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LARGE IGNEOUS PROVINCES, MANTLE PLUMES AND METALLOGENY IN THE EARTH'S HISTORY

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The proceeding will be interesting for geologists dealing with mafic/felsic igneous complexes and their metallogenic specialization.

Compliers of the Abstract volume:
Academician of RAS Mikhail I. Kuzmin
PhD Vasiliy A. Belyaev
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ORE-MAGMATIC SYSTEM OF ULTRABASIC-BASIC INTRUSIONS OF THE MIDDLE AND SOUTHERN TIEN-SHAN (UZBEKISTAN)

R. Akhundjanov, S.O. Zenkova, F.B. Karimova, S.S. Saydiganiev
Institute of Geology and Geophysics named by Kh.M. Abdullaev, Academy of Sciences of Republic of Uzbekistan, Tashkent, rkh.akhundjanov@mail.ru; salanj-1812@mail.ru

Ultrabasic-basic magmatism in the Western Tien-Shan expressed by the Late Precambrian to the Mesozoic in different geodynamic settings: rift, oceanic, active margin with island arcs, a series of mantle-crustal plume areas and intraplate (Akhundjanov et al. 2014; Dalimov, Ganiev, 2010; Evolution of … 1986).

The data show, that after the apogee of Late Precambrian acid magmatism and before the emergence of the main tholeitic dikes existed the time gap more than 100 m.a. In the Southern Tien-Shan the most ancient is dunite-harzburgite-gabbro association ore-bearing by chromium, platinum group metals and gold. I.Kh. Khamrabaev (2003) in the chromite ores found high contents of rare earth elements. It is assumed, that along deep faults inculcated mantle magma, which composition corresponding harzburgites. Converting them into serpentinites with chromite mineralization occurred as a result of phenomena subduction and tectonic melange. Ultrabasic-basic magmatism fixed in the Southern Tien-Shan also the formation of picrite-diabase-basalt association (table).

Following by age olivinite-wehrlite-pyroxenite-gabbro and gabbro-diabase association, ore bearing on iron and titanium.This rocks of Tebinbulak intrusive and dykes of Malguzar in Southern Tien-Shan. In the above rocks and ores observed inverse correlation between chromium and titanium. In the ultrabasic-basic magmatism specially allocated forming of graphite mineralization associated with Beltau (Taskazgan) intrusive, which locate in the Kuldzhuktau mountains (Kyzylkum), consisting, mostly gabbro-norite, augite and hornblende gabbro and gabbro-diorite. Among them observed areas, passing in pyroxenites and anorthosites. Peridotites (Lherzolites) observed as small bodies among gabbroids andit's amount less 1% of the area of the intrusive. Gabbroid intrusives, being potentially mineralized on graphite, have accessory-mineral and geochemical specialization on titanium, copper, nickel, cobalt and precious metals. Ores spread in include the intrusive carbonate rocks and in the massif (Baranov et al. 1978). Graphite nature in ultrabasites and basites presented as the primary component of peridotite magma and as a result of interaction with carbonates (Akhundjanov et al. 2014; Baranov et al. 1978; Shteinberg, Lagutin, 1984).

Given below the special features of Kuldzhuktau intrusives allow to suppose their related to magmatism of "hot spots": a variety of rock composition (wehrlites, lherzolites, troctolites, pyroxenites, norites, gabbro-norites, gabbro, anorthosites); their conformity with lime-alkaline (normal) row, potassium-sodium series of rocks; low and moderate alumina content; melano- and mesocratic, sharp predominance of ferrous iron oxide over; enrichment of magmatogenic minerals of iron and titanium; presence in rocks and ores heightened amounts of chromium, vanadium, nickel, cobalt, copper, gold and platinum, palladium; saturation of rocks such fluidogen minerals as a graphite, rare earth bearing – apatite, zircon, sphene, epidote; development of serpentine, chlorite, calcite, prehnite, sericite and other post-magmatic minerals.

Melts of Late Paleozoic pyroxenites, hornblende pyroxenites and associated with them formations of monzogabbro-sienodiorite-ongorhiolite-leucogranite and trahidolerite-syenite-ongorhiolite associations (table) emerged as a result of activation (revival) under the influence of intratelluric fluids of mantle diapir, fixed in the upper crust as a "high-speed inclusion" (Chatkal-Kurama plume by T.N. Dalimov (Dalimov, Ganiev, 2010)).

Authors seems, that in the territory of Uzbekistan expressed ultrabasic-basic intrusives, mainly of two genetic types: 1) forming from the result of functioning of fluid-rich ore-magmatic systems, typical for "hot spots" (Kyzylkum-Nurata region); 2) as a result of mantle diapirism and mixing of magmas of ultrabasic and basic composition with crustal material, which is inherent to active margins (Chatkal-Kurama region).

Ultrabasic-basic associations and related mineralization of Uzbekistan

Types of magma, geodynamic conditions	Rows of magmatic formations	Ore formations	Ore deposits
Ultrabasic, mantle, oceanic, rift	Dunite-harzburgite-gabbro	Chromite, magmatic, with noble metals	Taskuduk, Chengeldy (Tamdytau)
	Picrite-diabase-basalt, 420 m.a., S_3, $^{87}Sr/^{86}Sr$=0,7040	Same	Osmansai (Nuratau) Nadir (South Fergana)
	Low-titaniferous olivinite-wehrlite-pyroxenite-gabbro	Titanomagnetite, ilmenite, magmatic with noble metals	Tebinbulak (Sultanuizdag)
	High-titaniferous gabbro-diabase, 411 m.a., D_1, $^{87}Sr/^{86}Sr$=0,7048	Titanomagnetite, ilmenite, magmatic	Malguzar (North Nuratau)
Mantle-crust, mixed «hot spot»	Peridotite-gabbroid; gabbro-plagiogranite, 343 m.a., C_2, $^{87}Sr/^{86}Sr$=0,7054	Graphite, copper-nickel, sulfide; magmatic with noble metals, Se, Te	Taskazgan (Beltau) Kuldzhuktau, Shavaz, Aktepe
Mantle-crust, metamagmatic, continental «hot spot»	Monzogabbro-syenite diorite-adamellite-leukogranite, 308-276 m.a., C_3-P_1, $^{87}Sr/^{86}Sr$=0,7054-0,7067	Copper-nickel, copper-molybdenum, gold-silver, gold-sulphide, silver, rare-metal	Kalmakyr, Kochbulak, Kosmanachi, Charmitan, Kokpatas, Aktepe, Adrasman, Sargardon, Oygaing, Liangar
	Trachydolerite-syenite-ongorhyolite, 278-260 m.a., P_1-P_2, $^{87}Sr/^{86}Sr$=0,7070-0,7116	Rare metal, fluorite	Shavaz, Charkasar, Chauli

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LATE PALEOZOIC AND EARLY MESOZOIC RARE-METAL GRANITES OF LARGE IGENOUS PROVINCES OF BAIKAL REGION AND MONGOLIA: COMPARATIVE GEOCHEMISTRY AND MAGMA SOURCES

V.*S. Antipin*[1]*, O. Gerel*[2]*, A.B. Perepelov*[1]*, D. Odgerel*[3]
[1]Vinogradov Institute of Geochemistry SB RAS, Irkutsk, Russia,antipin@igc.irk.ru
[2]Mongolian University of Science and Technology, Ulan-Bator, Mongolia, gerel@must.edu.mn
[3]Institute of Geology and Paleontology, Mongolian Academy of Sciences, Ulan-Bator, Mongolia,d_odgerel@yahoo.com

The Central Asian fold belt (CAFB) experienced in Phanerozoic intense granitoid magmatism with formation of the vast areas encompassing huge batholiths of the Siberian craton: Angara-Vitim and Dauria-Khentey. In the Late Paleozoic and Early Cenozoic the peripheral zones underwent the rare-metal granitic magmatism associated with rare-metal mineralization (Yarmolyuk, Kuzmin, 2012). The petrological and geochemical studies provided the data on rare-metal Li-F granites formed with a gap about 100 Ma within different age large igneous provinces (areas) of the Mongol-Okhotsk belt.

Late Paleozoic rare-metal granites produce a series of multi-phase massifs, e.g. Kharagul 318±7 Ma, Bitu-Dzhida 311±10 Ma and Urugudei 321±5 Ma), which are involved in the intrusive-dyke belts in the west of the Khamar-DabanRange. The first two show intrusive rock exposures from 8 to 10 km^{2}, and more complicated structure. The rocks of the early phases of these intrusions are produced by medium-grained, in places porphyry-like biotite granites containing fluorite (to 1.4%) and magnetite (to 1.2%). In the Bitu-Dzhida massif the second phase is produced by leucogranites replaced by the phase of amazonite-albite granites. The late phase of the Kharagul massif is composed of topaz-bearing microcline- and amazonite-albite granites making up an extended intrusion and a series of 10 dykes, most of them occurring amongst hosting gneisses and crystalline schists. Feldspars in late granites consist of paragenetic microcline and albite (Ab 3-7), whereas lithium micas hold protolithionite, zinnvaldite, at times associated with lepidolite and lithium fengite-muscovite in the apical part of the intrusion. In contrast to granites of the early phases the late rare-metal granites contain topaz (to 1.5 %), columbite-tantalite, kassiterite, rarely monzanite and zirtolite. The intrusion and dyke complex of the Khamar-DabanRange, where rare-metal granites occur, as well as Utulik dyke complex formed by elvan, ongonite and topazite are associated with Sn and W ore mineralization. It consists of stockwork zones, vein bodies and mineralized breccias. The early ore formations with Sn-W and topaz contain fluorite and tourmaline; the late type of mineralization is represented by quartz-feldspar-topaz-cryolite veins bearing phenocrysts of kassiterite and volframite (Chernov et al., 1988).

The Early Mesozoic epoch was marked by formation of the enormous magmatic area with Dauria-Khentey batholith sitting in the central part (230-190 Ma) and rifting zones over its periphery with the rare-metal granite massifs.

In the Early Mesozoic, in contrast to the Late Paleozoic area of magmatism, small intrusions (Abdar massif ~ 10 km^2, 212-209 Ma) of rare-metal Li-F granites within the Abdar-Khoshutulinsky series of granitoids coexist with sizable plutons of rare-metal magmatism (Zhanchivlansky ~ 70 km^2, 227-195.3 Ma; Baga-Gazrynsky ~ 120 км^2, 197.4 Ma.) (Kovalenko et al., 2003). The central part of the Abdarsky massif encompasses medium-grained leucogranites with biotite; it is rimmed by the zone of amazonite-albite granites, also occurring in the apical parts of domes as aplite granites with schlierens of quartz-microcline pegmatites. The Bagagazryn massif, one of the largest in Mongolia, contains both leucogranites of the main phase and fine-grainedleucogranites. Rare-metal Li-F granites of the Janchivlan massif produce small domal intrusions named Bural-Khangay, Urtu-Khangay and Urtu-Gotszogor filled with microcline-albite, amazonite-albite and albite-lepidolite granites. Feldspars in the Early Mesozoic rare-metal granites represent oligoclase-albite, mica are referred to Li-Fe type of protolithionite, zinnwaldite and lepidolite, in places in association with Li fengite-muscovite.The rocks incorporate accessory minerals: fluorite, topaz, zircon, allanite, apatite, monacite, ilmenite, magnetite, columbite-tantalite, cassiterite, tourmaline. The Early Mesozoic Li-F granites of Mongolia are genetically related to Sn-W mineralization as ore-bearing veins and greisens, as well as Sn-Ta-Nb mineralization associated with albite-lepidolite granites and albitites.

The evolution of different age rare-metal granites of the Baikal region and Mongolia discloses their reference to the same geochemical of Li-F granites (fig. 1). It is expressed by growth of concentrations F, Li, Rb, Cs, Sn, Be, Ta and Pb and reduction of Sr, Ba, Zn, Zr, Th and U contents in formation of multi-phase intrusions. These geochemical data confirm the magmatic genesis of rare-metal Li-F granites. However this process of fractionation crystallization and magma differentiation is terminated with formation of albitite, microclinite and muscovite greisens being metasomatic formations associated with rare-metal mineralization.

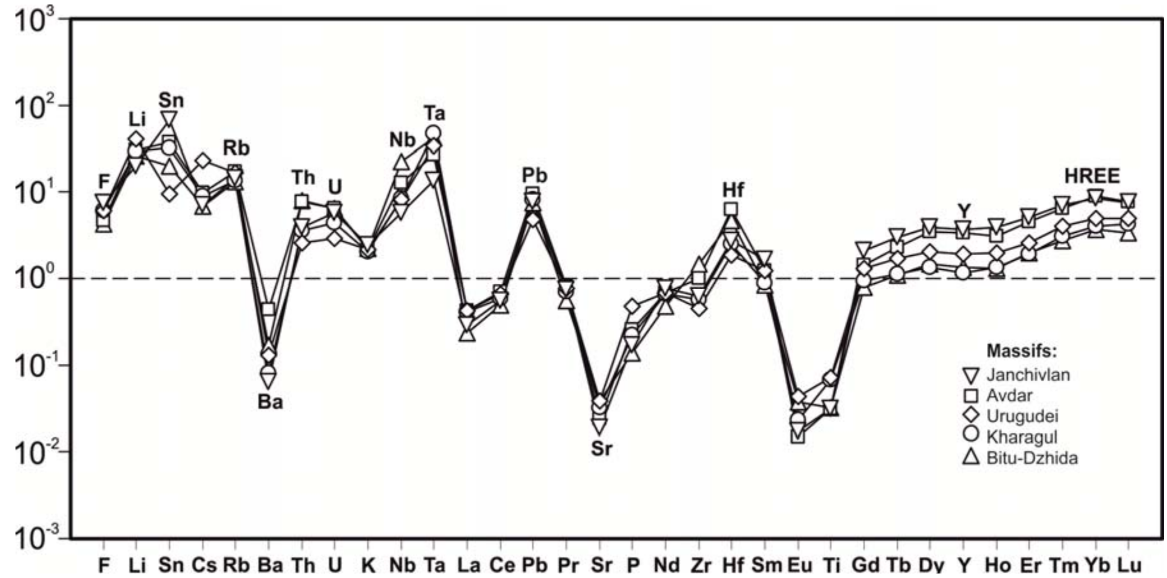

Fig. 1.Distribution of rare elements in Li-F amazonite-albite granites of Baikal region and Mongolia. Content elements ppm normalized to the composition of the bulk continental crust (Rudnick, Gao, 2003).

The isotope characteristics of granites of Bitu-Dzida massif agree with the model of formation of the initial granitoid melts at the level of low horizons of continental crust, partial melting of biotite-bearing granulites due to the rise of the asthenospheric mantle diaper (plume). Composition and isotope-geochemical features of supposed magma-forming substratum correspond to the characteristics of Precambrian crust of the Baikal region with the model age T_{DM}= 1260 Ma. The rare-metal Li-F granites of studied provinces are intra-plate formations geochemically different from the Early Paleozoic collision granitoids. This could be caused by the influence of deep-seated source on the occurrence of rare-metal magmatism.

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USAGE OF ECLOGITE THERMOBAROMETRY FOR MANTLE PETROLOGY

I.V. Ashchepkov[1], N.V. Vladykin[2], Z.V. Spetsius[2],
A.M. Logvinova[1], H. Downes[3], T. Ntaflos[4].
[1]V.S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia;
igor.ashchepkov@igm.nsc.ru
[2] Institute of Geochemistry SD RAS, Favorsky str. 1a, Irkutsk, 66403; vlad@igc.irk.ru
[3]Birkbeck College, University of London, UK, h.downes@ucl.ac.uk

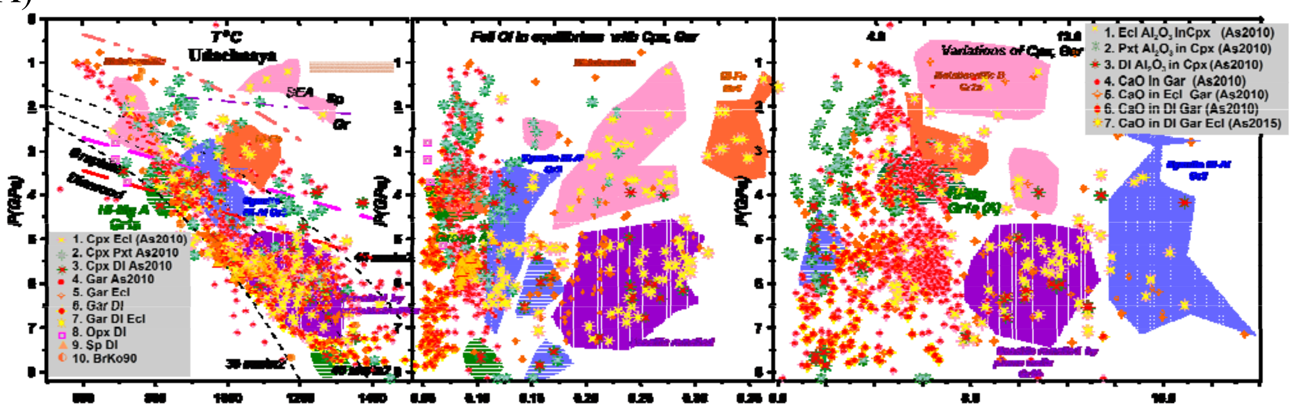
Monomineral thermobarometry for clinopyroxenes (Ashchepkov et al., 2010) and garnets (Ashchepkov et al., 2015) allow estimate the positions of 4 different eclogite groups including Mg- ,Fe-, Ca-rich and metabasaltic in the subcratonic lithospheric mantle. The Fe rich group referred to the ancient tonalites and heir derivates formed in the Early stages when the commonly mark the middle part of mantle section and so called pyroxenite layer. The Ca-rich eclogites including grospydites are common in the middle part and lower part of SCLM. They are of different origin. Specific coesite – kyanite bearing varieties probably refer to the subduction if silicic crust and their interaction with the mantle rocks. The Al- Ca and Fe low rich protolith may also correspond to the high Mg-tonalites. The Mg – rich eclogites of low are mostly partial melts in peridotite mantle appeared under the plume influences of due to subducted related fluids. The common "tholeite basaltic" eclogites are of different type origin. Those which are detected in the upper part of mantle sections

According to the KD practically all eclogites are melted and a few samples show the relic ophitic structures evidences about their sources as lower ophiolitic gabbro. The P-Fe#, X diagrams often show increasing of incompatible elements with the decreasing pressure which corresponds to magmatic differentiation if rising melts. The basaltic magma cumulates are very common in the upper part of the mantle sections in some region like in Wyoming (Ashchepkov et al., 2004) and Slave cratons (Heaman et al., 2006).

An opposite the progressive melting and reactional interaction of the partial melts with peridotites could produce an opposite tendencies. Cumulative eclogites from the plume melts are commonly produce the trends which are starting from the lithosphere base. The Gar- Cpx derivates from carbonatitic type melt are often crystallizing near the graphite – diamond boundary where the alkali carbonatite-silicate melts are breaking and became immiscible.

The examples from the different terranes of cratons and their parts shows that the positions of the different groups of eclogites in mantle sections are individual.

A)



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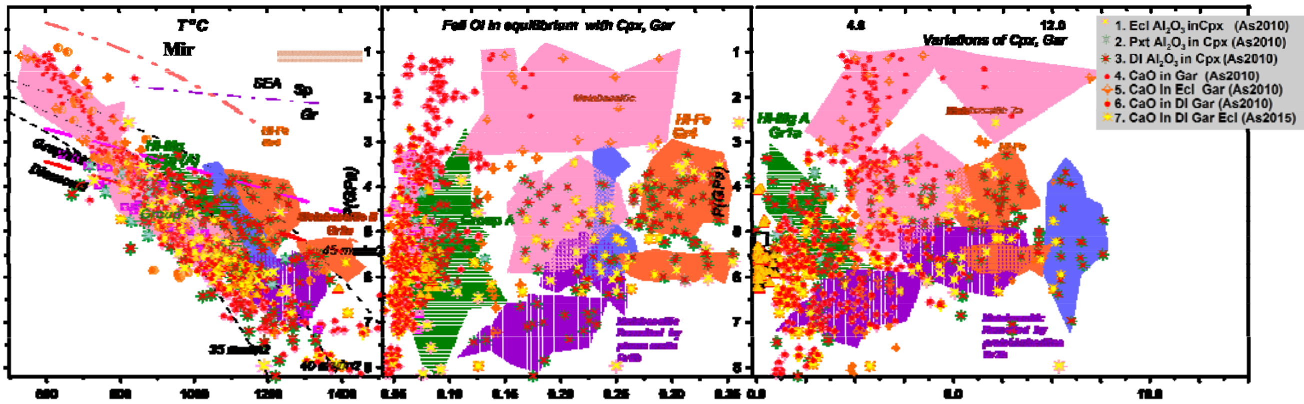
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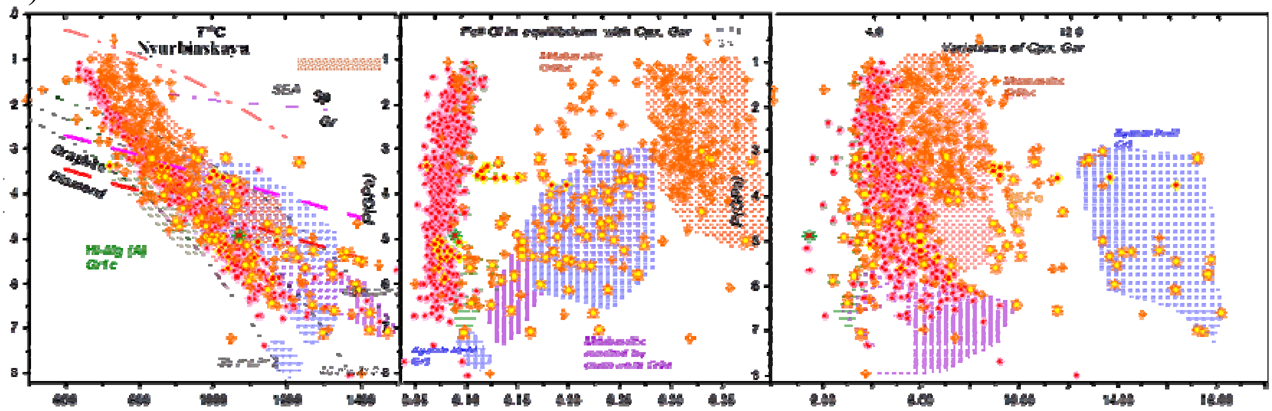
3. DI Al2O3 in Cpx (As2010)
4. CaO in Gar (As2010)
5. CaO in Ecl Gar (As2010)
6. CaO in DI Gar (As2010)
7. CaO in DI Gar Ecl (As2015)

C)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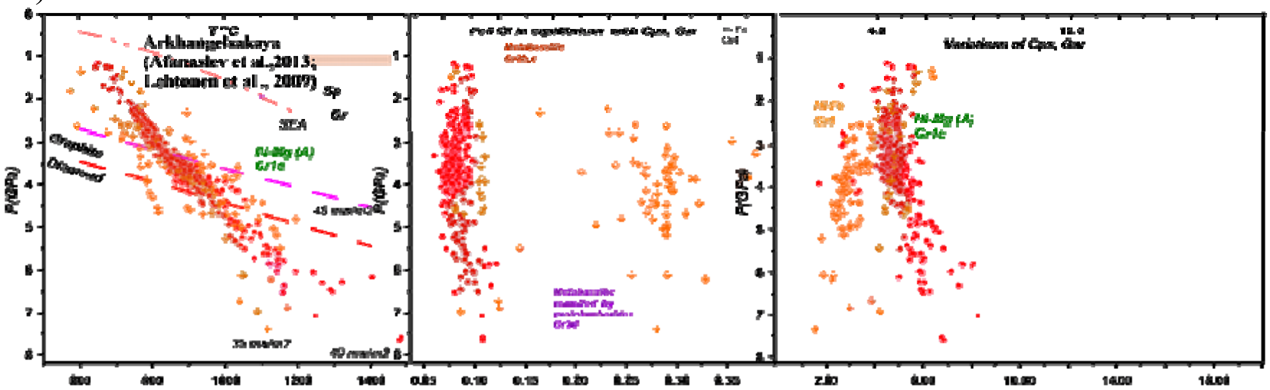
Variations of Cpx, Gar

D)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(Afanasiev et al.,2013;
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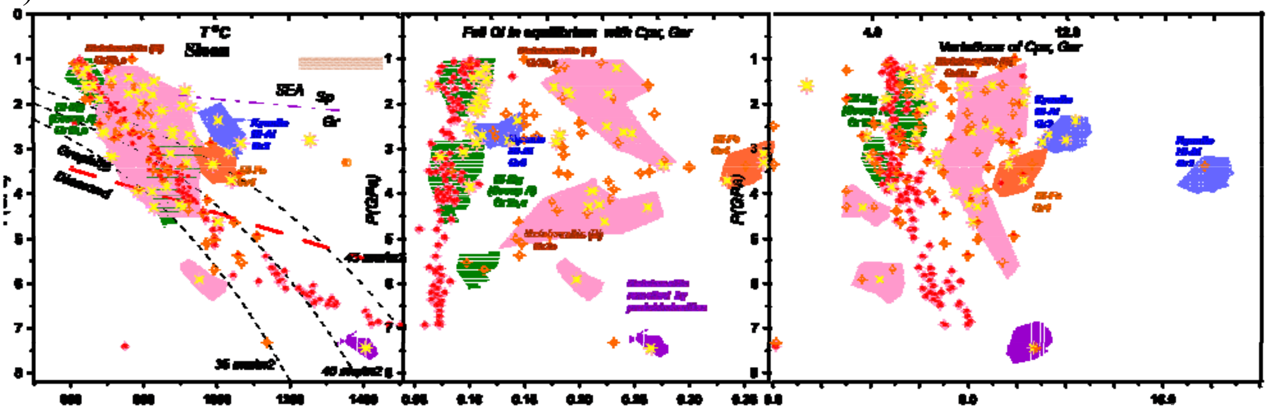
Diamond
Fell Ol in equilibrium with Cpx, Gar
Variations of Cpx, Gar

E)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F)

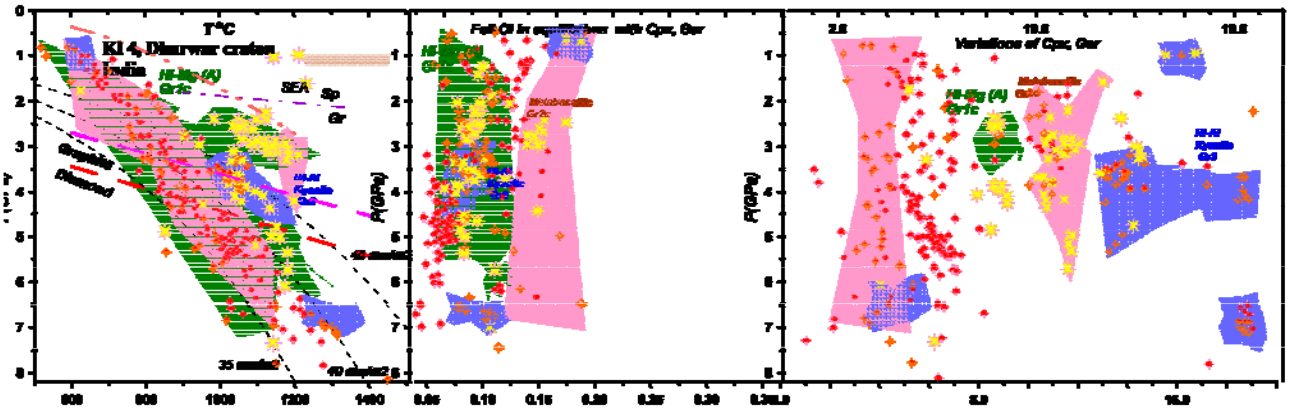

Fig.1 PTX diagram for xenoliths and minerals concentrates from: A) Udachnaya pipe; B) Mir pipe; C) Nyurbinskaya pipe; D) Arkhangelskaya pipe; E) Sloan pipe (Wyoming Craton);F) Kl1 pipe (Drhavar craton). Symbols: 1. Cpx: T^{o}C Nimis &Taylor, 2000 - P (GPa) Ashchepkov et al., 2010) for common eclogites; 2. The same for pyroxenites; 3. The same for diamond inclusions; 4 Garnet (monomineral): T^{o}C (O'Neill &Wood, 1979) - P (GPa) Ashchepkov et al., 2010); 5. The same for eclogitic diamond inclusions. 6. The same for peridotitic diamond inclusions; 7. The same for eclogitic garnets. 8. Opx for diamond inclusions: T^{o}C (Brey & Kohler, 1990) - P (GPa) (McGregor, 1974); 9. Chromite for diamond inclusions: T^{o}C (O'Neill & Wall, 1987) - P (GPa) (Ashchepkov et al., 2010); 10. Opx- Gar: ToC – P (GPa) (Brey & Kohler, 1990). Position of conductive geotherms are after Pollack & Chapman (1977) and the graphite – diamond transition after Kennedy and Kennedy (1976); the line above after Day (2012). Shaded areas are labeled according to the divisions described in introduction.

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LA-ICP-MS STUDY OF APATITE FROM THE ARSENTYEV FE-TI-V-P DEPOSIT, TRANSBAIKALIA, RUSSIA

R.A. Badmatsyrenova
Geological Institute SB RAS, Russia, brose@gin.bscnet.ru

Magmatic rocks containing economic concentrations of iron, titanium, vanadium and phosphorous are comonly associated with gabbro and related rocks. Apatite is a nearly ubiquitous accessory phase in igneous rocks due to the low solubility of P_2O_5 in silicate melts and the limited amount of phosphorus incorporated into the crystal lattices of the major rock-forming minerals [3]. Apatite is an important carrier of many trace elements, and can control the budget of Sr and REE, especially in rocks with high apatite contents. This study presents apatite LA-ICP-MS trace element concentrations data from layered gabbro and disseminated apatite-titanomagnetite ores from Arsentyev intrusion, Transbaikalia [1]. Apatite is one of the main REE carriers in this simple and exhibit flat REE patterns. The apatite crystals from the all gabbro and ores samples can be classified as apatite-(Ca, F) with 2 - 3.5 wt % of F. In the layered gabbro apatite crystals are 0.1 to 0.8 mm long and 0.1 - 0.2 mm wide. No zonation was noted. Sr contents ranges from 835 to 1095 ppm (mean value 920 ppm). Chondrite (C1)-normalized REE patterns of apatite are dominated by strong REE fractionation (La_N/Yb_N = 0.66 - 12.20), weak negative Eu anomalies (Eu/Eu^* = 0.65 - 0.79).The content of REE in apatite from gabbro find out usual for basalts character of distribution.

Equant apatite-(Ca, F) crystals from apatite-titanomagnetite ores are 0.1 to 0.6 mm long and up to 0.7 mm wide. They are unzoned. Analysed crystals show moderate and relatively consistent Sr contents (819 - 2064 ppm; mean value 1100 ppm). REE patterns are characterized by very strong fractionation (La_N/Yb_N = 1.45 - 20.96). At the same time, apatite from disseminated apatite-titanomagnetite ores in comparison with apatite from gabbro does not find out europium minimum (Eu/Eu^* = 0.62 - 0.98).

A range of magmatic processes may be responsible for the formation of this deposit. Fractional crystallization is an efficient mechanism that adequately explains compositional variations in this deposit (Charlier et al., 2008).

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GEOLOGICAL AND GEOCHEMICAL FEATURES OF THE DIFFERING IN AGE MONCHETUNDRA MASSIF ROCKS (KOLA PENINSULA)

E.S. Borisenko[1], *E.L. Kunakkuzin*[1,2], *P.A. Serov*[1]
[1]Geological Institute of KSC RAS, Apatity, Russia
elena.s.borisenko@gmail.com, serov@geoksc.apatity.ru
[2]Murmansk State Technical University, Murmansk, Russia
kunakkuzin_evgeniy@mail.ru

The Monchetundra massif is situated in the central part of the Kola Peninsula (Russia) and belong to the Paleoproterozoic East-Scandinavian Large Igneous province enclosing Cr, Ni, Cu, Co, Ti, V and PGM-bearing deposits (Mitrofanov, 2009). Geology and internal structure of the massif is a combination of mafic rocks differing in formation age and a complex of mafic dykes, formed during multiple intrusion.

The oldest rocks of the massif are massive to foliated metagabbrides, which is located in the southern and southwestern parts of the massif. These rocks have yielded zircon U-Pb ages of 2521±8 Ma (Bayanova et al., 2010), 2516±12 Ma (Nerovich et al., 2014).

Differentiated trachytoid gabbronorites occurring along northeastern flank of the Monchetundra massif yield U-Pb age of 2505±6 Ma, 2501±8 Ma (Layered intrusion…, 2004), 2507.5±7.7 Ma, 2504.4±2.7 Ma (Borisenko et al., 2013). The main rock varieties are medium to coarse-grained mesocratic gabbronorites and their amphibolized derivatives. A direction of trachytoid structure conforms to a northwestern strike of the massif and its dip is 30°-40°SW.

The central part of the massif is *vaguely layered* and composed of mainly massive coarse-grained leucocratic gabbronorites, gabbros and their amphibolized derivatives. Melanocratic and olivine-bearing varieties are less common in the massif. At the bottom of the massive leucocratic gabbronorites and gabbros sequences, these rocks alternate with layers of troctolites, which strike NW (320°) and dip 30° SW. Zircon and baddeleyite U-Pb ages of these rocks are 2471±9 Ma, 2476±17 Ma (Bayanova et al., 2010), 2471±2 Ma (Borisenko et al., 2013).

Contact between massive and trachytoid varieties of the massif mafic rocks is marked by a presence in the latter lenticular and bedded bodies of youngermassive leucogabbro. Such relationships between these rocks seem to be have formed during intrusion of younger rocks into trachytoid gabbronorites (Borisenko et al., 2013).

Pegmatoid varieties of gabboic rocks are common among massive coarse-grained leucocratic gabbronorites and gabbros as pods (2453±4 Ma (Mitrofanov et al., 1993)) and cutting veins (2445.1±1.7 Ma (Nerovich et al., 2014)).

Dyke complex is represented by dykes of dolerites differing in age with varying geochemical characteristics (Nerovich et al., 2014), as well as bodies of melanocratic troctolites - harrisites.

The Monchetundra mafic rocks of normal alkalinity are characterized by high Al_2O_3 content caused by the predominance of plagioclase among rock-forming minerals. The most of mafic rocks contain 20-26 wt.% Al_2O_3, whereas mesocratic gabbronorites and trachytoid gabbronorites show lower content (14-18 wt.% and 13-16 wt.% respectively). MgO content for the most part ranges from 1,0 to 9,9 wt.%; content of TiO_2 is low (up to 0,46 wt.%).

In the primitive-mantle normalized multielemental pattern, the mafic rocks of the Monchetundra massif show negative anomalies in some high field strength elements (Zr, Nb, Hf, Ta) and positive anomalies in large-ion lithophile elements (Rb, Ba, Sr). The studied mafic rocks have similar moderate *fractionated*REE patterns with enrichment in LREE relative to HREE - $(La/Yb)_n$=2,07-7,52 and *well*-defined *positive Euanomaly (*Eu/Eu*=1,21-2,26).

According to the recent Sm-Nd and Rb-Sr isotope-geochemical data the differing in formation age mafic rocks of the Monchetundra massif are characterized by mainly negative

ε_{Nd}(T) values (with rare exceptions), *Paleo*- to*Mesoproterozoic* T_{DM}model ages and low $^{87}Sr/^{86}Sr$ ratio (0.700 – 0.704) (Kunakkuzin et al., 2015). Formation of the massif, as well as the other similar mafic-ultramafic intrusions of the Fennoscandian shield (e.g. Fedorov-Pansky, Mt.*General'skaya*, Monchepluton, Olangskaya group, Portimo-Penikat-Kemi), is caused by action of long-lived (2.52-2.39 Ga) lower-mantle plume (Bayanova, Mitrofanov, 2012; Mitrofanov et al., 2013).

Thus, the main varieties of the Monchetundra mafic rocks differ in age of formation, textural and structural features and have similar geochemical characteristics. The general similarity of REE patterns of all mafic rocks suggest that they seem to have derived from a common source, and isotope-geochemical Nd-Sr data is typical for rocks enriched in lithophile elements of a mantle source. Variations of isotope-geochemical data between different groups of mafic rocks are likely to be associated with the evolution of the mantle source during long-lived plume action.

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GEOCHEMISTRY AND PETROGENESIS OF BASALTIC LAVA FLOWS OF THE WAI SUBGROUP, DVP WESTERN INDIA

Babita R. Choudhary [1], Gajananrao N. Jadhav [1]*

National Research Tomsk State University, Faculty of Geology and Geography (Siberia), Russia,
choudhary.r.babita@gmail.com

The Deccan volcanic province (DVP) in western India represents one of the largest accumulations of the continental flood basalt. The Indian subcontinent passes through a magmatic activity phase that occurred at the K-T boundary (65 Ma), which has been due to hot spot activity. The period of Deccan trap magmatism in India was accompanied by a state of tension, connected with the breaking up of Gondwanaland; and compression, associated with initiation and formation of the Himalaya. The crustal movements at the end of the cretaceous period were effectively dominant in tectonically active zones (rifts) in western India. This caused the production of alkalis and nephelinitic magmas associated with the Deccan traps, derived through low degree of partial melting. Deccan Basalt spread in western ghat 7000 km^2 and cover an area about 518,000 km^2 (Mahoney et al., 1982; Cox and Hawkesworth, 1985; Beane et al., 1986; Lightfoot et al., 1990; Melluso et al., 1995; Melluso et al., 2002; Higgins and Chandrasekharam, 2007, Choudhary and Jadhav, 2014). The present work has been carried out in parts of DVP which stratigraphically fall in the Wai subgroup (uppermost subgroup of DVP).The study included field-petrography and geochemical investigation. The enormous spread of lava flows are distinguished from each other in terms of time as well as geochemistry. The whole rocks contain MgO ranging from 4.8 to 7.1 wt%, TiO_2 from 1.8 to 4.6 wt%, SiO_2 from 47 to 52 wt% and Al_2O_3 from 12 to15.5 wt%. The Mg number (Mg#) was on the lower side, ranging from 36 to 50. The general trend of incompatible element concentrations increasing from lower Poladpur to upper Mahabaleshwar flows with increasing Zr and the linear array are consistent with a suggested fractionation of olivine and clinopyroxene. The much lower Mg# represents that the magma was modified significantly by fractional crystallization and crustal assimilation. The trend of sensitive Ba and K_2O and insensitive Zr, Nb, Y and TiO_2 elements and oxides reveal that the fractionation recorded in these lavas. Crystal fractionation involved the removal of plagioclase and ferromagnesian minerals from basaltic magmas with less than 7 percent MgO. Less than 7 % MgO demonstrated that the gabbro fractionation trend had been similar with the characteristic of several other continental flood basalt occurrences. Zr/Y and TiO_2 (> 1.8 wt. %) appear to have been generated by fractional crystallization starting from enriched mafic precursors, suggested their origin from incompatible element-rich mantle. Ba was noted as a boundary marker element between the Ambenali (47.3 to 63.9 ppm Ba) and Mahabaleshwar (83.1 to 180 ppm, majority of the samples were more than 100 ppm) formations.In comparison to the Ambenali formation, Mahabaleshwar formation flows were affected more by crustal materials, which left a signature consisting of enriched levels of K, Rb, Ba, Ti and P. The high values of the ratios between large ion lithophile elements and Nb are evidence of a crustal input in the Wai subgroup formation flows.

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THE LATEST GEODYNAMICS OF ASIA

I.S. Chuvashova[1,2], *S.V. Rasskazov*[1,2]
[1]Institute of Earth's Crust SB RAS, Irkutsk, chuvashova@crust.irk.ru
[2]Irkutsky State University, Irkutsk

The latest stage of the Earth's dynamics lasted about 90 Ma (Rasskazov, Chuvashova, 2013). A character of these processes in Asia has been estimated from (1) interpretation of geophysical data, (2) spatial or spatial-temporal distribution of volcanism in the late Mesozoic and Cenozoic, and (3) relations between the volcanism and low-velocity mantle anomalies. The mantle structure beneath volcanic areas has been studied using 3D-velocity models for the relatively shallow and deeper mantle (up to 300 and 700 km, respectively). The distribution of anomalies in the shallow mantle models usually differ from the generalized shallow parts of the deeper seismic images. The former yield more accurate spatial position for shallow melting anomalies, so those up to 700 km are used in this work only for recording melting anomalies related to the transition layer 410–660 km.

In terms of the origin and depth, local decreasing of seismic velocities might signify: (1) a plume, starting from the lower thermal boundary layer of the mantle, (2) a counterflow from the lower mantle after an avalanche of slab material from the transition layer through its lower boundary 660 km, (3) a melting anomaly of a domain that extends above the transition layer at depths of 200–410 km, (4) a melting anomaly of a domain that occurs beneath the lithosphere at depths of 50–200 km, (5) a melting anomaly of the lower part of the lithosphere, activated due to rifting, and (6) a melting anomaly at the crust–mantle boundary originated through delamination of an orogenic root. A melting anomaly in the upper mantle may be associated, on the one hand, with rifting or orogenesis in the lithosphere, on the other hand, with a plume or a counterflow from the lower mantle.

Our understanding of the latest geodynamics in Asia is based on studies of the spatial-temporal volcanic evolution in the Cretaceous-Paleogene and Neogene-Quaternary time intervals in three key areas (Central Mongolia and Sayans, Baikal and Western Trans-Baikal, and Northern Trans-Baikal) with involvement in interpretation of the published velocity-models of the mantle. We use the models of S-wave tomography up to depths of 300 and 700 km by Yanovskaya and Kozhevnikov (2003) and Kozhevnikov et al. (2014).

We assume that melting anomalies at the transition layer beneath the selected key areas were a result of a collapse into the lower mantle of slab material that was accumulated at the transition layer before closing the Mongolia-Okhotsk Bay of Paleo-Pacific and similar closing of the Solonker paleoocean. The anomalies resulted from counterflows penetrated through the transition layer from the lower mantle at the beginning of the latest geodynamic stage. From the hypothesis on the temperature-dependent phase control of transition layer boundaries, it follows that a thermal (thermo-chemical) flux from the lower mantle should be identified both at the base and top of the transition layer. Spatial coincidences of low-speed anomalies related to both boundaries beneath South Gobi and South Pri-Baikal indicate the absence of differential lateral movement of the material at this level during the latest geodynamic stage. And vice versa, the mutual spatial separation of anomalies 600 and 400 km under Northern Trans-Baikal reflects lateral movement of the material in the transition layer beneath East Asia due to the effects of subduction into the transition layer at first the Kula-Izanagi slab and then the Hokkaido-Amur flexure of the Pacific slab.

The lateral motion of the Pacific plate along the Asian margin changed to subduction between 22 and 17 Ma. At this time interval island-arc volcanism was initiated in Northeastern Honshu and within-plate volcanism distributed in the vast area of Central and East Asia from Japan to Sayans. A transition to the subduction was accompanied by the back-arc opening Sea of Japan at about 15 Ma, quick clockwise rotation of Southwest Japan and formation of the oblique Honshu-Korean slab flexure. The direct Hokkaido-Amur slab flexure that coincided with the direction of convergence between Pacific plate and Asia was formed due to subsequent subduction provided by counter movements of the Pacific plate at the speed of 10 cm×year^{-1} and Asia that shows the current speed of 3 cm×year^{-1}, as inferred from GPS data on the Irkutsk station that located at its stable part.

The Cretaceous-Paleogene volcanic fields in South Gobi are offset over 600 km from the transition layer melting anomaly. The vector of the lithosphere shift to the east-southeast was provided mostly by general motion of the Asian lithosphere. A small northward drift was added due to the Indo-Asian convergence. Late Cenozoic volcanism in the Hangay-Belaya orogenic zone was derived from shallow melting anomalies of 50–150 km that belong to the Sayan-Mongolian low-velocity domain. The resulting east-southeast vector of the lithosphere motion relative to the low-speed anomalies coincided with the one in the South Gobi, but with the amplitude reduction to 300 km. The average speed of the lithosphere 2 cm×year^{-1} was characteristic of the past 15 Ma. Assuming the same velocity of the lithosphere movement in South Gobi in the past 15 Ma, we obtain the average velocity estimate of the lithosphere motion in Central Mongolia ca. 0.4 cm×year^{-1} during the preceding period from 90 to 15 Ma.

The Cretaceous-Paleogene Isinga and Khushinda volcanic fields of the Western Trans-Baikal are shifted over 350–400 km relative to the melting anomaly at the transition layer beneath the Southern Pri-Baikal. The resulting vector of the lithosphere shift was directed east-southeastwards due to the general motion of Asia supplemented by the northeastern drift with almost similar amplitude. This exceeded the convergence-related component of the lithosphere movement at the same direction in Central Mongolia. The increasing northeastern drift of the lithosphere in Western Trans-Baikal was apparently associated with left-lateral shearing in the northeastern part of the Baikal Rift Zone. Offset over 300 km of the Bereya volcanic center relative to the center of the melting anomaly of 250–300 km yields the Late Cenozoic speed estimate for the lithosphere motion ca. 2 cm×year^{-1}. The initial 16–14 Ma high-Mg lava eruptions were indicative for the local hot flax in the sub-lithospheric mantle.

Finally, the mantle velocity structure of Asia shows patterns of asthenospheric counterflows beneath the moving lithosphere. The flow existed under the Western Trans-Baikal was directed towards the Baikal Rift Zone and the one created under the Orkhon-Selenga low-mountainous area towards the Khubsugul-Darkhat rift segment that belong to the Hangay-Belaya orogenic zone. We suggest that the lithosphere was rifted due to the counterflow dynamics initiated within melting anomalies. Lithospheric extension in the Baikal Rift Zone was dynamically associated with the development of the directly-subducted Hokkaido-Amur flexure of the Pacific slab.

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SR-O ISOTOPE SYSTEMS AND SOURCES FOR COLLISION-RELATED GRANITOIDS OF THE MONGOLO-OKHOTSK OROGENIC BELT (EXEMPLIFIED BY THE UNDINSKY COMPLEX, EASTERN TRANSBAIKALIA)

S.I. Dril, S.A. Sasim, Yu.V. Noskova

Institute of Geochemistry, Siberian Branch of the Russian Academy of Sciences, Irkutsk, Russia, sdril@igc.irk.ru

All geodynamic models proposed for the origin of the Central-Asian Orogenic Belt, including the Mongol-Okhotsk Orogenic belt (MOB) suggest that these folded structures were produced mainly by accretion (collision) of island arcs, accretionary wedges, turbidite terranes of the continental slopes, etc. to the Siberian paleocontinent (Parfenov, Popeko, Tomurtogoo, 1999). The most outstanding feature of collision events that accompanied the successive closure of thePaleoasianOcean is the vast expanse of collision-related granitic intrusions stretching from the Central Mongolia through the Eastern Transbaikalia and Upper Amur Region to the Northeast China. In East Transbaikalia these granitoids form the Undin complex while in the Upper Amur Region they are a part of the Urushin complex.

In the Eastern Transbaikalia the most part of batholiths and smaller complexes of the Undin Belt lies on the boundary of the Argun terrane of the passive continental margin and Onon terrane of the accretionary wedge of the MOB (Parfenov, et al., 2003). The basement of the former is composed of the Neoproterozoic granitoids of the Dyrbylkei complex and Late Neoproterozoic and Early Paleozoic metamorphosed volcanogenic-sedimentary sequences. The latter mainly contains the Middle Paleozoic metamorphosed volcanogenic-sedimentary sequences which include the metasediments of the turbidite nature and metavolcanics with scarce metamorphosed deep-water siliceous rocks. The granitoids form the extensive areas, being frequently located within both terranes that makes possible the evaluation of the effect of different substratum on the granitic magmas. Rb-Sr isotope age of complexes of the second (major phase) of Undin granites is 250 +/-4, 265 +/-1, 275 +/-34 MA (Kozlov et al., 2003).

Figure 1 demonstrates Sr-O isotope system for the granitoids under study. Different models of mixing of hypothetic mantle and upper crust substances (models I-IV) are calculated in order to estimate the contribution of the "mantle" and "crust" components. The models of mixing of mantle substance with "mature" upper crust matter (models IV and III) can account for the specific features of the Undin (Kuryumdin complex) collision-related rocks. These rocks occur within the Argun terrane with the Neoproterozoic crystalline basement.

However, the major part of granitic composition cannot be described by this model as they form a steeper trend as compared to that of models IV and III. This contradiction is not the case if we assume that the crustal component has less radiogenic Sr composition as opposed to the value $^{87}Sr/^{86}Sr_{(0}$ =0,719 accepted for the upper continental crust that is illustrated by mixing models (I and II) which demonstrate the values of the crust source as $^{87}Sr/^{86}Sr_{(0}$ =0,712 and 0,708, correspondingly.

Thus, variations of strontium and oxygen isotope compositions in the studied granites can be explained by mixing of mantle substance with crust source for which $^{87}Sr/^{86}Sr_{(0)}$ values lie within 0,708-0,712 at $\delta^{18}O$=12-15 that corresponds to models I and II. Such a source could include terrigenous-sedimentary and volcanogenic-sedimentary formations of the Paleozoic accretionary complexes subsided as a result of the collision at such crust levels where they could serve as protolith for melting granitic magmas. Wide variations of Rb/Sr (0,02-3,4) and $^{87}Sr/^{86}Sr_{(275MA)}$ (0,706-0,716) valuesin metasediments suggest various types of a source for sedimentary material in accretion complexes of the MOB, including the essential contribution of the mature crust substance. However, recalculation of $^{87}Sr/^{86}Sr$ values in metasediments for an age of Undin collision-related granites (275 Ma), shows that for that time span the majority of compositions of metasedimentary rocks within Sr-O isotope system (Fig. 1) corresponded to models I, I (A)and II.

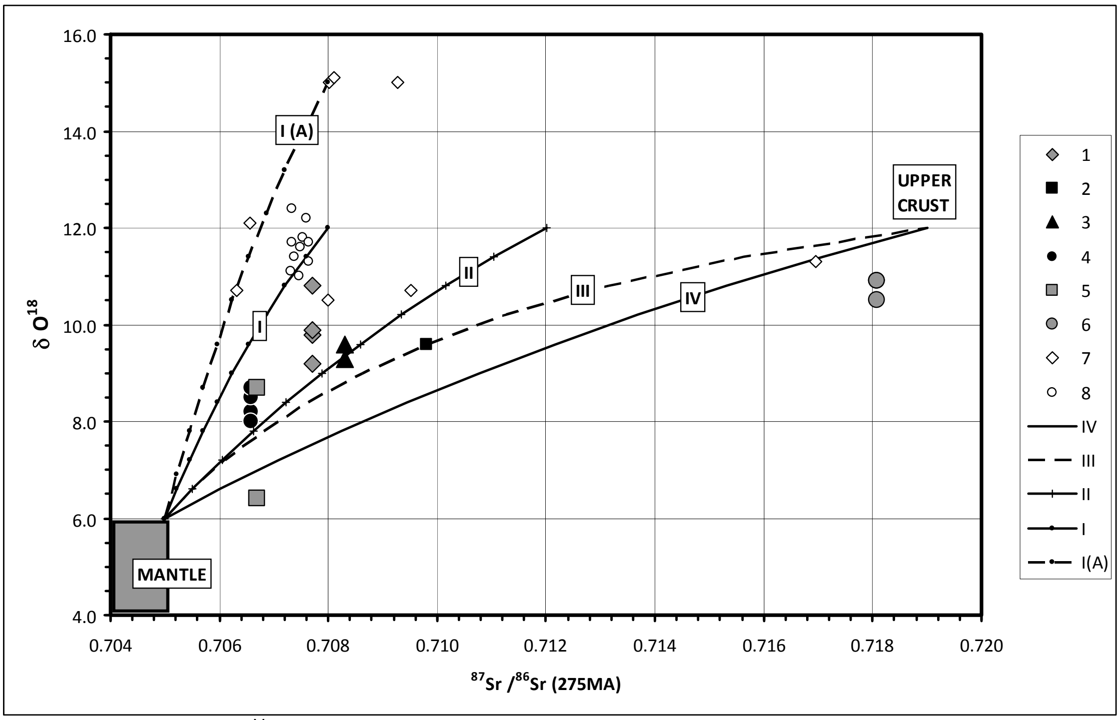

Fig. 1.^{87}Sr^{86}Sr$_{(0)}$ - δ^{18}O diagram for the Undin granitoids and metaterrigenous rocks of the Onon terrane of the accretionary wedge (MOB). The massifs of the Undin complex: (1) Verkhneundin, (2) Kuryumdin, (3) Gazimur, (4) Margutseks and (5) Ust-Telengui; (6) Dyrbylkei Neopreterozoic granites (Argun terrane basement); (7) – compositions of metasediments of the Kulindin, Dzhorol, Onon and Chindat formations, East Transbaikalia, recalculated for an age of 275 MA, as an example of accretionary wedge metasediments (Mongol-Okhotsk Belt); (8) - figurative points of compositions of metapelites, Kheivan formation, Kamchatka (Grigoriev, Lobov, 1993), as an example of metasediments of the Cretaceous island arc prism, Kamchatka. Models of mixing of substance from mantle and crust sources with the following values (^{87}Sr^{86}Sr$_{(0)}$ =0,705, Sr=1000ppm, δ^{18}O=6 and ^{87}Sr^{86}Sr$_{(0)}$ =0,719, Sr=350ppm, δ^{18}O=12 accordingly) (IV); ^{87}Sr^{86}Sr$_{(0)}$ =0,705, Sr=500ppm, δ^{18}O=6 and ^{87}Sr^{86}Sr$_{(0)}$ =0,719, Sr=350ppm, δ^{18}O=12 accordingly (III); and also (II), (I) and (I (A), δ^{18}O=15) – models of mixing of mantle component (Sr=500ppm) with hypothetical crust reservoirs with ^{87}Sr^{86}Sr$_{(0)}$ =0,712 and 0,708 accordingly.

Thus, the Precambrian upper continental crust couldn't be a source for the investigated Undin granitoids . The contribution of this source is only evident in some blocks with the Neoproterozoic basement (Kuryumdin massif). The crust source with low ^{87}Sr/^{86}Sr <0,712 values, Rb/Sr =0,08 and δ^{18}O=12-15 is more probable. It can be compared with the Paleozoic sedimentary and volcanogenic-sedimentary complexes of accretionary wedges, involved in magma generation as a result of collision.

