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Chapter 2

The Role of the Andesitic Volcanism in the Understanding of Late Mesozoic Tectonic Events of Bureya-Jziamysi Superterrain, Russian Far East

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Additional information is available at the end of the chapter

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1. Introduction

At the moment Bureya-Jziamysi superterrain is a very discussable geological object [1]. It is distinguished as a component of Amur plate or a part of a microcontinent [2] of the eastern part of Euroasia (Fig. 1a). Nowadays a kinematic model is obtained [3] that describe the dislocation of Euroasian and Amur plates as independent tectonic units (Fig. 1a). The GPS-calculations [4, 3] showed that the eastern border of Amur plate goes along of the one of the branches of Than-Lu fracture system (Fig. 1a). The branch is also an eastern border of Bureya-Jziamysi superterrain. The northern border is identified by its contact with Mongol-Okhotsk orogenic belt and correlates to the northern border of Amur plate [5]. On the west and south the superterrain is framed with Paleozoic and early Mesozoic orogenic belts: South Mongolian – Khingan, Solonkersky, Vundurmiao [5, 6]. South Mongol – Khingan orogenic belt separates it from Argun superterrain that is also a component of Amur microcontinent (Fig. 1b).

There are almost no controversies about the time of the connection of the researched area to the Argun superterrain in the literature. The authors [7, 2 et al.] agree that these tectonic events took place in the second half of Paleozoic. And than the newly formed Amur microcontinent, together with the north Chinese plate, moved to the north and accreted to Siberian platform at Early Cretaceous supported by the data of [8], at late Jurassic by the data of [9] or at the end of Paleozoic [10].

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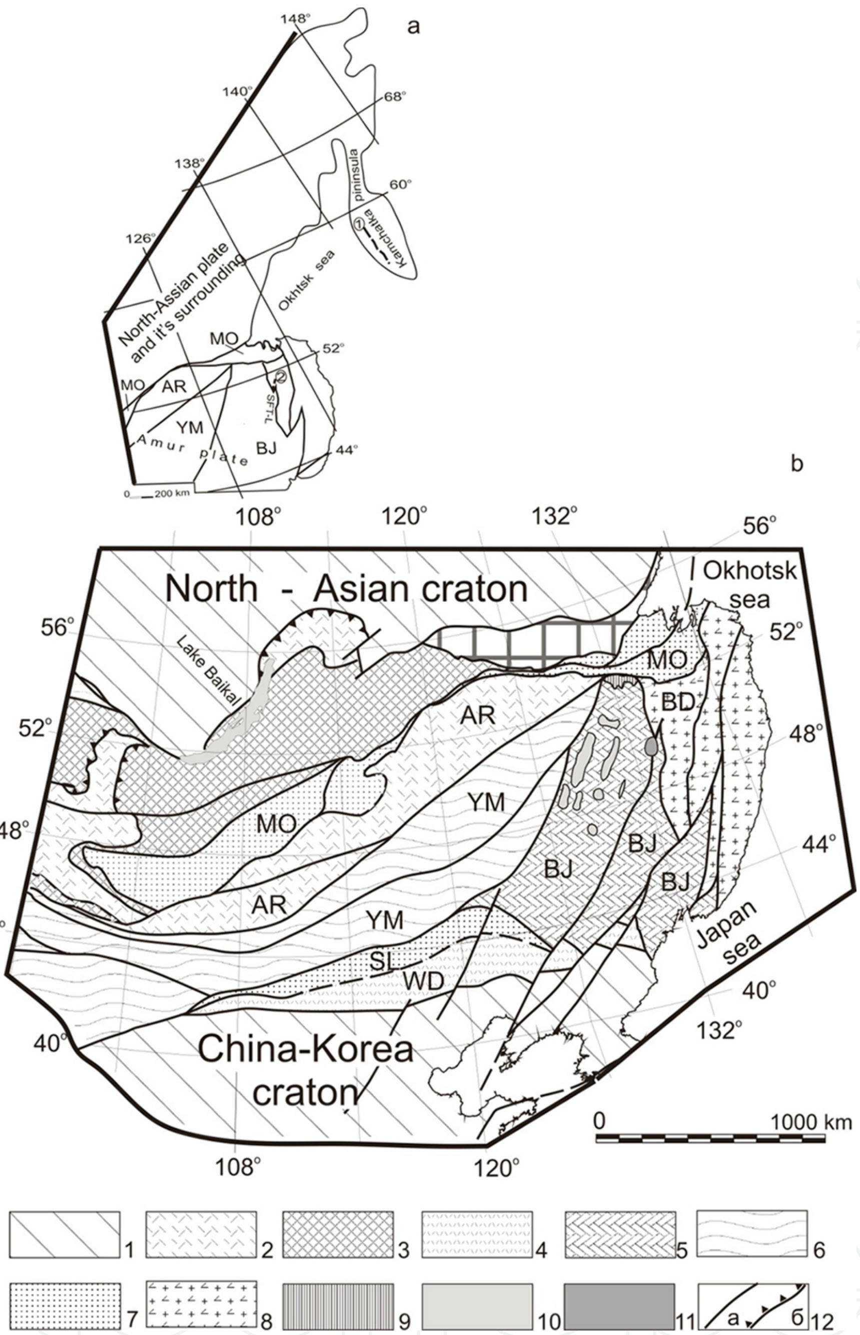

Figure 1. Schemes of the major tectonic structures dislocation. a). Regional scheme. The mountain ridges mentioned in the text are shown with the dotted line: 1 – Sredinnyi, 2 - Small Khingan. b). Bureya-Jziamysi superterrain and it's surrounding: Cratons (1): North Asian, Sino-Korean. Orogenic belts and the fragments of orogenic belts: Late Riphean (2), Late Cambrian – Early Ordovician (3), Silurian (4), Early Paleozoic (5), Late Paleozoic (6), Late Paleozoic – Early Mesozoic (7), Late Jurassic - Early Cretaceous (8). Volcanoes field complexes: Burunda (9), Pojarka (10), Stanolir (11). Tectonic contacts (12). a, b). Letter marks: YM – South Mongolian – Khingansky, SL – Solonker, WD – Vundurmiao; superterrains – BJ – Bureya-Jziamysi, A- Argunian, terrain – Badzhal terrain, SFT-L - the system faults Tan-Lu. The scheme is made by [5].

It is considered that the border between the Amur microcontinent and the Mongol-Okhotsk structure was amalgamated at the late Mesozoic period by volcano-plutonic complexes of early-late Cretaceous [6]. High precision geochronology and chemical composition of the complexes deny the late Mesozoic unity in the evolutional process of the superterrains that formed the Amur microcontinent. For the Argun superterrain and South Mongolian – Khingan orogenic belt the following stages of the volcanic activity are stated: 147 Ma – sub-alkaline rhyolitic intra-plate complex, 140-122 Ma – calc-alkaline volcano-plutonic complex of intermediate composition with subductional origin, 119-97 Ma – bimodal volcano-plutonic intra-plate complex [11]. Bimodal volcano-plutonic complexes accompany the closure of Mongol-Okhotsk basin in the frames of western link of Mongol-Okhotsk belt [12] and of the eastern link [13]. But the analogues of the rocks are absent in the zone of the connection of Mongol-Okhotsk belt and Bureya-Jziamysi superterrain.

2. Late Mesozoic volcanism of Bureya-Jziamysi superterrain

The volcanic complexes that are developed in the frames of Bureya-Jziamysi superterrain differ from the same formations that are developed in the frames of the Argun superterrain in the South Mongol-Khingan orogenic belt both by the time of the formation and by the material composition. Volcanites of Bureya-Jziamysi superterrain traditionally refer to the three different volcanogenic complexes: Low Zeya – central and western part of the investigated territory; Khingan-Okhots (Khingan-Olonoi zone) – east and south-east, Umlekan-Ogodzha (Ogodzha zone) – north. Volcanites of the Low Zeya volcanic zone are represented by Early Cretaceous rhyolites (137 Ma) and andesites of the Poyarka complex (117-105 Ma) [11, 14, 15]. Ogodzha zone is formed with the Burunda andesite complex (111 – 105 Ma). Its rocks are developed along the northern border of Bureya-Jziamysi superterrain. Khingan-Olonoi zone is represented by two Early Cretaceous complexes in the frames of the superterrain: the Stanolir andesites (111-105 Ma) and the rhyolite-alkaline dacite complexes (101.5 – 99 Ma) [16, 17, 18, 11]. The volcanites of acidic-alkaline composition correspond to typical intraplate formations by their petrochemical characteristics [11]. Thus, in the composition of each of the volcanic complexes of andesite formation is separated, such as: Poyarka, Burunda, and Stanolir andesites.

