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Type intrusive series of the Far East belt of lithium-fluoric granites and its ore content

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Abstract. The evolution and ore content of granitoid magmatism in the Far East belt of lithium-fluoric granites lying in the Russian sector of the Pacific ore belt have been studied. Correlation of intrusive series in the Novosibirsk-Chukotka, Yana-Kolyma and Sikhote-Alin granitoid provinces of the studied region allowed to establish the unity of composition, evolution, and ore content of the Late Mesozoic granitoid magmatism. On this basis, a model of the type potentially ore-bearing intrusive series of the Far East belt of lithium-fluoric granites has been developed: complexes of diorite-granodiorite and granite formations → complexes of monzonite-syenite and granite-granosyenite formations → complexes of leucogranite and alaskite formations → complexes of rare-metal lithium-fluoric granite formation. The main petrological trend in granitoid evolution is increasing silicic acidity, alkalinity, and rare-metal-tin specialization along with decreasing size and number of intrusions. At the end of the intrusive series, small complexes of rare-metal lithium-fluoric granites form. The main metallogenic trend in granitoid evolution is an increasing ore-generating potential of intrusive complexes with their growing differentiation. Ore-bearing rare-metal-granite magmatism of the Russian Far East developed in the Late Cretaceous and determined the formation of large tungsten-tin deposits with associated rare metals: Ta, Nb, Li, Cs, Rb, In in areas with completed intrusive series. Incompleteness of granitoid series of the Pacific ore belt should be considered as a potential sign of blind rare-metal-tin mineralization. The Far East belt of lithium-fluoric granites extends to the Chinese and Alaskan sectors of the Pacific belt, which allows the model of the type ore-bearing intrusive series to be used in the territories adjacent to Russia.

***Keywords*:** intrusive complex; intrusive series; granitoid formation; rare-metal lithium-fluoric granite; ore content; Far East; Pacific ore belt

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Introduction. The subsoil of the Russian sector of the Pacific Ore Belt (POB) encloses thousands of deposits of various metals. Russia ranks first in the world in explored reserves of tin and third in tungsten reserves. In the Far East, 2.1 million tons of tin, 0.4 million tons of tungsten were explored, the largest reserves of gold, silver, lead, zinc, copper, fluorite, mercury, antimony, etc., were estimated. The share of rare metal production in the POB compared to the world production is: Li 45.6 %, Be 74 %, Bi 61 % [1]. The discovery of large rare-earth metal deposits is possible in the region. Mineral resources of the Russian sector of the POB are concentrated in 1,100 deposits and 9,300 ore occurrences associated primarily with granitoid magmatism [2-4].

The most ore-bearing rocks of the Far East – lithium-fluoric granites (LFG) – are the apex of evolution of the Pacific magmatism and originate in focal geodynamic structures with mantle roots [5]. Areas of rare-metal-tin-bearing magmatism form the transregional Far East LFG belt, which is the main metallogenic structure of the outer POB zone and extends to the Southeast Asia [6-8] and

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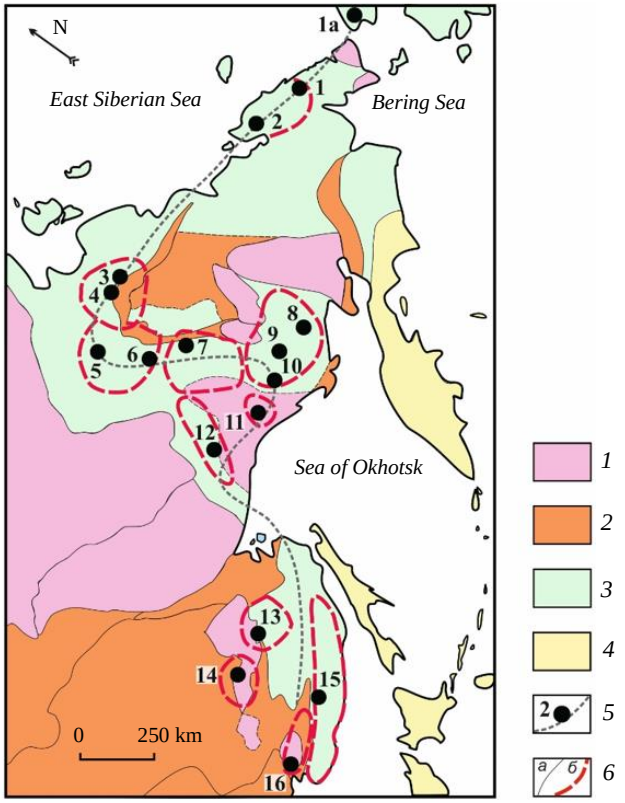

Fig1. Far East belt of lithium-fluoric granites in the Russian sector of the Pacific ore belt

1 – cratons and median massifs; *2* – fold systems of pre-Mesozoic consolidation; *3-4* – zones of Pacific ore belt: outer tin-tungsten (*3*) and inner copper (*4*) zones of Meso-Cenozoic consolidation; *5* – strike line of the Far East belt of lithium-fluoric granites and areas of rare metal-tin-bearing intrusive series: 1 – Iultin, 2 – Kuyviveem-Pyrkakai, 3 – Central Polousnaya, 4 – Deputatskaya, 5 – Central Yana, 6 – South Yana, 7 – Chibagalakh-Erikit, 8 – South Omsukchan, 9 – Orotukan, 10 – Ayan-Yuryakh, 11 – Nilgysyg, 12 – Akachan, 13 – Verkhne-Urmi, 14 – Khingan, 15 – Bikino-Malinovskaya, 16 – Khanka; 1a – Lost River, Alaska; *6* – boundaries of tectonic zones (*a*) and granitogene ring megastructures (*b*) after [5]

North America [9-11] (Fig.1). An urgent problem is the study and reconstruction of the evolution of ore-bearing granitoids of the POB, which contribute to the metallogenic analysis of the Russian Far East and adjacent territories of the USA and China [12]. For this, it is necessary to distinguish the time series of granitoid complexes – intrusive series, to carry out their lateral correlations and reconstruct the history of magmatism.

The aim of the paper is to distinguish the main evolution trends of granitoid magmatism and its ore content in the Russian sector of the POB by identifying and correlating the intrusive series with complexes of rare-metal-tin-bearing granмaccites and developing their gen-era-lized image – the type intrusive series of the Far East LFG belt.

Geological position of the Far East granitoids. Academician S.S.Smirnov divided the POB into the inner copper and the outer tin-tungsten metallogenic zones [4] (Fig.1). The inner zone is characterized by the predominance of Cenozoic volcanic formations. The outer (intracontinental) zone is composed of Mesozoic folded strata with Paleozoic and Precambrian blocks penetrated by numerous Mesozoic granitoid intrusions. Granitoids of the outer zone determine the unique productivity of the POB and are the object of our study [5, 13].

Granitoid magmatism was preceded by mafic magmatism of the subduction and island-arc evolution stages of the region, but basic rocks have a much smaller scale than granitoids [14-16]. The process of granite formation in the Late Mesozoic occurred over a vast area of the Far East and covered not only the Mesozoic folded structures of passive and transform continental margins, accretionary complexes, but also marginal continental volcanogenic belts, ancient Paleozoic and Proterozoic massifs [17-19]. The independence of granitoid distribution on the type and age of the enclosing structures was clearly manifested in the location of the LFG intrusions [5, 20]. Among the granitoid massifs, the Jurassic-Cretaceous intrusions are markedly prevalent; they owe their origin to two tectonic events: collisions of the pre-Mesozoic massifs (Kolyma, Okhotsk, Bureya, etc.) and continental structures of Northeast Asia (Siberian Craton, Aldan Shield, Caledonides and Hercynides of the Central Asian Belt); subduction of the Pacific plates along the margins of the Eurasian continent [14, 21, 22].

