemical differentiation from mantle. Due to large fractionation of Sm and Nd during formation of granitoids and felsic volcanics from

Table 1
Sequence and correlation of tectonic and magmatic events in the Central-Asian Mobile Belt

Epoch (Ma)	Oceanic segment	Continental segment	
		Convergence setting	Intraplate setting
Neoproterozoic (1000–570)	Dunzhugur ophiolites (1020 Ma)	Fragments of continental-margin and riftogenious types magmatic belts in the Precambrian TuvinoMongolian, Central-Mongolian and Barguzinsky microcontinental blocks: bimodal volcanics associations, basic intrusions, granite and subalkaline granite plutons (850–700 Ma)	Grabens along of southern and south-western margins of the Siberian craton: basaltic dykes swarms, ultrabasic rock–carbonatite complexes(720–670, 600–540 Ma). Riftogenesis and breackup of Rodinia, opening of the Paleo-Asian ocean
Neoproterozoic–Cambrian (570–510)	Ensimatic island arcs (ophiolite belts)? in the Altay and Sayan regions, northern Mongolia and Transbaikalia. Picrite–basalt and basalt–andesite associations, layered gabbro plutons (570, 530 Ma)	?	?
Ordovician (500–450)		Altay, Sayan, northern Mongolia, Transbaikalia Collision of Precambrian microcontinental blocks and Neoproterozoic–Cambrian island arcs of Caledonian paleoocean (500–480 Ma), concolidation of Caledonian mobile belt (superterrain): collisional and post-collisional granodiorite–granite batholites (500–440 Ma)	Faults zones: layered gabbro (500–480 Ma), alkaline and peralkaline syenites and granites (490, 460 Ma) plutons
Late Ordovician–Devonian (450–360)	Ensimatic island arcs (ophiolite belts) in the southern Mongolia (450–400 Ma). Basalt and basalt-andesite associations, gabbro, gabbro–diorite and tonalite plutons	Collision of Caledonian superterrain and the Siberian craton, formation of the North-Asian paleocraton (450–410 Ma) Mountain, Mongolian and Gobian Altay Altay active continental margin of the North-Asian paleocraton: granodiorite–granite and granite plutons, basalt–andesite and andesite–dacite–riolite associations (440–360 Ma)	Altay, Sayan and northern Mongolia Faults zones in the Altay active continental margin of the North-Asian paleocraton and intracontinental setting: alkaline gabbro (440–360 Ma), alkaline and peralkaline syenites and granites (450–370) plutons, bimodal basalt–trachiriolite–komendite associations (420–410 Ma, 400–380 Ma)
Late Devonian–Early Carboniferous		Collision of the North-Asian paleocraton and island arcs of Hercinian paleoocean, concolidation of Hercinian mobile belt (superterrain). Metamorphism, folding (350 Ma)	
Carboniferous–Permian (340–250)	Ensimatic island arcs (ophiolite belts) of the Mongolo–Okhotsk (320 Ma) and Solonker (Late Carboniferous–Early Permian) basins	Mongolia, Transbaikalia Carboniferous South-Mongolian active continental margin of the North-Asian paleocraton: andesite, andesite–dacite–riolite, riolite–trachiriolite association and granodiorite–granite and monzonite–granosyenite–granite plutons	Siberian mantle hot spot in the active continental margin: granodiorites and granites of the Barguzine batholite (330–290 Ma); alkaline and peralkaline granites, syenites, alkaline gabbro and carbonatites (310–280 Ma) in the Sinnir and Udino–Vitim rift zones
		Late Carboniferous–Early Permian Mongolo–Transbaikalian active continental margin of the North-Asian paleocraton: andesite, andesite–dacite–riolite, riolite–trachiriolite associations; granite–leucogranite and monzonite–granosyenite plutons (300–270 Ma)	Mongolian mantle hot spot in the in the active continental margin: granodiorites, granites and leucogranites of the Khangay batholite (270–250 Ma); bimodal basalt-komendite association and alkaline and peralkaline granite plutons in the Gobi–Tan–Shan (310–380 Ma), Gobi-Altay (270–260 Ma) and North-Mongolian (265–250 Ma) rift zones
Triassic–Early Jurassic (240–180)		Collision of the North-Asian and Sino-Korean cratons at the western part of Mongolo–Okhotsk trough: granodiorite–granite, leucogranite and granosyenite plutons	Mongolian mantle hot spot in the collisional zone of the North-Asian and Sino-Korean cratons: granodiorites and granites of the Khentey batholite (220–200 Ma); alkaline, peralkaline and Li–F granites plutons, basalts and bimodal basalt–komendite associations (230–195 Ma)

(*continued on next page*)

Table 1 (*continued*)

Epoch (Ma)	Oceanic segment	Continental segment	
		Convergence setting	Intraplate setting
Middle Jurassic–,Late Cretaceous (170–70)		Culmination of collision of the North-Asian and Sino-Korean cratons: granitoids of the Uda–Stanovoy batholite (150–120 Ma)	Western-Transbaikalian, Eastern-Mongolian and Gobi–Altay rift zones: bimodal basalt–komendite–carbonatite and alkaline basalt assciations (160–70 Ma)
Ceinozoic (60–0)			Central-Asian mantle hot field: alkaline basalts associations of the Southern-Khangay, Southern-Transbaikalian, Western-Transbaikalian, Dariganga, etc. hot spots

the 'mantle' sources and relative constancy of the Sm/Nd ratio in intracrustal processes (melting, metamorphism, erosion and sedimentation) Sm–Nd isotope systematics of felsic igneous rocks are widely used to determine the age of the continental crust formation, and to evaluate their possible sources (DePaolo, 1988). Different aspects of Nd isotopic data interpretation are discussed in detail in numerous publications (Allegre and Ben Othman, 1980; Liew and McCulloch, 1985; Arndt and Goldstein, 1987; DePaolo, 1988; DePaolo et al., 1991; and references in these publications), so we have considered only the principal questions necessary to understand our approach.

The age of the continental crust is the amount of time the crustal rocks has been isolated from the mantle sources (DePaolo et al., 1991). This age, in contrast to ages of crystallisation or later thermal and orogenic reworking of continental crust, is calculated as the Nd model age T_{DM} relative to depleted mantle (DM). It corresponds to the time when continental material has the same Nd isotopic composition as mantle source.

To characterise sources of igneous rocks the $\varepsilon_{Nd}(T)$ value is used (DePaolo, 1988). It is usually accepted that positive $\varepsilon_{Nd}(T)$ values indicate short-lived juvenile rock sources whereas negative values of $\varepsilon_{Nd}(T)$ attest formation of rocks by reworking of long-lived crustal materials. However, because parental felsic melts can be generated by partial melting of mixed sources of various ages, such interpretation is not always straightforward. In case of mixed sources Nd model ages have little geological significance and do not signify crust-forming events (Arndt and Goldstein, 1987). Moreover, anatexis of 'juvenile' continental crust shortly after its formation led to formation of granitoids with positive $\varepsilon_{Nd}(T)$ values but do not reflect addition of new juvenile material. From the above, the criteria of the 'true' crust-forming are positive $\varepsilon_{Nd}(T)$ values close to those of DM and Nd model ages close to crystallisation ages.

In terms of geological processes, 'juvenile' continental crust can be formed by, for example, partial melting of subducted oceanic crust (basalts with Nd isotopic characteristics of DM) and overlying mantle wedge in an island arc setting when first calc-alkaline magmas derive and the $^{147}Sm/^{144}Nd$ ratio changes from mantle (0.2137) to crustal (0.11 ± 0.02) values. However if contamination of source or primary melts by crustal material takes place, $\varepsilon_{Nd}(T)$ values will be lower than in DM and model ages will be older than ages of crystallisation. In thus common in geology case crystallisation age determined independently by U–Pb zircon method indicate age of crust-forming event.

It is generally supposed that Sm/Nd ratios do not change in intracrustal processes such as anatexis, high-grade metamorphism, weathering, sedimentation and crystal fractionation (Taylor and McLennan, 1985) and single-stage evolution is assumed. In some cases, e.g. highly fractionated granitoids, the Sm/Nd ratio can significantly change and two-stage Nd model ages T_{DM2} should be employed (Keto and Jacobsen, 1987). To minimise the effect of Sm–Nd fractionation in intracrustal processes we apply two-stage Nd model ages T_{DM2} for crustal (S-type) granitoids and metasedimentary rocks whereas for 'juvenile' felsic igneous rocks we employ singe-stage Nd model ages.

The $\varepsilon_{Nd}(T)$ values were calculated using the present-day values for a chondritic uniform reservoir (CHUR) $^{143}Nd/^{144}Nd = 0.512638$ and $^{147}Sm/^{144}Nd = 0.1967$ (Jacobsen and Wasserburg, 1984). The model ages T_{DM} were calculated using a model (Goldstein and Jacobsen, 1988), according to which the Nd isotope composition of depleted mantle has evolved linearly since 4.56 Ga ago and has the present-day value $\varepsilon_{Nd}(0) = +10$ ($^{143}Nd/^{144}Nd = 0.513151$ and $^{147}Sm/^{144}Nd = 0.2137$). The two-stage Nd model ages T_{DM2} were calculated using the crustal mean ratio $^{147}Sm/^{144}Nd = 0.12$ (Taylor and McLennan, 1985).

Nd isotopic data have been obtained mainly at the Institute of Precambrian Geology and Geochronology of the Russian Academy of Sciences, St Petersburg. Details of analytical technique are given in Kotov et al. (1995). Used here $^{143}Nd/^{144}Nd$ ratios from our and another laboratories are normalised relative to $^{143}Nd/^{144}Nd = 0.511860$ in the La Jolla Nd standard. Details of Rb–Sr isotope analyses are given in Kovalenko et al. (1999a).

Initial $^{87}Sr/^{86}Sr$ ratios for alkaline rocks with high Rb/Sr ratios were calculated for crystallisation ages that were

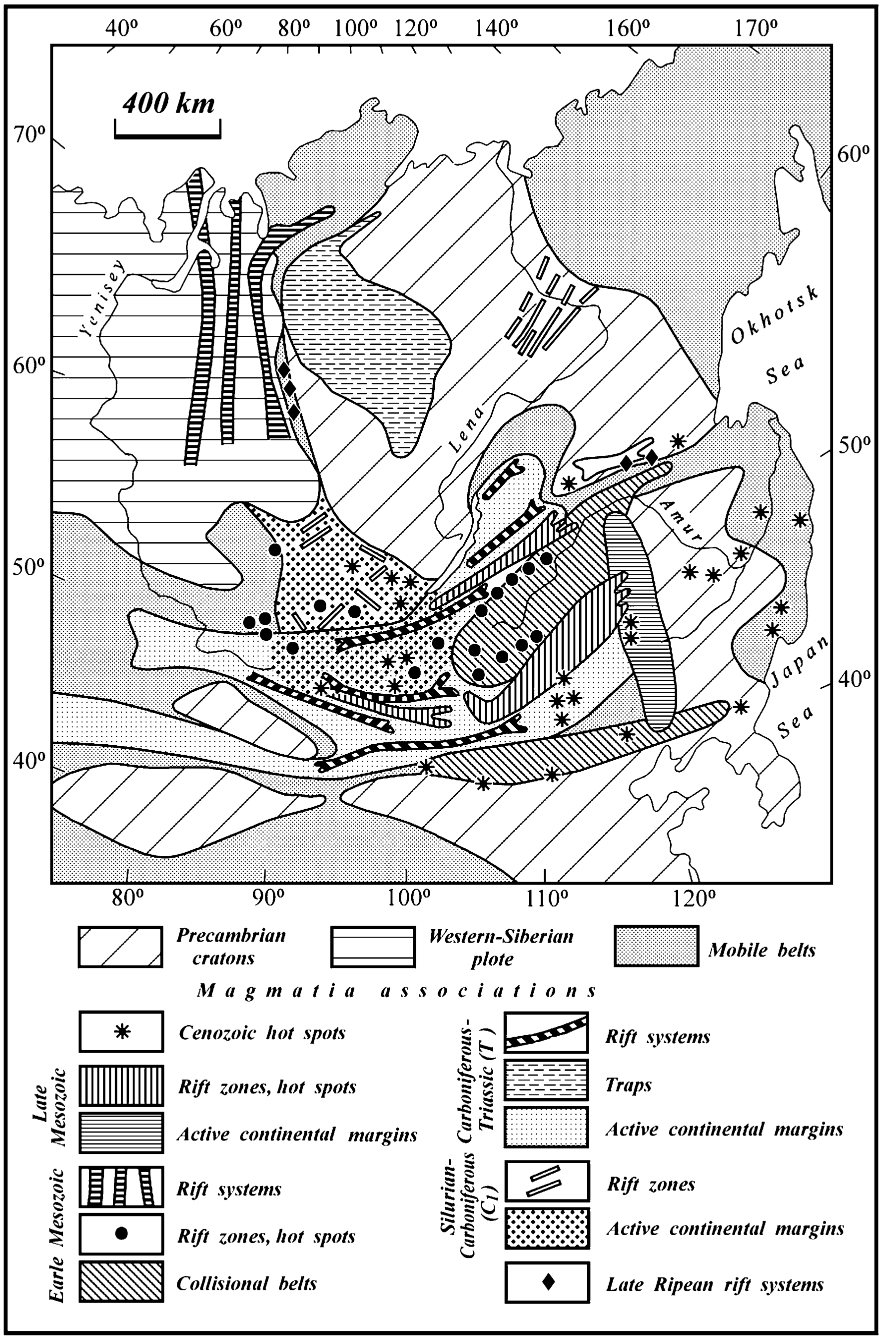

Fig. 2. Simplified map of convergent margins and intraplate Phanerozoic magmatism in Northern Asia.

determined by U–Pb zircon, Ar-Ar on hornblende methods. Also minerals with low (< 10) Rb/Sr ratios have been used to calculate initial $^{87}Sr/^{86}Sr$ from Rb–Sr isochrons.

4. Nd isotope provinces of the CAMB and sources of granitoids

In this section we summarized all published and newly obtained and still unpublished Nd isotopic data for the granitoids and related rocks of the CAMB as well as for adjacent terrains of the Siberian Craton (Kozakov, 1993; Frost et al., 1998; Jahn et al., 1998; Neymark et al., 1993, 1998; Khain et al., 1995a,b; Kotov et al., 1995, 1999; Kovach et al., 1996a,b, 1999a, 2000; Kovalenko et al., 1996a,b,c,d, 1999a,b, 2001a,b, 2002; Salnikova et al., 1996, 2000; Kozakov et al., 1997, 2002a,b, 1999a,b; Kruk et al., 1999; Larin et al., 1997, 1999, 2002; Vorontsov et al., 1997; Yarmolyuk et al., 1995, 1996, 1997a,b, 1999a,b, 1998, 2000, 2001 and references in these publications). These data are used to distinguish isotopic provinces, i.e. crustal provinces that are characterised by distinct variations of

Nd model ages and $\varepsilon_{Nd}(T)$ values (DePaolo, 1988; DePaolo et al., 1991). The results are presented as Nd model ages on Figs. 3 and 4 and as $\varepsilon_{Nd}(T)$ values on diagrams ε_{Nd}-Age (Figs. 5 and 6). These data allow us to delineate four isotopic provinces of the CAMB—Precambrian, Caledonian, Hercynian and Indosinian.

