Geomaterials, 2020, 10, 66-90
https://www.scirp.org/journal/gm
ISSN Online: 2161-7546
ISSN Print: 2161-7538

Ore Forming Systems (Fe, Ti, Ni, Pb, Zn, Noble Metals) of the Transbaikalia Neoproterozoic Greenstone Belts

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How to cite this paper: Tatarinov, A.V. and Yalovik, L.I. (2020) Ore Forming Systems (Fe, Ti, Ni, Pb, Zn, Noble Metals) of the Transbaikalia Neoproterozoic Greenstone Belts. *Geomaterials*, **10**, 66-90.
https://doi.org/10.4236/gm.2020.103005

Received: July 1, 2020
Accepted: July 27, 2020
Published: July 30, 2020

Abstract

It is shown that the ore-forming systems (OFS) of the Vendian-Riphean Greenstone belts (GSB) in the Transbaikalia region were formed in a wide age range: from the Riphean to the Cenozoic. They are grouped into 6 metallogenic types. The noble metal type is divided into 6 metallogenic subtypes differed in time duration intervals of functioning. OFS evolution wore multistage nature inherited from the composition of the GSB primary rocks, with a tendency of the ore generating processes remobilization and regeneration (dynamometamorphism) changing over time by rejuvenation (shoshonite latite and picrobasalt magmatism, mud volcanism).

Keywords

Ore-Forming Systems, Noble Metals, Ore-Generating Processes, Dynamometamorphism, Age, Evolution

1. Introduction

Over the past decades, the doctrine of mineral deposits has taken a sharp turn towards the concept of "Ore-forming systems" (OFS). Its appearance for theoretical as well as applied metallogeny opens up new ways and opportunities for creating more advanced geological and genetic deposits models of minerals various types, developing ore-bearing criteria and expecting strategies. The data in Table 1 show differences in definitions and approaches to OFS typification among researchers who have made a great contribution to the development of the concept under consideration. However, these differences are not fundamental, since they characterize certain elements or parts of the OFS.

Table 1. Ore-forming systems (OFS) in interpretation of various authors.

Authors	Definitions, types and features of OFS
Smirnov, [1]	In relation to the genesis of ore deposits the OFS are regarded as combinations of interrelated geological processes, circumstances and situations, defining conditions of their formation.
Krivtsov, [2]	The OFS generally unite: sources of ore material, transporting agents and energy; ways of transportation of ore material carriers; areas of unloading of carriers and accumulation of ore material; dispersal areas of transporting agents. Characteristic features of the OFS—multistage character of ore material concentration, polygenic and polychronous ore-formation, its discontinuity.
Ivankin, Nazarova, [3]	There was an OFS typization suggested. There are heterogeneous metallogenic rows, considering the diversity of mantle-crustal interactions and geodynamic situations, magmatism and forms of the Earth's degassing: mantle orthomagmatic, magmagenic mantle-crustal, magmagenic intracrustal, intratelluric (orthopneumato-hydrothermal), intratelluric with the "cold" type of fluid evolution ("naphthometallogenic").
Konstantinov, [4]	The formation of ore deposits is defined by the integrated effect of multilevel OFS in the Earth's crust. There are OFS defined, which are zonally distributed across the section of the crust (top-down): lithogenesis, geothermal convection, ultrametamorphism and magma generation, plastic flow and lateral metal migration.
The metallogenic code of Russia, 2012	The OFS are connected in time and space: sources of energy, ore material and transporting agents (ore-generating geological formations); ways of transportation of ore material and areas (environments) of its accumulation (ore-bearing and ore-generating geological formations). According to the character and the features of ore material carrier ore-forming systems are divided into three main groups—hydrogenous (exogenous), hydrothermal (endogenous) and melt (magmatic).

The basic provisions of the OFS concept (energy sources, ore matter, transporting agents, areas and mechanisms of ore accumulation) have become widely used in the creation of geological and genetic deposits models of minerals various types. The appearance of numerous isotope-geochemical data for determining the age of mineralization, ore-bearing complexes containing strata for many deposits in Russia and abroad caused the need to introduce in OFS model construction such indicators (elements) as the duration and their formation multi-staging, the change in time of primary ore-generating and ore-centering processes by subsequent processes of remobilization, regeneration, and rejuvenation [5] [6].

For the territory of Transbaikalia, represented by the Sayany-Baikal and Mongol-Okhotsk orogenic belts as part of the Central Asian folded belt, two metallogenic directions are traditionally developed, differing in approaches in assessing the tectonic-geodynamic settings of the OFS and mineral deposits formation. The first is based on the mobilist concept of lithospheric plates tectonics and terrains regional schemes made on its base. The second direction gives preference to the plume tectonics.

Models of the Transbaikalia region OFS and deposits, created on the basis of largely abstract tectono-geodynamic ideas of the plate tectonics concept followers [7]-[12] are characterized by a number of disadvantages:

- weak or not taken into account at all: the ore preparation processes, the duration and discontinuity of mineralization;
- the mechanisms of mobilization and concentration, sources of ore matter during the OFS evolution from their origin to the final stages of development are not fully looked;
- the correlation between tectonic-geodynamic regimes and ore-forming processes in the OFS formation is practically not examined;
- many model metallogenic constructions, especially for the Mongol-Okhotsk orogenic belt, do not cover the Riphean (Neoproterozoic) "roots" of the OFS, do not take into account the ore-geochemical inheritance peculiar to the final steps, stages of ore genesis.

Prior to our work, from the positions of plume tectonics and intraplate continental riftogenesis, OFS model constructions for the Vendian – Riphean Greenstone trough structures of Transbaikalia were developed only by a small number of researchers [6] [13] [14] [15].

Thus, according to D. V. Rundquist [6], the OFS formation of the Sukhoy Log deposit took place over the course of about 700 million years, starting from the Neoproterozoic to the Cenozoic inclusive. He identified 6 epochs of ore genesis, which characterize 3 periods of the OFS development: ore preparative, ore formation and transformation (rejuvenation).

The authors of the proposed article generally share the approaches of researchers to the problem of the Transbaikalia region, based on the concept of plume tectonics, except for some questions concerning the discussion of individual OFS such elements as ore matter sources and mechanisms for its mobilization, concentration.

Greenstone belts of Riphean age were first identified on the Tuareg and Afro-Arabian shields of North Africa [16]. Later they were allocated in the East Sayany and Yeniseiridge [17]. In North Transbaikalia, the Olokit trough (riftogenic Greenstone belt), previously attributed to the lower Proterozoic GSB, was considered as the most important Riphean ore-forming structure, which is associated with the formation of two super-large deposits-Sukhoy Log (Au) and Kholodny (Pb, Zn) [13] [14] [18].

The formation age period of the previously allocated [19] [20] early Proterozoic Baikal-Vitim Greenstone belt, including the Olokit structure, was later defined as the Riphean (1060 - 550 million years) [21]. In addition to deposits of noble and non-ferrous metals, uranium deposits, ferruginous quartzites formation which is one of the most important minerogenic features that distinguish Greenstone belts from ophiolite ones, are also associated with it.

2. Objects and Research Methods

Our generalization of geological and geophysical materials and especially data of recent years isotope geochemistry in Transbaikalia [18] [22] [23] [24] [25] showed the validity of E. Yu. Rytsk with co-authors [24] conclusion that "new geological, geochronological data do not agree with the proposed paleogeodynamic schemes". Therefore, in order to remove contradictions and inconsistencies between data on ore deposits, geological and geophysical re-study of the 1:200,000 scale, data of specialized geological, mineralogical and isotope-geochemical investigations, a new approach to minerogenic constructions for a number of important minerals (Fe, Ti, Ni, Pb, Zn, noble metals) is proposed for the territory of Transbaikalia, which is to identify the ore-forming systems (OFS) various minerogenic types of the Vendian Riphean riftogenic Greenstone belts, formed in a wide age range and characterized by different duration of functioning time intervals. It is assumed that the evolution of ore-forming systems had the multi-step character inherited from the primary rocks composition (mainly basite-ultrabasite complexes) of Greenstone belts, with an ore-generating processes tendency to be changed in time.

The authors of the article paid special attention to the study of ore objects with noble metal mineralization of Transbaikalia large ore regions -Lena (Sukhoy Log and Pervenets deposits), North Baikal (Mukodek) Muya (Samokut area, Yubileyny, Irba and Irokinda fields), Baunt (Troitsk, Gorny and Talikit fields, Tsipikan zone), Baley (Baley and Taseevo deposits), as well as Pre-Shilka (Kara ore field, Pilnya and Pogrom fields) and Onon-Tura (Ilya and Dybyksa fields) auriferous zones [26]-[32]. A set of methods was used, including structural-geological, lithological-petrographic, mineral-geochemical and isotope-geochemical researches. The study of individual auriferous deposits (Darasun, Karalon, Kedrovo), many manifestations, as well as gold placers, was limited by visual inspection with stone material sampling and subsequent work on the material composition investigation of ores, rocks, schlich concentrates by various chemical-analytical and physical methods. At the same time, the authors sought to obtain the missing new information that complements the published data, and allows us to develop OFS formation models. Depending on the deposits study degree, the reliability level of previously published data describing individual elements, OFS development steps for the above-mentioned auriferous areas and zones, various approaches were used.