The distribution of granitoids is determined by ring geostructures – epicenters of deep focal structures – from ring structures with an area $n{\cdot}10^3$ km^2 (areas of granitoid series and ore districts) and megastructures $n{\cdot}10^4$ km^2 (groups of similar granitoid series and ore regions) to regional structures $n\cdot10^5$ km^2 (granitoid and ore provinces). Three granitoid provinces were distinguished: Novosibirsk-Chukotka (NChP), Yano-Kolyma (YaKP) and Sikhote-Alin (SAP). They contain 11 granitoid areas controlled by deep focal megastructures [5] (Fig.1).

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Methodology. The study of a complex system of granitoids over the giant territory of the Far East requires a comprehensive formational analysis of petrological, metallogenic, tectonic, geochronological, and geodynamic information. The study is based on the materials of forty years of field and laboratory work of the author in the ore districts of Chukotka, the Amur Region and Yakutia, including data of large-scale geomapping of the Verkhne-Urmi, Verkhne-Badzhal, Komsomolsky, Pyrkakaj, Egekhai and Tigriny ore clusters. The author's collection of granites (15 thousand specimens and samples) was studied at the PGO "Dalgeologiya", "Buryatgeologiya", "Sevzapgeologiya", "Nevskoye", Chaun-Chukotka Geological Exploration Expedition, at the Centers for Collective Use of the Mining University, the Institute of the Earth Sciences of Saint Petersburg State University, Yaroslavl Branch of FTIAN RAS, VSEGEI, IGGD RAS, Technoinfo Ltd. The database comprises over 20,000 analyses of granites (ICP-MS, AAS, XRF, SEM, EPMA, SIMS, CL, XRD), more than 100 isotopic age determinations.

Subdivision and correlation of granitoids of the Far East LFG belt were carried out using materials of the State Geological Map (Gosgeolkarta) at scales of 1:1,000,000 (27 sheets) and 1:200,000 (24 sheets) [23]. The Legends of Gosgeolkarta-1000/3 sheet series served as the basis for regional correlations [24]. The used serial legends were updated in 2015 and allow identifying most of granitoid complexes [25-27]. Data on granitoids of the Far East published in the papers by experts of Saint Petersburg Mining University, DVGI, SVKNII, DVIMS and ITIG DVO RAS, IGABM and IGKh SO RAS are used in the work.

The correlation principles of granitoid formations and identification of intrusive series are described in the source [28]. *An intrusive series* is considered as a set of successive complexes of different formations, similar in age, localization, and forming within the structural-compositional zone at a certain stage of intrusive activity. *An intrusive complex* is a set of successive intrusive phases that manifests itself in a fixed geological space and time and is ordered in respect of changes in rock composition and appearance [29, 30].

Formational analysis of regional geological information was carried out following the recommended procedure [28-31]: subdivision and mapping of granitoid intrusions; distinguishing of granitoid complexes and determination of their formational belonging; distinguishing of series (time series) of granitoid complexes in ore districts; regional correlation of granitoid series laterally and distinguishing of the groups of similar series of granitoid complexes within the granitoid metallogenic provinces of the NChP, YaKP, SAP. An increasingly broader synchronization of intrusive series of the same type was carried out with abstraction from particular details of the structure of complexes and served as the basis for revealing the evolution trends of granitoid magmatism in the POB.

Formational analysis is based on the ideas of S.M.Beskin and Yu.B.Marin about the formations of rare-metal granites [32]. The methodology for typification of rare-metal granitoids was developed in [33-35]. Models of the transform continental margin [19, 22] and deep focal structures [5] served as the geodynamic basis for the analysis. The basic postulate was the general sequence of granitoid series formation: a complex of basic granitoids → a complex of mesocratic granites → a complex of moderately rare-metal leucogranites → the main ore-bearing complex of rare-metal microcline-albite granites [33, 34]. In regional correlations, the LFG complexes which retain the characteristic features of composition and structure across the territory, had a marking value [36].Valid complexes of monzonitoids and leucogranites of the Far East were also markers.

The methodological problem of granitoid correlation is heterogeneity of the POB: intrusive complexes and series form areas with different geodynamic regimes and spectra of magmatic formations (volcano-plutonic and plutonic belts, magmatic regions, and areas) [37]. We distinguished three types of plutonic areas: in folded structures of the Verkhoyanides, in zones of tectono-magmatic activation of ancient massifs, and in marginal continental volcanogenic belts. One should also mention the problem of a mismatch in the age of granitoid complexes determined using geological and isotope-geochemical data [36].

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The method of calc-magnesial evolutionary trends by S.M.Beskin was applied in this work, which allows evaluating metallogenic prospects of granitoid series using the petrochemical parameters of early complexes of calc-alkaline granites and leucogranites. The dependence of MgO content in granitoids on CaO was applied, and the following parameters were considered as indicator parameters: slope of linear MgO-CaO trend to CaO axis, CaO content at MgO 1 % and MgO content at CaO 2 % [33].

At the final stage of the research, an interregional correlation of the groups of granitoid series of the same type in the POB provinces [24] was performed, and a model of the type intrusive series of the Far East LFG belt was developed. The analysis of ore content of intrusive complexes and series is based on the concept of a relationship between tin and rare-metal mineralization and granitoid magmatism [3, 32, 38]. Magmatic control of mineral sources is established according to the data of Gosgeolkarta-1000/3; 200/2. The concept of *a commercial type of deposits* (natural geological and mineralogical type of deposits during exploitation of which at least 1 % of the world production of the raw material type is extracted) is used as a scientific and methodological basis [39].

Granitoid complexes of the Far East LFG belt. In the first half of the XX century, the attention of researchers of the Far East territories was focused on the giant batholiths of diorite-granodiorite and granite formations. They were associated with gold and tin presence in the POB. But along with large massifs of the Kolyma granites and the Okhotsk granodiorites, minor and medium granitoid intrusions with elevated alkalinity and silica acidity – leucogranites, granosyenites, etc., occurred in the region. Nowadays, the Mesozoic granitoid complexes of four formational series are distinguished in the Far East [40]: the Late Jurassic-Early Cretaceous complexes of diorite-granodiorite and granite formations (hereinafter, granites) [15, 40, 44]; the Early-Late Cretaceous complexes of monzonite-syenite and granite-granosyenite formations (hereinafter, monzogranites) [41-43]; the Early-Late Cretaceous complexes of leucogranite and alaskite formations (hereinafter, leucogranites) [44-46]; the Late Cretaceous complexes of rare-metal lithium-fluoric granite formation (hereinafter, the LFG) [31, 47, 48]. Distinguishing and correlation of intrusive complexes of the Far East are based on the materials of Gosgeolkarta-1000/2-3 (sheets K-52–53, L-52–53, M-52–53, O-53–56, P-54–57, Q-1, Q-53–55, Q-59–60, R-1, R-53–55, R-58–60 and Gosgeokarta-200/1,2 – sheets L-53-XXII, M-53-XV, XIV, P-55-XXII, P-56-IX, Q-53-IX, X, Q-54-XIX, XX, Q-55-XIX, XX; R-59-XXI, XXII, XV, XVI) [23, 25-27].