2.1. Poyarka andesite volcanic complex

Poyarka andesite volcanic complex [19, 11] was formed mostly on the tectonic stress-released zones, commonly referred as riftous. The beginning of their formation of these andesites coincides by the time period with the outpour of large volume rhyolites in the beginning of Early Cretaceous. The rocks of Poyarka complex are represented by small singular outcrops. They are mostly described on the drill logs uncovered by the deep boreholes. According to the open casts the main rock types of the volcanic complex are various andesites that form the covering and subvolcanic facies of volcanites that make more than 50% of the total volume of the volcanites of the complex. Volcanogenic-sedimentary rocks of the covering facies – eg. Poyarka suite – are divided into two parts by their chemical composition and by the floristic signatures indicating specific ages: 1) lower part and 2) upper part. The lower part has got a polyfacies composition but its genesis and sedimentary features both horizontally and vertically. Upwards along the open-cast proluvial deposits are changed into alluvial lake-swamp deposits. Non-volcanic sediment accumulation was parallel to the volcanic activity. As a result of this, the terrigenous formations are gradually replaced by volcanogenic rocks to the edge of the sedimentary basins indicating the proximity of the volcanic source. The base of Poyarka suite concordantly occurs on the covering volcanites of silicic composition. Where the coverings are absent, it lays on the Premesozoic foundation. The thickness of the volcanosedimentary succession is not more than 400 m.

The upper part of the suite consists primarily of primary volcanites. The volume of volcanites concordantly increases in the open-cast of the lower part of the suite. The volcanites are represented by the intermediate –to-basic lavas, pyroclastic rocks and clastogenic lavas. The top of the open-cast ends up with relatively thin (up to 20 m) alternating alleurolits and argillits with rare interlayers of sandstones, tuffaceous sandstones, tuffs, carbonaceous argillites with conglomerates and lens of the coals. Thickness of the volcanogenic component is laterally variable from 130 to 340 m.

The subvolcanic formations of the Poyarka complex are composed of andesites, basaltic andesites and diorite-porphyry bodies. They form laccolith, lopolith or sill bodies 20 km^2 or more. Petrochemical and geochemical compositions of the subvolcanic rocks correspond well to the composition of the covering part of Poyarka suite.

The biggest part of the Poyarka complex is mostly composed from andesites, rarely basalts, and rarely trachybasalt tu trachyandesites. These rocks are of black to dark gray, green-gray, sealing-wax color with a massive fluidal or almond-shaped texture; with a porphyric or serial-porphyric structure.

The sizes of the porphyric fragments are up to 4 mm, and total to an amount of about 5-60%. The structure of the main mass is – pilotaxite, hyalopilite, intersertal or cryptocrystalline. The spheroidal parting is characteristic for the basalts. The volcanites are divided into hornblende, hornblende-pyroxene, dipyroxene and biotite-hornblende. Olivine might be present in basalts and basaltic andesites. In all of the rocks types the main proportion of minerals are plagioclases with a composition for andesites - An_{35-55}, and for basalts or basaltic andesites - An_{53-68}. Dark colored minerals in these rocks are monoclinic and rombic pyroxenes or basaltic hornblende and rarely – biotite.

The main mass is formed by the lath-shaped plagioclase (up to 0.3 mm large), granules of pyroxenes, magnetits and volcanic glass, in different degree replaced by illite, chlorite and iron oxide. Accessory minerals are apatite, sphene, magnetite, ilmenite, and rarely zircon. Almonds are made by montmorillonite, chalcedony and calcite.

Tuffs of andesites and basaltic andesites are massive, stratified. The fragments make 20 – 80 % of the rock. Cement is almost fully replaced by the secondary minerals of chlorite, sericite, chalcedony, limonite, argillaceous minerals.

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2.1.1. Petrochemical and geochemical characteristics

By the petrochemical data the volcanites of Poyarka complex relate to moderate silica, basic – intermediate silica rocks. They are low in alkali content that is in a range of 2.1-5.9 wt.% (Fig. 2a). Na_2O constantly prevails over K_2O (Fig. 2).

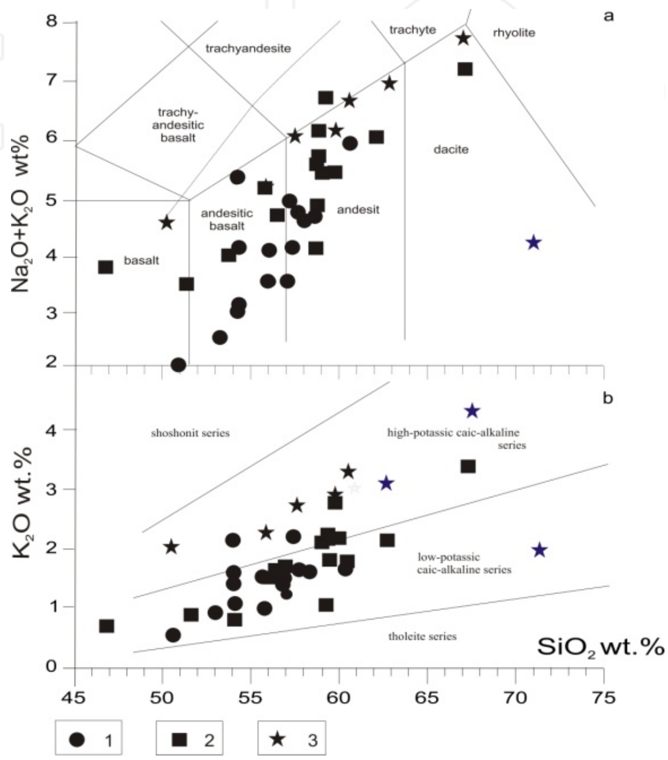

Figure 2. Classification diagrams for the rocks of volcano complexes of Bureya-Jziamysi supertarrain: a) (Na_2O+K_2O) - SiO_2; b) K_2O+SiO_2 [20]. The line of the separation of alkali and subalkali rocks by [21]. Complexes: Poyarka (1), Burunda (2); Stanolir (3).

The rocks belong to the low potassic, in rare cases – high potassic (K_2O = 0.9-1.6 wt.%) calc-alkali series (Fig 2b). The content of Na_2O is irregularly increasing with the growth of silica concentration. The basalts are alkali type. All the other types have potassium-alkali type (Na_2O/K_2O = 1.45 - 4.85). The MgO concentration changes from 9.37 wt.% (high-magnesial basalts, andesitic basalts, andesites) to 3.0 wt.% (moderate magnesial); all varieties are – moderate titanium (TiO_2 = 0.62-0.99 wt.%), ASI (with aluminum saturation index) = 0.9-1.4. By the content of MgO, CaO the volcanites of Poyarka complex are congruous to the volcanites of Burunda and Stanolir complexes and by their content of TiO_2 to the Burunda complex.

On the diagrams of the distribution of REE in the rocks of Poyarka complex (Fig. 3a) Eu anomaly absence or weak positive (Eu/Eu* = 0.89-1.05) and insignificantly prevalence of temporary over HREE (Gd/Lu)n = 2.5-4.5. On the diagram of the REE elements normalized to primitive mantle (Fig. 3 b) the Sr enrichment of the rocks (1029 ppm), Ba (443-642 ppm) is revealed by their impoverishment of Nb (>4-10 ppm), Ta (0.49 ppm), Rb (20.4-43.5 ppm), Th (1.70-4.97 ppm), Y (8-29 ppm), Ti (3100-3300 ppm).