4.1. Precambrian provinces

The 'Precambrian' provinces coincide with the Dzabkhan, Khangai, Tuvino-Mongolian, Barguzin and Altai microcontinental 'composite' blocks (Fig. 1). Jiamusi block in the NE China is another example of Precambrian microcontinent of the CAMB (Wu et al., 2000). They are recognized as rigid terrains or median masses within the Caledonian and Hercynian mobile belts. In common the structure of the microcontinental blocks is defined by presence of two rock-type associations—highly metamorphosed gneiss-carbonate complex, and terrigenous–carbonate complex, usually metamorphosed under the greenschists facies conditions. Typically, the gneisses have sedimentary protoliths (Yanshin, 1973, 1980). Volcanics are rare and distributed within restricted zones. On the base of geological data their Neoproterozoic age is proposed. Formation of volcanics is related to rift processes or active continental margins fixing subduction zones near by microcontinental 'composite' blocks margins (Ruzhentsev and Burashnikov, 1995; Kheraskova et al., 1995).

Another type of the 'Precambrian' provinces is represented by Baikal–Muya mobile belt and Dunzhugur ridge (Fig. 1). Neoproterozoic (ca 1.0–0.8 and 0.8–0.55 Ga) magmatic and tectonic events have been documented in these regions (Kuzmichev et al., 2001; Rytsk et al., 2001; Khain et al., 2002). However Nd isotopic data for Neoproterozoic rocks are not available and no conclusion about sources of granitoids can be made.

The Dzabkhan microcontinental composite block includes *the Baidarik (Baydrag) block* where the oldest tonalite–trondhjemite gneisses in the CAMB have been dated by SHRIMP method at 2833 ± 35 Ma (Kozakov et al., 2001). They are characterized by Archean Nd model ages $T_{DM} = 3.3–2.9$ Ga (Figs. 3 and 4) and $\varepsilon_{Nd}(T) = -1.7$ to

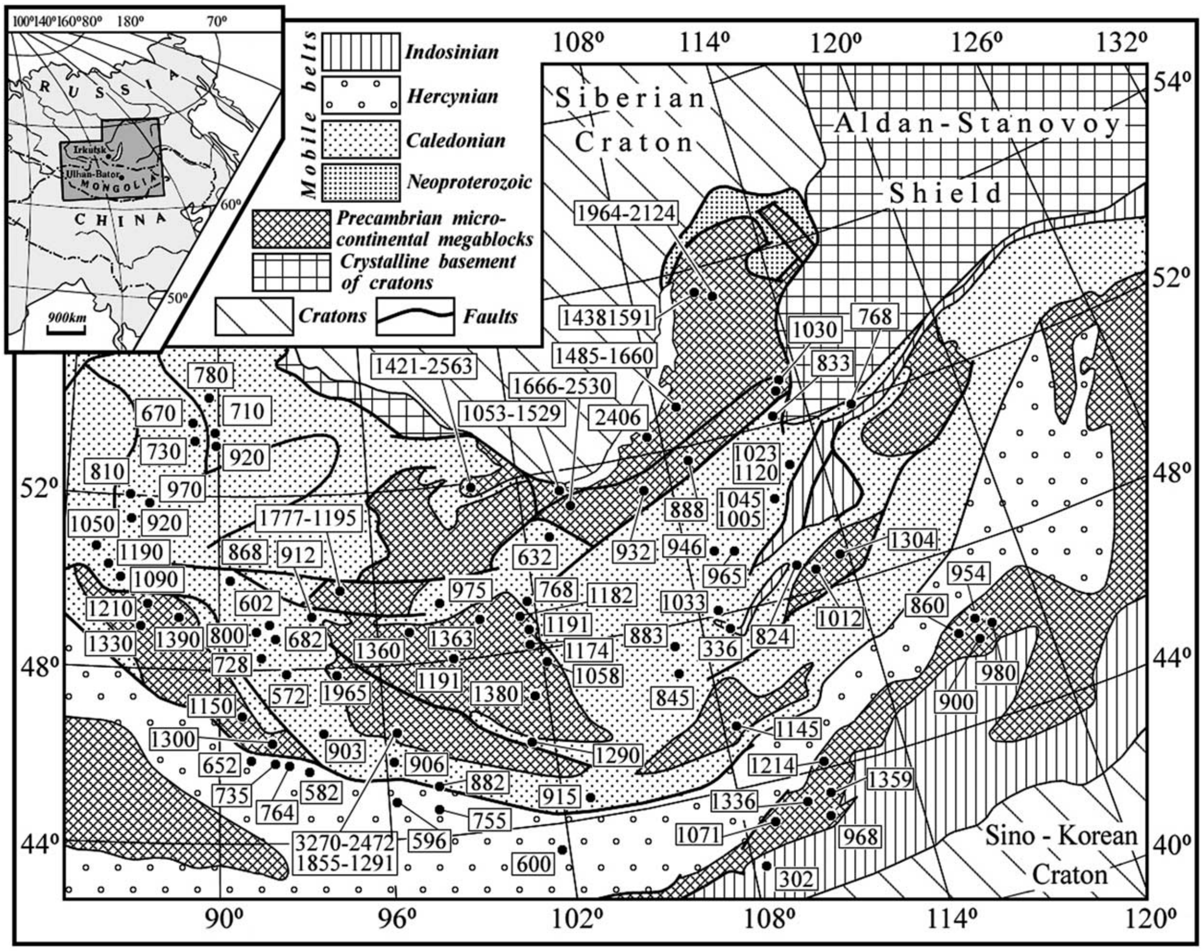

Fig. 3. Schematic map of sample localities and Nd model ages (in Ma) for felsic igneous rocks of the CAMB. Data sources from (Early Precambrian…, 1993; Khain et al., 1995; Kovalenko et al., 1996a,b,c,d; Kozakov et al., 1997, 2002a,b, 1999a,b; Kruk et al., 1999; Yarmolyuk et al., 1999a; and unpublished data of authors).

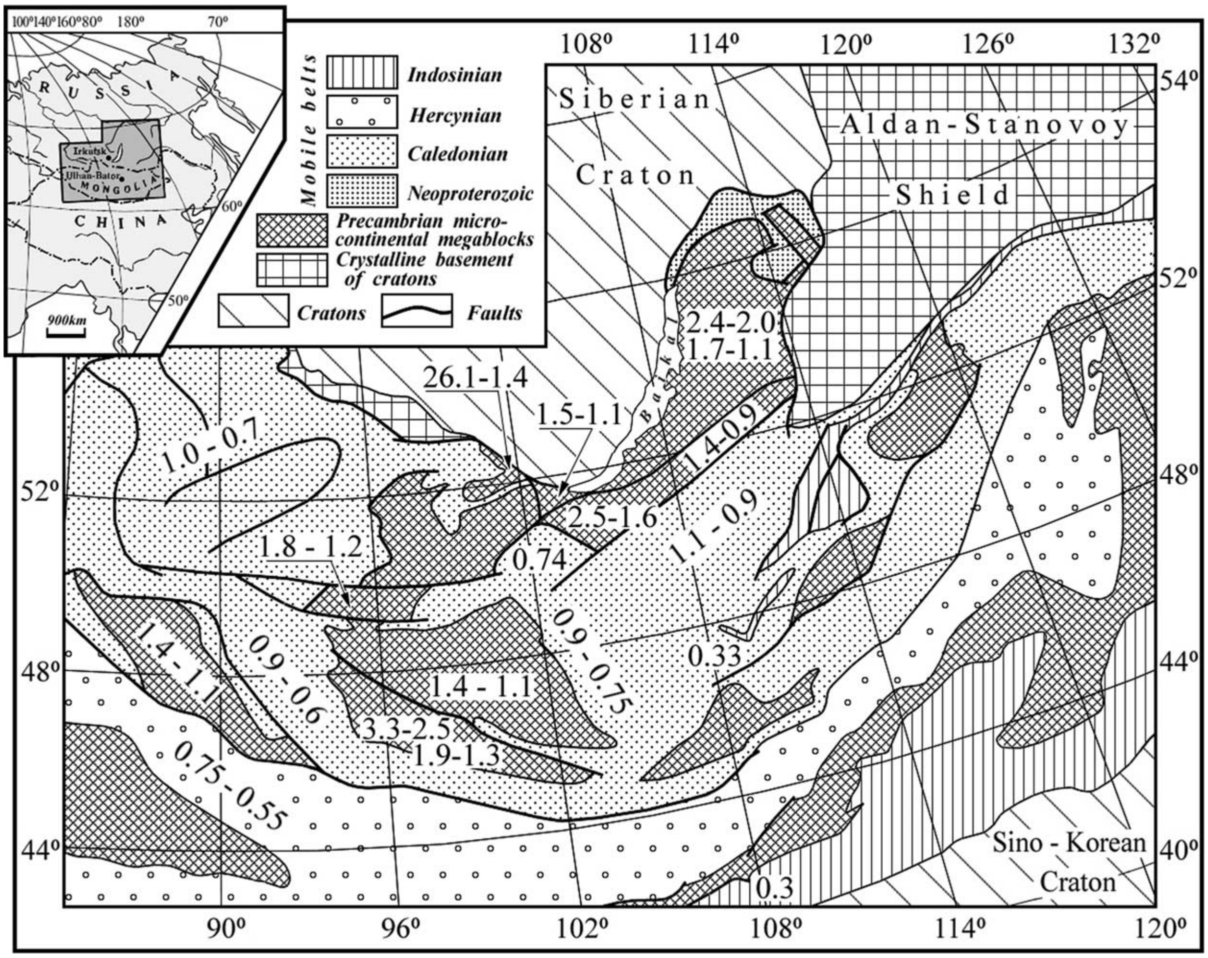

Fig. 4. Map of isotopic provinces of the CAMB. Variations of Nd model ages are shown in Ga. Data sources as in Fig. 3.

+1.9 (Fig. 5) (Kozakov, 1993; Kozakov et al., 1997). Paleoproterozoic granites with U–Pb zircon ages of 2364 ± 6, 2308 ± 4 Ma (Kotov et al., 1995), 1854 ± 5 and 1825 ± 5 Ma (Kozakov, 1993) have Archean (3.1–3.0 Ga) and Paleoproterozoic (2.5 Ga) Nd model ages T_{DM2}). Their $\varepsilon_{Nd}(T)$ values vary from −9.6 to −3.3 and −1.5, respectively. The semipelitic gneisses of the Baidarik block yield similar Nd isotopic characteristics—$\varepsilon_{Nd}(2.8) = +1.6$ to $+1.1$, $T_{DM2} = 3.0$ Ga. Geochronological and Nd isotopic data clearly indicate that the rocks of the Baidarik block had been formed from Archean and Paleoproterozoic sources.

Syntectonic tonalites mark collision of the Baidarik block with ophiolite-island arc complexes of the Daribi ridge at 490 ± 4 Ma (Kozakov et al., 2002a). They are characterized by Paleoproterozoic 2.0 Ga Nd model age (Fig. 3) and strongly negative value of $\varepsilon_{Nd}(T) = -8.8$ close to the Nd isotopic characteristics of host metasedimentary rocks ($T_{DM} = 1.9$ Ga, $\varepsilon_{Nd}(0.49) = -10.6$). Early and Late Paleozoic (ca 490–460 and 280 Ma) granitoids that intrude sedimentary cover of the Baidarik block yield a wide range of the $\varepsilon_{Nd}(T)$ values from −8.8 to −1.1 (Fig. 5) and Paleo- to Mesoproterozoic Nd model ages $T_{DM2} = 2.0$–1.2 Ga that clearly differ from those for Archean and Paleoproterozoic granites. Obtained data suggest that parental melts of Paleozoic granitoids were formed by partial melting of mixed sources composed by long-lived Archean crustal and possibly Early Paleozoic (Caledonian) juvenile material.

Only Paleozoic and Mesozoic granites have been studied in the *Khangai microcontinental composite block* (Fig. 1) that is bounded by structures of the Caledonian mobile belt on north, east and south and by the Baidarik block on the west and south-west. The most part of the Khangai microcontinental block are covered by the Devonian and Carboniferous terrigenous rocks of the Khangai trough. Basement rocks are exposed only in the erosion and tectonic windows. Numerous granitoid plutons that intruded both the basement and cover complexes belong to Khangai batholith that was emplaced 270–250 Ma ago (Yarmolyuk et al., 1997 a,b; our unpublished U–Pb zircon data). Independently of the crystallisation age the granitoids are characterized by Mesoproterozoic Nd model ages $T_{DM2} = 1.4$–1.1 Ga and $\varepsilon_{Nd}(T)$ values from −4.4 to +0.2 (Figs. 4 and 5) that could imply involvement in their petrogenesis of rocks of Mesoproterozoic age, or melting of mixed sources. Crustal granulite xenoliths from Shavaryn–Tsaram volcano

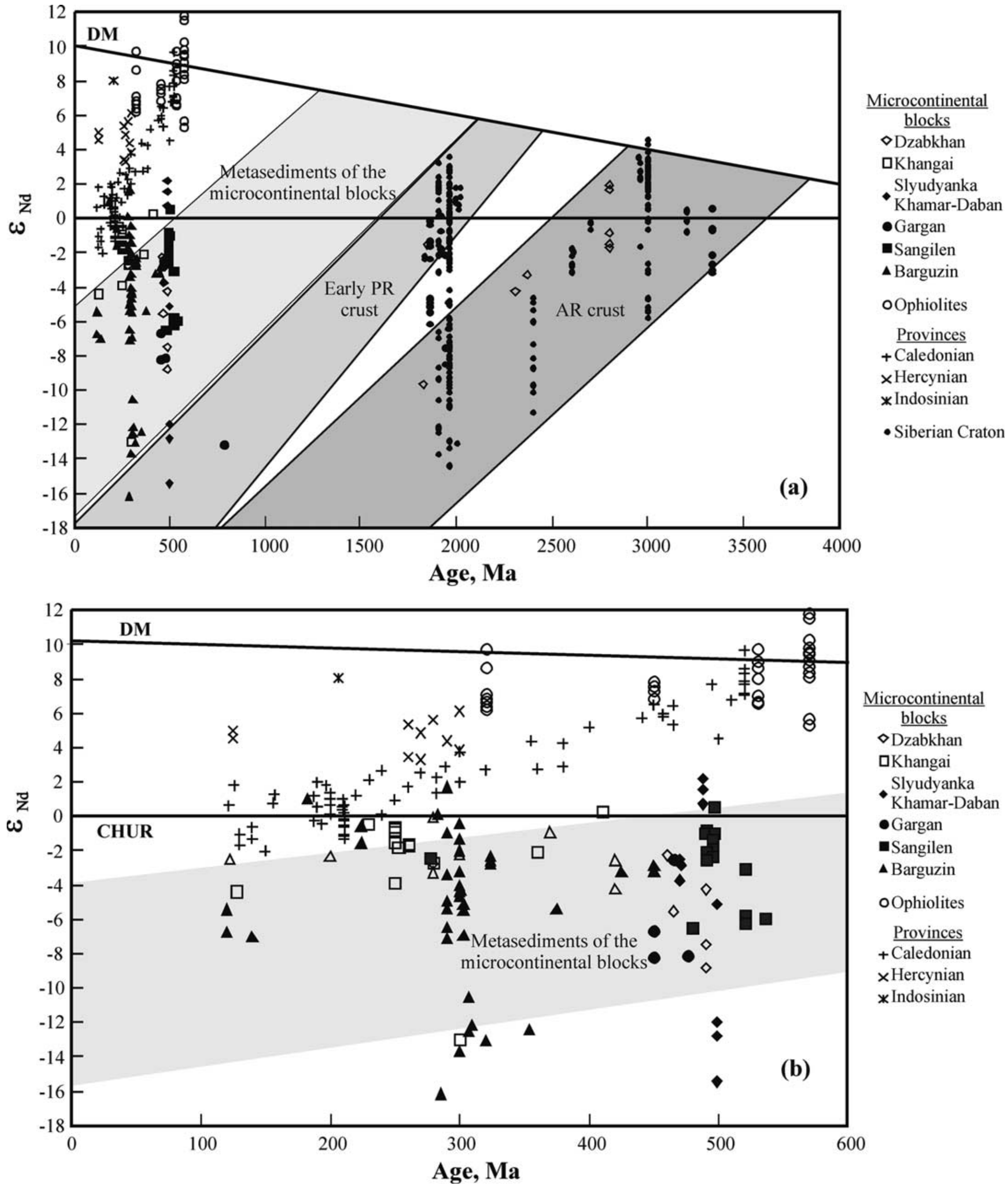

Fig. 5. (a) $\varepsilon_{Nd}(T)$ vs primary age diagram for rocks of the CAMB and southern part of the Siberian Craton. Nd isotope evolution fields for granitoids and terrigenous metasediments of the Siberian Craton and the microcontinental 'composite' blocks are shown for comparison. (b) $\varepsilon_{Nd}(T)$ vs primary age diagram for felsic igneous rocks and ophioloites of the CAMB. Nd isotope evolution fields for terrigenous metasediments of the Siberian Craton the microcontinental 'composite' blocks are shown for comparison. Data of the Siberian Craton from Neymark et al. (1993), Pavlov and Gallet (1998), Kotov et al. (1995, 1999), Salnikova et al. (1996), Kovach et al. (1996a,b, 1997, 1999), Larin et al. (1997, 1999, 2002), Jahn et al. (1998) and Frost et al. (1998); references in these publications and unpublished data of authors. Data of the CAMB from (Early Precambrian…, 1993; Khain et al., 1995a,b; Kovalenko et al., 1996a,b,c,d; Kozakov et al., 1997, 2002a,b, 1999a,b; Kruk et al., 1999; Yarmolyuk et al., 1999a; references in these publications and unpublished data of authors).

have similar Nd model ages 1.5–1.0 Ga that suggest isotopic uniformity of continental crust up to 50 km depth (Stosch et al., 1995; Yarmolyuk et al., 1999).