Geological and structural conditions of localization and petrological and geochemical features of granitoids in each of the four formation types depend on the tectonic position of intrusive massifs. However, the key features of composition, morphology, size, and ore content of granitoid bodies are determined by their genesis and place in the history of the region. Granite complexes are characterized by large, concordant, poorly differentiated plutons: batholiths, dome-shaped intrusives and stocks ranging in area from dozens to 1,500 km^2, composed of 80-90 % biotite, hornblende-biotite, sometimes binary granites, plagiogranites, and granodiorites. Minor early intrusions of diorites, quartz diorites, gabbroids, and monzonitoids are of subordinate importance. Stocks, dikes, and other bodies of the late phases composed of fine-grained or pegmatoid granites, aplites, pegmatites, granite-porphyries, granodiorite-porphyries, and quartz diorite-porphyrites are common (Table 1).

Monzogranite complexes enclose minor intrusives markedly discordant to folded structures: one- or two-phase stocks, plate-like intrusions with an area of the first square kilometers, dikes, and transverse dike belts. Medium massifs: large stocks, intrusive deposits, laccoliths ranging from 20 to n·100 km^2 are less common. Being multiphase, the massifs are composed of similar monzonitoids differing in modal mineral composition. Intermediate rocks dominate large massifs: monzonites, monzodiorites, syenites; minor intrusives and dike belts are dominated by monzogranites, granosyenites, quartz monzonites, monzoleucogranites and their porphyritic equivalents. Small (10-13 km^2) stocks and laccoliths of alkaline granosyenites, alkaline granites and leucogranites, dike belts of lamprophyres are relatively rare.

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Table 1

Intrusive massifs of valid complexes of diorite-granodiorite and granite formations of the Russian Far East

Intrusive massif[1]	Intrusive complex	Province[2]	Conditions[3]	Deposit[4] (type of commercial mineral)
Taureran*	Taureran	NChP	FS	
Pytlyan	Chukotka	NChP	FS	
Elikchan	Baky-Derbeke	YaKP	FS	
Verkhne-Tirekhtyakh	Baky-Derbeke	YaKP	FS	Titovskoe (B, Sn)
Tirekhtyakh	Baky-Derbeke	YaKP	FS	
Bolshoi Canyon	Canyon	YaKP	FS	Bolshoi Canyon (Sn)
Chjorgo	Kolyma	YaKP	FS	Mal'dyak (Au)
Uaza-Insky	Uaza-Insky	YaKP	FS	
Gromada	Bystrinsky	YaKP	FS	
Polimetallichesky	Svetlinsky	YaKP	FS	Khakandin (Mo)
Magadansky	Magadansky	YaKP	MCVB	
Peresypkinsky	Basugun'ya	YaKP	FS	Natalka (Au)
Odonkan	Tas-Kystabyt	YaKP	FS	
Surginsky	Okhotinsky	YaKP	MCVB	Surkho (Sn, W, Au)
Ergelyakh	Levo-Dzholakag	YaKP	FS	Yakutskoe (Au)
Tarbaganakh	Uemlyakh	YaKP	FS	
Gorbilinsky*	Khungari	SAP	FS	
Synchuga	Badzhal-Dusse Alin	SAP	MCVB	Syuigachan (W)
Priiskovy	Tatibinsky	SAP	FS	
Taudemi	Taudemi	SAP	TMA	

Notes. [1] An example of a massif (petrotype or close to it); polyformational plutons are marked with an asterisk. [2] Granitoid provinces. [3] Conditions of localization: FS – folded structures of Verkhoyanides; TMA – dome-block structures in zones of tectono-magmatic activation of the Precambrian-Paleozoic massifs; MCVB – marginal continental volcanogenic belts. [4] An example of a deposit, large and medium deposits are underlined (according to the Rosnedra classification: https://www.rosnedra.gov.ru).

Monzogranite intrusives are sometimes combined with preceding granite and late leucogranite complexes. They are often enclosed into granite and leucogranite complexes as additional or vein phases [23, 25-27]. Polygenic nature of plutons is one of the problems in subdivision of granitoids of the Far East: in modern schemes, many complexes of granodiorites, adamellites and granites with phases of monzogranites, granosyenites and quartz monzonites are identified. At the same time, in the course of formational analysis, the researchers assign the phases of these complexes to different formations – granite, leucogranite, granite-granosyenite, etc. [42, 44]. The Petrographic Code allows unifying rock associations of different families and orders closely connected by space-time relations [29, Art. III.4.4], into a single magmatic complex. Characteristic examples of heterogeneous plutons enclosing monzogranite intrusions are the Velitkenai (Taureran, NChP), Linlinei (Linlinei, NChP), Tanyurer (Murgal, NChP), East Polousnensky (Yana, YaKP), Negayakh (Negayakh, YaKP), Arangas (Gorbatovsky, YaKP), Levo-Seimkan (Seimkan, YaKP), Iret-Malkachan (Kongalinsky, YaKP), Tumansky (Dukchinsky, YaKP) and others (Table 2).

Leucogranites are represented by biotite and two-mica leucogranites varying from normal to moderately alkaline, less often by alaskites. Granites, leucogranite-porphyries, aplites, and pegmatites occur in subsidiary amounts in leucogranite massifs. Granitoids compose concordant and discordant two-three-phase massifs of medium size (10-350 km^2): intrusive deposits, stocks, laccoliths. Despite the multiphase nature, leucogranite intrusives are petrographically rather uniform, but in the apical parts they have a pseudo-layered structure: are penetrated by intrusive sheets of aplite-like granites, granite-porphyries. In volcanogenic belts, leucogranite massifs are represented by bismalites and etmolites of volcanic depressions composed of rhyolitic ignimbrites. Areal greisenization processes complicate composition of leucogranites in dome-like roof projections.

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Table 2

Intrusive massifs of valid complexes of monzonite-syenite and granite-granosyenite formations of the Russian Far East

Intrusive massif[1]	Intrusive complex	Province[2]	Conditions[3]	Deposit[4]
Kuivyveem	Ekitykyn	NChP	MCVB	
Ostrokamenny	Nunligran	NChP	MCVB	
Velitkenaj*	Taureran	NChP	TMA	Gatlya (Sn)
Gytchen	Monzogranitic	NChP	MCVB	
Pevek*	Chukotka	NChP	FS	Val'kumei (Sn)
Palyansky	Chukotka	NChP	FS	Western Palyanskoe (Hg)
Khara-Sis	Dzhakhtardakh	YaKP	MCVB	Dzhakhtardakh (Sn)
Dikes of Yana, Derbeke rivers	Khunkhadin	YaKP	FS	Khunkhadin (W)
Negayakh*	Negayakh	YaKP	FS	Shturmovskoe (Au)
Arangas*	Gorbatovsky	YaKP	TMA	
Mevchan	Kongalinsky	YaKP	MCVB	
Nyavlenginsky	Dukchinsky	YaKP	MCVB	Nyavleginskoe (Au)
Tsentralny Shchelochnoi	Neorchan	YaKP	FS	
Bilikan	Bilikan	YaKP	FS	Khatakchan (Au)
Yalokokhchan	Yalokokhchan	YaKP	FS	
Pravo-Ot-Yuryakh	Middle Yudoma	YaKP	FS	Ambal (Sn)
Silinsky	Myaochan	SAP	FS	Festival'noe (Sn, W)
Bolodzhok	Dayansky	SAP	FS	Blizhnee (Sn)
Pravo-Valinkui	Ulunga	SAP	FS	Shumnoe (Sn)
Ust-Mikulinsky	Tatibinsky	SAP	FS	Ust-Mikulinskoe (Sn, W)
Sopka Moskalenkova	Monzonitoid	SAP	TMA	Kontaktovoe (Sn)

Notes. See Notes to Table 1.