Lena region

A set of petrographic and mineralogical methods was used to solve the following issues [33]:

- search for evidence and justification of the spatial and gold mineralization genetic relationship with the riftogenic Greenstone belt (buried by [20], whose basite-ultrabasite complex is assumed to be based on the Bodaybo synclinorium Riphean section;
- dynamometamorphic (tectonic-metamorphic) origin clarification [34] of gold mineralization;
- a new mud-volcanic type justification of Cenozoic age gold mineralization

for the Lena district-as the final step (tier) of the ore-forming system formation.

Muya and Baunt regions

The main objectives of minerogenic and structural-material investigations were [29] [30] [32]:

- the tectonic, structural-morphological, formation-genetic, mineral and geochemical typification of noble metal objects based on detailed lithological-petrographic and mineral-geochemical studies of reference sections, ore-bearing and ore-hosting structural-material complexes;
- the spatial-genetic relationship identification of ore mineralization with Vendian-Riphean volcanic-plutonic basite-ultrabasite complexes. The solution of whether the latter belong to continental riftogenic or accretion-subduction magmatic series;
- the study of oremineralization relationship with dynamometamorphic transformations of various petrotypes rocks.

Baley region

Lithological-petrographic, mineralogical and geochemical studies of auriferous rocks and ores from samples taken in the Baley and Taseevo quarries were carried out [35]. Special attention was paid for obtaining the information necessary to create a geological and genetic model of the "Baley" type ore-forming system (source of ore matter, genesis of ore-bearing complexes, PT formation conditions, fluids composition, evolution steps).

Pre-Shilka and Onon-Tura zones

The tectonic structures of auriferous deposits and fields, lithological and petrographic mineralization control, the ores material composition and ore-hosting complexes were studied. Core material research and mineralogical testing of surface and underground mine workings were widely used. Great importance was attached to mapping thrust structures and associated dynamometamorphic complexes of different composition, tectonic-metamorphic transformations of different ages granitoids, Precambrian rocks of ultrabasite-basite series [27] [29] [31].

3. Research Result

3.1. Main Structural and Geological Features of the Vendian Riphean

Greenstone belts

The Vend-Riphean GSB of Transbaikalia (**Figure 1**), whose distribution area matches the Riphean isotope province by 90% [24] [25], have characteristics, on the one hand, peculiar to the early-middle Precambrian GSB, and on the other hand—to the intra-continental rifts of the Phanerozoic.

In most structural-geological and material characteristics, they are very similar to the "secondary" (type II) Greenstone belts of the middle Proterozoic riftogenic origin, laid on the Archean-lower Proterozoic granite-Greenstone base of

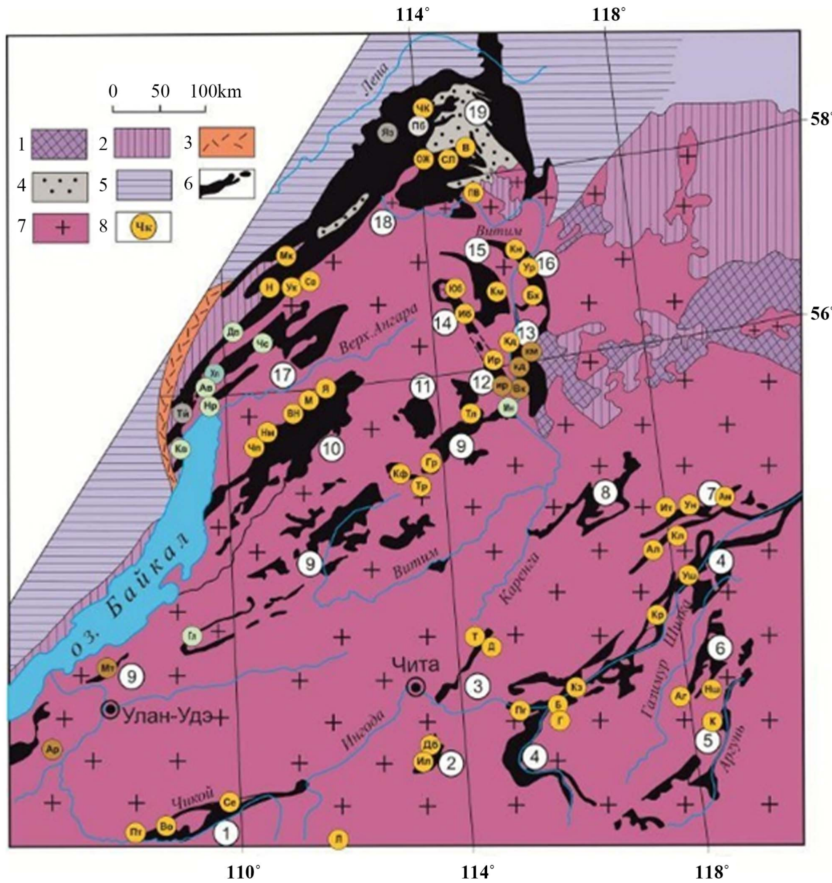

Figure 1. Vendian-Riphean Greenstone belts layout, Transbaikaliaore deposits spatially and genetically related with them. 1—Granulite-gneiss areas; 2—Granite-Greenstone areas (Ar-PR1); 3—Akitkan volcanoplutonic belt (PR1); 4—Riphean deposits of the passive continental margin; 5—Phanerozoic cover of the Siberian platform; 6—Vendian-Riphean Greenstone belts (figures in circles): 1—Chikoy, 2—Tura, 3—Kruchina, 4—Onon-Shilka, 5—Argun, 6—Gazimur, 7—Amazar, 8—Karenga-Olyokma, 9—Kurba-Vitim, 10—Barguzin-Kotera, 11—Uakit, 12—Bambukoy, 13—Tuldun, 14—Kelyana-Irokinda, 15—Gukit-Parama, 16—Karalon-Bakhtarnak, 17—Tiya-Olokit, 18—Baikal-Patom, 19—Nechyora-Patom; 7—Phanerozoic granitoids with rift system complexes; 8—Ore fields, deposits, mineral occurrences: Fe-Tiya (Ty), Yazov (Yaz); Cu-Ni (±PGE)-Chaya (Cha), Baikal (Dv), Avkit (Av), Nyurundukan (Nr), Kivilya (Kv), Goltsy (Gl), Marinkin (Mn); Ni-Co (PGE?): The Pravaya Bystraya(Pb); Fe-Ti (±V,P) Vitimkan (Vk), Irokinda (Ik) Kedrovaya (Ke), Kamenny (Ka), Arsentyev (Ar), Meteshikha (Mt); Pb-Zn-Kholodny (Khl); Au (Ag, ±PGE)-Chyortovo Koryto (CHk), Ozherelye (Ozh), goletsVysochayshy (V), Sukhoy Log (SL), Pervenets-Vernin (PV), Mukodek (Mk), Severny (Sv), Ukuchikta (Uk), Nerunda (N), Karalon (Kr), Uryakh (Ur), Bakhternak (Bkh), Kamenny (Km), Yubileyny (Yb), Irba (IB), Irokinda (IR), Kedrovaya (Kd), Talikit (T), Gorny (G), Karaftit (Kf), Troitsk (Tr), Aksay (I), Medvezhy (M), Verkhny Nyandony (Vn), Namama (Nm), Chipikan (Chp), Amazar (A), Ukonik (Uk), Itaka (It), Klyuchevsky (Kl), Aleksandrovsky (Al), Ushumun (Ush), Kara (Kr), Novaya Shirokaya (Nsh), Alenguy (Ag), Kozlovsky (K), Kazakov (Kz), Baley (B), Golgotay (G), Pogrom (Pg), Talatuy (T), Darasun and Teremka (D), Dybyksa (Db), Ilya (Il) Serginsky (Ce), Voskresensky (Vo), Petrovsky (Pt), Lyubava (L).

cratons with "primary" (type I) GSB [36]. E. B. Nalivkina classified the GSB of the Pechenga-Varzuga rift and Vetreny belt on the Baltic, as well as the Michigan rift on the Canadian shields as type II.

The main features of the Transbaikalia Vend-Riphean GSB are: 1) the vast majority of them were formed on the passive continental margin of the Siberian craton (probably on the continental shelf of the supercontinent Rodinia), which was repeatedly exposed to fragmentation by superplumes (**Table 2**), with the formation of a lystric faults system (faults, shift-throws, fault-shifts) and near-shift basins of the "pull-apart" type [37] [38] in the early (R1-R2) step of the GSB formation.