The Tuvino–Mongolian microcontinental composite block consists of the Slyudyanka, Khamar–Daban, Sangilen and Gargan blocks (Fig. 1).

The metasemipelites of the *Slyudyanka block* have undergone granulite facies metamorphism and were intruded by syntectonic trondhjemites at 488 ± 0.5 Ma and post-tectonic granites at 471 ± 2 Ma (Kotov et al., 1997; Salnikova et al., 1998; Reznitskii et al., 2000). Metasedimentary rocks are characterised by Paleoproterozoic Nd model ages $T_{DM2} = 2.2–1.9$ Ga ($\varepsilon_{Nd}(0.49) = -11.8$ to -7.7) that imply their derivation from mainly Paleoproterozoic sources. Syntectonic granitoids have slightly positive $\varepsilon_{Nd}(T)$ values of $+2.2$ to $+0.7$ and latest Mesoproterozoic Nd model ages $T_{DM} = T_{DM2} = 1.2–1.0$ Ga whereas post-tectonic granites

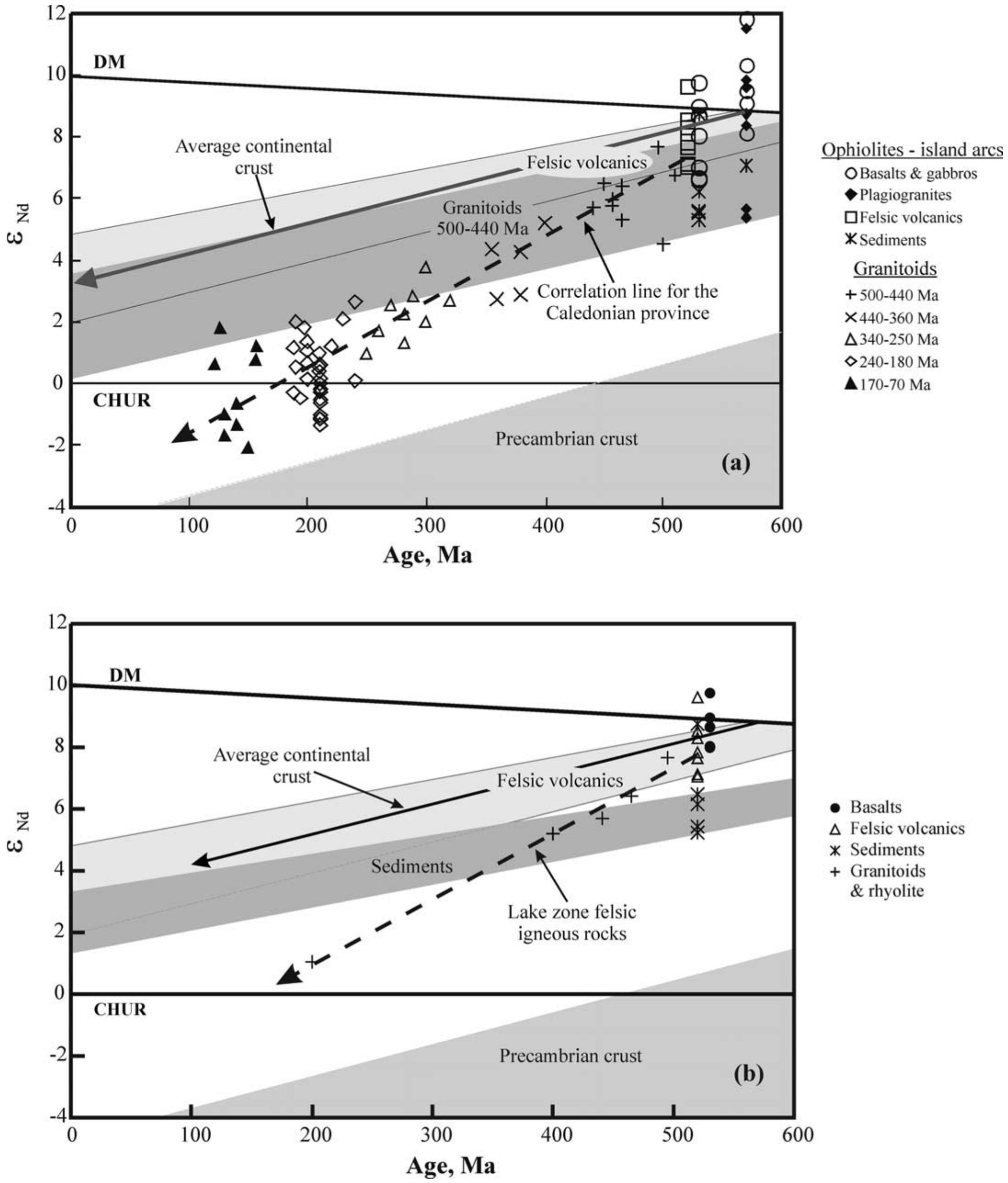

Fig. 6. $\varepsilon_{Nd}(T)$ vs primary age diagram for rocks of the Caledonian province of the CAMB (a) and Lake zone of the same province (b). Average continental crust is defined with $^{147}Sm/^{144}Nd$ ratio of 0.12. Nd isotope evolution fields are defined as follows: 'Felsic volcanics'—felsic volcanics of island arc complexes of the Lake zone; 'Granitoids 500–400 Ma'—granitoids emplaced into island arc complexes; 'Sediments'—sedimemts of the ophiolite–island arc complexes of the Lake zone; 'Precambrian crust'—metasediments of the microcontinental blocks. Data sources as in Fig. 5.

yield older Nd model ages $T_{DM2} = 1.5–1.4$ Ga ($T_{DM} = 1.4–1.2$ Ga) and more negative values of $\varepsilon_{Nd}(T) = -3.7$ to -2.5 (Figs. 4 and 5). T_{DM2} model ages for the granites (ca 500 Ma) of the *Khamar–Daban block* vary mainly from 2.5 to 2.2 Ga with $\varepsilon_{Nd}(T) = -15.5$ to -12.0. Geochronological and Nd isotopic data for granitoids of the Slyudyanka and Khamar–Daban blocks suggest that their parental melts were produced by partial melting of long-lived crustal material probably of Paleoproterozoic age and more younger possibly Neoproterozoic sources.

The known oldest rocks of the *Gargan block* are tonalites of the Sumsunur complex with U–Pb zircon age of 785 ± 11 Ma (Kuzmichev et al., 2001) that mark collision of the Gargan block with ca 1.0 Ga old the Dunzhugur ensimatic island arc (Khain et al., 2002). These tonalites yield strongly negative $\varepsilon_{Nd}(T)$ of -13.2 (Fig. 5) and an Archean–Paleoproterozoic Nd model age T_{DM} of 2.5 Ga ($T_{DM2} = 2.6$ Ga) (Figs. 3 and 4). Ordovician (476 ± 14 and 450 ± 36 Ma) granites presenting remobilised basement have younger model ages $T_{DM2} = 1.9–1.8$ Ga and $\varepsilon_{Nd}(T) = -8.2$ to -6.1 (Khain et al., 1995 b). The tonalites of the Tannuola complex (465 Ma) have lowest T_{DM} age of 1.4 Ga and $\varepsilon_{Nd}(T) = -2.5$. There are no available geochronological and Nd isotopic data for basement gneisses of the Gargan block. That is why we can only suggest their Archean or Paleoproterozoic age. In summary, Neoproterozoic–Early Paleozoic granitoids of the Gargan block were formed by reworking of Paleoproterozoic to Archean basement with addition of Neoproterozoic material.

The *Sangilen block* consists of metasedimentary sequences with different geological histories (Kozakov et al., 1999a,b, 2001; Salnikova et al., 2001). The early amphibolite facies metamorphic event took place in the Moren complex at 536 ± 6 Ma. The sedimentary rocks of the Erzin complex were undergone granulite facies metamorphism at 494 ± 11 Ma (Salnikova et al., 2001). The Erzin, Moren and Naryn supracrustals were juxtaposed to one another and 570 ± 2 Ma old Agardag ophiolites (Pfander et al., 1997) at 521 ± 12 to 497 ± 3 Ma. T_{DM2} model ages of terrigenous metasediments of these complexes vary from 2.2 to 1.4 Ga (Kozakov et al., 2003) that together with SHRIMP data on detrital zircons (ca 750–700 in the Moren complex and 900–800 Ma in the Erzin complex) (Kozakov et al., 2001; Salnikova et al., 2001) suggest their derivation mainly from Neoproterozoic granitoids formed in an Andean-type active continental margin.

The granitoids of the Sangilen block were mainly intruded during 536 ± 6–521 ± 12 Ma and 497 ± 4–489 ± 3 Ma events. The granitoids emplaced before collision of the Sangilen block and the Agardag ophiolite complex are characterized by Nd model ages $T_{DM2} = 1.8$–1.5 Ga and $\varepsilon_{Nd}(T)$ values from -6.2 to -3.0 (Figs. 4 and 5) (Kozakov et al., 2003). Geological and Nd isotopic data imply their formation by partial melting of country rocks. The second group of granitoids yield younger Nd model ages of 1.4–1.2 Ga and $\varepsilon_{Nd}(T) = -2.5$ to $+0.5$. It would suggest derivation of primary melts from long-lived crustal materials tectonically juxtaposed with short-lived juvenile sources.

The Barguzin microcontinental composite block (Fig. 1) is fringed on the north, north-west and south-west by The Baikal–Muya and Dzhida mobile belts and on the south by Early Cambrian Udino–Vitim volcanic zone. It consists of mainly Late Carboniferous (ca 330–290 Ma (see summary and references in Yarmolyuk et al. (1997)) granitoids that form the huge Barguzin batholith. Unfortunately there are no geochronological data available about protoliths ages of country metamorphic and sedimentary rocks. On the base of geological and Nd isotopic data this megablock could be subdivided into the Barguzin–Vitim and Udino–Vitim structure zones. The granitoids of the Barguzin–Vitim zone are characterized by wide range of Nd model ages $T_{DM2} = 2.4$–2.0 and 1.7–1.1 Ga (Fig. 4) with peak at 1.65–1.35 Ga and $\varepsilon_{Nd}(T)$ values of -16.2 to -10.6 and -7.1 to -0.4, respectively (Yarmolyuk et al., 1999) (Fig. 5). The granitoids with Paleoproterozoic Nd model ages are distributed along the north-western margin of the Barguzin-Vitim zone near Baikal Lake where highly metamorphosed rocks are exposed. The granitoids of the Udino-Vitim zone that were formed in an active continental margin setting don't show Paleoproterozoic Nd model ages (Fig. 4). They are characterised by $T_{DM2} = 1.4$–0.9 Ga and $\varepsilon_{Nd}(T) = -3.4$ to $+1.7$. Nd as well as Sr and Pb–Pb on feldspars isotopic data suggest formation of granitoids primary melts by partial melting of lower crust with possible addition from 'juvenile' sources (Yarmolyuk et al., 1997 a).

Granitoids of the *Altai microcontinental composite block* (Fig. 1) situated among the Hercynian mobile belts posses slightly negative $\varepsilon_{Nd}(T)$ values from -3.3 to -0.1 and Mesoproterozoic Nd model ages of 1.3–1.1 Ga (Figs. 4 and 5) (Kruk et al., 1999). According to Hu et al. (2000) the Chinese Altai Mountains is composite terrane probably formed by accretion of Phanerozoic subduction complexes with entrained Proterozoic basement rocks as microcontinental blocks.

In summary, it is necessary to note that the Baidarik block of the Dzabkhan microcontinental 'composite' block is the only one well-documented microcontinental fragment of the CAMB with Archean basement. Probably within the Gargan block there is also Archean or Paleoproterozoic basement. At the present time only Paleozoic and Mesozoic granitoids are identified in other microcontinental 'composite' blocks of the CAMB. They are characterized by Paleo- to Neoproterozoic Nd model ages (2.5–0.9 Ga) and wide range of $\varepsilon_{Nd}(T)$ values from -16.2 to $+2.2$ that suggest involvement in generation of their primary melts a long-lived crustal as well as more juvenile probably Neoproterozoic sources. A conspicuous feature of the microcontinental 'composite' blocks is mainly Mesoproterozoic Nd model ages from ca 1.6 to 1.1 Ga (Fig. 5) that are not characteristic for basement rocks of the Siberian Craton (Kovach et al., 2000).

4.2. Caledonian province

The tectonics and magmatism of the Caledonian mobile belts that coincide with the Caledonian isotope province of the CAMB are described by Kovalenko et al. (1995) and Dergunov et al. (2001). Magmatic evolution of the Caledonian province started from formation of ophiolites in ensimatic island arc and back-arc settings (Khain et al., 1995; Kovalenko et al., 1996c,d; Kuzmin et al., 1996). Plagiogranites from ophiolite complexes dated by the U–Pb zircon method yield Vendian (Neoproterozoic-III) ages ca 570 Ma (570 ± 2 Ma in the Agardag complex, Pfander et al., 1997; 573 ± 6 Ma, Daribi complex, Kozakov et al., 2002a; 568 ± 4 Ma, Khan–Taishiri complex, Gibsher et al., 2001). Gabbros from the Bayan–Khongor and Lake zone ophiolite complexes were dated by Sm–Nd isochron method at 569 ± 21 Ma (Kepenzhinskas et al., 1991) and 527 ± 43 and 522 ± 13 Ma (Kovalenko et al., 1996c,d). Basalts and plagiogranites of the Lake zone, Khan–Taishiri, Agardag and Bayan–Khongor island arc complexes are characterized by high positive $\varepsilon_{Nd}(T)$ values from $+9.6$ to $+8.0$ that are close to average DM values (Fig. 6). Some gabbros and plagiogranites from the Bayan–Khongor complex yield $\varepsilon_{Nd}(T)$ values of +11.8 to +11.5 that are higher than in DM. Gabbros from Lake zone island arc complex shows $\varepsilon_{Nd}(T) = +7.0$ to +6.6 and plagiogranites from the Daribi ophiolites are characterized by 'low' $\varepsilon_{Nd}(T)$ values of +5.6 to +5.4. Nd isotopic data suggest that rocks of Vendian–Cambrian (?) ophiolite complexes were formed from heterogeneous variously depleted mantle sources. Such heterogeneity could be partly caused by subduction of variable amounts of sediments with different isotopic composition or/and by influence of subduction-derived fluids or addition from enriched plume source (Kovalenko et al., 1996d).