Leucogranite intrusions of the Far East are often combined with the preceding large plutons of the granite formation [17, 34, 49]. Such polyformational plutons are assigned in Gosgeolkarta-1000 to the Early-Late Cretaceous intrusive complexes, in which leucogranite bodies act as phases: Taureran (Taureran, NChP), Telekai (Telekai, NChP), Pyrkanaivaam (Chukotka, NChP), East Polousnensky and Omchikandin (Yana, YaKP), Negayakh (Negayakh, YaKP), Dusse-Alin (Badzhal-Dusse Alin, SAP), Pervomaisky (Voznesensky, SAP), etc. [23, 25-27] (Table 3).

Table 3

Intrusive massifs of valid complexes of leucogranite and alaskite formations of the Russian Far East

Intrusive massif[1]	Intrusive complex	Province[2]	Conditions[3]	Deposit[4]
Telekai*	Telekai	NChP	MCVB	Vodorazdel'noe (Sn)
Ekug	Ekug	NChP	FS	Ekug (Sn)
Enmyvaam	Leurvaam	NChP	MCVB	
Linliney*	Linliney	NChP	MCVB	
Svetly	Taureran	NChP	FS	Svetloe (W, Sn)
Yanranai	Chukotka	NChP	FS	Prospektorskoe (Sn)
Omchikandin	Yana	YaKP	FS	Tikhoe (Sn)
Takalkan	Yana	YaKP	FS	Takalkan (Be, W)
Ynnakh-Khai	Baky-Derbeke	YaKP	FS	Ege-Khaya (Sn)
Arga-Ynnakh-Khai	Baky-Derbeke	YaKP	FS	Ulakhan-Egelyakh (Sn)
Chalba	Kolyma	YaKP	FS	Chalba-1 (Sn, W)
Kuranakh	Omsukchan	YaKP	TMA	Valentinovskoe (Sn)
Egorlyk	Omsukchan	YaKP	MCVB	Egorlyk (Sn)
Dneprovsky	Omsukchan	YaKP	FS	Dneprovskoe (Sn)
Omchan	Omchan	YaKP	MCVB	Teutedzhak-Fofan (W)
Verkhne-Ten'ka	Neorchan	YaKP	FS	Khenikandzha (Sn, U)
Baryllyelakh*	Tas-Kystabyt	YaKP	FS	Burevestnik (Sn, W)

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End of Table 3

Intrusive massif[1]	Intrusive complex	Province[2]	Conditions[3]	Deposit[4]
Arkhimed	Nyut	YaKP	MCVB	Blizkoe (Be, Mo)
Levo-Ot-Yuryakh	Kyutep	YaKP	FS	
Ketandin*	Ketandin	YaKP	MCVB	Kuchchugui (Mo)
Dusse-Alin*	Badzhal-Dusse Alin	SAP	FS	Sredneippatinskoe (Sn, W)
Khingan	Khingan-Olonoy	SAP	MCVB	Khingan (Sn, In)
Dal'nearminsky*	Ol'ginsky	SAP	FS	Rudnoe (Sn, W)
Pervomaisky*	Voznesensky	SAP	TMA	Yaroslavskoe (Sn)

Notes. See Notes to Table 1.

Rare-metal LFG appearing in many geological maps as alaskites or apogranites compose mainly two-phase complexes of minor intrusions in rare-metal-tin-ore clusters. The complexes comprise dike fields of ongonites and small (1-5 km^2) stocks, harpolites, etmolites of lithium-mica microcline-albite granites [13, 31, 50] (Table 4).

Table 4

Intrusive massifs of valid complexes of rare metal lithium-fluoric granite formation of the Russian FarEast

Intrusive massif[1]	Intrusive complex	Province[2]	Conditions[3]	Deposit[4]
Iultin	Iultin	NChP	FS	Iultin (W, Sn)
Solnechny	Iultin	NChP	FS	Solnechnoe (Sn, W)
Kulyuveem	Pyrkakai	NChP	FS	Pyrkakai (Sn)
Kainvaam stocks	Kainvaam	NChP	FS	Prospektorskoe (Sn)
Odinoky	Omchikandin	YaKP	FS	Odinokoe (Sn, W, Li)
Polyarny	Omchikandin	YaKP	FS	Polyarnoe (Sn, W, Ta)
[Deputatsky]*	Omchikandin	YaKP	FS	Deputatskoe (Sn)
Kester	Kester	YaKP	FS	Kester (Sn, Ta, Nb, Li)
Tumanny	Kester	YaKP	FS	Tumannoe (Sn, Ta, Li)
Verkhne-Burgali	Kester	YaKP	FS	Burgali (Li, Ta, Sn)
Sphynx	Erikit	YaKP	FS	Sphynx (W, Sn)
[Nevsky]	Nevsky	YaKP	MCVB	Nevskoe (Sn, W)
West Orotukan	Orotukan	YaKP	FS	Klimovskoe (Sn)
[Butugychag]	Butugychag	YaKP	FS	Butugychag (Sn, U, Ta)
Nyut stocks	Nilgysyg	YaKP	MCVB	
West Kyutep	Akachan	YaKP	FS	Magan (Sn, W)
Dozhdlivy	Pravo-Urmi	SAP	MCVB	Pravo-Urmi (Sn, W, In)
Obmanijsky	Obmanijsky	SAP	MCVB	Olonoy (Sn, Cu)
Tigriny	Tigriny	SAP	FS	Tigrinoe (W, Sn, Li)
[East Kandoma]	Tigriny	SAP	FS	Stlannikovoe (Sn, W, Li)
Voznesensky	Voznesensky	SAP	TMA	Voznesenskoe (F, Ta, Nb, Li)

Notes. See Notes to Table 1. * In brackets – blind intrusions.

Ore presence in granitoid complexes of the Far East LFG Belt. Ore content of granites is insignificant. Sometimes massifs of the Kolyma, Canyon, Baky-Derbeke, Svetlinsky, Okhotinsky, Levo-Dzholakag, Badzhal-Dusse Alin complexes are accompanied by small deposits of skarn (W, Au, Sn, B), quartz (Au, Sn, W), silicate (Sn, W, U), sulfide (Ag, Pb, Zn, Au, Bi), porphyry (Mo, Cu) commercial types. An exception are large deposits Natalka (Au) and Agylki (Cu, W, Au) in East Yakutia, presumably, associated with the Basugun'ya and Uemlyakh complexes, respectively [23] (see Table 1). Occurrences of quartz and silicate types are relatively diverse: veins, stockworks, mineralized zones of tourmalinization, chloritization, and sulfidization. [14, 22, 45].