In the upper Riphean and Vendian the basins of this type are sometimes transformed into structures like "depressed synclines" of mud volcanic areas with fluid-clastogenic lithogenesis (fluid-clastogenic sedimentary formations), typical for carriage-thrust compression structures (for example, Imnyakh, Khomolkho, Aunakit, Vacha etc. suites of the Baikal-Patom GSB); 2) in deep geophysical sections of the earth's crust, the Vendian Riphean GSB, as well as the type II belts of the Baltic shield, are fixed by inclined, probably inheriting the morphostructure of listric faults, narrow density protrusions and high-speed zones of the crust-mantle mixture. They are confined to the largest deep faults, which are laid on the Precambrian cratonic base of the Siberian platform consolidated in the Archean—middle Proterozoic, and have a long history of formation. Individual segments (fragments) of these faults were repeatedly activated over a long period of time, starting from the lower Proterozoic and ending with the Cenozoic. As examples, we present well-studied deep faults that spatially control the placement and formation of the two longest GSB (see **Figure 1**) of the Baikal-Patom (Akitkan-Djerba and Alekan-Maly Tuyukan) and Onon-Shilka (Mongol-Okhotsk). According to the data [39], the Akitkan-Djerba deep fault originated in the lower Riphean (drop), continuing to be formed as a drop up to the Vendian inclusive. Then it was activated (thrust, upthrow) in the lower and middle Paleozoic. The same time steps and kinematics also characterize the history of the Alekan-Maly Tuyukan deep fault. Only, in contrast to the Akitkan-Djerba one, its activation continued in the upper Paleozoic and Triassic (upthrow). A. N. Demin with co-authors [40] established the following time sequence of the Mongol-Okhotsk deep fault development and a series of fault zones feathering it: Riphean-right and left shifts, as well as interfaced tension cracks. The maximum amplitude of the earth's crust blocks movement for individual shifts is

Table 2. Formation steps of the Transbaikalia Vendian-Riphean Greenstone belts [18] [21] [22] [23] [24] [25].

Steps million years	Age intervals based on isotope-geochronological Dating data (million years)				The estimated age of the superplume manifestation, million years
	Sedimentary and mud-volcanic formations	The volcanic rocks of basic-ultrabasic series	The plutonic ultrabasite-basite complexes	Volcanites of intermediate-acid composition	
Early 1600-810	1600-850	1100-900	1100-840	840-810	1000 and 850
Middle 900-650	900-850	830-650	830-675	850-650	850 and 730
Late 700-550	665-585	700-550	618-585	650-590	730 and 610

estimated at 20 km. The tension cracks are oriented in the sub-meridional and sub-latitudinal pressure; PZ1—activation of the right-side shift system; PZ2 - PZ3—stretching conditions accompanied by volcanism; PZ3 and MZ1—formation of two shift systems. Herewith, particularly intense tectonic movements occurred in the C1 - T1 interval under compression deformation conditions. These researchers also noted the formation in R3-V and Cambrian and O1 of near fault deflections made by volcanogenic-terrigenous-carbonate strata with a total thickness of up to 8 km. The formation duration and kinematics of deep faults and feathered them the tectonic disturbances determine the morphostructural pattern (see **Figure 1**) and the geological structures nature of the Vendian Riphean GSB. An example of the Baikal-Patom and Onon-Shilka belts comparison (**Figure 2**, **Figure 3**) just shows how much more complicated the morphostructure of the second (**Figure 2**) one compared to the first (**Figure 3**) one, as well as the structure of its profile, characterized by the melange structures presence, and the powerful development of Paleozoic dynamometamorphites zones [42]. These dynamo-metamorphites areas, previously included as part in the stratified formations of Kulinda and Onon suites in ophiolite cross section [43] and trace the complex sigmoidal-branching morphological structure of the Onon-Shilka belt. They are believed to have originated in the D-C period during shear dislocations [42].

3.2. Rocks Volcanic-Plutonic Associations of the Vendian-Riphean Greenstone Belts

The volcanic-plutonic magmatic associations of the Transbaikalia Vend-Riphean GSB have a great similarity to those typical of the "secondary" Greenstone belts (type II) that perform the middle-Proterozoic rift zones of the Baltic shield. According to data [36], the volcanogenic rocks of the type II Greenstone belts belong to the trachyandesite-basalt, andesite-basalt and picrite-basalt petrochemical series, and plutonic complexes are mainly represented by gabbro-verlitic, peridotite-pyroxenite—norite and alkaline-gabbroid formational petrotypes.

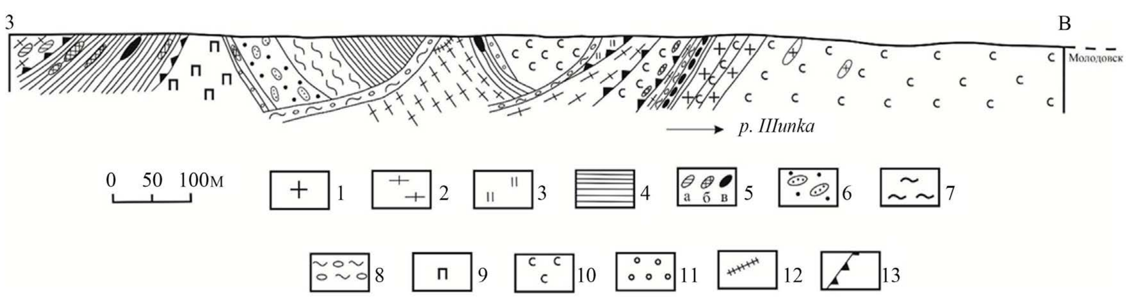

Figure 2. Molodovo geological profile of the Onon-Shilka Greenstone belt structure fragment (left Bank of the Shilka river). 1—Diorites; 2—Biotite-actinolite-plagioclase dynamoslates on diorites; 3—Dynamoslates on granodiorites; 4—Biotite and biotite-hornblende gneiss blastocataclazites on gabbroids; 5—Budins: a-epidote-garnet-pyroxene dynamometamorphites on anorthosites with titanium-magnetite and ilmenite mineralization, b-amphibolites, b-serpentinites; 6—Brecciated garnet-pyroxene rocks; 7—Foliated serpentinites; 8—Zones of serpentinite melange with actinolithite boudines; 9—Partially biotized, amphibolized, talcosed plagiopyroxenites; 10—Massive serpentinites; 11—Ferruginous quartzites; 12—Plagiogranite dike; 13—Thrusts.