Sediments associated with igneous ophiolite rocks have variable $^{147}Sm/^{144}Nd$ ratios of 0.2146–0.1834 and 0.1485–0.1248, $\varepsilon_{Nd}(T)$ values from +8.7 to +7.1 and +6.5 to + 5.3, respectively (Fig. 6). Nd model ages for sediments with $^{147}Sm/^{144}Nd < 0.15$ are 0.94–0.76 Ga that are close to T_{DM} of felsic volcanics and granitoids of island arc complexes.

Andesite–basalts, andesites and dacites of the island arc complexes of the Lake ophiolite zone yield the same range of the $\varepsilon_{Nd}(T)$ values from +9.6 to +7.0 as basalts and gabbros (Fig. 6) but with lower $^{147}Sm/^{144}Nd$ of 0.1529–0.1073 compared to 0.1859–0.1504. Nd model ages T_{DM} for felsic volcanics vary from 0.74 to 0.56 Ga and are slightly older than their crystallization age. Nd isotopic data imply that long-lived enriched crustal materials were involved in petrogenesis of primary melts of juvenile sialic crust of the Caledonian province.

The Caledonian orogeny at the CAMB was terminated by collision of island arc complexes and microcontinental blocks at ca 490 Ma ago that expressed in amphibolite to granulite facies metamorphism of island arcs and microcontinental rocks (Kovalenko et al., 1996c; Kozakov et al., 1999a,b, 2002a; Salnikova et al., 2001). Syn- and post-collisional granitoids of tonalite–granodiorite–granite composition intruded the island arc complexes at 510 ± 7 to 507 ± 14 Ma in the Dzhida zone, 495 ± 5, 465 ± 10 and 441 ± 5 Ma in the Lake zone (unpublished data of authors), 490 ± 4 Ma in the Daribi complex (Kozakov et al., 2002a) and 457 ± 3–451 ± 6 Ma in Tannuola complex (Kozakov et al., 2001; Salnikova et al., 2001). They exhibit crustal $^{147}Sm/^{144}Nd$ ratios (~0.135–0.105), high positive values of $\varepsilon_{Nd}(T) = +7.7$ to +5.2 and Neoproterozoic Nd model ages $T_{DM} = 0.74$–0.61 Ga ($T_{DM2} = 0.77$–0.60 Ga) similar to model ages of the felsic volcanics (Kozakov et al., 2003). On the ε_{Nd}-Age diagram (Fig. 6) the points of Nd isotopic composition of these granitoids lie in and below of the Nd isotope evolution field for the felsic volcanics that suggest progressive involvement of the long-lived crustal sources in the formation of granitoid melts.

Granites of the Caledonian province belt that were formed in the active continental margin setting of the Hercynian paleocean at ca 440–360 and 340–250 Ma (Table 1) show decreasing $\varepsilon_{Nd}(T)$ values (+4.3 to +2.7 and +3.8 to +0.9, respectively) and increasing Nd model ages ($T_{DM2} = 0.92$–0.76 and 0.96–0.77 Ga) and fall in and below the field of Nd isotopic evolution of island arc igneous rocks (Fig. 6). Note that granitoid formation in the Caledonian province after island arcs—microcontinents collision was related with processes in Hercynian and Indosinian mobile belts as well as with intraplate processes. Nd isotopic data suggest that in the studied areas there was no significant addition of new juvenile material to the continental crust from depleted mantle sources during these magmatic events.

Mesozoic granitoids related to the collision of the North-Asia and Sino-Korean continents and intraplate igneous activity (Table 1) posses slightly positive to negative values of $\varepsilon_{Nd}(T) = +2.6$ to −2.1 (Fig. 6) and Neo- to Mesoproterozoic Nd model ages $T_{DM2} = 1.1$–0.8 Ga and approach to Nd isotopic composition of Paleozoic granitoids emplaced within Precambrian microcontinental 'composite' blocks (Fig. 5). On the ε_{Nd}-Age plot (Fig. 6) the Mesozoic granitoids lie mainly between fields of Nd isotope evolution for the island arc felsic igneous rocks and terrigenous metasediments of the microcontinental blocks. It indicates that parental melts of the Mesozoic granitoids most probably were formed from mixed sources consisting of relatively juvenile 'Caledonian' and long-lived crustal materials.

In summary, granitoids of the Caledonian mobile belt are characterized by narrow limits of Nd model ages of 1.1–0.55 Ga (Figs. 3 and 4) and $\varepsilon_{Nd}(T)$ values (±3 units) for granitoids close in age (Fig. 6).

4.3. Hercynian province

This province belongs to the South Mongolian mobile belt. It borders the Caledonian mobile belt and from the south, transit to the Hercynian structures of the north-west China and then Kazakhstan and are cut by younger structures of the Great Hinjiang in eastern China. As in the Caledonian mobile belt magmatic evolution of the Hercynian province starts from formation of ophiolite complexes in ensimatic island arc environment (Ruzhentsev and Burashnikov, 1995; Dergunov et al., 2001) (Table 1). According to geological data the ophiolites of the Gobi Altai were formed in the Late Ordovician—Early Silurian (Dergunov et al., 2001). Poorly defined Sm–Nd whole rock isochron gives age of ca 450 Ma (our unpublished data). At this time oceanic basins with turbidite sedimentation were formed. Island arcs with greywacke sedimentation had been formed during Silurian and Devonian whereas collision of the Hercynian island arcs with the Caledonian continent occurred in the Middle Carboniferous time. Thus geological data suggest that Hercynian continental crust of the CAMB had been formed by transformation of oceanic crust via subduction to juvenile island arc and continental crust.

Available Nd isotopic data are in agreement with this conclusion. Basalts of the ophiolite complex are characterized by high values of $\varepsilon_{Nd}(0.45) = +7.9$ to +6.9 close to but lower than those of average depleted mantle (+9.0) (Fig. 5). Reduced $\varepsilon_{Nd}(T)$ values could result from more enriched mantle sources (Kovalenko et al., 1999). Granitoids and felsic volcanics with ages of ca 300–260 and 125 Ma also show high positive $\varepsilon_{Nd}(T)$ values from +6.1 to +3.3 and Neoproterozoic–Cambrian Nd model ages $T_{DM2} = 0.8–0.5$ Ga (Figs. 3 and 4). It should be particularly emphasized that granitoids of the Hercynian province have higher $\varepsilon_{Nd}(T)$ values than similar age granitoids of the Caledonian province. Nd isotopic data allow us to suggest that felsic igneous rocks of the Hercynian province of the CAMB were formed by partial melting of young juvenile sources with some addition of old crustal material and indicate distinct—'Hercynian'—crust-forming event in the CAMB. After formation of syn-collisional felsic magmatic rocks development of granitoids in the Hercynian province have continued in response to subduction processes in the Indosinian mobile belt and intraplate activity.

4.4. Indosinian province

Two mobile belts—Mongolo–Okhotsk and Solonker—represent the Indosinian province of the CAMB. The Mongolo–Okhotsk mobile belt was formed during the final stage of the Mongolo–Okhotsk oceanic basin formation—between the Siberian Craton and the Xing'an–Bureya microcontinental megablock. The Solonker mobile belt was formed in the course of collision between the North Asia and Sino-Korean continents. Formation of ensimatic island arc ophiolites occurred 320 Ma ago (Pb–Pb zircon age; O.Tomurtogoo, pers. comm.) in the Mongolo–Okhotsk belt and in Late Carboniferous–Early Permian time in the Solonker mobile belt (Ruzhentsev et al., 1990; Dergunov et al., 2001). These data are in agreement with the age (309 ± 8 Ma) of island arc rocks of the Baolidao complex (Chen et al., 2000). According to geological data (Ruzhentsev et al., 1990; Dergunov et al., 2001) the deformation and metamorphic events in the Solonker mobile belt took place in Late Permian–Triassic time. In the Dzhargalantuin trough the collision had finished at ca 210 Ma ago (Yarmolyuk et al., 2002).

Nd isotopic data for rocks of the Indosinian province are meager. Ophiolite basalts of the Mongolo-Okhotsk mobile belt are characterised by $\varepsilon_{Nd}(0.32) = +9.8$ to $+6.2$ (Fig. 5). Tonalites-trondhjemites of the Zhanchivlan pluton (207 ± 7 Ma) of the Dzhargalantuin trough yield $\varepsilon_{Nd}(T) = +8.0$ and $T_{DM} = 0.33$ Ga (Fig. 3) and have been formed from juvenile island arc crust with little addition of long-lived crustal material. Granitoids of the southern part of the Solonker mobile belt have variable values of $\varepsilon_{Nd}(T) = +2.4$ to -2.2 and $T_{DM2} = 1.2–0.9$ Ga (Chen et al., 2000). These data are interpreted as due to contamination of parental melts by old crustal material.

In summary, the continental crust of the Caledonian, Hercynian and Indosinian provinces of the CAMB was formed from respective juvenile sources with addition of old crustal materials during separate crust-forming events. The granitoids of the CAMB can be subdivided on $\varepsilon(+)$ and $\varepsilon(-)$ types—first formed from mainly 'juvenile' and the second from mainly old crustal sources.

5. Sr–Nd characteristics of the intraplate magmatism of Central Asia

Sr and Nd data for intraplate magmatic rocks from Central Asia (Kovalenko et al., 1999a,b, 2001a,b, 2002; Yarmolyuk et al., 1995, 1996, 1997a,b, 1999b, 1998, 2000, 2001, 2002; Vorontsov et al., 1997; our unpublished data) are summarized in Figs. 7 and 8. The diagram also shows the evolution fields of common mantle sources (EM-I and EM-II enriched mantle, DM and HIMU) as well as the continental crust of Central Asia. The composition of continental crust is represented by the isotopic composition of granitoids from the vast Barguzin, Khangai and Khentei batholiths. Data for within-plate magmatic associations of Central Asia are plotted within the fields of all above model sources and are mainly located in the mantle correlation array. However, within-plate rocks of different age have distinct isotopic compositions (Figs. 7 and 8).

The composition of Neoproterozoic rare-metal carbonatites from Eastern Sayan Highlands are plotted mostly in the province for sources strongly depleted in Nd and Sr, between MORB and HIMU, but some of these rocks are relatively enriched in radiogenic Sr (Fig. 7). The rocks from the Middle Paleozoic within-plate magmatic provinces are also characterized by the positive, relatively constant $\varepsilon_{Nd}(T)$ values (often $>+5$) and are similar with Neoproterozoic rocks having, however, less variation of initial $^{87}Sr/^{86}Sr$. As a whole, Sr and Nd isotopic compositions of the rocks from the Neoproterozoic and Early Palaeozoic provinces are relatively akin, although on average the Neoproterozoic association is somewhat enriched in radiogenic Sr relatively to Middle Palaeozoic rocks and are involved DM, HIMU, island arc and newly formed continental crust sources. The Late Paleozoic intraplate magmatic province (Central-Asian rift system) data points are partly (Gobi–Tian–Shan belt) plotted in the Middle Paleozoic field. However, most of them (Gobi–Altaian and Northern Mongolian rift systems) are located between DM, HIMU, the batholiths (Neoproterozoic continental crust) and EMII fields (Fig. 7). Single points are shifted to the EMI trend. Limited isotope data for the Mesozoic Mongolo–Transbaikalian within-plate province show that the sources of bimodal magmatic association are similar to Late Paleozoic rocks and are plotted in the Fig. 7 between of DM (or HIMU), continental crust and EM-II. Isotopic compositions of the Cenozoic intraplate rocks are also distributed between of DM (HIMU), continental crust (batholiths) and EM-I (Fig. 7 and 8).

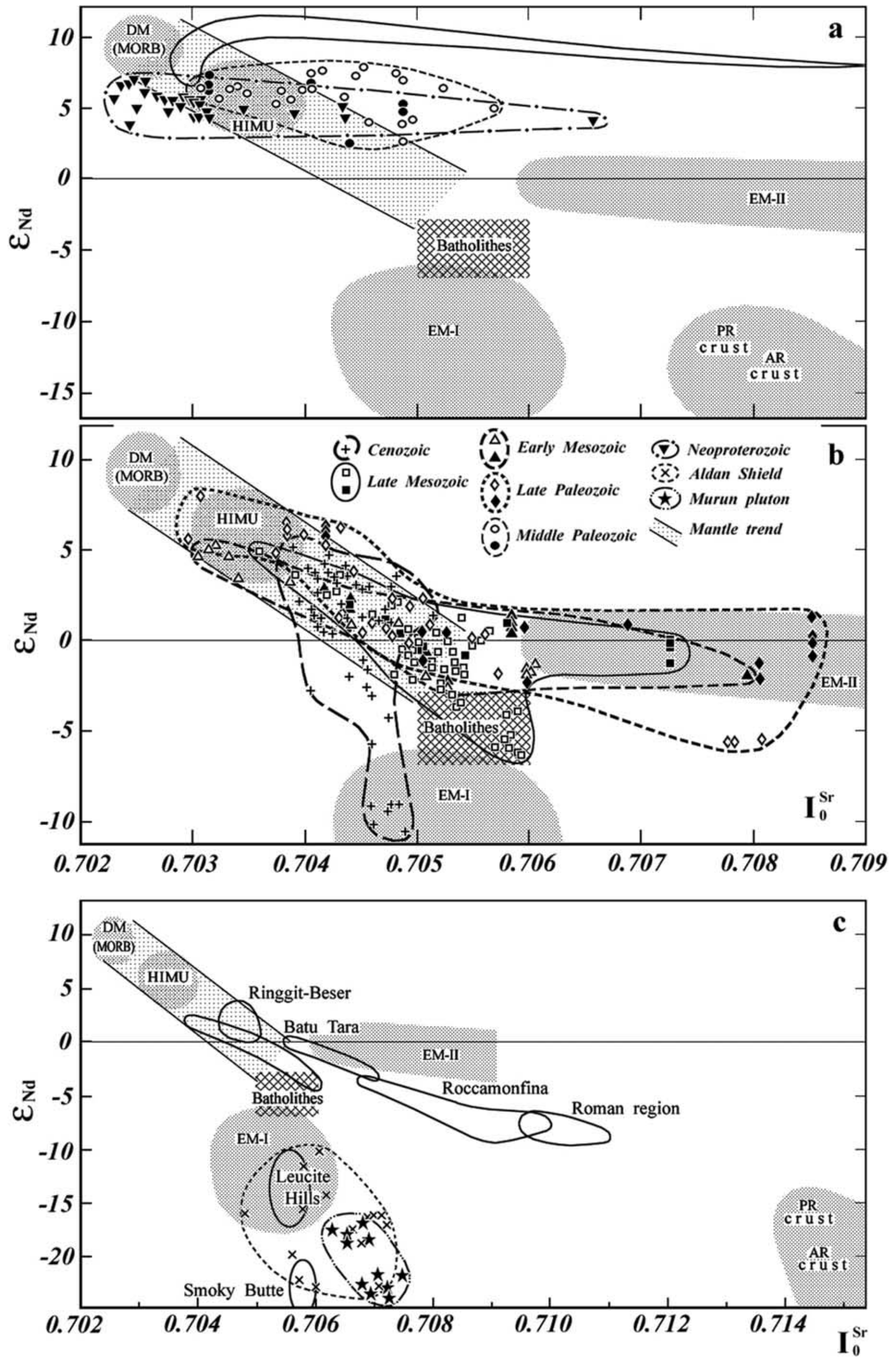

Fig. 7. $\varepsilon_{Nd}(T)$ vs initial $^{87}Sr/^{86}Sr$ diagram for itraplate magmatic rocks of the CAMB. Typical sources of mantle and continental crust are shown for comparison. Data sources from Kogarko et al. (1995), Yarmolyuk et al. (1995, 1996, 1997a,b, 1999b, 1998, 2000, 2001), Vorontsov et al. (1997) and Kovalenko et al. (1999a,b, 2001, 2002); references in these publications and our unpublished data. Fields DM, HIMU, EM-I and EM-II according to Zindler and Hart (1986). (a) Isotopic compositions of Neoproterozoic (carbonatites) and Middle Paleozoic (peralkaline granitoids, subalkaline basalts, nepheline syenites, etc.) alkaline rocks; (b) isotopic compositions of Late Paleozoic and Early Mesozoic alkaline rocks (peralkaline granitoids, comendites, pantellerits, subalkaline basalts); (c) isotopic compositions of Late Mesozoic (comendites, pantellerits, subalkaline basalts, phonolites, tephrites, etc.) and Cenozoic (subalkaline and alkaline basalts) alkaline rocks.