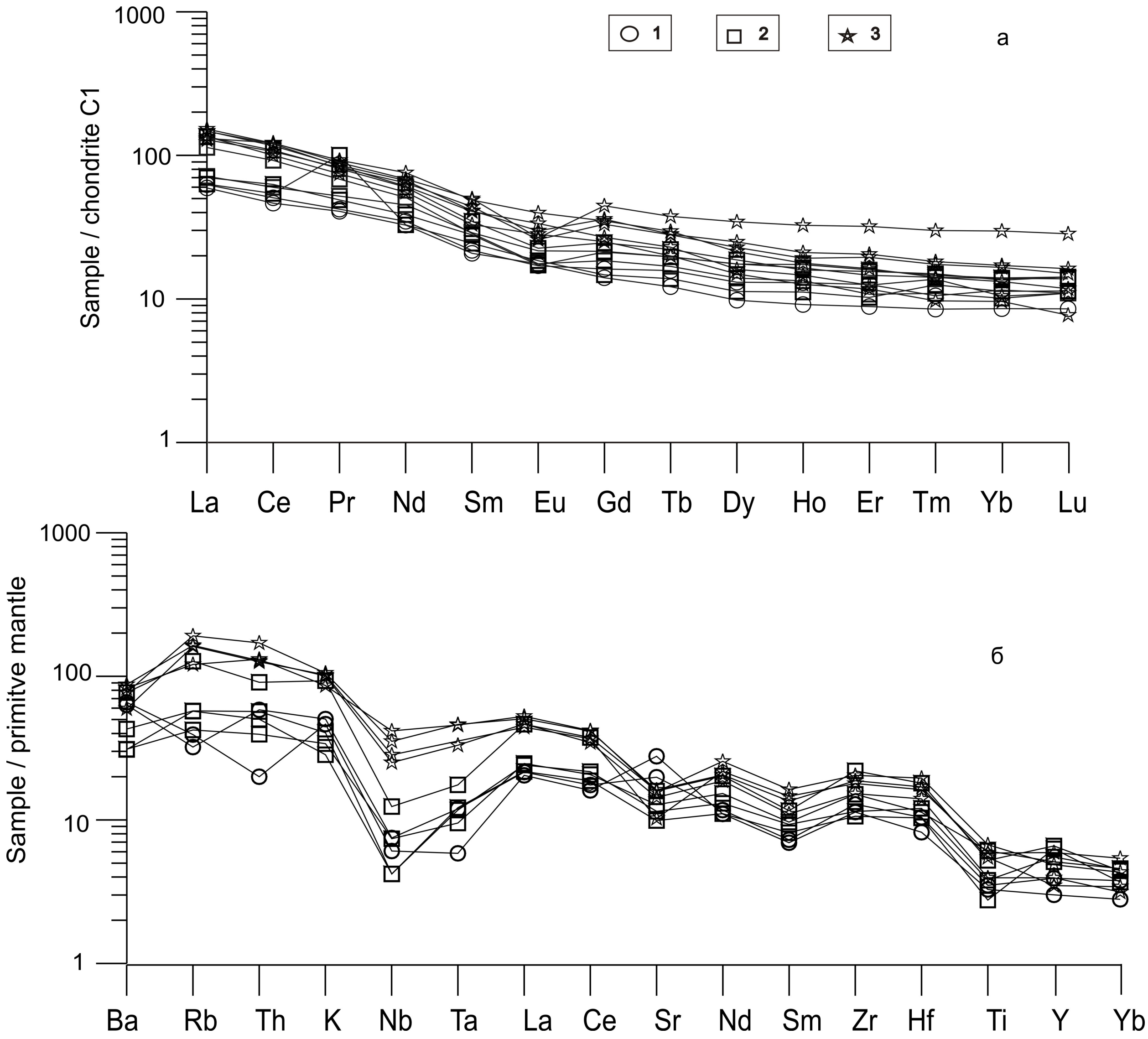

Figure 3. The concentration of the rare elements is normalized to chondrite composition (a) and to primitive mantle (b), in the formations of the volcanic complexes: 1 - Poyarka, 2 - Burunda, 3 - Stanolir. The composition of chondrite and primitive mantle are made by [41].

2.1.2. The age of the formation of the volcanic complex

For terrigenous formation of the Poyarka suite it is certain its Hauterivian-Barremian age based on the rich and complex fresh-water fauna and flora [22]. For the top part of the rock sequence it is characteristic an independent floristic complex which corresponds to an age of Aptian-Albian stage [19]. The similar age is given by palynology methods [19]. Thus, the age of the Poyarka suite is established as Hauterivian - Albian stage, and it displays of a volcanic activity, accordingly, occurred in an interval Aptian - Albian stage. The age is confirmed by radiometric geochronological datings as well (eg. $^{40}Ar/^{39}Ar$ a method) and yielded to an age of about 117 million years [15].

2.2. Burunda andesite volcanic complex

Burunda andesite volcanic complex is composed of tuffs and lavas mainly with intermediate composition and subordinate basic or more silicic volcanite types [23, 24, 13 et al.]. The rock types of the complex make variably broad lithological stripe from 3 to 30 km width on the border of the eastern flank of Mongol-Okhotsk orogenic belt and Bureya-Jziamysi superterraine (Fig. 4).

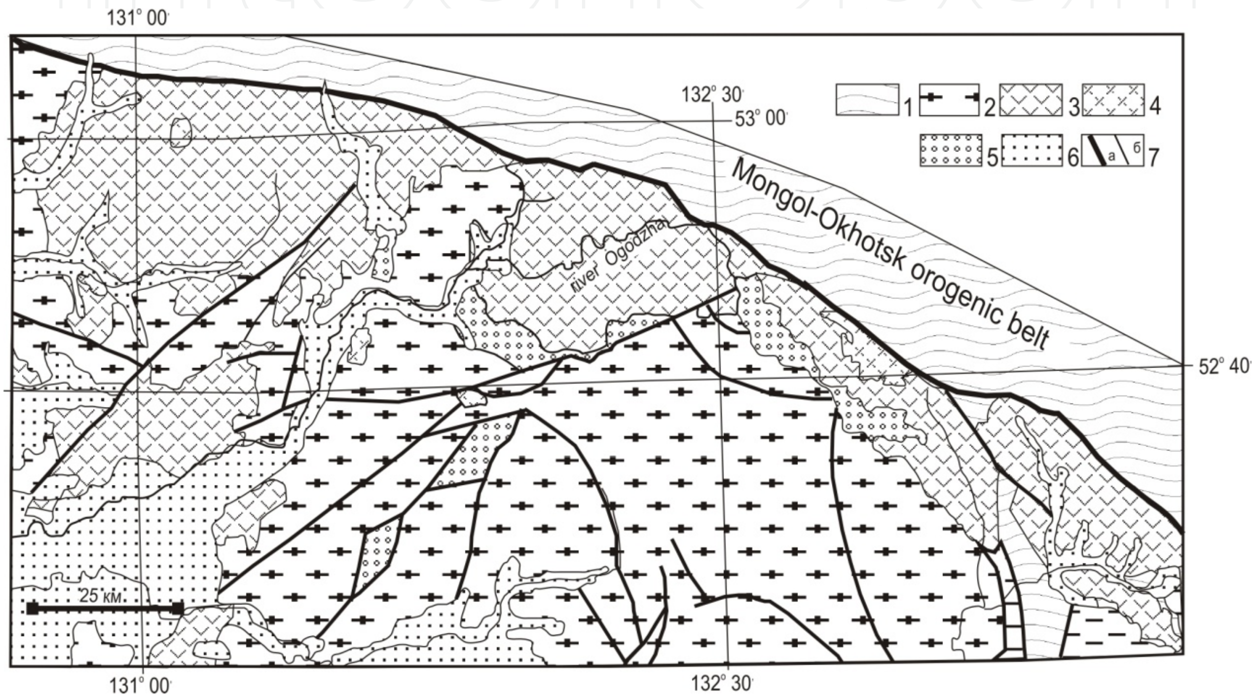

Figure 4. Scheme of dislocation of the rocks of Burunda complex. The rocks are: Paleozoic – Mesozoic of Mongol-Okhotsk orogenic belt (1), Paleozoic of Bureya-Jziamysi superterrain (2), integumentary volcanites of Burunda complex (3), and subvolcanic (4), terrigenic deposits of Ogodzha suite (5), friable deposits of quarter (6). Tectonic borders (7): a – a border between Mongol-Okhotsk orogenic belt and Bureya-Jziamysi superterrain, (b) other borders. Scheme is made by [14].

The complex is presented by covering facies, subvolcanic facies and vent facies which form a volcano-tectonic structure of about up to 40 km in diameter.

The open cast of the integumentary facies - *Burunda suite* – is represented by the lower undersuite that consists mostly of tufts in the base and in the top mostly of the lava rocks. The border between the suites goes symbolically by the beginning of the prevalence of lavas above tuffs in the rocks sequence. The estimated total thickness of Burunda is about 1050 m [22].

The volcanites inconsistently superpose Carboniferous to Early Cretaceous deposits of Ogodzha suite on the base of floristic evidences and have tectonic boundaries with the other undifferentiated Paleozoic rocks formations [23, 13, 24].

The lower part of the rock sequence is presented by tuffs and lava breccias of andesites and dacitic andesites, by tuff-terrigenous deposits with various dimensions of fragmental material, by argillites, by interbed and lenses of dacitic andesites, andesitic basalts and their lava breccias. Sometimes in the base there is a pack of tuffaceous conglomerate with the total thickness of more than 300 m. Tuffaceous conglomerates change into by tuffs of andesitic basalts - dacitic andesites. These tuffs have got various structures ranging from pelitic up to agglomerating, at prevalence psammitic varieties. The upper part of the rock sequence increases the lower part concordantly. It covers the lower part of the rock mass at less than 10 % of the area. Lavas are andesites and andesitic basalts. Dacitic andesites and dacites coexist in individual outcrops, and their underlying tuffs and lava breccias are rarely exposed.