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NEWLY RECOGNIZED 1353-1338 MA LIP OF SIBERIA AND FORMERLY CONNECTED NORTHERN LAURENTIA: SPECULATIVE IMPLICATIONS FOR THE VOISEY'S BAY ORE DEPOSIT

R.E. Ernst[1,2], D.P. Gladkochub[3], M.A. Hamilton[4], S.L. Kamo[4], S. Denyszyn[5], A.V. Okrugin[6], U. Söderlund[7]

[1]Department of Earth Sciences, Carleton University, Ottawa, Canada; Richard.Ernst@ErnstGeosciences.com

[2]Faculty of Geology and Geography, Tomsk State University, Tomsk, Russia

[3]Institute of the Earth's Crust, Siberian Branch of the RAS, Irkutsk, Russia,

[4]Jack Satterly Geochronology Laboratory, University of Toronto, Toronto, Ontario, Canada

[5]Centre for Exploration Targeting, School of Earth & Environment, U. Western Australia, Crawley, Australia

[6]Diamond and Precious Metal Geology Institute, Yakutsk, Russia

[7]Department of Geology, Lund University, Lund, Sweden

New Proterozoic LIPs of comparable scale to the c. 252 Ma Siberian Trap LIP have been discovered through a campaign of U-Pb dating of dolerite dykes and sills by the LIPs-Industry Consortium Project (www.supercontinent.org; Ernst et al. 2013). Here a new major 1353-1338 Ma LIP event is proposed.

Five U-Pb ages from Siberia and formerly adjacent Laurentia are used to define a new 1353-1338 Ma LIP of wide extent across the Siberian and northern Laurentian cratons (Fig. 1). Two possible pulses are recognized:

A c. 1350 Ma pulse is defined by two dated N-S dolerite dykes in Siberia separated by a distance of c. 2000 km: 1355 ± 29 Ma (preliminary age) from a sample in the Anabar Shield (reported herein), and a 1350 ± 6 Ma for the Listvyanka dyke in the Irkutsk region (reported herein). A matching age of 1353 ± 2 Ma was obtained from a sill in the Wellington Inlier of Victoria Island, northern Canada (reported herein), which in the reconstruction shown in Figure 1 is c. 800 km from the Listvyanka dyke.

A c. 1340 Ma pulse is recognized by a 1338 ± 3 Ma age obtained on an elongate gabbro-dolerite intrusion in the Goloustnaya massif in the Irkutsk region (reported herein) and a 1337 ± 2 Ma age obtained from a dolerite dyke on Devon Island in the Canadian Arctic (Denyszyn et al. 2007). These two 1338-1337 Ma units are c. 1000 km apart in the reconstruction shown in Figure 1.

The age agreement and scale of magmatism for each pulse are suggestive of a two-pulsed LIP linked to a single mantle plume. Additional units are provisionally linked based on similar ages (using less robust dating methods): 1339 ± 54 Ma (Sm-Nd) from the Verhkoyansk region (Khudoley et al. 2007), and 1336 ± 15 and 1313 ± 39 Ma (K-Ar) from Devon Island and northern Greenland, respectively (Dawes and Rex 1986; Frisch 1988).

An age similarity with the world-class magmatic (troctolitic-gabbroic) Voisey's Bay ore deposit in coastal Labrador, Canada (1333 ± 1 Ma, Amelin and Naldrett 1999) invites speculation about whether a portion of the 1353-1338 Ma plume migrated laterally beneath the lithosphere southward (for 2000 km) and could have played a role in the generation of the 1350-1290 Ma Nain Plutonic suite and the Voisey's Bay Ni-Cu ore deposit.

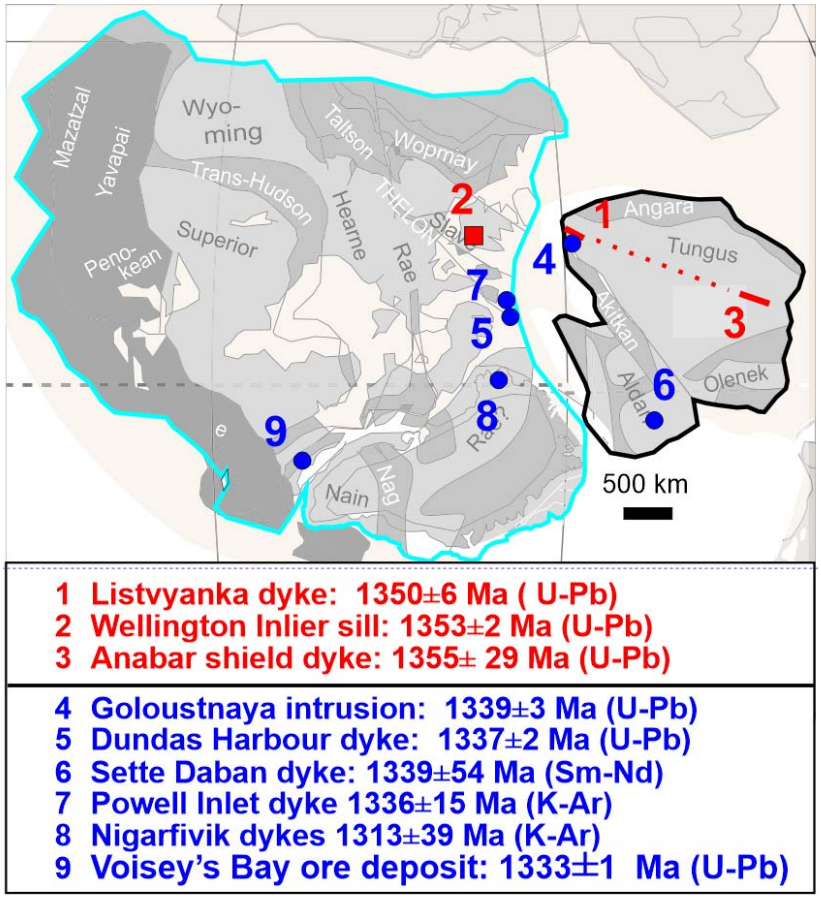

Figure 1: Magmatism of the proposed 1353-1338 Ma Listvyanka- Dundas Harbour LIP. Units linked to the c. 1353 Ma pulse (red) and c. 1338 Ma pulse (blue) are shown. Reconstruction is approximately after Evans and Mitchell (2011) with a gap added for the North Slope subterrane of Alaska, containing c. 720 Ma Franklin LIP magmatism (Cox et al. 2015).

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THE 1501 MA KUONAMKA LIP OF NORTHERN SIBERIA: U-PB GEOCHRONOLOGY, GEOCHEMISTRY, PGE POTENTIAL, AND LINKS WITH OTHER CRUSTAL BLOCKS

R.E. Ernst[1,2], A.V. Okrugin[3], R.V. Veselovskiy[4], S.L. Kamo[5], M.A. Hamilton[5], V. Pavlov[4], U. Söderlund[6], K.R. Chamberlain[7], C. Rogers[1]

[1]Department of Earth Sciences, Carleton University, Ottawa, Canada; Richard.Ernst@ErnstGeosciences.com

[2]Faculty of Geology and Geography, Tomsk State University, Tomsk, Russia

[3]Diamond & Precious Metal Geology Institute, Yakutsk, Russia

[4]Institute of Physics of the Earth, RAS, Moscow, Russia

[5]Jack Satterly Geochronology Laboratory, University of Toronto, Toronto, Canada

[6]Department of Earth & Ecosystem Sciences, Lund University, Lund, Sweden

[7]Department of Geology and Geophysics, University of Wyoming, Laramie, USA

The Siberian craton is best known for the 252 Ma Siberian Trap Large Igneous Province (LIP) which hosts the important Noril'sk Ni-Cu-PGE deposits. Recently however, comparable-scale Proterozoic LIPs have been discovered through a campaign of U-Pb dating of dolerite dykes and sills by the LIPs Industry Consortium Project (www.supercontinent.org; Ernst et al. 2013a). Here a new 1501± 3 Ma LIP in northern Siberia is profiled. [All ages reported below were determined by conventional U-Pb TIMS methods unless otherwise noted.]

U-Pb Geochronology: The Kuonamka LIP was originally recognized in the Anabar shield where an E-trending dyke was dated at 1503±5 Ma, with additional E-ESE-trending dykes correlated via paleomagnetism (Ernst et al. 2000). A newly dated dyke with an age of 1502±6 Ma allows this dyke swarm to be traced into the Riphean sediments on the western slopes of the Anbar shield for a distance of 270 km. A dolerite sill province, presumably fed by this dyke swarm, also cuts these Riphean sediments and yields matching ages of 1498±2, 1502±6, 1503±2, 1502±8, and 1493±9 Ma. A slightly younger (but less precise) age of 1466±14 Ma was obtained for a sill by the U-Pb SIMS method. Several hundred kilometres further east in the Olenek uplift, a Sololi sill yielded an imprecise SHRIMP age of 1473±24 Ma (Wingate et al. 2009) which is within uncertainty of the age of the Kuonamka event further west. Overall these data indicate that the Kuonamka LIP extends E-W for at least 700 km from the western slopes of the Anabar shield to the Olenek uplift. The age of the Kuonamka LIP can be summarized as 1501 ± 3 Ma (95% confidence), based on the weighted average of the seven U-Pb TIMS results.

Geochemistry and Nd-Sr isotopes: The dykes and sills of the Kuonamka LIP have a tholeiitic basalt composition with low MgO (4-7 wt%) and within-plate character on trace element classification diagrams. On a Th/Yb vs Nb/Yb diagram (Pearce 2008) the data plot between EMORB and OIB (closer to EMORB), and are only slightly displaced from the oceanic array indicating minimal crustal or mantle lithospheric contamination. Variable K, Pb, and Rb indicate minor alteration, Two subgroups are distinguished (average values are quoted below). Group 1 has slightly sloping LREE (La/Sm_N = 1.9) and HREE (Gd/Yb_N= 1.8), with no negative Nb-Ta anomaly, slight negative Sr and P anomalies, and moderate TiO_2 (2.2 wt%). Group 2 has slightly steeper LREE (La/Sm_N = 2.3), and HREE (Gd/Yb_N= 2.3), strong negative Sr anomaly and weak negative P anomaly, is slightly higher in TiO_2 (2.7 wt%) and other incompatible elements, and is transitional to an alkaline composition. Isotope systems (Rb^{87}-Sr^{86} and Sm^{147}-Nd^{143}) for Group 1 and 2 show negligible variation, with age-corrected eSr ranging from 9.0 to 17.2, and eNd ranging from 1.02 to -0.42 suggesting a primitive mantle source with the same geochemical composition over the full range of partial melting. The combined lithogeochemical characteristics therefore suggest that the mantle source of these magmas was not DMM (depleted MORB mantle). Rather the data are consistent with a single primitive mantle plume source for all samples that could have melted at variable depths (consistent with the different HREE slope for the two groups).

Six of the U-Pb ages are associated with Group 1 magmatism, five of these (all TIMS ages) are consistent with emplacement between 1498-1503 Ma. Given its matching chemistry the sample with the more imprecise U-Pb SIMS age of 1466±14 Ma also likely has a true age close to that of the other Group 1 samples. Only one sample from Group 2 is dated (1502 Ma) and has some geochemical characteristics transitional to Group 1. Thus the precise age of Group 2 is not yet known but on the basis of its steeper HREE pattern could slightly precede Group 1 magmatism, representing deeper (earlier) melting in the ascending mantle plume.

PGEs: Platinum group minerals have been found in placers along the AnabarRiver (eastern side of Anabar shield) which are linked to layered intrusions recognized by geophysics along the AnabarRiver (Okrugin 1998; Okrugin et al. 2009). Given the prominence of the 1501 ± 3 Ma Kuonamka LIP in northern Siberia, it should be considered that these undated intrusions and the associated placer PGEs could belong to the Kuonamka LIP.

Continental Reconstruction:The 1501 ± 3 Ma Kuonamka LIP of northern Siberia can be linked with dykes and sills dated at 1500 Ma (U-Pb) from the combined São Francisco – Congo craton. Reconstruction of these blocks is supported by limited paleomagnetism (Ernst et al. 2013b) but also by a close similarity in the trace element geochemistry of the 1500 Ma magmatism from the different blocks. This reconstructed Kuonamka LIP (of northern Siberian and São Francisco-Congo cratons) would span a region more than 2000 km across.

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LONG-TERM NEIGHBORS: RECONSTRUCTION OF SOUTHERN SIBERIA AND NORTHERN LAURENTIA BASED ON MULTIPLE LIP BARCODE MATCHES OVER THE INTERVAL 1.9–0.7 GA

R.E. Ernst[1,2], U. Söderlund[3], M.A. Hamilton[4], K.R. Chamberlain[5], W. Bleeker[6], A.V. Okrugin[7], A.N. LeCheminant[8], T. Kolotilina[9], A.S. Mekhonoshin[9], K.L. Buchan[6], D.P. Gladkochub[10], A.N. Didenko[11], J.A. Hanes[12]

[1]Department of Earth Sciences, Carleton University, Ottawa, Canada; Richard.Ernst@ErnstGeosciences.com

[2]Faculty of Geology and Geography, Tomsk State University, Tomsk, Russia

[3]Department of Earth and Ecosystem Sciences, Lund University, Lund, Sweden

[4]Jack Satterly Geochronology Laboratory, University of Toronto, Toronto, Ontario, Canada

[5]Deptartment of Geology and Geophysics, University of Wyoming, Laramie, Wyoming, USA

[6]Geological Survey of Canada, Ottawa, Canada

[7]Diamond and Precious Metal Geology Institute, Yakutsk, Russia

[8]Geological Survey of Canada (retired), 5592 Van Vliet Rd., Manotick, Ontario, Canada

[9]Institute of Geochemistry, Irkutsk, Russia

[10]Institute of the Earth's Crust, Siberian Branch of the RAS, Irkutsk, Russia

[11]Kosygin Institute of Tectonics and Geophysics, Khabarovsk, Russia

[12]Dept. Geol. Sci. & Geol. Eng., Queen's University, Kingston, Ontario, Canada

Precise U-Pb dating from southern Siberia and northern Laurentia provides multiple matches between the Large Igneous Province (LIP) records of both crustal blocks. Most important is the recognition of two dominant Proterozoic LIP events of northern Canada (725-715 Ma Franklin and 1270 Ma Mackenzie) in southern Siberia (Figs. 1 and 2), as well as recognition in both crustal blocks of 1350-1340 Ma and 1750 Ma intraplate magmatism. These, along with more speculative comparisons at the other times (Table 1), yield a robust match of the magmatic barcodes of southern Siberia and northern Laurentia between 1750 and 725 Ma, affirming a close fit between these blocks. Additional matches at ca. 1900 and 1885-1870 Ma, prior to the final assembly of Laurentia or Siberia, suggest a similar fit between southernmost blocks of Siberia and the Slave-Rae craton of northern Laurentia. On the basis of the barcode matches, and associated dyke trends, we propose that the Irkutsk promontory of southern Siberia was near Banks Island of northern Canada (e.g. Figs. 1 and 2) over the interval 1.9-0.72 Ga with a gap to accommodate a restored North Slope subterrane of Alaska that contains Franklin LIP magmatism (Cox et al. 2015, Lithosphere).

Table 1 Matching of LIP units in northern Laurentia and southern Siberia (updated and expanded from [1]).

Age (Ma)	Northern Laurentia	Southern Siberia
1920-1900	Hearne (d), part of Snowbird LIP [2, 3]	Angaul (d) [4]
1880-1870	Ghost -MaraRiver - Morel LIP (s) [2, 3, 5]	Kalaro-Nimnyrsky LIP (d, g) [6, 7]
1750	McRaeLake (d), HadleyBay (d), Cleaver (d); Kivalliq (g) [2, 3, 8]	Timpton LIP (d) [2, 4]
c.1720-1700	Pelly Bay (d) [9]	Byraiy (d) Ulkan-Bilyakchan (vp) [6, 10]
1640-1630	Melville Bugt LIP (d) [3]	"Nersa" (s) [11]
1380	Midsommerso – Zig Zag Dal LIP (s, f), [3]	Chieress (d) (n. Siberia with possible continuation in to s. Siberia) [2, 4]
1350-1340	Burnside sill (Wellington Inlier) [6]	Listvyanka (d) [6]
1270-1260	Mackenzie LIP (d, f, s, l) [2, 3, 9]	Srednecheremshanskii (l) [6, 7]
725-715	Franklin LIP (d, s, f) [2, 3, 9]	Irkutsk LIP (d, l, f) [12, 13]

d = dyke swarm, s = sill province, l = layered intrusions, f = flood basalts, (g) granitic units, (vp) volcano-plutonic complex

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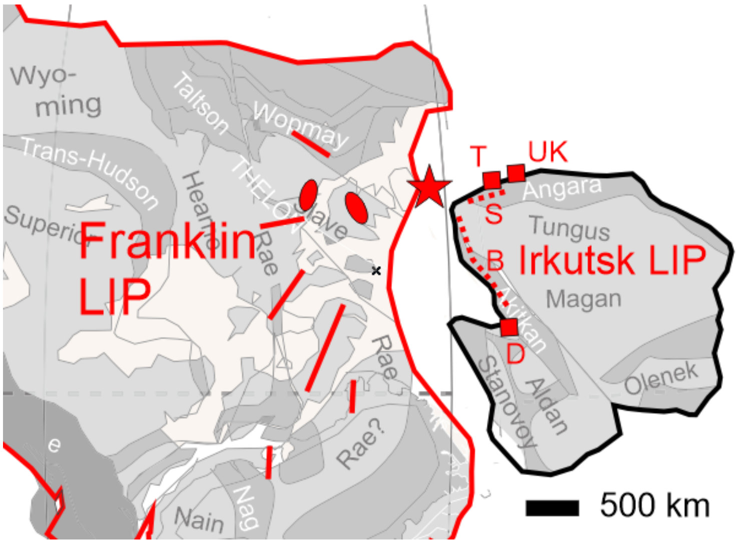


Figure 1: Radiating dyke swarm of 725-715 Ma Franklin LIP of northern Laurentia with plume centre (star). Proposed continuation of the Franklin LIP into southern Siberia on the basis of coeval ages obtained for the Dovyren (D), Upper Kingash (UK), and Tartai (T) mafic-ultramafic intrusions (red squares) in terranes adjacent to craton [12, 13]. Sayan (S) and Baikal (B) swarms yield ca. 700-800 Ma Ar-Ar ages (e.g. [4]) and may also belong to the Irkutsk LIP (to be tested by U-Pb dating). Reconstruction of Siberia and Laurentia is approximately that of Evans and Mitchell (2011, Geology) and with a gap added for the North Slope subterrane of Alaska (containing Franklin age magmatism) (Cox et al. 2015, Lithosphere).

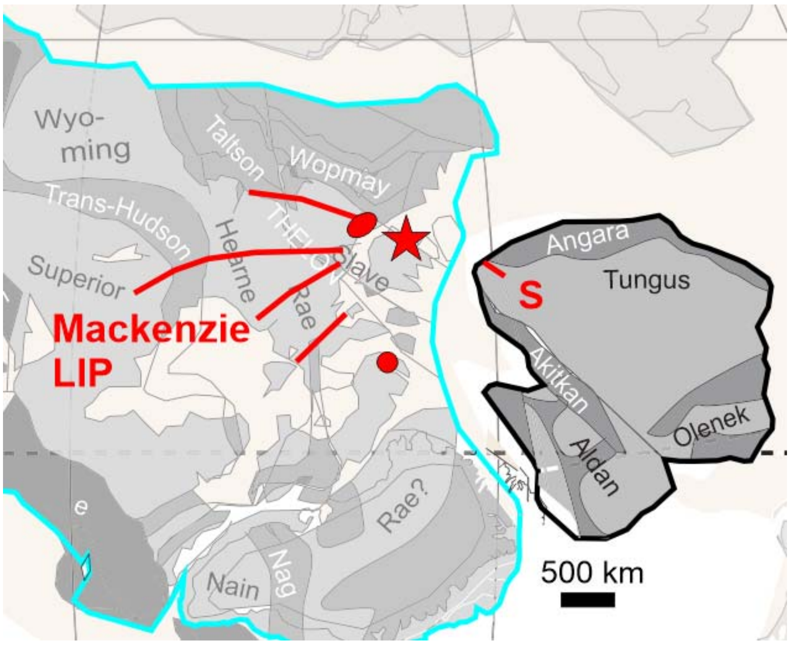


Figure 2: Generalized radiating Mackenzie dyke swarm of northern Laurentia with plume centre marked by star. Matching U-Pb age of 1260 Ma U-Pb age produced for Srednecheremshanskii (S) dyke [6, 7]. The S dyke also approximately points to the Mackenzie plume centre. Reconstruction of Siberia and Laurentia as in Figure 1.

MAFIC SILLOGENESIS* IN DEPRESSION STRUCTURES OF THE CENTRAL ASIAN FOLD BELT

G.S. Fedoseev[1,2]
[1]Department of Mineralogy and Petrography of the Novosibirsk State University
[2]Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia
fedoseev@igm.nsc.ru

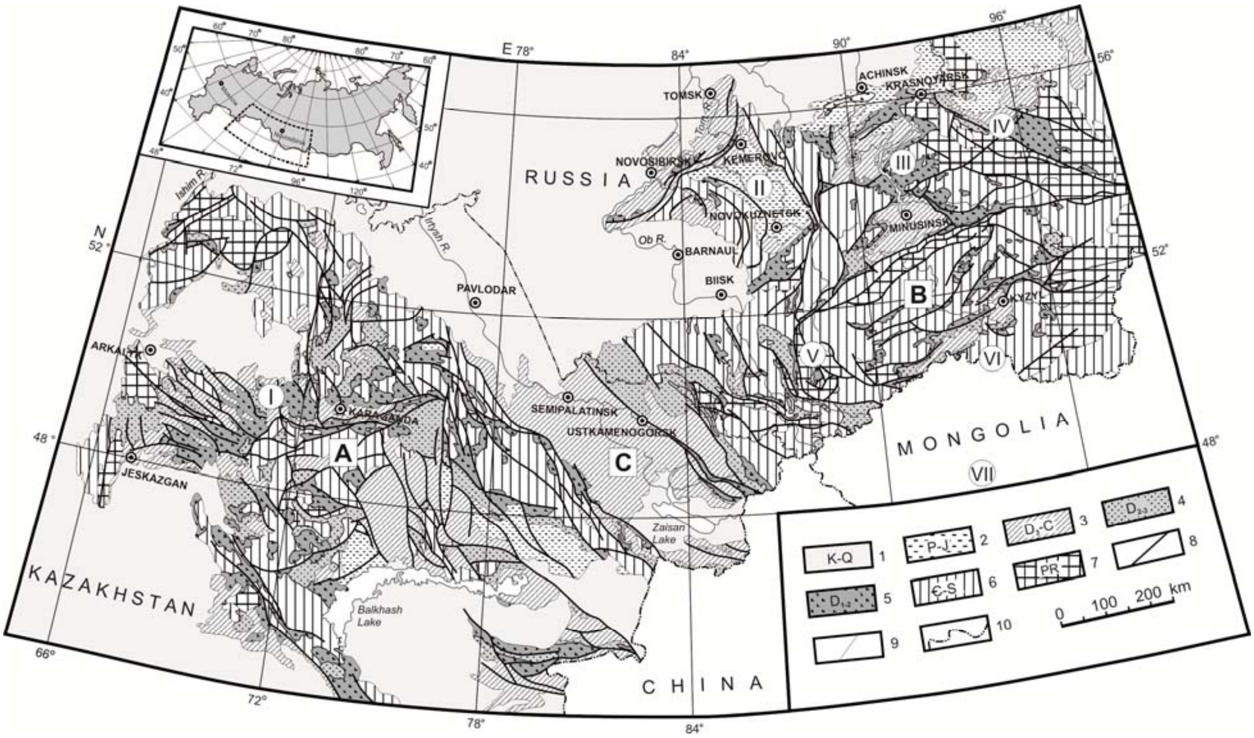
For the first time LIPs were identified as areas of plume-related basaltoid rocks occurrence. Apart from these, vast territories composed of granitoids were attributed to this category of magmatic formations (Large ..., 2011). The basaltic provinces are known both within the continents and oceans, while granitoids predominantly occur in the fold (mobile, orogenic) belts. There is a certain contrast both in the structures which are either basaltoid or granitoid, and in facial belonging – either effusive (continental and oceanic) or intrusive (solely continental). According to current views, extensive magmatic activity in the Earth's history is commonly connected with plumes. However, the crust-mantle interaction apparently is not restricted to the polarity of the compositions and homogeneity of forms of the implementation of magmatic formations produced by the deep-seated magma chambers of basic and acidic compositions. In this respect, the region of "combined" magmatism of the middle part of the Central Asian fold belt, referred to as the Kazakhstan-Altai-Sayan province (KASP), is of a particular interest (Fedoseev, Vorontsov 2010) (Fig.).

The main body of igneous rocks in the KASP were formed during the Early and Middle Devonian. However, it cannot be ruled out that the first local magmatic manifestations occurred in the Late Silurian, while the last ones took place during the Upper Devonian and Early Carboniferous. Geodynamically, the KASP is a part of the junction area of active continental margins of cratons while tectonically it is a zone of scattered rifting characterized by the presence of basaltoids.

For the province under discussion, there are two alternative scenarios of magmatism development during the Devonian period, i.e. traditional (homodromous) and proposed (antidromous). According to the first scenario, initially basalt series formed which was followed by the accumulation of pyroclastic and volcanogenic formations of acid and intermediate composition alternating with clastic molassoids. The process is treated as multistage-cyclic one. Each cycle begins with basic rocks and terminated with acid pyroclastites whose amount increases in the upper part of the section. Simultaneously melts of different composition are generated from the deep-seated chambers throughout the KASP and occur in the volcanic form.

According to the second scenario, magmatic rocks were formed in the reverse order: firstly, from the crustal chambers there formed a thick series of effusive-pyroclastic rocks of acid and intermediate composition with a significant proportion of lens and series of terrigenous rocks. With some time gap, in places of local downwarping of the Earth's crust and the resulting depression mafic magma began to inflow from the upper mantle sources. But it did not reach the surface and emplaced as dike-sill complexes which are impossible in the first scenario. Among the possible reasons of underestimation of this factor could be incorrect diagnostics of lava paleoflows by convergent features (vesiculation, glassy textures, etc.) and the underestimation of the interaction between magma and poorly cemented rocks (Fedoseev, 2001).

Thus, in the history of intracratonic and marginal basins the sillogenesis, as mass formation of low-depth sills, is considered in the context of the presence of two types of deep-seated magmatic sources (Vorontsov et al., 2015), as well as an indicator of accelerated downwarping of the basin bed (Fedoseev, Vorontsov 2011).



Schematic geological map of the Kazakhstan-Altai-Sayan igneous province
(after Sokolov R.I, 1992; simplified)

Formations: 1 – sedimentary Mesozoic-Cenozoic; 2-5 – deposits of the platform mantle: 2 – sedimentary Permian-Jurassic, 3 – terrigenous Late Devonian-Carboniferous, 4 – volcanic-terrigenous of Middle-Late Devonian, 5 – terrigenous-volcanogenic Early-Middle Devonian; 6-7 – deposits of consolidated bases: 6 – Cambrian-Silurian complex dislocated calciferous and terrigenous-volcanic, 7 – Proterozoic metamorphosed; 8 - faults; 9–10 – Boundaries: 9 – formational, 10 – state. Fold areas: A – Kazakhstan, B – Altai-Sayan. Major sedimentary basins: I – Kazakhstan fragmented, II – Kuznetsk, III – Minusinsk, IV – Rybinsk-Agul, V – Uymeno-Lebedskiy, VI – Tuva; VII – area of the Devonian rift structures of Mongolia.

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** The Russian term "sillogenez" currently has no adequate translation into English. Attempts to use the terms "sill-formation, sills formation, sill genesis, sills-genesis, sillsgeny" are unsuccessful.*

EARLY MESOZOIC ALKALINE GRANITOID MAGMATISM IN MONGOLIA: EVDENCE OF PLUME ACTIVITY IN THE MONGOL-TRANSBAIKAL PROVINCE

O. Gerel[1], B. Munkhtsengel[1], J. Dostal[2]
[1]Department of Geology and Hydrogeology, Monglian University of Science and Technology, Ulaanbaatar, Mongolia
gerel@must.edu.mn; munkhtsenel@must.edu.mn
[2]Saint Mary's University, Halifax, Canada
jaroslavdostal@gmail.com

The alkaline granitic intrusions that rimmed the Khentei batholith of the early Mesozoic Mongol-Transbailkal igneous province have been the subject of intensive scientific research for almost 40 years, renowned for their debatable origin and rare-metal mineralization (Kovalenko et al., 1971; Gerel, 1990; Koval, 1998 and others). These intrusions occur in the North Gobi and Kharkhorin rift zones and form relatively small shallow plutons composed of alkali feldspar granites, leucogranites, syenogranites and quartz syenites.

We present new geochronological and geochemical data of the Dashbalbar and Bayan-Ulaan plutons in the North Gobi rift and Khugnukhan pluton in the Kharkhorin zone. The North Gobi rift consists of a number of depressions and grabens filled by Upper Permian to Upper Triassic fossiliferous clastic sedimentary rocks, which are intercalated with and overlain by bimodal volcanic suites (Yarmolyuk et al., 2002). These strata are underlain by fossiliferous Lower to Middle Devonian sedimentary sequences or Early Paleozoic to Neoproterozoic basement. These units were intruded by Early Mesozoic granitic plutons, which were subsequently overlain by the Early Cretaceous basaltic lavas. These igneous rocks are generally preserved in grabens or troughs and are commonly overlain by thick covers of Cretaceous and Quaternary sediments.

The granitoids of Dashbalbar pluton are shallow-seated dominantly amphibole-bearing alkali feldspar granite and quartz syenite that contain quartz-syenite/syenite enclaves. They are all composed of megacrystic mesoperthite, quartz, Ca-Na amphibole altered to biotite and rarely with pyroxene cores, magnetite and ilmenite. The pluton yielded a concordant U-Pb zircon age of 186 ± 1 Ma, and indicates rapid cooling though ca. 550°C (Dostal et al., 2014). The granitoids are evolved alkaline, A-type granites and quartz-syenites that are enriched in light REE's, but with distinct depletion of Eu, Sr and Ba, indicative of feldspar fractionation. The granitic rocks have εNd (t) values of ~+0.8 to + 1.4, which are slightly lower than εNd values + 1.4 to +1.6 in the syenites, although both have similar TDM model ages (~800- 970 Ma).

The 221Ma Bayan-Ulan granitic pluton is slightly older. It consists mainly of alkali feldspar granites containing mesoperthite with interstitial quartz, minor Ca-Na and Na amphiboles and rare Fe-rich biotite. Graphic texture is common. Granites are leucocratic typical ferroan, predominantly peraluminous with some rocks being peralkaline and metaluminous with the alumina saturation index A/CNK values ranging from 0.95 to 1.1 while the A/NK values range from 0.98 to 1.16. Most of the rocks are alkaline (A/NK< 1.15), have lower contents of Ba and Sr but higher Rb/Sr ratios. The granites have a range of εNd (t) values (~ +1.4 to + 1.7), and TDM model ages (mostly ~800 - 1,200 Ma.

The Khugnukhan pluton is situated in Khangai - Khentei fold belt and Kharkhorin NW-trending structural step (Yramolyuk et al., 2002). Stratigraphy is represented by sedimentary and metamorphic rocks of the Silurian, lower-middle Devonian and Carboniferous Formations, intruded by late Permian-early Triassic, and late Jurassic granitoiids. The Khugnkhan pluton composed of biotite granite and K-feldspar leucogranite. Previously this pluton was included into the late Mesozoic Ikh khairkhan Complex. However, granitic rocks of the Khugnukhan pluton show U-Pb zircon age of 208.0 ± 3.9 Ma, 206.4±2.3 Ma and 202.9±2.8 Ma (Munkhtsengel et.al, 2013).

Granites of the Khugnukhan pluton show high silica content, ranging from 73.75% to 79.39% SiO_2 and are mostly composed of K-feldspar leucogranite with small amount of biotite. The Khugnukhan granites are dominated by potassium feldspar and similar to within-plate A-type granites formed during post-orogenic setting. They plot on K-feldspar granite field in classification diagram, show A-type granite characteristic in terms of Nb-Ga/Al, and plot on within-plate granite field in tectonic discrimination diagram. Geochemical characteristics show A2 features, like high Ga ratio, depletion in Sr, Ba, P, Eu and enrichment by Rb, Li, Nb. They are mainly bitotite-bearing granites with Fe-rich siderophyllite. Such characteristics of the Khugnukhan granite are similar to other A-type granites formed in the margin of Khentey uplift.

The granitic magma likely was generated by partial melting of underplated Neoproterozoic mafic crust with a transitional to mildly alkaline basalts in the lower crust, followed by fractional crystallization dominated by feldspars.

The formation of the alkaline felsic magmas requires a heat source to generate an elevated temperature. Commonly invoked processes that could produce such a heat source include delamination, rifting accompanied by thinning of the lithosphere and a mantle plume. The A-type characteristics of the granite including their alkaline nature as well as their emplacement within a rift zone are consistent with both rift- and plume-related magmatism advocated by Yarmolyuk et al. (2011). The Mongolian plume would provide the heat source for the magmatism and would account for its zonal nature: normal granitoids (quartz diorite-granodiorite-granite) in the center of the Khentei batholith grading through leucogranites and Li-F granites towards the batholith margins to alkaline and peralkaline intrusions and lavas in the marginal rifts. Thus, the crust above the plume is more extensively melted in comparison to the margins where deeper and less extensive melting takes place.

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EVOLUTION OF HIGH-ALUMINA ALKALINE MAGMATISM IN THE CENTRAL ASIAN FOLDED BELT

I.F. Gertner, V.V. Vrublevskii, T.S. Krasnova
Tomsk State University, Tomsk, Russia, labspm@ggf.tsu.ru

One of important specific features of alkaline magmatism in structures of the Central Asian Folded Belt (CAFB) is its high content of alumina. Unlike alkaline-ultrabasite complexes of central type, which have been developed within ancient cratons or in consolidated blocks of their boundaries, these rock associations always have in their composition petrographic varieties enriched with feldspathoids, in particular with nepheline or leucite (ijolites and urtites, feldspathic ijolites and urtites, as well as leocotefrites (bereshites, juvites and leucite-rich syenites). An important petrochemical parameter for these rocks is that they belong to a miaskite series, which composition does not include alkaline dark-color minerals, as well as any signs of obvious enrichment in the most active volatile F- or Cl components. This can be observed in the Khibinsky, Lovozersk, or Ilimussaksk massifs. As a rule, these associations show in whole-rock composition high content of CO_2 that defines fassaitic type of clinopyroxenes and manifestation of interstitial carbonate. One of the proves for such a conclusion is presence of magmatic carbonatites as late “segregates” at the latest formation stages of alkaline-gabbroic plutons in Kuznetsk Alatau and Western Tuva.

Formation of alkaline complexes of miaskite series in folded structures usually takes quite long time and is assumed to undergo multiple impacts of one or several stages of plume activity onto centers of magma generation. Let us analyze this on the example of alkaline-basite complexes of the Western sector of CAFB (Kuznetsk Alatau, Gorny Altay, Tuva, and Northern Mongolia). Based on the results of our isotope studying of alkaline and middle alkaline basites from Kuznetsk Alatau and Gorny Altay, we determined a polychronous nature for formation of rocks with similar petrographic and geochemical composition (Vrublevsky et al., 2003; Krupchatnikov et al., 2012; Vrublevskii et al., 2014a). In both Kuznetsk Alatau and Gorny Altay, there were found complexes of at least three different ages: 1) Late Cambrian – Ordovician (Verkhnepetropalovsk Massif, complex “Edelveis”, Kokhtag complex); 2) Early Devonian (Kiya-Shaltyr, Dedovogorsk, Belogorsk, and Kurgusul Massifs); 3) Late Permian – Early Triassic (Goryachegorsk Massif and Chuysk lamprophyric complex). U-Pb isotopic dating (using SHRIMP method) of juvites from Northern Mongolia (Overmaargolsk Massif) yielded a Silurian age of 426.5±3.5 Ma (Vrublevskii et al., 2014b), mean while similar rocks from Western Tuva (Dahunur, Bayankol, Kharlin, and other massifs) are assumed to be formed in Upper Carbon – Early Permian (330-300 Ma) (Vrublevskii et al., 2014c).

An important element in forming high-aluminous rocks of alkaline series/sequence is processes of fraction crystallization and possible accumulation of an early subliquid phase of feldspathoids, in particular nepheline. However, there is a certain limitation. Real compositions of alkaline magmatic melts generated by mantle plumes correspond to subsolidus ratios of nepheline, pyroxene, and feldspars. In this case, a mechanism of crystallization differentiation would not allow accumulating early crystal phase of a feldspathoid, because this phase was not this one. In order for initial magmatic melt to “get into” a field of a primary nepheline crystallization, additional reactions are required that will provide accumulation of Al_2O_3 in residual melt. The most possible mechanism for such enrichment is interaction between silica melt and carbonate substrate. One of the first supporter of this hypothesis was R.A. Deli, who proved that nepheline syenites are formed in places of granites contacting with limestones. Practical application of this scheme is a technological process of agglomeration of nepheline ores with calcium carbonate implemented in the Achinsk factory in order to obtain free alumina. In 1960s, it has already been proven using simple thermodynamic calculations that neither "granite" magma nor basalt one has real temperature reserve sufficient for assimilation of a certain amount of calcic substrate so high-aluminous magmas can be obtained. However, a new concept suggesting active impact of mantle plumes on lithosphere lets us go back to those ideas them. Plume has much bigger energy reserve that allows eroding not only lithosphere mantle but also crust fragments including its carbonate component.

If we analyze lateral and temporal zoning of alkaline magmatism in Kuznetsk Alatau, Gorn Altay, Tuva, and Northern Mongolia, we can note following patterns. The most Western part of the region represented by Cambrian-Ordovician complexes is described by melanocratic profile and signs of metasomatism shown. Starting with Silurian manifestations, we can see obviously participation of high-aluminous varieties of juvites, feldspathic urtites (Mongolia), feldspath less urtites and juvites in Devonian (Kunetsk Alatau, Kiya-Shaltyr deposit, and Kurgusulsk Massif), then feldspathic ijolite-urtites and juvites in Carbon and Permian (Kharlinsk Massif in Tuva, Goryachegorsk Massif in Kuznetsk Alatau). Taking into account that the most high-alumina rocks localize among carbonate rocks or go through carbonate base of Cambrian folded substrate, we can assume that there was an active interaction between silica magmas and a certain crust component under impact of mantle plumes.

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THREE STAGES OF INTRACONTINENTAL MAFIC MAGMATISM IN THE SOUTH-EASTERN PART OF THE SHARYZHALGAI INLIER OF THE SIBERIAN CRATONIC BASEMENT

D.P. Gladkochub[1], T.V. Donskaya[1], R.E. Ernst[2,3], S.A. Pisarevsky[4], A.M. Mazukabzov[1] M.A. Hamilton[5]

[1]Institute of the Earth's Crust, Siberian Branch of the Russian Academy of Sciences, Irkutsk, Russia, gladkochub@mail.ru

[2]Department of Earth Sciences, Carleton University, Ottawa, Canada, Richard.Ernst@ErnstGeosciences.com

[3]Faculty of Geology and Geography, Tomsk State University, Tomsk, Russia

[4]Australian Research Council Centre of Excellence for Core to Crust Fluid Systems (CCFS) and The Institute for Geoscience Research (TIGeR), Department of Applied Geology, Curtin University, Perth, Australia, sergei.pisarevsky@uwa.edu.au

[5]Jack Satterly Geochronology Laboratory, Department of Earth Sciences, University of Toronto, Toronto, Canada, mahamilton@es.utoronto.ca

Numerous dolerite dykes cut the Precambrian rocks in the south-eastern part of the Sharyzhalgai inlier of the Siberian cratonic basement (near the village of Listvyanka and along the Krugobaikal railway). Three different generations of the dykes, related to different stages of Siberian evolution in this area, have been recognized on the basis of geological, geochemical and geochronological data.

The first group of dykes is exposed along the coast of the Lake Baikal near the village of Listvyanka. These include one relatively thick dyke (30 m) and several smaller dykes. The dykes are sub-vertical with NNE trend (10-20°). Mineralogically, they are dominated by clinopyroxene and plagioclase with minor hornblende, biotite, quartz and ore minerals. The U-Pb baddeleyite age of the thick dyke is 1350 ± 6 Ma. The chemical composition of these dolerites (Listvyanka swarm) correspond to subalkaline basalts ($Na_2O + K_2O$ = 2.8 – 3.5 wt %). The rocks are differentiates (Mg# = 38 – 54) of the tholeiitic series (FeO*/MgO = 1.8 – 3.4) with a high content of TiO_2 (1.6 – 3.5 wt %) and of P_2O_5 (0.2 – 0.4 wt %). A clear positive Nb-Ta anomaly in the multi-element spectra suggests an OIB affinity. Incompatible element ratios such as Th/Ta, Zr/Nb, Nb/Y, Zr/Y also suggest that these dolerites are close to OIB basalts in composition and may be plume-related (e.g. Condie 2005). Geochemical characteristics are consistent with the suggestion that these dolerites were generated during a plume-related Mesoproterozoic intra-continental extension, and likely represent part of the plumbing system of a Large Igneous Province (LIP) (e.g. Ernst 2014)

Dykes belonging to the second group are dominant in the area (Nersa swarm). Mineralogically, these are dolerites, sub-vertical and with a nearly E-W trend (260-280°). Their thicknesses vary from 1 to 15 m. The main rock-forming minerals are clinopyroxene and plagioclase, but minor olivine is present, along with orthopyroxene, hornblende and titanomagnetite. The age of these dykes is considered to be ~740-720 Ma due to their geochemical similarities with nearby dated dykes emplaced into the southern part of the Siberian Craton (Gladkochubetal. 2010a). Their chemical compositions also correspond to subalkalic tholeiitic basalts ($Na_2O + K_2O$ = 1.5 – 3.1 wt %; FeO*/MgO = 0.8 – 2.1). Mg# varies from 50 to 73. These dolerites have low concentrations of TiO_2 (0.5 – 1.2 wt %) and P_2O_5 (0.05 – 0.10 wt %), and weakly fractionated REE spectra (La/Yb_n = 1.4 – 4.5). Multi-element spectra show clear negative Nb-Ta and Ti anomalies. High (1.05 – 2.08) Th/La_{pm} ratios are similar to those of the continental crust and are characteristic for these dolerites. The $\varepsilon_{Nd}(t)$ value in the analysed dolerite is -10.1. Altogether the isotopic and geochemical data indicate that the dolerites of the second group have been formed as the result of crustal or lithospheric contamination of a primitive mantle source. The emplacement of these and other south Siberian mid-Neoproterozoic dykes may be related to the breakup of supercontinent

Rodinia (Gladkochubetal. 2010a). In particular, these are potentially part of a 725-716 Ma intraplate magmatic event that is linked to the Franklin LIP of formerly adjacent northern Laurentia (e.g. Ernst et al. 2012).

The third group of narrow dykes is exposed along the Krugobaikal railway, and is hereby referred to as the Krugobaikal swarm. These dykes are also steeply dipping with a roughly E-W trend. Their thicknesses vary from a few tens of centimetres to two meters. All dykes of this swarm consist of dolerite. The central parts of thicker dykes are coarse-grained dolerites, while their marginal parts are very fine-grained. These rocks contain olivine, plagioclase and clinopyroxene phenocrysts. The matrix additionally contains biotite, titanomagnetite and ilmenite. A sample from coarse-grained dolerite of the central part of one of these dykes has been dated by U-Pb (zircon) method at 275 ± 4 Ma, which is consistent with the paleomagnetic analysis (Pisarevskyetal. 2006). These Permian dolerites are highly alkaline ($Na_2O + K_2O = 4.0 – 6.0$ wt %). They have high contents of TiO_2 (1.6 – 3.9 wt %) and P_2O_5 (0.3 – 0.7 wt %). In the multi-element spectra there are clear negative Nb-Ta anomalies and positive Sr anomalies. The Th/La_{pm} ratio in all Krugobaikal dolerite dykes is less than 1 (0.34 – 0.52). Initial $\varepsilon_{Nd}(t)$ values are between +3.4 and +7.3; they do not correlate with the SiO_2 content. Altogether the isotopic and geochemical data indicate a mixed mantle source with both recycled and enriched components (Condie 2005). These dykes were probably emplaced during the interaction of a mantle plume with the subducted slab of the Mongol-Okhotsk Ocean (Gladkochub et al. 2010b).

We conclude that at least two out of three dyke generations in the south-eastern part of the Sharyzhalgai inlier of the Siberian cratonic basement have been related to mantle plumes.

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MESOPROTEROZOIC MANTLE PLUME BENEATH THE NORTHERN PART OF THE SIBERIAN CRATON

D.P. Gladkochub[1], T.V. Donskaya[1], A.M. Mazukabzov[1], R.E. Ernst[2,3], S.A. Pisarevsky[4]
[1]Institute of the Earth's Crust, Siberian Branch of the Russian Academy of Sciences, Irkutsk, Russia, gladkochub@mail.ru
[2]Department of Earth Sciences, Carleton University, Ottawa, Canada, Richard.Ernst@ErnstGeosciences.com
[3]Faculty of Geology and Geography, Tomsk State University, Tomsk, Russia
[4]Australian Research Council Centre of Excellence for Core to Crust Fluid Systems (CCFS) and The Institute for Geoscience Research (TIGeR), Department of Applied Geology, Curtin University, Perth, Australia, sergei.pisarevsky@uwa.edu.au

Mesoproterozoic igneous complexes are rather locally distributed within ancient cratons. One such complex is the "Kutunghe mafic sill" which is located on the Olenek uplift of the northern Siberian craton. This sill can be traced in N-E direction over a distance of about 22 km. Its thickness reaches 70 – 100 m. The age of this sill is 1473 ± 24 Ma (baddeleyite, SHRIMP-II) (Wingate et al. 2009). Geological, petrological and geochronological investigation of this sill provides following results:

1) According to geochemical characteristics, this dolerite sill corresponds to a typical OIB which was produced with mantle plume input;

2) Primary mantle melts of this dolerite sill were only weakly affected by crustal contamination. This conclusion is supported by isotopic values ($\varepsilon_{Nd}(t)$ ranging from -0.8 to +0.6) and also by the occurrence of inherited zircon grains in studied samples. However, in general, this dolerite sill can be considered as nearly primary;

3) A synthesis of geological observations and geochemical characteristics suggest the emplacement of this dolerite sill during a period of intra-plate extension;

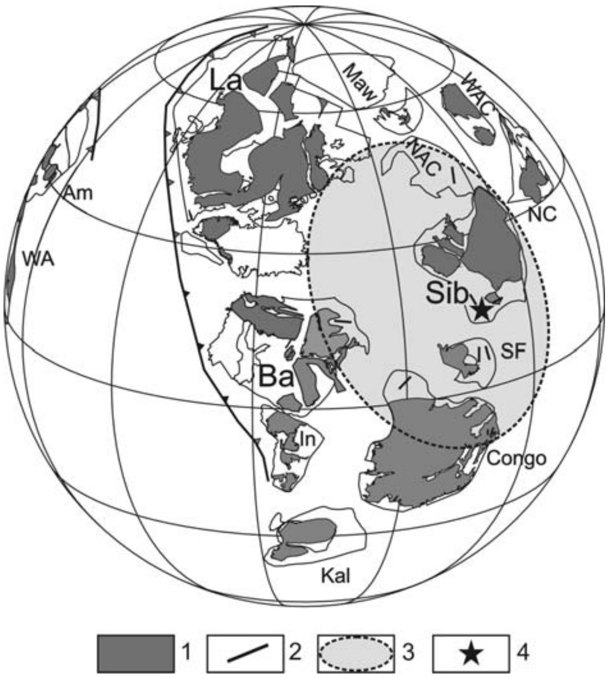

Fig. 1. Nuna (Columbia) supercontinent in Early Mesoproterozoic (modified after Pisarevsky et al. 2014).

1 – Archean basement of ancient cratons; 2 – Early Mesoproterozoic (~ 1.50 – 1.45 Ga) mafic dyke swarms and igneous complexes; 3 – the area of mantle plume influence; 4 – suggested head of mantle plume.

La – Laurentia; NAC – North Australian craton; WAC – West Australian craton; Maw – Mawson craton; Sib – Siberian craton; SF – San Francisco craton; Congo – Congo craton; Kal – Kalahari; Am – Amazonia; WA – West Africa; NC – North China craton; In – India.

4) Early Mesoproterozoic (~1.50 – 1.45 Ga) mafic complexes of the Olenek and Anabar uplifts of the Siberian craton (Veselovskiy et al. 2006; Ernst et al. 2000) and mafic intrusions from other ancient cratons such as Congo, San Francisco (Ernst et al. 2013) and Baltica (Ernst and Buchan 2001; Söderlund et al. 2006) can be united into a Large Igneous Province (LIP) linked to a mantle plume (Ernst et al. 2014; Gladkochub et al. in press). According to paleogeographic reconstructions (for instance, Ernst et al. 2013) all these cratons were located near to each other (Fig. 1) in the Nuna (or Columbia) supercontinent.

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A POSSIBLE ROLE OF THE SUPERPLUME IN GENESIS OF UNIQUE KATUGIN RARE METAL DEPOSIT (ALDAN SHIELD)

D.P. Gladkochub[1], A.M. Larin[2], A.B. Kotov[2], N.V. Vladykin[3], V.P. Kovach[2], E.V. Sklyarov[1, 4], T.V. Donskaya[1], S.D. Velikoslavinskii[2]

[1]Institute of the Earth's Crust, Siberian Branch of the Russian Academy of Sciences, Irkutsk, Russia, gladkochub@mail.ru

[2]Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences**,** Saint Petersburg, Russia, abkotov-spb@mail.ru

[3]Institute of Geochemistry, Siberian Branch of the Russian Academy of Sciences, Irkutsk, Russia, vlad@igc.irk.ru

[4]Far East Federal University, Vladivostok, Russia, skl@crust.irk.ru

The Katugin rare metal deposit (unique in terms of resources of Ta, Nb, Zr, Y, REE) is located in the southern-western part of the Aldan shield. This deposit is enclosed in two granite massifs which composed by biotite-, biotite-amphibole-, amphibole-aegirine- and aegirine-bearing alkaline granitoids. The age of granitoids was determined by U-Pb zircon method as 2066 ± 6 Ma (Larin et al. 2002). The synthesis of modern geological, geochronological, mineralogical and geochemical data supports the hypothesis on magmatic origin of the Katugin deposit (Larin et al. 2002; Levashova et al. 2014) instead of methosomatic model as it was considered earlier (Arkhangelskaya et al. 1993).

The recognizing of geodynamic settings which controlled the forming of Katugin deposit, proposed in this issue, is based on analyses of geochemical and isotopic characteristics of the granitoids which belong to Katugin complex. These granitoids demonstrate high values of alkalinity (Na_2O+K_2O до 12.3 wt %), agpaitic index (NK/A = 0.96 – 1.71) and mafic index (f = 0.96 – 1.00). They have extremely high contents of Rb, Li, Y, Zr, Hf, Ta, Nb, Th, U, Zn, Ga, REE, F, and lower concentrations of Ca, Mg, Al, P, Baи Sr. The concentrations of incompatible elements mentioned above gradually increase from biotite- and biotite-amphibole-, through amphibole-aegirine- to aegirine-bearing granitoids. There are clear negative anomalies in Ba, Sr, Eu and positive anomalies in Th, U, Nb, Ta, Zr и Hf on primitive mantle normalized patterns of these granitoids.

According to discrimination criteria of Eby (1992) alkaline granitoids of Katugin complex belong to A_1 type. The origin of such granitoids could be explained by development of OIB-type source.

Granitoids of Katugin complex demonstrate negative and close to CHUR values of $\varepsilon_{Nd}(t)$ = 0.0 ÷ -1.9. The calculation of Nd model ages of these rocks gave following results: $t_{Nd(DM)}$=2.7-2.6 Ga and $t_{Nd(DM-2st)}$ = 2.7-2.5 Ga. On the diagram «□$_{Nd}$(t) – age» compositions of studied granitoids plot to the field between line of evolution of isotopic composition of Nd in CHUR and area of isotopic composition of Nd in Archean continental crust of the southern-western part of the Aldan shield. These observations together with geochemical characteristics of granitoids allows to explain the origin of initial melts which were responsible for the forming of these rocks by crustal – mantle interaction. Relatively high values of incompatible element rations such as Th/Ta = 0.6–1.5; Zr/Nb = 2.5–3.1 and Nb/U up to 62 testify on OIB-type melts as possible source of mantle material (Kovalenko et al. 2009).

In terms of tectonics the Katugin rare metal deposit is located just in the triple-point area where ancient aulacogene and two branches of oceanic structures (closed in the Paleoproterozoic) meet to each other. It is very important that Paleoproterozoic (2.2 – 1.8 Ga) intra-plate igneous complexes and number of large and unique mineral deposits (Ta, Nb, Zr, Y, REE, Fe, Ti, V, PGE, Cu) are widely distributed in this area. Such compact localization of different types of mineral deposits which were produced during rather narrow time period, together with geochemical and isotopic characteristics of ore-bearing granitoids of Katugin complex, allow us suggest that igneous activity between 2.2 and 2.1 Ga in the area studied was directly related to mantle superplume.

Geochemical and isotopic investigations were supported by Russian Foundation for Basic Research (project 13-05-12075) and Russian Scientific Foundation (project 14-17-00325) consequently.

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GEOCHEMICAL EVIDENCE OF PLATINOIDS IN ULTRABASIC ROCKS OF THE SHOUTHERN TERMINATION OF NORTH-ASIAN CRATON

O.M. Glazunov[1], T.A. Radomskaya[1], S.V. Salaev[2]
[1]Institute of Geochemistry SB RAS, Irkutsk, Russia, glazunov@igc.irk.ru
[2] «SibNedra», Irkutsk, Russia

In the Sayansk nickel-platinum-bearing province the haloes of ultrabasic rocks occur in three large Precambrian terranes: Sharyzhalgay, Birusa and Kansk.

It is truly important to compare ore-magmatic systems (OMS) of different ages. Irrespective of age variations, the ultrabasic rocks of peridotite-pyroxenite-gabbro composition share copper-nickel specialization.

In the Sharyzhalgay terrane deformed bodies of ultrabasites in Archean gneisses contain accumulated HREE, positive Eu anomaly, their age being 2.5 Ga (Grudinin et al., 1984). PGE are scattered either in the dispersed form or as clusters. They show steady Os > Ru ratio with dominance of Pt over Pd, that is comparable with the chondrite value and points to the protoxide medium of the mantle (Vinogradov, 1971). Considering Pd/Ir and other platinoids, they are close to the Archean komatiites and PGE (Maier et al., 2003), as well as garnet peridotites common for regional mantle (Fig.).