Based on the data for the Permian–Triassic traps of the Siberian Craton and the Western Siberian riftogenic associations of the same age, Yarmolyuk and Kovalenko (2000) have concluded that the intraplate magmatic activity has been controlled by similar-composition mantle sources during of the Late Paleozoic and Mesozoic. These sources differ in the composition from the Middle Paleozoic within-plate sources as well as from the later (Cenozoic) intraplate magmatic associations. The Cenozoic within-plate magmatism is represented by high alkaline basic rocks that are

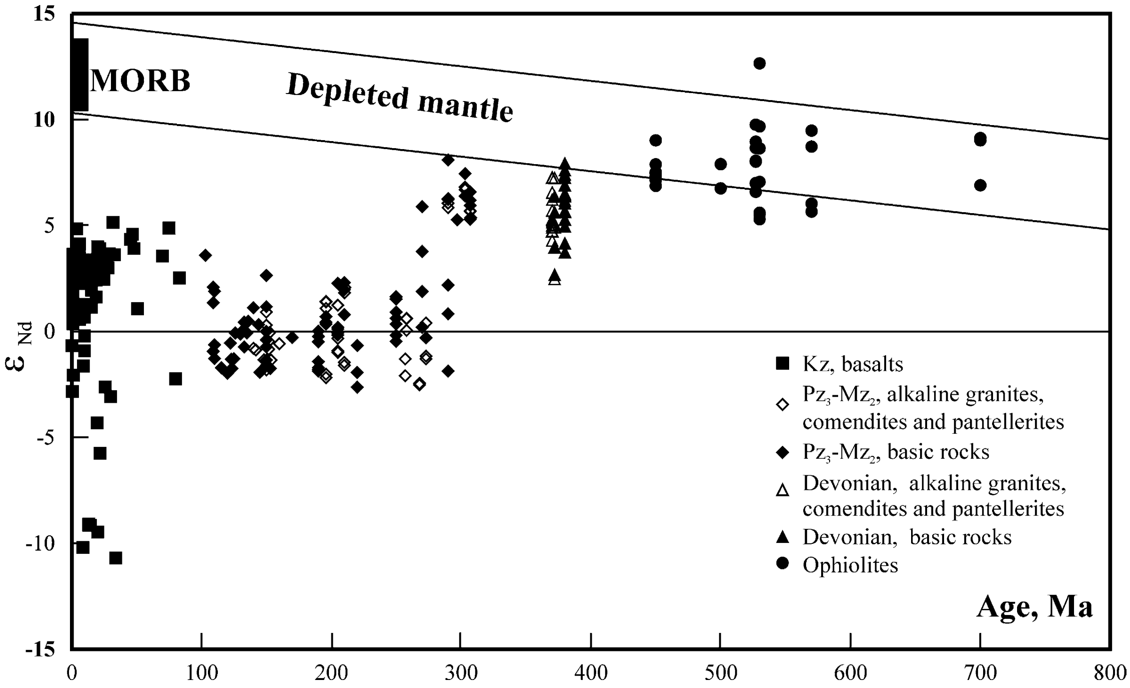

Fig. 8. $\varepsilon_{Nd}(T)$ vs primary age diagram for within-plate basic and felsic rocks of the CAMB. Data sources as in Fig. 7.

widespread within Central Asia. As Fig. 7 shows, the isotopic compositions of these rocks are flanked by DM (HIMU), EM-I, batholiths and EM-II fields.

6. Discussion

6.1. Isotope structure and mechanisms of continental crust formation

On the base of Nd isotope data for granitoids two types of the continental crust in the CAMB could be distinguished—isotopically homogenous (small variations of Nd isotopic composition for garnitoids of close in age) and isotopically heterogeneous (large variations of $\varepsilon_{Nd}(T)$ and T_{DM}) (Fig. 5). Continental crust of the Caledonian, Hercynian and Indosinian mobile belts belongs to the first type whereas the continental crust of the microcontinental 'composite' blocks to the second.

Isotopically homogenous crust continental crust of the Caledonian, Hercynian and Indosinian provinces of the CAMB is characterized by similarity of Nd isotopic composition (± 3 $\varepsilon_{Nd}(T)$ units) of granitoids of the similar ages and their mainly positive $\varepsilon_{Nd}(T)$ values (the $\varepsilon_{Nd}(+)$ granites, according to Kovalenko et al. (1996b). This crust is typified by wide distribution of basic rocks of the ophiolite and island arc complexes and associated sediments. It is important to note that $\varepsilon_{Nd}(T)$ values for granitoids of similar age increase and Nd model ages decrease in direction from the Caledonian to Hercynian and probably to the Indosinian provinces (Fig. 5). It could be caused by continuous accretion of all more young juvenile crust from the north to the south during consolidation of the CAMB.

Felsic igneous rocks of the Caledonian and Hercynian provinces are characterized by Nd model ages of 1.1–0.6 and 0.8–0.5 Ga (Fig. 4) that are older than ages of the earliest magmatic rocks (ca 570 and 450 Ma, respectively). Such phenomena may be explained by partial melting of juvenile crust of respective ages. However, rocks of such crystallization ages are not known in the Caledonian and Hercynian provinces (Dergunov et al., 2001). On the other hand, older Nd model ages could result from melting of mixed sources consisting of juvenile components with high positive $\varepsilon_{Nd}(T)$ values and long-lived crustal material with low negative values of $\varepsilon_{Nd}(T)$ and old (Mesoproterozoic to Archean) Nd model ages. We suppose that the second reason is much more real because of studied ophiolite complexes always consist of basic and felsic volcanics (juvenile material) and terrigenous sedimentary rocks. Recently we have discussed such model on more limited data (Kovalenko et al., 1996a). Now new geochronological and Nd isotopic data are available for island arc complexes of the Caledonian province. That is why the mechanisms of continental crust formation will be considered using this example.

Fig. 6a shows Nd isotopic compositions for rocks of the Caledonian province as a whole and Fig. 6b shows Nd isotopic data for magmatic (basalts, andesites and dacites) and sedimentary rocks of island arc complexes and granitoids from the Lake zone of the western Mongolia. Sediments interbanded with volcanics of basalt-andesite-dacite association are characterized by lower $\varepsilon_{Nd}(T)$ values mainly of +6.5 to +5.2 (opposite to +9.8 to +8.1 in basalts and +9.6 to +7.0 in andesites and dacites) (Fig. 6b) and older Nd model ages $T_{DM} = 0.98-0.76$ Ga (0.68–0.56 Ga in felsic volcanics). Most likely it is caused by addition of sediments from surrounding continental blocks into oceanic basins. We suggest that juvenile continental crust (island arc felsic volcanics) of the Caledonian province was formed by partial melting of mantle sources and subducted sediments (Kovalenko et al., 1996a) and assimilation - fractional crystallisation—contamination of parental melts by sediments intercalated within the arc crust. Syn- and post-collisional granitoids (ca 495–440 Ma) of the Lake zone yield older Nd model ages $T_{DM} = 0.73-0.60$ Ga and $\varepsilon_{Nd}(0.52) = +7.9$ to $+6.5$ that lie between those for felsic volcanics and sedimentary rocks. On the ε_{Nd}-Age diagram (Fig. 6b) the points of Nd isotopic composition for the granitoids fall in and below the field of Nd isotopic evolution of felsic volcanics. It implies that melting of island arc volcanics and associated sediments could explain increasing Nd model ages and decreasing $\varepsilon_{Nd}(T)$ values in the Caledonian crustal rocks even for earliest granitoids.

The correlation line approximating isotopic compositions of granitoids of the Caledonian province as a whole and Lake zone in particular has a slope that corresponds to $^{147}Sm/^{144}Nd$ ratio of 0.03 (Fig. 6a and b). No terrestrial reservoir could have so low ratio. Most probably this line corresponds to mixing line of juvenile continental crust and long-lived crustal materials (sediments) when ever-younger granites are formed with progressive addition of an old crustal component. We suggest that after Caledonian accretional–collision processes (500–480 Ma; Table 1) composition of granitoid sources changed in time due to erosion of microcontinental blocks that are characterized by Mesoproterozoic to Archean Nd model ages. Such addition will increase Nd model ages of continental crust as whole and make the correlation line steeper (Fig. 6). Constant erosion of Precambrian microcontinental blocks and possibly the basement of the Siberian Craton could explain the increasing proportion of such sediments after its collision with the CAMB. For example, the Early Mesozoic granites of the Khentei batholith that were formed by partial melting of sediments of the Khentei trough have $\varepsilon_{Nd}(T)$ values from -0.2 to -1.4 whereas sediments yield $\varepsilon_{Nd}(T) = -2.5$.

On other hand, a similar effect may have resulted from tectonic mixing (tectonic layering of the lithosphere) during collision of island arcs and microcontinental blocks. As result of such layering the fragments of microcontinental crust could have been transferred to basement of island arcs complexes on sloping overthrust sheets and vice versa. Dipping of melting isotherms will increase proportion of material situated in the basement of the crust (Kovalenko et al., 1999b).

In summary, juvenile continental crust of the Caledonian and, probably, the Hercynian and Indosinian provinces have been formed in island arc setting with involvement of crustal materials (in form of sediments) during accretion–collision processes of island arcs–microcontinental blocks amalgamation. Ever-younger granitoids were formed by successive reworking of such tectonically layered continental crust with progressive addition of erosion products from microcontinental blocks.

Nd isotope compositions of granitoids of the microcontinental blocks vary between wide limits even for rocks of similar age. As a rule, the Phanerozoic granitoids of the microcontinental blocks have negative $\varepsilon_{Nd}(T)$ values and can be typified as ε_{Nd} (−) granites (Kovalenko et al., 1996a).

Terrigenous metasediments of the microcontinental blocks (excluding the Baidarik block) that comprise their basement are characterized by T_{DM} from 2.2 to 1.3 Ga (Fig. 5) (Salnikova et al., 2000; Kozakov et al., 2003; and unpublished data). It is necessary to note that Nd model ages younger than ca 2.1 Ga are not typical for basement of the Siberian Craton (Kovach et al., 2000). Thus, another non-Siberian source with younger Nd model ages should be involved in the sedimentation. We suggest that terrigenous and carbonate rocks of the microcontinental blocks were formed within the shelf of the Rodinia supercontinent (Kovalenko et al., 1999b; Yarmolyuk et al., 1999a). Mesoproterozoic island arc complexes and Paleoproterozoic–Archean basement of the supercontinent were the sources of the sediments. Deep sections of the microcontinental blocks were deformed and metamorphosed during Caledonian accretion–collision processes. As a result microcontinental blocks like the Sangilen block (Kozakov et al., 1999a,b, 2001; Salnikova et al., 2001) have combined metamorphosed Neoproterozoic sediments, weakly or non-metamorphosed carbonate rocks and the Caledonian island arc complexes. Isotopic data for granitoids are in agreement with model of vertical zoning of microcontinental blocks when old continental crust is underlined by or interbanded with the Caledonian juvenile crust (Kovalenko et al., 1996a; Kozakov et al., 1997, 2003; Salnikova et al., 2001). Melting of such isotopically heterogeneous sources could explain wide variations of model ages and $\varepsilon_{Nd}(T)$ in granitoids emplaced in the microcontinental blocks.

The intraplate magmatic activity in the CAMB was practically synchronous with orogenic magmatism (Table 1) due to different depth of source regions and also gave input to chemical composition of the CAMB continental crust. In fact all post-collision granitoids can be classified as intraplate granitoids. As a result of the heat flow from mantle plumes and within-plate basic melts the intraplate magmatism caused a remelting of continental crust that led to more contrast chemical but not isotopic differentiation of the crust.

Jahn et al. (2000a,b) show that the granitoids of the classic Caledonian and Hercynian belts of Europe belong to the $\varepsilon_{Nd}(-)$ type of our classification while the granitoids of Caledonian and Hercynian mobile belts of the CAMB belong to mainly $\varepsilon_{Nd}(+)$ type. We propose that Caledonian and Hercynian continental crust of Europe comprise significant part of old crustal materials whereas continental crust of the Caledonian and Hercynian provinces of the CAMB contains mainly short-lived 'juvenile' components. Such differences probably related to various mechanisms of continental crust formation. Caledonian and Hercynian mobile belts of the CAMB had been formed by amalgamation of island arcs and Precambrian microcontinental blocks. This mechanism could be named 'island arc accretionary' mechanism with formation of 'accretionary orogens' (Windley, 1995). Regions where $\varepsilon_{Nd}(-)$ granitoids are predominant were formed mainly by collision of old continental blocks and such mechanism could be named 'continental collision' mechanism with formation of 'collisional orogens' (Windley, 1995). On the other hand, long-term intraplate magmatic activity in the CAMB had led to repeated remelting of the Caledonian and Hercynian continental crust after its consolidation up to 120 Ma ago. As a result postorogenic granites formed within Caledonian and Hercynian provinces inherit its Nd isotopic signatures, i.e. have similar Nd model ages and positive but lower $\varepsilon_{Nd}(T)$ values, that increase amount of the $\varepsilon_{Nd+}(+)$ granitoids in the CAMB.

6.2. Estimation of the crustal growth rate

Jahn et al. (2000a,b) and the authors of this article (Kovach et al., 1999; Kovalenko et al., 2001b) have concluded that the main impulse of juvenile crust-forming activity in the CAMB occurred during Phanerozoic time. According to traditional ideas, the generation of the terrestrial continental crust was almost completed to the Archean–Proterozoic boundary, and further geological history accomplished only by redistribution of old crustal material (see references in Jahn et al. (2000a,b)). According to Jahn et al. (2000a,b) within the CAMB the continental crust growth during of Phanerozoic was significant and proportion of juvenile component are estimated as 70–100%.