Subvolcanic bodies of the Burunda complex have rather various morphology including stocks, laccoliths, lopoliths, sills with less than 2-3 km² surface area and dykes. These subvolcanic bodies are made of andesites, granodiorite-porphyries, diorite-porphyrites, and rarely dacites.

The main representatives of the complex are andesites hornblende - pyroxene, plagioclase-hornblende, bipyroxene and hornblende. These are massive dark grey or greenish rocks with porphyritic structure. Porphyritic minerals are formed by plagioclase (An_{36-46}), clino-and orthopyroxenes, and green hornblende. The main mass has got the hyalopilitic, microlitic, intersertal, and hyaline or pilotaxitic structure. Laths of plagioclase and fine grains of dark colored minerals, similar to phenocrystals are defined in the texture of the main mass of rocks. Accessory minerals are ilmenite, magnetite and apatite, and among secondary minerals sericite, chlorite, carbonate, epidote, zeolites and limonite prevail. Basalts contain olivine from 1 up to 15 %, an oligophyric structure and zoned plagioclase appear in them (An_{80} - a nucleus, An_{36-46} - periphery). Sphene is added to accessory minerals, among secondary serpentine and iddingsite appear. Porphyritic texture in dacitic andesites are presented by zoned plagioclase An_{30-65}, clino-and (or) orthopyroxene, hornblende, biotite, quartz, olivine (singular minerals). The main mass consists of volcanic glass (up to 20 %) in which laths of plagioclase, grains of pyroxenes, hornblende, quartz, scales of biotite and accessory (ilmenite, magnetite, spinal) are defined. Secondary formations are similar to those in andesites, and on plagioclase additionally albite develops. Dacites are presented by light grey, greenish, lilac, massive or almond-shaped rocks with a fine or average porphyritic structure.

Porphyritic rocks contain plagioclase An_{20-47}, hornblende, biotite, quartz, muscovite, and in single cases clinopyroxene. The main mass has a microfelsitic, hyalopilitic or poikilitic structure and is combined with the quartz-feldspathic unit. Accessory minerals are presented by apatite, zircon, sphene and ore minerals. Comagmatic to integumentary volcanites and subvolcanic bodies differ by a greater degree of crystalline texture. The change of structure within the limits of one body is characteristic from thickly- to rarely-porphyric textures.

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2.2.1. Petrochemical and geochemical characteristics

Rocks of the Burunda complex are characterized by wide fluctuations of the silica content, 47-66 wt.%, and they belong to moderate to low silica rock formations (Fig. 2a). Low-alkaline rocks are those of having Na_2O/K_2O = 1.1-3.5. Change of the Na_2O concentration with increase of SiO_2 fluctuates within the limits of 1.0 wt.%, and it maintains K_2O increases more than three times. The concentration of MgO in the rocks changes from 7.78 wt. % to 1.46 wt. %. The rocks are moderate and high titanium. According to the content of Al_2O_3, all varieties of the complex relate to the high aluminiferous rocks with ASI = 0.9-1.3, mainly low potassic calc -alkali series (at the content of SiO_2> 60 % - to high potassic calc -alkali series) (Fig. 2b).

For the REE distribution (Fig. 3a) the volcanic complex has the following characteristics: 1) poorly expressed Eu anomaly (Eu/Eu* = 0.74-0.85), 2) insignificant prevalence of the content of normalized LREE over the intermediate $(La/Sm)_n$ = 2.5-3.8, and 3) changeable prevalence of the intermediate elements over HREE $(Gd/Lu)_n$ = 1.0-5.0. Rocks are moderately enriched with Sr (230-910 ppm), Zr (121-301 ppm), Hf (178-212 ppm), Ti (2887-6190 ppm), Y (19-31 ppm), and are impoverished with Ta (0.39-0.72 ppm) and Nb (<5-13 ppm) (Fig. 3b).

2.2.2. The age of the formation of the volcanic complex

The age of the rocks of the Burunda volcanic complex was estimated to be as early as Cretaceous based on sporadic age data on fossil flora, spores and pollen from tuffaceous rocks from dispersed outcrops [19, 23]. Radiometric isotope dating ($^{40}Ar/^{39}Ar$) on samples of covering and subvolcanic facies of rocks of the volcanic complex resulted comparable ages with those inferred from paleontological data within the limits of technical errors. Magmatic lithoclasts from volcanogenic sediments and coherent magmatic bodies yielded an age of 108-105 Ma for the volcanic complex that represents the beginning of Albian in the Upper Cretaceous [25]. The Rb-Sr isochrone is revised for the subvolcanic dacites [23]. It defines the age of the rocks as 109.3±1.2 Ma. Age of 111 Ma was obtained by $^{40}Ar/^{39}Ar$ dating method for the andesites of Burunda suite recently [11].

2.3. Stanolir andesite volcanic complex

Stanolir andesite volcanic complex forms the fields of volcanites of north-eastern direction at the foot of Small Hingan range and it is spatially combined with younger (101-99 Ma) acidic (silicic) - alkaline volcanic formations. Therefore the rocks preserved in the surface is complex and unfortunately insignificant, as they are over covered by fields of younger volcanites making to understand the volcanic stratigraphy difficult (Fig. 5).

Stanolir volcanic complex is composed of rock formations of covering, subvolcanic and vent-filling clastogenic lavas and lava foot/top breccias) facies [26, 27, 17, 18, 11, et al.]. The basic rock formations in the structure of Stanolir volcanic complex belong to andesites, trachyandesites, seldom andesitic basalts, dacites and rhyolite dacites, as well as their subordinate pyroclastic rock types including various ignimbrites.

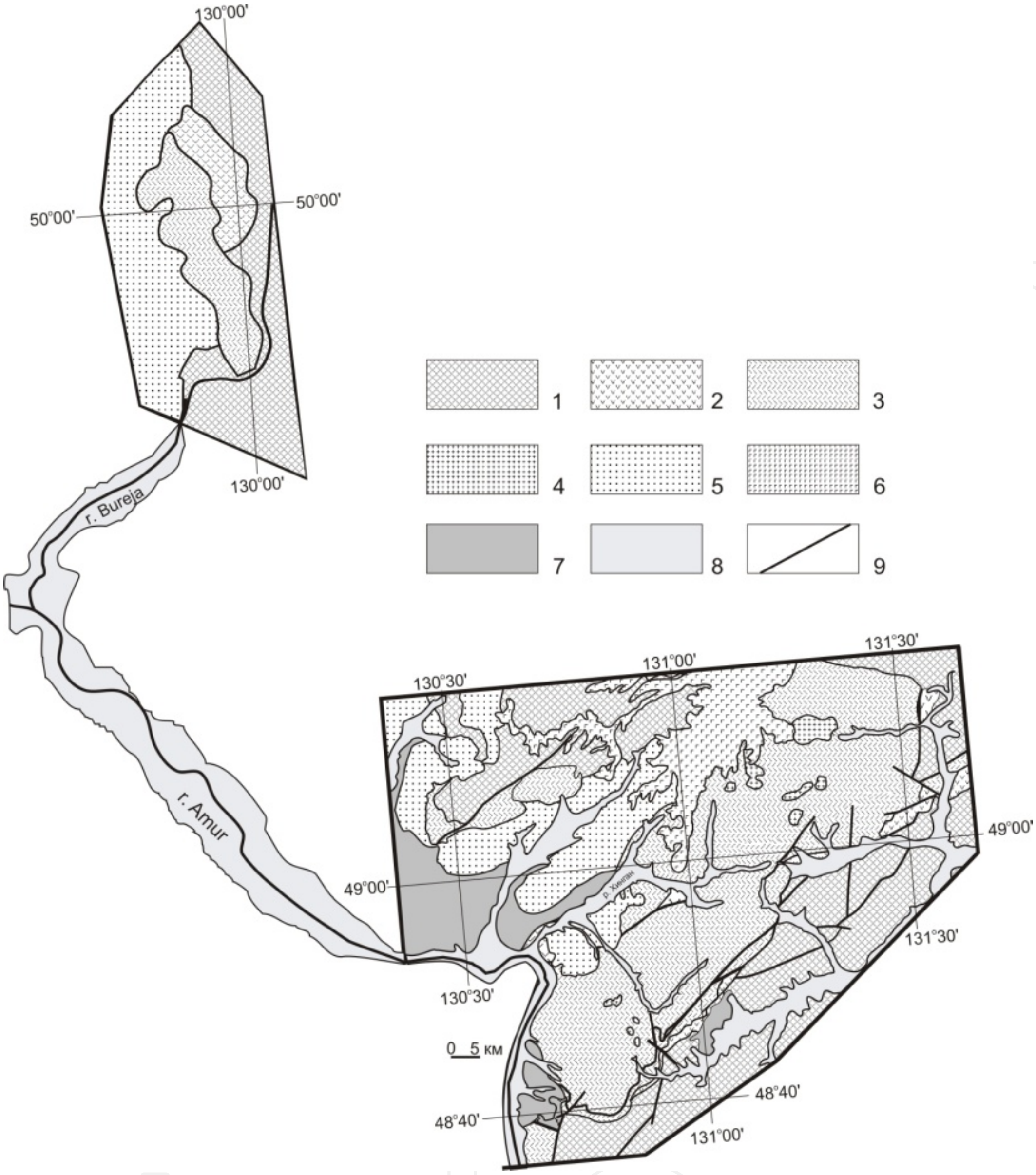

Figure 5. Scheme of the dislocation of the volcanites of Stanolir complex. Made on the base of [14] and by the authors data. The rocks are: Pre-Mesozoic magmatic and metamorphic formations (1); Early Cretaceous volcano-plutonic complexes: Stanolir complex – (2), acid-alkali composition (3), subvolcanic bodies of granitoids of the acid composition (4).Lower and upper Cretaceous sedimentary rocks (5), Cenozoic basalts (6), Lower Cenozoic sediments (7), modern sediments of the valleys of the river-bed (8), tectonic borders (9).