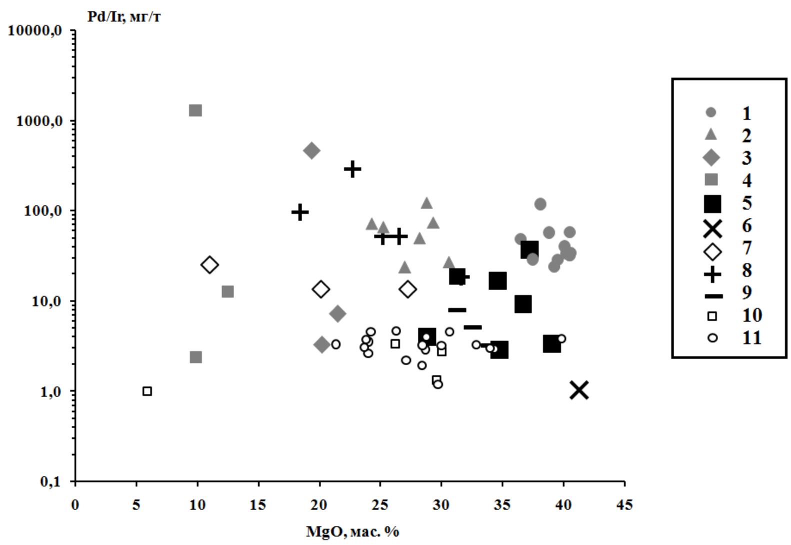

Fig.Pd/IrtoMgORatio in rocks of ultrabasite-basite massifs of the Kansk, Birusa and Sharyzhalgay n terranes of Precambrian period.

1-6 – massifs of the Kansk terrane: 1-4 – Kingash (1 – dunites, 2 – wehrlites, 3 – clinopyroxenites, 4 – metagabbro), 5-6 – Idarsky Belogorie (5 – apoharzburgite serpentenites, 6 – garnet lherzolite of the Igilsky massif); 7 – Zhelossky massif of the Birusa terrane (after Salaev A.V.); 8-11 – massifs of the Sharyzhalgay terrane: 8 – peridotites of Krutaya Guba in Archean gneisses, Bulunsky block, massifs: 9 – Kunduy, 10 – Khogot; 11 – komatiites (Maier et al., 2003).

Within Kansk terrane there are ultrabasic rocks with the richest platinoid-copper-nickel mineralization occurring in the Kingash deposits with the age 1387 ± 40 Ma. They are distinguished by petrological-geochemical zonation with element distribution over entire section and high contents in liquation «horizons» of the natural part of lopolite (PGE reaching 17 ppm). In the rocks and ores Pd > Pt. Ores contain bismuth telluride of Pd: sobolevskite, kotulskite, maichenerite, etc. Vividly expressed tendency to recognizing native PGE is established in association with high-ferruginous pentlandite and high-sulfur pyrrhotite. Platinum as the chemical active element to oxygen is widespread in the zones of serpentinization. Sorption affinity of palladium to halogenides results in formation of rich platinoid «reefs» similar to those of large deposits (Stillwaterand others) (Glazunov, Radomskaya, 2010). High geochemical index (Pt+Pd+Rh/Os+Ir+Ru=20) points to the picritoid source in contrast to the Archean apokomatiite peridotites (with index 2-3) (Naldrett, 2014).

Ultrabasites of the Birjusa terrane show diversity of massif shapes, heterogeneous composition of rocks and ores, enrichment with mostly refractory elements. In addition to nickel, sulfide ores have high PGE concentrations (>10 ppm) with ratio Ru > Os. Distribution of nickel is correlated with MgO. The main PGE carriers are sperillite, irarsite, bismuth tellurides Pd (Mekhonoshin, Kolotilina, 2011). In places alluvium contains Os-Ir fusions.

OMS evolution proceeded via fractionation of the Archean komatiite mantle with exertion in Proterozoic of the picritoid ingredient enriched in Pd-Pt-Bi-Te-Cu-Ni.

PGE concentration and segregation in apokomatiite ultrabasites of the Archean age is feasible under partial melting, cumulative recrystallization and metasomatism of parental melt. Alternating geodynamics of ultrabasite emplacement of the Birusa terrane is reflected in the diapirism footprints and gradients of composition.

Ultrabasites of the Kingash ore field are formed under subcontinental setting of the early rifting. Increased isotope ratios $^{87}Sr/^{86}Sr = 0.7060 – 0.7066$ at low values of $^{143}Nd/^{144}Nd = 0.5125 – 0.5130$; εNd = 2.6 – 3.8; $\delta S^{34} = -1.4 – (+2.0\ \%)$ correspond to the anomalous mantle component EM-II.

Extensive high-resourceful, relative to Pd-Ni-Cu, ultrabasic magmatism in the Kansk terrane coincided with the stages of accretion of folded framing with the North-Asian Craton. Time span 1460– (1387 ±40) Ma is the proper time for ore generation and enrichment of mantle with PGE and chalcophyles.

Thermal pre-history of regional OMS, as stated by Dobretsov (1980) may be explained by activity of intratelluric flows and plume.

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3D MODEL OF THE HEAD OF A PALEOPROTEROZOIC PLUME IN THE SOUTHERN SIBERIAN CRATON

B.I. Gongalsky[1], A.L. Galyamov[1], G.D. Pavlovich[2], A.V. Petrov[2], K.Yu. Murashov[1]
[1]Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry (Institution of the Russian Academy of Sciences), Moscow, Russia, brgon@mail.ru ;
[2]Russian State University for Geological Exploration, Moscow, Russia, gpavlovich@mail.ru

Paleoproterozoic magmatism is associated with one of the three major peaks (spurts) of increased continental crust production (Dobretsov, Buslov, 2011). It gave rise to many unique ore deposits (Bushveld, Witwatersrand, etc.) In Russia, it is represented by the large North Transbaikalian metallogenic province at the southern margin of the Siberian Craton. Unique copper (Udokan, >25 Mt Cu), vanadium and titanium (Chiney), tantalum and niobium (Katugin) and other (PGM, silver, gold, uranium etc.) ore deposits are clustered here.

During the Late Paleoproterozoic times, rift basins of the Akitkan Belt and the Kodar–Udokan zone in the southern part of the Siberian Craton were gradually filled with volcanic-sedimentary and sedimentary deposits. Paleoproterozoic magmatic rocks of the Udokan–Chiney region are represented by large granitoid massifs of the Kodar Complex (Kodar, Kemen etc.) and ultramafic–mafic massifs of the Chiney Complex (Chiney, Luktur, MyLove, Verkhniy Sakukan etc.) Mafic massifs were emplaced in a setting of postcollisional extension after the completion of collision and accretion events responsible for the assemblage of the Siberian Craton (Gladkochub et al., 2012).

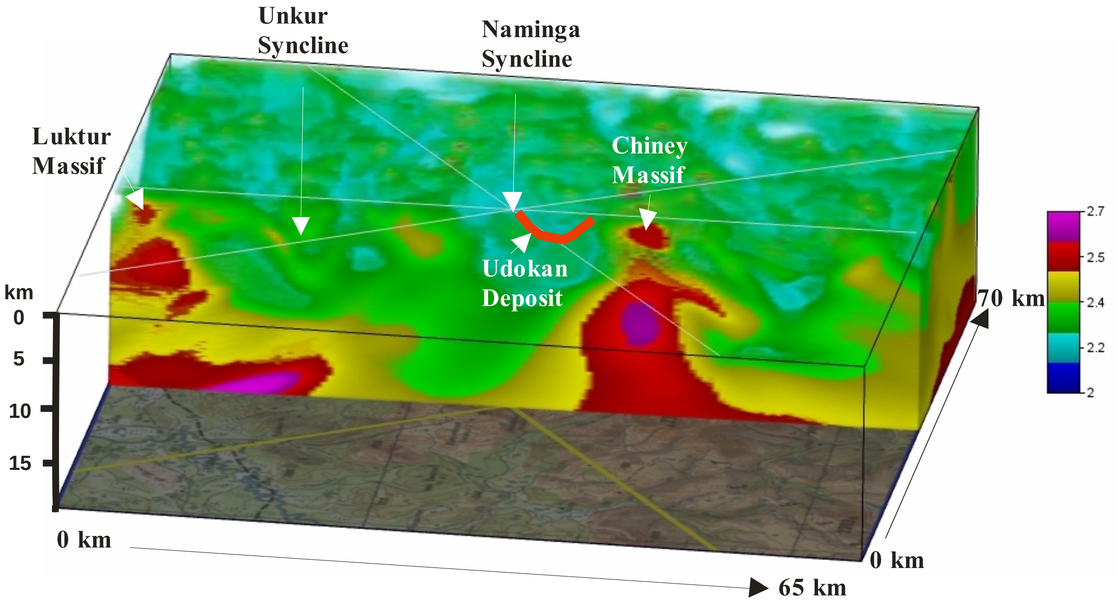

Fig. 1. Cross section of gravity mass distribution across the Luktur and Chiney massifs and the Unkur and Naminga synclines with cupriferous sandstone deposits (Unkur and Udokan).

The age of gabbroids of the Chiney Complex was determined by various methods as 1811–1880 Ma (Gongalsky, 2012) and the age of the postorogenic granites of the Kodar Complex, as 1876–1873 Ma (Larin et al., 2000).

Ultramafic–mafic and granite intrusions deformed terrigenous strata into anticlines and synclines (Fig. 1). Structural lows accommodated cupriferous sandstone deposits: the Udokan and Unkur deposits occur within the Naminga and Unkur synclines. Anticlines correspond to the ultramafic–mafic massifs of the Chiney Complex. As obvious from 3D models of gravity and magnetic fields (Petrov et al., 2011), the layered massifs exposed on the surface represent merely the heads of magmatic columns that extend downward as deep as 20 km or deeper

(Fig. 2). Weight of evidence suggests that these columns merge at depth and make up intermediate magma chamber or the upper boundary of a Paleoproterozoic mantle plume. Such magmatic columns were formed during multiple magma spurts. The similarity in isotopic datings of the Chiney gabbroids and Kodar granitoids attest to their belonging to a single regional magmatic event manifested by the rise of hot mantle rocks (mantle plume).

Rift basins filled with multi-kilometre clastic sequences suggest of the onset of crustal stretching and initial breakup of the supercontinent accompanied by mantle magma intrusion into crustal stretching and fault zones and subsequent drift of the split-off continental blocks.

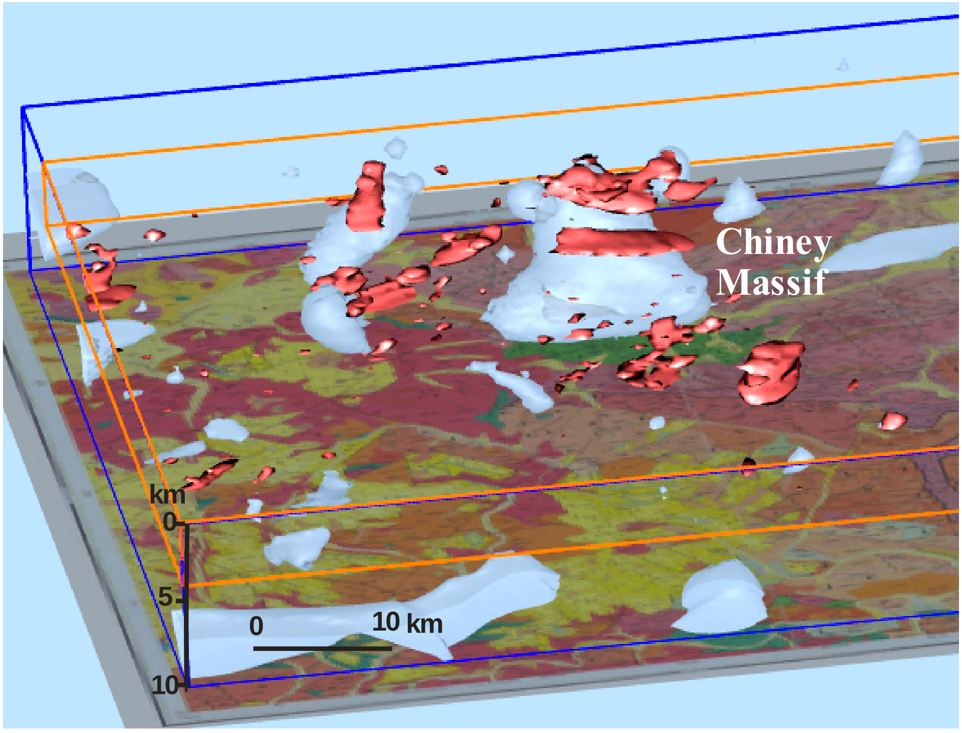

Fig. 2. Gravity (light grey) and magnetic (grey) anomalies associated with the Chiney Massif. The baseplate is the geological map of the region.

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MAFICDIKESAS INDICATORS OFTECTONIC ANDMAGMATIC PROCESSES IN THE SOUTHERN SIBERIANCRATON

B.I. Gongalsky[1], N.A. Krivolutskaya[2], Yu.G. Safonov[1]

[1]Instituteof Geology of OreDeposits, Petrography, Mineralogy and Geochemistry, Moscow, Russia, brgon@mail.ru,[2]Vernadsky Institute of Geochemistryand Analytical Chemistry, RAS, Moscow, Russia, nakriv@mail.ru

Ultramafic-mafic complexes are regarded as indicators of large tectonic reconstructions from the Archaean to the present time. They are often associated with plume magmatism. This situation is typical of the northern and central parts of the Siberian platform, where Mesozoic rocks of the trap formation are widespread. Young volcanic and sedimentary rocks are eroded significantly inside the southern part of platform, thereby there is an opportunity to study the early stages of magmatism and associated mineralization in this province. The most important area in this regard is the Kodar-Udokan region where metamorphosed basic rocks take part in the structure of Kodar and Kalar Archean blocks and in Late greenstone belts (Olondinsky et al.) as well. Paleoproterozoic layered intrusions of the Chineysky complex located in Kodar-Udokan region are regarded as the mark of an ancient plume magmatism. Superlarge deposits (Udokan, Chineysky massif) and other smaller were formed during this period of time.

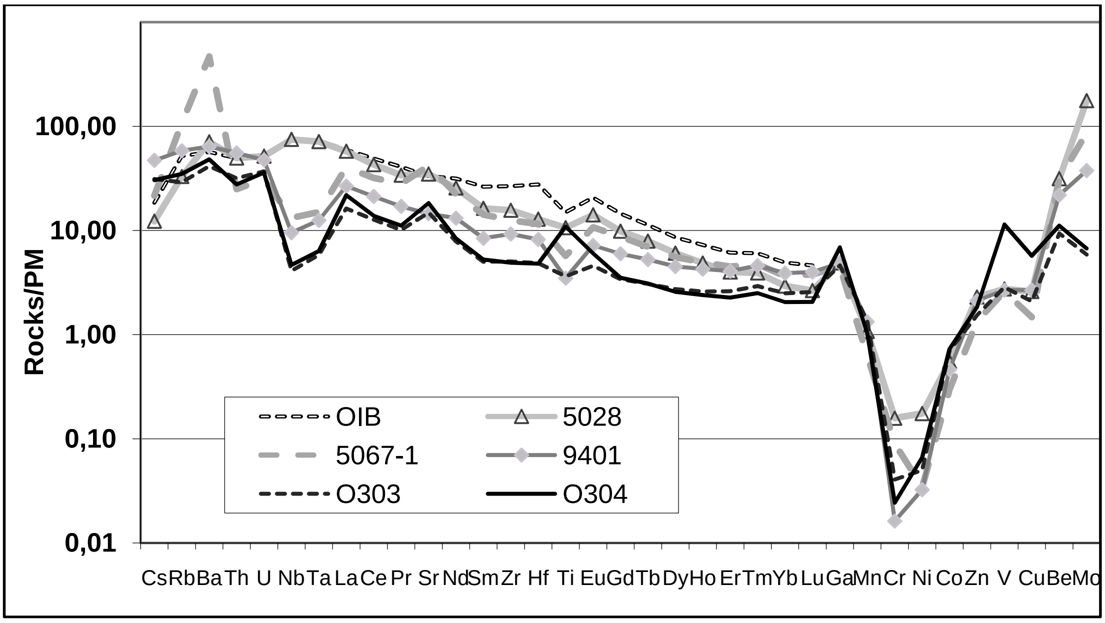

Figure 1. Spider-diagram for rocks from the Kodar-Udokan area (normalized to the primitive mantle, Hoffman, 1987). Gabbro-dolerites, sample No: 5028 - quaternary, 5067-1 Mesozoic subalkaline, 9401 - Udokan Main dike; rocks of the Chineysky complex: 0303 - norites, 0304 - titanomagnetite gabbro.

In addition to large intrusions many dikes located in this area form several belts (Gladkochub and others, 2012). They include numerous bodies of different age: dikes belonging to the Chineysky complex itself (1,81-1,87 Ma; Gongalsky, 2012), the Dorossky complex (Riphean-Cambrian), Mesozoic and Cenozoic. The gabbro-dolerites dikes framed the Chineysky massif have a radial orientation to the Maylavsky massif. At this moment, the age determination for these rocks was not done yet. We associate them with gabbro Chineysky (PR_1) and Dorossky (R) complexes, MZ basalts of the Chukchudinsky trough (Stupak, 1987) and N-Q Udokan lava plateau. However, geochemical features of dikes are different. According rare elements distribution they were subdivided into several groups, presumably differ by age. Thus, spider-diagrams for different samples (Fig. 1) demonstrate synchronous changes in the concentrations of the most elements. Patterns for Proterozoic rocks of the Dorossky and Chineysky complexes have a pronounced Ta-Nb anomaly, while Cenozoic sub-alkaline rocks lack of it and their topology coincides with the topology of the OIB. Gabbroids from the Chineysky complex have positive Sr and Ti anomalies. The same features are typical of the Main Udokan dike (up to 200 m), as well as for number of other dikes with low thickness.

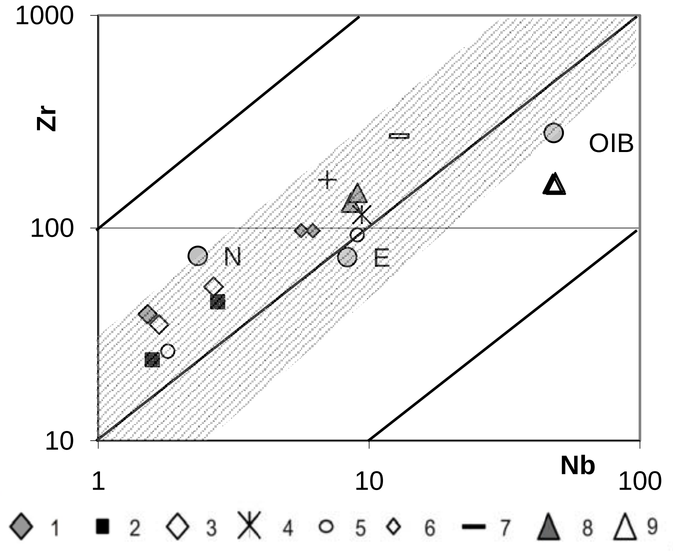

Figure 2. Nb - Zr diagram for rocks from the Kodar-Udokan area. Samples: 1-titanomagnetite-bearing gabbro from Maylavsky massif (Chineysky complex); 2-4 - Chineysky massif: 2 - titanomagnetite gabbronorites, 3 – norites, 4 - monzodiorites; 5 - gabbronorites from Lukursky massif (Chineysky complex); 6 - Main Udokan dike; 7- Mesozoic granosyenite porphyry, 8 - Mesozoic sub-alkaline basalts, 9 - Cenozoic basalts. E - E-MORB, N - N-MORB

Analysis of Zr-Nb diagram (Fig. 2) indicates that gabbroid of the Maylavsky, Luktursky and Chineysky massifs and many dikes form one rock group closed to N-MORB. Gabbro-dolerites from the Main Udokan dike, monzodiorites of the Chineysky massif and sub-alkaline basalts are close to E-MORB. KZ basalts and some dikes are similar to OIB in term of distribution of rare elements. Copper mineralization was found in intrusive rocks of different age. Thus, the Chineysky complex (PR_1) includes superlarge copper deposits in magmatic and sedimentary rocks, Dorossky complex contains copper mineralization in gabbro, MZ and KZ rocks concentrate native copper in basalts (Fig. 1)

Thus, inside the Kodar-Udokan area one can see products not only Paleoproterozoic plume magmatism, but also "echoes" of plume magmatism widespread far away from the territory, in Transbaikalia (Mesozoic) and Baikal (Cenozoic) plumes.

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MINERALOGICAL AND GEOCHEMICAL STUDY OF LHERZOLITES FROM TUMUSUN VOLCANO ALKALINE BASALTS (BAIKAL RIFT): REFERTILIZATION OR PARTIAL MELTING?

M.A. Gornova[1], S.I. Dril[1], A.B. Perepelov[1], K.-L. Wang[2], V.A. Belyaev[1]

[1]Institute of Geochemistry SB RAS, Irkutsk, Russia, mgorn@igc.irk.ru

[2]Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan

We studied peridotite xenoliths from basanites of the Tumusun volcano located in SW Baikal rift zone. Areas of Cenozoic basaltoid volcanism in Baikal rift zone were ascribed to the influence of Central Asian mantle plume (Yarmolyuk et al., 2003). Tumusun volcano is composed of olivine alkaline basalts, hawaiites and, rarely, basanites. Basanite magmas erupted on final stages of volcanism and formed on greater depth compared with hawaiite melts. Mantle xenolith from Tumusun basanites are first cm to 30 cm in size. Rock textures and mineral composition were studied using Superprobe JXA-8200 microprobe at Institute of Geochemistry SB RAS, Irkutsk. REE contents in pyroxenes were obtained with Cameca IMS-4F ion probe at FacilitiesSharingCenter "Diagnostics of Micro- and Nanostructures", Yaroslavl.

All xenoliths studied are spinel lherzolites with coarse-grained protogranular textures and reaction zones formed after primary minerals. Reaction zones after orthopyroxene are composed of secondary Ol, Cpx and K-Na feldspar. Clinopyroxene has rims and external zones of secondary Cpx with secondary Ol and Pl inclusions. Spinel is surrounded by simplectite of secondary spinel and K-Na feldspar. The Opx reaction zones become thinner from xenolith rim to the center. Cpx and Sp reaction zones are wider in contacts with Opx reaction zone or feldspar veins. The cores of primary minerals are homogeneous and have identical composition both in rim and center of xenoliths. Compared to primary minerals, secondary Ol have lower Mg# and NiO; secondary Cpx show lower Al_2O_3, Na_2O and higher Mg# and CaO; secondary Sp is characterized by higher Cr#. The relationships in primary and secondary minerals compositions are common to lherzolite xenoliths with reaction mineral zones, e.g. Sal Island, Cape Verde (Shaw et al., 2006). The studied Tumusun peridotites show reaction zone relationships that agree with experimental studies of lherzolite interaction with SiO_2-undersaturated alkaline melts at one atmosphere (Shaw, Dingwell, 2008). The reaction zones formation in Tumusun lherzolites could be explained in course of two-stage model (Shaw, Dingwell, 2008): 1) incongruent Opx dissolution under influence of basanite melt, leading to formation of Ol ± Cpx and silica-alkali-rich melt; 2) incongruent dissolution of Cpx and Sp by action of silica-alkali-rich melt resulting in secondary Sp and Cpx crystallization. Experimental works show that, in such a process, unreacted mineral cores are homogeneous and have compositions similar to those of source rock lherzolite.

In Tumusun lherzolites, Mg# of primary Ol is varied in range 89.3-91.1 and correlates well with Mg# of primary pyroxenes. Cr# of primary Sp changes from 8.3 to 17.5. In samples with the most magnesian Ol, the Mg# increase in Ol is not accompanied by increase of Cr# in Sp. In pyroxenes, Al_2O_3 decreases while Cr_2O_3 increases. Al_2O_3 contents in Opx correspond to moderate melting degrees, while Al_2O_3 in Cpx indicate low melting degrees. Both pyroxenes are depleted in Cr_2O_3. Cpx have unfractionated distribution of M-HREE. In most samples, Cpx is depleted in LREE, the rest samples show non-regular L-MREE patterns in Cpx, with no correlation between La and Yb. Cpx is enriched in Yb relative to abyssal peridotites Cpx, and Ti-Yb correlation is also absent. No difference in minerals chemistry between LREE-depleted or L-MREE-enriched Cpx rocks was found: rock-forming minerals have similar range and do not fall into independent fields. The range of equilibrium temperatures are overlapped (1007-1108ºC and 1007-1074ºC, correspondingly).

The numerical modeling of Ti and REE contents in clinopyroxenes show that lherzolites could be produced as a result of 4-12 non-modal fractional melting of the mantle that started in the garnet and was continued in the spinel facies. The model can explain the features in the mineral composition using the data on major elements. The enrichment of clinopyroxenes by L-MREE is likely explained by the chromatographic effect resulting from pore flow of some amount of the melt from fractures along which the alkaline basalts uplifted.

The fertile lherzolites with depleted REE spectra in clinopyroxenes could be produced as a result of the reaction of the lower lithosphere mantle with a large volume of basaltic melts when the mantle underwent the thermochemical erosion above the mantle plume. The peridotites enriched in LREE might have formed in upper layers of the sequence that demonstrate low melt/rock values as was described for the peridotite xenoliths from alkaline basalts Mega, Eastern African rift (Bedini et al., 1997). This process can explain the occurrence of minerals of almost constant composition in LREE-depleted lherzolites (Le Roux et al., 2007). The refertilized Lherz lherzolites with LREE-depleted Cpx as opposed to the Tumusun lherzolites demonstrate wide variations of the modal composition. Moreover, they show a narrow scatter in Mg# in Ol, Opx, Cpx, Cr#Sp and higher Mg# in Cpx with comparable Mg# in Ol and Opx. The minerals from Lherz lherzolites show the specific features, that exclude their production as a result of partial melting: lack of correlation between Mg# and Cr# in pyroxenes, negative correlation of Al_2O_3 and Cr_2O_3 contents in orthopyroxenes, low Al_2O_3 concentration in Opx, similar Na_2O, TiO_2 contents in pyroxenes and a lack of a positive correlation between TiO_2 contents in Cpx and the rock. Thus, the compositions of minerals from Tumusun lherzolites agree well with the partial melting model.

Tumusun lherzolites have the fertile composition and are different both from the Archean cratonic and the Early Paleozoic island arc lithosphere mantle, which could be suggested under the Tumusn volcano. High equilibrium temperatures of spinel lherzolites point out an insignificant thickness of the lithosphere mantle that correlates well with geophysical data concerning the astenosphere uplift under the Baikal Rift (Zorin et al., 1989). So, it can be suggested that the Tumusun lherzolites represent the lithosphere mantle that was produced out of cooled astenosphere substance and replaced the former lithosphere during the Neogene magmatism in the Baikal Rift Area.

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LARGE MESOZOIC MAGMATIC PROVINCE OF GRANITOIDS IN GOLD METALLOGENY OF THE NORTHERN PACIFIC RIM

N.A. Goryachev
North-East Interdisciplinary Scientific Research Institute n.a. N.A. Shilo FEB RAS (NEISRI FEB RAS), Magadan, Russia, goryachev@neisri.ru

Large granitoid magmatic provinces Northern Pacific Rim are discussed. These provinces include of granitic plutons more than 15% of the area and have a high gold potential (including placers) - hundreds and thousands tons of Au. These include (table 1): California (approximately 800 t), British Colombia (about 200 tons), East-Central Alaska and Yukon (about 1000 t), Chukotka (about 700 tons), Yano-Kolyma (more than 3000 tons), Mongol-Okhotsk belt (about 2500 tons).

The basis of all of the provinces are large Late Jurassic – Early Cretaceous orogenic belts of accretion (Arctic), collision (Omineka, Yana-Kolyma) and transform plate boundaries of origin. Granite plutons, accompanying metamorphism, and gold mineralization are located of common structures in them. A relatively narrow time interval formation of granitic plutons and associated metamorphism (variations in 5-10 million years) is typical. Metamorphism can to be as early (pre-plutonic) and synchronous with plutons. Gold mineralization (orogenic and intrusion-related types) formed nearly simultaneously, and slightly later (1-10 million years) then plutons and after metamorphism. Granitoid plutons and gold mineralization was formed in two stages usually. There is evidence that gold ores formed sometimes earlier than the main mass of granitoid plutons (California). Than the famous of Mother Lode vein system in California? Unique crystalline gold nuggets originated during the formation of ore deposits of Mother Lode vein system under the influence of granitic magmatism peak of Sierra Nevada Range. Gold mineralization has controlled by granite and metamorphic domes and large domes very often (Omineka, and Yano-Kolyma). Geological and geophysical data show that large areas of gold mineralization formed at shoulders plutono-metamorphic zones and large domes (example Yano-Kolyma belt, Yukon-Tanana area). It should be noted the close to zero sulphur isotopic composition of sulfides in ores that associate with large granitic-metamorphic domes, and relatively light isotope sulfur composition that typical for orogenic gold-quartz and intrusion related gold deposits which associated with granitic intrusions, or located in remote apical zone of granitic-metamorphic domes.

Granitoid formation is crust orogenic process in which occurs the mobilization of gold from clastic sediments of the upper crust and complex rocks of bottom crust, as evidenced by Pb-, Sr-, S-isotope data. However, mantle derivatives (dike swarms belt and gabbroid intrusions) often preceding the formation of granitoids may play a role by this process, especially during accretion and transform margin tectonic processes.

Such combination of granitoid plutons, granitic-metamorphic domes and gold mineralization would in large areas rather by not chance. It suggests an important role of plutonic-metamorphic processes and their accompanying fluid streams that existed within the structural carcass of orogenic belts, when forming such large magmatic and ore provinces.

Table 1.Major granitoid and gold province of northern Pacific Rim.

Regions	Granitoid types, (Age)	Accompanying metamorphism (Age)	Gold mineralization location (Age)	Gold deposit types
California (USA - California-Sierra Nevada and Klamath Mts.)	I type, magnetite series (160-146 and 120-100 Ma – Tobish et al., 1990; Shweikert et al., 1999)	Linear zones, greenshist facies (146-137 Ma – Tobish et al., 1990)	Belts (152-140 and 135-104 Ma – Marsh et al., 2008; Bohlke, Kistler, 1986; Elder, Cashman, 1992)	Orogenic gold-quartz deposits
Omineka (USA - East Central Alaska, and Canada - Yukon and British Columbia)	I - and S-types, magnetite and ilmenite series (160-120 and 110-89 Ma - Newberry et al., 1995; McCoy et al., 1997; Goldfarb, 1997; Goldfarb et al., 2008 Emond, 1992; Mair et al., 2006, 2011)	Granitic-metamorphic domes and large areas, up greenshists to amphibolite facies (160-110 and 124-94 Ma - Dusel-Bacon et al., 1995; Rushton et.al., 1993; Mortensen, 1990)	Local areas and belts (152-131 and 95-86 Ma - Mortensen, 1990; Rushton et.al., 1993; Sketchley et al., 1986; Dawson et al., 1989)	Orogenic gold-quartz and gold-sulfide deposits; intrusion related Au deposits
Arctic (USA -Northern Alaska and Russia - Chukotka and North-East Yakutia)	I - type, ilmenite series (117-89 Ma - Till, Dumolin, 1994; Amato et al., 1994; Miller et al., 2013; Katkov, 2009; Miller, 1994)	Granitic-metamorphic domes, up greenshists to amphibolite facies (130-105 Ma – Gel'man, 1995; Goryachev, 1998; Amato et al., 1994; Moore et al., 1994).	Local areas and belts (130-102 Ma – Goryachev, 1998; Volkov and Sidorov, 2001; Otto et al., 2009)	Orogenic gold-quartz (dominant) and gold-sulfide deposits; intrusion related Au deposits
North-East Russia (East of Yakutia, Magadan Region)	I- and S- types of ilmenite series (153-140 Ma – Akinin et al., 2009; Newberry et al., 2000; Goldfarb et al., 2014)	Metamorphic zones and areas with granitic plutons (160-135 – Sustavov, 1995; Akinin et al., 2003).	Large belts (148-130 Ma – Goryachev, 1998, 2003; Goldfarb et al., 2014; Goryachev, and Pirajno, 2014)	Orogenic gold-quartz and gold-sulfide deposits; intrusion related Au deposits
Mongol-Okhotsk area (Northern part of Mongolia, and Russia - Transbaikalia and Amur Region)	I -, S- A-types (200-130 Ma – Spiridonov et al., 2006; Goldfarb et al., 2014; Goryachev, and Pirajno, 2014)	Granitic-metamorphic domes and linear zones, up greenshists to amphibolite facies (160-140 Ma).	Belts and local areas (190-122 Ma – Cluer et al., 2005; Sorokin et al., 2013; Goldfarb et al., 2014; Borisenko et al., 2012; Goryachev, and Pirajno, 2014)	Orogenic gold-quartz, gold-sulfide and gold-tourmaline-polysulfide deposits; intrusion related Au deposits

ULKAN PALEORIFT STRUCTURE IN THE SOUTH-EASTERN ENVIRONS OF THE SIBERIAN PLATFORM: AGE, CONDITIONS, GEODYNAMIC SETTING AND METALLOGENY

V.A. Guryanov, A.Yu. Peskov
Kosygin Institute of Tectonics and Geophysics, Far East Branch, Russian Academy of Sciences, ul. Kim Yu Chena, 65, Khabarovsk, 680000 Russia; e-mail: guryanov_v@mail.ru

A stage of late Paleoproterozoic intra-plate magmatism represented by a contrasting series of sedimentary-volcanogenic rocks, granitoids and basites of the Ulkan VPC is clearly recognised within the south-eastern environs of the Siberian platform. Both sub-alkaline rocks of the potassic series and alkaline granitoids and volcanics of the sodic series highly enriched in incompatible elements are characteristically present in the Ulkan paleorift (Guryanov, 2007, Guryanov et al., 2013) (Fig. 1). The formation of these rocksinintraplateanorogenicconditions was linked to the mantle plume activity at 1.77-1.70 Ga (Guryanov et al., 2012).

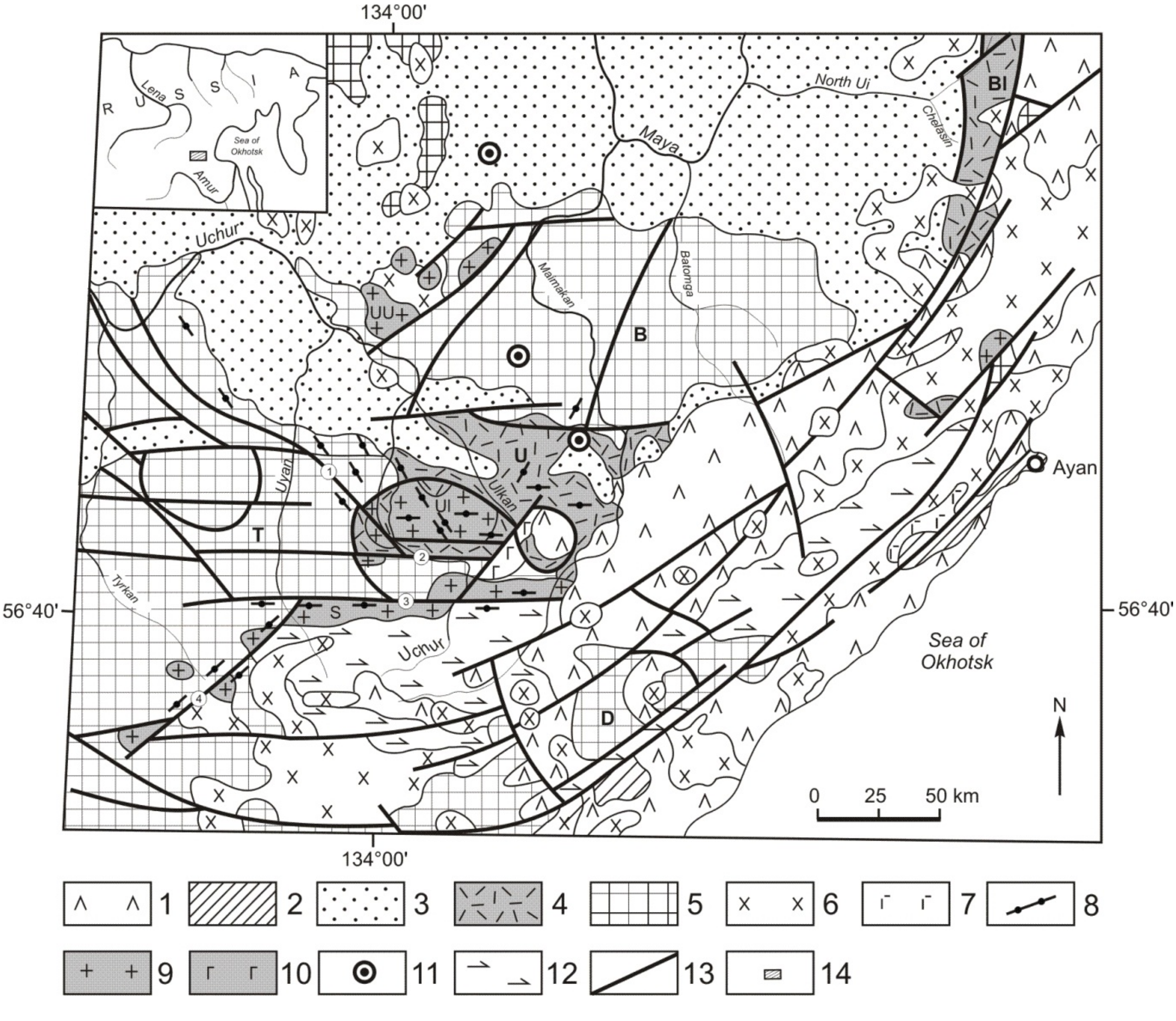

Fig. 1. Geological scheme of southeastern margin of the Siberian Platform. (*1*) Cretaceous volcanics of Okhotsk–Chukotka volcanic belt; (*2*) Paleozoic terrigenous and carbonate sequences of Ayan–Shevli Pericratonic Trough; (*3*) Cambrian–Mesoproterozoic volcanic–sedimentary and terrigenous–carbonate rocks of Uchur–Maya Plate; (*4*) Paleoproterozoic Ulkan (U) and Bilyakchan (Bl) volcanic–sedimentary troughs; (*5*) Archean crystalline rocks of Siberian Platform basement: Batomga (B), Tyrkan (T), and Dzhugdzhur (D) blocks; (*6*) Cretaceous granitoid plutons; (*7*) Paleozoic gabbroic rocks; (*8*–*11*) Paleoproterozoic intrusions: (*8*) basic dikes of the Maimakan Complex, (*9*) granitic rocks of Ulkan Complex, (*10*) gabbroic rocks of Gekundan Complex, (*11*) ultramafic rocks of Konder Complex; (*12*) anorthosite of Old Dzhugdzur Complex; (*13*) fault; (*14*) studied area (inset). Faults (numbers in circles): 1, Uchur–Elgetei; 2, North Uchur; 3, South Uchur; 4, Ukikan. Plutons (letters in figure): Ul, Ulkan; S, South Uchur; UU, Upper Ugayan.

Five stages are recognised in the development of the Ulkanpaleoriftsystem, which can begrouped into threemajor phases based on a number ofgeodynamicfeatures (Guryanov, 2007). At the first stage, processes of extension and downwarping as a result of the Archean basement faulting triggered the development of the near-EW-trending Ulkan graben. At the second stage, a powerful heat flow and the ascending hotspot-type mantle diarpir that triggered the formation of the domal uplift were characteristic of the geodynamic setting of the bimodal differentiated series formation related to the central-type volcanic activity (Guryanov et al., 2012). The initiation of the three-armed intra-continental rift system is linked to this hotspot. Emplacement of basite dykes of the Maimakan Complex records the stage of its stabilisation as the final stage in the development of this structure.

The Ulkan paleorift structure has features of a three-armed geometry indicative of intense rifting due to hotspot activity. Volcanics and granitoids of the Ulkan Complex were formed in the intra-continental environment of extension accompanied by rising of the mantle plume (Larin, 2011). The Ulkan alkali-leucogranite massif was such a hotspot-type diarpir (Guryanov et al., 2012). The area of convergence of basite dyke swarms coinciding with the area of development of alkali-granite magmatism and alkali metasomatism at the centre of the massif was a likely epicentre of the hotspot. Granites and basites of the Ulkan VPC were formed through mixing of two different melts: essentially crustal and essentially mantle.

Rising of the mantle diarpir in the rear part of the south-eastern Siberian platform was accompanied by a strong heat flow and hence tectonothermal recycling of rocks of different blocks in the south-eastern part of the Aldan shield.

Anorogenic magmatism of this type is clearly recorded in the interval between 1.77 – 1.70 Ga along the south-eastern and south-western flanking of the Siberian platform, in the North American platform and northern China. This magmatism occurred 150-200 Ma after the completion of orogenic processes in hosting fold structures of collision belts.

We emphasize that the Ulkan district is one of the most promising-looking ore districts of the Russia Far East and East Siberia (Guryanov, 2007; Guryanov et al., 2013). Over 140 occurrences of Be, Nd, Ta, U, Zr, TR, Ti, Li, Au, Ag, Mo, Sn, W, and P have been located within it. They are grouped within and on the periphery of the Ulkan alkali-leucogranite massif. In terms of metallogeny the massif is a unique ore district with rare-metal and rare-earth mineralisation, as well as U and Au. More than 30 hardrock targets have been preliminary assessed, which correspond to large-, medium-, and small-size deposits. Potential resources of the district (thous. t): U – 534, Nb_2O_5 – 710, Ta_2O_5 – 37, BeO – 431, ZrO_2 – 160, LiO_2 – 0.165, TR – 4184, Th – 13, Mo – 267, Au – 178 t, and Ag – 493 t (Malyshev et al., 2014).

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PRISTANOVOY ZONE OF THE PALEOPROTEROZOIC COLLISION – A NEW PLATINUM-COPPER-COBALT-NICKEL PROVINCE ON THE SOUTHEASTERN PERIPHERY OF THE SIBERIAN PLATFORM

V.A. Guryanov, V.S. Prikhod'ko, A.Yu. Peskov
Kosygin Institute of Tectonics and Geophysics, Far East Branch, Russian Academy of Sciences, ul. Kim Yu Chena, 65, Khabarovsk, 680000 Russia; e-mail: guryanov_v@mail.ru

The Pristanovoy collision belt is a junction area between two large tectonic structures, the Aldan granulite-gneiss and Dzhugdzhur-Stanovoy granite-greenstone terranes. The belt includes (from west to east): Kurulta, Zverev, Tangrak, Sutam, Tuksani, Dzhanin, and Dzhugdzhur tectonic blocks (Fig. 1) formed by granulite-facies metamorphic rocks of different strata of the granulite-gneiss mega-complex (Guryanov et al., 2014). On the whole, it is a huge, 1300-km long, roughly east-west trending zone of tectonic melange. In the gravitational field (Bouguer gravity) this zone is delineated by the extensive, roughly east-west trending axial gravity maximum flanked on both sides by the linear gravity minimums. The axial maximum correlates throughout with granulite-facies rock outcrops and tabular ore-bodies and dykes, laccoliths, rarely stocks and intrusions of mafite-ultramafite (1.9 – 1.7 Ga; Guryanov et al., 2012, 2014). The layerwise occurrence of deep granulites with multistory mafite-ultramafite bodies revealed by geology methods has depth extent becoming even more clearly pronounced. It is found that the multilayered occurrence of mafic intrusions and ore-bodies within ore fields and their areal extent in the Kun-Manie, Tuksani, Geran, Sutan districts and the Tokinsky Stanovik district is an important structural aspect for the formation of deposits containing Cu, Ni and Pt within the Pristanovoy collision belt. Thus over 160 tabular bodies and dykes of mafite-ultramafite have been located by now, as well as traced in stream beds and in drill holes to depths of 200 to 800 m, in the adequately explored Kurumkan ore field 31 km long and 1 to 3 km wide. Approximately 70% of ore bodies is localised in the axial part of the field where they are arranged in several layers (3 to 16) along low-angle strike-slips and detachment.

The confinement of the abovementionedstructural features to the boundaryof the Aldanand Stanovoy mega-blocks suggests that they formed under conditions of intensecompressionwhich was accompanied by theirtectonicintrusion intothe upper layers ofthe Earth's crust. It is found that fault systems tracing the Pristanovoy fold-thrust zone extend through the crust and are conjugate to the channels feeding the mantle material into the Earth's crust. The geological structure of this zone is indicative of crustal reworking under conditions of collisional compression which extended as far down as its basement.

The available data on nickel-mafic ultramafites of the Pristanovoycollision belt from the Olondo River in the west tothe coast ofthe Sea of Okhotskin the east make it possible to significantlyexpand the boundaries ofand prospects forthe regionand to rank it as the platinum-copper-cobalt-nickel Severostanovoyprovince (Guryanov et al., 2014). It includes the Kun-Manie group of deposits, deposits Chineiskoe and Burpalinskoe, the Kalar-type, Burpalin-type, Sutam-type and Utuk-Makit- type occurrences in the west, a set of PGM-cobalt-copper-nickel targets with Nyandomi, a Lantar-type deposit, in the Dzhugdzhur gabbro-anorthosite batholiths in the east (Fig. 1). Based on geochemical survey data, the areal extent of small orebodies and discrete mafite-ultramafite intrusions is delineated within the belt by elevated Ni, Cu, Co, Cr, V, Mn, Pt, and Pd in soils and streams. A total of at least 20 zones are presumed to host mafite-ultramafite ore bodies that fall into four mineragenic types: wehrlite-clinopyroxenite-gabbro (Burpalin type), gabbronorite-websterite-harzburgite(Sutam type), pyroxenite-gabbro-anorthosite (Chiney and Lantar types), andgabbronorite-websterite-lherzolite(Kun-Manie type). The Kurumkan ore field of the Kun-Manie group of deposits, where prospect evaluation surveying has been carried out and Ni, Cu, Co, Pt, and Pd reserves have been approved, indicates the highest potential for PGM-Cu-Ni mineralisation (Guryanov et al., 2009). Large-scaleintegrated geologic and geophysical studies on theStanovoycollision zonehave shown thatit can beclassified as one of thelargestmineral targets of the Russia Far East and Eastern Siberia.

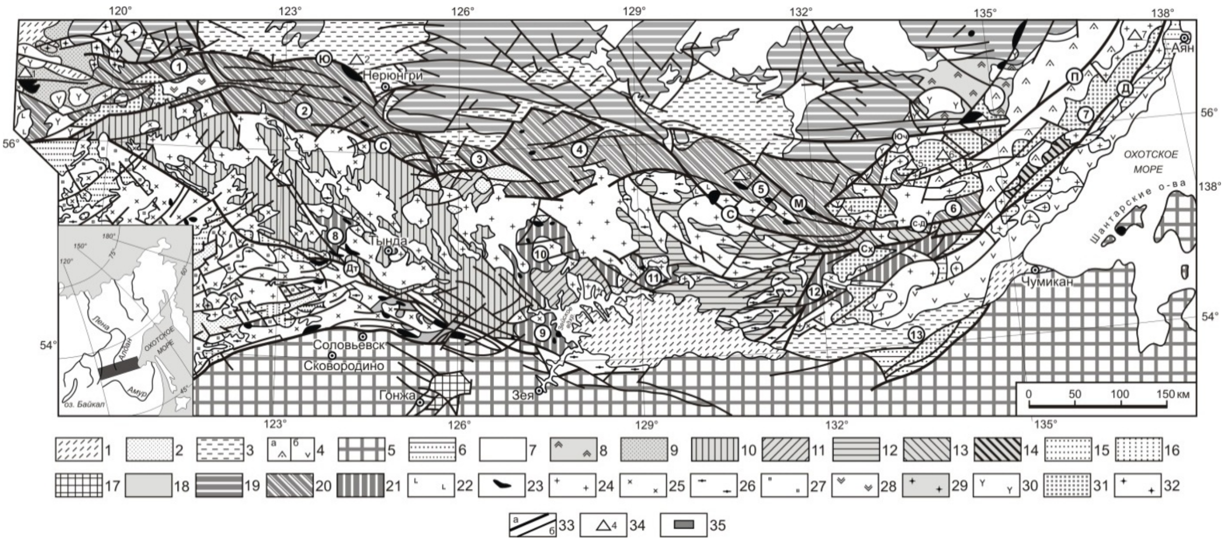

Fig. 2.1 Schematic geologic structure of the Pristanovoy belt and Dzhugdzhur-Stanovoy fold area (*after V.A. Glebovitsky et al.,2009, revised and expanded by V.A. Guryanov, 2013*): 1 – Neogene-Quaternary basins; 2-3 – Cretaceous (2) and Jurassic (3) basins; 4 – volcanic depressions of the Okhotsk-Chukotka zone: a – Preddzhugdzhur, б – Dzhelon; 5 – essentially Paleozoic undifferentiated complexes of the Mongol-Okhotsk belt and Amur terrane; 6 – Paleozoic undifferentiated rocks of the Ayan-Shevli pericratonic trough; 7 – platform cover (R-V-Є); 8 – Ulkan Group (PR_1); 9 – Udokan Group (PR_1); 10-12 – complexes of the Dzhugdzhur-Stanovoy terrane (AR_2): Ilikan Group (10), Mulmugin Formation (11), Kupuri and Zeya Groups (12); 13 – Uda-Maya Group; 14 – Kiran-Lavli Group; 15-16 – complexes of the Selenga-Stanovoy terrane (AR_2): Tungir Group (15), Ust'-Gilyui Group (16); 17 – Gonzha Group (PR_1); 18 – Dzheltulakh Group (PR_1); 19 – undifferentiated granulite complexes of the Aldan Shield (AR-PR_1); 20 – granulite complexes of the Pristanovoy belt (AR-PR_1); 21 – granulite blocks within the Dzhugdzhur-Stanovoy fold area (AR-PR_1); 22 – alkaline basalt (N-Q); 23 – basite-hyperbasite intrusions, undifferentiated (PR_1-MZ); 24 – granitoids of the Tynda-Bakaran, Uda-Zeya, Irakan, Uda, and Dzhugdzhur complexes (J_3-K_2); 25 – granitoids of the Pozdnestanovoy and Tukuringri complexes (PR_1); 26 – granitoids of the Tok-Algoma Complex and their analogues; 27 – granitoids of the Amanan Complex (P-T); 28 – intrusions of alkaline rocks (Tass massif, PZ_1); 29 – granitoids of the Balykhtak Complex (AR_2); 30 – granitoids of the Ulkan and Kodar complexes (PR_1); 31 – anorthosite (AR_2-PR_1); 32 – granites of the Chara-Udokan Complex (AR_2); 33 – faults: a – master (border): С – Stanovoy, Ю – Yuzhnoyakutsky, М – Maisky, Юч – Yuzhnouchursky, П – Predzhugdzhur, Д - Dzhugdzhur, С-Д – Salga-Dzhanin, Сх – Sekhtagsky, Дт – Dzheltulak, б – others. 34 – deposits and occurrences of PGM-Cu-Ni ores (1 – Chineiskoe, 2 – Burpalinskoe, 3 – Utuk-Makitskoe, 4 –Kun-Manie, Malyi Kurumkan and Kubuk deposits, 5 – Bogide, 6 – Kendeke, 7 – Nyandomi); 35 – the study area inset. The numbers in the circles are blocks: 1 – Kurulta, 2 – Zverev, 3 – Tangrak, 4 – Sutam, 5 – Tuksani, 6 – Dzhanin,7 – Dzhugdzhur, 8 – Larbi, 9 – Dambuki, 10 –Bryantin, 11 – Tok, 12 – Chogar, 13 – Baladek.

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EARLY CARBONIFEROUS MANTLE MAGMATISM PRODUCING TITANIUM-MAGNETITE ORE IN THE GORNY ALTAI

N.I. Gusev, S.P. Shokalsky
Russian Geological Research Institute (VSEGEI), St.-Petersburg, Russia
nikolay_gusev@vsegei.ru; sergey_shokalsky@vsegei.ru

In the South-West Altai, the Harlovsky layered intrusion occupies an area of 10km^2, has a rounded shapeanda concentrically zoned structurewithlayers dipping toward the center ofthe massif.It is composed of four intrusive phases (Shokalsky, 1990): (1) subalkaline gabbroids often layered to pyroxenite and anorthosite; (2) monzodiorite and diorite porphyry; (3) quartz monzodiorite; (4) granosyenite. The southern part of the intrusion contains dykes ranging in composition from dolerite to kersantite and granosyenite porphyry. The ore bodies are 10 lodes of mineralized gabbro of 10 to 140 m thick, enriched with magnetite, titanomagnetite and ilmenite. Resources of seven orebodies in the central part of the massif are 1.73 billion tonnes of ore at an average grade of Fe_t – 15.3%, TiO_2 – 5.92%, V_2O_5 – 0.086%. Anorthosite indicates the main trend of liquation in the magma chamber during the initiation of the Harlovsky massif (Gusev, Gusev, 2013).

Massivemeso- andleucogabbrohave elevatedgrades ofrare andrare-earth elements, similar to those in monzodioriteandsyenite(Fig. 1). Layered high-Ti melanogabbroandanorthosite are depleted in Cs, Rb, Ba, Th, UandREE. Gabbroids are characterized bypositive anomalies ofTi, Ta, Nbtypical ofintraplate magmatism. Monzodioriteand syenite are more enriched withrare and REE elements with negativeSrandTi anomalies (Fig. 1). The rare and rare-earth elementgrades in dyke rocks are similar to those in monzonitoids.