Herein, we try to estimate the crustal growth rate in Phanerozoic time based on our data available for the CAMB that, as was mentioned above, amalgamate WE-trending mobile belts located between the Siberian and Sino-Korean cratons. Our study focused on the central segment of the CAMB with size of about 2.5 Mkm^2. The continental crust of this belt was formed mainly from Neoproterozoic to the Early Mesozoic time (1000–200 Ma). Some older crustal segments are extremely limited. Four main crustal provinces are distinguished within the CAMB: the Precambrian, Caledonian, Hercynian and Indosinian, which occupy approximately equal-size areas. Therefore we can evaluate the crustal growth rate during of different stages of the geological history of the CAMB. The age of earliest ophiolite complexes built a province has been used as proper reference point. Thus, the duration of crust-forming episode for the Caledonian province was estimated as at 570–490 Ma, the Hercynian province formation episode has last at ca 450–320 Ma and the Indosinian province formed during at 340–200 Ma. Therefore, the durations of each province formation are comparable and were about 80–140 Ma. For simplicity we assume that duration of crust-forming events for microcontinental blocks was the same.

The continental crust of the CAMB is characterized by the thickness is at about 50 km (Zorin et al., 1999) and from this point is comparable with many other regions having the mature continental crust (Reymer and Schubert, 1984). Therefore, above data on the volume of the continental crust in the CAMB and the age limits of its formation allow us to estimate the continental crust growth rate during of latest billion years. Thus, we suppose that the territory of the studied part of the CAMB was grown by newly formed continental crust on about 0.31 Mkm^2 per each 100 Ma. Estimation for separate isotope provinces gives more high growth rate—about 0.42 Mkm^2 per each 100 Ma. To compare this growth estimation with crustal formation processes in the Earth scale we should to emphasize that the studied CAMB is belongs to Eurasian Caledonian and Hercynian belt extended from the eastern margin of Asia to British Isles (Mossakovsky, 1975) and makes about of its quarter. The Caledonian and the Hercynian structures build up also mobile belts of the Ural, Appalachian, Eastern Australia, which are coeval with considered region of the CAMB. If to suppose that CAMB takes no more than 1/7 from the total volume of the Earth's continental crust formed during of time interval 1000–200 Ma, the average rate of the crust growth could be evaluated as more than 2.2 Mkm^2 (110 Mkm^3) per 100 Ma. From our point of view, this minimum estimation is less than average rate of the Earth's continental block formation (3.73 Mkm^2 per 100 Ma) calculated based on the uniformity of crust formation processes during of the Earth history. Our calculations are similar to estimation of grustal growth rate in Mesozoic and Cenozoic time (1.1 km^3/y) (Samson and Patchett, 1991; Reymer and Schubert, 1984). Presumably, it is demonstrating some deceleration of crust formation rate at the geological time but undoubtedly indicate that these rates are comparable from one stage to another one.

6.3. Geodynamic scenario for the evolution of the CAMB

General tectonic scenario of the CAMB is still controversial. Sengor et al. (1993) suggest the growth of Central Asia is by successive accretion of subduction complexes along a single magmatic arc. According to the evolution of the CAMB could be outlined in a frame of multistage model including 'step-by-step' formation of Caledonian, Hercynian and Indosinian accretionary-orogenic belts. To constrain a principal geodynamic model for the evolution of the CAMB it is necessary to take into consideration the following critical points:

1. The break up of Rodinia was caused by the Southern-Pacific hot mantle superplume activity (Maruyama, 1994).
2. The microcontinental blocks of CAMB with Precambrian basement represent shelf regions of Rodinia. Sediments derived by erosion of island arcs and continental margins were deposited on shelf and subsequently recovered by carbonate deposits.
3. Accretionary–collision processes occurred during of the Caledonian mobile belt evolution (closure of the Caledonian basins of the Central-Asian paleoocean) and amalgamation of the Caledonian composite terrain took place during the short period of ca 500–480 Ma.
4. The ages of the orogenic complexes decrease from north to south, away from the Siberian Craton margin (according to modern geographical position).
5. There is no evidence for Caledonian collision processes and magmatic activity within the southern margin of the Siberian Craton.
6. The tectonic boundary between the Siberian Craton and the CAMB is characterized by strike slip movementst.
7. The intraplate magmatic activity within the Caledonian terrains of the western segment of the CAMB continued since Late Cambrian to the Late Devonian (490–360 Ma) without any significant interruption. This and composition of magmatic rocks (subalkaline and alkaline basalts, sienites and granites) as well as their isotopic and geochemical characteristics indicate plume character of the intraplate magmatism and its stable position over the Altai-Sayan mantle plume.
8. Available paleomagnetic data demonstrate that the Siberian Craton, unlike the Altai-Sayan terrain, during 460–360 Ma, experienced a large-scale transposition ($\sim 20°$) to the north (Powell et al., 1993; Gurnis and Torsvik, 1994; Scotese, 1994; Li et al., 1995; Pavlov and Gallet, 1998; Dergunov et al., 2001; Kravchinsky et al., 2002).
9. At least the western part of the Caledonian microcontinent of the CAMB was spatially separated from the Siberian Craton at the Ordovician and Silurian (Zonenshain et al., 1990). Probably they were amalgamated during Early Devonian time, when the intraplate magmatism had spread beyond the Altai–Sayan terrain to adjacent regions of the Siberian Craton.

A possible geodynamic scenario for the evolution of the CAMB based on the outlined critical points is given in Fig. 9 and briefly described below.

Following the Rodinia supercontinent break up (Fig. 9a), fragments of the continental crust (microcontinental blocks with Precambrian basement), as well as intervening island arcs and back arc basins representing a proto-Caledonian isotope province, drifted in the same direction as the Siberian Craton. In Early Cambrian time, this ‘structural collage’ was involved into the zone of influence of the North-Asian mantle hot field (Fig. 9b and c). Oceanic plateaux and islands with subalkaline high-Ti basalts formed within this zone. At the present time they take part as tectonic sheets in geological structure of ophiolite complexes of the CAMB (Kovalenko et al., 1996d; Al’mukchamedov et al., 1996; Gusev and Peskov, 1996). During of time interval 530–490 Ma the rates of lithospheric movements reached up 40 sm/year (Torsvik et al., 1996). The collision of rapidly drifted Precambrian and Caledonian lithosphere fragments with oceanic islands occurred at ca 500 Ma and has lead to the creation of the Caledonian microcontinent (Fig. 9c). As was mentioned above, the collision process spread from the outer edge (relative to modern boundary with the Siberian Craton) to inner edge of the collisional collage. During the collision event the margin of the Caledonian microcontinent has overlapped the Altai-Sayan mantle hot spot thereby initiated the long-term within-plate magmatic activity in the region (Fig. 9c and d). For example, first alkaline rock complexes (alkaline sienites and granites, Li–F granites, gabbro-monzonites) in the Sangilen block of the Tuvino–Mongolian microcontinent were formed in similar age interval (490–465 Ma) with regional metamorphism of amphibolite and greenschist facies (497–480 Ma) (Kozakov et al., 1999a,b, 2001; Salnikova et al., 2001). Alkaline rocks were formed from the mantle source regions ($\varepsilon_{Nd}(T) = +4.5$ to $+1.0$) opposite to normal granites derived mainly from long-lived crustal sources ($\varepsilon_{Nd}(T) = -6.2$ to -3.0) (Kozakov et al., 2002a). The collision of the Caledonian microcontinent with the Siberian Craton was completed by Devonian time and occurred apparently along the transform fault boundary (Zonenshain et al., 1990). This idea accounts for absence of any trace of magmatic and metamorphic processes usually accompanying the frontal collision within the craton and at the Caledonian mobile belt and also explains displacement character of the southern margin of the Siberian Craton as well as the truncation of folding structures of the Caledonian microcontinent (Fig. 9d).

During Late Devonian time the Siberian continent and incorporated adjacent Caledonian microcontinent (Caledonian mobile belt) moved to the inner zones of the mantle hot field. To the Carboniferous the Siberian continent and Caledonian microcontinent collided with island arcs that were formed between the mantle hot field oceanic islands. As a result of this collision event the Hercynian mobile belt was formed and newly formed active continental margin extended beyond at least of two hot spots—the Siberian and Mongolian—connected to the common ‘mantle hot field’ (Yarmolyuk et al., 2000, 2001). Influence of these hot spots on the continental margin continued during Permian and Triassic time and produced remarkably large-scale magmatic within-plate activity in the Central Asia at the time interval 300–190 Ma.

It seems that the Northern-Asian continent during Late Paleozoic and Early Mesozoic time was located above the hot mantle field and experienced only rotation (Yarmolyuk

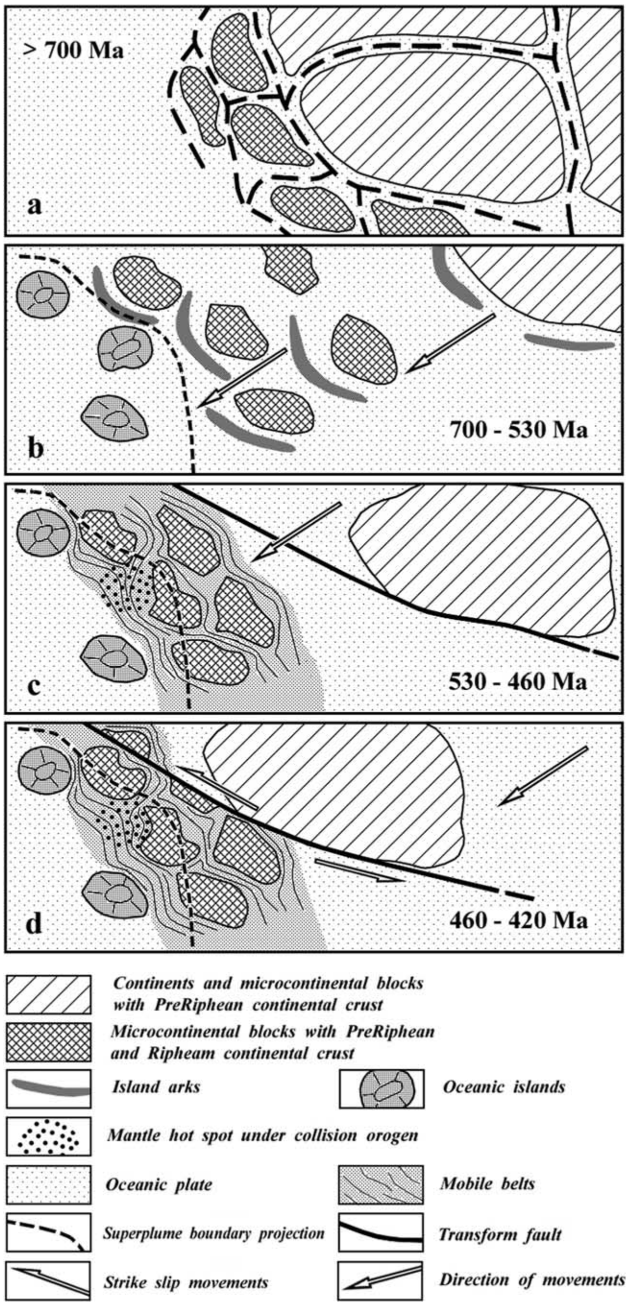

Fig. 9. Model of formation of the CAMB as result of collision of island arcs and microcontinental blocks of the Paleoasian ocean with oceanic island system of the North-Asian mantle hot field. See explanations in text.

et al., 2000; Yarmolyuk and Kovalenko, 2000). This time the lithosphere plate included the Northern-China Craton and adjacent frontal island arc complexes were drifting toward the Northern-Asian Craton from the margin, opposite to the hot mantle field. Oblique collision (scissors-type) of two cratons resulted in oceanic basin closure and formation of the Indosinian mobile belt.

Consequently, the growth of the continental crust of the CAMB occurred mainly in a result of collision of young terrains (island arc, back arc basins complexes and shelf fragments) with mantle-derived oceanic islands. The old (pre-Caledonian) continental crust was not involved in these collisional process on a very large scale. Thus, products of erosion of the Neoproterozoic terrains have been added to the Caledonian island arc complexes and products of destruction of the Caledonian microcontinent and Neoproterozoic terrains combined with the Hercynian island arcs etc. Furthermore, the isotopic composition of continental *crust* within the above isotopic provinces could be changed due to processes of tectonic layering in the basement of collided terrains the juvenile crust with older continental masses, for example at the collision of the Caledonian island arcs and microcontinental blocks.

The particular feature of the Siberian Craton and the CAMB collision occurred after the Caledonian microcontinent creation is ‘soft’ collision scenario without of metamorphism and producing of collisional granitoids. Correspondingly, there were no processes of tectonic ‘crowding’ and layering accompanied with mixing of heterogeneous crustal material. Obviously, that is why continental crust of the isotope provinces of the CAMB retained their isotopic characteristics after collision with the Siberian Craton.

7. Conclusions

1. The following isotope provinces have been recognised in the CAMB on the basis of geochronological and Nd isotopic data: ‘Precambrian’ ($T_{DM} = 3.3–2.9$ and 2.5–0.9 Ga), that is considered as fragments of the continental crust of the ‘old’ continents, ‘Caledonian’ ($T_{DM} = 1.1–0.55$ Ga), ‘Hercynian’ ($T_{DM} = 0.8–0.5$ Ma) and ‘Indosinian’ ($T_{DM} = 0.3$ Ga) that coincide with coeval tectonic zones and formed at 570–475, 420–320 and 310–220 Ma.
2. The Precambrian province appear as the basement of microcontinental blocks. The basement protoliths were formed not early 800–750 Ma ago afterward the Rodinia supercontinent break up, as a result of erosion of passive margins of former-Rodinia cratons. The Caledonian, the Hercynian and the Indosinian provinces with juvenile crust produced as a result of depleted mantle transformation into the oceanic crust, than transition and finally into the continental crust. The Precambrian continental crust of the microcontinent is underlying by or intermixed with younger ‘juvenile’ crust that expressed in it isotopic heterogeneity. The continental crust of the Caledonian, Hercynian and Indosinian provinces is isotopically homogeneous and was produced from respective juvenile sources (as a result of depleted mantle transformation into the oceanic crust, then transition—and finally into the continental crust) with addition of old crustal material in the island arcs or active continental margin environments during distinct crust-forming events. After collision of the Caledonian,

Hercynian and Precambrian terrains young postcollisional granites were formed from respective continental crust and inherit its isotopic signatures. By this means the crustal growth in Central Asia had episodic character and important crust-forming events (‘Caledonian’, ‘Hercynian’ and ‘Indosinian’) took place in the Phanerozoic. Oceanic crust of the CAMB was produced by melting of depleted mantle with some share of enriched (plume) mantle.

3. Intraplate magmatism preceded and accompanied permanently other magmatic activity in the CAMB, and, finally, has terminated the igneous activity in the belt.
4. Formation of the CAMB was connected with break up of the Rodinia supercontinent in consequence of creation of the South-Pacific hot superplume. The microcontinental blocks of the CAMB were also formed at this time. Subduction of cold lithosphere beneath the Siberia continent that was broken from the Rodinia resulted in formation of ‘cold’ lower mantle under the modern CAMB and its consolidation by accretion (since the Cambrian) of the microcontinental blocks and Caledonian, Hercynian and Indosinian island arcs. Young continental crust was formed at the time of their closing. Within-plate magmatism proceeding with accretion and continued during formation of the CAMB was caused either by influence of the long-term South-Pacific plume or the Asian plume damping since the Devonian, which could be ridged over by the drifted Siberia during Middle Paleozoic time.

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References

Allegre, C.J., Ben Othman, D., 1980. Nd–Sr relationship in granitoid rocks and continental crust development: a chemical approach to orogenesis. Nature 286, 335–342.

Arndt, N.T., Goldstein, S.L., 1987. Use and abuse of crust-formation ages. Geology 15, 893–895.