Covering facies - *Stanolir suite* - lies on Pre-Mesozoic crystalline basin rocks and Early Mesozoic granitoids. It composed of lavas and pyroclastic rocks of andesites, trachyandesites, andesitic basalts, trachybasalts, dacites, and also volcanogenetic and normal non-volcanic terrigenous rocks. Normal non-volcanic terrigenous rocks are located mainly in the base of the suite. Tuffs from aleurolite to coarse fragments are present in the rock sequences. Non-volcanic terrigenous rocks are relatively rare and small volume fraction of the entire volcanic complex. These terrigeneous rocks are dominantly arkose sandstones with less than 10 m in thickness commonly interbedded with coaly slates that contain up to 50 % charred vege-

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tative detritus [26]. The general thickness of integumentary facies reaches 930 m, and it contains a cumulative lava flow units of an estimated thickness of about 150-460 m [22].

The basic representatives of the complex are andesites of plagioclase-pyroxene or plagioclase-pyroxene-amphibole. Plagioclase An_{45-48} forms grains up to 3 mm in the size. Secondary formations are widely developed. In andesitic basalts insets are presented by plagioclase An_{46-53}, monoclinic pyroxene - augite and olivine (up to 5 %). Olivine sometimes is completely replaced by iddingsite. Trachybasalts are characterized by greater crystallisation of the main mass. They are divided into pyroxene and olivine varieties. The porphyres of plagioclase in basalts correlate with plagioclases of An_{55-63}. In the main mass there are plagioclases with $An_{45-48.}$ Olivine is established both in porphyres and in the main mass.

2.3.1. Petrochemical and geochemical characteristics

Volcanites of Stanolir complex correspond with moderate silica concentration rock types interbedded with some, low SiO_2 varieties as well as some more acidic, silica-enriched rock varieties (Fig. 2) providing some petrochemical peculiarities to this volcanic complex. The rocks relate to the two groups by the content of the alkalias are characterized as the main-moderate of moderate alkalinity and moderate-acid of normal alkalinity (Fig. 2a) of potassic-natrium type (Na_2O/K_2O = 0.7-1.6). The sum of alkalis naturally increases from the basic varieties to the acidic rocks (Na_2O+K_2O = 4.88-7.37 wt. %), at almost constant content of Na_2O (3.05 - 3.73 wt %) and proportionally increasing K_2O (1.83-4.26 wt. %) toward the silicic rock types. All varieties of the rocks are representatives of calc-alkaline rocks (Fig. 2b) of high potassium content. The rocks are moderately magnesial, in occasional cases they are low magnesial by the content of TiO_2, but all the other varieties are high titanium formations except for moderately titanium trachybasalt, ASI = 1.04-1.31.

The rocks are characterized with moderate concentrations of Ba (430-696 ppm) and Rb (43-135 ppm) [16, 17, 18, 11]. The quantity of Rb increases from trachybasalt to dacite. The content of Sr has an opposite tendency of change (642 - 190 ppm). Moderate and moderately high concentrations are peculiar to the rocks which noticeably increase from the main rocks to moderate acid; eg. Zr (129 - 412 ppm), Hf (3 - 13 ppm), Nb (7 - 39 ppm).

REE (Fig. 3a) are characterized by inconstancy of display of negative Eu anomalies. For moderately alkaline main-moderate rocks exhibit an almost full absence of Eu-anomalies and an $(Eu/Eu^*)_n$ = 0.94-0.99 ratio is established. However Eu-anomalies are clearly shown in andesite-basalts, some andesites and dacites, where the amount of $(Eu/Eu^*)_n$ falls to a range of 0.56 - 0.70 (Fig. 3a). LREE slightly prevail above intermediate - $(La/Sm)_n$ = 2.6-4.0, at non-uniform prevalence intermediate above HREE - $(Gd/Lu)_n$ = 2.3-10.8.

The contents of Ba (430 - 700 ppm) and Rb (43 - 135 ppm) are moderate; and the contents of Zr (170 - 400 ppm), Hf (4 - 13 ppm), Nb (18 - 39 ppm), Ta (1.36 - 1.90 ppm) are moderately raising, with irregular growth of their concentration from the basic rocks to moderate acid. On the diagrams of normalization of the rocks composition to a primitive mantle (Fig. 3b) a clear Ta-Nb minimum is established, but with smaller amplitude, than on these diagrams for rocks of Poyarka and Burunda complexes, and poor expressed negative anomaly concerning Sr (190 - 642 ppm). The composition of the other elements matches with the elements of Poyarka and Burunda complexes almost completely.

2.3.2. The age of the formation of the volcanic complex

The values of the isotope plateau age, that were defined by the $^{40}Ar/^{39}Ar$ method for the matrix of andesites and dacite, yielded to a range of 109 – 105 Ma and when calculating by the isochrone line the values has changed slightly to an age of 104-111 Ma [16, 17, 18, 13].

Therefore, the interval of 105-111 Ma is the most suitable interval of the formation of the volcanic component of Stanolir complex. The radiometric ages correlate with the age estimates based on previous floristic data [28].

3. Evolution of the Late Mesozoic volcanism on the territory of Bureya-Jziamysi superterrain

The continental volcanism in the end of Late Mesozoic correlates to three age stages in the frames of the northern flank of Bureya-Jziamysi superterrain: 1) the beginning of Early Cretaceous (136 Ma), 2) Aptianian - Albian (117 – 105 Ma), 3) the end of Early Cretaceous – Albian (101 – 99 Ma). The spreading of the volcanic formations in the beginning of Early Cretaceous is timed to the contour of Amur-Zeya depression. The Amur-Zeya depression continues on south-western direction as Songliao depression on the territory of China. In the limits of Songliao depression the acid volcanites aged 136 ± 0.3 Ma [29] are stated. The belonging of the two volcanites to the intraplate formations is well confirmed by the petro-geochemical characteristics of the rocks of the volcanic complex [11].

Low potassic andesites of Poyarka volcanic complex are formed on the territory of the superterrain in the end of early Cretaceous (117 – 105 Ma). They are depleted by highly charged elements (Nb, Ta, Zr, Hf) and are enriched by Sr, Ba. Such geochemical characteristics are peculiar to the products of subduction-related volcanism, what is also confirmed by series of discrimination diagrams of major element oxides and minor element and element ratio values commonly used for geodynamical discriminations of magmatic suites (Fig. 6, 7, 8).

Judging by the presence of a spheroidal jointing of lavas and by the presence of the carbonaceous layers in the lower and upper part of the exposed covering rock facies, the outflow of lavas occurred under conditions of shallow coastal areas in a continental basin, which is in good concert with other researchers' interpretations [33].

The rocks are also compared with over subduction-related rock formations petrochemical characteristics (Fig. 6, 7). Correlation among incoherent elements the studied rocks are in close similarities with young island arc volcanites of Kamchatka (Fig. 8) that show strikingly similar values obtained from rocks especially from the Poyarka complex. The rocks of Burunda complex are the closest ones to the island arc formations lay on continental crust by the ratio La/Yb – Sc/Ni (Fig. 8).