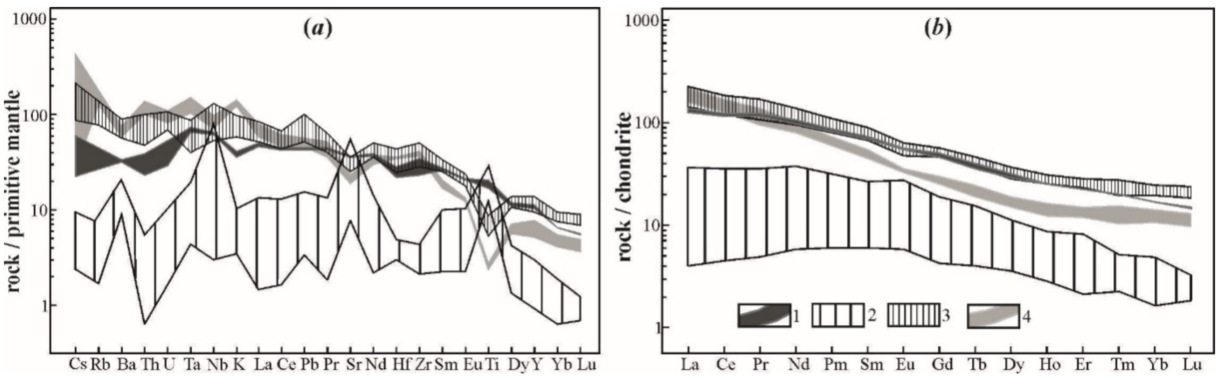

Fig. 1. Charts forrocksof the Harlovsky intrusion

1– massive meso- andleucogabbro(SiO_2 47.6-48.8%; Al_2O_3 15.24-15.39%; TiO_2 3.36–4.07%; Fe_2O_3t 12.85%);2-3-layeredseries.2-high-Ti melanogabbro (SiO_2 25.7 -28.3%; TiO_2 5.80–6.55%; Al_2O_3 5.27 – 8.43%; Fe2O3t 37.8 – 39.2%) andgabbroanorthosite(SiO_2 44.1%, TiO_2 2.55%, Al_2O_3 23.5%; Fe_2O_3t 9.19%); 3-monzodiorite, quartz monzonite,andsyenite of second and thirdphases; 4-granosyenite of fourth phase.

Layered gabbro and gabbroanorthosite are characterized by positive values of εNd (T) from +7.9 to +8.5, and negative values of εSr (T) -16.6 and -16.75, indicating PREMA-type mantle source. Nd-model age of gabbro protolith $T_{Nd}DM_{2st}$ is 0.41 to 0.44 Ga. Anorthosite has εNd (T) = +7.9, εSr (T) = -9.1 and $T_{Nd}DM_{2st}$ = 0.46. In quartz monzodiorite of 342+5 Ma, εNd (T) decreases to +1.9; there is positive value of εSr (T) = +8.3 and older Nd-model age of protolith $T_{Nd}DM_{2st}$ (0.96 Ga). According to the Nd and Sr isotopic compositions, rocks of the Harlovsky intrusion are located in or close to the mantle sequence of rocks (Mantle array).

U-Pbzirconage(SHRIMP II) of 344± 6 – 325.2 ±5 Ma was obtained for rocks of the Harlovsky massif (Fig. 2) of total longevity ofmore than 20 Ma.There are two discrete age ranges: the first of 344-340 Ma is associated with the time of intrusion of the bulk of magma from which massive gabbro, monzodiorite, and granosyenite were crystallized. Monzodiorite with Nd-model age of protolith of 0.96 Ga contains inherited zircon of 544 Ma. The second range of ages of about 332 Ma is shown by layered ore gabbro with Nd-model age of protolith of 0.41-0.44 Ga as well as quartz monzodiorite. This is the age of layered rock series formation during the liquation and possible supply of additional portion of monzonitoid magma. Concordant U-Pb zircon age of 325.2 ± 5 Ma was obtained for porphyry granosyenitedykes.

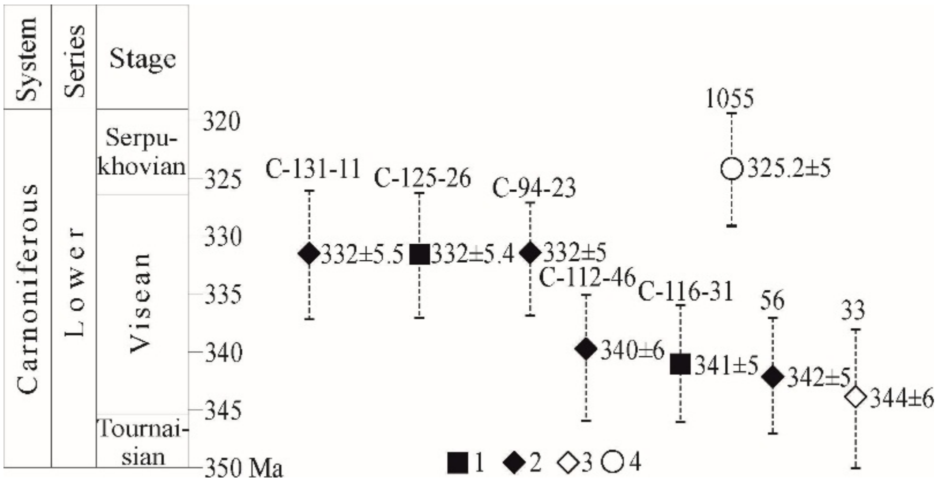

Fig. 2. U-Pbages(SHRIMP II) of the Harlovsky intrusion

1-gabbro; 2-monzonitoids; 3-granosyenite; 4- of porphyry granosyenite dyke. Topset - sample number, to the right - the agein Ma.Dashed line is confidence interval.

The formation model of the Harlovsky massif involves activity of PREMA-type heterogeneous plume source with Early Devonian Nd-model protolith age of 0.41 Ga, and a source close to the bulk composition of the Earth(BSE – Bulk Silicate Earth). The latter is apparently associated with the involvement in the magma formation of the bottom of continental lithosphere (Nd-model protolith age of 0.96 Ga). Magma from the plume source accumulated in the shallow chamber, where it separated in the field of liquid immiscibility into two melts: one of mafic composition enriched with Fe and Ti, another is monzonitoid. The melt enriched with Fe-Tioxidesseparated from the mafic magma andstratified intohigh-Ti gabbroids andanorthosite to form ore deposits. According to La/Nb ratio (0.71-0.79 – massivegabbroids;0.21-0.47 – high-Ti layered gabbro;0.17– gabbroanorthosite; 0.4-1.13 – monzodiorite; 0.73-0.81–granosyenite;0.74-1.11–kersantites andgranosyeniteporphyry dykes), parental magma of the Harlovsky massif was probably picritic andseparated mainlywhile melting the enrichedasthenospheric mantle.

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DID THE SIBERIAN TRAPS TRIGGER PERMO-TRIASSIC BOUNDARY MASS EXTINCTION?

B. He, Y.-T. Zhong, Y.-G. Xu
State Key Laboratory of Isotope Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Science, Guangzhou 510640, China

The Siberian Traps are widely considered to be a potential trigger of Permo-Triassic Boundary (PTB) mass extinction mainly based on synchroneity between the Siberian Traps and the extinction. However, this temporal link is indirect and only roughly constrained by absolute radiometric dating on both volcanic ashes around the PTB in South China and intrusives of the Siberian Traps. If these two events (the Siberian Traps and PTB extinction) occurred over a very short period, this synchroneity link could be problematic since analytical precision of the dating techniques is only about 0.1-1%. This study elucides both direct and relative temporal relationship between PTB extinction, the Siberian Traps and acidic volcanic ashes in South China, based on newly acquired mineralogy, whole-rock geochemistry, in-situ U-Pb and Hf-O isotopic data on the clay layers around the PTB at ten sections in South China.

Results show that clay layers around the PTB in South China are mainly altered volcanic ashes. In terms of geochemistry, the PTB claystones are divided into two groups. Group 1 is pure acidic volcanic ashes. They are located below the PTB mass extinction horizon (e.g., Bed 25 at Meishan section, which is exactly on the main extinction horizon) in South China. Peak of PTB acidic volcanism at five sections in South China is also located at the main extinction horizon. This direct temporal coincidence and volcanic intensity cognation with biological context collectively highlight the role of the PTB volcanic ashes on the mass extinction event at PTB. This can be taken as direct evidence for the major role of PTB volcanism in the PTB main extinction horizon, irrespective of the exact ages of these ashes. Group 2 claystones are mixture of acidic ashes and basaltic tuffs. They are distributed above the PTB main extinction horizon (e.g., Beds 26, 28 at Meishan section), comprising of acidic volcanic ashes (70%) and subordinate basaltic substance (30%). This substantial input of basaltic mass to claystones cannot be explained by change of volcanic nature, sedimentary environment andterrigenous clasts. Instead, it is most likely from the Siberian Traps because of voluminous volcaniclastic rocks (including tuffs) in the lower part of volcanic succession in the Siberian LIP. From a relative timing perspective, the Siberian Traps postdated the PTB main extinction horizon. In addition, global warming inferred from conodont O isotopes also began just after the main extinction horizon. If this warming were caused by the Siberian flood volcanism, it rules out the possibility of the Siberian Traps as the trigger of the PTB main extinction event.

We thus propose that the PTB acidic volcanic ashes in South China may have triggered the PTB main extinction event, with a scenario similar to that described by a ‘volcanic ash winter’ model. The Siberian Traps may have been responsible for Early Triassic extinction and ecological evolution, as a consequence of greenhouse effect.

Key words: Permo-Triassic boundary mass extinction; Siberian Traps; volcanic ashes; South China; geochemistry; volcanic ash winter; greenhouse effect

LATE PALEOZOIC MANTLE-CRUST MAGMATISM IN EASTERN KAZAKHSTAN AS A RESULT OF TARIM MANTLE PLUME ACTIVITY

S.V. Khromykh[1,2], E.N. Sokolova[1,2], G.N. Burmakina[3], P.D. Kotler[1,2]
[1]Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia, serkhrom@mail.ru
[2]Novosibirsk State University, Novosibirsk, Russia
[3]Geological institute SB RAS, Ulan-Ude, Russia

On the territory of Eastern Kazakhstan in the Late Paleozoic the diverse large-scaled magmatism manifested - gabbro-picrite, gabbro-granitoid, granodiorite-plagiogranite, granite-leucogranite, rare metal granite associations presented (Vladimirov et al., 2008). In report the results of study of gabbro-granite intrusions and rare metal granites as indicators of mantle-crust interaction are presented.

Gabbro-granite intrusions have large (from 100 to 300 km^2) isometric shape. In their structure there are identified two groups of rocks: 1) Mafic, represented by gabbro (Pl + CPx ± Hbl), Bt-Hbl gabbro or diorites (Pl + Hbl + Bt ± Cpx) and monzonites (Pl + Kfs + Amf + Bt + Qtz); and 2) Granitoid, represented by granosyenites (Pl + Kfs + Qtz + Amf + Bt), granites (Qtz + Pl + Kfs + Bt + Amf) and leucogranites (Qtz + Pl + Kfs ± Bt ± Grt). Between rocks of these two groups the events of magmatic mingling are found that evidence about synchronous intrusion of mafic and granitoid magmas. Compositions of rocks of mafic and granitoid groups have independent trends in two-component diagrams and show distinct differences in contents of K_2O, Al_2O_3, MgO, CaO, TiO_2, P_2O_5. Mafic rocks have heightened alkalinity include K_2O (up to 2 wt.% in gabbro, 2.5 wt.% in diorites, 5.6 wt.% in monzonites) and can be attributed to subalkaline rocks. It noted the predominance of LREE over HREE, maximums in concentration of Ba, K, Ti, Zr, Sr. Results of isotopic analysis of Sm-Nd and Rb-Sr systems show that initial $^{87}Sr/^{86}Sr$ ratios enriched in radiogenic Sr relatively depleted mantle ($^{87}Sr/^{86}Sr$ = 0.7036 – 0.7041) and εNd(T) differ from +6.1 to +6.96. Isotopic compositions of mafic rocks correspond to values of OIB and components of mantle plumes. So, mafic rocks of our intrusions are result of differentiation of subalkaline picro-dolerite magmas with "plume" geochemical features. Granitoid rocks characterized by heightened contents of alkalis include K_2O (from 3 to 6 wt.%), their compositions in two-component form single trend with decrease contents of Al_2O_3, FeO, TiO_2, MgO, CaO from granosyenites to leucogranites. LREE predominance over HREE, there are minimums in concentration of Ba, Sr, Eu and Ti, which deepened from granosyenites to leucogranites. So, rocks of granitoid group are result of differentiation of subalkaline granosyenite magmas that was formed by melting of crust sources under effect of mafic magmas.

Rare metal granitoids represented by Chechek and Akhmirovka dike belts of granite-porphyries and ongonites. Dikes have length up to several kilometers and thickness up to 5 m. Dike rocks contain phenocrysts of Qtz, Kfs, Ab, and light Mica. Accessory minerals are topaz, apatite, fluorite, cassiterite and tantalite-columbite. Rocks are subalkaline with weak predominance Na above K (Na_2O/K_2O = 1–1.5). The main features of their composition are high contents of rare lithophilic elements and fluorine. Rocks of Chechek belt may be distinguished on two groups: 1) Rare metal rocks (Li+Rb+Cs up to 1000 ppm, F up to 0.45 wt. %, REE_{tot} = 40–100 ppm); and 2) High Rare metal rocks (Li+Rb+Cs up to 2500 ppm, F up to 1.4 wt.%, P_2O_5 up to 0.35 wt.%, REE_{tot} = 3–15 ppm). Rocks of Akhmirovka belt have high contents of rare alkalis (Li+Rb+Cs up to 4000 ppm) and REE_{tot} (up to 110–180 ppm). Study of composition of melt inclusions in Qtz show that they correspond to rocks composition. Melt inclusions from Qtz from High Rare metal rocks distinguish in heightened content of P_2O_5, F, rare lithophilic elements (Cs 80–115 ppm, Rb 350–720 ppm, Be 40–70 ppm against Cs 25–60 ppm, Rb 170–250 ppm, Be 10–12 ppm in Rare Metal rocks), lower contents of Sr and Ba and REE_{tot}. The appearance of two types of rocks in dike belts due to differences in the composition of the melts themselves. Manifestations of rare metal granitoids are traditionally associated with the processes of formation of granitoids of Kalba complex (D'yachkov, 2012) but the area of rare metal granites is local. Consequently, the processes of intrachamber differentiation of granitic magmas of Kalba complex do not lead themselves to the formation of rare metal granitic magmas. According to the models of metamagmatic aging (Zagorski et al., 2014), a special ore-concentrated fluids (F, P_2O_5 as example) separated from the mantle magmas can play an important role in these processes.

Geochronological data indicate sub-synchronous manifestations of gabbro-granite intrusions and rare metal granite dike belts. For firstby U-Pb method (SHRIMP-II) on zircons from monzonites the age in 284±5 Ma was determined and by $^{40}Ar/^{39}Ar$ method on biotite from gabbro the age in 280±3 Ma was determined. For second by $^{40}Ar/^{39}Ar$ method on early-magmatic unaltered phenocrysts of Li-Mica the age in 286±3 Ma was determined. Thus, on the territory of Eastern Kazakhstan the processes of mantle-crust interaction occur sub-synchronous but on two differing mechanism. In the first case – direct interaction of mantle magmas with crustal substrates and anatectic melts and than their synchronous intrusion. In the second case – thermal and fluid influence of mantle magmas on the crust substrates and introduce of some specific elements in crustal chambers of granitoid magmas, their differentiations with formation of rare-metal granite melts. Geochronological data confirm the relationship between the processes of mantle-crust interaction with the manifestation of the activity of the Tarim mantle plume (Dobretsov et. al., 2010; Xu et. al., 2014).

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THE SOURCE REGION OF FLOOD BASALTS IN THE HYDROUS TRANSITION ZONE

A.V. Ivanov
Institute of the Earth's Crust SB RAS, Irkutsk, Russia, aivanov@crust.irk.ru

It is generally believed that some abnormal geological processes in the Earth's core, mantle, and/or crust cause large igneous province (LIP) origin. Cratonic flood basalt volcanism, an important subclass of LIP, is of particular interest because it is typically emplaced through thick and cold lithosphere. A cold cratonic geothermal gradient is expected to prevent melting of the lithosphere, whereas thick lithosphere hampers melting at sublithospheric depths due to the pressure effect, which suppresses magma generation. The prevention of melt production is especially true if the potential source of melting is volatile free. At a normal mantle geothermal gradient, dry peridotite starts melting if lithosphere is thinned to ~60 km or thinner. For melting of dry pyroxenite and eclogite, the reduction of the lithospheric thickness could be less: to ~80 and 130 km, respectively. If not thinned, the cratonic lithosphere at its base is too cold for generation of magma unless it is volatile rich.

High temperature within an upwelling mantle plume, which is up to 300 °C higher compared to normal mantle (e.g., Campbell, 2005), or increasing temperature due to upper mantle internal warming (radioactivity, reorganization of convective flow, thermal blanketing by supercontinents, etc.) to about the same high temperature (e.g., King and Anderson, 1998; Coltice et al., 2007; Anderson, 2011) may produce melting of the eclogitic part of a composite thermochemical plume (Yasuda and Fujii, 1998; Sobolev et al., 2011), floating an eclogitic blob (Korenaga, 2004; Anderson, 2007) at the base of thick cratonic lithosphere. However, generation of a high-volume flood basalt province would still require thinning of the lithosphere via either rifting or delamination, and further decompression melting irrespective of the assumed source of the eclogite, delaminated continental crust (e.g., Anderson, 2005; Lustrino, 2005), or recycled oceanic crust (e.g., Korenaga, 2004; Sobolev et al., 2011). Melting of withinlithospheric metasomatic veins (carbonated or micaceous) is possible with slightly elevated temperature from the cratonic geotherm, but there should be a reasonable explanation for the increase in the temperature. Usually, heating from a plume is invoked (e.g., Gallagher and Hawkesworth, 1992).

This leads to a paradoxical situation, despite the flood basalts are usually considered to be sourced by a hot lower mantle plume, it is not the temperature which produces large volume of magma in the plume models. It is either reduction of lithospheric thickness or addition of fusible component into the plume. The high temperature is not critical parameter. Moreover, short duration of flood basalt volcanism is not consistent with thermal nature of mantle plumes, because thermal processes are very inertial.

Here I suggest that the mantle transition zone (MTZ) is the ultimate source of flood basalt plumes/diapirs. The MTZ is constantly refertilized via subduction by mafic (fusable) components (Ringwood, 1991) and radioactive elements (Safonova, Maruyama, 2014). It is also the major water mantle reservoir (Ohtani, 2005). Large MTZ plumes/diapirs, which are sufficient for generation of flood basalts, are generated due to abnormal mode of the MTZ refertilization connected to either ultrafast subduction or concentrated long-term subduction. Such mode of subduction is sufficient to transport water into the MTZ, probably, in form of ice VII (Bina and Navrotsky, 2000). The process of water transport into the MTZ via abnormal mode of subduction, slab stagnation, following slab warming and water release, wet plume/diapir formation and their rise to the sublithosphere, decompression-driven voluminous melting at ~ 200 km depth and flood basalt volcanism is responsible for origin of continental flood basalt provinces (Ivanov and Litasov, 2014).

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PLATINUM GROUP ELEMENTS DISTRIBUTION IN PERMO-TRIASSIC BASALTS OF SIBERIAN LARGE IGNEOUS PROVINCE

A.E. Izokh[1,2], A.Ya. Medvedev[3], G.S. Fedoseev[1,2], G.V. Polyakov[1]
[1]VS Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia
izokh@igm.nsc.ru
[2]Novosibirsk State University, Novosibirsk, Russian
[3]Institute of Geochemistry SB RAS, Irkutsk, Russia, amedv@igc.irk.ru

The most of economically PGE-Cu-Ni deposits are confined to ultramafic-mafic magmatism of large igneous provinces (LIP). For example there are PGE-Cu-Ni deposits of Kola-Karelia region (Monchegorsk, Fedorova-Pana, Penikat, Koillismaa, Kivakka, Lukkulaisvaara), which relates to two LIPs – Mistassini and Matachewan (Ernst et al., 2013). In the southern part of Siberian Craton are known a lot of PGE-Cu-Ni deposits linked with ultramafic-mafic magmatism of different age. The Chiney deposit (1880 Ma) relate to the Superior LIP (Canada). The Yoko-Dovyren intrusion and Kingash PGE-Cu-Ni deposit are connected to the Franklin LIP (Ernst et al. 2013, Polyakov et al. 2013). The unique deposits of Norilsk area are confined to most high-temperature zone of Siberian traps (250 Ma) which is considered as central part of mantle plume head (Dobretsov et al. 2010). The confinement of PGE-bearing Cu-Ni deposits to the central parts of plumes are distinctly manifested for Emeishan and Tarim events. Such close association of PGE-Cu-Ni deposits to ultramafic-mafic trap magmatism is explained by high degree of mantle melting and relatively high concentrations of PGE in primary melts.

We studied spatial and chronological patterns of PGE distribution in the basalts produced by Siberian Permo-Triassic mantle plume. As objects we selected basalts of rift and flood units of Norilsk area (SG-9 drill hole), flood basalts from the central part of Tunguska depression (Lower Tunguska), Kuzbass traps (Southern Siberia) andtrachybasalt from Semeitau volcano-plutonic assemblage (Eastern Kazakhstan).

Based on geochemical data of the distribution of PGE in basalts related to Permo-Triassic Siberian plume it was shown that the early stage rift basalts in the central part of the Siberian LIP is characterized by extremely low PGE content, whereas picrites and flood tholeiites contain high concentrations of PGE (Fig. 1.). The peripheral areas both the rift (Semeytau) and the flood units (Kuzbass traps) are characterized by low concentrations of PGE. The high contents of platinum group elements in magmas of the head of the plume are the cause of high productivity of the ultramafic-mafic magmatism connected with the traps. Increased potassium content in the magmas and high concentrations of PGE in the head of the mantle plume, probably, were caused by the arrival of deep substance from the core-mantle boundary, as follows from the thermo-chemical model of the Siberian plume (Dobretsov et al. 2010).

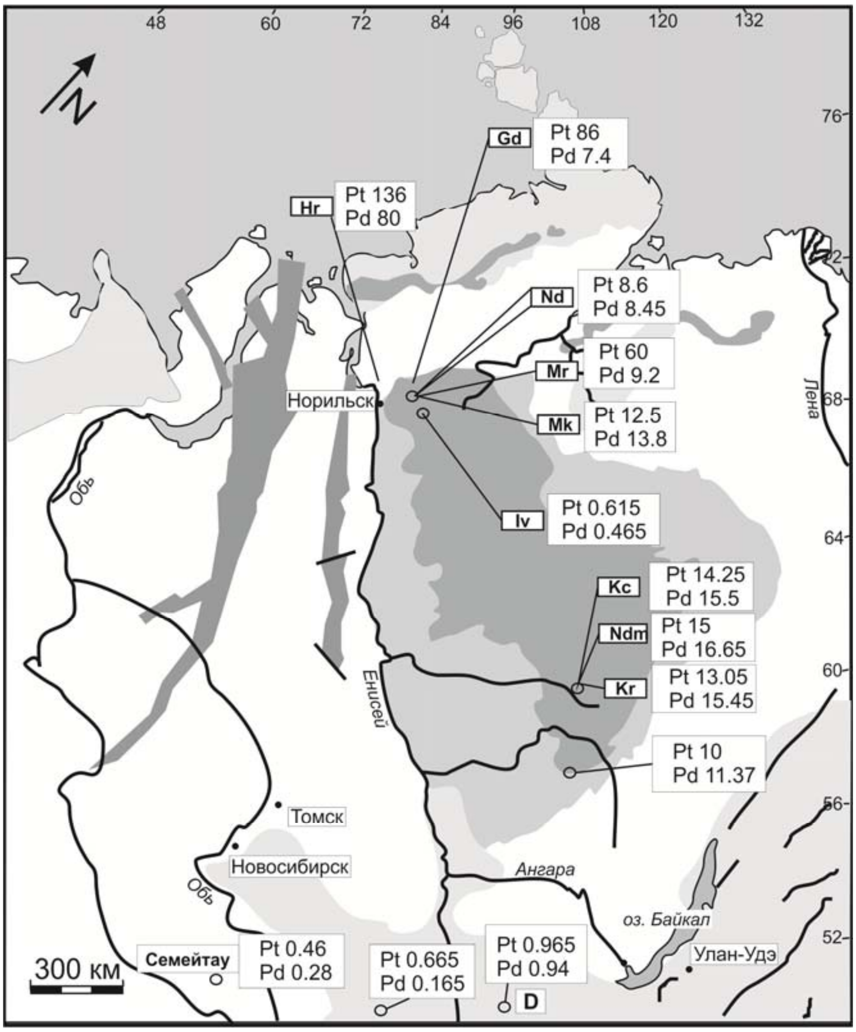

Fig. 1. The scheme of the distribution of Permo-Triassic Siberian magmatism connected with Siberian large igneous province. The circles indicate points of sampling of the examined specimens with specifying of the Pt and Pd contents (mg per ton). Units: : Iv – Ivakinskaya; Mk – Mukulaevskaya; Mr – Morongovskaya; Nd – Nadezhdinskaya; Gd – Gudchikhinskaya; Hr – Kharaelakhskaya; Kc – Kochechumskaya; Ndm – Nidymskaya; Kr – Korvunchanskaya

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LIP OF NON-PLUME ORIGIN – CRETACEOUS MAGMATISM IN THE RUSSIAN FAR EAST: EXAMPLE FROM THE SIKHOTE-ALIN OROGENIC BELT

Bor-ming Jahn[1,], Galina Valui[2], NikolaiKruk[3, 4], V. Gonevchuk[2] , Masako Usuki[1] and Jeremy T. J. Wu[1]*

[1]Department of Geosciences, National Taiwan University, Taipei, Taiwan 106
bmjahn@ntu.edu.tw

[2]Far Eastern Geological Institute, Russian Academy of Sciences, Vladivostok, Russia

[3]Institute of Geology and Mineralogy of Siberian Branch,
Russian Academy of Sciences, Novosibirsk, Russia

[4]Novosibirsk State University, Novosibirsk, Russia

Large Igneous Province (LIP) is not necessarily of plume origin. Abundant granitoids and/or silicic volcanic rocks occur in the Russian Far East, forming large silicic igneous province (SLIP), but they are related to the Pacific plate subduction. We present herein our recent study on the granitoid generation in the Sikhote-Alin Range which is an important accretionary orogen of the Western Pacific Orogenic Belt. 24 granitoid samples from various massifs in the Primorye and Khabarovsk regions have been analyzed. Zircon dating revealed that, granitoids in the coastal Primorye intruded into the Cretaceous Taukha Accretionary Terrane from ca. 90 to 56 Ma, whereas those along the Central Sikhote-Alin Fault zone in Primorye intruded the Jurassic Samarka Accretionary Terrane during ca. 110 to 75 Ma. The "oldest" monzogranite (131 Ma) was emplaced in the Lermontovka area of the NW Primorye Region. Granitoid massifs along the Central Sikhote-Alin Fault zone in the Khabarovsk Region formed from 109 to 58 Ma. Thus, the most important tectonothermal events in the Sikhote-Alin orogen took place in the Cretaceous.

Geochemical analysis indicates that most samples are I-type granitoids. They have initial $^{87}Sr/^{86}Sr$ ratios ranging from 0.7040 to 0.7083, and initial Nd isotopic ratios, expressed as $\varepsilon_{Nd}(T)$ values, from +3.0 to -5.0 (mostly 0 to -5). The data suggest that the granitoid magmas were generated by partial melting of sources with mixed lithologies, including the subducted accretionary complex ± hidden Paleozoic-Proterozoic basement rocks. Based on whole-rock Nd isotopic data, we estimated variable proportions (36-77%) of juvenile component (= mantle-derived basaltic rocks) in the gneration of the granitic magmas. Furthermore, zircon Hf isotopic data ($\varepsilon_{Hf}(T)$ = 0 to +15) indicate that the zircon grains crystallized from melts of mixed sources and that crustal assimilation occurred during magmatic differentiation.

The quasi-continuous magmatism in the Sikhote-Alin orogen suggests that the Paleo-Pacific plate subduction was very active in the Late Cretaceous. The regular progression of granitic intrusion ages from 80 to 56 Ma in the Taukha Terrane may reflect oblique underflow of the Paleo-Pacific plate beneath the Eurasian continental margin. Subduction was not only manifested by granitic intrusion, but also by abundant silicic volcanism. The Late Cretaceous Paleo-Pacific plate motion probably changed from parallel or sub-parallel to oblique relative to the continental margin of the Sikhote-Alin, leading to the change of magmatic source region and geochemical characteristics of the derived igneous rocks. Late Cretaceous rapid sea-floor spreading at ca. 100 Ma induced highly active subduction and led to voluminous magmatism in the entire Circum-Pacific realm. Finally, the present age and isotopic study lends support to the hypothesis of geologic and tectonic correlation between Sikhote-Alin and SW Japan.

Keywords: Sikhote-Alin, accretionary orogen, granitoids, juvenile crust, zircon age, Sr-Nd-Hf isotope compositions, Cretaceous magmatism.

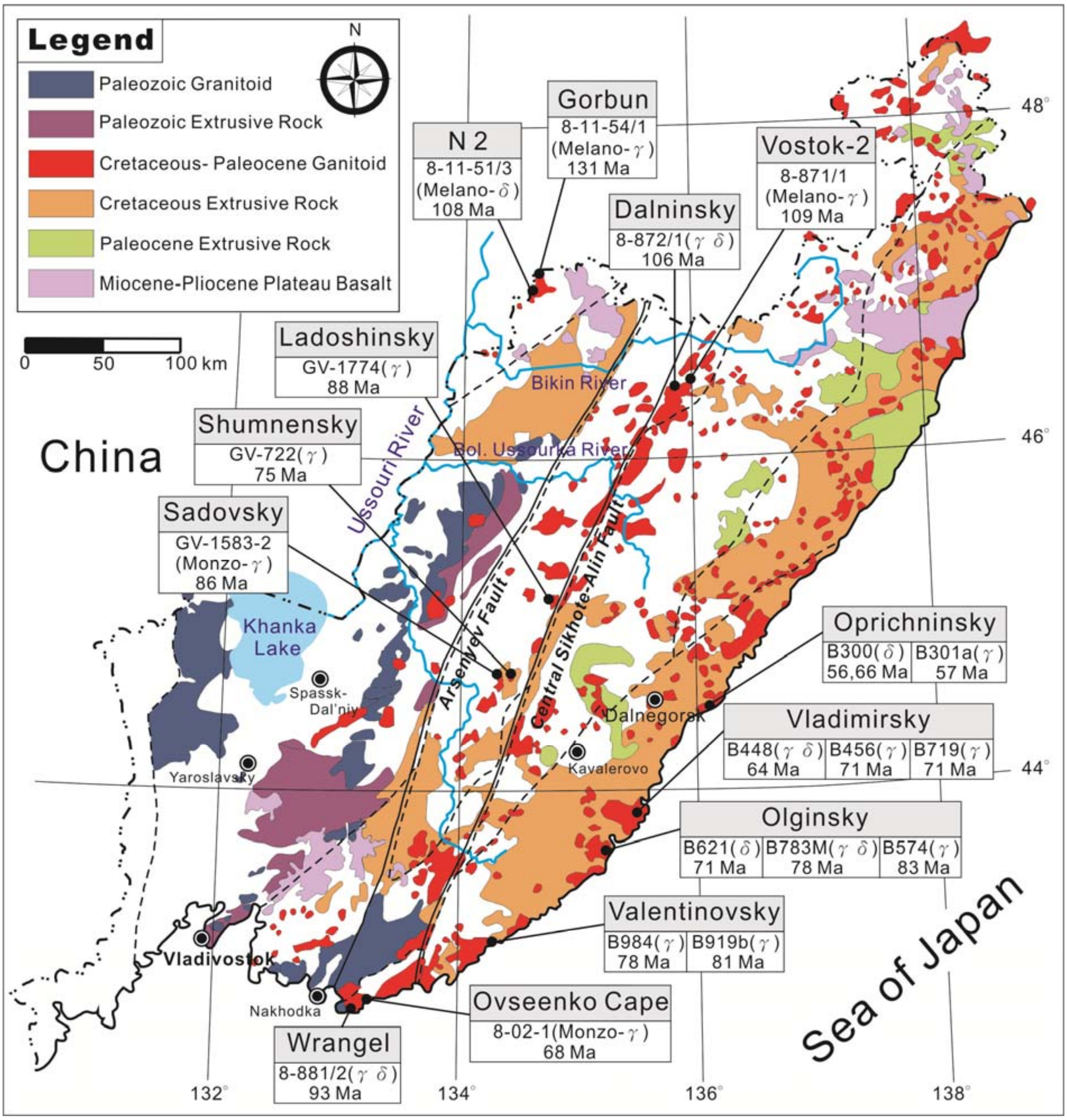

Fig. 1. .Distribution of granitoids and extrusive (volcanic) rocks in the Primorye region, Sikhote-Alin (Khanchuk, 2006). Sampling localities and new zircon age data are also shown. At each sample locality, the sample number, rock-type and zircon age are given in a rectangular box. Symbols:□□ = granite, □ = diorite, □□ = granodiorite.

AGES, MANTLE SOURCE AND TECTONIC CONTROL OF KIMBERLITE VOLCANISM IN SIBERIAN PLATFORM

S.I. Kostrovitsky, D.A. Yakovlev
Institute of Geochemistry SB RAS, Irkutsk 664033, Russia, serkost@igc.irk.ru

Yakutian kimberlite province consists of 21 fields of different ages, which contain about 1000 pipes and dykes. The new U-Pb ages, together with previously reported geochronological constraints, suggest that kimberlite magmas formed repeatedly during at least 4 episodes: Late Silurian-Early Devonian (419-410 Ma), Late Devonian-Early Carboniferous (376-347 Ma), Late Triassic (231-215 Ma), and Middle/Late Jurassic (171-156 Ma).

The spatial distribution of kimberlite pipes within Yakutian province is subordinated to linear tectonic control. There are three the main linear zones (Viluy-Markha, Daldyn-Olenek and Olenek-Anabar), which concentrate the all kimberlite fields. In particular, the extent of Daldyn-Olenek zone, in which are 11 kimberlite fields of different ages, amount to about 1000 km (and 100-150 km wide). Linear tectonic control of spatial distribution of kimberlite pipes we can see on the map of Daldyn and Alakit-Markha connected fields. There is linear zone of length >100 km and width 5 km contains more 40 pipes. The existence of linear oriented “corridors” for distribution of kimberlite fields is a typical picture and for other kimberlite provinces of World.

Kimberlite rocks are known to be characterized by wide variations in rock-forming oxides There are some factors that are responsible for the diversity of chemical compositions of rocks. One of the factors can be conventionally called primary-magmatic. It implies that the regional differences in the composition of kimberlites recorded either throughout the Yakutian Province or within its separate fields stem from the originally different compositions of the initial kimberlite fluxed melts. The steady differences on the chemical composition of kimberlites from different pipes, clusters, fields of pipes let us to distinguish petrochemical types (Kostrovitsky et al, 2008). Kimberlites can vary in the content of such oxides, as of Fe, Ti, K.

At the Yakutian province are developed high-Mg kimberlites (FeOtotal<8%, TiO2<1%), forming high-diamondiferous deposits (for example, Internatsional’na, Ayhal, Nurbinska so on); Mg-Fe kimberlites (8-12% FeOtotal, 1-2% TiO2), forming the most common deposits, such, as Mir, Udachnaya, Jubileynaya so on; FeTi kimberlites (10-15% FeOtotal, 2-6% TiO2), which are developed on the North of Yakutian province and which don’t form diamond deposits. The expediency of recognizing petrochemical types is confirmed by the study of composition characteristics of rock-forming and accessory minerals. For example, the Fe and Ti-rich kimberlite usually contains olivine with a widely varying composition (from 7 to 14% fayalite end-member), picroilmenite being predominant in heavy fraction. The megacryst garnet is found only in Mg-Fe and Fe-Ti types (№ 3-5) and is practically absent in types 1 and 2. The high-Mg kimberlites contain olivine with usually no more than 7–8% fayalite, the heavy fraction being dominated by garnet and Cr-spinel rather than by picroilmenite (for example, in the Aikhal and Internatsional pipes).

Specifics of incompatible elements distribution within each group of rocks is independence or slight dependence of the level of element concentrations on petrochemical composition. It is evident that high-Mg, low-Ti and low-K (pottasic) (type 1) kimberlites and fairly high-Fe, high-Ti (type 3), and at times in the northern fields high-K, high-Ti, very high-Fe kimberlites (type 4) within each group of rocks show a close level of concentrations of incompatible elements and a similar shape of spider diagrams. Most of isotope characteristics of kimberlites and related rocks of the Siberian Platform correspond to the earlier studied Type 1 basaltoid kimberlites from different provinces of the world: Points of isotopic compositions are in the field of weakly depleted mantle.

The most important feature of distribution of isotopic and trace-element compositions (incompatible elements) is their independence of the chemical rock composition. It is shown that the kimberlite formation is connected with, at least, two independent sources, fluid and melt, responsible for the trace-element and chemical compositions of the rock. It is supposed that, when rising through the heterogeneous lithosphere of the mantle, a powerful flow of an asthenosphere-derived fluid provoked the disintegration of lithosphere mantle rocks and the subsequent capture of the debris, their partial assimilation. These processes led to a significant change of primary melt composition, to the formation of different types of petrochemical kimberlite. But the geochemical specialization of kimberlites is due to the mantle fluid of asthenosphere origin, which drastically dominated in the rare-metal balance of a hybrid melt-fluid. It should be borne in mind that, pyroclastic kimberlite (breccia) from pipes are more hybrid, than massive coherent kimberlite.

We suppose, that the primary composition of kimberlite melt-fluid was in fact the composition of asthenosphere melt being close to alkaline picrite basalt one saturated with high CO_2. The genetic relation of kimberlites with basaltoids is indicated by a spatial and temporal affinity of their formation (Carlson et al, 2006; Lehmann et al, 2010; Tappe et al, 2012), similarity of the pattern of incompatible elements distribution, presence of megacryst minerals in alkaline basaltoids, Pyr-Alm garnet included, and finally, model calculation of parent melt composition for low-Cr megacryst minerals; it showed this composition to be typical for the alkaline basaltoid (Jones, 1980).

Considering the composition of mantle xenoliths captured by the ascending flow of kimberlite mantle-fluid, the onset of the hybridization process should be referred to the boundary of asthenosphere and mantle lithosphere. The most deep-seated xenoliths are deformed lherzolites, which experienced the direct metasomatic effect of asthenosphere melt (Nixon, Boyd, 1973; Burgess & Harte, 2004). Thus, we assume that the source of primary kimberlite melt-fluid asthenosphere was. At the asthenosphere level there was differentiation of melt-fluid which was responsible for formation of its different parts with varying melt to fluid ratio and possibly varying content of alkalis (K_2O). The outbreak of asthenosphere substance through lithosphere mantle proceeded by different scenarios:

(a) With a noticeable dominance of fluid component kimberlites were formed by the capture and contamination of high-Mg, high-Cr rocks of lithosphere mantle that caused formation of high-Mg kimberlites. That corresponds to model of Russell (2012).

(b) With a considerable proportion of melt phase depending on its ratio with fluid phase there formed magnesium-ferriferous and ferriferous-titaniferous petrochemical types of kimberlites. There is no doubt that in formation of these kimberlite types the contamination of lithosphere material was the case, however at the much lower level than in formation of high-Mg kimberlites.

This model logically explains steady differences of petrochemistry of kimberlites making up clusters of different pipes, fields of pipes and even province. The model clarifies presence or absence of low-Cr, high-Ti megacryst association of minerals, with its crystallization proceeding in the melt phase of asthenosphere source of kimberlites.

A surprising aspect of the mantle primary source of kimberlite is its very close, almost identical isotopic geochemical composition. The kimberlites of different ages, located in different parts of the Yakutian province at a distance of more than 1,000 km (for example, the southern diamond fields and Kuoyka field, located on the North of province) do not differ from each other in Sr-Nd-Hf isotope systematic. This fact should serve as the basis of our discussion on the mantle kimberlite sources.

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ON THE PROBLEM OF SULFATE SULFUR ASSIMILATION BY SULFIDE MELT

V.I. Kosyakov[1], E.F. Sinyakova[2], A.S. Borisenko[2], V.A. Shestakov[1]
[1] A.V. Nikolaev Institute of Inorganic Chemistry SB RAS, Novosibirsk, Russia, kosyakov@niic.nsc.ru
[2] V.S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia, efsin@igm.nsc.ru

The copper-nickel deposits in the layered mafic intrusions are distinctive element in metallogeny of large igneous provinces (LIP), associated with mantle plumes. The Norilsk ore district localized within the Siberian large igneous province is a typical region for occurrence of such world-class deposits. The problem of sulfur sources and formation of large massive sulfide ore deposits is a matter of considerable debates on the genesis of these deposits. It is assumed that their formation is associated with participation of sulfur from two sources, magmatic and borrowed from evaporite deposits hosting ore-bearing intrusions (Ryabov et al., 2000). The participation of sulfate sulfur from evaporites in the formation of sulfide ores of the Norilsk Cu-Ni deposits is confirmed by its isotopic composition. Thus, it is established that sulfur of copper-nickel ores is enriched in the heavy isotope (12-15‰) as compared with sulfur of mantle magma. Anhydrite commonly occurs as xenoliths in the ore-bearing rocks of mafic intrusions and in the form of magmatic anhydrite crystals in the Norilsk massive sulphide ores. Their magmatic origin is proved by the presence of melt inclusions of sulfate-sulfide composition (Ryabov et al., 2000, Li et al., 2009, Ryabov, Borovikov, 2011). According to some authors, the proportion of sulfur borrowed from sulphates of the surrounding host evaporites is up to 50% of its total content in the ores.

The interaction between sulfide magma and sulphate rocks must lead to the formation of specific assemblages that do exist in nature. The formation of such parageneses is related to the physico-chemical processes proceeding on the immediate contact of sulfide melts and sulfate rocks. However, physico-chemical conditions of their occurrence and peculiarities of sulfate-sulfide interaction are unknown. It has been suggested that this process may proceed only in the presence of reducing agents such as carbon, hydrogen, hydrocarbons. However, this hypothesis requires correct justification by experimental studies and thermodynamic modeling of sulfate-sulfide interaction.

The verification of the proposed mechanism for enrichment of the ore bodies by the heavy sulfur isotope and assessment of the corresponding conditions can be performed using thermodynamic modeling of the interaction between sulfide melt and anhydrite combined with test experiments.

Sulfide magma is a complex system consisting of more than 25 geochemically essential components. Sulfate rocks are also polymineral. However, thermodynamic modeling may be restricted by considering the simplest system formed from anhydrite $CaSO_4$ and some common minerals, consisting of the main ore-forming components. Note that to obtain the rough estimates it is enough to determine the conditions of phase and chemical equilibria in the sulfate-sulfide system consisting only of crystalline phases. The same chemical reaction will proceed in such system as well as in a high temperature system with the participation of sulfide melt. Therefore, the results of modeling are easy to extrapolate to higher temperatures area.

Thermodynamic calculations were performed using data collection and software from the thermodynamic section of the Data Bases of Properties of Electronic Materials created at the Institute of Inorganic Chemistry SB RAS. Missing data on the thermodynamic properties of minerals were taken from (Shvarov, 2008). The calculations were performed in the range 550-1250 K at 1 atm. Apart from determining the amount of condensed phases the equilibrium composition of the gas phase has been calculated.

Consider the results of the calculations on the example of interaction between anhydrite $CaSO_4$ and chalcopyrite $CuFeS_2$. It is found that heating the mixture results in the interaction of compounds with the formation of CaS, the amount of which increases with increasing temperature. The interaction is recorded in the calculation starting from 850 K, when 1 mole of $CaSO_4$ produces 4.5 10^{-6} mol CaS. At 1200 K the CaS output is 50.0%. The released oxygen is consumed mainly for the formation of Fe_3O_4, as well as gaseous forms SO_2, SO and S_2O.

The addition of carbon accelerates decomposition of anhydrite and at 1200 K more than 80% of anhydrite decomposes. However, below 850 K CaS output decreases slightly due to the formation of $CaCO_3$.

To verify the correctness of calculations we carried out an experiment to study the interaction between the anhydrite and sulfide melt. After annealing of the charge of $Cu_4Fe_8S_8$ composition in anhydrite-lined evacuated quartz ampoule at 865^0C and subsequent quenching we obtained the sample with a quasi-eutectic structure, in which rounded CaS and Sr-$CaSO_4$ microinclusions border the unfacetted haycockite grains. In addition, near the edge zone there are small segregations of $CaSO_4$ crystals, while the free surface of the specimen is covered with a crust composed of anhydrite with inclusions of haycockite, bornite, and chalcopyrite. The results obtained indicate to the chemical interaction between Fe-Cu sulfide melt and solid $CaSO_4$. These data are consistent with the thermodynamic calculations.

Note that the geochemical system describing the assimilation of sulphate sulfur into the sulfide copper-nickel melt, in accordance with the results of thermodynamic modeling, must suit the following requirements. 1) The initial sulfide magma must be essentially enriched in ore-forming metals (Fe, Ni, Cu). 2) The system must include stable chemical compounds containing CaO. 3) The system must include the mobile components responsible for the proceeding of the chemical reactions in the geological time scale.

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PETROLOGY AND ISOTOPIC DATING OF KALBA-NARYM GRANITE BATHOLITH (EAST KAZAKHSTAN)

P. Kotler[1,2,3], S. Khromykh[1,2], A. Vladimirov.[1,2,3], N. Kruk[1],O. Navozov[4], V. Khubanov[5]
[1] Novosibirsk State University, 630090, Novosibirsk, Russia,
[2] Institute of geology and mineralogy SB RAS, 630090, Novosibirsk, Russia
[3] Tomsk State University,Tomsk 634050, Russia
[4] "Topaz" geological exploration company LTD, Oskemen, 070001, Kazakhstan
[5] Geological Institute of SB RAS, Ulan-Ude, 670047, Russia
pkotler@yandex.ru

Kalba-Narym granitoid batholith, located on the territory of Eastern Kazakhstan, is one of the largest intrusion on the territory of the Central Asian Orogenic Belt (CAOB). Batholith is an important part of the Altai Collision System, formed in the late Paleozoic collision between Siberian and Kazakhstan continents (Vladimirov et al., 2008). Batholith rocks intrude Devonian-Carboniferous sediments of Kalba-Narym terrane, which is interpreted as a forearc basin. From the northeast Kalba-Narym batholith is bounded by Irtysh Shear Zone, which is the largest transregional fault in Central Asia.

Kalba-Narym granitoid batholith is composed of rocks of five intrusive complexes (Navozov et al., 2011). The earliest complexes are Kalguta and Kunush complexes, which compose small hypabyssal massifs, volcanoplutonic structures and northwest trending dike belts. They are represented by, potassium-sodium granodiorites and granites, dacite and rhyodacite (Kalguta complex) and biotite plagiogranites (Kunush complex). According to U-Pb Dating (LA-SF-ICP-MS, Geological Institute of SB RAS, Ulan-Ude) these complexes have age – 308-304 Ma and 303-300 Ma, respectively. The isotopic composition of Nd and Sr for Kalguty complex are εNd (t)= +3.33-3.44, $T_{DM\text{-}2st}$=795-804 Ma, $^{87}Sr/^{86}Sr$= 0.7046-0.7047, and for Kunush complex are εNd (t)= +6.7, $T_{DM\text{-}2st}$=525 Ma, $^{87}Sr/^{86}Sr$= 0.7028-0.7034. The main part (approx. 70%) of Kalba-Narym batholith is presented by rocks of Kalba complex, forming large massifs up to 2-5 km thickness, composed of biotite granodiorite, biotite- and two-mica granites. U-Pb age of the first phase Kalba complex rocks – 296-293 Ma, second phase – 288-285 Ma. Kalba granites associate with the rare metal pegmatites, forming large deposits of Li, Be, Cs, Ta and Nb with Ar-Ar istopoic ages about 295-285 Ma. The isotopic composition of Kalba complex rocks are εNd (t)= +0.81-1.94, $T_{DM\text{-}2st}$=906-1000 Ma, $^{87}Sr/^{86}Sr$= 0.7049-0.7059. The youngest rocks of batholith are the rocks of Kainda and Monastery complexes, which form chain of large isometric massifs on the south-western side of the batholith. The Kainda complex is represented by porphyritic biotite granite, Monastery - by leucogranites and two-mica granites. U-Pb age of the Kainda complex rocks are 288-287 Ma, and the Monastery rocks are – 285-283 Ma. The isotopic composition of Nd and Sr for Kainda complex are εNd (t)= +1.67, $T_{DM\text{-}2st}$=930 Ma, $^{87}Sr/^{86}Sr$= 0.704, and for Monastery complex – εNd (t)= 3.50-4.32, $T_{DM\text{-}2st}$=704-773 Ma, $^{87}Sr/^{86}Sr$= 0.7044.

Obtained new geochronological data allow us to determine the maximum interval of granitoid complexes formation in ~ 25 million years (308 - 283 million years). There are the following formation stages: 1) 308–300 Ma – the melting of metabasic basement of Kalba-Narym terrane and mixing with melts of crustal substrates (Kalguta and Kunush complexes); 2) 298–288(?) Ma – gradual lifting of granite-formation front and the melting of sedimentary-metamorphic rocks of terrane (crustal substrates) with the participation of juvenile fluids (Kalba complex and rare metal pegmatites); 3) 285-280 Ma – new pulse of crustal substrates melting (probably remelting of restites from previous melting or melting of leucosomes of migmatites in the basement of the terrane) (Kainda and Monastery complexes).

It should be noted, that the obtained geochronological data coincide with the data on the age of mafic magmatism in the adjoint Chara zone – 293-280 Ma (Khromykh et. al., 2013), and with the data on the age of magmatism in Northwest China – 320-270 Ma on granitoids, gabbroids and trap basalts of Tarim and Dzungaria (Mao et al., 2008; Chen et. al., 2010), the formation of which is responsible of the Tarim large igneous province as a result of the activity of the Tarim mantle plume (Xu et. al., 2014).

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EARLY DEVONIAN MAGMATISM IN ALTAI MOUNTAINS: RELATION OF PLUME- AND PLATE-TECTONIC FACTORS

N.N. Kruk[1], V.I. Krupchatnikov[2], N.I. Gusev[3], V.V. Vrublevsky[4]
[1]Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia, kruk@igm.nsc.ru
[2]JSC «Gorno-Altaiskaya expedition» (JSC GAE), Maloyeniseiskoe, Altai region, Russia, VIKRUP@yandex.ru
[3]AP Karpinski Russian Geological Institute, Saint-Petersburg, Russia, Nikolay_Gusev@vsegei.ru
[4]Tomsk state university, Tomsk, Russia, labspm@ggf.tsu.ru

Early Devonian stage of evolution of Central Asia characterized by two contrast regimes: rift caused by mantle plume activity and continental caused by subduction of oceanic lithosphere of Ob-Zaisan basin under Siberia continental margin. Relations of magmatism of these two regimes are not clear yet and are the subject of constant debate. In this report the problem is considered by the example of the Altai and neighboring regions.

Early Devonian rift processes appeared on the territory of Altai, Kuznetsk Alatau, Sayan, Tuva and Northern Mongolia. At this time the large depressions with heightened alkalinity bimodal volcanism and small intrusions of sub-alkaline and alkaline gabbroids were formed (Yarmolyuk et. al., 2000; Shokalsky et al., 2000; Babin et al, 2004; Vorontsov et al., 2013; etc). Most of volcanic centers (Minusa, Tuva and Agul depressions) have intracontinental position; only Uimen-Lebed' and Tel'bess depressions are less than 300 km from the edge of the Siberian paleocontinent. Devonian volcanic complexes related with evolution of Active Continental Margin (ACM) form number of linear zones on the territory of Altai, Salair, Tom'-Kolyvan' fold belt, Mountain Shoria and Kuznetsk Alatau (Shokalsky et al., 2000). Area of active volcanism extends into the continent for 250-300 km that is comparable to the width of magmatic belts of modern ACM. Felsic volcanites from basement of Minusa depression have the Late-Pragian age (407.5±0.2 Ma, Babin et al, 2004) whereas intrusion of youngest basaltic sills near Shira lake occurs at border of Middle and Late Devonian (386±2 Ma, Vorontsov et al, 2013). Paleontological data from sedimentary rocks associating with "suprasubducting" volcanites in Rudny and Gorny Altai show that acitve volcanism here started not earlier than Late Emsian. The evolution of volcanic belts of ACM lasted until the end of the Middle Devonian.

Thus, most of the volcanic centers of Early Devonian rift system located outside the area of influence of the Active Continental Margin and initial rift magmatism in these areas started 5-10 Ma years before than ACM was forming. In this respect, the Early Devonian magmatism in Eastern Altai is most interesting as area with "interference" of geodynamic settings.

Early Devonian magmatic formations of region are parts of two large belts: Altai-Minusa (D_{1-2}) and Altai-Salair (D_2-C_1) (Shokalsky et al., 2000). Volcanism of first belt is represented by rocks of Aksai complex in the south-eastern part of the Altai. The predominant varieties are rhyolites, rhyodacites and dacites with subordinate role of trachybasalts and trachyandesibasalts. Age of rocks are 402-405 Ma. Among basalts the two groups determined: high-titanium and low-titanium (Vrublevsky et al, 2006). For the rocks of first group the high ferruginosity, low concentrations of Sr and Ba, sharp enrichment of HFSE and REE are typical. The rocks of second group are low-titanium, low-phosphorus, more magnesia and alumina and have lowest concentration of HFSE and REE, higher concentrations of Sr and Ba. For all the differences are typically expressed weakly selective depletion of Nb and Ta that typical for "suprasubduction" basalts. OIB-like basatls are absent. Dacites and rhyodacites varies from normal to sub-alkaline and often eriched in HFSE and REE.

Gabbro-granite and granitoid intrusions with age of 410–400 Ma confined to framing of large faults. Gabbroids presented by low-Ti rocks of the normal range with common concentrations of REE and selectively depleted in Ta and Nb. Granitoids are vary widely in composition and belong to different geochemical types (from tonalites thruogh Ca-alkaline to sub-alkaline).

Volcanic formations of Altai-Salair belt in Eastern Altai presented by pocks of Nyrnin and Sagan complexes. Among the first the basalts prefer, among the second - dacites and rhyolites. Basalts have heterogeneous composition. Lower part of section compose low-Ti alumina difference of normal alkalinity that have common concentrations of incoherent elements. At the basement leucocratic sub-titaniferous basalts lie that enriched in HFSE and REE and showing weak geochemical signs of rock of suprasubduction genesis. The upper section is composed of high-alumina basalts and andesibasalts depleted in HFSE compared with REE. Felsic rocks are mostly sub-alkaline with common concentrations of HFSE and REE.

In general basalts compared with the typical rocks of back-arc parts of ACM are depleted in LILE, weak enriched in REE compared with HFSE and their composition corresponds intermediate position between typical basalts of back-arc parts of ACM and rocks of Early Devonian "rift system". This suggests that evolution of ACM (it back-arc part) at the end of Early Devonian took place under the influence of mantle magmas of plume genesis.