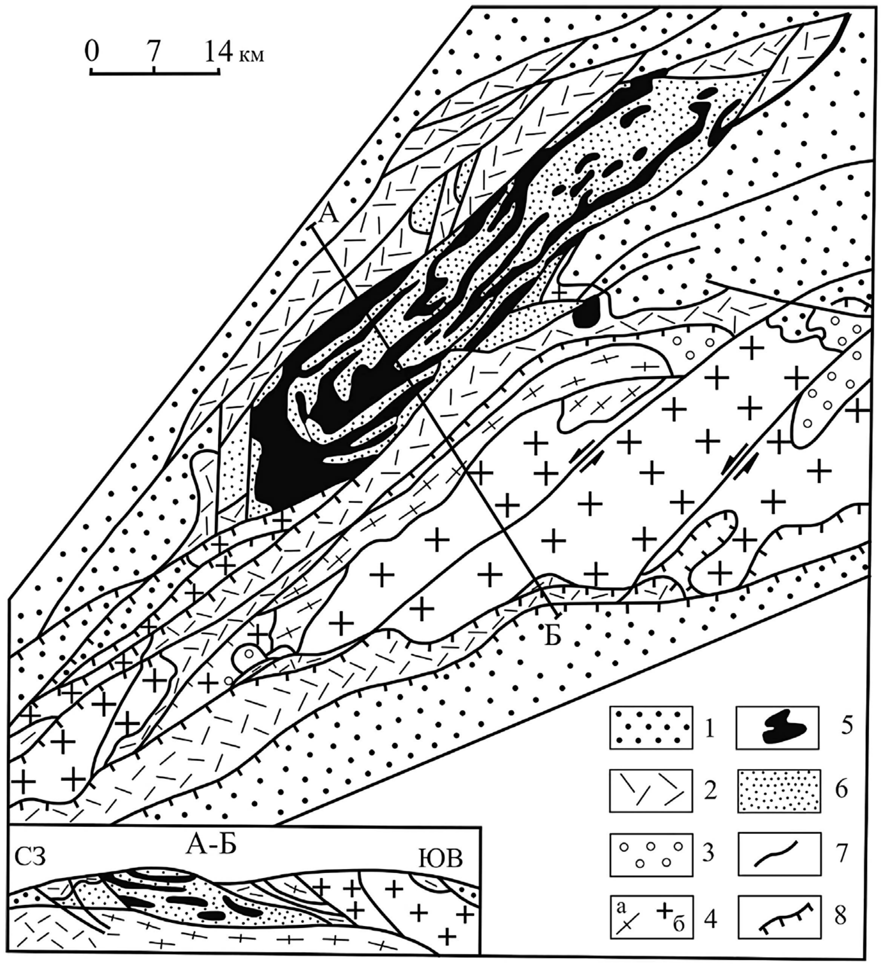

Figure 3. Bystraya fragment structure of the Vendian-Riphean Baikal-Patom Greenstone belt. Handwritten materials of state geological survey works of the 60 - 80 s of the XX century and published data were used [39] [41]. 1—Gneiss-granites and migmatites, the Chuya-Kodar complex granites of the Greenstone belt foundation; 2 - 6—Dynamometamorphic complexes of the Greenstone belt, related to stratified and magmatic formations (shown in parentheses): 2—carbon psammite cataclasite and dynamoslates, conglomerate like tectonobreccias ("terrigenous formation-Balaganakh series"); 3—conglomerate like tectonobreccias, dynamoslates on volcanites of basic composition, ferruginous quartzites ("volcanogenic-terrigenous formation of Medvezhy Suite"); 4—quartz psammite apogranite cataclasites and high-alumina dynamoslates ("purpol suite"); 5—amphibolites, dynamoslates and blastomylonites of actinolite, plagioclase-chlorite-actinolite, plagioclase-epidote-chlorite composition, serpentinites, actinolite-serpentine shales with carbonate on the main and ultrabasic rocks of the komatiite-tholeite association ("vulcanogenic-plutonic basite-ultrabasite complex"); 6—arcose sandstones, gravelites, conglomerates, tuffs, tuffites ("tuffogenic-terrigenous formation"); 7—shifts and other discontinuous disturbances of not identified kinematics; 8—thrusts.

Many petrologists, as a result of many years detailed specialized research, identified by E. B. Nalivkina rocks of picrite-basalt petrochemical type, were assigned to the komatiite series, including peridotite and basalt (often with spinifex structures) komatiites, as well as boninites [44]. Herewith, a specific petrochemical group of basalt komatiitesis identified, called "vetrenites", peculiar totype II Greenstone belts of Baltic shield intracraton rifts (Vetreny belt, Imandra-Varzuga, etc.). It is also represented by foliated ultrabasite-basite massifs, norites dikes and gabbro-norites of the Fennoscandian and Canadian shields. This group of rocks bears the traces of intensive crust contamination of the primary komatiite melt (enrichment with lithophilic elements, increased content of alkalis and light rare earths). The main parameters of "vetrenite" magma were specified: MgO 9 - 18 wt%, TiO_2 0.5 - 1.0 wt%, SiO_2 < 53 wt% and its average chemical composition is given [44].

In geological cross sections of the Transbaikalia Vendian Greenstone belts the presence of metamorphosed komatiites with spinifex structures [45], basaltic komatiites, picrites, meymechites, picrobasalts, boninite-like rocks, potassium rhyolites, volcanites of the bimodal and basalt-andesite-rhyolite series had been identified. A large distribution of sub-alkaline varieties of basalts, andesites, and rhyolites is noted. Carbonatites of Vendian age, alkaline basites and ultrabasites are found in several belts. As for chemical composition, the basic volcanites of considered GSB (according to the discriminatory diagram of [46], except for single cases, refer to the field of continental plume associations. According to the Al_2O_3 and TiO_2 content the GSB basite-ultrabasite associations are represented by various types and series, from low-aluminaones to high-alumina ones, from low-titanite ones to high-titanite ones. The dioritoids bodies (gabbro-diorite-plagiogranite, tonalite-trondemite series)-products of metabasites (amphibolites) partial melting—are spatially and genetically related to the distribution fields of GSB ultrabasite-basite complexes.

For the Transbaikalia minerageny, the high-magnesian petrochemical series of the Vendian Riphean GSB volcanic-plutonic rocks are of the greatest interest because the ore-forming systems origin is related to them producing a large range of minerals deposits (Fe, Mn, Ti, Ni, Cr, Co, Cu, Pb, Zn, Mo, W, Au, Ag, platinum group elements).

By age, spatial location, manifestation scales, ore-geochemical, formation-petrographic features, high-magnesian petrochemical types, covering a number of ultrbasic, basic and medium rocks differing with SiO_2 content, form not similar combinations. Their various combinations, which are peculiar to one or another Vend Riphean GSB, also have similar features for fragments (segments) of the same belt. We believe that the main reason for the spatiotemporal formation-petrographic, petrochemical, and mineral-geochemical variability of high-magnesian volcanic-plutonic associations is the duration, intensity, and kinematics of the deep faults formation to which they are confined. This is probably due to the petrochemical differences between the high-magnesian volcano-plutonic associations of the northern (Buryatia) and southern (Transbaikalia Krai) parts of the Transbaikalia region (**Table 3** and **Table 4**). For example, boninite trends in the petrochemical composition evolution of high-magnesian igneous rocks are characteristic for the Transbaikalia northern part and the presence of spatially combined komatiite-meymechite series (for example, the Tyya-Olokit GSB [47].

Table 3. Chemical composition of high-magnesian rock types modified in different degree by dynamometamorphism of the volcano-plutonic association of the Northern. Transbaikalia Vendian-Riphean GSB. Data were used [12] [18] [27] [29] [30] [32] [39] [43].

Elements oxides	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	35.90	31.73	35.79	37.90	45.02	45.00	50.90	51.50	51.10	51.20	49.57	40.26	48.80	37.70	52.70
TiO_2	0.02	<0.02	0.26	0.27	0.34	0.59	0.18	0.34	0.29	0.23	0.38	<0.02	0.74	0.12	0.93
Al_2O_3	1.30	0.60	5.11	4.98	6.24	7.50	4.40	4.70	6.90	8.20	14.08	1.19	13.80	15.30	14.96
Fe_2O_3	9.54	2.84	6.98	6.04	2.74	1.73	1.89	0.01	2.90	1.50	2.09	0.99	0.94	0.87	2.46
FeO	3.57	5.36	7.54	7.13	9.24	8.11	7.43	8.60	7.60	8.63	5.87	3.99	8.88	4.63	5.80
MnO	0.26	0.10	n.d	n.d	n.d	0.17	0.21	0.13	0.19	0.20	0.16	0.12	0.17	0.10	0.12
MgO	35.45	31.83	29.00	28.24	22.16	22.28	19.09	19.37	16.52	14.82	12.42	19.05	10.74	10.23	8.13
CaO	0.50	2.26	2.87	3.85	7.16	7.76	12.34	11.39	10.82	12.90	11.65	6.90	12.15	8.66	6.90
Na_2O	0.10	0.02	0.09	0.09	0.10	0.27	0.46	0.67	0.95	0.35	1.58	0.02	1.58	0.20	3.10
K_2O	0.06	<0.01	0.05	0.05	0.05	0.05	0.48	0.15	0.52	0.06	0.74	0.15	0.37	3.61	1.93
P_2O_5	0.03	<0.05	n.d	n.d	n.d	<0.05	<0.05	<0.05	0.06	<0.05	0.02	<0.05	0.07	n.d	0.23
s.a.c.	13.16	25.02	9.90	10.66	6.80	6.02	2.38	2.83	1.74	0.38	1.22	27.03	1.28	17.61	2.00
Total	99.89	99.76	97.59	99.21	99.85	99.53	99.81	99.69	99.59	99.52	99.78	99.70	99.52	99.03	99.21

Vendian-Riphean GSB: Baikal-Patom—analyses 3 - 5; Kelyana-Irokinda—analyses 2, 6, 10 - 12, 14; Parama-Samokut—analyses 7 - 9; Selenga-Vitim—analyses 1, 11, 15. Petrochemical types: 1 - 4—peridotite komatiites; 5, 8, 12—boninites; 6, 7, 9, 10—basalt komatiites; 11, 13—basalt komatiites of the "vetrenite" type (according to the classification of V. S. Kulikov and co-authors, [44]). Note: n.d-content not detected; s.a.c—samples after calcination.

Table 4. Chemical composition of different degree dynamometamorphosed rocks of ultrabasite-basite stratified arrays in Onon-Shilka Greenstone belt profile.