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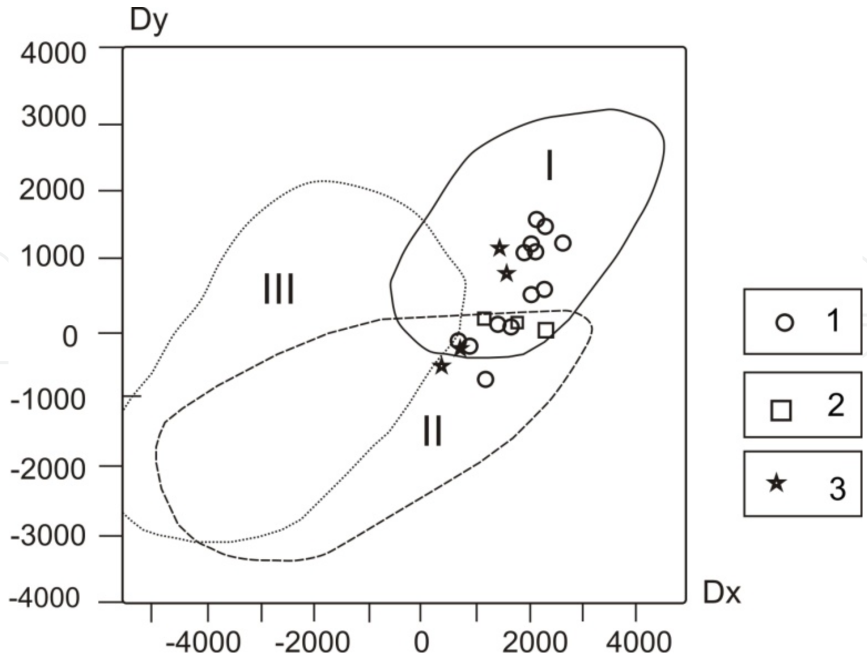

Figure 6. Discrimination diagrams for the definition of the tectonic situations. The rocks of Bureya-Jziamysi superterrain: Poyarka (1), Burunda (2), Stanolir (3). According to the data of: D_x/D_y [30] for the main rocks (D_x = (176.94* SiO_2) - (1217.77* TiO_2) + (154.51* Al_2O_3) - (63.1* FeOt) - (15.69* MgO) + (372.43* CaO) + (104.41* Na_2O) - (19.96* K_2O) - (873.69* P_2O_5) - 11721.488; D_y = (94.39* SiO_2) - (103.3* TiO_2) + (417.98* Al_2O_3) - (55.63* FeOt) + (57.61* MgO) + (118.42* CaO) + (502.02* Na_2O) + (6.37* K_2O) + (415.31* P_2O_5) - 13724.66). The fields of the basalts: I – island arcs, II – traps, III – continental rifts.

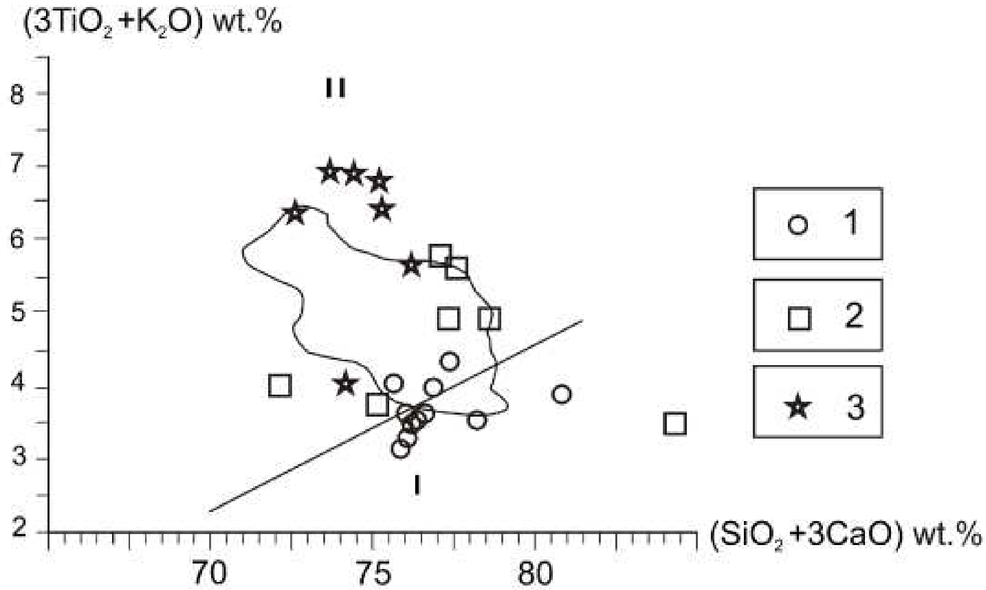

Figure 7. Discrimination petrochemical diagram for the rocks of the volcanic complexes based on the classification of [31].: Poyarka (1), Burunda (2), Stanolir (3). The situation of the volcanites of Okhotsk-Chukotica volcanogenic belt is marked with the contour on the diagram. Type of the associations: I – oceanic, II – continental-margin.

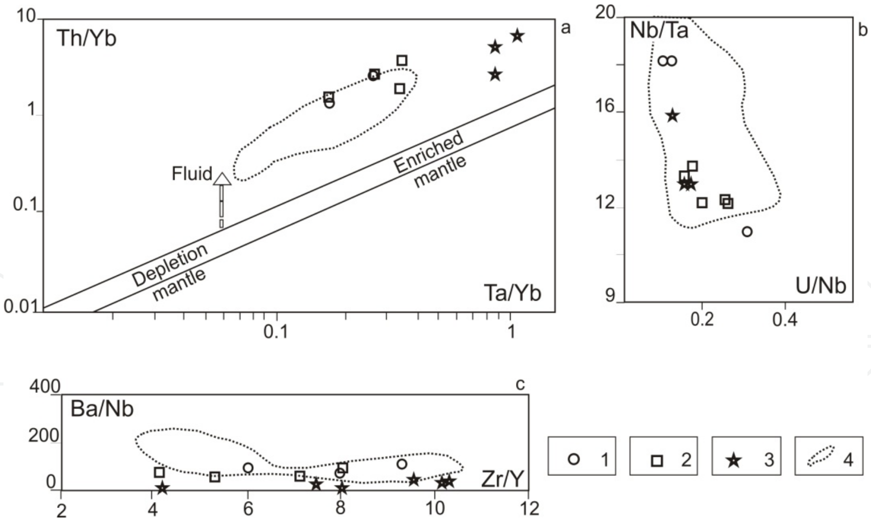

Figure 8. Diagram of the ratio of the incoherent element for the rocks of the volcano-plutonic complexes: Poyarka (1), Burunda (2), Stanolir (3), island arc type of Sredinniy of Kamchatka fault range island arc (4) by [32].

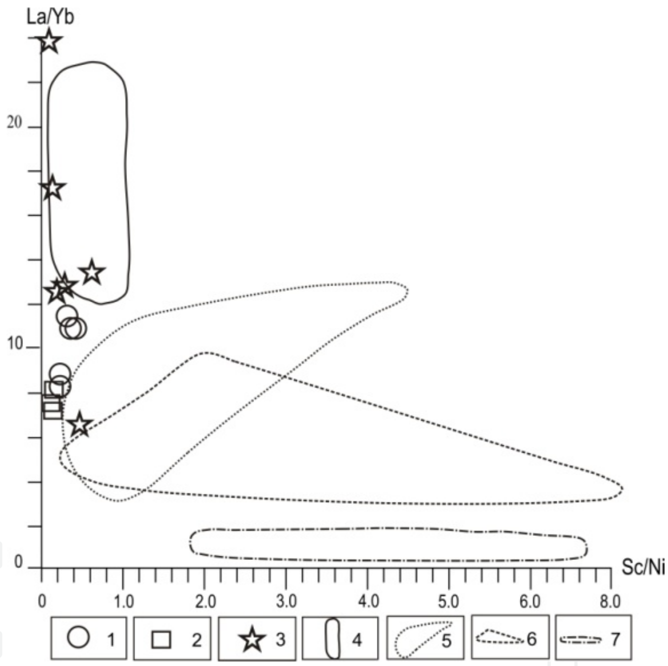

Figure 9. Ratio of the minor elements La/Yb – Sc/Ni in the volcanic complexes: 1 – Poyarka, 2 – Burunda, 3 – Stanolir. Fields of the rocks by the data of [34]: 4 – Andean active continental margin; 5 – island arcs laying on the continental crust, 6 – island arcs laying on the oceanic crust, 7 – low potassic oceanic basalts.

The values of the ratios of Burunda complex rocks are La/Yb<10; La/Ta = 30-102; Zr/Hf = 36.0-39.7 (almost constant). Such values are characteristic for the island arc rocks.

Along the eastern border of superterrain (by modern coordinates) during the period 108 – 105 Ma the andesites of Stanolir complex were formed. On the tectonic diagrams (Fig. 6, 7, 8, 9) they get into the fields of the subduction conditions of their formation. On the diagrams of the REE composition (Fig. 3b) they are characterized with higher content of Nb, Ta, Zr and lower content of Sr, with the conservation of the clear minimums of Ta and Nb, one of the typical values of subduction-related signatures [35, 36]. The proximity to boundary values of the ratios La/Ta = 18-23 [37] are characteristic for these rocks. By the correlations of such incoherent elements, as Nb/Ta - U/Nb (Fig. 8 b), it is inferred that the rocks are relate to the island arc formations. According to the correlation Th/Yb – Ta/Yb and Ba/Nb – Zr/Y (Fig. 8 a, c) the volcanites of the Stanolir complex are located on the continuation of the fields of the island arc formations.