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EVOLUTION OF PLUME MAGMATISM AND ITS ASSOCIATED LARGE IGNEOUS PROVINCES IN THE FENNOSCANDIA FROM THE ARCHEAN TO THE PALEOZOIC

V.V. Kulikova[1], V.S. Kulikov[1], Ya.V. Bychkova[2]
[1] Institute of Geology, Karelian Research Centre of RAS, Petrozavodsk, Russia, vkulikova@yandex.ru
[2] Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry, Russian Academy of Sciences, Moscow, Russia.yanab66@yandex.ru

Analysis of geological survey maps of the territory of Fennoscandia published in 21 century (Geological map .., 2001; Mitrofanov, 2001 and others.) and the authors study in this region show that over geological history (> 3 Ga) in the Archean, Proterozoic and Paleozoic (Kulikov, Kulikova, 2013 and others.) are fixed no lesser than 10 large-scale development of mantle mafic-ultramafic "plume" of magmatism (Ernst, 2007; Kulikov et al., 2015 et al.).

Early Archaean except Paleoarchean Vodlozero unit (Kulikova, 1993; Onezhskaya.., 2011 and others.) as a plume magmatic period is the least informative because of the wide tonalitization of primary crust.

Traces of Mesoarchean "plume" in the greenstone structures preserved – in the greenstone belts (GB) V. Finland, Karelia, Kola Peninsula and Arkhangelsk region. as komatiite basalt associations, widely represented in such GB as: Kuhmo-Suomussalmi-Tipasyarvi, Vedlozero-Segozero, Sumozero-Kenozero-Lacha and North Karelia, with the first identified magmatic pulses with a period of about 50 Ma (Holtta, 2012). Meso - and Neoarchean (3.0-2.5 Ga) komatiite-basalt association of different areas of Fennoscandia differ in reduce volume and changing of REE concentration (Vrevsky, 2000).

Sumian thermochemical superplume Paleoproterozoic (2.5-2.4 Ga) S- to 1.5 million. km2 preserved three paleorifts: Pechenga-Varzuga, Lapland and Windy Belt and feathering their structures (Kulikov et al., 2010a and 2010b) in the form of volcanic facies (komatiitic basalts, "boninite like" dikes and magnesia basalts) and well-known layered intrusions S. Finland, Karelia and the Kola Peninsula deposits of Cr, Ni, PGE.

Middle Paleoproterozoic (2.3-2.09 Ga) Jatulian plume magmatism, formed the appropriate lava plateau during the three phases of volcanic activity in the area of about one million. km2 in Finland, Sweden, Lapland, possibly in part, in the west of Karelia, refers to the number of researchers to trap type (Onezhskaya.., 2011, Svetov, 1979; Hanski, Melezhik, 2012). Mafic-ultramafic magmatism of Ludicovian period 2.05-1.96 Ga (Smolkin, 1992), or ~ 1.85 Ga (Martin et al., 2015) in Pechenga diverse special attention.

Occurrence of mafic magmatism with the LIP characteristics established in the: Vepsian (1.8-1.75 Ga, South Onega trough), Early (1.45 Ga, Ladoga graben) and Late Riphean (1.2 Ga, Kandalaksha- Onega graben in the White Sea) .In the Paleozoic (~ 400 Ma) is known alkaline ultrabasic magmatism with REE deposits and kimberlitic with diamonds in the Arkhangelsk region.

The evolution of plume magmatism in the Fennoscandian segment of the lithosphere reflects in the change of the parent magmas type in the Archean komatiitic to vetrenitic (Kulikov et al., 2010a, 2010c and others.) in Paleoproterozoic, tholeiitic in Jatulian, picrite (ferropicrite) – basaltic in Ludikovian, tholeiitic with alkaline trend in Riphean and alkaline ultrabasic and kimberlitic in Paleozoic (Onezhskaya.., 2011 and others.).

This trend is due both to changing the overall thermodynamics of the mantle and the core of the Earth, and the particularity of evolving plume due to its "precession" inside the crust.

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ISOTOPE-GEOCHEMICAL ND-SR FEATURES OF THE PALEOPROTEROZOIC PGE-BEARING MONCHETUNDRA MASSIF MAFIC ROCKS (FENNOSCANDIAN SHIELD)

E.L. Kunakkuzin, T.B. Bayanova, L.I. Nerovich, E.S. Borisenko, P.A. Serov
Geological Institute of KSC RAS, Apatity, Russian Federation kunakkuzin_evgeniy@mail.ru, bayanova@geoksc.apatity.ru, nerovich@geoksc.apatity.ru, elena.s.borisenko@gmail.com, serov@geoksc.apatity.ru

The Mochetundra massif located in the central part of the Kola Peninsula is the eastern branch of the largest Paleoproterozoic gabbro–anorthosite Main Ridge massif. The Monchetundra massif is a promising for finding economic noble mineralization along with Fedorovo–Pana complex, Mt. General'skaya, and Monchepluton with deposits and occurrences of Pt–Pd and Cu–Ni ores (Grokhovskaya et al., 2003; Nerovich et al., 2009).

Four groups of rocks differed in ages are presented in the massif (Borisenko et al., 2014; Kunakkuzin et al., 2015).

The results of Nd-Sr research of the mafic rocks differed in ages from the Monchetundra massif showed various isotope-geochemical features for each of varieties.

The oldest rocks of the massif (metagabbrides) show a wide range of $\varepsilon_{Nd}(T)$ values between +0.02 and -2.23 and Mezo- to Paleo-Archean T_{DM} ages. Trachytoid gabbronorites have more radiogenic Nd and Sr compositions than other rocks of the massif. The $\varepsilon_{Nd}(T)$ and T_{DM} values for them range from –1.70 to +1.42 and from 2.7 to 3.5 Ga respectively. The $\varepsilon_{Nd}(T)$ values for massive gabbronorites vary between -3.38 and +2.08, and T_{DM} ages for them are in the range from 3.4 to 2.7 Ga. Gabbro-pegmatites were formed at the final stage of massif forming and have negative $\varepsilon_{Nd}(T)$ values (-1.26 to -0.63) and T_{DM} of 3.2 to 3.0 Ga.

Forming of the Monchetundra massif rocks as well as other Fennoscandian mafic-ultramafic intrusions, such as Fedorovo-Panskiy massif, mt. Generalskaya, Monchepluton, Olanga complex, Portimo-Penikat-Kemi complex, is likely to connect with the long life lower mantle plume acting at the time of 2.52-2.39 Ga (Bayanova, Mitrofanov, 2012; Mitrofanov et al., 2013). The isotopic Nd and Sr data for the mafic rocks of the layered Fennoscandian intrusions indicate to forming from the enriched EM-I-type mantle source (Bayanova et al., 2009).

According to the diagram (fig.1), Monchetundra massive gabbronorites are characterized by less radiogenic Nd and Sr values compared to trachytoid gabbronorites. This difference is likely to connect with the evolution of the long life mantle reservoir. Perhaps, the plume melted a lower continental crust, and as a result, younger rocks have less radiogenic values of Nd isotope composition. In this cause, crust contamination has to change isotope Rb-Sr system, what is not observed, therefore, the volume of crust contamination was less.

However, a type of Monchetundra rocks source is controversial. According to REE data (Nerovich et al., 2009) the Monchetundra massif rocks characterized by low values of trace elements and lower Nb / U ratio (<10), which contradicts to EM-I-type mantle source. The Nb-Ta minimum indicates to the crustal contamination of rocks source (Nerovich et al., 2009; Nerovich et al., 2014), but, however, degree of it was slight. At the same time, there are samples of Monchetundra massif rock with elevated Nb / U ratio (up to 44) at its low concentrations. The reasons for this are unclear, but some local influence of EM-I-type mantle sources is determined by new isotope-geochemical investigations.

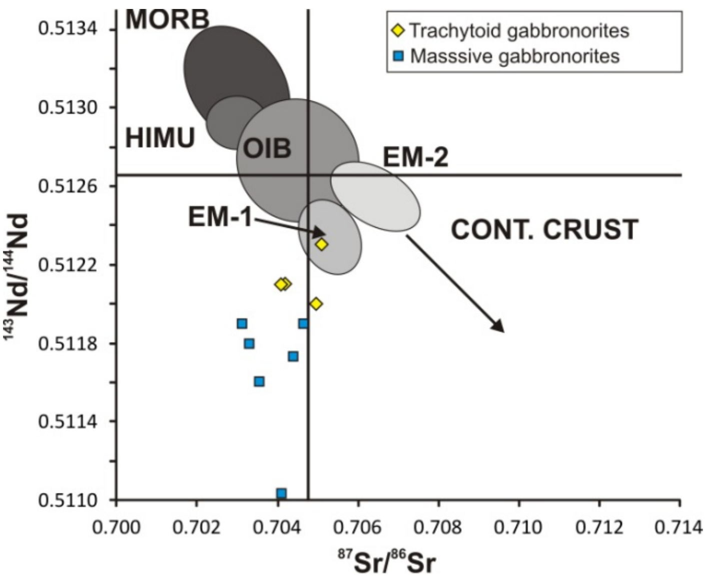

Fig.. 1. Correlation between Nd and Sr isotope composition of Monchetundra massif gabbronorites. Fields of mantle reservoirs MORB, OIB, HIMU, EM-1, EM-2 according by– (Hoffman, 1997).

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CHANGE IN TECTONICS STYLE DURING THE EARTH EVOLUTION (FROM ITS ORIGIN TO THE PRESENT)

M.I. Kuzmin
A.P. Vinogradov Institute of geochemistry, SB RAS, Irkutsk, Russia, mikuzmon@igc.irk.ru

We discuss the changes in tectonic movements since the Earth's origin to the present. In our current understanding, the proto-Earth gained most of its present day mass within the first 50-100 Ma and thefirst differentiation of the cosmic material that corresponded to carbonaceous chondrites, into metallic core and silicate mantle took place in about 50 Ma. The Moon, the Earth satellite, was formed at that time as well. The most probable hypothesis of moon formation states that it was produced due to the giant impact event between the Earth and an astronomical body. By that the time major part of the Earth's metallic core had been already formed. The Moon has a tiny metallic core and its composition is similar to that of the Earth's mantle. The geologic history of the Earth dates back from the Hadean aeon (4.5–4.0 billion years ago) and the first continental crust was generated at about that time. However, the pristine Hadean crustal rocks have not been preserved. The only known, direct present-day remnants of this crust preserved by now are detrital zircon grains with the age of 4.4. Ga. Detailed studies of the remnants of the crust, modeling of mantle processes as well as Lu-Hf and Re-Os model ages helped to develop the following reconstruction of the past. The data obtained suggest that triggering mechanism is the whole-mantle convection stretching from the core-mantle boundary to the solid relatively cold Earth's surface (Nebel et al., 2014).

The isotope data and trace element compositions of zircons show that the atmosphere composition of the proto-Earth was similar to the present, and the temperature of zircon crystallization was relatively low (about 700oC), that suggests the granitic primary melts. The multiple recycling events recorded within individual grains suggest that zircons subsided simultaneously with the Hadean continental rocks into the mantle while their further occurrence with komatiite-basitic magmas means their transportation to the Earth's surface. The differentiation of basic magmas resulted in small host reservoirs for zircons. The Earth experienced several asteroid-meteorite bombardments, caused a collapse of continental partly granitic crust. It is suggested that the granitic magmas were primary for the Hadean zircons. The fragments of the destroyed crust together with radiogenic isotopes and incoherent rare elements, residual melt reservoirs sank into deep mantle. In addition to the crust collapse the bombardments gave rise to a great number of basalts-komatiitic melts that can be regarded as the mantle turnover. In the Hadean aeon the asteroid-meteorite bombardments were of massive nature and resulted in almost a complete collapse of the primary crust except for its preserved remnants as zircons. A common equatorial supercontinent existed prior to 3.4 Ga. The Hadean and later on Archean crust was generated there. In the Archean the bombardments were not large-scale and covered only limited areas of the common subequatorial supercontinent. Those bombardments led to "sug-subduction" of the Archean basalt-komatiitic crust that sank into the mantle transforming into amphibolite-eclogite rocks, being parental for tonalite-trondhjemite-granodiorite associations of the Archean continental crust. Eruption of separate portions of the Archean mantle magmas and their evolution on the Earth's surface continued for about 300 Ma that is verified by similar age of juvenile zircons from the Archean cratons located on different continents. They form independent trends. The age of such trends are as follows 4,5; 4,2-4,3; 3,8-3,9 and 3,3-3,4 Ga. [Griffin et al., 2014]. They likely mark the asteroid bombardments in the Hadean-Archean.

Subcontinental lithosphere mantle (SCLM) began to form under the cratons between 3.3. and 3.5 Ga and is sufficiently different form peridotite of ophiolitic complexes. Peridotites from ophiolite complexes can point out the processes related to plate tectonics.

The metallic core began to form at about 3.4. Ga and was finally produced by 2.7. Ga. In the time span from 3.4 to 2.7 Ga the plume-related magmas demonstrate constant MgO content and temperature (Campbell, Griffiths, 2014). The inner metallic core had been finally formed that resulted in the increase of magnetic field intensity and thus its dipole nature. The paleomagnetic records staring from 2.7 Ga show the continent movements that is confirmed by the origin of supercontinents (e.g. Kenorland) [Li, Zhong, 2009]. The two-layer convection common to the upper and lower mantle likely started earlier as the equatorial supercontinent had to be broken by the superplume and a new supercontinent Kenorland started to form i.e. subduction processes began operating that is a direct evidence of plate tectonics.

The D" layer was produced between 2.7 and 2.0 Ga. After 2 Ga the plume temperature remained constant that is verified by a constant MgO content (about 21%). By that time D" layer likely attained its sufficient thickness and inner convection was typical of this layer that resulted in a constant temperature of uplifting thermochemical plumes (Cambell, Griffiths, 2014). At the same time perovskite transited into post-pervoskite (high-pressure phase of magnesium silicate). From radiogenic isotopic ratios in young basalts from oceanic regimes, two mantle domains (EM-1 and EM-2) have been defined from 2 Ga to the present (Hofmann, 1997). Those mantle reservoirs are regarded as sources of incoherent elements for within-plate igneous rocks. The depleted mantle (astenosphere) as a source for the mid-ocean ridge basalts was produced between 2.0 and 1.8 Ga.

Starting from that time interval the recent tectonic style started to operate. The endogenous processes involved all Earth's shells. The interaction between the astenosphere and lithosphere is responsible for large surface structures: fold mountains, oceanic spaces, subduction zones - the sites of the recent continental crust growth. The descending lithosphere slabs (cold mantle material) and ascending mantle material in hot mantle provinces or the so-called low shear velocity provinces produce the lower mantle convection and thus are responsible for the supply of thermochemical plumes to the Earth's surface that results in heat supply to the astenosphere the shell with the fine-cell convection responsible for lithosphere plate motion.

The substance of plumes is produced in the layer D", that is primarily stipulated by the descending lithosphere slabs, as well as light elements brought from the outer liquid core which are oxidized in this layer and thus provide a possibility for thermochemical plume origin and the recovered ferric iron sink into the core thus increase the core primarily the inner iron core. So, we see the interaction of all shells of the Earth.

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CO_2 EFFECT ON HETEROGENIZATION CONDITIONS OF SULPHATE-CHLORIDE-CARBONIC FLUIDS AND GOLD, PYRITE, AND MOLYBDENITE SOLUBILITY

Yu.V. Laptev[1], A.S.Borisenko[1], I.R. Prokopiev[1]
[1]V.S. Sobolev Institute of Geology and Mineralogy, SB RAS, Novosibirsk, Russia
laptev@igm.nsc.ru; borisenko@igm.nsc.ru; pro.kop@ngs.ru

Experiments are continuation of studies involving water-saline fluids of sulfate-chloride type (Laptev, 2014) as applied to a specific model of ore-metasomatic processes developed on the widely occurring magmatic formations (Borisenko et al., 2011). As a basis system we used 2m Na_2SO_4-0.5m NaCl-H_2O with addition of carbon dioxide in amounts corresponding to both homogeneous and heterogeneousstate of fluids (X_{CO2} varied in the range of 0 ÷ 0.21 at temperatures of 200 - 420°C and pressures 10 - 750 bars). The obtained data on the P-V-T properties of these fluids allowed us to carry out a parallel investigation of the gold and sulfides (molybdenite, pyrite) solubility as a function of the carbon dioxide content in the water-salinegas-bearing system.

Fluid pressure measuring techniquehas been used underits constant volume conditions and we constructed isochoric dependences in P-T coordinates for the temperatures of 200 - 420°C and pressures of 10 - 750 bar. The measured amount of carbon dioxide was charged as "dry ice" without contact with the aqueous solution. To systematize the conditions of our measurements we accepted the concept of the fluid specific volume in the form of "gross" value. Using the constant total weight of the solution and carbon dioxide (16 g) and volume of the autoclave (21 cm^3)(i.e. constant specific volume "gross" value), we investigatedthe effect of the solution / CO2 ratio onto the P-V-T properties of the system.

P-V-T measurements. As seen from the Fig.1, the break of a curve 1 at the point 325^{0}C – 75 bar corresponds to homogenization parameters for a fluid of 2m Na_2SO_4 – 0.5m NaCl – H_2O (22% Na_2SO_4 – 2.3% NaCl –H_2O), which is in a good agreement with data of our previous measurements (Laptev, 2014). The curve 2 is constructed based on the data of pure water-carbonic fluid with X_{CO2} 0.15. The break of this curve at the point 350^{0}C – 370 bars

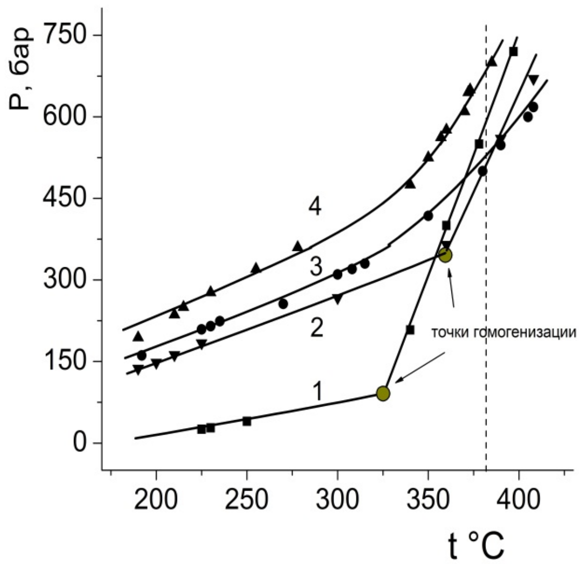

Fig. 1. Isochoric dependences in P-T coordinates for fluids of different composition. 1 - H_2O–2m Na_2SO_4–0.5m NaCl; 2 - H_2O–CO_2 (X_{CO2} = 0.15); 3 - H_2O–2m Na_2SO_4–0.5m NaCl–CO_2 (X_{CO2}=0.14); 4 - H_2O–2m Na_2SO_4–0.5m NaCl–CO_2 (X_{CO2}=0.21). Dash line shows temperature (380°C) for experiments with gold and sulfides.

is compatible with conventional results (Takenouchi, Kennedy, 1964). According to their results, the stability field of supercritical H_2O-CO_2 fluid covers all compositions at $T \geq 350^0C$. The curves 3, 4 with X_{CO2} 0.14 and 0.21 in 2m Na_2SO_4 – 0.5m NaCl solution have no breaks which is indicative of the existence of heterophase equilibrium between the water-saline liquid of higher density and CO_2-rich gas phase of lower density. Thus, as compared to the limiting parameters of fluid homogenization for the pure water-gas H_2O-CO_2 system (350^0C, 370 bar), the addition of salts with the above concentrations at X_{CO2}> 0.14 extends the area of heterogeneous state of water-saline-gas-bearing fluid at least up to 420^0C and 750 bar pressure.

Gold and sulfides solubility. Experiments on gold, molybdenite, and pyrite solubility in water-saline gas-saturated fluid of 2m Na_2SO_4 - 0.5m NaCl composition were carried out at temperature of 380^0C and pressures 525 - 675 bar. Elemental sulfur (0.06 m) was added into the autoclaves to create conditions corresponding to sulfide-sulphate equilibrium described by the reaction $4S(el) + 4H_2O \rightarrow 3H_2S + HSO_4^- + H^+$.

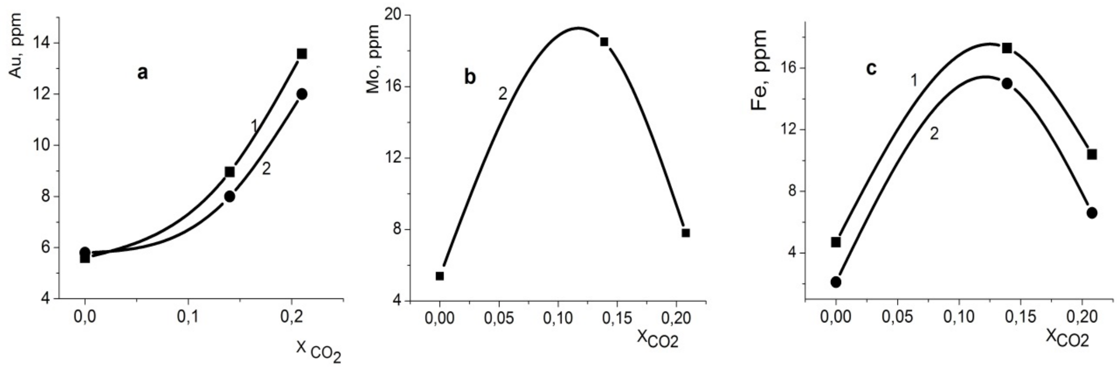

Fig. 2. Changes in the concentrations of Au (a), Mo (b), and Fe (c)on dissolving of gold, molybdenite, and pyrite in water-saline fluid when passing from its homogeneous state (without CO_2) to heterophase equilibrium with participation of CO_2-containing gas phase. 1- data on weight loss; 2 -chemical analysis of the solution composition.

The effect of CO_2 addition on the metal contents is quite evident (Fig. 2). Gold concentration increases monotonically with X_{CO2}increase. At average CO_2 content the curves for Mo and Fe shows their maximum concentrations. It is important that concentration values for all metals fall into the same interval, from 4 - 17 ppm. Complicated dependences of change of pyrite, molybdenite and gold solubility in Na_2SO_4-NaCl-CO_2-H_2O fluids as gas-liquid relationships change make it possible to consider fluid heterogenization as an important process to activate migration and precipitation of ore components.

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MATERIAL TRANSPORT AND VOLATILE BUDGET IN THE DEEP EARTH'S MANTLE

K.D. Litasov [1,2]
[1] V.S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia
[2] Novosibirsk State University, Novosibirsk, Russia
klitasov@igm.nsc.ru

The models considering fast mantle upwelling without an addition of volatile-bearing components are failed due to very high melting temperatures of mantle silicates. Without melting the material transport will be hardly possible. Thus, considering mantle plumes one should add fusible component to the system. In most geodynamic models fusible component is involved indirectly, for example, just changing the viscosity. Almost nobody try to consider the real process of melt movement through presumably non-porous mantle matrix or try to understand the nature of melt, which assist material transport in the very deep mantle. Some mechanisms, such as melt percolation or hydraulic magma fracturing, are applicable for lithospheric depths and cannot be considered as a reliable mechanism for deeper mantle with high plasticity and low porocity. The most likely mechanism, which can operate in the deep mantle to assist plume or diapiric ascent is the stress-driven dissolution-precipitation (Shatskiy et al., 2013), however, the possible fusible component of plume melt in the deep mantle is a matter of debates. Here, I discuss possible compositions of melt in the upwelling mantle, which can drive material transport under superplumes and hot spots originated from the transition zone of from the core-mantle boundary.

The most likely candidates for fusible chemicals in the mantle plumes are alkali-bearing species, C-O-H volatiles, and carbonates. An important requirement for plume motion would be stress-induced melting and dissolution-precipitation of the fusible component at the front and rear of the plume, respectively. For this process one would have a volatile-bearing melt with low solubility of silicates (ca. 5-15%, but not zero) at the temperature of mantle geotherm (or slightly higher). The possible candidates are alkali-bearing silicate melt, hydrous silicate melt, carbonatite melt, and hydrocarbon-bearing melt. Alkaline silicate melt and hydrous silicate melt cannot be considered, since a huge amount of silicate can be dissolved in these melts and the process of plume ascent will be easily terminated by progressive reactions with the surrounding silicate matrix. Carbonated or carbonatite melt is a likely candidate, especially for transition zone. Phase relations in the alkaline carbonatite systems indicate that major melting of subducted carbonates should occur at the transition zone depths (Litasov et al., 2013). Taking into account the amount of subducted carbonated (1-2 wt.% CO_2) in the top 500 m of model slab we proposed a model for mobile carbonatite melt diapirs, generating from the slab in the transition zone, migrating upwards, modifying and oxidizing possibly reduced mantle section, precipitating diamonds, creating enriched source regions, and initiating volcanism at the surface (Fig. 1). Dehydration of stagnant subducted slabs in the transition zone may accompany carbonatite diapir formation, however significant involvement of hydrous species into melting in the transition zone (Ivanov and Litasov, 2014; Safonova et al., 2015) is difficult due to very high solubility of water in ringwoodite and wadsleyite, the major minerals in the transition zone.

It should be noticed that carbonate or carbonatite melt may not survive through the lower mantle due to reduction to diamond or other carbon-bearing species (carbide) if we assume redox state of the lower mantle close to the iron-wustite (IW) buffer (Frost and McCammon, 2008). Thus, hydrocarbon-bearing or hydrous hydrocarbon-bearing melt might be the best candidate for the liquid portion of a mantle plume arising from the core-mantle boundary.

There is limited amount of information about hydrocarbon phase relations and reactions

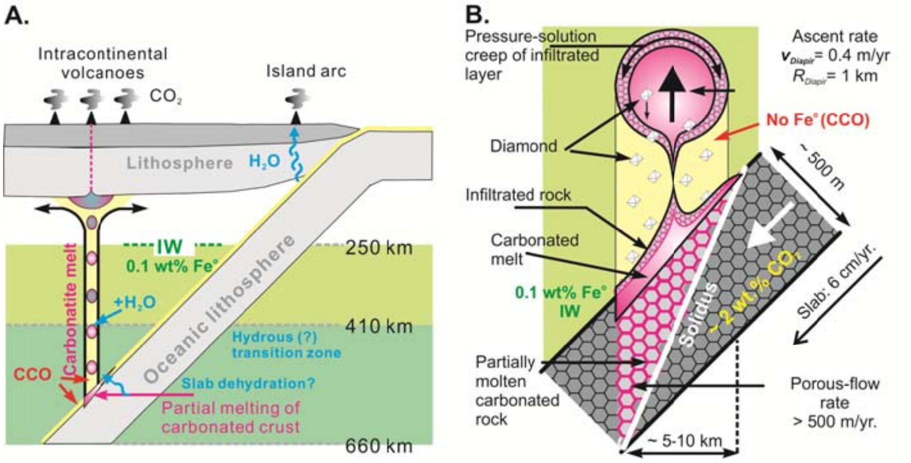

Fig. 1. A, a model of "big mantle wedge" implying decarbonatition of subducted slabs in the transition zone (applicable also for stagnant slabs); B, the formation of carbonated diapir providing the ascent of melts (Litasov et al., 2013). Oxygen buffers: CCO (diamond-CO_2) and IW (iron-wustite).

with silicates in the lower mantle due to an extremely difficult experimental setup. The data for melting of volatile-bearing peridotite in the system buffered by the IW buffer at 1-3 GPa indicated negligible solubility of silicates in coexisting CH_4-H_2O fluid (Taylor and Green, 1988). However, recent melting experiments on peridotite and eclogite systems with reduced C-O-H fluid at 3-16 GPa indicated significant solubility of silicates in the coexisting C-O-H fluid. The diamond or graphite traps contained abundant microinclusions of silicates after experiments (Litasov et al., 2014). The composition of fluid was not measured in the experiments, whereas theoretical estimates indicate a mixture of H_2O with methane and possibly heavier hydrocarbons. Similar fluid/melt containing H_2O and hydrocarbons with a relatively low solubility of silicate components along the mantle geotherm can exist through the lower mantle and can be considered as the most reliable candidate for the fusible component of mantle plumes from CMB (Fig. 2). In support of hydrocarbon-bearing melt/fluid in the deep mantle, we demonstrated recently that formation of a hydrocarbon mixture is highly probable under reducing conditions at the core-mantle boundary (Belonoshko et al., 2015).

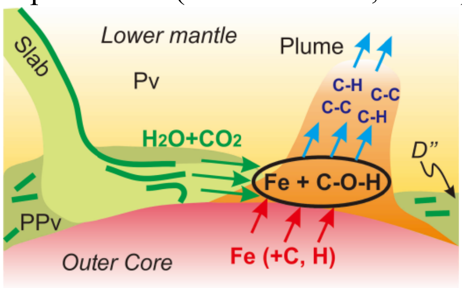

Fig. 2. Formation of unsaturated hydrocarbons marked as C-C and C-H bonds at the core-mantle boundary via reaction of C-O-H-bearing fluid/melt from subducting slab with Fe from the core. An alternative source for C and H would be the metallic core itself.

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GEOLOGY AND GEOCHEMISTRY OF RARE-METAL PEGMATITES FROM THE KOLMOZERO DEPOSIT (BALTIC SHIELD, RUSSIA)

L.N. Morozova, T.B. Bayanova, A.V. Basai, P.A. Serov, E.S. Borisenko, E.L. Kunakkuzin
Geological Institute of the Kola Scientific Center, Russian Academy of Sciences, Russia
morozova@geoksc.apatity.ru

The Kolmozero lithium-tantalum deposit is situated in the south-eastern part of the Kolmozero-Voronya ore field in the Baltic shield. The rare-metal pegmatites of the Kolmozero deposit are located in a metagabbro-anorthosite massif Patchemvarek on the boundary regional structures Archaean age – Murmansk terrain and greenstone belt Kolmozero-Voronya. The complex pegmatites thereare 12 veins. The length of the pegmatite bodies ranges to 1500 m and their thickness to 65 m. and traced to a depth of 500 meters. The pegmatites are characterized by weakly differentiated internal structures.

Rare-metal pegmatites consist of 30-35% quartz, 30-35% albite, 10-25% potassium feldspar, 18-20% spodumene and 5-7% muscovite. Accessory minerals are triphylite-lithiophilite, apatite, spessartine, columbite,tantalite, cassiterite, zircon (Gordienko, 1970)

It is found that the main components defining a mineral composition spodumene except of kind forming (Li, Al, and Si), are Fe, Na, K, and Mn, partly Ca and Mg. The spodumene contains of LiO_2from7.2 to8.08wt. %. Low concentrations of Rb_2O, Cs_2O and Sr_2O in spodumene due to the inclusions of muscovite and microcline.Scanning electron microscope (LEO-1450) instrument was used for detailed textural and chemical analysis of inclusions in spodumene. It is found that the spodumene with zoning structures - with bright zones and dark zones. Bright zonescomparedwith thedark areasare depleted inFe andenriched inRb. The inclusionsinspodumenepresentedPl, Qz, Ms, Ap, Grt,cassiterite, columbiteandtantalite.

The major element composition of the Kolmozero pegmatites is essentially that of a siliceous peraluminous leucogranite. SiO_2 contents vary from 72.2–75.9 wt.%, those of Al_2O_3 from 14.0–17.4 wt.%. MgO, TiO_2, CaO and Fe_2O_3, contents are low. The concentration ofNa_2O higher thanthe content ofK_2O. Content ofP_2O_5 andF (P_2O_5 = 0.18wt.%; F = 0.08-0.047 wt.%) closeto clarkgranite.The pegmatites are peraluminous with an average A/CNKL index of 1.91. They are geochemically specialized, displaying very low Ba (1.9–20 ppm), Sr (3.5–14.5 ppm), Y (0.20–0.46 ppm), ∑ REE (0.7–3.1 ppm), but high Li (465–17326 ppm), Ta (16-157 ppm), Nb (27-168 ppm) Cs (13-40 ppm), and Rb (263-1653ppm) contents. Values of fractionation indices like Mg/Li (0.5-0.01), K/Rb (18–97), K/Cs (35–88), Zr/Hf (4.8−7.4), and Nb/Ta (1.1–2.7) indicate the highly fractionated nature of the rare-metal pegmatites.

The zircons for the determination of U-Pb were selected from rare-metal pegmatites. The zircons showing weak oscillatory zoning and were characterized by high U content (656 −3035 ppm). The isotope U-Pb zircon age of pegmatites was 1994 ± 5 million years most likely, representing the age of fluid activity during hydrothermal stage.

Given the fact that the duration of the formation of rare-metal pegmatites, including the magmatic stage and hydrothermal stage does not exceed 50 million. Years (Lu et al., 2012), the age of the Kolmozero pegmatites can be estimated as Paleoproterozoic.

The deposit Kolmozero of spodumene pegmatite in the Baltic shield possess large-scale reserves of Li and Ta raw materials.

The rare-metalpegmatitesKolmozerocorrespondLCTpegmatites, to the albite-spodumene type and are characterized by weakly differentiated internal structures.

A characteristic feature of the trace element composition of albite-spodumene pegmatites is their enrichment highly incompatible ore elements – Li, Ta, Nb, Cs and Rb, and this depletion Ba, Sr, Y and REE.

The age of the Kolmozero pegmatites can be estimated as Paleoproterozoic.

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DIKES TITANIFEROUS DOLERITES OF THE MONCHA TUNDRA MASSIF – THE REAL REFLECTION OF THE COMPOSITION OF THE PALEOPROTEROZOIC PLUME KOLA REGION

L.I. Nerovich[1], T.B. Bayanova[1], E.S. Borisenko[1], P.A. Serov[1], E.L. Kunakkuzin[1,2]
[1]Geological Institute KSC RAS, Apatity,Russia
[2]MSTU, Murmansk, Russia
nerovich@geoksc.apatity.ru

Formation of Paleoproterozoic Pt-bearing intrusions in the Baltic shield is usually explained by the ascent of a large mantle plume in the central part of the Kola region (Sharkov et al., 2000; Layered Intrusions…, 2004). According to (Sharkov et al., 2000) Early Precambrian plumes are differed from the Phanerozoic and consisted of varying degrees of depleted ultramafic material. The study of Sm-Nd, Rb-Sr isotopic systems and distribution of trace elements in the rocks of dike-vein complex of the Moncha Tundra Massif indicates that the initial melt of Paleoproterozoic high-Ti ferrodolerites dikes (Ti-dol) were produced from a deep, OIB type plume source involving asthenospheric mantle component (Nerovich et al., 2014). OIB-like geochemical characteristics ofmaficmeltssimilar, to those ofTi-dol in the Moncha Tundra Massifin recent literatureare compared with theplumesource, and not onlyin oceanic,but also in continental environments(Nosova etal., 2008; Dupuy et al., 1995; Farmer,2003; Puffer, 2002).

As other high-Ti dolerite dikes in the Monchegorsk region, Ti-dol of the Moncha Tundra Massif have no geochemical analogues among volcanic rocks in the Pechenga–Imandra–Varzuga rift structure (Layered Intrusions…, 2004). U-Pbage on zircon from the Ti-dolis2450±10 Ma. The Ti-dol are noted for high Sm and Nd concentrations and have positive εNd (from +0.47 to +5.95 for an age of 2.45 Ga); the I_{Sr} values for them are 0.7028 and 0.7029. The Ti-dol are characterized by high TiO_2/Na_2O ratios, which are an important criterion for elevating the depths at which the melts were derived from the mantle (Ryabchikov, 2005). These ratios are as high as 4.1.

The high concentrations of incompatible elements, including REE, and their differentiated normalized patterns ($(La/Yb)_N$ = 9.3–14.3) of the Ti-dol in the Moncha Tundra Massif make these rocks similar to oceanic-island basalts (OIB). Similar to other rocks with OIB-like characteristics (Hofmann, 1997; Tomlinson, Condie, 2001), the Ti-dol in the Moncha Tundra Massif have high Nb/U (48–60), Th/Yb (1.5–1.98), and Ta/Yb (1.1–1.44) at low Zr/Nb (5–7) ratios. Also, similar to other OIB, these rocks are generally enriched in incompatible elements and have Ta–Nb maxima but are relatively poor in Rb and Ba, which suggests that the source of the Ti-dol did not contain a crustal component (Fig. 1). At the same time, the somewhat elevated La/Nb ratio (0.84–1.16), which are more typical of MORB, likely indicate that the source, which was obviously enriched in incompatible elements, contained asthenospheric mantle component. This is most probable for dikes, whose multi-element normalize patterns exhibit strong relative depletion in LILE, as is usually characteristic of derivatives from the MORB source (Nerovich et al., 2014).

All of the above suggest a certain contribution of a deep plume component to the source material of Ti-dol of the Moncha Tundra Massif. The Ti-dol reflect the composition of the Paleoproterozoic mantle plume. These very suitable the definition as “plume fingers” that uses in his works A. Shchipansky (Shchipansky, 2008). The contribution of depleted material to the source of Ti-dol can be explained by the capture of asthenospheric mantle material by the ascending plume.

Among all studied rocks of the Moncha Tundra Massif, a contribution of plume material is reliably discerned only in the rocks of Ti-dol dikes (Nerovich et al., 2014). The rocks of the layered complex of the Moncha Tundra Massif have extremely low concentrations of most incompatible elements, their weakly differentiated REE patterns, Nb minima, relative enrichment in U, Ba, Sr, and sometimes also Rb, low Nb/U ratio, predominantly negative εNd values (Nerovich et al., 2009). This “depletion” of the composition of the rocks is most consistent with a high degree of melting of the lithospheric mantle that was depleted in incompatible elements after Archean crust-forming processes above an ascending mantle plume. The involvement of a crustal component

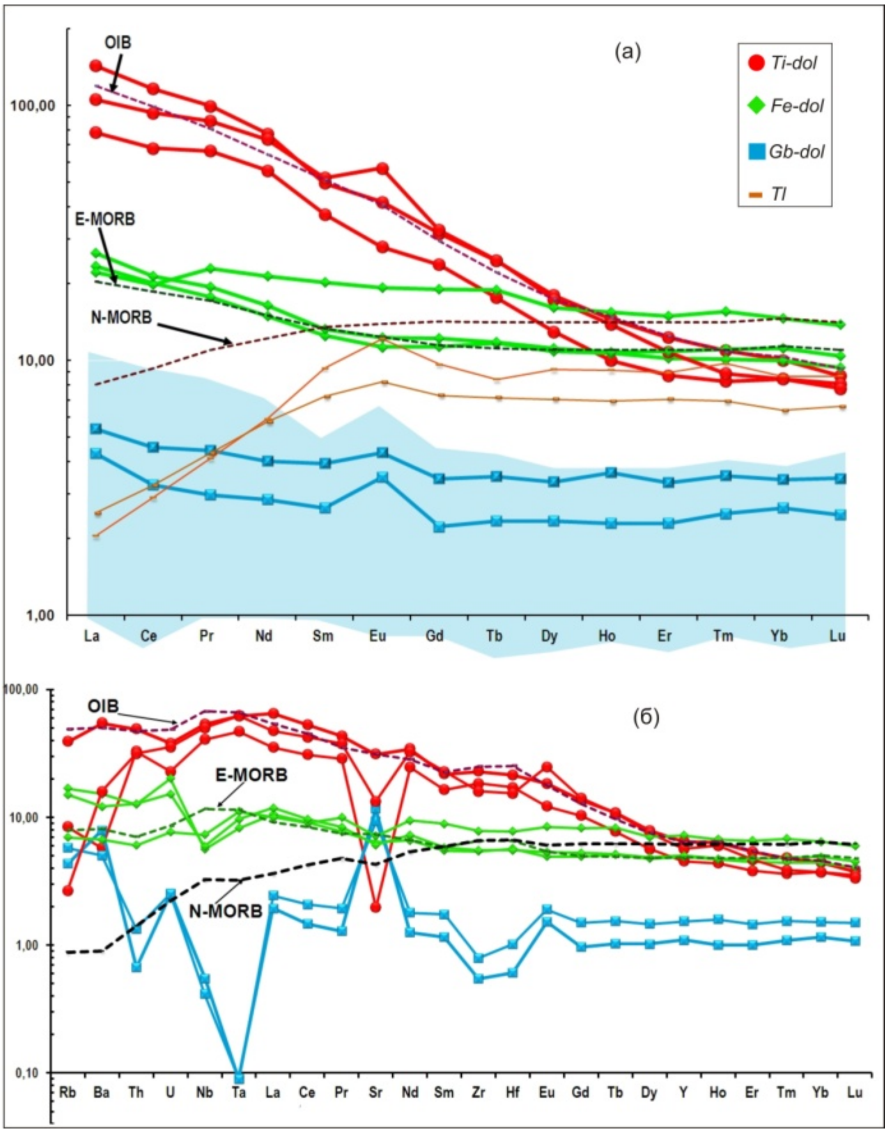

Fig. 1.(a) Chondrite – (Boynton, 1984) and primitive mantle-normalized (Sun, McDonough, 1989) trace-element patterns of dolerites from the Moncha Tundra Massif (Nerovich et al., 2014) and low-K tholeiites (Tl). The blue field corresponds to the composition of the layered complex of the massif (modified after (Nerovich et al., 2009). OIB – oceanic_island basalts, N-MORB – mid-oceanic ridge basalts, E-MORB – mildly enriched mid-oceanic ridge basalts (all according to (Sun, McDonough, 1989)).

predetermined the relative enrichment in LILE and Nb minima. Only in a few samples of rocks from the layered complex show an increase in the Nb/U and Nb/Y ratios at low concentrations of these elements in the rocks, but the reasons for this case are still uncertain. It is reasonably to think that the plume acted, first and foremost, as a heat source for the rocks of the massif, and its role was limited to large-scale the melting of lithospheric mantle material. At the same time, the newly discovered fact that the Moncha Tundra Massif hosts Paleoproterozoic dikes whose parental melts were derived from deep-sitting plume sources, provides evidence that plume-tectonic processes played a determining role in the Paleoproterozoic evolution of the Baltic Shield.

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FORMATION PROCESS AND LIGHT ELEMENTS OF THE EARTH'S CORE

E. Ohtani [1,2]
[1]Department of Earth Science, Graduate School of Science, Tohoku University, Sendai, Japan
[2] V.S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia
ohtani@m.tohoku.ac.jp

Major light elements in the Earth's core are considered to be Si, O, and/or S based on geochemical and cosmochemical arguments. In the early stage of the planetary formation, the core formation process started by percolation of the metallic liquid though silicate matrix because the Fe-S-O or Fe-S-Si eutectic temperature is significantly lower than the solidus of the ultramafic silicates (Terasaki et al., 2011). Therefore, the Fe-FeS-FeO or Fe-FeS-FeSi eutectic liquid enriched in S could have been formed and separated by the percolation process in the early stage of the planetesimal accretion. The major light elements of the core at this stage will be sulfur.

The internal pressure and temperature increased with the growth of the Earth, and metallic iron depleted in S was molten. The molten metallic iron can dissolve both Si and O as shown experimentally by several authors. The core forming metallic liquid separated and descended into the bottom of the magma ocean, wherethe metal would have been in equilibrium with silicate magma at around 40-60 GPa. Then the core separation occurred by the Rayleigh-Taylor instability (Abe and Matsui, 1986). Thus, the Earth's core contains S, Si, and O by this stage of core formation.

The partitioning experiments between solid and liquid iron alloys indicate that S is partitioned into the liquid metal, whereas O is weakly incorporated into the liquid. On the other hand, hcp-Fe coexisting with the metallic liquid favors Si (Sakairi et al., 2015). This contrast of Si and S partitioning provides remarkable difference in compositions of the solid inner core and liquid outer core of the Earth. We also conducted melting experiments of the Fe-S-Si system at high pressure, indicating that the core adiabats in large planets such as Earth and Venus are lower than the solidus and liquidus curves of the system. The partitioning and melting experiments indicate that the inner core of large terrestrial planets crystallized from the center of the molten core and created the Si-rich inner core with Si-depleted and S-enriched outer core.

Based on melting behaviors of the Fe-S-Si system and partitioning of S, Si and O between the outer and inner cores, the equation of state, and sound velocity of iron-light element alloys, we examined the plausible distributions of the light elements in the outer and inner cores of the Earth.

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HIGH-Ti ALKALINE ULTRABASIC-BASIC ROCKS IN THE RIVER BASIN OF ANABAR AS A CONTINUATION OF THE MAIMECHA-KOTUY PROVINCE

A.V. Okrugin
Diamond and Precious Metals Geology Institute, SB RAS, Yakutsk, Russia
a.v.okrugin@diamond.ysn.ru

Discussed are high-Ti alkaline ultrabasic-basic rocks in the basin of the Anabar river (Fig.). They are compositionally similar to alkaline basaltoids of the Maimecha-Kotuy province which permits extending it farther to the northeast up to the Anabar River. Also found in the river basin of Anabar are gold, platinum and diamond placers with associated minerals of rare metal and radioactive elements. Extending along the northern slope of the Anabar shield is the Ebe-Khaya dyke swarm (Tomshin et al, 1997) where, along with the Permo-Triassic trappean dolerites, trachydolerites are recognized (Table, analyses 1-2). In the Anabar R. mouth area (Airkat Cape) there are exposed Triassic high-Ti picrite basalts and melanephelinites (Table, analyses 3-5) which occur in the axial part of the Tigyan-Anabar swell (Okrugin et al, 2014), and are also associated with the tholeiitic dolerites of the trap formation.

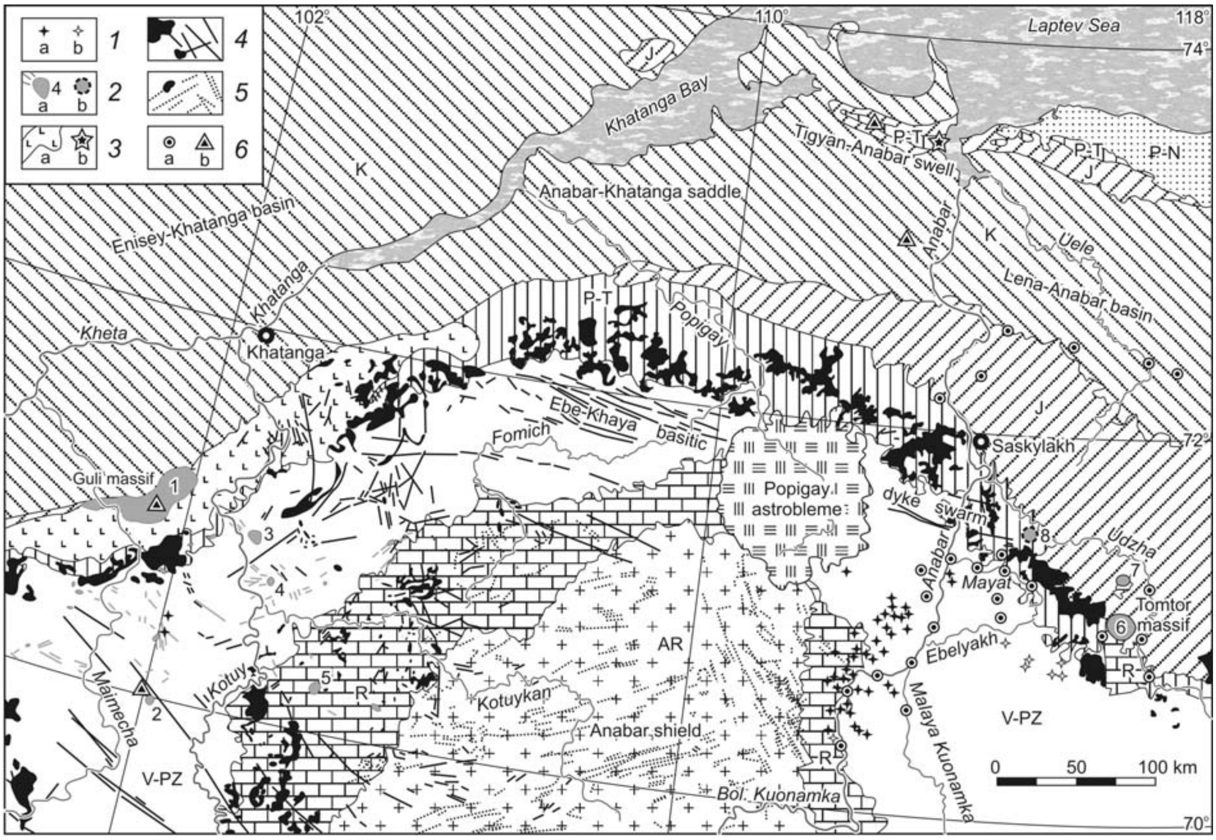

Fig. Distribution of magmatites and Au-Pt placers in the northern Siberian platform: *1* – kimberlite (a) and basite (b) pipes; *2* – intrusions and dikes of alkaline and ultrabasic rocks with carbonatites: a – defined (1 – Guli, 2 – Buor-Yuryakh, 3 – Odikhincha, 4 – Kugda, 5 – Magan, 6 – Tomtor, 7 – Bogdo), b – assumed (8 – Chuempe); *3* – basalt and alkaline basaltoid effusions (a) and picrite basalts, Anabar R. mouth (b); *4* – P-T dolerite and trachydolerite sills and dikes; *5* – Precambrian basites; *6* – gold placer with Fe-Pt (a) and Ir-Os minerals (b).

Chemically, the discussed rocks of the Anabar River basin differ from typical P-T tholeiitic dolerites of the trap formation in having higher TiO_2, K_2O, P_2O_5 and lower SiO_2 contents and in sharply increased amount of LREE as compared to HREE. Yet they are similar in these values to the alkaline picrite basalts, picrites (Table, analyses 8-10) and meimechites (analyse 11) developed in the northern Siberian platform within the Maimecha-

Kotuy province of ultrabasic-alkaline rocks and carbonatites, which is indicative of a wide distribution of high-Ti alkaline picrite magmatites in the Anabar region. Depending on the degree of fractionation of olivine and Ti-Cr spinellides, these melts can generate complexes of ultrabasites, picrites, alkaline rocks and carbonatites with Au-Pt and rare metal mineralization.

Table. Compositions of basite, picrite basalt, picrite and meimechite

Oxide	Ebe-Chaya zone		Anabar R. mouth			Tomtor massif		Kugda	Ayan R.	Guli massif	
	1	2	3	4	5	6	7	8	9 [1]	10 [1]	11 [1]
SiO_2	47,03	43,75	44,24	40,34	40,24	34,60	31,61	42,51	42,90	38,70	37,20
TiO_2	1,47	5,98	4,57	5,75	4,42	3,21	2,42	4,16	4,05	3,37	1,48
Al_2O_3	14,97	11,20	8,72	9,60	6,63	12,13	6,47	10,35	7,49	4,33	2,17
Fe_2O_3	2,32	5,68	7,01	8,24	5,32	7,67	8,41	7,37	5,02	7,09	6,17
FeO	10,70	8,48	7,36	6,86	8,69	4,07	5,34	6,57	8,49	7,92	6,00
MnO	0,20	0,18	0,23	0,25	0,25	0,26	0,12	0,19	0,14	0,22	0,16
MgO	7,22	5,34	10,12	8,73	16,48	6,85	14,79	7,65	16,31	22,52	33,84
CaO	11,33	9,30	11,54	11,69	11,52	16,44	12,81	11,87	8,26	8,68	3,91
Na_2O	2,27	2,89	1,78	2,81	2,01	3,35	1,08	3,95	1,28	0,66	0,18
K_2O	0,66	2,37	1,90	2,34	1,39	2,66	2,04	2,33	0,93	0,94	0,14
P_2O_5	0,18	1,13	0,57	0,87	0,60	1,03	0,84	0,49	0,24	0,45	0,17
LOI	1,54	3,55	1,88	2,52	1,68	7,40	13,85	2,62	4,03	4,53	7,33
Total	99,89	99,85	99,92	99,98	99,23	99,67	99,78	100,06	99,14	99,41	98,75
n	19	38	1	2	1	3	3	4	6	16	21

Additionally, in the Anabar region there are known fields of Mesozoic kimberlite and carbonatite pipes as well as the R-D Tomtor complex of alkaline rocks and carbonatites accompanied by small transverse dykes, sills and pipes of melteigite and Ol-melilitite (Table, analyses 6-7) with the Ar-Ar ages of 379±3 Ma determined at IGM SB RAS (Novosibirsk, analyst A.V. Travin). One of the ferroan platinum grains taken from the Mayat R. placer contains a polymineral inclusion of diopside, nepheline, phlogopite, amphibolite and titanomagnetite, which corresponds, in its bulk composition, to the rocks of the ijolite-melteigite series (Okrugin et al, 2014). Direct ^{190}Pt-^{4}He dating of four grains of Fe-Pt alloys from the placer revealed the age of 259±9 Ma (Okrugin, Yakubovich, Gedz, 2015). This all suggests the relationship between the PGM from the placers in the river basin of Anabar and the P-T complexes of alkaline-ultrabasic rocks.

Formation of different-aged associations of magmatites of alkaline ultrabasic-basic composition indicates that formation of marginal structures in the northeastern Siberian platform in Riphean, Devonian and Permo-Triassic times was related to rifting processes. Thus, the Anabar region may be considered as a promising area for the discovery, along with Tomtor-type Nb-TR deposits, of Au-Pt mineralization associated with the complexes of alkaline ultrabasic rocks with carbonatites. Many of the rich source rocks of noble metals are likely buried beneath the Mesozoic strata of the Lena-Anabar basin, manifesting themselves at the surface as extensive Au-Pt placers (Fig.).

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THE CONTINENTAL MARGIN OF EASTERN ASIA: HOME OF A CRETACEOUS-CENOZOIC (VERY) LARGE IGNEOUS PROVINCE?

F. Pirajno
Centre for Exploration Targeting, University of Western Australia, 35 Stirling Highway, Crawley WA 6009, Australia

Mesozoic-Cenozoic intraplate tectonism and magmatism affected much of the eastern margin of mainland Asia, extending from Far East Russia, through the Baikal and Mongolia regions, to north-eastern and eastern China (Pirajno and Santosh, 2014).

The Mesozoic-Cenozoic tectono-magmatic belt along the continental margin of eastern Asia is undoubtedly the largest in the world. As shown in Figure 1, this magmatism extends well inboard of the east Asian plate margin and many of the intrusive complexes, commonly alkaline, and bimodal volcanic successions are within rift settings (e.g., Shanxi and Baikal rift systems; Figure 1), suggesting that intraplate mantle processes (and underplating?) were the primary cause for the emplacement of plutonic and volcanic rocks.