Element oxides and impurity elements	1 (10)	2 (7)	3 (9)	4 (6)	5 (6)	6 (4)	7 (5a)	8	9
SiO_2	38.89	40.46	44.48	50.96	51.24	51.47	45.35	48.26	45.14
TiO_2	0.05	0.05	0.10	0.82	1.23	0.82	4.87	0.84	1.36
Al_2O_3	2.13	2.56	10.62	9.81	8.77	10.08	21.47	9.22	9.76
Fe_2O_3*	7.39	7.76	9.96	9.14	9.70	8.87	10.98	11.66	11.29
MnO	0.11	0.01	0.23	0.13	0.16	0.14	0.12	0.13	0.14
MgO	36.57	36.12	16.82	15.35	16.87	15.82	1.26	15.04	15.86
CaO	0.30	0.34	13.17	6.29	8.69	6.39	3.83	11.26	12.00
Na_2O	<0.20	<0.20	1.41	1.98	1.65	2.28	4.92	0.80	1.18
K_2O	0.01	0.01	0.88	1.90	1.39	1.76	2.28	0.30	0.42
P_2O_5	0.01	0.01	<0.1	0.20	0.23	0.27	0.10	n.d.	n.d
s.a.c.	14.82	12.50	2.39	3.66	n.d	2.22	4.40	2.40	3.39
Total	100.28	99.82	100.06	100.24	99.93	100.12	99.58	100.01	100.01

1 - 7 sample analyses results, taken from Molodov profile. In brackets—the rocks name, listed in the symbols to Figure 2; 8 - 9 apopyroxenite amphibolites from the Kara aurifereous field. Petrochemical types of high-magnesian rocks: 1, 2—peridotite komatiites; 3 - 6, 8, 9—basalt komatiites of the "vetrenite" type (according to classification of Kulikov and co-authors, [44]); 7—ore anorthosite; n. d.—content not detected; s.a.c—sample after calcinastion.

Moreover, in this part of the region the foliated plutonic massifs are represented by four formational types: dunite-peridotite-gabbroid, dunite-troctolite-gabbroid, lherzolite-troctolite-gabbroid, anorthosite-pyroxenite-gabbroid ones. Relatively rare is the "vetrenite" branch of basaltic komatiites (Table 3). A specidic group of basalts with high magnesia number, related to the type of platform platobasalts known in profile of Medvezhevskaya suite on the southwestern flank of the Baikal-Patom GSB (published by [48]). The average chemical composition that we calculated from 18 analyses of these rocks (published by is as follows in wt%:

SiO_2—49.74, TiO_2—0.98, Al_2O_3—14.05, FeO*—12.08, MnO—0.20, MgO—10.15, CaO—10.15, Na_2O—2.27, K_2O—0.17, P_2O_5—0.18. At first glance, this group main petrochemical parameters of basic volcanic rocks correspond to the range of their vavriations for magma products of basaltic komatiites contaminated with crustal matter, *i.e.* "vetrenites". However, an average chemical compositions comparison of the considered platobasalts and "vetrenites" shows significant differences between them. First of all, this refers to the MgO content, which is almost four percent higher in "vetrenites". On the contrary, the platobasalts compared with the "vetrenites" are noted to have higher TiO_2 average concentrations (almost a third), Al_2O_3 and FeO* with minor variations in contents of Al_2O_3, CaO, Na_2O, K_2O and P_2O_5 (just above in platobasalts) and SiO_2 (slightly lower in platobasalts). E. Yu. Rytsk and V. S. Shalaev [48] consider platobasalts of Medvezhevskaya suite as the magmas products of the continental lithospheric mantle—homogeneous in composition and poorly differentiable, respectively, not subjected to contamination as basaltic komatiites of "vetrenits" type. They pointed out their analogy with platform traps of the Karoo and Deccan. Note that in the Medvezhevskaya suite Riphean volcanic rocks of Baikal-Patom GSB north-eastern flank (Bystraya fragment) weakly magnesian platobasalts are not known, and high-magnesian peridotite and basalt komatiites, sometimes with spinifex structures, are widespread.

Petrographic-formational and petrochemical features of high-magnesian volcanic-plutonic complex of the Transbaikalia southern part Vendian-Riphean GSB are as follows (**Table 4**): the gabbro-anorthosite component dominance in the layered arrays construction; the boninites petrochemical trend absence in the komatiite series formation; relatively wide-spread basalt komatiites of "vetrenits" type.

3.3. Geological-Tectonic and Material Characteristics of the Ore-Forming Systems Main Factors Formation

The main factors in the formation of a long, but intermittent multi-step evolution of the Transbaikalia Vendian Greenstone belts ore-forming systems are: 1) transformation of intracontinental Precambrian rifts, starting from the Archean into shear tectonic-metamorphic zones; 2) shoshonite-latite magmatism; 3) mud volcanism and other manifestation forms of the Earth cold degassing. These factors determine the main elements of ore-forming systems models that produce various mineragenic and genetic types of mineral deposits: sources of ore matter, mechanisms for the mobilization and concentration of ore components, conditions for localization and spatial placement, as well as ore-geochemical specialization and the manifestation scale of ore mineralization.

The first factor. Extended deep mantle-crustal faults characterized by a long multi-step formation history over a wide range of geological time are referred to shear zones. From the early Precambrian to the Mesozoic and Cenozoic. Herewith, the early morphotectonic pattern of the high fault activity early stages is inherited. Ural geologists made a great contribution to the research of shear zones, considering them as integral ore-bearing tectonic structures with polygenic and polychronous mineralization [49]. Using the example of the Ufaleian gneiss-amphibolite complex, they have well studied the shear zones laid down in the conditions of continental intracratonic rifting in the Riphean (1.95 - 0.98 billion years) and in the Phanerozoic passed five stages of activation (million years): 660-580, 480-440, 440-375, 375-320, 320-220. Thus, V. A. Koroteev *et al.* [49] in the Urals have been identified six steps of deep faults transformation into shear mineragenic zones, covering a large period of geological time, approximately equal to 1.7 billion years. Herewith, we note the appearance of an ore-bearing high-magnesian ultrabasite-basite volcano-plutonic association at two time periods of Riphean faults tectonic-magmatic activation—1980-980 million years and 440 - 375 million years.

Despite the differences in geodynamic and genetic approaches existing between the authors of this article and Ural geologists, we emphasize the empirically established similarity in the tectonic-metamorphic evolution of the Riphean intracratonic rifts of the Ural and Transbaikalia regions, manifested in the form of shear tectonic zones. First of all, this refers to the multi-step segment of a long time formation, the features of ore-geochemical and mineragenic specialization. The dynamometamorphism of seam tectonic zones, which determines the spatial geological features of ore zones and occurrences, *i.e.* the structure of ore fields, plays a key role in the multi-step formation of the TransbaikaliaVend-Riphean GSB ore-forming systems. It is the reason for the ore elements mobilization from various age and material composition of rock complexes that fell into the zone of near the fault tectonic activation, their transportation. Below we provide evidence of this role.

Construction and structures of shear zones

The shear zones with the Vendian-Riphean GSB represented by dynamometamorphic complexes with ore mineralization are classified into a number of hierarchical areal mineragenic taxa of various dimensions: ore-bearing areas and zones, ore nodes, zones, fields (deposits) and occurrences [27] [29] [32] [50] [51] [52]. Prior to our work, there were some attempts to identify large shear zones based on prevailing dynamometamorphic structures [42] [52]. So V. S. Kuteynikov and N. S. Kuteynikov [52] for the South-Eastern flank shear zone of the Baikal-Patom GSB, where the Kholodny Pb and Zn deposit is located, the tectonic-metamorphic structure is defined as a megamelange containing arrays of ultrabasite-basite composition as blocks—tectonic outcrops ranging in size from the first to tens of kilometers. According to their data the megamelange cementing substrate is represented by micaceous schales and argillites. A three-hundred-kilometer diaphtorite-shale dynamometamorphic belt tracing the shear zone of the Onon-Shilka GSB was identified by I. G. Rutstein [42]. However, as it is shown earlier by A. N. Demin [53], shear zones of the Transbaikalia Vend-Riphean GSB experienced at least five time steps of deformations during their formation: 1) early—R tectonite, 2) blastotectonite zones, 3) zone of tectonic breccias, cataclasites, mylonites, ultramylonites, 4) brittle deformations in the previously formed tectonites (chip cracke and mirror slide), 5) area kakirite (loose soil-dressy masses) This was the reason for a very heterogeneous tectonic structure of shear zones various segments and ultimately determined the variety of morphogenetic types of deposits ore-controlling structures we identified and studied during the long-term investigations of ore-forming systems, producing noble metal and polymetallic deposits. They are represented by tectonic polymictic melange, serpentinite melange, autoclastic melange, losange, mineralized structures of single-seam and multi-seam thrusts, as well as steeply falling shifts.