Al’mukchamedov, A.I., Gordienko, I.V., Kuz’min, M.I., Tomurtogoo, O., Tomurkhuu, D., 1996. The Dzhida zone: a fragment of the Paleoasian ocean. Geotectonics 30 (4), 279–294.

Belichenko, V.G., Sklyarov, E.V., Dobretsov, N.L., Tomuttogoo, O., 1994. Geodynamic map of the Paleoasian Ocean. Geology and Geophysics 35 (7–8), 29–40.

Berzin, N.A., Coleman, R.G., Dobretsov, N.L., Zonenshain, L.P., Xuchan, X., Chang, E.Z., 1994. Geodynamic map of the western Paleoasin Ocean. Geology and Geophysics 35 (7–8), 8–29.

Chen, J., Jahn, B.M., 1998. Crustal evolution of southeastern China: Nd and Sr isotopic evidence. Tectonophysics 284, 101–133.

Chen, B., Jahn, B., Wilde, S., 2000. Two contrasting paleozoic magmatic belts in northern Inner Mongolia, China: petrogenesis and tectonic implications. Tectonophysics 328, 157–182.

Condie, K.C., 1998. Episodic continental growth and supercontinents: a mantle avalanche connection? Earth and Planetary Science Letters 163, 97–108.

DePaolo, D.J., 1988. Neodymium Isotope Geochemistry: An Introduction, Springer, New York, 187 pp..

DePaolo, D.J., Linn, A.M., Schubert, G., 1991. The continental crust age distribution methods of determining mantle separation ages from Sm–Nd isotopic data and application to the southwestern United States. Journal of Geophysical Research 96, 2071–2088.

Dergunov, A.B., Kovalenko, V.I., Ruzhentsev, S.V., Yarmolyuk, V.V., 2001. Tectonics, magmatism, and metallogeny of Mongolia, Routledge Taylor and Francis Group, London and New York, 288 pp.

Didenko, A.N., Mossakovskii, A.A., Pecherskii, D.M., Ruzhentsev, S.V., Samygin, S.G., Kheraskova, T.N., 1994. Geodynamics of the Central-Asian Paleozoic Ocean. Geology and Geophysics 35 (7–8), 59–76.

Dobretsov, N.L., Kidryashkin, A.G., 1994. Deep geodynamics, OIGGM SO RAN, Novosibirsk, p. 300 (in Russian).

Frost, B.R., Avchenko, O.V., Chamberlain, K.R., Frost, C.D., 1998. Evidence for extensive Proterozoic remobilization of the Aldan shield and implication for Proterozoic plate tectonic reconstructions of Siberia and Laurentia. Precambrian Research 89, 1–23.

Gibsher, A.S., Khain, E.V., Kotov, A.B., Salnikova, E.B., Kozakov, I.K., Kovach, V.P., Yakovleva, S.Z., Fedoseenko, A.M., 2001. Late Vendian age of the Khan–Taishiri ophiolite complex in western Mongolia. Geology and Geophysics 42 (8), 1179–1185.

Goldstein, S.J., Jacobsen, S.B., 1988. Nd and Sr isotopic systematics of rivers water suspended material: implications for crustal evolution. Earth and Planetary Science Letters 87, 249–265.

Gordienko, I.V., 1987. Paleozoic magmatism and geodynamics of the Central Asia fold belt, Nauka, Moscow, p. 283 (in Russian).

Gurnis, M., Torsvik, T.H., 1994. Rapid drift of large continents during the Precambrian and Paleozoic: paleomagnetic constraints and dynamic models. Geology 22, 1023–1026.

Gusev, G.S., Peskov, A.I., 1996. Ophiolite of Eastern Transbaikalia: Geochemistry and origin. Geochemistry International 34, 650–663.

Hu, A., Jahn, B.M., Zhang, G., Chen, Y., Zhang, Q., 2000. Crustal evolution and Phanerozoic crustal growth in northern Xinjiang: Nd isotopic evidence. Part I. Isotopic characterization of basement rocks. Tectonophysics 328, 15–51.

Jacobsen, S.B., Wasserburg, G.J., 1984. Sm–Nd evolution of chondrites and achondrites. II. Earth and Planetary Science Letters 67, 137–150.

Jahn, B.M., Gruau, G., Capdevila, R., Cornichet, J., Nemchin, A., Pidgeon, R., Rudnik, V.A., 1998. Archean crustal evolution of the Aldan Shield, Siberia: geochemical and isotopic constraints. Precambrian Research 91, 333–363.

Jahn, B.M., Wu, F., Chen, B., 2000. Granitoids of the Central Asian Orogenic Belt and continental growth in the Phanerozoic. Transactions of the Royal Society of Edinburg 91, 181–193.

Jahn, B., Wu, F., Chen, B., 2000. Massive granitoid generation in Central Asia: Nd isotope evidence and implication for continental growth in the Phanerozoic. Episodes 23, 82–92.

Kepenzhinskas, P.K., Kepenzhinskas, K.B., Puchtel, I.S., 1991. Lower Paleozoic oceanic crust in Mongolian Caledonides: Sm–Nd isotope and trace element data. Geophysical Research Letters 18, 1301–1304.

Keto, L.S., Jacobsen, S.B., 1987. Nd and Sr isotopic variations of Early Paleozoic oceans. Earth and Planetary Science Letters 84, 27–41.

Khain, V.E., 2001. Tectonics of oceans and continents, Nauchnyi Mir, Moscow, p. 379 (in Russian).

Khain, E.V., Amelin, Yu.V., Izokh, A.E., 1995. Sm–Nd data about age of ultrabasic-basic complexes in the obduction zone of the western Mongolia. Transactions (Doklady) of the Russian Academy of Sciences. Earth Science Section 341, 791–796.

Khain, E.V., Neymark, L.A., Amelin, Yu.V., 1995. Caledonian stage of remobilisation of the Precambrian basement of the Gargan Glyba, Eastern Sayan (isotopic-geochronological data). Transactions (Doklady) of the Russian Academy of Sciences. Earth Science Section 342, 776–780.

Khain, E.V., Bibikova, E.V., Kroner, A., Zhuravlev, D.Z., Sklyarov, E.V., Fedotova, A.A., Kravchenko-Berezhnoy, I.R., 2002. The most ancient ophiolite of the Central Asian fold belt: U–Pb and Pb–Pb evidence from the Dunzhugur Complex, Eastern Sayan, Siberia, and geodynamic implications. Earth and Planetary Science Letters 6202, 1–16.

Kheraskova, T.N., Samygin, S.G., Ruzhentsev, S.V., Mossakovsky, A.A., 1995. Late Riphean continental margin volcanic belt of the East Gondwana. Transactions (Doklady) of the Russian Academy of Sciences. Earth Science Section 342 (5), 661–664.

Kogarko, L.N., Kononova, V.A., Orlova, M.P., Woolley, A.R., 1995. Alkaline rocks and carbonatite of the world: part 2, Former USSR, Chapman & Hall, New York, pp. 226.

Kotov, A.B., Kovach, V.P., Salnikova, E.B., Glebovitsky, V.A., Yakovleva, S.Z., Berezhnaya, N.G., Myskova, T.A., 1995. Continental crust age and evolution in the central Aldan granulite-gneiss terrain: U–Pb and Sm–Nd data on granitoids. Petrology 1, 97–108.

Kotov, A.B., Salnikova, E.B., Reznitskii, L.Z., Vasilev, E.P., Kozakov, I.K., Yakovleva, S.Z., Kovach, V.P., Berezhnaya, N.G., 1997. Age of metamorphism of the Slyudyanka crystalline complex, southern Baikal area: U–Pb geochronology of granitoids. Petrology 5, 338–349.

Kotov, A.B., Shemyakin, V.M., Salnikova, E.B., Kovach, V.P., 1999. Formation stages and isotope structure of the continental crust of the Sutam Block, Aldan Shield: evidence from Sm–Nd isotope systematics of granitoids. Transactions (Doklady) of the Russian Academy of Sciences. Earth Science Section 367, 695–697.

Kovach, V.P., Kotov, A.B., Salnikova, E.B., Berezkin, V.I., Smelov, A.P., Zagornaya, N.Yu., 1996a. Sm–Nd isotopic systematics of the Kurumkan subgroup, the Iengra Group of Aldan shield. Stratigraphy and Geological Correlation 4, 213–219.

Kovach, V.P., Velikoslavinskii, S.D., Kotov, A.B., Salnikova, E.B., 1996b. Sm-Nd isotopic systematics of the acid metavolcanites of the Fedorov group in the Aldan Shield (middle reaches of the Timpton river). Transactions (Doklady) of the Russian Academy of Sciences. Earth Science Section 347, 345–347.

Kovach, V.P., Kotov, A.B., Berezkin, V.I., Salnikova, E.B., Velikoslavinskii, S.D., Smelov, A.P., Zagornaya, N.Yu., 1999a. Age limits of high-grade metamorphic supracrustal complexes in the Central Aldan shield: Sm–Nd isotopic data. Stratigraphy and Geological Correlation 7, 1–14.

Kovach, V.P., Kovalenko, V.I., Yarmolyuk, V.V., Kotov, A.B., Kozakov, I.K., Salnikova, E.B., 1999b. Isotopic structure and crust-forming events of Central Asia: evidence for extensive continental crust growth in the Phanerozoic, Ninth Annual V.M. Goldschmidt Conference, LPI Contribution No 971, Lunar and Planetary Institute, Houston, pp. 160.

Kovach, V.P., Kotov, A.B., Smelov, A.P., Staroseltsev, K.V., Salnikova, E.B., Zagornaya, N.Yu., Safronov, A.F., Pavlushin, A.D., 2000. Evolutionary stages of the continental crust in the buried basement of the eastern Siberian Platform: Sm–Nd isotopic data. Petrology 8, 353–365.

Kovalenko, V.I., Yarmolyuk, V.V., 1990. Magmatic evolution in structures of the Mongolia. In: Zaitsev, N.S., Kovalenko, V.I. (Eds.), Evolution of Geological Processes and Metallogeny of the Mongolia, Nauka, Moscow, pp. 23–53, in Russian.

Kovalenko, V.I., Yarmolyuk, V.V., Bogatikov, O.A., 1995. Magmatism, Geodynamics And Metallogeny of Central Asia, Mico, Moscow, pp. 272.

Kovalenko, V.I., Yarmolyuk, V.V., Kovach, V.P., Kotov, A.B., Kozakov, I.K., Salnikova, E.B., 1996a. Sources of phanerozoic granitoids in Central Asia: Sm–Nd isotope data. Geochemistry International 34 (8), 628–640.

Kovalenko, V.I., Yarmolyuk, V.V., Kozakov, I.K., Kovach, V.P., Kotov, A.B., Salnikova, E.B., 1996b. Sm–Nd isotope provinces of the earth's crust in Central Asia. Transactions (Doklady) of the Russian Academy of Sciences. Earth Science Sections 348, 562–564.

Kovalenko, V.I., Pukhtel, I.S., Yarmolyuk, V.V., Zhuravlev, D.Z., Stosch, H., Jagoutz, E., 1996c. The Sm–Nd Isotopic systematics of ophiolites in the Ozernaya Zone (Mongolia). Stratigraphy and Geological Correlation 4, 107–113.

Kovalenko, V.I., Yarmolyuk, V.V., Pukhtel, I.S., Stosch, H., Jagoutz, E., Korikovsky, S.P., 1996d. Igneous rocks and magma sources of the Ozernaya Zone Ophiolites, Mongolia. Petrology 4, 420–460.

Kovalenko, V.I., Kostitsyn, Yu.A., Yarmolyuk, V.V., Budnikov, S.V., Kovach, V.P., Kotov, A.B., Salnikova, E.B., Antipin, V.S., 1999a. Magma sources and the isotopic (Sr and Nd) evolution of Li–F rare-metal granites. Petrology 7, 401–429.

Kovalenko, V.I., Yarmolyuk, V.V., Kovach, V.P., Budnikov, S.V., Zhuravlev, D.Z., Kozakov, I.K., Kotov, A.B., Rytsk, E.Y., Salnikova, E.B., 1999b. Magmatism as factor of crust evolution in the Central Asian fold belt: Sm–Nd isotopic data. Geotectonics 33, 191–208.

Kovalenko, V.I., Yarmolyuk, V.V., Kozlovskii, A.M., Ivanov, V.G., 2001a. Magmatic sources of alkaline granitoids and related rocks from intraplate magmatic associations in Central Asia. Transactions (Doklady) of the Russian Academy of Sciences. Earth Science Section 377A, 354–359.

Kovalenko, V.I., Yarmoluyk, V.V., Kovach, V.P., Budnikov, S.V., Kotov, A.B., Kozakov, I.K., Salnikova, E.B., Rytsk, E.Yu., 2001b. Isotope structure of crust and mantle in the Central Asian mobile belt: geochronological and Isotopic (Nd, Sr and Pb) data. Gondwana Research 4, 668–669.

Kovalenko, V.I., Yarmolyuk, V.V., Vladykin, N.V., Ivanov, V.G., Kovach, V.P., Kozlovsky, A.M., Kostitsyn, Yu.A., Kotov, A.B., Salnikova, E.B., 2002. Formation stages, geodynamic setting and sources of rare-metal magmatism of the Central Asia. Petrology 10 (3), 199–221.

Kozakov, I.K. (Ed.), 1993. Early Precambrian of the Central-Asian Mobile Belt, Nauka, Leningrad, pp. 180 (in Russian).

Kozakov, I.K., Kotov, A.B., Kovach, V.P., Salnikova, E.B., 1997. Crustal growth in the geologic evolution of the Baidarik block, Central Mongolia: evidence from Sm–Nd isotopic systematics. Petrology 5, 201–207.

Kozakov, I.K., Kotov, A.B., Salnikova, E.B., Bibikova, E.V., Kovach, V.P., Kirnozova, T.I., Berezhnaya, N.G., Lykhin, D.A., 1999a. Metamorphic age of crystalline complexes of the Tuva–Mongolia massif: The U–Pb geochronology of granitoids. Petrology 7, 177–191.

Kozakov, I.K., Salnikova, E.B., Bibikova, E.V., Kirnozova, T.I., Kotov, A.B., Kovach, V.P., 1999b. Polychronous evolution of the Paleozoic granitoid magmatism in the Tuva–Mongolia Massif: U–Pb geochronological data. Petrology 7, 592–601.

Kozakov, I.K., Kotov, A.B., Salnikova, E.B., Kovach, V.P., Natman, A., Bibikova, E.V., Kirnozova, T.I., Todt, W., Kröner, A., Yakovleva, S.Z., Lebedev, V.I., Sugorakova, A.M., 2001. Timing of the structural evolution of metamorphic rocks in the Tuva–Mongolian Massif. Geotectonics 35 (3), 165–184.

Kozakov, I.K., Salnikova, E.B., Khain, E.V., Kovach, V.P., Berezhnaya, N.G., Yakovleva, S.Z., Plotkina, Yu.V., 2002a. Early Caledonian crystalline rocks of the Lake zone in Mongolia: formation history and tectonics as deduces from U–Pb and Sm–Nd dating. Geotectonics 36 (2), 156–166.

Kozakov, I.K., Kovach, V.P., Kotov, A.B., Salnikova, E.B., Yarmolyuk, V.V., Zagornaya, V.V., Yu, N., 2003. Continental crust formation in the Tuvino–Mongolian Massif: Sm–Nd isotopic data. Petrology in press.

Kravchinsky, V.A., Konstantinov, K.M., Courtillot, V., Savrasov, J.I., Valet, J.-P., Cherniy, S.D., Mishenin, S.G., Parasotka, B.S., 2002. Palaeomagnetism of East Siberian traps and kimberlites: two new poles and palaeogeographic reconstructions at about 360 and 250 Ma. Geophysical Journal International 148, 1–33.