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Monzogranites are specialized in Sn, Au, Mo. The accompanying quartz veins, alkaline and silicic metasomatites (feldspatites, tourmalinites, chloritites, beresites, argillisites) contain ore mineralization concentrated in hundreds of small deposits and occurrences of tin, gold, and molybdenum. Deposits and occurrences of silicate (Sn, W, Hg), quartz (Au, Sn, Mo), sulfide (Sn, W, Pb, Zn, Cu, Co), skarn (W, Fe, B) commercial types are associated with massifs of the Taureran, Chukotka, Khunkhadin, Kongalin, Dukchin, Nyavlegin, Bilikan, Myaochan, and Tatibinsky complexes [23]. Bodies of the Middle Yudoma and Myaochan complexes control small porphyry Mo and Cu deposits. Polyformational massifs of monzogranites and leucogranites (Taureran, Negayakh, Tatibinsky complexes) comprise greisen occurrences of Sn, W [17, 43, 44]. No mineral resources shows have been recorded in association with alkaline granites of the Gorbatovsky, Neorchan and Yalokokhchan complexes. Monzogranites rarely generate medium and large deposits: Sn – Valkumej, Festival'noe, Dzhakhtardakh; Au – Yakutsk, Shturmovskoe; Hg – West Palyanskoe deposits are associated with the Chukotka, Myaochan, Dzhakhtardakh complexes [14, 19, 41] (Table 2).

Leucogranites are potentially ore-bearing granitoids in respect of Sn, W, and, to a lesser extent, Be, Mo. Large, medium, and small Sn, W deposits of greisen and quartz-vein commercial types are associated with the Telekaj, Taureran, Ekug, Kolyma, Baky-Derbeke, Omsukchan, Tas-Kystabyt, Badzhal-Dusse Alin, Olginsky, and Voznesensky complexes [23]. The Ekug, Leurvaam, Khingan-Olonoy complexes control porphyry tin deposits with associated In, Pb, Zn, Cu, Bi, As, Ag; Yana, Nyut, and Ketandin complexes – greisen deposits of Be, W, and Mo; the Omchan complex – skarn deposits of W, Au. Numerous tin deposits and occurrences with associated Zn, Pb, Ag, In, Cd, Bi, Ag silicate (tourmaline, chlorite, siderophyllite) and sulfide commercial types are associated with Chukotka, Baky-Derbeke, Yana, Omsukchan, Omchan, Neorchan, Kyutep, Badzhal-Dusse Alin complexes [17, 38, 43] (see Table 3). In leucogranites of the Taureran, Chukotka, Yana, Omsukchan, and Neorchan complexes, the occurrences of Be, Nb, Ta, and Sn are found in rare-metal-tin-bearing pegmatites including one medium-sized Be deposit – Priiskatel' [14, 23, 45].

Complexes of rare-metal LFG have the highest ore potential in the granitoid series of east Russia. The largest rare-metal-tungsten-tin deposits are genetically related to their formation: Pyrkakai stockworks, Odinokoe, Deputatskoe, Pravo-Urmi, Kester, Tigrinoe, Zabytoe, Voznesenskoe, etc. [14, 23, 47]. The main one is the combined greisen-tourmaline commercial type: ore bodies are composed of mineralized zwitters, topaz-mica greisens, fluorite glimmerites in combination with tourmalinite and chloritite [13, 14, 46]. Genetically and spatially zwitter-tourmalinite deposits are related to the Pyrkakai, Kainvaam, Omchikandin, Kester, Erikit, Nevsky, Orotukan, Nilgysyg, Pravo-Urmi, Tigriny, Voznesensky LFG complexes. They enclose the main volumes of Sn, W, Li, F reserves of the Far East and serve as sources of a number of associated strategic minerals: Ta, Nb, In, Bi, Cu, Rb, Be, Cs, Sc, U, Ge, Tl.

Greisen-tourmalinite type is combined with quartz-vein and topaz-vein commercial types of mineralization (Sn, W, Bi, Cu, In, Nb) generated by the Iultin, Pyrkakai, Omchikandin, Butugychag, Akachan, Pravo-Urmi, Obmaniysky, Tigriny complexes. Rare-metal-granite commercial type (Sn, W, Ta, Nb, REE) is of secondary importance; it comprises topaz-lithium-micaceous microcline-albite granites and ongonites of the Omchikandin, Kester, Tigriny, Voznesensky complexes (Table 4) [25-27, 34].

Discussion. *Type granitoid series of the Far East LFG belt.* In the Russian sector of the POB, there are noticeable differences in the morphology, size, composition, and ore content of granitoid complexes in each of the four described formational series. Intrusive complexes of the Mesozoic folded structures prevail; a major place in the geology and metallogeny of the region is held by granitoids of the volcanogenic and plutonic belts (see Tables 1-4). In order to identify the main trends in

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the evolution of granitoid magmatism and develop a typical intrusive series of the Far East LFG belt, an analysis of the composition, age, ore content of granitoid complexes was carried out, their correlation was performed, and intrusive series were identified using the author's and published data [23, 25-27]. When using metallogenic and geochronological data, preference was given to modern results of exploration work and isotope-geochemical dating of granitoids.

Sixteen intrusive series, including complexes of granites, monzogranites, leucogranites, and LFG, have been identified in the Far East LFG belt (Fig.1, Table 5). In some cases, the series comprise polyformational plutons or closely spaced intrusives of various formations. It has been established that the evolution of plutonic magmatism is directed from the Jurassic-Early Cretaceous calc-alkaline granite genesis of elevated basicity (granites) to the Late Cretaceous subalkaline-granite petrogenesis, which includes a successive formation of monzogranites, subalkaline leucogranites and the LFG. Increasing silica acidity and alkalinity are accompanied by a marked symbate decrease in the content of femaphilic petrogenic components, primarily Σ(CaO + MgO) (Fig.2). Among the Mesozoic granitoid series (J_3-K_2), the Khanka series in the southern Far East LFG belt is noted for its Early Paleozoic age (Є-O_3), which follows a similar trend in granite genesis evolution (Table 5).

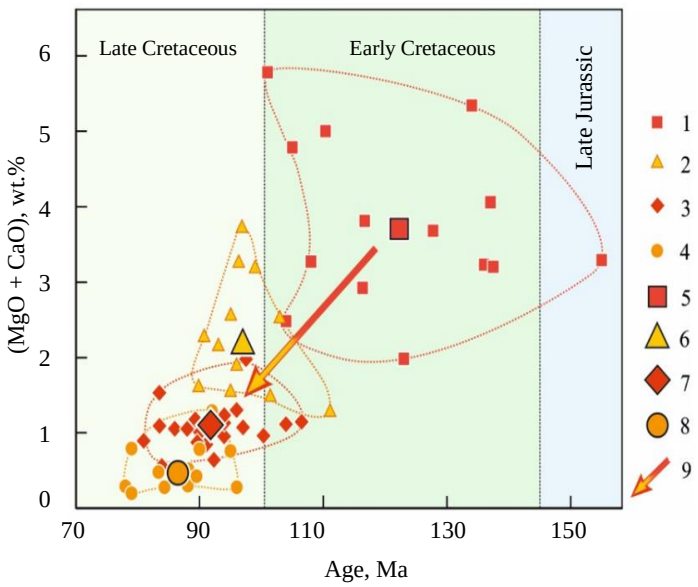

Fig.2. Age and petrochemical features of valid granitoid complexes of the Far East lithium-fluoric granite belt

1-4 – granitoid complexes of various formations (Tables 1-4): 1 – diorite-granodiorite and granite; 2 – monzonite-syenite and granite-granosyenite; 3 – leucogranite and alaskite; 4 – rare-metal lithium-fluoric granites; 5-8 – type granitoid complexes: 5 – granites, 6 – monzogranites, 7 – leucogranites, 8 – LFG; 9 – direction of evolution of granitoid complexes (type granitoid series). Shown are average ages of granitoids of complexes and contents of petrogenic elements by sources [23, 25-27] and the author's data, Paleozoic complexes of the Khanka series are not shown

The distinguished granitoid series of the outer POB zone are characterized by similar composition, ore content, age of intrusive complexes and common sequence of their formation (see Tables 1-5, Fig.2). This allows constructing a model of ore-bearing granitoid series of the Far East LFG belt – a typical intrusive series: granites → monzogranites → leucogranites → LFG (Fig.3).