Isotope-geochronological data for lavas and subvolcanic rock formations of the investigated volcanic complexes define the time of the formation of the magma component. But the beginning of their establishment has started prior the formation of the preserved coherent magmatic bodies as evidenced by the presence of basal thick volcanogenic terrestrial sedimentary successions part of the underlying sedimentary succession. It should be mentioned that the thickness of this component is almost the same for all complexes – 200 – 450 m. Tuffogenic – sedimentary successions of Poyarka volcanic complex was accumulated during Hauterivian – Barremian period which is more or les the same time frame for the Burunda volcanic complex which was inferred to have been accumulated during Barremian – Aptianian period [22].

It can be stated, that Poyarka volcanic complex started to form from the accumulation of the tuffogenic-sediment component at about 120 Ma. About 117 Ma large volume of lava outflow – part of the volcanic complex – took place. The analogical formations of Burunda complex started to form 111 Ma. Stanolir complex started to form about 108 Ma ago. The outflow of Poyarka volcanic complex were near-continues till Albian – 107 Ma. That is the time when lava outflow of Burunda and Stanolir volcanic complexes begins.. All the volcanites belong to calcareous-alkaline low and high potassic series. They are characterized with snbductional type origin based on the distribution pattern of the minor elements such as for instance the concentration of Nb and Ta is low while the concentration of Ba, Rb, K, Ti, Sr are relatively high

The diagram (Fig. 10) illustrates the formation of the initial melt for the three complexes occurred at the expense of the melt of peridotite.

By the correlation of Tb/Yb normalized to chondrite –C1 [39], that make less than 1.8 (except some of the trials of Stanolir complex) it can be stated that, spinel peridotites were the magma-forming substratum for the formation of the andesite of the volcanic complex. By all that the stage of the melt of the substratum of the spinel peridotite was decreasing from the volcanites of Poyarka complex to the volcanites of Stanolir complex (Fig. 32). The coefficient of REE = 2.5-4.3. (K_{REE} = 0.1La/Yb+Ho/Yb+(Dy+Ho)/(Yb+Lu) by [40], elements normalized to chondrite [41]). Such values confirm the presence of pyroxene in the melting substrata. By the ratio Ni/Co [42] the rocks of Poyarka (completely), Stanolir (mostly) and Burunda (subvolcanic) complexes are derivatives from the melts of the mantle. The derivatives of the melt of the lower crust formations are the lavas of Burunda complex and (rarely) Stanolir complex. Thus, the rocks of the three complexes can be partly examined as primary. It is confirmed by the absence (or a weak presence) of Eu anomalies, that is one of the criteria of the primary nature of magmas [43]. By the correlation of the incoherent elements: Nb/Ta - U/Nb (Fig. 7 b) the formations of the complexes are comparable with the rocks of the subduction type of the Sredinnii mountain ridge of Kamchatka. By the correlations Th/Yb-Ta/Yb (Fig. 7a) the volcanites of Stanolir complex are displaced to the side of the enriched mantle. The relations of the coherent elements (Ce/La, Zr/La, Nb/La, Th/La, Yb/La) are not only close to the constant values, but they also correlate with each other. This confirms the belonging of the rocks of the three complexes to a singular magmatic stage. The derivatives of the stage underwent the evolution because of the decay of the subduction processes in the frames of the researched region. Many authors connect the lowering of the concentration of Sr and growth of the concentration of Ce and Th with the "decay" of the subduction [44 - 49, 36]. It can be seen in the geochemical characteristics of the rocks of the researched complexes in the direction from the volcanites of Poyarka to the volcanites of Stanolir complex: Sr – from 1029 ppm to 153 ppm, Ce – from 28.52 ppm to 75.07 ppm, Th – from 1.7 ppm to 15.89 ppm. They belong to the singular magmatic process that confirms the ratio of Zr/Nb - Nb/Th. According to the ratio all this formations were melted from the source that is close to the source type EN [50] with the presence of a component of a depleted source. Series of the geochemical indicators (Nb/La, La/Ta, Ta/Th, et al.) show that magmas of the volcanites were also underwent by the contaminations of the crust material. According to the ratio Ce/Y (less than 4) and La/Nb (less than 3.5) the formation of the rocks of the researched complexes occurred at the expense of the mixture with the crust of the product of a partly melt of the spinel peridotite of the mantle [51].

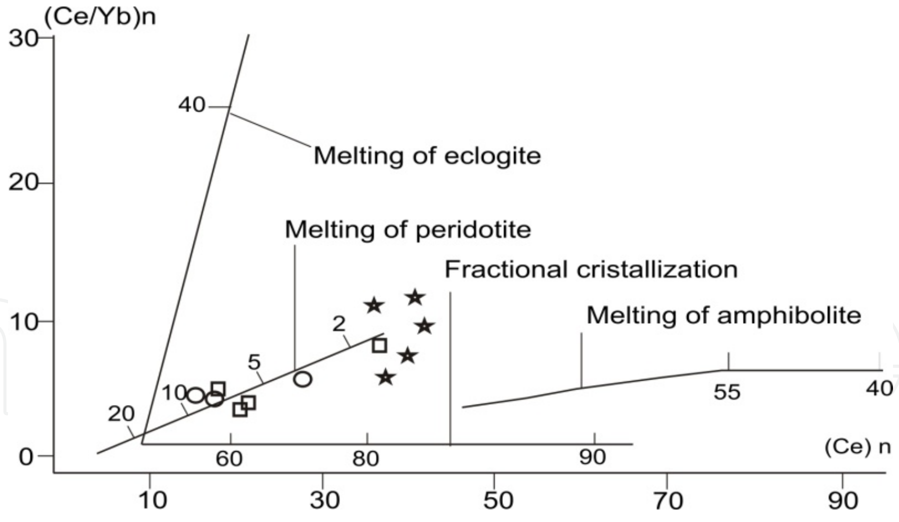

Figure 10. The location of the rocks of the andesite volcanic complexes on the diagram $(Ce/Yb)_n$-$(Ce)_n$ (conditional marks are listed on the fig. 8). The model trends of melting by [38].

Based on the comparison of the formation time, petro- and geochemical characteristics, belonging to the singular magmatic process of the rocks of the andesite formation of the northern flank of Bureya-Jziamysi superterrain of Poyarka, Burunda and Stanolir complexes, the followings can be stated:

1. By the ratio (Nb/La)n –(Nb/Th)n [52] the rocks of Burunda complex correspond with island arc lavas - the contaminated formations of the continental crust. The affection of the crust contamination is confirmed by the high values of the ratio $^{206}Pb/^{204}Pb$ (389.6) [23].

2. Formations of Burunda complex are inconsistently laying on the terrigene deposits of Ogodzha suite of Aptian – Albian age. The Ogodzha deposits are traced in the mining excavations under the formations of Burunda rock strata (Fig. 3). They are stated in singular tectonic blocks in southern direction. That points to a more wide development of the rocks as in primary variant. The coal-bearing deposits of the suite lay on the borders of Paleozoic and Early Mesozoic (Triassic) age of the superterrain transgressively. They form a flat monocline with the dip from 8 to 30^{o}. Tuff material is present in the composition of the suite. It points at the parallel volcanic activity during the Ogodzha sediment accumulation. The following intensification of the volcanic activity (111-105 Ma) leads to the formation of Burunda volcanic complex. It can be proposed that Burunda volcanites are a fragment of an island arc that was formed on the edge of Bureya-Jziamysi superterrain and the deposits of Ogodzha suite are part of a sediment complex formed in a behind-the-arc basin.

3. The volcanic activity completes in the frames of the researched territory by the formation of the acid – alkali volcano-plutonic complex at 101 – 99 Ma. The formations of the complex are characterized as intraplate origin. Their geochemical signatures indicate of its source is close to an enriched mantle in the primary melt of the source region of melts [11].

4. Geodynamic situations of the formation of the Late Mesozoic volcanic complexes of Bureya-Jziamysi superterrain

The first introductions about possible geodynamical situations in the frames of the researched region were made L.P. Sonenshein with co-authors (1990), who thought that Mesozoic magmatic formations could be a product of activity of a subduction-related volcanism or a "hot spot" activity. Farther the same variants were elaborated by V.V., Yarmoluk and B.I. Kovalenko [53, 54], I.V. Gordienko [55], V.G. Moiseenko [56]. B.A. Natalin proposed both subductional and collisional situations [57]. Chinese geologists [58] researched a model of the formation of Mesozoic magmatism in the situation of a transformed continental edge. Analogical point of view was presented by A.I. Khanchuk and V.V. Ivanov [59]. The high precision values about the age and the volcanites geochemical composition of the rocks of the volcano-plutonic complexes of the region were absent during the composition of the geodynamical reconstructions listed above. The values are partly derived at the present time.