The Mesozoic and Cenozoic extensional tectonics of eastern Asia are ultimately the surface expressions of mantle dynamics in the region. The record of dominantly Cretaceous magmatism in the eastern continental margin of Asia generally comprises A-type and alkaline granites intrusions, breccia pipes, felsic and alkali basaltic lavas. This magmatism suggests that mantle activity and/or lithospheric thinning, which probably began in the Mid-Jurassic is known in China as Yanshanian tectono-thermal event. In eastern China volcanic eruptions migrated from the circum-Bohai basins to the Luxi uplift, with ages ranging from 136-135 Ma to 124-115 Ma for the volcanic rocks in the Luxi area (Mao et al., 2008). Several carbonatite dykes in Badou and Xueye, Luxi area, with K-Ar ages of ca. 123 Ma, have also been recorded and are coeval with lamprophyre and felsic dykes (Mao et al., 2008). Other alkaline complexes and associated carbonatites that have Yanshanian ages (134 Ma, 122 Ma and 110 Ma) occur in the Shaanxi province and Shandong province. Alkaline ring complexes and carbonatites with ages of 130-125 Ma occur further north in Siberia in the Aldan region and Transbaikalia (Ripp et al., 2011; Borisenko et al., 2011), effectively extending the belt of Cretaceous intraplate alkaline magmatism of 2 to 3 thousand kilometres beyond China's borders to the north into eastern Russia. The Late Mesozoic age (125 Ma) Oshurkovo pluton, near Ulan-Ude south of Lake Baikal may be related to the same large-scale intraplate magmatism of the eastern Asian margin. The Oshurkovo pluton is apatite-rich and is composed of alkaline gabbros, syenite and carbonatite veins (Ripp et al., 2011).

A wide range of hydrothermal mineral systems are associated with the Cretaceous igneous activity along the eastern continental margin of Asia and generally hosted in orogenic or fold belts developed at the margins of stable cratonic blocks (Goryachev and Pirajno, 2014). These include porphyry, porphyry-skarn, low-S epithermal systems, Kiruna-style Fe deposits, precious metal lodes, polymetallic veins, intrusion-related Au lodes, REE and rare metals; commonly associated with A-type granitoids, alkaline complexes and carbonatites.

The period from 135 to 110 Ma is particularly important and appears to mark a series of intracontinental thermal events and the formation of mineral systems, which are mostly, but not all, superimposed on older geotectonic domains or terranes. The Yanshanian events in eastern China affected regions extending for up to 1,000 km westward along major zones of crustal weakness, such as the boundaries and sutures between the Yangtze and North China Craton and the crustal-scale north-northeast-trending Tan Lu Fault. Crustal weakness zones on the southern margin of the Siberian Craton (e. g. Lake Baikal rift system) and to the north between the Siberian Craton and the Verkhoyansk-Kolima block were similarly affected (Goryachev and Pirajno, 2014).

Given the nature of the magmatic rocks (bimodal and alkaline) and its intraplate setting, the continental margin of eastern Asia could be considered as a new type of LIP, which does not strictly adheres to the general definition (see Ernst (2014 and references therein), mainly because the eastern Asia LIP lacks flood basalts. Instead, this new type of LIP is largely confined to relatively small-scale rift settings.

Models that attempt to explain this igneous activity and its association with lithosphere thinning, extensional tectonics and the formation of volcano-sedimentary basins include: Pacific back-arc extension, hotspot-mantle plume, intraplate rifting and mantle delamination. Delamination probably resulted from thickening due to Triassic collision between the Yangtze, and the North China Cratons and the Siberian cratonic block. The hotspot-mantle plume model (Wilde et al. 2003) argues that a mantle avalanche was induced by the closure of the Palaeotethys Ocean at 180 Ma, followed by the rise of mantle plumes. However, the role of deep mantle plumes is somewhat arguable, given the diffuse nature of the intrusive and volcanic activity in the region and, as mentioned above, the absence of flood basalts. Magmatic activity continued, however, through to the Early Neogene along the entire continental margin of eastern Asia (Sengör et al. 1993). Delamination of subcontinental lithospheric mantle beneath isostatically compensated orogens results in an increase in gravitational potential energy and promotes uplift and horizontal extension with the development of rift basins. Isostatic uplift and upwelling asthenopheric mantle produce decompression melting and at the same time heating of the crust leads to anatexis and production of felsic magmas and A-type granitoids. It is important to note that comparable geodynamic settings of the same age are present in eastern Australia (Johnson, 1989), western North America (Wells and Hoisch, 2008) and western Europe (Schmincke, 2007*).* Wu et al. (2005) and Pirajno and Zhou (2015) suggested that a superplume event at about 130-120 Ma, which was responsible for the Ontong Java-Manihiki-Hikurangi and Kerguelen oceanic plateaux, may have been the far-field trigger to enhance subduction rates of the Palaeopacific east Asian continental margin. In turn, this would have led to or assisted delamination of the lithospheric mantle, resulting in asthenospheric upwelling, magmatic underplating, crustal melting and the development of A-type granitic magmas, dominantly felsic volcanism and lesser alkali basaltic volcanism in some regions (e. g. east China) and dominantly alkali basaltic volcanins further to the north along the eastern Asian margin and in associated rift structures.

In conclusion, the Cretaceous-Cenozoic tectono-thermal events that affected the continental margin of eastern Asia, may constitutes a new type of large igneous province, characterised by a diffuse distribution of dominantly bimodal magmatic products, generally confined within rift basins.

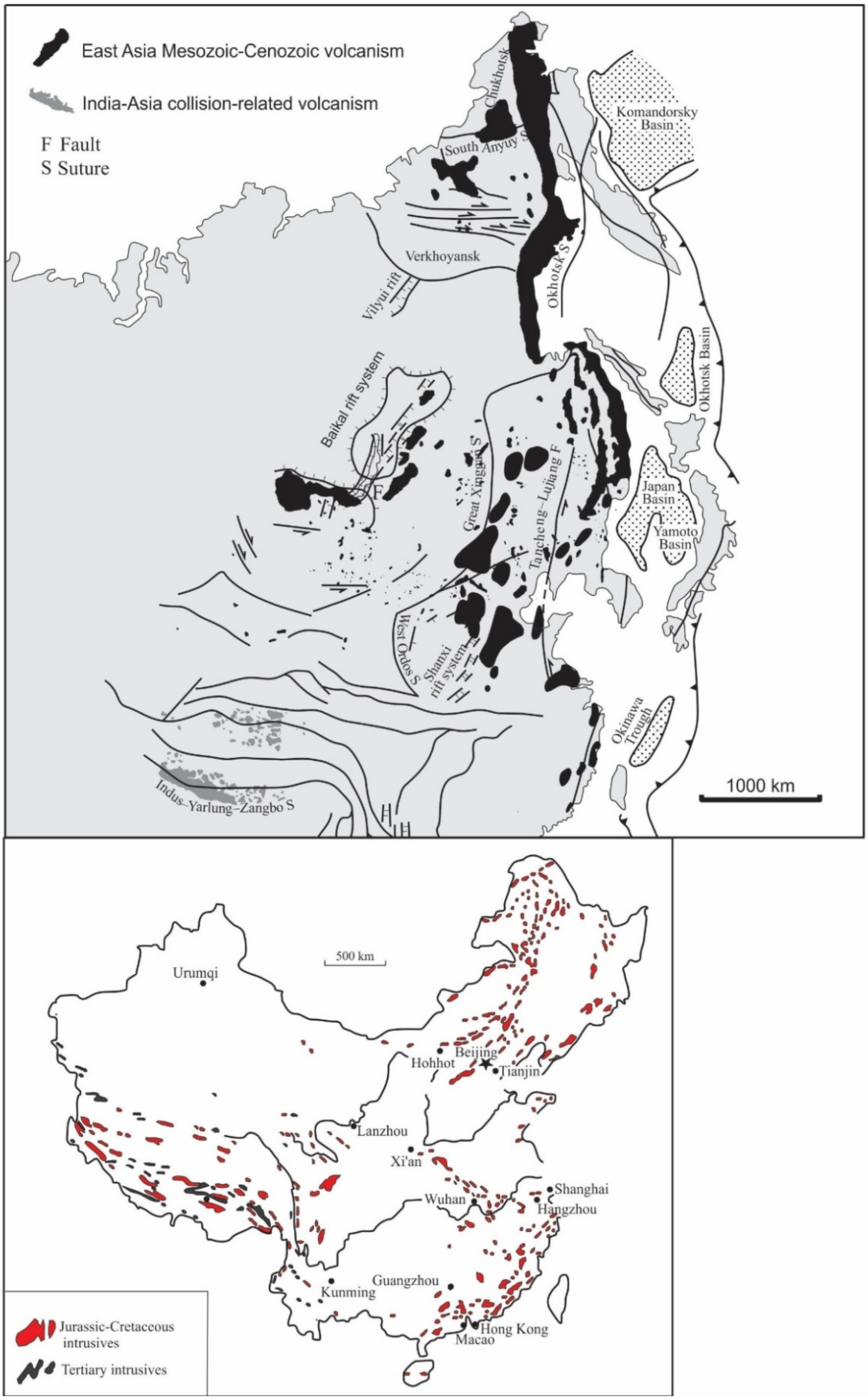

Figure 1. Top panel shows the extent of Mesozoic-Cenozoic volcanism in the eastern seaboard and interior of Asia; note that size of coloured polygons is only approximate and depict concealed or inferred extent. This volcanism is generally characterised by plateau basalts, lava shield, cinder cones and maars and felsic volcanics, commonly associated with graben structures; based on and modified from Whitford-Stark (1987),Sengör and Natal'in (1996) and Pirajno and Santosh (2014); bottom panel shows the distribution of granitic intrusions (mainly A-type) in eastern China and the collision-related intrusions in the Tibetan sector of the Alpine-Himalayan orogens. The vast extent of magmatism in the east-Asian continental margin suggest that it may considered as a LIP.

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EXTREMELY MAGNESIAN OLIVINES IN MAGMATIC ROCKS

P.Yu. Plechov[1,2], N.A. Nekrylov[1], M.S. Tikhonova [1], V.D. Shcherbakov[1]
[1]Geological faculty of Lomonosov Moscow State University, Moscow, Russia
pplechov@gmail.com
[2]Vernadsky Geochemistry Institute, Moscow, Russia

Large Igneous Provinces (LIPs) formed as a result of huge-scale melting processes in the Earth mantle. Most magnesian olivine grains in magmatic rocks are one of the main witnesses of the high degree of mantle melting. Olivine composition reflects mantle restite evolution during magma generation. The ranges of olivine phenocrysts composition in effusive rocks from difference geodynamic settings are shown in Figure 1. Only good quality analyses have been selected to avoid induced errors (Sobolev et al. 2007; Plechov 2008; Sobolev et al. 2009). The whole range of peridotitic olivine (all peridotites from GeoRoc database) is shown for comparison. High-Mg olivine with Fo_{90-93} has been found in any geodynamic environment, whereas $Fo_{>93}$ is found only in komatiites and kimberlites. Note, that $Fo_{>96}$ is not typical for magmatic rocks in general (Fig.1).

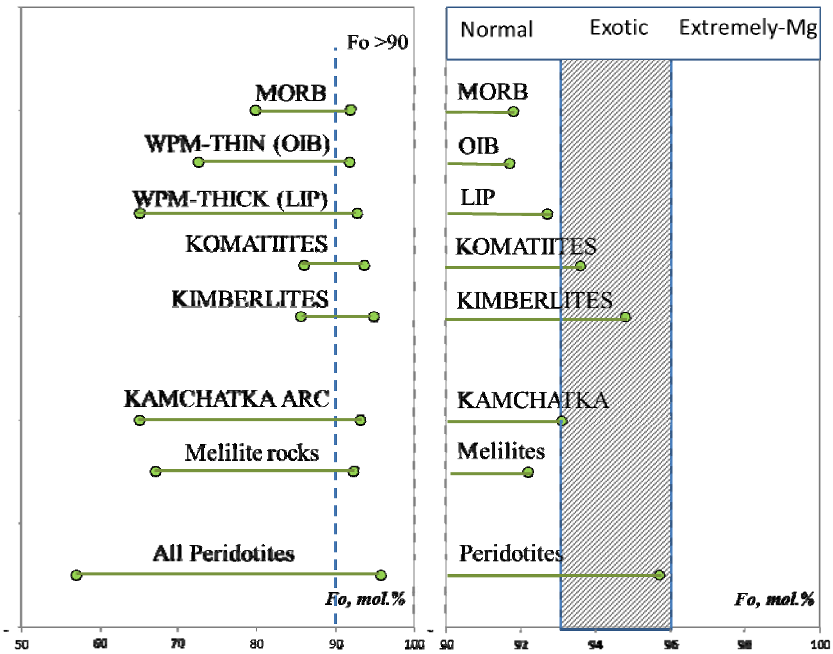

Fig. 1. Olivine composition ranges for magmatic rocks from different geodynamic settings. Data from Sobolev et al., 2007: MORB – modern mid ocean ridge basalts, WPM-THIN (OIB) – within plate magmas with thin lithosphere (<70 km), WPM-THICK – the same with thick lithosphere (>70 km), komatiites. Also shown kimberlite olivines (Sobolev et al., 2009), Kamchatka Holocene rocks (Plechov, 2008), melilitites and peridotites (both from GeoRoc database).

Olivines with Fo>96 are called here "extremely-Mg olivine" (Plechov et al., 2015), since several detailed descriptions of such olivine appeared in the literature during the last years (i.e. Blondes et al. 2012; Xiong et al.,2015, Plechov et al., 2015). A few bright examples of extremely-Mg olivine in magmatic rocks will be demonstrated and the conditions necessary for its formation will be discussed during presentation.

We identified some processes, which lead to sufficient increasing of olivine Mg-number:

1) Oxidation (black olivines)
2) Interactionwithcarbondioxidefluid
3) Re-equilibrationwithCr-Spinel

Composition of magmatic olivine can shift to more magnesian composition as a result of one of the suggested processes. At the same time, olivine can preserve initial concentrations of minor components and precise analyses enable to recognize such processes. We suppose that olivine with $Fo_{>93}$ in komatiites and kimberlites formed as a result of re-equilibration and preserve initial Ni concentrations (Fig.2). Re-equilibrated olivine composition is not extreme-Mg one and falls in transitional area. We chose the term “exotic olivines” for these analyses due to abnormal or absence of Fo-NiO correlation.

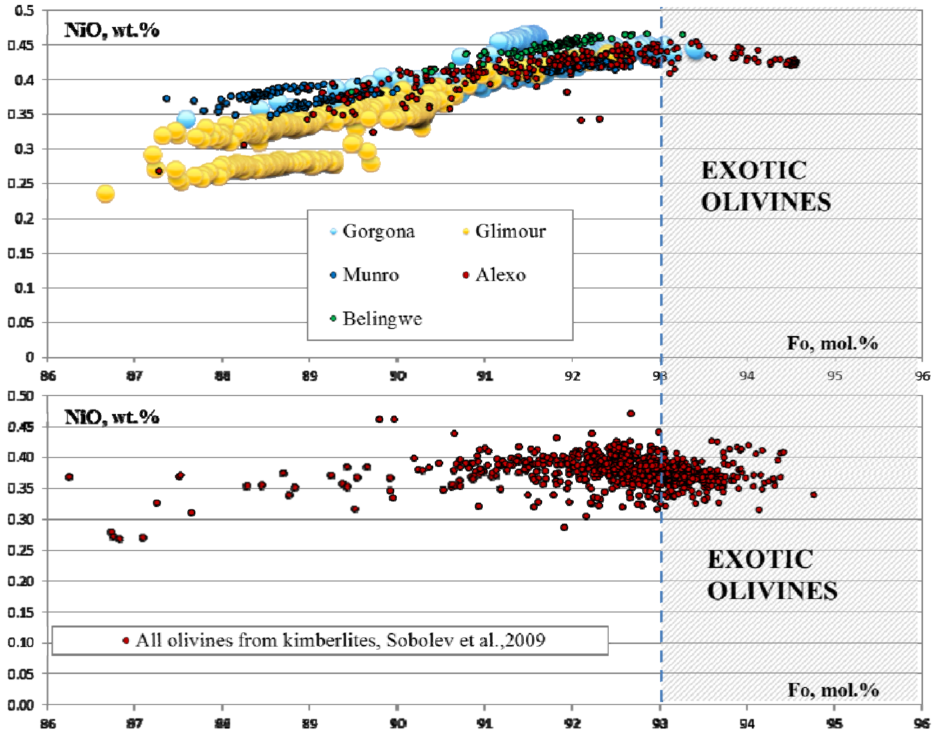

Fig. 2. NiO content in Olivine from komatiites (Sobolev et al., 2007) and kimberlites (Sobolev et al., 2009). The field for exotic olivine composition is shaded.

Olivines with $Fo_{>93}$ show inverse NiO-Fo correlation. This can be explained by primary olivine re-equilibration with partial preservation of Ni content. Further study of minor components in High-Mg and Extremely-Mg olivine should provide more detailed understanding of the process and allow use of olivine composition for more precise reconstruction of magma generation.

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DIVERSITY OF THE LEAD ISOTOPE RATIOS IN POLYFORMATION MAGMATITES OF THE KETKAP-YUNA MAGMATIC PROVINCE (ALDAN SHIELD) – AN EVIDENCE OF INTERACTION OF MANTLE DIAPIRS AND CONTINENTAL CRUST

V.F. Polin[1], S.I. Dril[2]
[1]Far East Geological Institute, FEB of RAS, Vladivostok, Russia, vfpolin@mail.ru
[2]Institute of Geochemistry, SB of RAS, Irkutsk, Russia, sdril@igc.irk.ru

The Ketkap-Yuna magmatic province (KKYMP) of Aldan Shield shows a complicated structure caused by the presence in its basement of blocks of the Archean and Paleo- and Meso-Proterozoic ages (the KKYMP structural scheme is given in (Polin et al., 2013)). The KKYMP formation, as with other zones of the Late Mesozoic polyformation magmatism of Aldan Shield, is related with the Late Jurassic-Early Cretaceous stage of the tectonomagmatic activization of the region. At that time period, due to the closing of the Paleozoic Mongol-Okhotsk Ocean and collision of the Siberian and North-Chinese cratons (Parfenov et al., 2003), changed in the Early Cretaceous time by the setting of sliding of the lithosphere plates of Californian type, a system of grabens of predominantly sublatitudinal strike was emplaced, within which the intraplate polyformation magmatism manifested itself widely. To solve the problem of the nature of sources and their relative contribution to the formation of the KKYMP polyformation magmatic complexes we used the method of the study of variations of the lead isotope composition along with the earlier obtained materials on geochronology, geochemistry, and isotopy of oxygen, strontium, and neodymium.

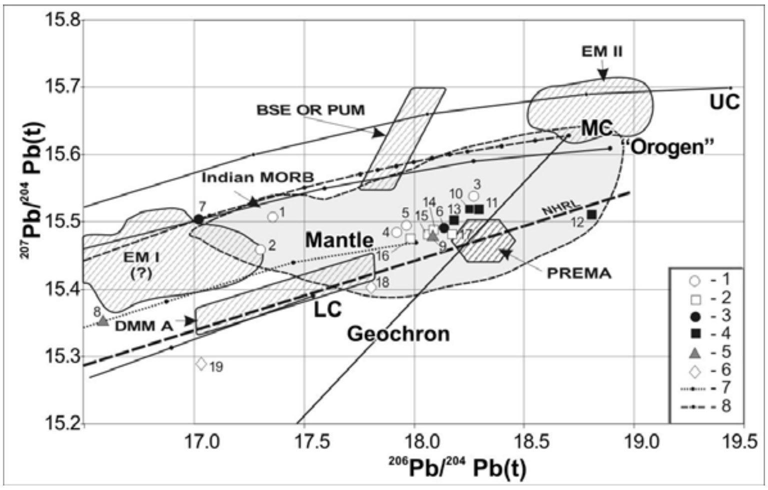

Fig. 1. Initial ratios of the lead uranogenic isotopes in the KKYMP rocks. Here and in Fig. 2: position of fields of compositions of the mantle components is taken from (Zindler, Hart, 1986) and crustal ones – from (Zartman, Doe, 1981). NHRL - Northern Hemisphere Reference Line (Hart, 1984); marks of the figurative points of rock complexes: 1 – Uchursky, 2 – Ketkapsky, 3 – Bokursky, 4 – Dar'insky, 5 – Kurungsky, 6 – crystalline basement of Aldan Shield. Line of the lead isotope evolution in the source of "orogen" type is given after Doe, Steisy (1982); those in the mantle and lower (LC), upper (UC), and "middle" (MC) crust were calculated using the Steisy-Kramers model.

The lead isotopic characteristics have been first studied in the rock specimens of the Early Cretaceous four complexes of the KKYMP: subalkaline dioritoid-granitoid Uchursky, monzonite-syenite-granosyenite Ketkapsky, foid- and alkali-syenite Dar'insky, phonotephrite-alkali-trachyte Bokursky, and recently distinguished (Polin et al., 2014) Late Cretaceous phonolite-nordmarkite Kurungsky. The data for the comparison were obtained on the lower crustal metamorphic rocks of the Batomgsky granite-greenstone field – a complex of the basement of the KKYMP eastern part. Distribution of the lead isotope ratios in the polyformation magmatites of the Province is shown in Figs. 1 and 2.

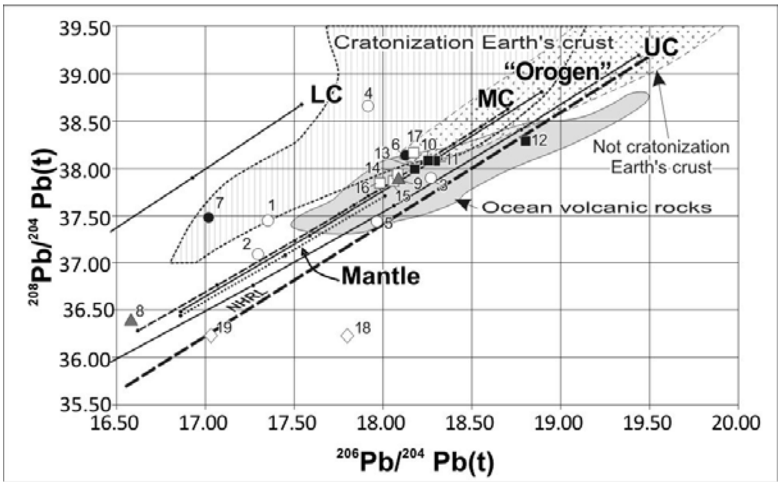

Fig. 2. Initial ratios of the lead thorogenic and uranogenic isotopes in the KKYMP rocks.
See Fig. 1 for symbols.

Wide variations of the lead isotope compositions observed in the KKYMP magmatites are explained by the heterogeneity of its sources. The alkali-basite rocks are apparently dominated by the lead of a mantle nature with an inessential role of the crustal lead; the alkali-salic and subalkaline magmatites demonstrate a moderate and important role of the lead from the lower crust formations in their composition. As a whole, the isotope composition of the basic and intermediate-basic volcanites and plutonites was obviously controlled by the mantle sources. In the intermediate-basic varieties such source type could be governed by the involving of the lower-crust basite and mesite metaplutonites and metavolcanites of Batomgsky block. The acid subalkaline melts may be interpreted as a result of melting of the metadacites-metatonalites, and sometimes metagraywackes. For the alkali-basite rocks the source of the parent magmas could be primordially the mantle one, close to the primitive mantle; for the alkali-salic rocks it may be the hybrid one with the participation of both the initially mantle alkaline melts and acid crustal matter as a contaminant.

We propose a model where the primary melts of the KKYMP alkali-basite rocks result from the melting of a small share of the primitive mantle, probably metasomatized (Kononova et al., 1995), through the preceding tectono-magmatic processes. The formation and injection of the alkali-basite melts were conditioned by the presence of the mantle diapirs of the "slab-window" type or the activity of the mantle plume according to the models of different authors (Parfenov et al., 2003; Yarmolyuk et al., 1995). The origination of the Early Cretaceous subalkaline magmatites of the KKYMP is related with the melting of the lower crust protolith with the participation of the alkali-basite mantle magmas as the heat sources and, probably, water and alkalis transported in the fluid component composition. The alkali-salic rocks are of the mantle-crustal origin.

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PETROPHYSICAL MODEL OF LITHOSPHERE BENEATH THE NORTH OF THE URALS

T.A. Ponomareva
IG Komi SC UB RAS, Syktyvkar, Russia
taponomareva@inbox.ru

A complex analysis of petrophysical and geological-geophysical data from the north of the Urals revealed two large petrophysical associations of rocks. These associations consisted of several geological formations united by the same regularity in changes of density and magnetic receptivity, correlational dependencies between physical properties of rocks and typical geophysical fields.

The first petrophysical association I comprises Lower Precambrian rocks of the Western-Uralian structural zone characterized by high density and mainly low magnetization. Low and average intensive negative magnetic and gravity fields are typical for this association. It includes three petrophysical groups of rocks (Ponomareva, Pystin 2014a; Ponomareva, Pystin 2014b) different in petrophysical connections between density and magnetic receptivity of rocks. Group Ia is represented by the rocks of gneiss-migmatite associations (Nyarta and Kharbei). Density values are in the interval 2.61–2.97 g/cm^3 and magnetic receptivity values are less than 100×10^{-6} SI units. There is a week inversely proportional dependency between the density and magnetic receptivity of rocks. The rocks of eclogite-schist associations (Nyarta and Kharbei) are referred to the second group Ib. Density values vary within the limits of 2.7–3.32 g/cm^3. Analysis of magnetic properties shows the broad range of magnetic receptivity values from tens to several hundred of SI units. Density and magnetic receptivity are directly proportionally connected. The third group Ic combines the rocks of granulitic-metabasitic associations (Khord'yu and Malyk). These rocks have the highest density values ranging from 2.94 до 3.12 g/cm^3. There is no density differentiation, neither laterally nor along the section, that allows to consider the Khord'yu and Malyk associations as monolithic blocks. Magnetic receptivity of rocks in these associations do no depend on rock's density. It may vary in a broad range that is connected with the diverse content of titanomagnetite in the rocks.

The second petrophysical association II combines the rocks of the Eastern-Uralian structural zone including different igneous (intrusive) rocks (from ultramafic to felsic), and also volcanic, volcanic-sedimentary and sedimentary rocks. This association is characterized by average- and strong intensive positive magnetic and gravity fields. It consists of three petrophysical groups of rocks differ from each other by physical properties and by the character of their inter-correlations.

The first group IIa contains ultramafic rocks of ophiolite association demonstrating high density (2.90-3.10 g/cm^3) and average magnetization (400 – 750×10^{-6} SI units). Specific feature of rocks of this group is the absence of any connection between density and magnetic receptivity. Physical properties of rocks varied during the serpentinization process. When the extent of serpentinization grows, dunites strongly lose their density and obtain magnetic properties. Harzburgites retain their density characteristics and almost lost magnetization under the similar conditions. The highest values of density and magnetic receptivity are found in voikarites. Average intensive magnetic anomalies and intensive Δg anomalies are detected above rocks of this group.

The second group IIb includes rocks of dunite-verlite-clinopyroxenite and gabbro associations and also volcanic mafic and rarely intermediate rocks. Intrusive and volcanic mafic rocks have higher density (from 2.80 to 3.20 g/cm^3) and magnetic receptivity (750×10^{-6} SI units) values. The stable directly proportional dependency is found between density and magnetic receptivity. Rocks od this group generate intensive magnetic and gravity fields.

The third petrophysical group IIc comprises felsic and moderately felsic intrusive and effusive rocks and also volcanic-sedimentary and sedimentary rocks characterized by average density (from 2.65 to 2.68 g/cm^3), weak and average magnetization (from 1 to 750×10^{-6} SI units). The general feature of rock in this group is the absence of dependency between density and magnetic receptivity. Physical properties of rock may vary due to the differences in mineral composition of rocks. Alternating-sign anomalies of magnetic and gravity fields are found above these rocks.

Summarizing the data on physical properties of rocks in the north of the Urals the scheme showing evolution of petrophysical characteristics of geological bodies of different age (PR–KZ) was constructed. This scheme reflects the long history of geological development of lithosphere of the Polar Urals. The obtained results are important for comprehensive interpretation of geological-geophysical data and is used for construction of the physical-geological model of the Earth's crust and upper mantle of the region.

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GEOLOGIC POSITION OF THE ONEKA INTRUSIVE COMPLEX (WESTERN SIBERIAN PLATFORM)

S.N. Prusskaya[1], Yu.R. Vasil'ev[2]
[1] Siberian Federal University, Krasnoyarsk, Russia, Prusskaja@yandex.ru
[2]Institute of Geology and Mineralogy, SB RAS, Novosibirsk, Russia, Tomilen@uiggm.nsc.ru

The Siberian platform differs from other ancient platforms is an unusually wide occurrence of trap-magmatic rock (Sobolev, 1936). The bulk of the intrusive trap is concentrated in the Tunguska sineclise, in positive structures, sucy as the Bakhta megascarp.

On the Bakhta megascarp is exeule petrographic-petrochemistry carrelations of intrusive rocks to well (petrographic structure → petrographic condition → formation).

On the petrolodies investigation was give off and trace for intrusive complexes: Katangskiy, Kuzmovskiy, Agatskiy – daik-wall, Oneka's, but Oneka's give off for the first time (Prusskaya. 1993, 2007).

The intrusive traps form mainly sheets subparallel to the strata of the sedimentary cover (sillami), but mark and constitution build differention dividing into layers – the Oneka intrusive complex or Oneka tectono-magmatic structures.

The Oneka intrusive complex recognired on prospecting for hydrocarbons in the western Siberian platform, in the northern half of the Bakhta megascarp Tunguska sineclise (Prusskaya, Vasil'ev. 1993-2013).

The average content of MgO in rocks of Oneka intrusive complex is 9,26±2,68 wt%, varying in rocks of single wells from 3,33 to 17,94 wt%, which indicates a hidh degree of differentiation intrachamber initial melt. Fibered series of rocks contains disseminated sulfide mineralization.

Depending on most oxides and content TiO_2, MgO, K_2O Oneka intrusive complex relates to the petrochemical type of differentiated intrusions of the Norilsk-Harallahskaya province.

Intrusion is a basic structurally-forming factor of this comples geoblock. It was established that constituent of Onekskiy orogenic comples is characterized by boss chonolith intrusions presence and difficult dendrite dikes named intrusuons apophysis. It is peculiar frame work igneous complexes and volcanostructure. The main feature of intrusive complexes locating within the zone is their connection with sublatitudinal and submeridional deep-earth fractures intercepts. Number of positive local structures, which were mapped by seismic exploration within Tanachy-Moktakonskaya zone, should be considered as typical volcano-structures. The are made with explosive material, including subvolcanic intrusions as well as huge stratified intrusions (onekskiy type). Formation of zone layered intrusions as well as Onekskiy complex was a conseguense of deep mantle processes that contributed to intrusive complexes formation, which have potential of the Norilsk type copper-nickel ores bearing.

The petrochemical composition of the Oneka intrusion rocks correlates well with geochemical data (contents of the group elements Sr, Ba and other (Sharapov, 2001). All studied rocks have medium contents of group elements (V, Cr, Ni, Co) commensurate with those in flood basalts (Vasil'ev and other, 2007).

The work done confirms the potential prospects of discovering ores of the Norilsk type pricelinecom the study of the West Siberian platform.

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INTRAPLATE NORMAL AND CA-RICH IGNEOUS ROCKS ASSOCIATED WITH CARBONATITES IN WEST BALUCHESTAN, MIDDLE EAST

A. Romanko[1], A. Savichev[1], S. Stepanov[1], S.M. Tabatabaeimanesh[2]
[1]Geological Institute, RAS, Moscow, Russia, [2]Isfahan University, Isfahan, Iran

We present some interesting materials on poorly studied Neogene-Quaternary igneous rocks of Baluchestan and Sistan Province, East Iran, Middle East. They were received by our group led by much known regional trio - Drs. E. Romanko, A. Houshmandzadeh, and M.A.A. Nogol Sadat. Some important features on the rock studied are as follows: mainly K-Na subalkaline rock affinity (also alkaline one too) with a middle K), not very High-Ti, not high, deep 87Sr/86Sr (ISr) = 0.7039 +/- 000.2 (trachyandesite) and 0.7049 +/- 000.18 (trachybasalt, both data by GIN RAS, Russia) alongside the 0.7049 on a volcanite (Camp & Griffis, 1982), LREE-enrichment with a high LREE/HREE (La – more than 32 ppm), and a characteristical Eu/Eu* more than 1.1; up to high – 1/3 of CaO and up to a high - 0.45% of Sr in basic trachyandesites (meaning the real carbonatites ca 200 km to the east, Hanneshin, Afghanistan), complex correlation of some characteristical elements; then-High-Ti (rhutile, Ti-hornblende) and High-Ca phases (clinocoizite, also, Ca- rich ceolite – vayrakite is proposed), replacement of primary minerals due to a fairly strong rock-fluid interaction.

Northeast tectonic–magmatic-metallogenic (economic regional Cu-Au +/- Pb, Zn, poor Ag, PGE, As, Hg, Bi etc. - ex., Anarak deposits (E. Romanko, 1984)) zonation, related to the famous subduction of the Arabian plate exists, ex. (calc-alkaline /1/ – intraplate /2/): 1: Eocene shoshonites – Paleocene-Oligocene calc-alkaline intrusives - Miocene-Recent calc-alkaline volcanic (-plutonic) rocks and 2: Paleogene? (Lut block)-Neogene subalkaline rocks - Quaternary Afghanistan carbonatites etc. Alpine compression on the moderate subductional depths up to 200 km (Trubitsyn et al., 2004) in the Central Iran, at least, partly compensated, as proposed, by contemporaneous/ younger, Pg?-N-Q intraplate magmatism of the Eastern Iran / Afghanistan and nearby structures.

Special warm grateful to outstanding regional trio - Drs. E. Romanko, A. Houshmandzadeh, and M.A.A. Nogol Sadat, also to Dr. V.V. Slavinsky.

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THERMODYNAMIC PARAMETERS OF MANTLE PLUME MATERIAL

I.D. Ryabchikov[1], L.N. Kogarko[2]
[1]Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry RAS, Moscow, Russia, iryab@igem.ru
[2]Vernadsky Institute of Geochemistry and Analytical Chemistry RAS, Moscow, Russia,kogarko@geokhi.ru

Temperature, pressure and oxygen potential characteristic of the material of mantle plumes may be gained either through the investigation of ultramafic magmas attributed to the plume environment, or by the analysis of phase equilibria involving minerals included into diamonds, which are transported from the sublithospheric zones.

It has been experimentally demonstrated that at PT-parameters of sublithospheric zones substantial part of ferrous iron in peridotitic material must be disproportionated with the formation of Fe_2O_3 and iron-rich metallic alloy. Under these conditions carbonate components should be reduced with the formation of diamond or carbides. Nonetheless, the presence of carbonate-rich melts in lower mantle is confirmed by the studies of mineral inclusions in the diamonds of lower-mantle source (Kaminskiy et al., 2015a). It demonstrates that lower mantle is heterogeneous with respect to redox characteristics.

In order to assess redox-potential of lower mantle mineral-forming systems I performed thermodynamic analysis of phase equilibria of rock-forming minerals of pyrolitic lower mantle with carbon-bearing crystalline compounds demonstrated that the field of diamond stability is separated from that of Fe-rich metallic alloy by the field of co-existence of iron carbides with prevailing silicates and oxides (Fig. 1). It implies that the formation of diamond in lower mantle requires more oxidizing conditions by comparison with the predominant part of this geosphere.

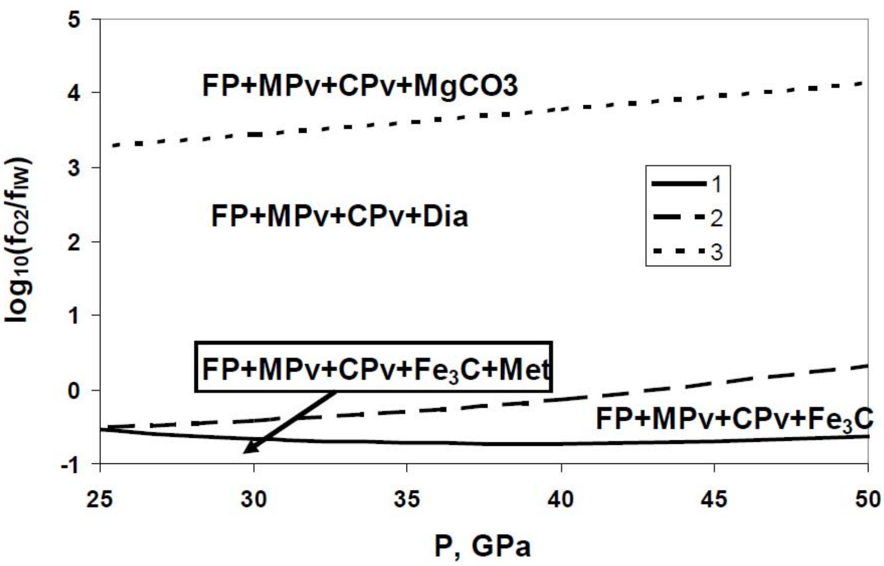

Fig. 1. Stability fields of lower mantle mineral assemblages (oxygen fugacity is normalized by iron wuestite buffer). FP is ferropericlase, MPv is Mg-rich silicate perovskite, CPv is Ca-rich silicate perovskite, Dia is diamond and Met is Fe-rich metallic alloy.

The absence of metallic phase among the minerals of low-mantle diamond-bearing paragenesis is consistent with the high (about 1% - Fig. 2) Ni contents in ferropericlases trapped by diamond (Ni should be intensely extracted by Fe-rich alloy). The elevated redox potential is corroborated by the measurements of Fe3+/ΣFe values in ferropericlases included in diamonds transported from lower mantle (Kaminskiy et al., 2015b).

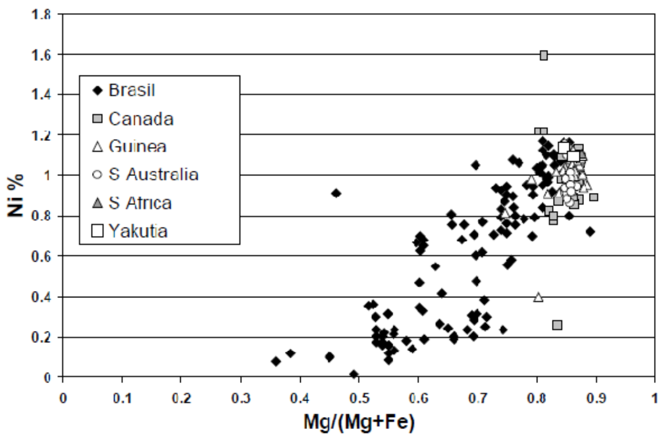

Fig. 2.*FP* inclusions in diamonds of lower mantle origin with Mg-numbers appropriate for metaperidotite bulk composition all cluster around 1 % of Ni. Some outliers may correspond to lower f_{O2} values.

The most likely cause of increasing oxygen fugacities is the displacement of redox equilibria with the growing temperature towards the decreasing amount of Fe-rich alloy and finally its complete disappearance (Fig. 3). An important role in the genesis of diamonds may be played by the appearance of carbonate-phosphate and silicate melts their migration and interaction with the surrounding rocks.

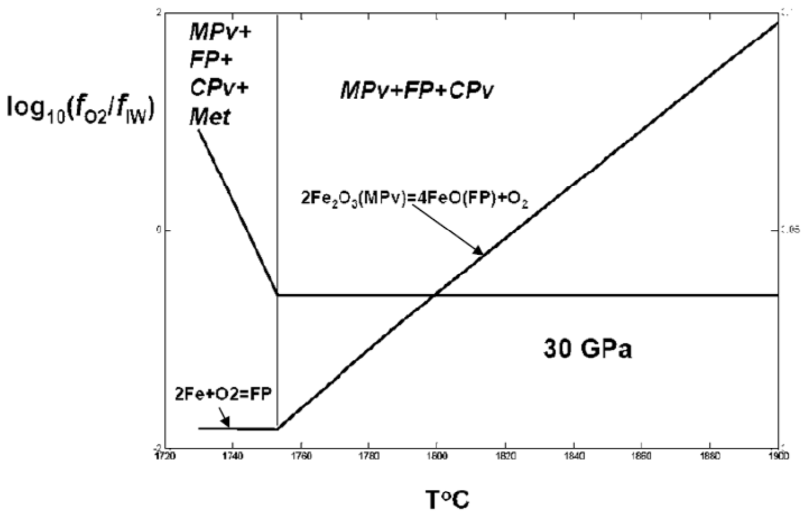

Fig. 3.Effect of temperature on redox equilibria in lower mantle of pyrolitic composition. Left vertical axis is logarithm of oxygen fugacity normalized to IW buffer, right vertical axis is a number of Fe^{3+} atoms in *MPv* per one oxygen.

The link of sublithospheric diamond formation with high temperature conditions follows from the confinement of such processes and to mantle plumes. Kimberlites are also related to the mantle plume environment.

In order to characterize thermodynamic parameters prevailing in the mantle source of ultrabasic magmas related to plume environment we performed the analysis of large collection of experimental data on equilibria spinel – melt at controlled oxygen fugacities. It has been demonstrated that the activity of FeO in silicate melts identical to natural magmas may be described by the regular solution model which takes into consideration interaction of all cations with silicon and also interactions of calcium and alkalis with aluminum. This model permitted to develop new geooxometer for spinel + magma phase assemblages suitable for natural systems under the conditions close to the liquidus of magmatic process.

This new version of geoxometer has been applied to the estimates of oxygen potential characteristic for magmas of plume environment including Siberian meimechites, Hawaiian picrites and picrites from large igneous provinces (LIPs) of Emeishan and Greenland. It has been found that in the majority of cases magmas related to the activity of deep seated mantle plumes are characterized by oxygen potential higher than magmas belonging to midocean ridge magmatism.

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ORE GENERATING FLUID-MAGMATIC SYSTEMS OF GIANT NOBLE AND NONFERROUS METAL DEPOSITS IN PROVINCES – REGIONS OF PLUME MAGMATISM

Yu.G. Safonov
Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry, Moscow, Russia, safonov@igem.ru

Ore generating fluid–magmatic systems (OGFMS), in the author's opinion, are responsible for the inception of ore-forming systems proper and for their geochemical-metallogenic specialization and productivity as well as the structural–morphological controls of ore localization and general spatial distribution. Analysis of giant and unique ore deposit formation conditions, which was carried out within the framework of collaborative studies of large and superlarge ore deposits (Large…, 2006), suggests that analysing giant deposits are distinguished primarily for the intensity of ore formation processes that led to their formation. It was found that these processes are triggered by the high energy of mantle–core interaction expressed by the determinative direct participation of mantle magmas in ore forming system development as well as the active influence of these magmas and the associated fluids upon the crustal substratum. The accumulated data on the problem of ore giants provides a possibility to recognize the problem of common and distinguishing features of Precambrian and Phanerozoic ore generating fluid-magmatic systems within the framework of the theory of plume metallogeny. Manifestations of plume magmatism in Precambrian provinces, let alone its implications for ore formation, are given little attention, whereas the available data on the general trends of formation and spatial distribution of Au-Cu-Ni-Co-Pt-Pb-Zn and other ore deposits within Precambrian shields suggest of their generally similar spatial distribution within various structural (geodynamic) zones, from trans-regional to local, recognized by the author in compliance with the adopted Tectonic Code (Mezhelovskiy *et al.*, 2014). The Precambrian gold giants such as Kalgoorlie (Australia), Porcupine, and Kirkland Lake (Canada), Kolar (India), located in greenstone belts, are characterized by obvious relationship with abyssal OGFMS. The long-known fact that ore-bearing greenstone belts, which has been developed in association with arch-dome structures, demonstrate relations with the abyssal magmatism, that controlled them, but is not always referred to as plume magmatism. Nevertheless, the signatures of various plumes, thermal as well as thermochemical, appear to be distinct enough. The results of the ongoing studies of the unique Witwatersrand uranium–gold field suggest that the geodynamic setting of its formation and mineralization was probably created by abyssal magmatism. For instance, data, provided by the adherents of its most popular genetic model as a metamorphosed paleoplacer (Frimmel, Heannigh, 2015), namely, the oldest gold dating of ~3 Ga and its mantle origin, as based on Re/Os ratios, suggest that possible hardrock sources of these paleoplacers were superlarge Mesoarchean stockwork gold deposits. The importance of Re-Os geochemical data is beyond doubt and requires special consideration. The age span of Precambrian gold mineralization related to mantle magmatism is wide and includes not only the Meso- and Neoarchean, but also the Middle Proterozoic times. Such relationship is characteristic of the known Olympic Dam deposit with giant Cu, U, and Au and large Ag and REE reserves. The geological setting of the field within the Gawler Craton and eastern active orogenic belts with age-equivalent (~1600 Ma) Pb-Zn-Ag mineralization in known Broken Hill area as well as uranium deposits generally correspond to the marginal zone of a large plume within an uraniferous lithospheric block.

Accumulated data on the metallogeny of various manifestations of Phanerozoic plume magmatism are more abundant than those for the Precambrian (Dobretsov *et al.*, 2010; Pirajno *et al.*, 2009 and others). The latter studies discuss metallogenies of the Siberian, Tarim and Emeishan Permotriassic superplumes and the associated large igneous provinces (LIPs) and territorial taxa. The latter include ore regions of Central Europe, South China and others. Ore giants within the latter two regions are scarce but their numbers increase if we take into account ore clusters of closely spaced ore deposits that probably originated from a common ore-generating system. In addition to giant Cu-Ni-Pt deposits, they contain contrastingly rich productive systems with Au–As, Ag–Sb and Au–Hg mineralization. Worthy of notice is the fact that five-element formation deposits are associated with uranium deposits. This association is also characteristic of the known East Kurama ore region within the Chatkal–Kurama Plume. This plume accounts for the formation of significant gold, uranium and superlarge silver deposits such as the Aktepe (five-element formation), Greater Kanimansur (silver–base metal formation) and the Almalyk porphyry Cu–Mo–Au deposit. Of special interest among the ore-forming fluid-magmatic systems under review is the system that created the unique (~5000 t gold) Muruntau Deposit. It is located in a block of clastic rocks intruded by dykes of various compositions, in above-intrusion position and near the granite–granodiorite pluton exposed on the surface by erosion. The known model of the ore generation system of this deposit (ore area) reflects eclogitization of the lower crust and the general probable relationship of Au and W to different alkali basalt magma differentiation products as in other ore deposits related to plume magmatism.

Unfortunately, only approximate reconstruction of the structure and architecture of ore-generating system formation and location settings compliant with the general concepts of plume geodynamics is still possible for the examples of ore deposits of various types discussed above.

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FACTORS DETERMINING THE SIZE OF THE ASTHENOSPHERIC ZONES GENERATING INTRAPLATE LARGE PROVINCE OF IGNEOUS ROCKS

V.N. Sharapov, Yu.V. Perepechko, K.E. Sorokin
V.S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia
vik@igm.nsc.ru

The spatial scales, development time and composition zoning of basic and granitic magmas melts in paleo- and contemporary large igneous provinces (LIPs) are determined based on the mapping of igneous rocks in continental and oceanic segments of the Earth. Two types of contours of intraplate magmatic systems are revealed: a quasi-isometric contour with a diameter of 200-400 km; and extended "subrift" areas of the anomalous mantle with magma sectors, whose width is comparable with transverse dimension of isometric volcanic zones. According to geological and topographic estimates the size of the continental LIPs varies within the range of 1-2.5 thousand km. Mathematical modeling of convection in the upper mantle was carried out in the framework of hydrodynamics of high-viscosity compressible fluid in the Boussinesq approximation with due consideration of the main phase transitions occurring in the upper mantle and in the layered lithospheric plate (Sharapov et al., 2008). Authors consider scenarios of decompression melting in the upper mantle during the formation of the vertical and longitudinal convection cells at the appearance of hot spots in the event of perovskite transition, as well as upon imposition of hot spots on the developed convection in the upper mantle for the areas under lithospheric plates, uniform in thickness, with a complex morphology of the lower boundary. Dimensions of symmetrical hot spots with non-uniform temperature distribution varied within the range of 100-850 km. There was certain mismatch between the calculated sizes of the decompression melting areas for vertical convection cells and the sizes of the actual magmatic areas of Siberian Traps. Vertical convection cells are not characterized by cyclical development of asthenospheric zones. However, the cyclical nature is peculiar to the development of Paleozoic and post-Paleozoic magmatic systems of central, south-eastern and southern parts of the Asian continent that testifies the need to modify the used LIPs plume nature model. In case of forming the ordinary asthenospheric zones in the vertical convection cells (at a rate of hot spots ~ 100-350 km) the maximum size of the decompression melting zones is close to the aspect ratio value for the convection cells in the upper mantle (~ 700 km). The increase in cell size to 1 thousand km is possible with a few hot spots and merging of neighboring cells. In this case, asthenospheric zones with the length exceeding the specified aspect value can be considered as "superplume" ones. Their formation can take place over hot spots 350-500 km in size at temperatures on the boundaries between the upper and lower mantles $T_b \geq 1850°C$. The problem arises to determine the thermodynamic conditions of such large cells formation. Thus, when $T_b \geq 2000°C$, after the initial stage of convective cells development to form asthenospheric zones, instability develops, leading in some cases, to the periodic change of melting scale. The appearance of the temperature fluctuations in the form of a hot spot can cause the merger of neighboring convective cells resulting in appearance of abnormally extended asthenospheric zones. The presence of the phase boundary between the mantle reservoirs may create conditions in the upper mantle, where a relatively small thermal or tectonic perturbations lead to the merger of the ordinary cells into an unstable transitional structures, whose evolution causes relatively rapid, in terms of geology, development of extended zones of decompression melting, followed by formation of stable asthenospheric zones of the smaller scale. Temporal characteristics of such evolution of melting zones are consistent with the known parameters of formation both the Paleozoic and younger magmatic complexes.

Numerical calculations showed that the emergence of large LIPs type Siberian Permian-Triassic traps or Ontong Java volcanic plateau, apparently is associated with the emergence in the upper mantle of horizontal convection cells, in which the length of the asthenospheric zones may exceed 2 thousand km. The second feature in the temperature variation in such cells is temporally inhomogeneous appearance of the melting areas, whose formation periodicity is close to the values established empirically for both a common LIPs time line (Prokoph et al., 2001), and regional areas of the Central Asian fold belt (Dobretsov, 2013). Most low-frequency harmonics of cyclical manifestations correspond to the latest 100 million years. For this segment of the geological history of the Earth a vast empirical material has been accumulated in terms of dating of manifestations of magmatic complexes, which formed the deposits of epicontinental porphyritic formation of Pacific Ocean margins (Sharapov et al., 2013). For lithospheric oceanic plates, homogeneous in thickness, in the case of formation of the horizontal convective cells at a temperature over 1800°C at the lower boundary of the upper mantle, the emergence, development and cyclical decay of large cells and, consequently, the segmentation of the lithospheric plate, take place (Lowman, Larvis, 1999). The size of these segments is similar to that observed in MOR and volcanic ridges (Niu and Batiza, 1994). At that, the imposition of hot spots on such structures stabilizes their growth dynamics.

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COMPOSITION OF SHIBEINGOL GABBRO-MONZONITE-GRANOSYENITE COMPLEX (LAKE ZONE OF WESTERN MONGOLIA)

Y.Y. Shelepov[1,2], *R.A. Shelepaev*[1,2]
[1]V.S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia
shelepov@igm.nsc.ru; rshel@igm.nsc.ru
[2]Novosibirsk State University, Novosibirsk, Russia

The Shibeingol complex consists of 11 intrusions of the Lake Zone including a set of rocks from gabbros to alkaline granites. Isotope-geochronological studies show that among these intrusions are present different ages association by different authors: Early Devonian, Middle-Early carbon, Late Permian and Late Triassic. Petrotype of the Shibeingol complex is the Shibeingol intrision indicates Late Triassic age (U-Pb, zircon, SHRIMP II, 214±3 Ma; Ar-Ar, biotite, 213,7±5,4 Ma). The Triassic association also include the Ulgiin-Nuur monzonite-granosyenite inrusion (Ar-Ar, biotite, 217,9±5,5 Ma), located 50 km south of petrotypes and characterize similar textures and composition of the rocks. Data of the age of this intrusion lets to allocate a new stage of development of Late Triassic magmatic event in the Lake Zone of Mongolia.

The Shibeingol intrusion is located in the northwestern part of the Lake Zone of Western Mongolia (the northwestern part of the Hirgis subterrane of the Lake terrane (Tectonic…, 2002)). In plan intrusion has an oval shape, and are stretches from west to east, its dimensions are 14 x 7 km. The rocks of the intrusion are intrusive contact with the Silurian - Upper Devonian terrigenous-volcanogenic sediments of Tsagaan-Shivuut and Shibeingol strata, with the formation of hornfels and skarn. In the Shibeingol intrusion possible to allocate intrusive, volcanic and hypabyssal associations, each of which has a multi-phase texture. Intrusive association consists of four phases, hypabyssal and volcanic associations include 2 and 4 phase respectively. Among the rocks prevail granosyenites (3rd intrusive phase) on the modern erosion shear.

The Ulgiin-Nuur intrusion is located in the western part of the Hirgis subterrane of the Lake terrane (Tectonic…, 2002). In the plan intrusion has an oval shape, and are stretches from north-west to south-east, its dimensions are 4.8 x 3.2 km. It structure is present only intrusive association, consisting of two phases, which correspond to the composition of the second and third intrusive phases of the Shibeingol intrusion.

The first intrusive phase of the Shibeingol intrusion are present monzogabbro, which is identical trachybasalt of the first volcanic phase. 2nd phase are present porphyritic monzodiorites, quartz monzonite and monzodiorites, 3rd are present quartz syenite and granosyenites, 4th are present granite. The rocks of the 2nd and 4th phases are equivalent among the rocks of volcanic and hypabyssal associations: monzodiorite-porphyry, akerites, trachyandesites, leucogranite-porphyry, rhyolites and trachyrhyolites, and the rocks of third phases are equivalent only among the volcanic associationwhich are latites.

The main rock-forming minerals of the Shibeingol intrusion are K-Na feldspar (continuous series of albite to sanidine), plagioclase ($An_{6\text{-}85}$), biotite and quartz. Are less common amphibole which develops around clinopyroxene submitted magnesian hornblende and edenite, clinopyroxene (Wo 38-47%, #Mg=72-87%), olivine ($Fo_{67,4\text{-}67,9}$)and orthopyroxene (#Mg=68-70,5%). Accessory minerals of rocks: magnetite, ilmenite, apatite, sphene and zircon.