Type series reflects *the main petrological trend in evolution of granitoids of the Far East LFG belt* – an increase in silica acidity, alkalinity and rare-metal-tin geochemical specialization with decreasing size and number of intrusions, which corresponds to the main global trends in the evolution of ore-bearing granitoid magmatism [30, 32, 35]. The main volume of intrusive complexes (granites and monzogranites) formed in the Early Cretaceous, and the peak of magmatism, regardless of the geodynamic setting in the terranes, falls on the Early/Late Cretaceous boundary (100 ± 10 Ma) [42, 44]. At the same time, most of ore-bearing granitoid complexes appeared in the Late Cretaceous including the final low-volume complexes of rare-metal LFG [13, 31, 47].

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Table 5

Rare-metal-tin-bearing intrusive series of the Far East belt of lithium-fluoric granites

Focal megastructure[1]	Focal structure[2]	Intrusive complexes[3]				Granitoid series with LFG[5]
		Complex of granites	Complex of monzogranites	Complex of leucogranites	Complex of lithium-fluoric granites[4)]	
Novosibirsk-Chukotka granitoid province						
I – Chaunskaya	Iultin	Taureran K_{1-2} (Veshkap)	Murgal K_2 (Verchne-Tanyurer)	Iultin K_2 (Zapadno-Iultin)	Iultin K_2 (Solnechny)	Iultin (1)
– « –	Kuiviveem-Pyrkakai	Chukotka K_{1-2} (Purga)	Ichuveem K_2 (Ichuveem belt)	Chukotka K_{1-2}(Severny)	Pyrkakai K_2 (Kulyuveem)	Kuiviveem-Pyrkakai (2)
– « –	Kuiviveem-Pyrkakai	Chukotka K_{1-2} (Pyrkanayan)	Ichuveem K_2 (Inroginai)	Chukotka K_{1-2} (Kuiviveem)	Kainvaam K_2 (Kainvaam stocks)	Kuiviveem-Pyrkakai (2)
Yana-Kolyma granitoid province						
II – Polousnaya	Central Polousnaya	Baky-Derbeke K_1 (Baky)	Dzhakhtardakh K_2 (minor intrusions)	Yana K_{1-2}(Omchikandin)	Omchikandin K_2 (Polyarny)	Central Polousnaya (3)
– « –	Deputatskaya	Baky-Derbeke K_1 (Arga-Emneken)	Dzhakhtardakh K_2 (minor intrusions)	Yana K_{1-2}(Deputatsky)	Omchikandin K_2 ([Deputatsky])	Deputatskaya (4)
III – Verkhne-Yanskaya	Central Yana	Kolyma J_3 (Kuren'insky)	Khunkhadin K_2 (Khunkhadin)	Baky-Derbeke K_1 (Arga-Ynnakh-Khai)	Kester K_2 (Kester)	Central Yana (5)
– « –	South Yana	Kolyma J_3 (Chibagalakh)	Khunkhadin K_2 (Khunkhadin)	Baky-Derbeke K_1 (Burgali)	Kester K_2 (Verchne-Burgali)	South Yana (6)
IV – Verkhne-Indigirskaya	Chibagalakh-Erikit	Kolyma J_3-K_1 (Khayargastakh)	Alazeya K_2 (minor intrusions)	Negayakh K_1 (Negayakh)	Erikit K_2 (Volshebnik)	Chibagalakh-Erikit (7)
V – Verkhne-Kolymskaya	South Omsukchan	Bystrinsky K_{1-2} (Bystrinsky)	Kongalin K_2 (Sinij)	Omsukchan K_2 (Levo-Omsukchan)	Nevsky ([Nevsky-2])	South Omsukchan (8)
– « –	Orotukan	Siberdyk J_3 (Bokhapcha)	Kongalin K_2 (Verchne-Tal`sky)	Omsukchan K_2 (Verchne-Orotukan)	Orotukan K_2 ([Zapadno-Orotukan])	Orotukan (9)
– « –	Ayan-Yuryakh	Siberdyk J_3 (Siberdyk)	Bilikan K_2 (Khatynnakh)	Neorchan K_2 (Zapadno-Butugychag)	Butugychag ([Butugychag])	Ayan-Yuryakh (10)
VI – Okhotskaya	Nilgysyg	Tas-Kystabyt J_3 (Tas-Kystabyt)	Bilikan K_2 (Olbot)	Nyut K_2(Nyut)	Nilgysyg K_2 (Nyut stocks)	Nilgysyg (11)
VII – Yuzhno-Verkhoyanskaya	Akachan	Uemlyakh K_1 (Uemlyakh)	Sredne-Yudoma K_{1-2} (Sredne-Yudoma)	Kyutep K_2 (Kyutep)	Akachan K_2 ([Zapadno-Kyutep])	Akachan (12)
Sikhote Alin granitoid province						
VIII – Bureino-Badzhalskaya	Verchne-Urmi	Myaochan K_2 (Dzhaki-Unakhta)	Myaochan K_2 (Orokot zone)	Badzhal-Dusse Alin K_2 (Verchne-Urmi)	Right Urma K_2 (Dozhdlivy)	Verchne-Urmi (13)
IX – Bira-Khinganskaya	Khingan	Burinda K_1 (Tatakan)	Butakan-Churkinsky K_2 (Kamenushinsky)	Khingan-Olonoy K_2 (Khingan)	Obmanijsky K_2 (Obmanijsky)	Khingan (14)
X – Primorskaya	Bikino-Malinovsraya	Tatibinsky K_1 (Izluchinsky)	Ulunga K_2 (Burelomny)	Bachelaza K_2 (Tigriny, Bolshoi stock)	Tigriny K_2 (Tigriny, Maly)	Bikino-Malinovskaya (15)
XI – Khankaiskaya	Khankaiskaya	Taudemi Є (Tafuin)	Monzonitoid O_1 (Lipovaya conical hill)	Voznesensky O_1 (Yaroslavsky)	Voznesensky O_3 (Voznesensky)	Khankaiskaya (16)

Note. [1] After [5]. [2] After [43]. [3] Age of complex, in brackets – petrotype. [4] In square brackets – blind intrusions. [5] In brackets number in Fig.1. Data used [23, 25-27].