All the suggested geodymanical reconstructions include the interdependence of North-Asian and Sino-Korean cratons and platforms of the oceanic crust of the Pacific.

Northern border of Bureya-Jziamysi superterrain is a southern border of Mongol-Okhotsk orogenic belt. Along the belt the Late Mesozoic formations of the bimodal series are developed [12, 13]. The formation of the complexes occurred under conditions of collisional compression, agreed by the approaching of North-Asian and Sino-Korean cratons and a possible influence of plume on the area that is under conditions of the collisional compression. The bimodal complexes have a lineal separation in the frames of Mongol Okhotsk belt. But on the East their separation is framed by the structures of Bureya-Jziamysi superterrain. It might be proposed that the given theory had not suffered such processes. The Chinese geologists worked out a scheme of tectonic development for the territory of Bureya-Jziamysi superterrain on the results based on a seismic transect Manchzhuria – Suifankhe laid transversely the Songliao depression [58, 60]. It is stated that the extension, provoked by the changes of the Izanaga plate movement dominated in Late Jurassic – Early Cretaceous in the Songliao basin [58, 55]. According to the data [61] a sharp change of the direction (on 50°) and speed (from 5.3 to 30 cm per year) of the subduction of Izanaga plate under the eastern edge of Bureya-Jziamysi superterrain took place at about 135 Ma. This provoked the formation of series of the left displacements CB and C-CB extension and formation of the rift-like structures [58]. The structures were field with coal-bearing terrigenous sediments and volcanic formations of acid composition. During the period a complex of acid volcanites aged 136 Ma is forming in the frames of the studied territory.

Farther than 136 – 120 Ma the territory became as a passive continental edge. The temporal stage of the formation of Poyarka, Burunda and Stanolir volcanic complexes relates to the moment when the Izanaga plate changed its movement direction from northern to north-western. With that, the angle of the turn of the plate was almost 30° [61]. During the period there was a flat subduction of the oceanic plate under the eastern edge of Asia with a speed more than 20 cm per year [61]. That's why the formation of the rocks on the continental crust under the conditions of the subduction seems to be possible.

Paleomagnetic data were obtained by U.S. Bretshtein and A.V. Klimov [6] for the main tectonic units of the southern part of the Far East of Russia (Fig. 11). According to the data, during the Jurassic the Bureya-Jziamysi superterrain was at large distance from the North-Korean plate. The distance was about a few thousands of kilometers.

140 Ma the superterrain (Bureya block dew to [62]) was located much more on the north from it's nowadays dislocation according to the data of geological and geophysical including GPS data [62].

Thus, it might be proposed, that during the period 120 – 105 Ma there was a volcanic activity on the territory of Bureya-Jziamysi superterrain which was controlled by the subduction processes. During the period the volcanic formations were loosing their typical subduction petro-chemical characters, for instance the composition of Sr decreased while the amount of Nb, Ta, Rb, K, Ti increased over time. Such values in the composition of the rocks show the attenuation of the active subduction processes. The temporal stage of the formation of the rocks of the three complexes correlates to the stage of the flat subduction of the oceanic plate Izanaga under the edge of Bureya-Jziamysi superterrain. The biggest magmatic activity took place during the period of the change in the movement direction of the oceanic plate from almost northern to north-western with the growth of speed till 23.5 cm per year [61].

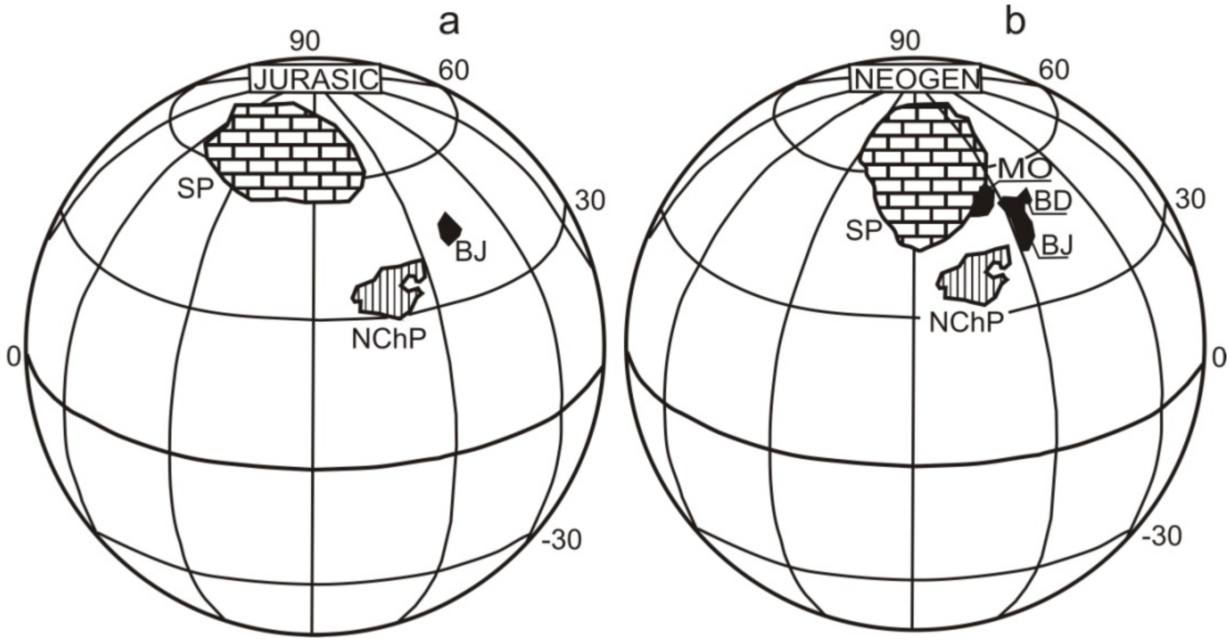

Figure 11. Palinspatic reconstruction of the location of the main tectonic units of the south of the Far East of Russia in Jurassic (a) and Neogene (b) by U.S. Bretshtein and A.V. Klimov [6]. SP – Siberian plate NChP – North-Chinese plate, BJ – Bureya-Jziamysi superterrain (by U.S. Bratshtein and A.B. Klimov – Khingan – Bureya plate), MO – Mongol-Okhotsk terrain, BD – Badzhal terrain

The magmatic processes decay completely in the interval of 105–101 Ma on the territory of Bureya-Jziamysi superterrain. The situation of the continental “riftogenesis” or the situation of a transforming continental edge begins to appear 101 Ma [59, 63], what was reflected on the formation of the acid – alkaline rocks of the intraplate volcano-plutonic complex. As the most possible tectonic scenario by the formation of the volcano-plutonic complex the author examines the collision of Bureya-Jziamysi and Badzhalsky terrains [11] which is confirmed by the paleomagnetic data (Fig. 10).

5. Conclusion

On the base of the confrontation of the formation time, petro- and geochemical characteristics, belonging to a singular magmatic focus of the rocks of andesite formation of Bureya-Jziamysi superterrain, the Poyarka, the Bureya and the Stanolir volcanic complexes, it might be stated that their formation happened more or less simultaneously (with a leading at the formation of Poyarka complex at the beginning). All the formations of the studied volcanic complexes have similar characteristics and are related to subductional volcanites of calc alkali series. The changes of the content of major- and minor element composition of the volcanic complexes may be explained by the mixture of the mantle source, fluids at the partial melt of the lower continental crust and a subducting plate at its contact with the mantle. The last fact is confirmed by the presence of “adakite component” – the shows of melt of the oceanic plate in the rocks of Poyarka and Burunda complexes: the presence of magnesial andesites and andesites, high concentrations of Sr and Ba, low concentrations of HREE with the high ratios of La/Yb and low ratios of K/La. Thus, it might be proposed that the existence of a simultaneous volcanic activity during 120 – 105 Ma on the territory of Bureya-Jziamysi superterrain, conditioned by the subductional processes. During the period, the volcanic formations loose their typical subductional signatures as reflected by the lower Sr concentration of the rocks, the increase in concentration of Nb, Ta, Rb, K, Ti, what is inferred to be connected to the decay of the active subduction processes.

The dislocation and the geochemical characteristics of the rocks of the complexes show the dislocation of the moving of the subducted oceanic plate. Its northern territory was pointing to the side of the ocean at that moment. It might be also proposed that Bureya-Jziamysi superterrain was not a component of Amur microcontinent during the period of the formation of the three complexes, but it was an independent geological object. Its annexation to the Amur microcontinent occurred much later than Albian.

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