In general, to the rocks of the Shibeingol intrusion are typically higher alkali content (Na_2O + K_2O from 5.3 wt.% in the basics rocks to 12 wt.%, in the intermediate of composition of rocks) because of what in the classification TAS - diagram point of the rocks fall into the field of moderate-alkali and alkali petrochemical series. Although high concentrations of alkali, alkaline silicate in the rocks is not observed due to the high content of alumina (Al_2O_3 = 12-18, rarely up to 22 wt.%, A_{NK} 0,68-0,95).

All the rocks of the Shibeingol intrusion are described common features in the spectra of distribution of rare earth elements (REE), normalized by chondrite CI (McDonough et al. 1992). They are characterized by high concentrations of REE (from 230 ppm in rhyolites to 1019 ppm in quartz syenites), and the enrichment of LREE (La/Yb_N=8,1 - 30,1). By Eu anomaly, and the distribution of HREE, the spectra can be divided into two types.The first type are characterize of the monzogabbro, trachybasalts, monzodiorites and monzonites that is rocks first and second phases. Their spectra are characterized by the absence of Eu anomaly, and a monotonic decrease in the concentrations of REE from mild to severe (Tb/Lu_N=1,4 - 3,2). The second type of spectrum allocation are typical to rhyolites, quartz syenites and granites, they are present a marked negative Eu anomaly (Eu/Eu*=0,3 - 0,4), and the distribution of HREE almost flat, sometimes has a positive slope (Tb/Lu_N up 0.6).

At the multielement spectra normalized by the primitive mantle (McDonough et al. 1992), we can distinguish two types of distributions, as well as among the spectra distribution of REE. All spectra are characterized by an enrichment of LILE (K and Ba) and depleted in some HFSE (Nb, Ta), as well as Th and U, which indicates the presence of aqueous fluid in the lithospheric mantle. The rocks of the first phase is also characterized by a positive anomaly for Sr and Ti, and for intermediate rocks - an anomaly for Sr absent or weak negative.Basic rocks are enriched in Ti and Zr and Hf are depleted relative to the second phase of the rocks. Rocks of third and fourth phases and their intrusive, volcanic and hypabyssal equivalents have a significant negative anomaly for Sr, Ba and Ti, as well as the positive anomaly of Zr and Hf.

Monzogabbro, trachybasalts, monzodiorites and granosyenites are characterized by positive values εNd(T) (1.2 - 2.4), which corresponds to the isotopic parameters of the Early Paleozoic crust of the Lake terrane (Yarmolyuk et al. 2013).

From the isotope-geochronological and geochemical data suggest that the Shibeingol and Ulgiin-Nuur intrusions belong to the same stage of the Late Triassic magmatic event. On the basis of the content of trace elements (minimum of highly charged (Nb, Ta), enrichment of LIL elements) we can assume that the parental basaltic melt of the Shibeingol intrusion are formed by the melting of mantle with supra-subduction geochemical characteristics.The absolute values of the age of 214 ± 3 Ma.of the rocks of the Shibeingol and Ulgiin-Nuur intrusions and their geological position responsible intraplate stage of development of the western segment of the CAFB according paleotectonic reconstructions of other authors (Badarch et al. 2002).

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THE ORIGIN OF GRANITOIDS OF RAPAKIVI FORMATION BY PLUME TECTONICS OR BY SUBDUCTION PLATE-TECTONIC?

E.M. Sheremet
Institute of Geochemistry, Mineralogy and Orebearing NAS,
Kiev, Ukraine, EvgSheremet@yandex.ru

Existence of subduction geodynamic settings in Proterozoic of the Ukrainian Shield has been arguable. Petrochemical and metallogenic zonation in the Azov Region described in the monograph (Azarov et al., 2005) corresponds mostly to Andean geodynamic setting. In the Central and West parts of the Ukrainian Shield occurrence of plutons of anorthosite-rapakivi-granite formation (ARGF) at the final stages of Proterozoic tectono-magmatic activation is identical to occurrence of alkaline magmatites in the rear part of subduction zone in the Azov Region, although it has a number of differences.

Manifestations of ARGF plutons are global and do not exclusive prerogative of the Ukrainian Shield. According to Mitrokhin (2001) most of anorthosite-rapakivi-granite complexes (ARGC) are located in the Northern hemisphere where they are concentrated within the Laurasian Group of ancient platforms: East European Platform, North American Plate and Siberian Platform. Just in the Northern hemisphere the most typical complexes of rapakivi granites and subplatform anorthosites are located that form six regional petrographic provinces: Ukrainian, Baltic, Labrador, Siberian, Central-American and Greenland

The main conclusions on the global expansion of ARGF according to (Mitrokhin, 2001) come down to that intrusions of ARGF gravitate toward margins of the ancient platforms, where together with subalkaline diabase dike swarms as well as volcanogenic series of subalkaline composition, form extended belts of anorogenic magmatism. Most of volcanic-plutonic complexes of ARGF occur within Paleoproterozoic crust provinces. Some of the complexes gravitate toward the boundaries of Paleoproterozoic provinces with Archean. Isotopic age of the complexes of ARGF varies discretely in the range 1.27–1.81 Ga; maximal age peaks (Fig. 5.3) are 1.5–1.6 Ga, 1.62–1.66 Ga and 1.74–1.80 Ga.

An interesting feature of rapakivi granite plutons is also that at the final stage of their making rare-metal granites and rare-earth syenites have been forming. For the Ukrainian petrographic province ARGF are Perzhanian and *Lezniki rare-metal granites and Yastrebenka rare-earth syenites of the Korosten pluton;* Ruske Pole rare-metal granites and Velikoviskovsk rare-earth syenites of the Korsun-Novomirgorod pluton; Kamennaya mogila rare-metal granites and South Kalchik (azov) rare-earth syenites of the East Azov subalkaline-alkaline pluton. They are spread mainly at the circumference of plutons. For Lithuanian petrographic province these are rare-metal granites of the Baltic Shield: at the Kola Peninsula – the Yuvoaiv complex, in the south part of the Baltic Shield – Kumi stock of the Vyborg rapakivi pluton, leukogranites of the final stage of the Salmi Massif of rapakivi granites, leukogranites of the final stage of the Laitila Massif (Eurajoki stock, Finland).

The origin of rare-metal granites of Phanerozoic regions is considered from a position of plate tectonics. Geodynamic setting of the Mongolia-Okhotsk belt (for Mesozoic of the Mongolia-Okhotsk belt that includes also Transbaikalia) is similar to the Late Cainozoic geodynamic setting of the west of North America with the range of magmatism in the core of which are granite-granodiorite batholites, and circumference is composed of rocks of increased alkalinity and rare-metal granites (Zonenshain et al., 1976, 1990) Hercynian province of rare-metal granitoids of Western Europe (Ore Mountains) is located in the zone of calc-alkali magmatism. For Hercynian magmatic range tectono-magmatic zonation has been established which is similar to Mesozoic of the Mongolia-Okhotsk belt. According to (Nikolsky et al, 1971) Europe in the Upper Paleozoic (270–290 Ma) was a northern continental margin of Paleothetis with the Zavarnitsky-Benioff zone downgoing under the European continent.

The origin of granitoids of rapakivi formation is explained mainly by plume tectonics, which is based on the idea of the rising of mantle diapir in tension zones confined to up-going plumes of mantle convective currents. In some ways there is similarity between formation of subalkaline-alkaline magmatism and rare-metal granites in the zones of Phanerozoic subduction and formation of granitoids of rapakivi formation due to plume.

To our opinion, existence of subduction plate-tectonic settings in Proterozoic eon is much more attractive than plume tectonics because the rising of mantle diapir could be the result of subsequent dipping of the Benioff zone downwards into the mantle, its disturbance and rising of fluids carried heat and moving components including alkalis. Rifting is typical feature of subduction settings. If there are convective mantle plumes, they have caused movement of lithosphere plates.

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ORIGIN OF MAGMAS ACCORDING TO MODERN DATA ON HOT ACCRETION OF THE EARTH

V.S. Shkodzinskiy
Diamond and Precious Metal Geology Institute, Siberian Branch, Russian Academy of Sciences, Yakutsk, Russia, shkodzinskiy@diamond.ysn.ru

According to the hypothesis for cold accretion of the Earth, which prevailed in geology, it was generally assumed that interior part of the Earth was never melted. That is why, magmas had to be formed by separation of fusions in deep-seated rocks, sub-melted by 0,1-15% due to radiogenic heat release. Correctness of this assumption is not proved yet, but numerous data contradicting this assumption are determined. Experiments (Arndt, 1977) shoed that, fusions are not separated from peridotites during their melting by less than 30-40% due to high strength of framework of intergrown minerals. It is confirmed by autochthony of anatectic vein material in migmatites, even at its occasionally observed maximum content – 40-45%. In mantle xenoliths, the are no signs of partial melting and there many phenomena of replacements of high temperature minerals by low temperatures ones. Judging by xenoliths, temperature of mantle lithosphere below platforms was decreased 200^0 C every billion years (Shkodzinskiy, 1977). This indicates that, there are no processes of heating and partial melting in it. Theory of fusion isolation cannot explain origin of acid magmas and continental crystalline crust, because acid fusions could occur in primary ultrabasic material only at pressure less 3-4 kb (Green, 1973). However, in case of cold accretion, temperature $1000\text{-}1100^0$ never existed at depth of less than 10-15 km, which is necessary for sub-melting of this material by 3-5%.

Modern planetologic and petrologic data indicate hot accretion of terrestrial planets and global oceans of magma, fractioning on them. Hot formation of the Earth is indicated by occurrence of trends of magmatic fractionation in mantle xenoliths, decrease of average isotope ages and temperature of crystallization of different mantle rocks fully in accordance with these trends, projection of the lines of Archean paleogradients into the area of very high temperature (up to $1000\text{-}1100^0$) on the earth's surface and many other data. Considering hot formation of the Earth enables fundamentally new way to solve all the problems of magma genesis and to conclusively explain features of composition, accommodation and evolution of magmatism (Shkodzinsliy, 1977).

Many data indicate that, Earth core was formed before the mantle, due to adhesion of magnetized iron particles in protoplanetary disk. Very fast accretion resulted in initially higher temperature of the core in comparison with the mantle, and later led to occurrence of convection in it. Silicate material, that fell out to the core, was melted under the influence of compact heat release. Near-bottom parts of originated magma ocean were crystallized due to pressure increase of neogenic upper parts. Settled crystals formed ultrabasic rocks of the lower mantle, and melts buried among them – eclogites. Because of low gravity at still small Earth and lower depth of the early ocean, pressure at its floor was low. That is why, low-baric residual melts from acid to tholeiite composition were formed. Layering in magma ocean was formed due to their location according to the densities.

After the termination of accretion, ocean which depth was about 240 km, due to layering, was cooling, crystallizing and fractioning from top to bottom. Fractionation of acid layer led to formation of enderbites and gray gneisses from cumulates and ancient granitods from residual melts, composing crystalline rock in the Archean time. The rise of magmas and their differentiates from layers with average and basic composition, led to formation of diorites, basites, autonomous anorthosites, syenites and alkali granitoids mainly in the Proterozoic time. Formation of alkali-ultrabasic complexes and carbonatites, mainly in the Late Proterozoic and Paleozoic times, was caused by intrusion of high-baric residual liquids (melts) of this layer. Long-term accumulation in residual melt led to huge amount of rare and trace elements in many of these rocks. Kimberlites were formed from residual melts of near-bottom peridotite layer mainly in the Phanerozoic time. Decompression-friction submelting during squeezing out and floating of the most acid rocks of crystalline crust in collision zones is a cause of formation of huge granitoide batholiths in them.

When substance of the lower mantle, heated up by the core, was floating, eclogites decompressionally melted in it, because they are by hundreds of degrees more fusible than ultrabasic cumulates. Almost all eclogites had tholeiite composition due to formation from low-baric residual melts. Therefore, when they were decompressionally remelted during the rise, only tholeiite magmas were formed regardless of melting depth. This explains huge abundance of tholeiite basites both in oceans with thin lithosphere and in continental areas. Here, low-temperature lithosphere extended to big depth and therefore, its low-baric melting could not occur, which is necessary for tholeiite formation. Different acid magmas were formed during low-baric fractionation of tholeiite magma chambers in plumes, different alkali magmas were formed during high-baric fractionation below thick lithosphere, intrusing mainly after tholeiite basites. The deepest alkali magmas carried out high-grade diamonds from large placers with kimberlite primary sources.

In subduction zones cooling and fractionation of asthenospheric chambers of tholeiite magmas under the influence of descending cold lithosphere led to formation of different residual melts (from acid shallow to alkali deep and magmatic rocks identical to them in composition. Rheomorphism of crystalline acid crust could be accompanied by formation of large intrusions of granitoides at margins of the continents. Only magmatic fractionation is the reason of diversity of magmatic rock composition.

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EVIDENCE OF PLUME-TECTONICS IN THE OLKHON COLLISIONAL SYSTEM (CENTRAL ASIAN OROGENIC BELT)

E.V. Sklyarov[1,5]*, V.S. Fedorovsky*[2]*, A.M. Mazukabzov*[1]*, D.P. Gladkochub*[1]*, T.V.Donskaya*[1]*,*
A.V. Lavrenchuk[3]*, A.B. Kotov*[4]
[1]Institute of the Earth crust SB RAS, Irkutsk, Russia, skl@crust.irk.ru
[2]Geological Institute RAS, Moscow, Russia, west45@migmail.ru
[3]Institute of Geology and Minaralogy SB RAS, Novosibirsk, Russia
[4]Institute of Precambrian Geology and Geochronology RAS, Sankt-Petersburg, Russia
[5]Far East Federal University, Vladivostok, Russia

The Olkhon Early Paleozoic accretion-collision system (terrane) is situated in the West Baikal Region (Olkhon Island and Near-Olkhon Area). This terrane belongs to the north-eastern part of the Central-Asian Orogenic Belt. The terrane has a composite structure and consists of many segments of various geodynamic settings. Now deep level rock associations of this collision system are exposed on the surface. Several episodes of evolution of this collisional system have been recognized: early thrust-related deformations, including sheath folds; later doming, and the latest strike-slip-related deformations. The latter are the most prominent and visible in the recent structure. All these episodes have been related to oblique collision of the terrane to the Siberian craton.

According to available geochronological data accretion and collision events took place in the time interval 510 – 460 Ma. Along with collision-related magmatic and metamorphic complexes there are some evidences of some magmatic and metasomatic events not explained in terms of collision or accretion. We interpret them to be related to plume-tectonics, superimposed on collisional events, and according to geochronological data taking place in the time interval 475-455 Ma.

In general, plume-related complexes of the Olkhon terrane are listen bellow and given on Fig. 1:

a) Sub-alkaline gabbro of the Tazheran complex (460 Ma (Fedorovsky et al., 2010);

b) Syenite and Ne-syenite of the Tazheran complex (455-465 Ma (Sklyarov et al., 2009));

c) Sub-alkaline gabbro-granite mingling dikes (460 Ma (Fedorovsky et al., 2010));

d) Sub-alkaline gabbro-syenite mingling massif (460 Ma (Fedorovsky et al., 2010));

e) Tholeiite gabbro-granite mingling dykes (470 Ma (Sklyarov et al., 2001);

f) Medium-, high-, and ultra-high metasomatic rocks, sometimes with unique minerals (kilhoanite, pavlovskite, galuskinite etc.) (Sklyarov et al., 2009; Sklyarov et al., 2013; Starikova et al., 2014);

g) Injection carbonate complexes (veins, marble-syenite mingling, marble mélange) (Sklyarov et al., 2013);

h) Rare-metal granite of the Ainsky complex (465 Ma, unpublished data).

We think that in near future new plume-related complexes in the area studied could be discovered.

Kinematic effects of the plume tectonics are shaded by the predominant collision-related strike-slip tectonics. If plume-related deformations have been realized in pure shear setting, oblique collision-related events took place in pure shear setting. Interference of simultaneous collision- and plume-related processes have provided a complex structure of the Olkhon collisional system, all features of which are not recognized till now.

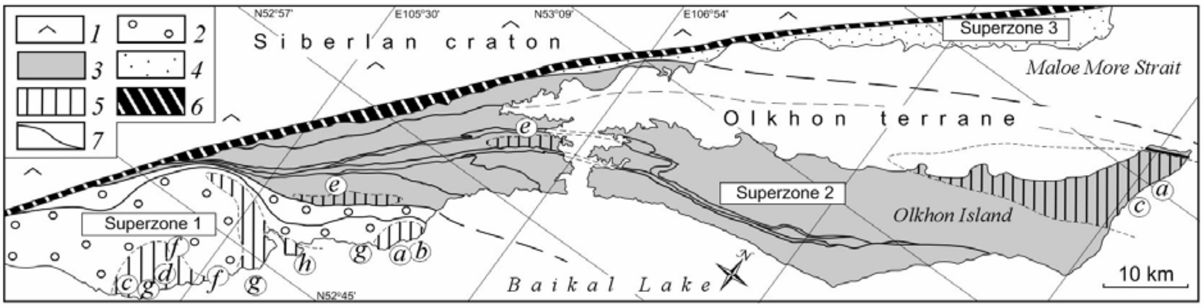

Fig. 1. Location of syn-collisional plume-related complexes in the Olkhon terrane (West Baikal Region)

1 – Siberian craton; 2-4 – Early Paleozoic Olkhon composite terrane: 2 – superzone 1; 3 – superzone 2; 4 – superzone 3; 5 – location of plume-related complexes; 6 – collisional suture between Siberian craton and terrane; 7 – blastomylonite sutures, boundaries of principal strike-slip domains, composing collisional collage. *a, b, c, d…* - see explanation in text.

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PLATINUM GROUP MINERALS IN DOLERITE OF THE ALEXANDRA LAND ISLAND (FRANZ JOSEF ARCHIPELAGO)

E.V. Sklyarov[1], *Yu.V. Karyakin*[2], *N.S. Karmanov*[3], *N.D. Tostykh*[3]
[1] Institute of the Earth crust SB RAS, Irkutsk, Russia; skl@crust.irk.ru
Far Eastern Federal University, Vladivostok, Russia, skl@crust.irk.ru
[2] Geological Institute RAS, Moscow, Russia, yukar@ginras.ru
[3] Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia, tolst@igm.nsc.ru

Magmatic complexes of the Frantz Joseph Archipelago (FJA) belong to the large Jurassic-Cretaceous Barents Sea Igneous Province. According to their volume they are similar to the Siberian trapps, and some researches defined a large Barents Sea - Amerasia Superplume (Karyakin et al., 2010; Shipilov et al., 2009) related to the Iceland hot sport (Kuzmin et al., 2014). The Alexandra Land Iceland, composed of dolerite lava flows with rare dolerite and gabbro-dolerite dykes, is the westernmost in the FJA. Rocks of the upper flow contain disseminate Au-Pd-Cu minerals. Platinum group minerals (PGM) have been found in polished thin section in association with numerous grains of native copper. The fine grains of PGM are clustered as chains at the contacts of plagioclase and clinopyroxene or along cracks in these minerals.

PGM have been analyzed on electron microscope LEO 1430VP (Geological Institute SB RAS, Ulan-Ude). Recalculated to atomic percent they can be subdivided to two clusters belonging to Cu−Au−Pd and Pd−Cu−(Te+Sb+S+As) systems. According to formula coefficient the minerals of the first system are pretty good calculated to several compounds (Fig. 1a). The richest in gold phase has formula Au_2PdCu and may be defined to two ordered phases: Au_3Cu or AuCu, depending of structural position of palladium. The second compound in this system (Au,Pd)Cu – may be regarded as Pd-bearing cuproauride ($AuCu_{cub}$) or tetra-auricupride ($AuCu_{tetr}$), where aurum is partly substituted by Pd. The third compound may be calculated as $Au(Cu,Pd)_3$ and corresponds to Pd-bearing auricupride $AuCu_3$.

In all PGM of the system Pd−Cu−(Te+Sb+S+As) the sum of palladium and cupper is more than 70 at.%. All compounds in which chalcophile elements are minor elements, plot in the diagram (Fig. 1b) between skaergaardite (PdCu) and nielsenite (Cu_3Pd). But most of the compounds contain a significant amount of Sb, Te, S and As in varying ratio and plot to the wide field of compositions. Some of them are stoichiometrically similar to $(Pd,Cu)_3(Sb,Te,As,S)$, typical for early described unnamed phases (Podlipsky et al., 2015; Stumpfl, 1961). Native cupper in association with PGM contain up to 0.41 wt% of S.

Similar mineral associations, described before in tholtiitic gabbro of the Skaergaard massif in Greenland (Rudashevsky et al., 2004), were proposed to be the products of active influence of low-temperature fluids, transporting Cu from sulfur ores (Holwell et al., 2011), superimposed to primary platinum mineral association. Morphology of the PGM, low temperature of their formation (according to experimental data), presence of native S-bearing cupper and absence of Fe-Ni-Cu-sulphides in the associations, support a secondary nature of the investigated mineral associations.

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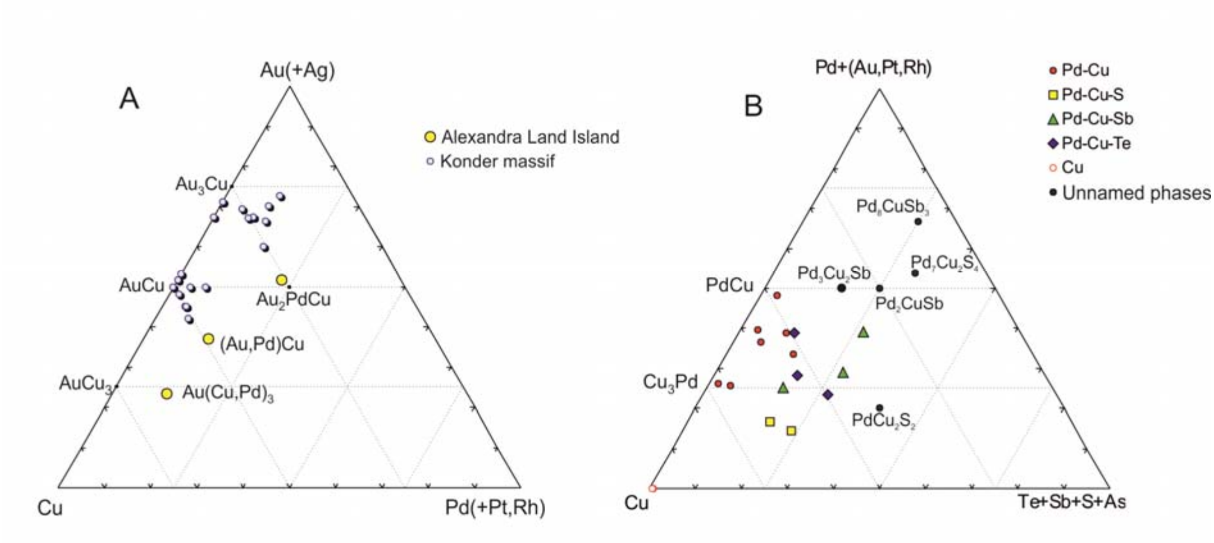

Fig. 1. Composition of solid solution in Au–Pd–Cu system (A), data of Konder massif after (Nekrasov et al., 2004); and in Pd–Cu–(Te,Sb,S,As,S) system (B). Unnamed phases after (Podlipsky et al., 2015; Stumpfl, 1961).

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EVOLUTION OF THE COMPOSITION OF SIBERIAN CRATONIC LITHOSPHERE DURING THE INTERACTION WITH SIBERIAN FLOOD BASALT (SFB) PROVINCE

N.V. Sobolev [1], A.V. Sobolev [2], D.V. Kuzmin [1], A.A. Tomilenko [1], V.G. Batanova [2], A.M. Logvinova [1], A.V. Tolstov [1], S.I. Kostrovitsky[3], D.A. Yakovlev [3]

[1] V.S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia, sobolev@igm.nsc.ru

[2] ISTerre, Universite Joseph Fourier, Grenoble, France,

[3] A.P. Vinogradov Institute of Geochemisrty SB RAS, Irkutsk, Russia

The Siberian flood basalt (SFB) province is the largest terrestrial province with the estimated volume of igneous rocks up to 5 million cubic km. The majority of SFB erupted over less than one million years at 252 Ma (Burgess et al. 2015). The Siberian craton also hosts one of the largest kimberlite province emplaced within 450-140 Ma (Davis et al. 1980). The main epochs of kimberlites emplacement took place in Devonian (344-364 Ma) producing principal diamond mines including Udachnaya mine and in Triassic (about 240 Ma) with only one, Malokuonapskaya kimberlite pipe dated by SHRIMP (U-Pb method on zircon) 226±6 Ma (Sobolev et al.2015a) with near-commercial diamond grade. This indicates the availability of complete lithospheric cross section. This pipe contains flood basalt and peridotite xenoliths. We report here preliminary data on mineralogy of this hypabyssal (Mitchell. 2008) kimberlite containing fresh olivine. Homogeneous cores of zoned olivine with Fo 77.3-93, with average Fo 88.9 (n=363), are different in compositional range from those of Udachnaya olivines (Fo 85-94), with average Fo>92, as well as from other studied kimberlites worldwide (Amdt et al. 2010; Foley et al. 2013; Kamenetsky et al. 2009; Sobolev et al., 2009b; Sobolev et al. 2015b). Outer rims compositions are also different (Fo 85-86 and 89-90 respectively). Concentrations of Ni, Mn, Co, Ca, Cr, Al, Ti, P, Na and Zn were measured by EPMA using an innovative method which has been developed based on earlier publication (Sobolev et al. 2007). It made possible to obtain external precision down to 10 ppm (2SD) and detection limit down to 2 ppm. High resolution compositional maps of olivine zoning for all mentioned elements are produced. Eighteen percent of representative olivine samples are characterized by low Fo 77.3-85. Clear zoning and/or inhomogeneities in concentration of some trace elements, P in particular, are detected in the cores of studied olivines. Similar trend in Fo range but with considerably lower proportion of low Fo olivines is typical of barren Triassic Los dike and younger Jurassic Olivinovaya kimberlite. The absence of a correlation between decreasing Mn/Fe in olivine cores and Ni/(Mg+Fe) which is typical of shallow olivine phenocrysts of basaltic magmas testifies on the redistribution of Mn from olivine into garnet at lower temperatures and high pressures (Balta et al. 2011). The compositional peculiarities of olivines from Malokuonapskaya pipe are really unique testifying on refertilization of deep part of Siberian cratonic lithosphere within 350 and 230-225 Ma. This was predicted by earlier developed models (Sobolev et al. 2009a).

The difference in olivine mineralogy of hypabyssal kimberlites predated (Devonian Udachnaya) and postdated (Triassic Malokuonapskaya and Los) SFB may suggest recorded effect of SFB on Siberian lithosphere which is less pronounced for barren shallower Los dike and younger Jurassic Olivinovaya kimberlites.

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DEPOSIT POGROMNOE – NON-TRADITIONAL INDUSTRIAL TYPE OF GOLD MINERALIZATION IN TRANSBAIKALIA

A.M. Spiridonov, L.D. Zorina, Z.I. Kulikova, A.E. Budyak, A.V. Parshin, L.A. Pavlova, E.M. Granina

A.P. Vinogradov Institute of Geochemistry, SB RAS, Irkutsk, Favorsky st. 1 a, Russia, sam@igc.irk.ru

Transbaikalia is one of the largest metallogenic provinces on the south-east of Russia that includes 46 gold deposits and over 1000 gold occurrences. Gold mineralization occurs here everywhere. The gold mineralization in Transbaikalia was generated during a significant span of time from the Late Paleozoic to the Early Cretaceous. However, a major part of gold deposits were produced either in the Middle-Late Jurassic (collision stage) or in the Early Cretaceous (rifting stage). They are controlled by the Mongol-Okhotsk suture. This structure is a result of the Early-Middle Jurassic collision of the Siberian and Mongol-China continents (Zorin et al., 1998; Zorin et al., 2001; Spiridonov et al., 2006).

The majority of deposits are with gold-quartz, gold-sulfide-quartz and gold-sulfide ore types. Each ore type unites several mineral types depending on the composition. A great number of deposits are proved to belong to gold-copper-porphyry ore type that is considered to be the most perspective. The largest and commercial deposits of this type include the ones located within the Darasun (Prokof'ev et al., 2010) and Kariisk (Zhmodik et al., 2009) ore-magmatic systems.

The epitermal gold-silver type (e.g. Balei Deposit) is also of commercial importance. The gold-carbon and gold-scarn deposit types are expected for the region as well.

A new type of gold deposits occurring in the sequences suffered the dinamometamorphic processes has been of particular interest recently. Their formation is linked to the geodynamic processes occurring in zones resulting from the collision of the Siberian craton and surrounding terranes giving rise to boudinage, mélange and fluidal texctures. This type in Tranasbaikalia can be exemplified by the deposit Pogromnoe.

Many deposits are located within the Mongol-Okhotsk suture zone possess a long history of formation starting from the collision stage marked by early (in cases pre-ore) metasomatic transformation of host rocks and terminating at the rifting stage with syn-ore (including the mineralization) transformation of host rocks. It was verified by a number of scientists and exemplified by deposits of the Darasun, Kariisk, Lyubavin, Balei, Bistrinsko-Shirokinskaya, Aprelkovo (including the deposit Pogromnoe) ore-magmatic systems (Zorin et al., 1998 Spiridonov et alk. 2006; Prokof'ev et al., 2010; Zhmodik et al., 2009). It can be accounted for a longer formation of the Mongol-Okhotsk suture, its accretion-collisions and post-accretion history (Zorin et al., 1998; Gordienko, Kuzmin 1999; Zorin et al., 2001).

Mineralogical-geochemical features of metasomatites and ores from the gold deposit Pogromnoe being non-traditional for Transbaikalia have been studied. The deposit was produced in the Early Cretaceous during the rifting stage and occurs within the dynamoclastic sequence of the Mongol-Okhotsk suture zone.

Gold mineralization includes two morphological types of ores: stockwork quartz-carbonate-arsenopyrite-pyrite in metasomatically altered effusive rocks (orebody-1) and veinlet-vein quartz (with disseminated sulfide mineralization) in altered carbon-bearing black shale (orebody-10).

The gold mineralization is hosted in the strongly altered volcanogenic-sedimentary rocks of the Butorovskaya unit (Shadoron complex, J_{2-3}) changed to metasomatites (by composition) and dynamoclatites (by texture and structure). Metasomatites were produced and ore process proceeded in several stages. Abundant propylites were produced in the early stage (J_3); tectonoshales and albitophyres were generated in the pre-ore stage; sericitolites and albite-carbonante-sericite-quartz metasomatites (quartzites) were produced in syn-ore (productive) stage. ^{40}Ar-^{39}Ar age of stockwork system of ore-hosting fractures and metasomatites produced in the pre-ore stage is 139,5±1,8 Ma.

Gold-bearing rocks in the deposit include pre-ore and syn-ore metasomatites superimposed on volcanics hosting sulfide mineralization (gold concentrators are pyrite II and III and arsenopyrite-I, II) and altered carboniferous black shale (gold concentrators are veined quartz and arsenopyrite-II**).** Gold accumulation is favored by intense silicification, abundant quartz-sulfide and sulfide fine veinlets, fine disseminated sulfide mineralization.

By its genesis the deposit Pogromnoe belongs to the deposit formed in compression zones with the contribution of mantle gold-bearing fluids. In authors opinion the sources of those fluids are ore-producing granitoids of the Amudzhikan-Sretensk intrusive complex occurring within the Aprelkovo ore-magmatic system (Os'kin and Urguchan massifs). This conclusion is confirmed by Pb isotope composition ($^{207}Pb/^{204}$и$^{206}Pb/^{204}$) for pyrites and arsenopyrites of gold-bearing ores from the deposit Pogromnoe that provides an evidence for "mantle" origin. ^{40}Ar-^{39}Ar age of ore-producing granites of the Aprelkovo ore-magmatic system is 131,0±1,2 Ma.

Gold in ores is native, high-grade and significantly high-grade. In terms of gold potential Pogromnoe deposit is worthy of attention as a new industrial type of gold mineralization in Transbaikalia.

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THE SEQUENCE OF MAGMATIC EVENTS WITHIN THE NAKYN KIMBERLITE FIELD

M.D. Tomshin[1], A.V. Travin[2], K.M. Konstantinov[3]
[1]Diamond and Precious Metals Geology Institute, SB RAS, Yakutsk, Russia, tmd@diamond.ysn.ru
[2]Institute of Geology and Mineralogy, SB RAS, Novosibirsk, Russia, travin@uiggm.nsc.ru
[3]Scientific Research Geological Enterprise AK "ALROSA", Mirny, Russia, KonstantinovKM@alrosa.ru

Since the discovery of the Nyurbinskaya kimberlite pipe in the Middle Markha region, the question of its relations with a dolerite dike dividing it into two bodies at a depth of 300 m remains open. The fact of the pipe division may indicate that the dike is younger than the kimberlites. Yet, there is information (Kiselev et al., 2004; Sablukov et al., 2010) that kimberlites of the pipe contain xenoliths of dolerites which attest the reverse. Analysis of currently available factual data, including the results of isotope dating of magmatites in the region, gave a better insight into the structure of the pipe and the sequence of the emplacement of magmatites in the Nakyn kimberlite field. Most of the dolerite dikes in the Middle Markha region are located in the faults of the Vilyui-Markha zone. From K-Ar, $^{40}Ar/^{39}Ar$ and Sm-Nd isotope dating (Zemnukhov et al., 2005; Maschak et al., 2004; Vincen et al., 2010), the dikes are Frasnian-Famenian in age (368.5-377.5 Ma), which is, in general, consistent with the age of dolerites within the Vilyui-Markha dike swarm. They are also comparable both petrographically and petrochemically.

The formation of the kimberlite bodies at the Devonian-Carboniferous boundary (364, 365 Ma according to Agashev et al., 2004) was followed by the emplacement of cross-cutting alkali basites in the Early Carboniferous. Age determinations of the latter obtained by the K-Ar method - 338.2; 344.8 Ma (Vincen et al.), 339, 340 Ma (our data) and by the $^{40}Ar/^{39}Ar$ method – 338-342.4 Ma (Vincen et al.) and 341 Ma (our data) are quite close. Though the alkali basites are petrographically and petrohemically similar to the pre-kimberlite basites, they have higher TiO_2 (over 5%) and K_2O (up to 3%) contents.

Spatially associated with the bodies of alkali basites are explosive breccias (Tomshin et al., 1998) formed at their sides. Subject to brecciation were consolidated rocks of alkali basites and their enclosing sedimentary rocks, which were the source material for the explosive breccias. Brecciation was accompanied by active Mg-K metasomatosis. The latter led to transformation of basites into high-Mg (occasionally up to 9-15% MgO) and high-K (up to 9%K_2O) varieties. Isotope dating of the cementing mass of the explosive breccias by the Sm-Nd method (Maschak et al., 2004) and by the $^{40}Ar/^{39}Ar$ method (our data) yielded the age range of 331-321.9 Ma, which indicates that magmatic events in the region ended in the formation of explosive breccias.

Analysis of the available factual data for the Nyurbinskaya pipe, including those for the zone of contact between the kimberlites and dolerites, unambiguously showed that present here are dolerites of the dike, rocks of alkali basites, and explosive breccias, i.e. all the rocks which are identified beyond the limits of the kimberlite body. New $^{40}Ar/^{39}Ar$ data obtained for the rocks of the dolerite dike (368.5 and 371.7 Ma – our data, and 374.4 Ma according to Kiselev et al., 2014) show that the dike is pre-pipe (the age of kimberlites is 364 Ma according to Agashev et al., 2004). This is also supported by geological evidence – the basites are cut by the kimberlites. It is known (Tomshin et al., 1998) that the main body of the Nyurbinskaya pipe was formed in two phases. First to form at the subvolcanic phase were porphyry kimberlites, followed by autolithic kimberlite breccias formed at the second (volcanic) phase. The upper part of the pipe is almost completely made up of autolithic kimberlite breccias which contain numerous variously sized (5-10 cm to 7-10 m) fragments of porphyry kimberlites. It is reasonable to suggest that after the emplacement of the Nyurbinskaya dike there occurred the intrusion of porphyry kimberlites along its northwestern side (first phase). Between the dolerites and kimberlites, a block of sedimentary rocks separating them is preserved. Then, autolithic breccias of the second phase were formed along the southeastern side of the dike. Forming the crater of the pipe, they slid over the apical part of the dike, crushed it, and captured , as xenoliths, porphyry kimberlites of the first phase. After the pipe emplacement, a thin body of alkali basites was formed along the contact between the autolithic kimberlite breccia and the dolerite dike. The basites produced a thermal effect on the dolerites and kimberlites, which was more pronounced at the front of emplacement. Explosive breccias that subsequently formed along the contact zone disintegrated both basites and kimberlites, and metasomatically transformed them into a complex kimberlite-basite brecciated rock. It is studying these rocks (Sablukov et al., 2010; Kiselev et al., 2004) that revealed the presence of trap xenoliths in the Nyurbinskaya pipe kimberlites.

Thus, the data available suggest that magmatic activity in the Khannya-Nakyn interfluve began with the formation of the Vilyui-Markha dike swarm. Then, kimberlites were emplaced followed by alkali basites. It all ended in the formation of explosive breccias.

Paleomagnetic data obtained for the dolerites of the pre-kimberlite dike indicate that they have similar directions of the natural residual magnetization vectors to the kimberlites of the Nyurbinskaya pipe. This is indicative of the close time of their formation (Konstantinov et al., 2014), and is at variance with the conclusion (Sablukov et al., 2010) about a significant time interval between the formation of the kimberlites and the pre-pipe basites.

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GRANITOID AREAS AS A CONSEQUENCE OF MANTLE PLUMES? (EXEMPLIFIED BY THE ANGARO-VITIM BATHOLITH)

A.A. Tsygankov[1,2], *V.B. Khubanov*[1,2], *A.V. Travin*[3,4], *E.N.Lepekhina*[5], *G.N. Burmakina*[1], *T.N. Antsipherova*[1,2], *O.V. Udoratina*[6]

[1]Geology Institute, SB RAS, Ulan-Ude, Russia, *tsygan@gin.bscnet.ru*

[2]Buryat State University, Ulan-Ude, Russia

[3]V.S. Sobolev Institute of Geology and Mineralogy, SB RAS, Novosibirsk, Russia

[4]National Research Tomsk State University, Tomsk, Russia

[5]Center of Isotopic Research, A.P. Karpinsky Russian Geological Research Institute, Sankt-Peterburg, Russia

[6]Institute of Geology, Komi SC UB RAS

In our current theoretical ideas and empirical data the major part of the large granitoid batholiths are accompanied by mantle basite magmatism. Moreover, a number of investigations relate the salic (granitoid) melts with the energetic influence of mantle magmas on the crust substratum as only the crust magma-generation can promote to the origin of giant granitoid areas. Along with this the empirical data for different granitoid province in the world suggest that the share of basites is very scarce and the temporal and genetic relations of basites and granitois are not well studied.

In the Western Transbaikalia the Late Paleozoic granitoids occupy the area of about 200 000 sq km, forming one of the largest granitoid provinces. The occurrences of basites, which are associated with the granitoids (either spatially or genetically?) are numerous, however they are not large by volume. The most largest among them include gabbro-monzonite and gabbro-monzonite-syenite complexes. In addition the basites are found as synplutonic intrusions, occurring in many granitoid massifs, complex dikes and mafic inclusions.

We obtained new data on isotope age, geologic structure and composition of several different-type basite occurrences in the Western Transbaikalia. These data, given below provide a clear evidence for the synchronous occurrence of basite and granitoid magmatism in the Late Paleozoic and a s a consequence is an important argument in the discussion on the geodynamics of the Late Paleozoic granite formation.

The Orefe'ev gabbro-monzonite pluton is located in the south-western part of the Ulan-Burgasy Ridge in the right side of LapchakhaRiver (a right tributary of Angyr-ItanstinRiver). The massif with a size as 6 x 2 km has an irregular lense-like shape and is mainly composed of amphibole gabbro, transiting into monzogabbro, monzodiorites and monzonites. Fresh olivine-biotite gabbronorite occur as well. We sampled zircons from those rocks for isotope dating (SHRIMP-II, Center of Isotopic Research, A.P. Karpinsky Russian Geological Research Institute). The concordant age obtained from 8 spots is 290 ± 5 Ma, MSWD=0.44.

The Shalutin massif consisting of amphibole-biotite fine-grained gabbro is an example of synplutonic basite intrusion. This is a sill-like intrusive body, whose apical part is accompanied by the mingling zone and numerous mafic inclusions in the host quartz syenites. On the other hand the lower contact is chilled and includes almost black fine-grained rocks with pilotaxitic microtexture and rare plagioclase phenocrysts. A true thickness of the gabbroid body is not likely over 30-40 meters. The isotope dating by Ar-Ar method was done for amphibole from two samples, collected in the center of the intrusion. $^{40}Ar/^{39}Ar$ spectrum of amphiboles shows plateau at 289.7 ± 2.1 and 1.3 ± 2.4 Ma, corresponding to almost 60 % and over 90 % of isolated ^{39}Ar, correspondingly. The obtained ages are overlapped with the age of host quartz syenites within the analytical error.

The third type of studied basite occurrences includes the complex dike in the Late Paleozoic (285-278 Ma) Ust-Khilok monazite-quartz-syenite complex that stretches in the right side of the Selenga River from the Khilok River mouth to Ulan-Ude city. The complex dike is a body of the complicated morphology and intermediate composition varying from simple microgabbro to mixed microgabbro-quartz-syenite. The share of salic component, “cementing” the rounded basitic globules is not over 10-15 % of the total volume. The zircons from the mafic part of the dike yield an age of 282.4 ± 5.6 Ma, MSWD = 3.6 (LA-ICP-MS, Geology Institute SB RAS, obtained from 9 spots); the zircons from the salic part provide an age on 17 spots as 282.3 ± 3.6 Ma, MSWD = 0.2, the host quartz syenites yield an age from 7 spots as 288.9 ± 4.3 Ma, MSWD = 0.84. These data suggest two conclusions: 1) the complex dike was intruded as a heterogeneous mixture (mechanically mixed basite and salic melts) into consolidated but still relatively hot pluton; 2) basite magmas were intruded in the same magmatic stage that was responsible for the origin of large plutons.

Geochemical data obtained for basite occurrences of different types indicate their similarity. The phlogopite garnet-bearing –lherzolite mantle is considered as a source for the Late Paleozoic basites. This mantle was melted in “hydrated” conditions that was ensured by phlogopite decomposition at the pressure of 25 Kbars and temperature of over 1000^0C. In our viewpoint it accounts for the so-called supra-subduction geochemical features of basites, that contradicts a common within-plate geodynamic nature of the Late Paleozoic magmatism.

On the whole the specific features of the Late Paleozoic magmatism of the Western Transbaikalia was stipulated by spatial-temporal combination of low-energy mantle plume with the final stage of the Hercinian orogeny. At an early magmatic stage the plume gave only a heat effect on the rocks of the relatively heated (as a result of the Hercynian folding and thrusts) crust. A “hot” viscous (plastic) crust was not easily permeable for mantle magmas. Thus, the conductive heat transfer was predominant at the first stage that agrees well with vast spread of autochthonous granites (about 20% of the Barguzin complex) and lack of “mantle’ signatures in allochthonous varieties.

Mixing of mantle basite and crustal salic magmas at different hypsometric levels marked the transition from the crustal granitic to mixed mantle-crustal including all (likely except for alkaline granites) post-Barguzin complexes. The Late Paleozoic magmatism of Transbaikalia is regarded as post-orogenic; however it was initiated by the mantle plume and was evolved under its effect. Thus, large granitoid within-plate provinces were produced as a result of plume influence in the regions marked by the termination of orogenic movements.

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CENOZOIC ALKALINE-BASALTIC MAGMATISM OF DARKHAT DEPRESSION IN NORTH MONGOLIA: EVOLUTION, SOURCES AND ORIGIN OF MAGMA, TECTONIC ACTIVITY

S.S. Tsypukova[1], A.B. Perepelov[1], E.I. Demonterova[2], A.V. Ivanov[2], A.V. Travin[3], S.I. Dril[1], Yu.D. Scherbakov[1], D. Odgerel[4], M.Yu. Puzankov[5]

[1] Vinogradov Institute of Geochemistry SB RAS, Irkutsk 664033, Russia, region@igc.irk.ru
[2] Institute of the Earth Crust SB RAS, Irkutsk 664033, Russia, dem@crust.irk.ru
[3] Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia, travin@uiggm.nsc.ru
[4] Institute of Paleontology and Geology MAS, Ulan-Bator, Mongolia, d_odgerel@yahoo.com
[5] Institute of Volcanology and Seismology FEB RAS, Petropavlovsk-Kamchatky, Russia, puzankov@kscnet.ru

Cenozoic alkaline-basaltic magmatism of the Darkhat depression(Northern Mongolia) is submerdional tectonic structure occurring in the south-west of the Baikal rift zone. Considering new geochronological research the magmatic activity proceeded through two separate stages. The early stage is dated by Early Oligocene - E_3^2 (26.84±0.15 Ma, $^{40}Ar/^{39}Ar$). Volcanic complex of the first stage is represented by fragments of lava columns and rare subvolcanic bodies of basaltic trachyandesites in the Shishigt-gol River valley and on the left bank of Hogorgyn-gol River. After a break ~20 Ma the second and final stages (Later Miocene – Early Pliocene) of magmatism – N_1^3-N_2^1 (6.32-5.10 Ma, $^{40}Ar/^{39}Ar$) connected with formation of two volcanic complexes different in composition of rocks. They contain trachybasalt complex forming extensive lava flows within Hogorgyn-gol and Shishigt-gol River valleys. Besides, there are hawaiites, basanites and phonotephrites hosted by eroded volcanic shield of uplift at the Ih Esam-uul, Noort-uul and Darsh-uul mounts and Beduuryn-gol River basin.

Late Oligocene basaltic trachyandesites are different from the second stage rocks in low concentrations of Al_2O_3, CaO, HREE and Y. They also have higher concentrations of TiO_2, P_2O_5, Sr, Zn, Sn and Ga, high fractionation of REE (La/Yb=28-32, Sm/Yb=7.8-9.3) and could be derived by 3-4% melting of Grt-bearing harzburgite or orthopyroxenite (Fig. 1.).

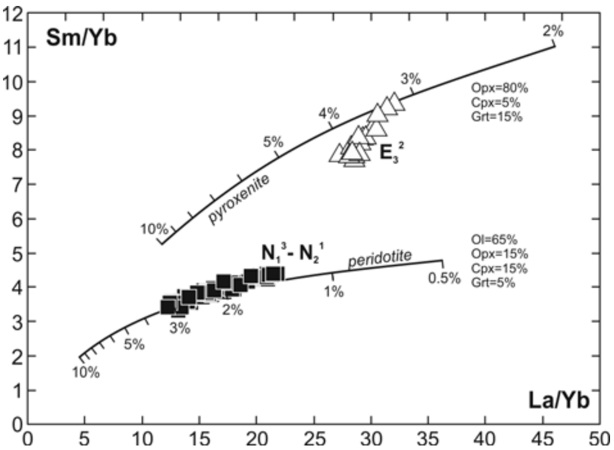

Fig. 1. Formation conditions of basaltic magmas of the Darkhat depression La/Yb-Sm/Yb plot (ppm).

The plots and values show the of degree of partial melting of pyroxenites and peridotites (%). E_3^2 – basaltic trachybasalts of Late Oligocene stage, N_1^3-N_2^1– trachybasalts, hawaiites, basanites and phonotephrites of Late Miocene – Early Pliocene stage. Ol, Opx, Cpx and Grt – mineral composition of the source. Distribution coefficients «mineral/liquid» are borrowed from literature data used for model calculation.

Despite the real differences between trachybasalts and hawaiites-basanites-phonotephrites comlexes of the second stage (N_1^3-N_2^1) of magmatism in the Darkhat depression. They are related by their origin (La/Yb=13-21, Sm/Yb=3.4-4.4) and agree with the model of melting of Grt-bearing peridotites with variations of melting degree from 3 to 1.5 % (Fig. 1). According to this model trachybasaltic magma formed at relatively high degrees of melting of peridotite substrate, distinguished by their high magnesium (Mg#>0.62), and significantly lower concentrations of many LILE and HFSE (Ba, Rb, Zr, Nb and REE). In the direction to basanites and phonotephrites from hawaiites toward the basanites and phonotephrites melting degree becomes lower, and emerging magmas along with increasing alkalinity and alumina successively enriched LILE rare elements. Although in the Darkhat depression phonotephrites participate in their formation processes of fractional crystallization of hawaiite magmas. The real features of rocks of different age stages are recognized in their paragenesis. Basaltic trachyandesites of the early stage and trachybasalts of the second stage are dominated by Ol phenocrysts, whereas hawaiites and basanites are show presence of Pl phenocrysts, Cpx, besides Ol, and most alkali varieties contain Lc and Ne.

As isotope data point out, the magma sources at different stages of volcanic evolution of the Darkhat depression show signs of heterogeneity (Fig. 2). It is to note, that at the early stage of the Late Oligocene volcanic activity formation of magmas basaltic trachyandesites was contributed by the source of EM II type. This is indicated by noticeably higher values of $^{87}Sr/^{86}Sr$ and $^{208-206}Pb/^{204}Pb$, typical for this rock type. The plume source EM II could be connected with recycled lower crust material supply. Late Miocene-Early Pliocene second phase of volcanic activity in the Darkhat depression is associated with tectonic activity proceeding within the Baikal rift zone. At this point, alternate sources of the substance in terms of passive rifting could participate in the formation of magma enriched mantle EM I type and moderately depleted lithospheric mantle.

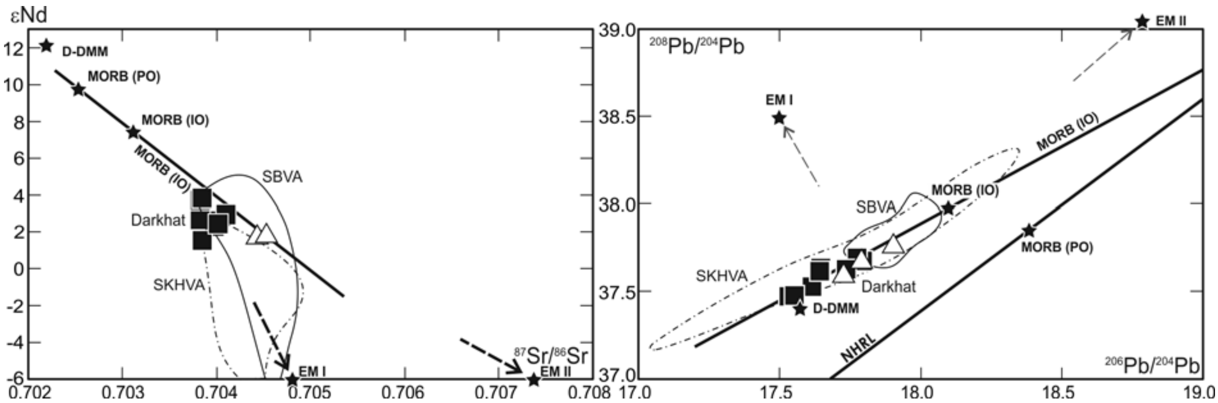

Fig. 2. Isotope characteristics of Cenozoic basalts of the Darkhat depression.
Field of basaltoid rock composition: SBVA – South Baikal Volcanic Area (Yarmoluk et al., 2003), SKHVA – South Khangai Volcanic Area (Svatenkov et al., 2010). Points of basaltoid composition are shows in Fig. 1.

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POST-DEVONIAN TECTONICS OF THE NE FENNOSCANDIA INFERRED FROM APATITE FISSION TRACK DATING OF THE KHIBINA MASSIF (KOLA PENINSULA)

R.V. Veselovskiy[1,2], *S.N. Thomson*[3], *A.A. Arzamastsev*[4,5], *V.S. Zakharov*[1]

[1]Moscow State University, Geological Faculty, roman.veselovskiy@ya.ru

[2]Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, Russia

[3]Department of Geosciences, University of Arizona, Tucson, USA, thomson@email.arizona.edu

[4]Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences, Saint-Petersburg, Russia, arzamas@ipgg.ru

[5]Saint-Petersburg State University, Russia

The thermal history of the Kola Peninsula area of NE Fennoscandia remains almost fully unknown because of absence of any thermochronological data such as apatite and/or zircon fission track or (U-Th)/He ages. In order to fill this gap and to constrain the post-Devonian erosion and exhumation history of this region, we present the results of apatite fission track (AFT) dating of eleven samples selected from the cores taken from different depths of the northern part of the Khibina intrusive massif. This alkaline magmatic complex is located at the center of Kola Peninsula and formed at about 370 Ma (Kramm and Kogarko, 1994). Samples were analyzed from depths between +520 to -950 meters and yielded AFT ages between 290-268 Ma with an average age uncertainty (1σ) of ±30 Ma. Mean track lengths (MTL) lie between 12.5-14.4 μm. We used the most reliable AFT ages and distribution of MTL in two samples, corresponding to depths of +280 and -920 m to conduct inverse time-temperature modelling of the Khibina massif. Thermal histories that best predict the measured data show three stages: (1) 290-250 Ma – rapid cooling from >110°C to 70°C/50°C for lower/upper sample correspondingly; (2) 250-50 Ma –a stable temperature stage; (3) 50-0 Ma – slightly increased cooling rates down to modern temperatures. We propose that the first cooling stage is related to late-Hercynian orogenesis and was connected with extensive uplift of the continental landmasses. The nature of the second cooling stage could be a result of Cenozoic cooling of global surface temperatures (Zachos et al., 2001, 2008). It is important, that similar Cenozoic cooling recorded by thermochronometers in northern Alaska has also been attributed to changes in paleosurface temperature (O'Sullivan, 1999). Obvious coincidence of the modelled t-T paths and Cenozoic cooling curve is in agreement with this suggestion. As well as cooling of paleosurface temperatures, part of the Cenozoic cooling stage could be related to uplift and erosion associated with tectonics accompanying with opening of Arctic oceanic basin and/or with a drift of Fennoscandia above the Icelandic plume. The obtained data show that geothermal gradient at the center of Kola Peninsula has remained close to the modern value of 20°C/km for at least the last 250 Myr. Taking into account this geothermal gradient estimation, the AFT data show that the Khibina massif has been exhumed not more then 5-6 km in the last 290 Myr. This volume of erosion is in agreement with earlier estimated depths of the Khibina massif formation based on geophysical data.