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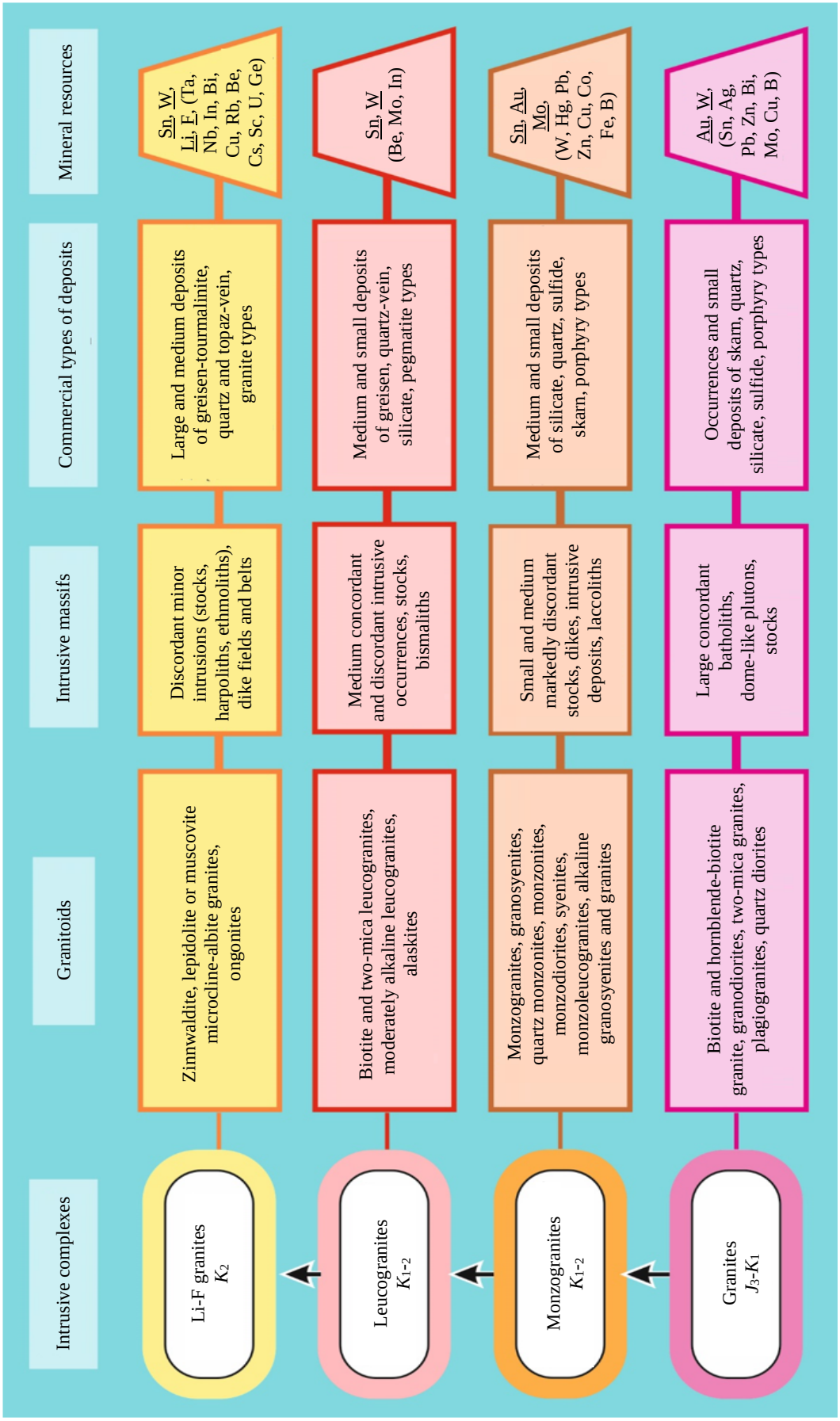

Fig.3. Type intrusive series of the Far East belt of lithium-fluoric granites and its ore content. In brackets secondary mineral resources are given. Granitoids are listed in accordance with their occurrence order, commercial types of deposits – by decreasing reserves. Large intrusive massifs with an area $n \cdot 100$- 1,500 km^2; medium –10-$n \cdot 100$ km^2; minor – the first square kilometres

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The type granitoid series comprises the products of two types of tectono-magmatic events: collisional interaction and activation of the Precambrian-Paleozoic massifs and Mesozoic structures of the POB; subduction interaction of the Asian continent with the Pacific plates. Collisional granitoids are represented by granites in combination with leucogranites, basic and intermediate monzonitoids, and granitoids of the Pacific tectogenesis comprise leucogranites, monzogranites, and the LFG. As the analysis of serial legends of Gosgeolkarta-1000/3 of the East of Russia shows, these two groups of granitoids are close in space due to the common sources and transportation routes of magmas and partially synchronous formation. It can be presumed that the type intrusive series
reflects grading of crustal granite magmatism by mantle monzogranite magmatism under the influence of mantle diapirs in deep focal structures [5]. Later, this leads to melting of leucogranite magma, and finally, local chambers of rare-metal subalkaline-leucogranite magma appear and the LFG form [34].

In the adjacent territory of China, these geodynamic processes led to a similar scenario of granite formation. The eastern margin of Asia was covered by the Late Mesozoic Yanshan tectono-magmatic activation, which determined a successive formation of granite and monzogranite complexes of the Yangtze series, and then of leucogranite complexes of the Nanling series in Jiangxi Province, Inner Mongolia, Khingan and other areas [6, 7, 51]. The Yanshan tectogenesis led to development of intraplate rare-metal-granite magmatism and formation of the southwestern extension of the Far East LFG belt – from Khingan to South China (Qitianling, Qianlishan, Zuishan, Xishan, etc., complexes) [7, 8, 52]. In the Late Cretaceous, the LFG belt also expanded in the northeastern part. In Alaska, in the Caledonides and Precambrian metamorphic sequences of the Seward Peninsula, a chain of LFG stocks and dikes formed: Lost River, Kougarok, Sleitat Mountain [10, 11].

Ore content of the type intrusive series in the Far East LFG belt. The driving forces of magmatism in the Far East LFG belt are heat, magma, and fluid flows in mantle windows of the Pacific lithosphere plate, which subsides during lateral or oblique (transform) movement at the boundary with the Eurasian plate [9, 19, 22]. At the final evolution stage of granitoid series, under the influence of mantle diapirs, massifs of ore-bearing lithium-fluoric granites form similar to the LFG of other tin-ore regions of the world [32, 34] and identified in the POB at the end of the XX century. Such a late discovery of ore-generating granites in the richest resource region is due to objective reasons: small size and weak erosion of the LFG intrusions, their localization within massifs of the preceding granitoids, and the absence of characteristic visual signs of the LFG (green amazonite, pink lepidolite, etc.) [14, 23, 47]. In the largest ore clusters (Deputatsky, Pyrkakai, Iultin, etc.), the LFG are hidden at deep horizons, but their presence is marked by areas of ongonite dikes [13, 31, 48].

Type granitoid series of the Far East can serve as a basis for the geological genetic model of rare-metal-tin-bearing ore-magmatic system with the LFG. This is an ideal intrusive series that determines the complex ore genesis and the formation of the largest deposits of Sn, W, Ta, Nb, Li, Be, Cu, Bi, In, U, fluorite and other minerals. Based on the collected data, the ore content prospects of granitoid complexes of the type intrusive series were assessed applying the procedure of calc-magnesial evolutionary trends [33]. Evolution of granitoids from weakly ore-bearing granites and monzodiorites to the most ore-bearing LFG is accompanied by depletion in calcium and magnesium. According to the petrochemical data on granites, monzogranites and leucogranites, an evolutionary trend was obtained with the following parameters: slope to CaO axis 55°, conditional starting content CaO_{start} (at MgO content of 1 %) 2.10 wt.% (Fig.4). Empirical data show that a significant slope of the calc-magnesial trend and a rather high CaO_{start} value correspond to granitoid series of normal or slightly elevated alkalinity ending in complexes of subalkaline lithium-fluoric granites and commercial tin, tungsten,

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lithium, tantalum, and other rare-metal mineralization (trend slope 55-65°, CaO 0.9-2.7 wt.%. Examples of such complexes are the Erzgebirge complex in Germany, Janchivlan complex in Mongolia, Etykin and Orlovsky complexes in Transbaikal area etc. [33].