Deformation mechanism of ore material mobilization and concentration in the shear zones

The mobilization and concentration of ore elements to industrial values was carried out by a deformation mechanism (destruction, recrystallization and re-recrystallization, fluids formation) in the course of a multi-step dynamometamorphic transformation of GSB primary rocks. It is assumed that the release from the primary rocks, redistribution and accumulation of ore components occurred due to mechanochemical reactions of new chemical compounds and minerals formation in the conditions of shift tectogenesis. For example, the most productive ore bodies with noble metals, occurred in the process of GSB basite series rocks dynamometamorphism was a result of the latter transformation by scheme: orthoamphibolites—(cataclasites, mylonites and pseudotachylites)—dynamoslates of albite-quartz-sericite composition ("berezites")—granular quartz. To substantiate this conclusion and the dynamometamorphic genesis of industrial ore mineralization in shear zones at the Mukodek auriferous field of the Baikal-Patom GSB [26] special geochemical investigations were conducted (**Figure 4**, **Table 5**). From the analysis of their results it follows:

- at an early step (stage) of dynamometamorphism, the original GSB volcanites acquire an increased geochemical background of native Au (14 mg/t). Herewith, almost 99% of its particles are in a fine dispersed state (2 - 6 microns)
- at the second step of dynamometamorphism, on average, the number of Au particles increases by more than 2 times, while the proportion of very fine particles decreases by almost 19%. The average content of Au increases by 10 times, *i.e.* there is a process of its mobilization and concentration. With a significantly increased level of dynamometamorphic complex rocks gold mineralization composing the ore zones, the Au particles distribution trend (**Figure 4**) is complementary to that of primary rocks ;
- at the final step, about 40% of fine gold is enlarged with an avalanche-like growth of its average contents (more than 100 times);
- with increasing gold content and enlargement during ore formation, a strong positive correlation between the number of its particles and concentrations persists in early metavulcanites. There is a sharp increase in the very gentle inclination angle (7˚) of the correlation field characteristic for metavulcanites to 25˚ in dynamometamorphites of auriferous zones and to 65˚ in ore bodies.

Table 5. Gold and silver microparticles concentrations in dynamometamorphites of the Mukodek auriferous field [26].

Scintillation emission spectral analysis data	Hosting strata metavolcanites (812 million years)	Auriferous zones (321 million years)	Ore veins (284 million years)
Average values of registered Au particles number (pcs)	5	12	29
The same for Ag-Au alloys	0.3	7	21
Percentage of Ag-Au alloy particles	5.8	37.4	42.5
Average values of registered Ag particles number (pcs)	13	2750	3595
The thinnest fraction percentage (2 - 6 microns) of Au particles	98.7	80.8	61.2
The same for Ag	95.5	98.1	77.1
Average Au content (g/t)	0.014	0.14	1.66
Ag contents range (g/t)	0.0 - <0.03	<0.03 -1.1	0.19 - 2.7 (average 1.24)

Note. Dynamometamorphytes mineral composition: hosting strata metavolcanites—actinolite-epidote-chlorite-plagioclase; auriferous zones—chlorite-sericite-quartz-carbonate-plagioclase with sulfides; ore veins—albite-dolomite-quartz.

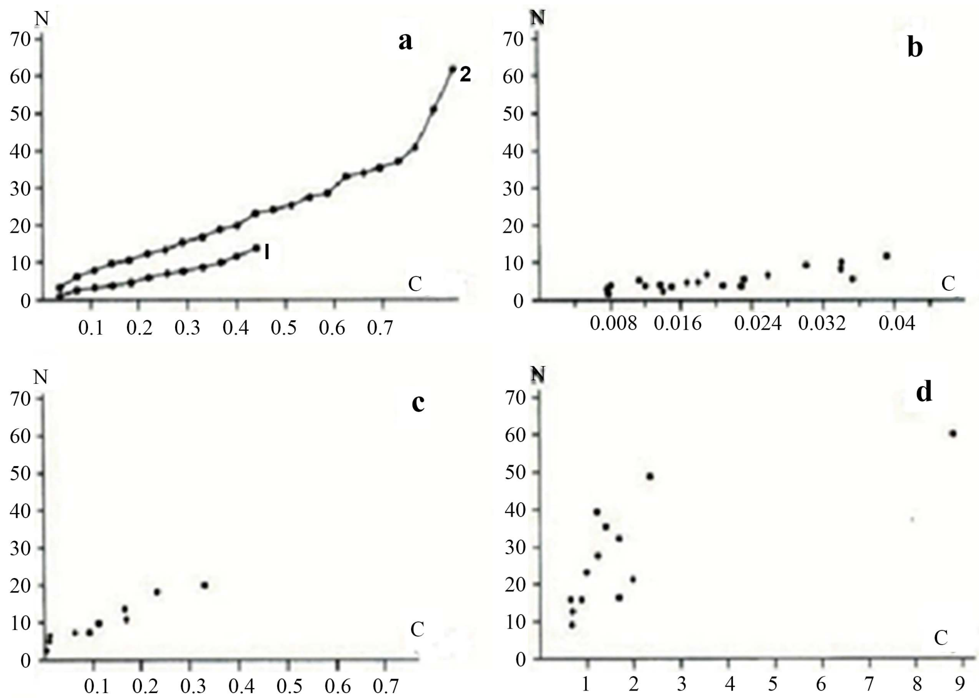

Figure 4. Diagrams showing three-stage gold concentration during the dynamometamorphites formation of the Mukodek auriferous field in the Baikal-Patom Greenstone belt. Compiled by A.V. Tatarinov and published in the article [26]. (a) The distributions trends of the gold microparticles number (N) and their content in g/t (C) barren metavolcanites of hosting strata (1) and auriferous zones (2); (b) The correlation graph between the number of particles (N) and Au contents g/t (C) in barren metavolcanites; (c) The same in dynamometamorphic complex of auriferous zones; (d) The same in vein dynamometamorphites of industrial ore bodies.

The behavior of Ag in dynamometamorphism processes is similar to gold, except for the enlargement of its particles (**Table 5**).

The second factor is shoshonite-latite magmatism.

Rocks of shoshonite-latite volcanic-plutonic complexes of Paleozoic and Mesozoic ages are the most important source of the multicomponent ores substance of dynamometamorphic Genesis in the GSB suture zones [29] [50]. They complement the list of Vendian ultrabasite-basite Vulcan-plutonic series and spatially associated dioritoids of similar age (gabbro-diorite-plagiogranite, tonalite-trondhjemite series)—being products of partial melting of metabasites, inheriting the ore-geochemical specialization of early magmatic ultrabasite-basite. Rocks of the Paleozoic shoshonite-latite series are mainly represented by gabbroids, monzonites, syenites arrays of the atarkhan complex with an age of 468 ± 8 million years, and Mesozoic (233-188 million years)—subvolcanic dikes of the petrochemical series: tephrite, shoshonite (trachybasalt), latite (trachyandesitobasalt).

The third factor is mud volcanism in all the variety of morphostructural, material and genetic forms of its manifestations. Recently identified by the authors, the South Siberian area of Mesozoic-Cenozoic and modern mud volcanism [54] covers the entire distribution territory of the Transbaikalia Vendian Riphean GSB. It has been found that it plays a particularly important role in the final spteps (Cretaceous - Cenozoic) of OFS formation of producing noble metal mineralization of such well-known large areas as Lena and Baley, as well as polycomponent ores of the Mykert-Sanzheyevka field [33] [35] [50]. Mud volcanoes litho complexes compose the compensatory usually shallow (less than 2 km) depressions. The depth of their foci is estimated at 3.5 - 15 km. The main reason for the generation of fluids that induce mud volcanism in continental rifts is dynamometamorphism [55]. Mud volcanism morphostructures, considered by many researchers as "pipes of Earth cold degassing", provide large-scale migration, concentration, vertical fluidodynamic redistribution of ore components, their transit from the lower levels of the earth's crust to the day surface. As an example illustrating this conclusion, we present a section of the Baley auriferous field (of the same-named OFS).

According to our ideas, the Baleiy ore field is a sub-vertical degassing pipe of Cretaceous age. On the surface, it is represented by a compensatory mud-volcanic depression of 6 × 8 km, complicated by 2 converging dome structures [11], the dimensions of 1 × 1.1 km (Baley) and 1.6 × 1.9 km (Taseyevso), composed mostly of geyserites and to a lesser extent pelito-silt-psammite, breccia products of mud-volcanic lithogenesis (**Figure 5**). The domed structures are well emphasized by a concentric system of gentle discharges resulting from the influence of fluid pressure. Siliceous formations of geyserite type occur up to a depth of 180 m. The number of their bodies decreases sharply from 40 - 70 m. With depth, the dome structures are gradually replaced by a crater-type morphostructure, whose section at the interval of 180 - 600 m is represented by "travertinized"