Kruk, N.N., Rudnev, S.N., Vladimirov, A.G., Zhuravlev, D.Z., 1999. Sm-Nd isotope systematics of granitoids from the Western Altai–Sayan Fold Zone. Transactions (Doklady) of the Russian Academy of Sciences. Earth Science Section 366, 569–571.

Kuzmichev, A.B., Bibikova, E.V., Zhuravlev, D.Z., 2001. Neoproterozoic (800 Ma) orogeny in the Tuva–Mongolia Massif (Siberia): island arc—continent collision at the northeast Rodinia margin. Precambrian Research 110, 109–126.

Larin, A.M., Amelin, Yu.A., Neymark, L.A., Krymsky, R.S., 1997. The origin of the 1.73–1.70 Ga anorogenic Ulkan volcano–plutonic complex, Siberian Platform, Russia: inferences from geochronological and Nd–Sr–Pb isotopic data. Annales of Academy Brasil Sciences 69, 296–312.

Larin, A.M., Nemchin, A.A., Krymsky, R.Sh., Kovach, V.P., 1999. Sm–Nd isotope limitations on the genesis of granite rapakivi of the Kodar complex, the western Aldan-Stanovoi Shield. Transactions (Doklady) of the Russian Academy of Sciences. Earth Science Section 369, 1195–1197.

Larin, A.M., Kotov, A.B., Kovach, V.P., Glebovitsky, V.A., Salnikova, E.B., Zablotsky, E.M., Zagornaya, N.Yu., 2002. Continental crust formation stages in the of the central part of the Dzhugdzhur-Stanovoy Mobile Belt: Sm-Nd isotopic data on granitoids. Transactions (Doklady) of the Russian Academy of Sciences. Earth Science Section.

Li, Z.-X., Zhang, L., Powell, C.McA., 1995. South China in Rodinia: part of the missing link between Australia–East Antarktica and Laurentia? Geology 23, 407–410.

Liew, T.C., McCulloch, M.T., 1985. Genesis of granitoid batholiths of Peninsula Malaysia and implications for models of crustal evolution: evidence from a Nd–Sr and U–Pb zircon study. Geochemica et Cosmochemica Acta 49, 587–600.

Maruyama, S., 1994. Plume tectonics. Journal of Geological Society Japan 100, 24–49.

Mossakovsky, A.A., 1975. Orogenic structures and volcanism of the paleozoids of Eurasia and their role in the continental crust formation process, Nauka, Moscow, pp. 298.

Mossakovsky, A.A., Ruzhentsev, S.V., Samygin, S.G., Kheraskova, T.N., 1994. Central Asia fold belt: geodynamic evolution and formation history. Geotectonics 27 (6), 445–474.

Mossakovsky, A.A., Puscharovsky, Yu.M., Ruzhentsev, S.V., 1998. The earth's major structural asymmetry. Geotectonics 32 (5), 339–353.

Neymark, L.A., Kovach, V.P., Nemchin, A.A., Morozova, I.M., Kotov, A.B., Vinogradov, D.P., Gorokhovsky, B.M., Ovchinnikova, G.V., Bogomolova, L.M., Smelov, A.P., 1993. Late Archaean intrusive complexes in the Olekma granite-greenstone terrain (eastern Siberia): geochemical and isotopic study. Precambrian Research 62, 453–472.

Neymark, L.A., Larin, A.M., Nemchin, A.A., Ovchinnikova, V.G., Rytsk, E.Yu., 1998. Anorogenic nature of magmatism in the Northern Baikal volcanic belt: evidence from geochemical, geochronological (U–Pb), and isotopic (Pb, Nd) data. Petrology 6, 124–148.

Pavlov, V., Gallet, Y., 1998. Upper Cambrian to Middle Ordovician magnetostratigraphy from the Kulumbe river section (northwestern Siberia). Physics of the Earth and Planetary Interiors 108, 49–59.

Pfander, J.A., Kroner, A., Kozakov, I., Oidup, C., Jochum, K.P., Todt, W., 1997. Early Paleozoic oceanic crust in Central Asia: a back-arc type (?) ophiolite zone in Tuva (southern Siberia). Ophiolite symposium and field excursion, Abstracts. Geological Survey of Finland, Special Publications 26, 26., pp. 42.

Powell, C.Mc.A., Li, Z.X., McElhinny, M.W., Meert, J.G., Park, J.K., 1993. Paleomagnete constraints on timing of the Neoproterozoic breakup of Rodinia and the Cambrian formation of Gondwana. Geology 21, 889–892.

Pusharovsky, Yu.M., 1997. The main tectonic asymmetry of the Earth: Pacific and Indo-Athlantic segments and their relationships, Tectonic and Geodynamic Phenomenas, Nauka, Moscow, 8–24 (in Russian).

Read, H.H., Watson, J., 1975. Earth History, Later Stages of Earth History, Macmillan Press, London, Part II.

Reymer, A., Schubert, G., 1984. Phanerozoic addition rates to the continental crust and crustal growth. Tectonics 3, 63–77.

Reznitskii, L.Z., Kotov, A.B., Salnikova, E.B., Vasil'ev, E.P., Yakovleva, S.Z., Kovach, V.P., Fedoseenko, A.M., 2000. The age and time span of the origin of phlogopite and lazurite deposits in the southwestern Baikal Area: U–Pb geochronology. Petrology 8 (1), 66–76.

Ruzhentsev, S.V., Badarch, G., Voznesenskaya, T.A., Markova, N.G., 1990. Tectonics of the Sowthern Mongolia. In: Zaittzev, N.S., Kovalenko, V.I. (Eds.), Evolution of Geological Processes and Metallogenesis of Mongolia, Nauka, Moscow, pp. 111–116, in Russian.

Ruzhentsev, S.V., Burashnikov, V.V., 1995. Salairides tectonics of the western Mongolia. Geotectonics 5, 25–40.

Ruzhentsev, S.V., Mossakovsky, A.A., 1995. Geodynamics and tectonic development of Paleozoid of the Central Asia as a result of interaction of Pacific and Indo-Atlantic segments of the Earth. Geotectonics 4, 29–47.

Rytsk, E.Yu., Amelin, Yu.V., Rizvanova, N.G., Krimsky, R.Sh., Mitrofanov, G.L., Mitrofanova, N.N., Perelyaev, V.I., Shalaev, V.S., 2001. Age of rocks in the Baikal–Muya fold belt. Stratigraphy and Geological Correlation 9, 315–326.

Samson, S.D., Patchett, P.J., 1991. The Canadian Cordillera, as a modern analogue of Proterozoic crustal growth. Australian Journal of the Earth Science 38, 595–611.

Samson, S.D., McClelland, W.C., Patchett, P.J., Gehrels, G.E., Anderson, R.G., 1989. Evidence from neodimium isotopes for mantle contributions to Phanerozoic crustal genesis in the Canadian Cordillera. Nature 337, 705–709.

Samson, S.D., Hibbard, J.P., Wortman, G.L., 1995. Nd isotopic evidence for juvenile crust in the Carolina terrane, southern Appalachians. Contribution to Mineralogy and Petrology 121, 171–184.

Salnikova, E.B., Kovach, V.P., Kotov, A.B., Nemchin, A.A., 1996. Evolution of continental crust in the western Aldan shield: evidence from Sm–Nd systematics of granitoids. Petrology 4, 105–118.

Salnikova, E.B., Sergeev, S.A., Kotov, A.B., Yakovleva, S.Z., Steiger, R.H., Reznitskiy, L.Z., Vasil'ev, E.P., 1998. U–Pb zircon dating of granulite metamorphism in the Sludyansliy Complex, Eastern Siberia. Gondwana Research 1, 195–205.

Salnikova, E.B., Kotov, A.B., Reznitsky, L.Z., Natman, A., Kovach, V.P., Sergeev, S.A., Yakovleva, S.Z., Barash, I.G., Belyaevsky, N.A., 2000. Geochronology of the Slyudyanka crystalline complex (southern Prebaikalie. In: Isotope dating of geological processes: new methods and results. I Russian conference on isotope geochronology. GEOS, Moscow, 324–326 (in Russian)

Salnikova, E.B., Kozakov, I.K., Kotov, A.B., Kroner, A., Todt, W., Bibikova, E.V., Nutman, A., Yakovleva, S.Z., Kovach, V.P., 2001. Age of Palaeozoic granites and metamorphism in the Tuvino–Mongolian Massif of the Central Asian Mobile Belt: loss of a Precambrian microcontinent. Precambrian Research 110, 143–164.

Scotese, C.R., 1994. Continental drift. The PALEOMAP Project, Department of Geology, University of Teas at Arlington. pp. 80

Sengor, A.M.C., Natal'in, B.A., Burtman, V.S., 1993. Evolution of the Altaid tectonic collage and Paleozoic crustal growth in Eurasia. Nature 364, 299–307.

Stosch, H.G., Ionov, D.A., Puchtel, I.S., 1995. Lower crustal xenoliths from Mongolia and their bearing on the nature of the deep crust beneath central Asia. Lithos 36, 227–242.

Taylor, S.R., McLennan, S.M., 1985. The Continental Crust: its Composition and Evolution, Blackwell Scientific Publications, Oxford, pp. 312.

Torsvik, T.H., Smethurst, M.A., Meert, J.G., Van der Voo, R., McKerrow, W.S., Brasier, M.D., Sturt, B.A., Walderhaug, H.J., 1996. Continental break up and collision in the Neoproterozoic and Paleozoic—a tale of Baltica and Laurentia. Earth-Sciences Review 40, 229–258.

Vladimirov, A.G., Gibsher, A.S., Izokh, A.E., Rudnev, S.N., 1999. Early Paleozoic granitoid batholiths of Central Asia: abundance, sources, and geodynamic formation conditions. Transactions of the Russian Academy of Sciences. Earth Science Section 369A (9), 1268–1272.

Vorontsov, A.A., Yarmolyuk, V.V., Ivanov, V.G., Sandimirova, G.P., Pakholchenko, Yu.A., 1997. Sources of basaltic melts for Devonian Rift bimodal igneous associations of Central Asia: evidence from trace-element and strontium isotopic data on basic rocks from Northeastern Mongolia. Petrology 5 (3), 208–222.

Windley, B.F., 1995. The Evolving Continents, Wiley, New York, pp. 526.

Wu, F., Jahn, B., Wilde, S., Sun, D., 2000. Phanerozoic crustal grouth: U–Pb and Sr–Nd isotopic evidence from the granites in northeastern China. Tectonophysics 328, 89–103.

Yanshin, A.L. (Ed.), 1973. Tectonics of People Republic of Mongolia, Nauka, Moscow, pp. 357, in Russian.

Yanshin, A.L. (Ed.), 1966. Tectonics of Eurasia, Nauka, Moscow, pp. 450, in Russian.

Yanshin, A.L. (Ed.), 1980. Tectonics of Northern Eurasia, Nauka, Moscow, in Russian.

Yanshin, A.L. (Ed.), 1989. Geological formations map of the Mongolia People Republic, GUGK USSR, Moscow, Scale 1:1500000.

Yarmolyuk, V.V., Kovalenko, V.I., 1991. Riftogenous Magmatism of the Active Continental Margin and it Ore-Bearing, Nauka, Moscow, p. 263 (in Russian).

Yarmolyuk, V.V., Kovalenko, V.I., Ivanov, V.G., Samoilov, V.S., 1995. Dynamics and magmatism of late Mesozoic-Cenozoic mantle hot spot, southern Khangai (Mongolia). Geotectonics 28 (5), 391–407.

Yarmolyuk, V.V., Kovalenko, V.I., Ivanov, V.G., 1996. The intraplate late Mesozoic-Cenozoic volcanic province in Central East Asia as a proection of the mantle hot field. Geotectonics 29 (5), 395–421.

Yarmolyuk, V.V., Budnikov, S.V., Kovalenko, V.I., Antipin, V.S., Goreglyad, A.V., Salnikova, E.B., Kotov, A.B., Kozakov, I.K., Kovach, V.P., Yakovleva, S.Z., Berezhnaya, N.G., 1997. Geochronology and geodynamic setting of the Angara–Vitim Batholith. Petrology 5 (5), 401–414.

Yarmolyuk, V.V., Ivanov, V.G., Kovalenko, V.I., 1998. Sources of intraplate magmatism of Western Transbaikalia in the late Mesozoic Cenozoic: trace-element and isotope data. Petrology 6 (2), 101–124.

Yarmolyuk, V.V., Kovalenko, V.I., Kovach, V.P., Budnikov, S.V., Kozakov, I.K., Kotov, A.B., Salnikova, E.B., 1999a. Nd-Isotopic Systematics of Western Transbaikalian crustal protoliths: implications for Riphean crust formation in Central Asia. Geotectonics 33, 271–286.

Yarmolyuk, V.V., Samoilov, V.S., Ivanov, V.G., Vorontsov, A.A., Zhuravlev, D.Z., 1999b. Composition and sources of basalts in the late Paleozoic rift system of Central Asia: geochemical and isotopic data. Geochemistry International 37, 921–935.

Yarmolyuk, V.V., Kovalenko, V.I., 2000. Geochemical and isotopic characteristics of the anomalous mantle of Northern Asia in the late Paleozoic–early Mesozoic: data on intraplate mafic magmatism. Transactions of the Russian Academy of Sciences. Earth Science Section 375A, 1427–1431.

Yarmolyuk, V.V., Kovalenko, V.I., Kuzmin, M.I., 2000. North Asian superplume activity in the Phanerozoic: magmatism and geodynamics. Geotectonics 34 (5), 343–366.

Yarmolyuk, V.V., Kovalenko, V.I., 2001. The Late Riphean breake up of Siberia and Laurentia and intraplate magmatism. Transactions of the Russian Academy of Sciences. Earth Science Section 379 (5), 525–529.

Yarmolyuk, V.V., Litvinovsky, B.A., Kovalenko, V.I., Jahn, B.M., Zanvilevich, A.N., Vorontsov, A.A., Zhuravlev, D.Z., Posokhov, V.F., Kuz'min, D.V., Sandimirova, G.P., 2001. Formation stages and sources of the peralkaline granitoid magmatism of the Northern Mongolia-Transbaikalia Rift Belt during the Permian and Triassic. Petrology 9, 302–328.

Yarmolyuk, V.V., Kovalenko, V.I., Salnikova, E.B., Budnikov, S.V., Kovach, V.P., Kotov, A.B., Ponomarchuk, V.A., 2002. Tectono-magmatic zonality, sources of magmatic rocks and geodynamic of the Early Mesozoic Mongolo—Zabaikalian magmatic area. Geotectonics 36 (4), 293–311.

Zanvilevich, A.N., Livinovsky, B.A., Andreev, G.V., 1985. Mongolo–Zabaikalian province of alkaline granites, Nauka, Moscow, p. 232 (in Russian).

Zindler, A., Hart, S., 1986. Chemical geodynamics. Annual Review of Earth Planetary Sciences 14, 493–571.

Zonenshain, L.P., 1972. The Geosynclinal Theory and its Application to the Central Asias Orogenic Belt, Nedra, Moscow, pp. 240.

Zonenshain, L.P., Kuzmin, M.I., Natapov, L.M., 1990. Geology of the USSR: a plate tectonic synthesis. AGU Geodynamic Series 21, 242.

Zorin, Yu.A., 1999. Geodynamics of the western part of the Mongolia–Okhotsk collisional belt, Trans-Baikal region (Russia) and Mongolia. Tectonophysics 306, 33–56.