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EARLY PALEOZOIC Pt-BEARING BELT OF ALTAI-SAYAN AREA (SOUTHERN SIBERIA): DEBATE ON ALASKAN-TYPE INTRUSIONS CRITERIA

A.V. Vishnevskiy[1,2]
[1]VS Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia
vishnevsky@igm.nsc.ru
[2]Novosibirsk State University, Novosibirsk, Russia

The Cambrian-Ordovician ultramafic-mafic magmatism in the Altai-Sayan area is characterized mainly by island arc and accretionary-collisional geodynamic settings. Numerous plagioperidotite-gabbronorite and peridotite-pyroxenite-gabbro intrusions of this age are known in the Western Mongolia. There are also numerous ultramafic-mafic and mafic intrusions located in the Eastern Tuva region, Mountain Shoria and Kuznetsk Alatau areas of southern Siberia (Russia). The age of many of which still remains uncertain, although a Cambrian-Ordovician seems likely.

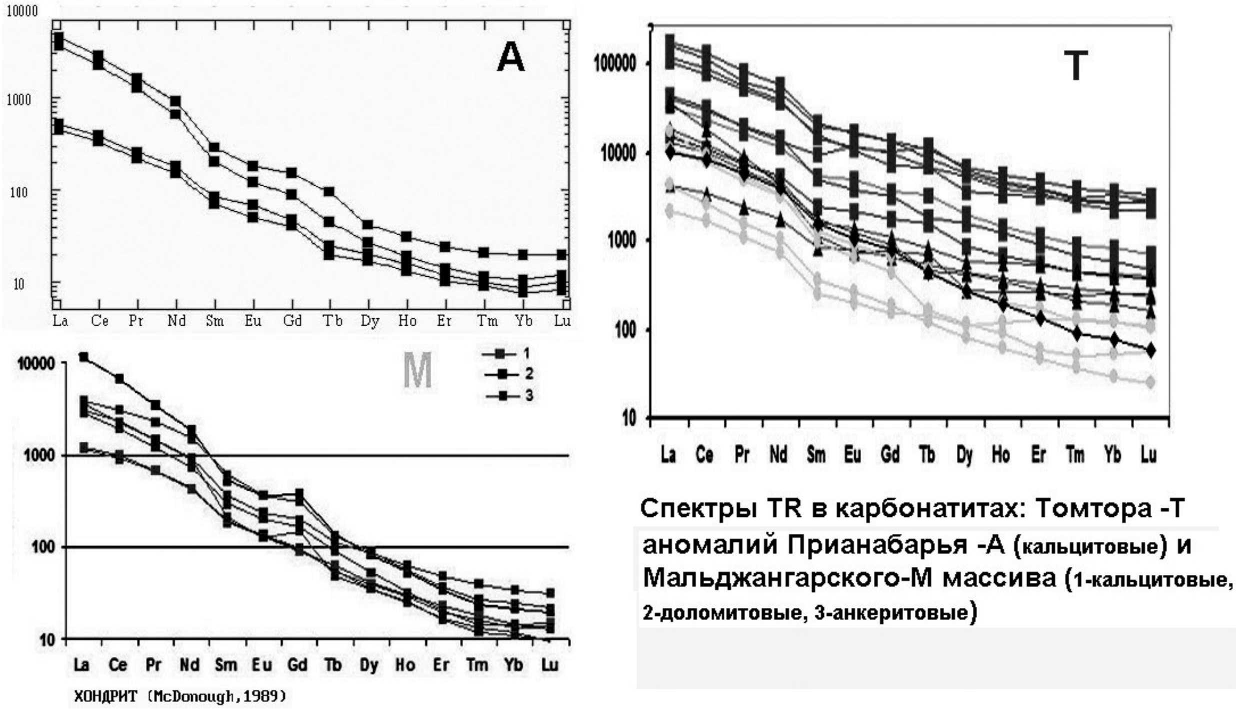
The majority of PGE minerals in gold placers of the Altai-Sayan fold belt (from about 200 placers) are Ru-Ir-Os alloys and associated with numerous fragments of ophiolites that are observed in suture zones of this complicated collage of different terranes. However, in some placers Pt-Fe alloys and isoferroplatinum are predominant. These placers form spatially discrete areas and, presumably are derived from ultramafic-mafic bodies. In some cases, this relationship is quite obvious, while in others it is debatable or even doubtful. The most well-studied occurrence of isoferroplatinum and Fe-Pt alloys in the gold placers is located in alluvials of small rivers flowing from the south to the Ureg Nuur Lake in NW Mongolia. It is suggested that the source of this minerals are rocks of the Uregnuur volcano-plutonic association includes sills, dikes and picrite flows, olivine and diopside basalts and the Nariynsalinskiy intrusion, which consists of dunite, wehrlite, Hbl-bearing clinopyroxenite and olivine hornblendite. The lithological assemblage, together with the island arc geochemical characteristics, the high K/Na ratio, as well as the isoferroplatinum mineralization itself suggest a genetic link between the Uregnuur volcanoplutonic association with classical intrusions of the Ural-Alaskan type, such as dunite-wehrlite-clinopyroxenite-gabbro intrusions of SE Alaska, zoned intrusions of the Urals Platinum Belt and intrusions of the Fifield area in Australia. Thus, it possible that the Early Paleozoic ultramafic-mafic intrusions in Altai-Sayan area form an extended intrusive belt and associated isoferroplatinum and Fe-Pt alloy placers. In addition, there are certain analogies between the Uregnuur volcanoplutonic association, which includes high-Ca ankaramite-like diopside basalts, and the ultramafic-mafic intrusions of the Barangolskiy Complex comagmatic with Cambrian island-arc diopside basalts of the Ust'-Sema Formation in the Altai Mountains, and with bodies of the Lysogorskiy Complex in Mountain Shoria, some of which are considered to be comagmatic with diopside-augite basalts.

In the last decade there has appeared a lot of papers, especially by Chinese authors in which many ultramafic-mafic bodies are considered as Ural-Alaskan type. However, these intrusions are often has quite different geochemical characteristics of rocks, or even does not contain ultramafic rocks, not to mention the zonal structure. It is necessary to more thoroughly analyze the compliance with specific criteria of Ural-Alaskan type intrusions and every time indicate the differences from the classical objects of this type.

PETROLOGY OF SUPER GIANT RARE-METAL DEPOSITS IN PLUME-RELATED ALKALINE ROCKS (EASTERN ANANBAR AREA)

N.V. Vladykin
Institute of Geochemistry, SB RAS, Irkutsk, Russia, vlad@igc.irk.ru

Two rare-metal carbonatite occurrences are found in the Eastern Anabar Area. They include the super giant Tomtor and Maldzhangarsky massifs. The Maldzhangarsky massif was recently penetrated by bore hole to a depth of 100m and is composed of calcite, dolomite and ankerite carbonatites. Silicates rocks have not been discovered yet, they likely occur at a greater depth. The massif is located in the south-east of the Anabar shield. The massif has an ellipse-like outcrop with a diameter of 4.5. km. In addition to carbonatites the carbonatite tuffs occur as well (Vladykin, 2008). TR spectra in carbonatites is given on Figure.



Спектры TR в карбонатитах: Томтора -T аномалий Прианабарья -A (кальцитовые) и Мальджангарского-M массива (1-кальцитовые, 2-доломитовые, 3-анкеритовые)

The Tomtor massif is located eastwards of the Anabar shield on the western slope of the Udzhin uplift. This massif with an area of about 250 sq. km shows a rounded shape and is a ring intrusion with a central carbonatite stock. Its central part consists of carbonatites including ore-bearing tuffs and the outer part is composed of alkaline and nepheline syenites, whose outcrops occupy about 70% of its total area. From the east and west the carbonatites are surrounded by crescent-shaped ijolite bodies. Numerous dikes, sills and diatremes of K-ultrabasic rocks (Porshnev, Stepanov, 1980) including lamproites are found here. The massif cuts the Riphean carbonate-terrigenous deposits of the Ulakhan-Kurungsk formation and overlapped by the Permian primarily terrigenous and Triassic volcanogenic rocks.

The data (Vladykin, 2009) show that two major stages can be recognized in evolution of the massif. The first stage gave rise to the following association of magmatic rocks: pyroxenites and Bt-pyroxenites → mellilites and ijolites, → nepheline and alkaline syenites, → carbonatites. The second stage is related to the eruption of volcanic rocks. In addition, the picrite-lamproite sills and dikes were intruded and the diatremes of kimberlite-like K-ultrabasic rocks and phosphate-carbonate tuffs were produced.

The current K-Ar and Rb-Sr ages of different igneous rocks of the Tomtor pluton range from 800 to 250 Ma (Zaitsev et al., 1992). Such a great scatter is likely related to superimposed processes. To resolve the problem on the Tomtor massif age and its rare-metal mineralization we have obtained U-Pb zircon age of alkaline syenites and ore-bearing tuffs as well as $^{40}Ar/^{39}Ar$ age of micas from carbonatites, lamproites and syenites.

The obtained data suggest that the Tomtor igneous rocks were produced in two stages. They were crystallized in the time spans of 701-675 and 414-387 Ma. These ages well agree with the stages of the within-plate magmatic activity. A number of complexes containing rare-metal alkaline-ultrabasic rocks were produced in the Late Riphean. They mainly occur at the craton's margins along the south-western boundary of the Sharyzhalgai uplift (Belaya Zima, Tagnin, Zhidoi) up to the Aldan shield (Ingili, Arbarastakh massifs) in the east. These massifs were produced between 700 and 630 Ma in marginal faults of the Siberian craton which resulted from the breakup of a large block (Laurasia) from the Rodinia supercontinent.

The Devonian magmatic activity is better explained by the effect of the Vilyui plume on the eastern margin of the Siberian craton. This effect resulted in the lithosphere ruptures and origin of the Vilyui LIP with a radial system of rifts, faults and dike belts. The latter includes the Sette-Daban rift system that is associated with a number of alkaline-basic massifs and carbonated-related rare-metal-rare-earth deposits including Gornoozerskoe, Voin, Gek, Povorotnyi. The ages of massifs are mainly estimated as the Early-Middle Devonian (400-370 Ma). The intrusion of kimberlites is also related to the Devonian plume.

Our data suggest that these two stages can be explained by the cyclic plume activity in the Eastern Anabar Area.

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PLUME (GEOCHEMICAL AND ISOTOPE) SIGNATURE OF LATE MESOZOIC RIFTING VOLCANISM WITHIN THE UDA RIVER SECTOR, WESTERN TRANS-BAIKAL REGION

A.A. Vorontsov, T.Yu. Komaritsyna
Institute of Geochemistry SB RAS, Irkutsk, Russia, voron@igc.irk.ru

In the Late Mesozoic period the Western Trans-Baikal (WTB) region was involved in the intra-plate activity, which resulted in origination of the WTB rift zone further referred to as (WTBRZ) (Yarmolyuk et al., 1995). From west to east it encompasses the Dzhida, Tungusska, Khilok, Ilka-Kizhinga and Uda sectors. Each sector includes systems of depressions developing along with the intense magmatic activity. The Uda sector involves the Uda, Eravna and Zazinsky depressions. Based on K-Ar data and geological evidence some stages of magmatism have been recognized: (1) Middle Jurassic (174-170 Ma), (2) Late Jurassic (160-154 Ma), (3) Early Cretaceous (143-135 Ma), (4) Middle-end of the Early Cretaceous (131-111 Ma), (5) onset of Late Cretaceous (82-77 Ma), (6) end of Late Cretaceous (72-70 Ma) and (7) Eocene (53-51 Ma).

The structure of different age magmatic associations of the Uda sector is composed of rocks which compositions vary from basic to acid. On the boundary about 135 Ma some truly significant changes in the nature of volcanism occur, e.g.: a sharp decrease in the volcanic rock bulk, transition from differentiated associations to basaltoids causing disappearance of volcanics with SiO_2 content over 54 mass %, appearance in associations of alkaline volcanics along with moderately alkaline ones and then a gradual increase of their proportion at completion phases.

The group of basaltoids unites the rocks with silica content ranging from 41.5 to 54 mass %. They all have increased contents of lithophyle elements against the composition of OIB alkaline basaltoids (Sun, McDonough, 1989). The Uda volcanics contain more Ba, Sr, P, Zr, as well as LREE. The HREE, Th and U contents are close to the abundances of these elements in OIB. Much lower contents are common only for Ta, Nb, Ti, however they are significantly higher than in the reference sample of basaltoids of IAB-типа [Kelemen et al., 2003]. On the diagrams of normalized distribution (relative to primitive mantle) these elements produce the concentration minimum, that is reflected in high ratios of La/Ta (15-45), La/Nb (2-4), and that typifies basalts of subduction settings. While volcanism was evolving, the compositions of basaltoids experienced some changes. This primarily concerns the growth of Ta and Nb contents in rocks up to the disappearance of Ta-Nb minimum in rocks of young age groups (83-51 Ma). It is to note, that the contents of the other incompatible elements are practically invariable.

Within the Uda sector Sr and Nd isotope compositions of basaltoids correspond to the mantle sequence by the features of varying isotope signature in time. In a general sense, they fall into the range of values: εSr (T) from -7.2 to 16.1 and εNd (T) from -1.7 to 3.6. Mostly enriched in radiogenic Sr are volcanic rocks of the initial (Mid-Jurassic-Early Cretaceous) stages, their compositions on the εSr(T) - εNd(T) plot are displaced towards model enriched mantle source EMII. In contrast, the isotope compositions of Late Cretaceous rocks are more depleted relative to the radiogenic strontium and more enriched in radiogenic Nd, that defines their displacement into the field of compositions towards the PREMA source. Proper pattern of isotope composition variations is observed in the rocks of the other segments of WTBRZ. These variations indicate a sequential change of (a) Late Jurassic-Early Cretaceous melt source rich in radiogenic Sr ($\varepsilon Sr >> 0$) and depleted in radiogenic Nd ($-2 < \varepsilon Nd < 0$) and (b) Early–Late Cenozoic source having lower contents of radiogenic Sr and higher radiogenic Nd ($-1 > \varepsilon Sr > -8$ и $+3 < \varepsilon Nd < +5$).

Specific compositions of the Uda sector volcanics and the pattern of their change in time agree well between the western and eastern sectors of WTBRZ, as well as the other Late Mesozoic-Cenozoic rift zones of Central Asia. This evidence suggests similar geodynamic conditions for formation with the mantle plumes involved.

Magmatism of WTBRZ and features of its development differ drastically from the magmatic processes proceeding on the convergent boundaries of the Mongol-Okhotsk marine basin and Pacific Ocean. The products of the latter are grouped into magmatic belts conformable with the zones of convergence; their composition is produced by differentiated magmatic associations with geochemical features common for the rocks of supra-subduction zones.

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NEW TEXTURAL AND MINERALOGICAL CONSTRAINTS ON THE ORIGIN OF THE XINJIE FE-TI-V OXIDE DEPOSIT IN THE EMEISHAN LARGE IGNEOUS PROVINCE (SW CHINA)

C.Y. Wang
[1]Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China
wang_yan@gig.ac.cn

Layered mafic-ultramafic intrusions in the Panxi region, SW China, such as the Panzhihua, Hongge, Xinjie and Baima intrusions, are parts of the ~260 Ma Emeishan large igneous province (ELIP) (Zhou et al., 2008). These layered intrusions are volumetrically small relative to the world-known layered intrusions such as the Bushveld Complex in South Africa (cf. Namur et al., 2010). However, a distinct feature of the intrusions in the Panxi region is that large volumes of Fe-Ti oxide ores occur in the middle to lower parts of the intrusions. How such large amounts of Fe-Ti oxides re accumulated in the layered intrusions in the Panxi region is enigmatic.

The Xinjie layered intrusion hosts both Fe-Ti oxide and platinum-group element (PGE) sulfide mineralization. The intrusion can be divided, from the base upward, into Units I, II and III, in terms of mineral assemblages. Units I and II are mainly composed of wehrlite and clinopyroxenite with small amounts of Fe-Ti oxides, whereas Unit III is mainly composed of gabbro. PGE sulfide-rich layers mainly occur in Unit I in the lower part of intrusion, whereas thick Fe-Ti oxide-rich layers mainly occur in Unit III in the upper part of the intrusion. An ilmenite-rich layer occurs at the top of Unit I.

Fe-Ti oxides include magnetite and ilmenite. Both cumulus and intercumulus magnetite occurs in Units I and II. Cumulus magnetite grains are commonly euhedral and enclosed within olivine and clinopyroxene. They have high Cr_2O_3 contents ranging from 6.02 to 22.5 wt.% (Fig. 1), indicating that they are likely an early crystallized phase from magmas. Intercumulus magnetite that usually displays ilmenite exsolution occupies the interstices between cumulus olivine crystals and coexists with interstitial clinopyroxene and plagioclase. Intercumulus magnetite has Cr_2O_3 ranging from 1.65 to 6.18 wt.%, lower than cumulus magnetite in Units I and II. The intercumulus magnetite may have crystallized from the trapped liquid. Large amounts of magnetite in Unit III contains Cr_2O_3 (<0.28 wt.%) much lower than magnetite in Units I and II (Fig. 1).

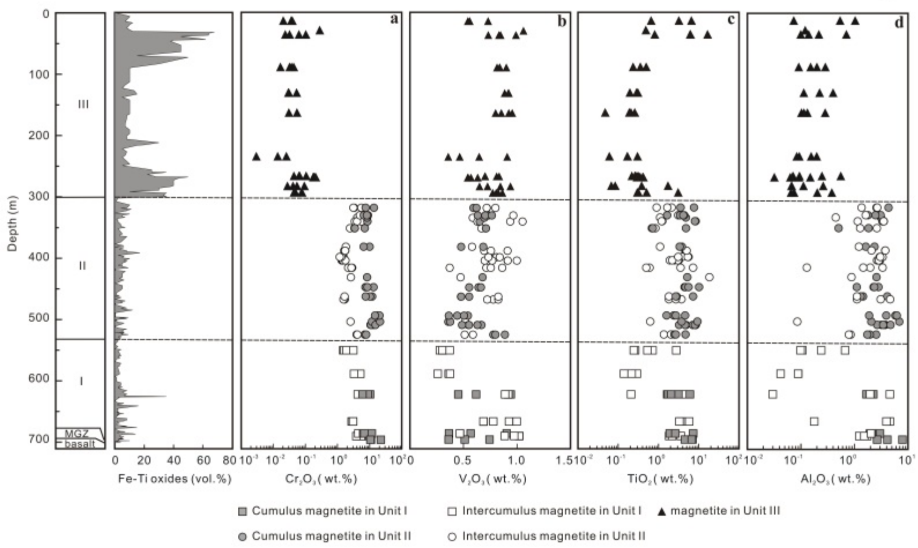

Fig. 1. Magnetite compositions of the Xinjie intrusion showing variations of Cr_2O_3 (a), V_2O_3 (b), TiO_2 (c) and Al_2O_3 (d) with stratigraphic position

Paired non-reactive microstructures, granophyre pocket and ilmenite-rich intergrowth (Fig.2), are representative of Si-rich liquid and Fe-Ti-rich liquid, supporting the existence of an immiscible Fe-Ti-rich liquid formed from an evolved ferrobasaltic magma. The Fe-Ti-rich liquid is estimated to contain 35.9 wt.% SiO_2, 26.9 wt.% FeOt, 8.2 wt.% TiO_2, 13.2 wt.% CaO, 8.3 wt.% MgO, 5.5 wt.% Al_2O_3, 1.0 wt.% P_2O_5. The composition of the Fe-Ti-rich liquid at Xinjie is comparable with the Fe-rich melts in the Skaergaard and Sept Iles intrusions.

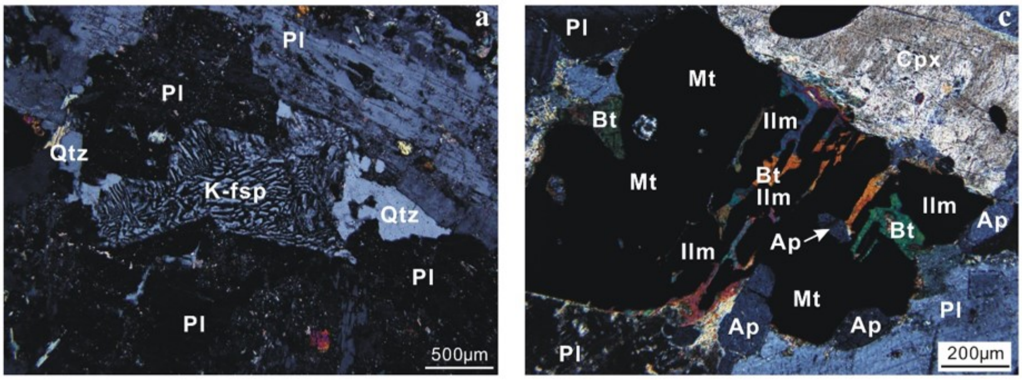

Fig. 2. Photomicrography of mineral intergrowths in Unit III of the Xinjie intrusion. a- granophyric intergrowths composed of K-feldspar (K-fsp), quartz (Qtz) and plagioclase (Pl) fill the planar-sided pockets between plagioclase. Under cross-polarizer, transmitted light. Sample x308; c- ilmenite-rich intergrowths with biotite (Bt) and apatite (Ap). Under cross-polarizer, transmitted light. Sample x265.

We conclude that the cumulus, Cr-rich titanomagnetite in the ultramafic rocks of Units I and II crystallized before or concurrent with early crystallized olivine and clinopyroxene. Intercumulus, relatively Cr-rich titanomagnetite in Units I and II crystallized from trapped liquids and crystallized later than cumulus olivine, clinopyroxene and Cr-rich titanomagnetite. Large amounts of Cr-poor magnetite in Unit III may have formed from immiscible Fe-Ti-rich melts and make up the richest Fe-Ti oxide gabbro layers of the Xinjie intrusion.

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GEOCHEMICAL FINGERPRINTS IN VITIM MANTLE XENOLITHS REVEAL PROGRESSIVE UPWELLING OF ASTHENOSPHERIC MANTLE IN LATE CENOZOIC

K.-L. Wang[1], *M.I. Kuzmin*[2], *S.Y. O'Reilly*[3], *W.L. Griffin*[3], *A. Vorontsov*[2], *N.J. Pearson*[3], *Y.-H. Chien*[1]

[1]Institute of Earth Sciences, Academia Sinica, Taipei, Taiwan, kwang@earth.sinica.edu.tw

[2]Institute of Geochemistry, SB RAS, Irkutsk, Russia

[3]CCFS/GEMOC, Macquarie University, Sydney, Australia

Mantle xenoliths from a picrobasalt quarry in Miocene (14 Ma) and Holocene (~0.65 Ma) basalts of the Bulykhta Riverside and Kandidushka volcanoes in the Vitim volcanic plateau, SE Siberia, have been studied to characterize the subcontinenal lithospheric mantle (SCLM) beneath the region. These xenoliths are dominantly spinel-, garnet-, or garnet–spinel-bearing lherzolites with minor pyroxenites. Equilibrium temperatures and pressures of garnet-bearing lherzolies in Miocene basalts range from 1110 to 1250 °C and 22 to 28 kbar, whereas those in Holocene basalts have similar temperatures (1110–1180 °C) but lower pressures (20 - 21 kbar). The latter thus yield a shallower geotherm than the former. The Fo contents of olivine in these lherzolites range from 89.1 to 90.6, but most fall between 89.8 and 90.2. Trace-element patterns of clinopyroxenes (cpx) in the lherzolites can be divided into three types: depleted, enriched and intermediate. The depleted pattern are typical of unmetasomatised, refractory lithospheric mantle. The enriched and intermediate ones provide fingerprints of different metasomatic episodes. Some lherzolites contain amphibole and/or apatite as evidence of modal metasomatism. Whole-rock and cpx Sr–Nd isotopic ratios of lherzolites in Miocene basalts are more radiogenic ($^{87}Sr/^{86}Sr$=0.70225-0.70561 and $^{143}Nd/^{144}Nd$=0.51288-0.51303) than those in Holocene basalts ($^{87}Sr/^{86}Sr$=0.70244-0.70374 and $^{143}Nd/^{144}Nd$=0.51300-0.51329). It indicates the material sampled from the SCLM beneath the Vitim region in Holocene time is more depleted than the volumes sampled in the Miocene. Os isotope compositions of sulfides display simiar temporal variation; the lherzolites in the younger basalts have less unradiogenic ratios ($^{187}Os/^{188}Os$=0.1066-0.1318) than those in the older basalts ($^{187}Os/^{188}Os$=0.1168-0.1350). Both T_{MA} ages from the least-disturbed sulfides ($^{187}Re/^{188}Os$<0.07) and T_{RD} ages from higher-Re/Os sulfides yield model ages ranging from 0.5 to 3.2 Ga, with peaks around 1.4, 1.1, 0.9 and 0.5 Ga. The Miocene basalts sampled a deeper, more refertilised part of the Archean root, compared to the shallower part sampled by the Holocene basalts.

MANTLE PLUME AND STABILITY OF CRATONS

Q. Wang[1], *N. Bagdassarov*[2]
[1] State Key Laboratory for Mineral Deposits Research, Department of Earth Sciences, Nanjing University, Nanjing, 210046, China
qwang@nju.edu.cn
[2]Institute for Geosciences, University Frankfurt, Frankfurt am Main, 60438, Germany
nickbagd@geophysik.uni-frankfurt.de

Cratons are the ancient and stable cores of continents (>2.5 Gyr old), characterized by the thick (>180 km), cold (40 mW/m^2), refractory and rheologically strong lithospheric keel. The Archean crust accounts for only 7% of the total area of the continents, while studies of the global crustal growth history suggest that >60% of the present continental crust was formed in Archean (Belousova et al., 2010). Therefore, stability or destruction of cratons are closely related with crustal growth history of the Earth. Although magmatism-related thermal erosion has been regarded as one of the most important mechanisms for lithospheric thinning and craton destruction, it is noteworthy that several cratons contain large igneous provinces but still keep their long-term stability, e.g., the Siberian craton with the Siberian Traps in 250 Ma, the Yangtz craton with the Emeishan Flood Basalt Province in 260 Ma, and the Kaapvaal craton with the Bushveld Complex in 2055-2060 Ma. In addition, a strong shear velocity reduction in the lower mantle beneath southern and eastern Africa, which is referred as the African Superplume with a longevity of more than ~50 Ma (Steinberger and Torsvik, 2010).

Mantle plumes can produce high-degree mantle melting and develop large igneous provinces. Most cratonic lithospheric mantle shows a decrease in mean forsterite (Fo) content in olivine with depth, due to higher degrees of partial melting at shallow depth (Gaul et al., 2000). The homologous temperature of olivine, T/Tm, is defined by the ratio between the absolute temperature (in degrees Kelvin) of olivine and its solidus at certain pressure. Higher Fo number in olivine will increase strength of the lithosphere. On the other hand, partial melting can dramatically extract water from peridotites and change the water distribution in the upper mantle because $D_H^{peridotite/melt}$ is 0.005-0.013 (Hirschmann et al., 2009). Comparison between the MT data and the in situ electrical conductivity of mantle rocks in the North China Craton indicates that high resistive lithosphere correspond to partial melting in the crust-mantle boundary and the extremely dry peridotite residues, which reflect the preservation of dry, depleted Archean lithosphere (Wang et al., 2014). Consequently, magmatism-induced compositional change and dehydration will increase viscosity of the lithospheric mantle, which will stop the lithospheric thinning by thermal erosion and trigger lithospheric thickening after mantle plume activity. Therefore, mantle plume is not the key factor for craton destruction. Instead, it will cause the vertical crustal growth by the crust-mantle interaction. The balance between subduction-induced hydration and magmatism-induced dehydration plays an important role in the stability of cratons.

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CONTRASTING PLUME-LITHOSPHERE INTERACTIONS IN THE GENERATIONS OF PERMIAN LARGE IGNEOUS PROVINCES IN CHINA

Y.-G. Xu
State Key Laboratory of Isotope Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, 510640 Guangzhou, PR China

The Permian is an important period in the history of the earth, characterized by the emplacement of at least four large igneous provinces (LIPs) (Emeishan, Tarim, Siberian, and to a lesser extent the Panjal), world-class Ni-Cu-(PGE) sulfide deposits and Fe-Ti-V oxide deposits, and a number of major global events occurred almost simultaneously during the late Paleozoic (Isozaki, 2009), including the double mass extinctions at Permian-Triassic Boundary (PTB) and Guadalupian-Lopingian Boundary (GLB), ocean superanoxia, sharp C and Sr isotopic excursions, sea-level drop and the Illawara geomagnetic reversal. It seems that many sub-systems of the Earth are intimately linked during this particular period, ranging from the core-mantle boundary, lithosphere, atmosphere, hydrosphere and biosphere. This has tentatively been interpreted as the consequences of a Permian superplume activity (Isozaki, 2009; Xu et al., 2014). This paper summarizes some recent advances in the studies of the Emeishan and Tarim LIPs.

The Late Permian Emeishan basalts in SW China are erosional remnants of the voluminous mafic volcanic successions which were emplaced at ~259 Ma over a short period of less than 1 Ma. In order to characterize the crustal processes prior to the eruption of the Emeishan basalts, we examined the nature of the strata underneath the flood basalts (i.e., the Maokou Formation) and the contact between them, and compared paleogeography before and after the Emeishan volcanism. Systematic correlation and comparison of biostratigraphic units of the Maokou limestone, which lay underneath the flood basalts, reveal a domal thinning of the strata in the Emeishan LIP. The isopach for the remnant Maokou limestone is not randomly distributed, but delineates a roughly sub-circular shape. This suggests that the erosion is most likely due to the pre-volcanic domal crustal uplift, which agree remarkably well with those predicted by numerical modeling. Furthermore, systematic spatial variations are observed across the domal structure in the distribution and thickness of clastic and carbonate sediments, the extent of erosion, thickness, and chemistry of volcanic rocks, and the crust-mantle structure, which are best explained by a mantle plume.

The Early Permian magmatism in Tarim, NW China comprises diamondiferous kimberlites, lamprophyres, flood basalts, Fe-Ti oxide ore-bearing layered mafic–ultramafic intrusions, bi-modal dyke swarms, alkaline igneous complexes, rhyolites and pyroclastic rocks. The extent of this intraplate magmatism exceeds 250,000 km^2, making it comparable to LIPs. Three main magmatic episodes in the Tarim LIP, with the first being marked by ~300 Ma small-volume kimberlites, followed by two phases of bimodal magmatism at ~290 Ma and at ~280 Ma, respectively. The ~290 Ma flood basalts are widespread across the province, whereas ~300 Ma kimberlites and ~280 Ma ultramafic–mafic–felsic intrusions and dyke swarms only occur in the Bachu Uplift and around the margins of the Tarim craton.A plume incubation model is proposed to account for the temporo-spatial distribution of the Tarim LIP, in which different styles of plume-lithosphere interaction are emphasized. In the first two episodes, the mantle plume incubating the base of the craton provides the heat that triggered melting of the enriched components in the SCLM. In contrast, adiabatic decompression melting within the plume produced the ~280 Ma magmatic phase. Thinned spots and weak zones at the margins of cratons and mobile belts caused preferential channeling of plume flow and subsequent decompression melting. This explains the localized distribution of the ~280 Ma magmatism in the Tarim LIP.

LATE MESOZOIC MAGMATIC PROVINCE OF EAST ASIA AS A RESULT OF PLUME-LITHOSPHERE INTERACTION ON CONVERGENT PLATE BOUNDARIES

V.V. Yarmolyuk
Institute of the Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry (IGEM), Russian Academy of Sciences, Staromonetnyi per. 35, Moscow, 109017 Russia

A large magmatic province was produced as result of different geodynamic mechanisms in the East Asia in the Late Mesozoic. It is supposed that the province started its formation in the Middle Jurassic. An extended magmatic belt appeared in Transbaikalia as a result of the collision between the flanks of the Mongol-Okhotsk basin. Its occurrences mark the western boundary of the Argun block and stretch up to Big Khingan Ridge forming a vast north-west belt.

The interior part of the Eastern Asia with its recent shape was produced in the Late Jurassic and Early Cretaceous by the accretion from the Pacific plate. The magmatic activity accompanied the accretion and collision over vast areas of the Central and Eastern Asia. Two subprovinces can be recognized within the magmatic province: Eastern and Western differing in nature of the magmatism and geologic evolution.

Eastern subprovince. In the Late Jurassic and Early Cretaceous the magmatic events were associated with the origin of system of volcanic-plutonic belts. The migration of volcanic centers from the west to the east was accompanied by the formation of linear volcanic belts conformal with the accretion structures of the Pacific continental margin. Volcanic belts of Big (160-110 Ma ago), Small Khingan (including an area within Sunlyo (130-100 Ma ago), Tsyamusin complex (120-80 Ma ago), Sikhote-Alin (Late Cretaceous-Paleogene) were produced successively.

The magmatic associations comprise rocks with a wide scatter of composition (from basalts to rhyolites). Basalts bear signatures of subduction but at the same time demonstrate higher concentrations of a number of incompatible elements. A-type rhyolites are common to the acid varieties. The rocks with within-plate characteristics were predominant in different parts of the subprovinvce in the Early and particularly in the Late Cretaceous (Shang et al., 2011, Derbeko, 2011). Such non-standard composition of magmatic products was the reason for a number of models of magmatism origin (e.g. Zhang et al., 2011). It is no doubt that convergence at the boundary of the Pacific and Asian plates played a key role at that time in the evolution of the East Asia.

Western subprovince comprises a group of rift areas which are spatially separated: South-Khangai, Western Transbaikalia, Eastern Mongolian and Central Aldan whose origin is related to a small long-living mantle plume.

The comparison shows the similarity of these volcanic areas both in stages of formation and in the composition of volcanic products. The rocks of the early (Late Jurassic) stage demonstrate high alkalinity resulting in occurrence of rocks being depleted in silica (melanephelinites and melaleucites, leucites and nephelinites, phonolites, trachytes, trachyte-latite and their subvolcanic analogs. The average rocks were predominant.

The magmatic activity was intense in rift areas in the Early Cretaceous. Three phases of activity can be clearly recognized. The most intense activity was found 130-120 Ma ago. The eruption products include subalkaline basalts. The next magmatic stage (1150-125 Ma ago) involves trachyrhyolites, trachydacites and ongorhyolites as well as their intrusive analogs –leucogranites including Li-F varieties. Subalkaline basalts were erupted in the terminal Early Cretaceous. They were less significant as compared with those at the beginning of the Early Cretaceous, but filled the same grabens.

Episodic volcanic activity was common to the volcanic areas in the Early Cretaceous. Small volcanic fields characterized by insignificant eruptions appeared here. Their distribution was not clearly controlled. Basanites, alkaline basalts and teschenites are predominant amongst them.

Composition of magmatic associations. The magmatic associations of the Eastern subprovince contain rocks with a wide scatter of composition. They correspond to calc-alkaline differentiation trend and include basalts, andesites, dacites and rhyolites with the predominance of average and acid rocks. Magmatism was associated with volcanic belts occurring close to boundaries of the lithosphere plates. The basalts in these associations demonstrate relatively low titanium concentrations (TiO_2< 1.5 wt.%) as well as clear Ta and N b deficit. Such geochemical characteristics are typical of IAB-type subduction-related basalts.

Volcanic associations of the Western subprovince demonstrate the predominance of subalkaline basic rocks: trachybasalts, trachyandesibasalts as well as alkaline basaltoids. These rocks show high titanium content (TiO_2> 2 wt.%). Ta and Nb contents increase gradually from Nb/La <1 in the very beginning of the Early Cretaceous to Nb/La >1 in the Late Cretaceous rocks. By geochemical characteristics the rocks from the western segment can be compared with OIB-type basalts.

Model for the origin of the magmatic province. The difference in the composition of magmatic associations in the eastern and western sectors of the magmatic province indicates different geodynamic mechanisms and different sources for the magmatism. It is believed that the collision between the Siberian continent and the North-China craton was accompanied by a successive accretion of a number of terranes which later made the basis for the Amur microcontinent generated between these cratons. As a result, the eastern margin of the continent in its recent shape was finally produced.

The accretion was controlled by convergent processes from the Pacific Ocean. The latter are related to the formation of the Middle Jurassic complexes along the boundaries of the Argun block as well as Early and Late Cretaceous volcanic belts of the Big and Small Khingan and Sikhote-Alin.

In the Early Cretaceous margins of the Asian continent were involved into within-plate reworking processes which covered vast areas of the western part of the Pacific plate. As a result within-plate volcanic areas related to the activity of hot-fingers-type mantle plumes were produced in the western part of the magmatic province outside the influence of convergence processes. As the convergent boundary moved towards the east the influence of the within-plate processes expanded in the same direction and finally covered the Amur microcontinent. Thus, magmatic associations with within-plate characteristics appeared in the volcanic belts of the Big and Small Khingan at later stages.

MOBILITY OF ARGON IN PHLOGOPITE UNDER HIGH TEMPERATURES AND PRESSURES

D.S. Yudin[1], S.A. Novikova[1], A.V. Travin[1], E.I. Zhimulev[1], N.S. Tychkov[1], N.G. Murzintsev[1], T.N. Moroz[1]

[1]V.S.Sobolev Institute of geology and mineralogy SB RAS, Novosibirsk, Russia, yudin@igm.nsc.ru

$^{40}Ar/^{39}Ar$ ages obtained for phlogopites (from 697 Ma to 2.6 Ba) from deep xenoliths (from 2 to 4.3 GPa) of Yakutia kimberlite (Pokhilenko, Alifirova, Yudin, 2013) is much older then age of kimberlite intrusion (360-382 Ma) (Pearson et al., 1997; Kinney et al., 1997; Yudin et al., 2014). In this paper we attempt to understand the behavior of K/Ar isotopic system in minerals under great depths (lower crust, mantle) and specifically during transport of xenoliths in kimberlite melt.

In order to estimate the influence of pressure on the mechanism of argon diffusion in the phlogopite structure we conducted laboratory experiments using multiforce high-pressure "split-sphere" instrument (BARS - 300). Phlogopite from veins intersecting Slyudyanka metamorphic rocks (mine №2) was used for the experiments. Original phlogopite (Mg# ~ 92) are homogeneous in chemical composition and contains (in wt.%) TiO_2 ~ 1.2, F ~ 2.5, BaO ~ 1.0, Na_2O ~ 0.3 and up to 0.1 CaO, Cr_2O_3 and Rb_2O. In pseudohexagonal crystal of phlogopite (106 mm x 94 mm) the inclusion of other minerals were not found. Plates of 3 mm x 7 mm from the middle of the crystal growth zone of phlogopite were taken for the experiments.

Eight laboratory experiments were conducted: without heating, 30 kb; 700°C, 30 kb, 20 min; 800°C, 30 kb, 10 min; 800°C, 30 kb, 20 min; 800°C, 30 kb, 30 min; 900ºC, 30 kb, 20 min; 1000°C, 30 kb, 20 min; 1100°C, 30 kb, 20 min.

The activation energy of argon diffusion estimated by the slope of the Arrhenius diagram, constructed from the experimental data, corresponds to the value calculated for the thermally activated volume diffusion (~ 290 kJ/mol).From the data obtained it follows that the effective closing temperature of K/Ar isotope system in phlogopite increases only by 25°C with pressure rising to about 30 kbar , that doesn't explain the preservation of argon in phlogopite structure at high temperatures (above 1000°C) and at greater depths .

The problem of argon preservation in phlogopite structure under high-pressure conditions at temperatures much higher closing temperature of $^{40}Ar/39Ar$ isotopic system in phlogopite (Dodson, 1973; Giletti, 1974) is considered in Foland et al., 1979. It is known that argon in mica has higher solubility relative to the other mantle minerals (Foland, 1979; Roddick, Cliff, Rex, 1980; Dahl, 1996). As a consequence of the absence of other sinks, argon preferable enters the structure of phlogopite, rather than more dense crystal lattice of olivine, garnet or pyroxene. The situation can be considered in terms of model proposed by Baxter (Baxter, 2003). Mobility argon is described by volume diffusion inside the grain. Exchange of radiogenic argon between phlogopite and the environment occurs through intergranular space, that characterized by a relatively high mobility of argon and limited volume capacity. Migration of argon occurs to the nearest potential sink. Under the mantle conditions, phlogopite grains are the only such sinks. In this case, an effective accumulation of radiogenic argon in phlogopite beans allows to $^{40}Ar/^{39}Ar$ dating of mantle events. Destruction of rocks and the entering of mantle xenoliths in kimberlite melt leads to migration of argon through the intergranular space out of the xenolith. Since the rate of argon migration through the intergranular space is high, partial loss of argon preferentially take place on the periphery of the phlogopite grain. It is confirmed by $^{40}Ar/^{39}Ar$ studies (profile of $^{40}Ar/^{39}Ar$ age spectra of phlogopites from xenoliths indicates partial loss of radiogenic argon (Pokhilenko, Alifirova, Yudin, 2013)).

The above is confirmed by numerical modeling. Provided that the mobility of argon in phlogopite structure at high pressure takes place through the mechanism of thermally activated volume diffusion (confirmed by the experimental data), and the size of the diffusion domain is very large (argon is moved between the grains in the intergranular space), e.g. 1 km, then the phlogopite grains related by the intergranular space will accumulate all the radiogenic argon under high pressures and temperatures of about 1000°C, until the destruction of deep rock and it's individual pieces (xenoliths) penetration in the kimberlite melt.

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EVIDENCE FOR SUBDUCTED CRUSTAL SOURCES OF DIAMONDS FROM SUBLITHOSPHERIC MANTLE

D.A. Zedgenizov[1,2]

[1] V.S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia

[2] Novosibirsk State University, Novosibirsk, Russia, zed@igm.nsc.ru

Diamonds provide a unique opportunity to study parts of the mantle that remain inaccessible by any other means. Certain mineral associations in diamonds, such as majoritic garnet, calcic and Mg-perovskites with ferropericlase, have been interpreted as originating from sublithospheric mantle and may provide samples of the transition zone down to the lower mantle (Harte, 2011). Syngenetic inclusions in 59 diamonds from Sao-Luis river alluvial deposits (Juina, Brazil) were represented by phases of superdeep paragenesis as it was described previously. The dominated inclusions are majoritic garnets, ferropericlases, CaSi- and CaSiTi-perovskites, MgSi-perovskites, TAPP, SiO_2 phases, AlSi-phases, olivines and Fe-sulfides. Rare inclusions of clinopiroxenes, KFsp (K-hollandite?), CF, NAL, grossular, native iron, magnesite, $CaCO_3$+$CaMgSi_2O_6$ (composite inclusions) have been found in separate diamonds. All majoritic garnets we found are of metabasic affinity and in some cases associated with omphacitic clinopyroxenes.

The studied diamonds from Sao-Luis display wide variations of carbon isotopic compositions ($\delta^{13}C$) ranging from 2.7 to -25.3 ‰. The diamonds with inclusions of ferropericlase have very narrow range of $\delta^{13}C$ values from -2.1 to -7.7 ‰, which are closely similar to the “normal” mantle values (Cartigny, 2005; Stachel et al., 2009). From this observation, it can be suggested that their formation may proceed from isotopically homogeneous mantle reservoir that do not support the model of large primordial isotopic variability of carbon isotopes in primitiveEarth’s mantle with a predicted “pyrolite” composition. Diamonds with inclusions of majoritic garnet and CaSi- and CaSiTi-perovskites in many cases show marked differences from the expected “normal” mantle values of $\delta^{13}C$ values. Low $\delta^{13}C$ values (-10÷-25‰) have been observed exclusively in a series of superdeep diamonds with calcic-majorite garnets, Ca-silicates, aluminous silicates and SiO_2 from Sao-Luis.

The variations in $\delta^{13}C$ within individual diamonds may be attributed to either different source of carbon or fractionation effect during diamond growth. No correlation of carbon isotope composition and nitrogen content has been found in individual diamonds. It therefore appears that the cores and rims of the Sao-Luis diamonds precipitated from different fluids/melts with variable N/C ratios and/or under different growth conditions. The highly negative $\delta^{13}C$ values in the core of some diamonds (-20÷-25 ‰) potentially represent organic matter in sediments or altered basalts, and the lower $\delta^{13}C$ values may represent mixing trends towards “normal” mantle compositions (Schulze et al., 2004; Stachel et al., 2005). In this study, we have also described a series of diamonds which show opposite trend of change carbon source from primordial mantle to subducted/crustal (either biotic or abiotic carbon).

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THE FLUID PLUMES MODEL AND FORMATION MECHANISMS OF THE MAGMATIC RESERVOIRES OF TRAP EFFUSION

N.S. Zhatnuev
Geological institute SB RAS, Ulan-Ude, Russia
zhatnu@yandex.ru

At the present day the origin of large igneous provinces (LIP) associated with the mantle plumes and superplumes influence to the lithosphere. An example of LIPs are trap province, where in a relatively short time an effusion and intrusion of the huge amount of magma take place (Siberian Traps, Deccan Trapps, Emeishan Traps, Ontong Java Plateau etc.).

Now we give consideration to the idea of mantle plumes (MP). The hypothesis of mantle plumes originated from the hypothesis hotspots (Wilson, 1963; Morgan, 1971). Eventually it was developed as the idea of hot fields (Zonenschain, Kuzmin, 1983; 1992). The original plume model (Griffiths, Campbell 1990; Campbell, 2005) supposed convective upwelling of the material from the lower mantle, in consequent of which the well-known structure that called a "head and tail».

Russian researchers hypothesis (Letnikov, 2001; Dobretsov, 2008) suggest that the MP form in the process of burnt-through of a continuous channel from the core to the base of the lithosphere. However, the author of this paper (Zhatnuev, 2010) showed that in the extended magmatic channels there are high excess pressures that are much greater than the rocks hardness, and in this case there must be a catastrophic magma eruption to the surface through the lithosphere. In the studyof (Griffiths, Campbell 1990; Campbell, 2005), convective upwelling process is slow, and the time of it should be comparable to the mantle convection time. If such a mechanism would be possible to realize, we could observe vertical plumedeviation at a considerable angle (Puchkov, 2009).

Thus, a new model development with the parameters that would solve contradictions of known models is needed.

This paper's author has proposed the MP fluid model (Zhatnuev, 2012), that suggests the formation of fluid lenses at the core-mantle boundary (CMB), rising in gravitational field to the base of solid lithosphere and causing melting and formation of large magmatic reservoirs. The last can be a source of magma for supervolcanoes and LIP. The reservoirs' volumes and short period of their depletion by way of trap basalts outflow and intrusion are to be proved. It is assumed that the maturation of such reservoir takes place for rather long time beneath the thick lithosphere as numerous of flattened lenses that the plume head, that further ran into the one magmatic chamber. When the reservoir reaches its critical height, the intrusions and sills injection happens in a large scale, besides that, the magma erupts to the surface in the form of trap intrusions. With that, almost full depletion of the chamber, which occurs in this process, probably excludes the repeated global intrusion.

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MESOZOIC STAGE OF THE CARBONATITE AND KIMBERLITE MAGMATISM AT THE ANABAR AREA

S. Zhmodik[1,2], M. Buslov[1,2], P. Ivanov[3], E. Ayriyants[1], D. Belyanin[1,2], A. Borisenko [1,2]
[1]Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia, zhmodik@igm.nsc.ru
[2]Novosibirsk State University, Novosibirsk, Russia
[3]GOAO "Diamonds of Anabar", Yakutsk

Rich Quaternary alluvial diamonds deposits and relict erosion-karst valleys placer deposits of the Pliocene age are founded explored and successfully developed in the Anabar diamond-bearing area (ADA). Source-rocks for the diamonds are still not defined reliably. Numerous discovered kimberlite bodies of the Upper Triassic age are poor with diamonds or do not bear diamonds at all. In addition, kimberlite, lamprophyre and calcite-dolomite carbonatite pipe-shaped bodies were discovered in the area of Ortho-Yarginsk field (OYF). 152 uranium-lead age determinations for 150 zircon grains from carbonatites, kimberlites and lamprophyre of OYF ADA were performed using LA-ICP-MS method at the Hong Kong University at the high resolution mass spectrometer with ionization in inductively coupled plasma - Nu Plasma HR MC-ICP-MS. The obtained data suggest that carbonatite, kimberlite breccia and lamprophyre from OYF pipe bodies have close age of formation. Perhaps it is possible to describe kimberlite magmatism development time as an early to same time with carbonatite magmatism in the area. The average age of carbonatite breccias from pipe numbers 8 and 34, respectively, defined as 152.5 ± 1.3 Ma and 151.56 ± 0.44 Ma. Age of lamprophyre from pipe number 5 defined as 152.25 ± 1.2 Ma and age of kimberlite breccia from pipe 50 defined as 153.71 ± 0.73 Ma.

Morphological peculiarities and internal structure of the magmatic zircons (Fig. 1), dissolution traces and baddeleyite rim presence on the zircons surfaces and the trace elements composition in the zircons and apatites were studied. The data obtained suggests of the existence of kimberlite and carbonatite systems with different physical and chemical parameters, and probably, different fluid saturation.

The main part of the xenogenic zircons from kimberlite and carbonatite breccias are differs by morphology and internal structure following the cathodoluminescence data. They also differ by the level of elements concentrations and ratios of the trace elements. Those zircons correspond to metamorphic type. 207Pb / 206Pb-age determinations for xenogenic metamorphic zircons from kimberlite breccia varies from 1605 to 2090 Ma.

Age of the zircons with sector zoning and high amount of defects defined as 150.06 ± 1.01 million years to 149.12 ± 0.90 Ma and clearly below the age of zircons with a fine-striped zoning of growth.

Thus, the pipe-shaped bodies of the kimberlites, lamprophyre and calcite-dolomite carbonatite of the Upper Jurassic age (Fig. 2, 3) are wide-spreaded in the Ortho-Yarginsk field of the Anabar diamond-bearing area. Mid-Jurassic source of diamonds (kimberlites) on the basis of study of zircons from kimberlites and placers Anabar region stood earlier (Zaitsev, 2006; Grakhanov, Smelov, 2011). The formation of those bodies (kimberlites, lamprophyre and calcite-dolomite carbonatite) is associated with plume magmatism widely represented on the territory of the Siberian Platform: South-Khangai, East-Mongolian, West Transbaikal and Central Aldan (Kuzmin et al., 2010, 2014).

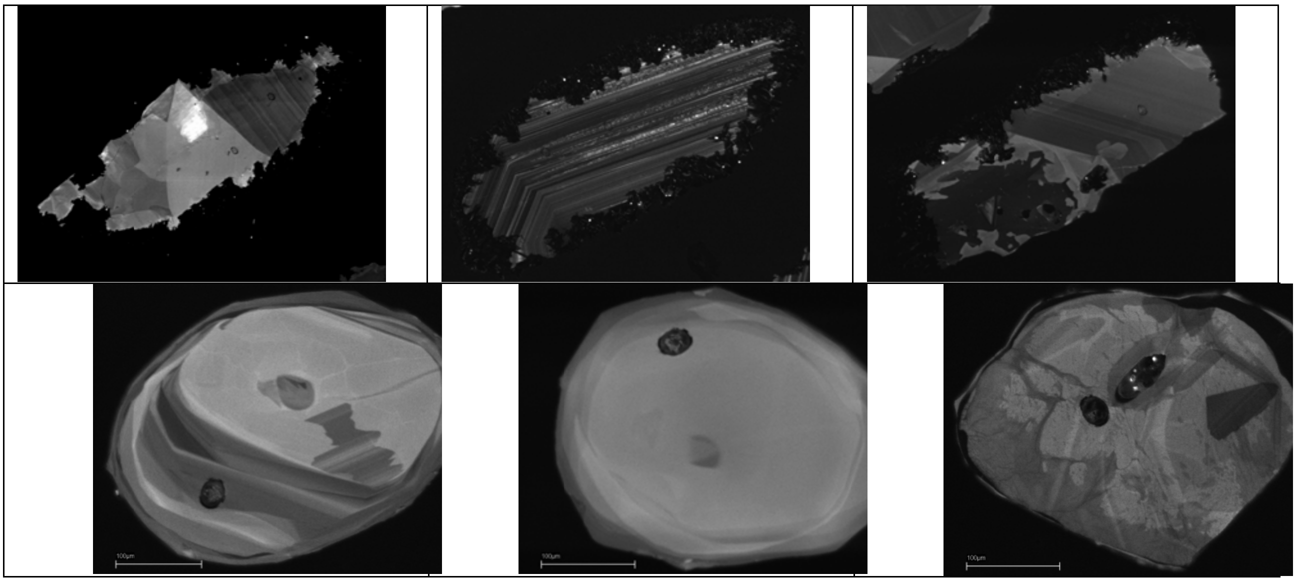

Fig. 1. Selected results of the cathodoluminescence studies for the zircon grains from carbonatite breccias with Upper Jurassic age (upper row) and xenogenic zircon grains of metamorphic origin from kimberlite breccia with Paleoproterozoic age (lower row).

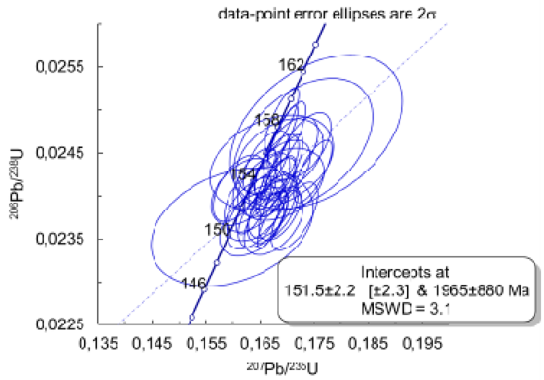

Fig. 2. Concordia plot for the zircons from kimberlite breccia (pipe 50). The average U-Pb age determination for the zircons is 153.7 ± 0.7 Ma. Discordia intersections at 151.5 ± 2.2 and 1965 ± 880 Ma.

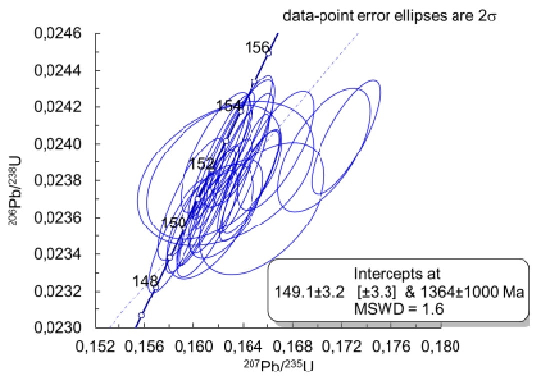

Fig. 3. Concordia plot for the zircons from carbonatite breccias (pipe 34). The average age of the zircons is 151.56 ± 0.44 Ma. Discordia intersections at 149.1 ± 3.2 and 1364 ± 1,000 Ma.

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LARGE IGNEOUS PROVINCES, MANTLE PLUMES AND METALLOGENY IN THE EARTH'S HISTORY

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