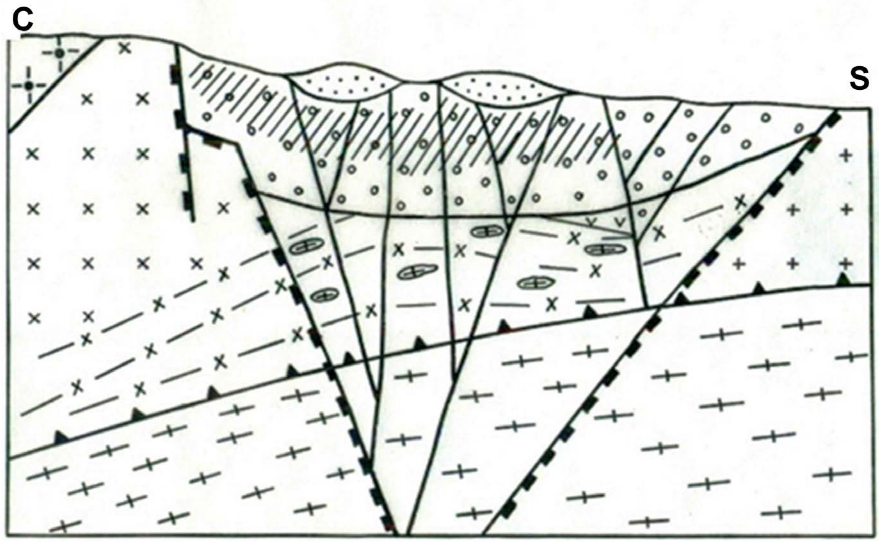

Figure 5. Structure profile of the Baley auriferous field. 1—Riphean rocks of the buried Greenstone belt; 2—Intensely cataclazed granitoids of the Undino complex (C3) with numerous remnants and mylonites xenoliths, dynamoslates on rocks of the Precambrian Greenstone belt; 3—Poorly modified granitoids of the Undino complex; 4—Jurassic granitoids of the Borschovochny complex; 5—Jurassic sedimentary-volcanogenic rocks of the Shadoron series; 6—Carbonated Cretaceous gas-water-mud volcanic complex; 7—Geyserites, to a lesser extent pelito-silt-psammite and breccia products of mud volcanic lithogenesis; 8—Zone of the most rich gold mineralization; 9—Tectonic disturbances; 10—Borders of the Baley degassing pipe.

(carbonated with a predominance of siderite) gas-water-mud volcanic complexes of Cretaceous age with the dominance of psammite-psephite and breccia-conglomerate varieties of rocks. The lowest part of the section up to a depth of 1000 - 1100 m is mostly intensely cataclazed granitoids of the Undine complex (C3) with numerous remnants (partly xenoliths) of mylonites and dynamoslans on the rocks of the Onon-Shilka Greenstone belt metamorphosed in RT conditions of amphibolite and epidote-amphibolite facies. A small part of the section consists of Jurassic sedimentary-volcanogenic rocks sidorovskoe series.

The processes of concentration of precious metals in the ore-rock complexes of the Balei field were determined mainly by the evolution of the C-O-N-N-S fluid system from reduced to highly oxidized compounds. The range of RT-conditions for the formation of mud-volcanic complexes of the Baley degassing pipe, taking into account the temperature of combustion of hydrocarbons, is: P = 3300 - 15 bar, T = 1000˚C - 70˚C [35].

3.4. Metallogenic Typification, Time Intervals and Ore-Rock Formations Complexes of Various Steps of Ore-Forming Systems Formation

Ore-forming systems (Fe, Ti, Ni, Pb, Zn, noble metals) of Transbaikalia Vendian-Riphean GSB were formed in the age range from Riphean to Cenozoic (Figure 6). They are grouped into five mineral types (Table 6). Noble-metal type

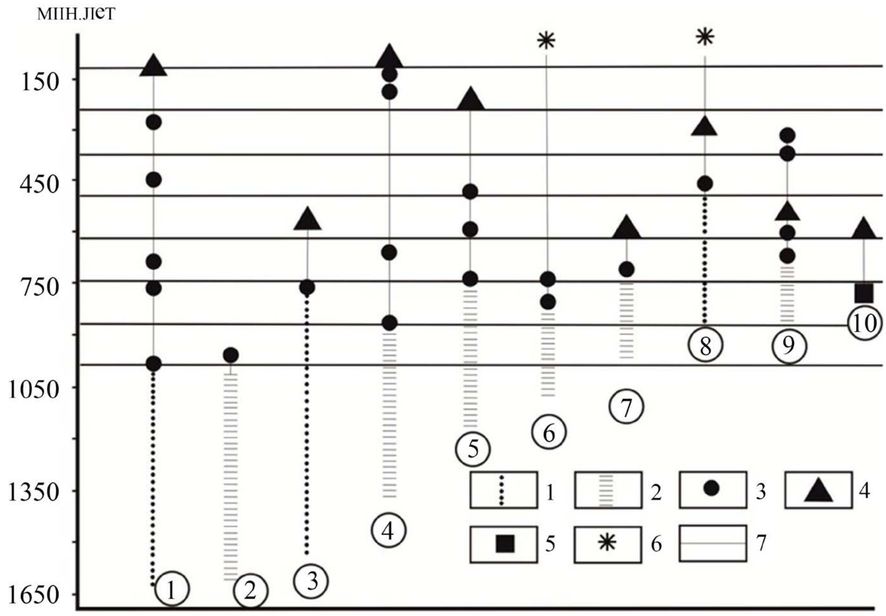

Figure 6. Time intervals of ore-forming systems formation (OFS) of the Vendian-Riphean Greenstone belts (summarizing the published data). Numbers in circles-OFS metallogenic types and subtypes. In parentheses are examples of the most studied ore deposits: 1—Nyandony (deposits and occurrences of Kamenny, Namama, Chipikan, Bakhtarnak, Troitsk); 2—Ironore (Tiya, Yazov deposits); 3—Pyrite-polymetallic (Kholodny deposit); 4—Darasun (Darasun, Kara, Itaka, Klyuchevsky, Ushumun deposits); 5—Irokinda (Irokinda, Gorny, Kedrovaya fields); 6—Baley (Baley, Taseevo deposits); 7—Copper-nickel (deposits and occurrences of Chaya, Baikal, Marinkin); 8—Bodaibo (Sukhoy Log, Chyortovo Koryto, Pervenets deposits); 9—Irba (Yubileyny, Irba fields); 10—Iron-titanium (Vitimkan, Irokinda, Kedrovaya mineral occurrences). 1 - 2—Isotope-geochemical ore preparative steps Dating of ore mineralization formation, *i.e.* rock complexes with appropriate ore-geochemical specialization (1—Carbonaceous carbonate-terrigenous formations of the passive continental margin rift structures; 2—Ultrabasite-basite complexes of Greenstone belts; 3 - 6—Isotope-geochemical dating of ore formation processes: 3—Reomobilization (dynamometamorphic), 4—Regenerative (dynamometamorphic), 5 - 6—Rejuvenation (5—Picrobasalt and shoshonite-latite magmatism, 6—Mud volcanism); 7—Estimated ages of superplume occurrence [6].

can be divided into six subtypes with different duration time intervals of operation, Dating to the early and final steps of the ore Genesis, the ore concentrations formation, correlated with the pulses of the plume activity and ages of plumes and superplumes (**Figure 6**). All metallogenic types of OFS are united by a commonality of ore matter primary sources, represented either by single or several geochemically specialized formations for a particular ore element, GSB rocks petrotypes: plutonic-volcanic ultrabasite-basite with boninite-like volcanites, black shale and dioritoids (**Table 7**). The OFS evolution had an inherited multi-step character [5], with a tendency to change in time ore-generating, ore-centering processes of reomobilization and regeneration (dynamometamorphism), and rejuvenation (shoshonite-latite and picrobasalt magmatism, mud volcanism) (**Table 7**).

The time interval of OFS multi-step formation is very long 1.5 - 0.4 billion

Table 6. A metallogenic types brief characterization of Riphean Greenstone belts ore-forming systems.

Metallogenic OFS types, subtypes of noble metal type. In brackets, their numbers shown in Figure 6	Age (million years) intervals of OFS formation (isotope-geochemical data)	Primary rock complexes with increased geochemical background of Fe, Ti, Ni, Pb, Zn, and noble metals	Deposits, mineral occurrences examples of suture tectonic zones
1	2	3	4
Nyandony subtype	1600-550	Carbonaceous volcanogenic-carbonate-terrigenous strata with volcanite bodies of picrite-basalt-andesite-rhyolite series	Kamenny, Namama, Chipikan, Bakhternak, Troitsk
Iron-ore	1580-927	Volcanogenic-sedimentary strata with diabases sills, basalts of the komatiite-toleite association	Tiya (same name ore zone), Yazov (Vitim iron-ore region)
Pyrite-polymetallic	1500-550	Carbonaceous-siliceous-carbonate-terrigenous strata with volcanites of the komatiite-basalt and basalt-rhyolite associations	Kholodny
Darasun subtype	1472-100	Plutonic ultrabasite-basite complexes of the komatiite-toleite association	Darasun, Kara, Itaka, Klyuchevsky, Ushmun,
Irokinda	1060-470	Volcano-plutonic ultrabasite-basite complexes of the komatiite-basalt-boninites series	Irokinda, Gorny, Kedrovsky,
Baley subtype	1050-114	Buried ultrabasite-basite komatiite-tholeiite association	Baley, Taseevo
Copper-nickel (±PGE)	937-600	Stratified arrays of dunite-peridotite-gabbro and dunite-troctolite-gabbro formations	Chaya, Baikal, Marinkin
Bodaybo subtype	870-<65	Buried basite-ultrabasite complex. Black shale formation of over rift depressions	Sukhoy Log, Chyortovo Koryto, Pervenets
Irba subtype	825-550	Komatiite-basalt-boninite volcano-plutonic association	Yubileyny, Irba
Iron-titanium (±V, P)	780-590	Stratified arrays of anorthosite-pyroxenite-gabbro formations	Vitimkan, Irokinda, Kedrovsky

Table 7. Ore-rock complexes of OFS various steps formation of the Transbaikalia Wendian-Riphean GSB.