Conditional starting MgO_{start} content (at CaO content of 2 %) is 0.94 wt.%; MgO_{start}/CaO_{start} ratio = 0.45. According to these parameters, the intrusive series of the Far East are non-perspective for the discovery of rare-metal pegmatites (MgO_{start} = 0.70-0.85 %; MgO_{start}/CaO_{start} = 0.20-0.45; trend slope 40-55°) and alkaline rare-metal granites (2.10-5.60 %; 1.60-6.00; 67-77°). MgO content and MgO/CaO ratio recorded in granitoids are characteristic of moderately alkaline granite series ending in the LFG complexes with accompanying greisen and quartz-vein tungsten-tin mineralization (trend parameters 0.80-1.60; 0.30-1.00; 54-72°). Based on the application of the procedure of calc-magnesial evolutionary trends, one can draw a conclusion on the potential ore content of the type intrusive series of the Far East LFG Belt. Intrusive complexes of leucogranites and the LFG produce rare-metal-tin mineralization of greisen, quartz- and topaz-vein commercial types as well as rare-metal-granite mineralization (tantalum-bearing cassiterite, tantalum-niobates, etc.) [3].

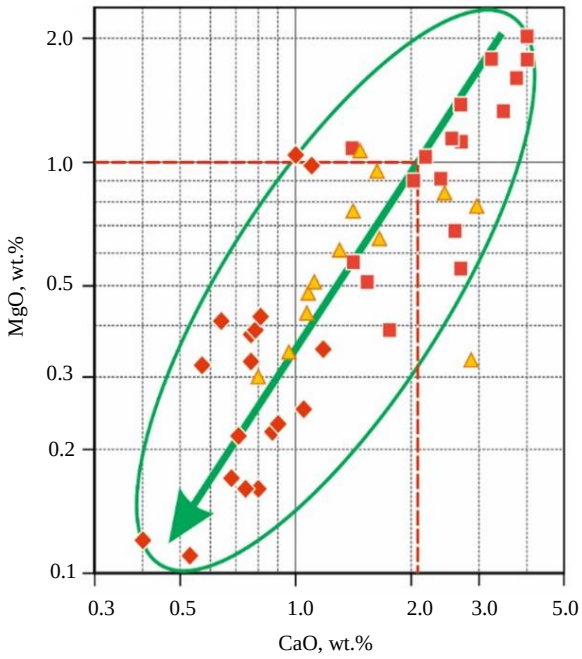

Fig.4. Calc-magnesial evolutionary diagram [33] of type intrusive series of the Far East belt of lithium-fluoric granites

See legend in Fig.2.
Green arrow shows the evolutionary trend of Late Mesozoic intrusive series granites – monzogranites – leucogranites

The presented model data are confirmed by a special metallogenic analysis of the Far East LFG belt. Early granite complexes are of limited minerogenic significance. They are associated with small skarn deposits of tin and boron as well as rare quartz-gold deposits (see Table 1). Over the entire study area, only one medium-sized tin deposit Named after Lazo of the cassiterite-silicate-sulfide formation is known, which is associated with granite formation [23]. Monzogranite complexes control small, sometimes large gold and tin deposits, small tungsten deposits. No mineral deposits are known in association with alkaline granites (Gorbatovsky and Yalokokhchan complexes) (see Table 2). Complexes of leucogranites are tin-bearing and potentially rare-metal-bearing. They are associated with large and medium placer and bedrock quartz-cassiterite deposits of greisen and quartz-vein types. Until the 1980s, they were considered the main sources of rare-metal mineralization (see Table 3). Rare-metal-tin-bearing granitoid series of the Far East end in complexes of rare-metal LFG representing ore-magmatic systems with highly productive zwitter-tourmaline complexes [23]. The largest deposits of Sn, W with accompanying rare metals are associated with the LFG: Pyrkakai stockworks, Odinokoe, Deputatskoe, Iultin, Polyarnoye, Kester, Khingan, Pravo-Urmi, Tigrinoe, Voznesenskoe (see Table 4).

Type granitoid series of the POB corresponds to the geodynamic type of moderately collisional initially normally alkaline plutonic series in folded zones according to the scheme of metallogenic typification by S.M.Beskin – Yu.B.Marin [34]. It reflects *the main metallogenic trend in granitoid evolution in the Far East LFG Belt*, i.e., an increase in ore-generating potential of intrusive complexes with their growing differentiation. Ore-bearing rare-metal-granite magmatism developed in the Late Cretaceous and determined the formation of large tungsten-tin deposits of the POB with associated rare metals Ta, Nb, Li, Cs, Rb, In.

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Practical significance of the type intrusive series in the east Russia is as follows: it allows predicting the most ore-bearing LFG and large rare-metal-tungsten-tin deposits based on mapping of early non-ore-bearing granitoid complexes of territories. The researchers of the POB distinguished a special evolution environment of ultra-acid granites and greisen deposits of Sn, W [3, 4]. Recent data allow clarifying these notions, add lithium-fluoric granites to the group of ore-generating granitoids of the POB, and supplement the Sn-W specialization with rare metals: Ta, Nb, Li, Be, In. Ore presence in the LFG is confirmed in the Nanling and Primorye tungsten-tin-bearing belts of China enclosing the richest ore clusters in Hunan, Jiangxi, Zhejiang, Fujian provinces [6, 8, 52]. The LFG complexes also control a series of rare metal-tin deposits in Alaska: Lost River, Kougarok, Sleitat Mountain, etc. [10, 11].

The article considers only ore clusters with completed granitoid series enclosing rare-metal LFG intrusions. In the POB there are many ore regions with incomplete intrusive series ending in potentially rare-metal-bearing complexes of leucogranites and alaskites. A part of these areas can comprise intrusions of ore-bearing LFG that have not been exposed by erosion and the associated tin and rare metal deposits. The incompleteness of granitoid series of the POB should be considered from not the petrological-petrochemical, but from the metallogenic point of view – as a potential sign of blind rare-metal-tin mineralization.

Conclusions

1. The Far East belt of lithium-fluoric granites lying in the Russian sector of the Pacific ore belt and extending into the adjacent territories of China and the USA is characterized by the unity of evolution and ore content of the Late Mesozoic granitoid magmatism, which allows distinguishing a typical ore-bearing intrusive series: complexes of diorite-granodiorite and granite formations → complexes of monzonite-syenite and granite-granosyenite formations → complexes of leucogranite and alaskite formations → complexes of formation of rare-metal lithium-fluoric granites.

2. The main petrological trend in the evolution of granitoids is an increase in silicic acidity, alkalinity, and rare metal-tin specialization with a decreasing size and number of intrusions. At the end of the intrusive series, small complexes of rare-metal Li-F granites form.

3. The main metallogenic trend in the evolution of granitoids is an increase in ore-generating potential of intrusive complexes with their growing differentiation. Ore-bearing rare-metal-granite magmatism developed in the Late Cretaceous and determined the formation of large tungsten-tin deposits of the POB in areas with completed intrusive series of associated rare metals Ta, Nb, Li, Cs, Rb, In. The incompleteness of granitoid series of the Pacific ore belt should be considered as a potential sign of blind rare-metal-tin mineralization.

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