OFS metallogenic types and subtypes, in brackets—GSB. Age range OFS formation, million years	Pre-ore	Ore formation steps		
		1	2	3
1	3	4	5	6
Iron ore Baikal-Patom 1580-927	Orthoamphibolites, partially granitized	Chlorite-actinolite-albite-epidote, plagioclase-actinolite-chlorite, quartz-chlorite-sericite-carbonate dynamoslates with hematite-magnetite mineralization		
Pyrite-polymetallic (Tiya-Ollokit). 1500-550	Orthoamphibolites, serpentinites	Graphite-garnet-quartz-double mica, graphite-carbonate-quartz-mica dynamoslates with strata-like deposits of quartz-sphalerite-galenite ores	Dynamometamorphic metasomatites, hydrothermalites of plagioclase-muscovite and quartz-muscovite composition with veinlet-disseminated polysulfide mineralization	

Continued

Copper-Nickel (Baikal-Patom, Tiya-Olokit, Kurba-Vitim). 937-600	Orthoamphibolites, serpentinites, anorthosites	Blastomylonite disseminated and veinlet-disseminated pyrrhotite-pentlandite ore on ultrabasites	Dynamometamorphic breccias, veins and veinlets	
1	3	4	5	6
Iron-titanium (Tuldun, Gukit-Parama, Kurba-Vitim, Onon-Shilka). 780-590	Orthoamphibolites, anorthosite, dioritoides	Chlorite-amphibolite and chlorite-epidot dynamoslates with ilmenite-titanomagnetite mineralization		
Bodaybo (Baikal-Patom, Bodaybo branch). 870-<65	Carbonaceous quartz-carbonate-sericite dynamoslates with pyrite, gold and PGE	Quartz-vein bodies of dynamometamorphic genesis (mechanometasomatites and mechanothermalites) with gold	Mud-volcanic (fluid-clastogenic-sedimentary) debris-like pyrite-magnetite with cassiterite and scheelite, as well as gold-quartz-limonite ores	
	Orthoamphibolites, serpentinites, anorthosites, dioritoids	Micaceous-chlorite-actinolite shales, beresite-like mechanometasomatites with sulfides, quartz and noble metals		
Baley (Onon-Shilka) 1050-114	Orthoamphibolites, serpentinites, dioritoids, vulcanites of the latite series	Actinolite-chlorite-albite, talc-serpentine-chlorite, biotite-epidote-amphibole dynamoslates with disseminated and veinlet-disseminated carbon-sulfide-noble metal mineralization	Gold-sulfide-quartz-tourmaline mineralization in dynamometamorphites on granitized metabasites	Ore-bearing geyserite-travertine complex and conglomerate-like breccias of mud-volcanic origin
Darasun (Kruchina, Onon-Shilka, Amazar). 1472-100	Orthoamphibolites, serpentinites, dioritoids, dunite-pyroxenite-anorthosite-gabbro stratified arrays, granitoids of the latite-shoshonite series	Propilite- and berezit like dynamometamorphites, blastomylonites and crystallized pseudotachylite of volcanogenic species ("porphyries", "felsites", "grorudites", "lamprophyres"). Noble metals in paragenesis with tourmaline, quartz, magnetite, pyrite and arsenopyrite.	Amphibole-containing dynamoslates, quartz veins of dynamometamorphic origin, argillizite-like dynamometamorphites, fluidoclastogenic breccias with ore quartz fragments. Polysulfide and sulfasalzine mineralization with noble metals	
Nyandony (Barguzin-Kotera, Gukit-Parama, Karalon-Bakhternak, Kurba-Vitim) 1600-550	Orthoamphibolites, serpentinites, dioritoids	Carbonaceous dynamo slates and psammitic cataclasites, rocks with a predominance of disseminated and veinlet-disseminated pyrite-pyrrhotite mineralization with noble metals	Listvenite-and beresite-like dynamometamorphites of the mylonite facies, chlorite-actinolite dynamoslates with a predominance of sulfide-polymetallic (Zn, Cu, Pb) and fahlore associations enriched with noble metals	
Irba (Kelyana-Irokinda) 825-550	Orthoamphibolites, serpentinites, dioritoids	Chlorite-plagioclase-amphibole mylonites, muscovite-quartz-plagioclase dynamoslates, dikes of crystallized pseudotachalites ("diorite porphyrites", "andesites"). The auriferous association of disseminated ore minerals (pyrite, pyrrhotite, pentlandite, ilmenite, magnetite, hematite, rarely chalcopyrite, sphalerite and galenite) is predominant	Quartz-carbonate dynamometamorphites of beresite-listvenite series, chlorite-sericite-albite-quartz, albite-quartz-sericite dynamoslates. Auriferous quartz-veinlet-vein type of ore mineralization with Pb, Zn and Cu sulfides, tetrahedrite and Ag, Au, Bi, Sb, Ni tellurides is predominant.	

Continued

Irokinda (Kelyana-Irokinda, Tuldun, Kurba-Vitim) 1060-282	Gneisses, crystalloslates, granulites, orthoamphibolites, calciphyres, serpentinites, dioritoids, granites, pegmatites	Beresite-like feld-spar-muscovite-carbonate dynamometamorphytes, listvenites. Auriferous association—pyrite-tourmaline-quartz—is predominant.	Sericite-chlorite mylonites, somerimes kalisparred, carbonate containing dynamoslates, dikes of crystallized pseudotachilites ("diabases"). Auriferous association-chalcopyrite-sphalerite-galenite overlaid on quartz veins is predominant.

years (Figure 6, Table 6). According to D. V. Rundquist and co-authors [55], a long multi-step development of ore formation processes is also inherent only in the continental crust. While mineral deposits in the oceanic and island-arc crusts appeared once in one relatively short-term stage (150 - 5 million years).

4. Conclusions

Transbaikalia is one of the oldest mining regions, with a rich and diverse resource potential of metal minerals many types, which occupies one of the leading places in Russia. In the XX century, its mineral resource base was replenished and improved due to the work of a number of large state geological exploration expeditions, the development of advanced forecast and specialized mineralogical research conducted mainly by industry institutes (VIMS, TsNIGRI, VostSibNIIGGiMC, ZabNII, etc. In the last 30 years, after the actual liquidation of state geological exploration expeditions and regional industry institutions (ZabNII and VostSibNIIGGiMS), interest in the problems of reproduction and expansion of the mineral resource base (especially noble and rare metals) has fallen sharply. The theoretical and methodological basis of expect-prospective works, based on modern realities, has ceased to improve.

A characteristic feature of metallogeny today is the rapid growth of researches aimed at forecasting, identifying new and non-traditional types of ore mineralization (genetic, mineral, technological). A special place among the latter belongs to deposits and occurrences with complex (polycomponent) ores that require detailed mineral and geochemical study, in connection with the effective technologies development for their enrichment, extraction of maximum number (5 - 6) of the components. This problem is one of the most urgent, especially for old mining areas, the mineral resource base of which can no longer be expanded due to the resources of "monometallic" deposits with rich contents of a particular ore component.

To successfully solve this problem, the authors of the article developed and proposed to a wide range of geologists a new mineragenic concept for Transbaikalia "ore-forming systems of the Vendian Riphean Greenstone belts", which is first of all acutely necessary for planning advanced expect-prospecting works to expand the raw material base of the currently most popular mineral-gold. During long-term research of ore-forming systems that produce noble metal mineralization, polycomponent ore clusters with gold dominance, the authors came to the conclusion that there is an urgent need to reorient the gold mining enterprises to identify and develop large-scale reserves (at least 100 tons with Au content-2 - 4 g/t), suitable for open-pit mining (up to a depth of 50 m) of area objects. Among the latter, the primary interest is represented by sulfide-disseminated and veinlet-disseminated with main quartz veins auriferous zones of dynamometamorphic origin in ultrabasite-basite associations of the rocks of the Vendian Greenstone belts. This type of auriferous zones, with estimated by us of gold hypothetical resources each 150 - 200 t, is identified in the range of Kelyana-Irokinda (Nizhny Samokut, Urba-Mladenets), Selenga-Vitim (Tsipikan, Talikit) and Onon-Shilka (Pre Shilka, Onon-Tura) GSB. They are recommended for exploration and evaluation works.

Acknowledgements

The authors are grateful to G. G. Tikhonova for the qualified English translation of this article. They are also grateful to N.G. Smetanina for the technical preparation of individual drawings for journal publication.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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