TECTONO-MAGMATIC ENVIRONMENT WITHIN THE CONTINENT-TO-OCEAN TRANSITION ZONE OF THE NORTHWESTERN PACIFIC

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ABSTRACT

The continent-to-ocean transition zone of the northwestern Pacific features magmatic rocks of different composition and age (Archean to Pleistocene) that exhibit gradational contacts. Regional undifferentiated basement includes migmatite-granite and anatectite granite of probable Early Archean age and teschenite-basalt and picrite-basalt complexes in Riphean to Lower Cambrian volcanic-sedimentary deposits. Magmatic processes of the Phanerozoic manifest themselves in the formation of ophiolite troughs of persistent occurrence. These troughs are evidence of the rejuvenation stages of the Paleozoic (0_2-T_3), Late Jurassic to Early Cretaceous (J_3-K_1), and Senonian (K_2km), of which only the Late Jurassic-Early Cretaceous (Neocomian) stage is complete. Ophiolite-forming processes occurred in the Paleozoic and mid-Mesozoic and probably in the late Precambrian. Plutonogenic ophiolites of Senonian age are not found. The median and marginal island arcs are contemporaneous with polycyclic troughs, except for during the Senonian, and composed of subalkalic and alkalic basalt and boninitoid. The marginal island arcs underwent intrusion of batholith-like tonalite-granodiorite plutons of gabbro-granite series through the Neocomian. The early orogenic stage (K_1a-K_2m) was characterized by the development of basalt molasse, a continuous gabbro-granite series in dikes and stocks, and alkalic gabbroids (K_2sn). During the late orogenic stage, Eocene through Early Miocene, ophiolite magmatism was replaced by granitoid magmatism, resulting in volcanic belts independent of major geologic structures of the Anadyr-Koryak system. These belts are dominated by felsic volcanics of the hypersthene series, with an increased potassium content, through Oligocene time. The history of magmatism was terminated during Pliocene to Pleistocene time with the deposition of subalkalic olivine basalts and ankaramites containing abundant ultramafite fragments.

Magmatic processes of the Anadyr-Koryak transition zone feature sodium petrochemistry pertinent to all groups of rocks ranging from Archean to Oligocene in age. In addition, there is an absence or sharp reduction in the presence of andesite through any of the regional tectono-magmatic stages.

INTRODUCTION

The Anadyr-Koryak geosystem in the northern Koryak Highlands is unique in its diverse and extensive magmatism, which occurred in a discrete-continuous process from Riphean to Pleistocene time. Magmatic complexes of a given stage are taken as indices of endogenic processes and evidence of the spatial and temporal evolution of the deep crust. Understanding these complexes in the context of the processes that formed them is one of the fundamental problems of geology. The evolution of magmatic processes is considered here from the viewpoint of a formation study (Kuznetsov, 1974). This paper includes data on the Koryak region obtained by the author and his colleagues in the last two decades, map compilations, and magmatic formation maps with explanatory notes.

Previous Work

Most publications on regional magmatic complexes deal with gabbro-ultramafite rock associations and include Kaigorodtsev (1961, 1966), Pinus et al. (1973), Markov et al. (1982), Palanjan et al. (1982), Ivanov (1979), Nekrasov (1980), Peive (1984), and Zimin et al. (1986). Data on ultramafic volcanics are included in articles by Zimin et al. (1979), Markovsky et al. (1985), and Bely et al. (1988); on boninitoids in Gelman et al. (1988), Zlobin et al. (1989), and Fedorov et al. (1990); on inclusions in alkalic basalts in Zanyukov et al. (1976), and others. Descriptions of eugeosynclinal volcanism are rare, but are presented in Ivanov (1981), Ivanov and Kolyasnikov (1988), Voinova (1986), Gelman and Epstein (1979), and Zlobin et al. (1989). Only a few publications deal with orogenic magmatic formations, such as Ivanov (1990), Ivanov et al. (1986), Morozov (1988), and Dagis (1990).

AREA DESCRIPTION AND MATERIAL STUDIED

The Pacific continent-to-ocean transition zone under consideration includes the Anadyr-Koryak and Olyutor geologic systems, which differ in type and age (Fig. 1). The Anadyr-Koryak geosystem is the continent-to-ocean transition zone of the northwestern Pacific. Structurally, this transition is expressed as a combination of heterogeneous and noncontemporaneous Precambrian basement rocks, long-term polycyclic ophiolite troughs and island arcs, late orogenic volcanic belts, nappe-imbricate tectonic elements, and lineaments (Ivanov, 1984).

Phanerozoic basement includes Lower Archean (?) crystalline and Riphean to Lower Cambrian greenschist structural complexes (Ivanov, 1989).

Blocks and outcrops of schists and gneiss are found in the Zolotogorsky, Tanyurer, and Taigonos uplifts along the periphery of the Anadyr-Koryak geosystem and in dike xenoliths of the Kamchatka Isthmus (Bogdanov et al. 1988); fragments of these rocks are present in serpentinite melanges. The crystalline sequence includes members consisting of two-pyroxene schist and amphibolite with garnet, clinopyroxene, anthophyllite, rhombic pyroxene, and cummingtonite with some evidence of initial high-magnesium basaltic rocks. A gneiss-granite subsheet, cross-cutting bodies, and alaskite veins are found in metamorphic rocks. The Lower Archean (?) ultra-metamorphogenesis is terminated by a migmatite-granite complex and associated anatectite granite.

The initial late Precambrian (Riphean through Lower Cambrian) volcanic-sedimentary eugeosynclinal rock sequence was subject to regional greenschist alteration. Teschenite-dolerite, picrite-basalt, and andesite-basalt

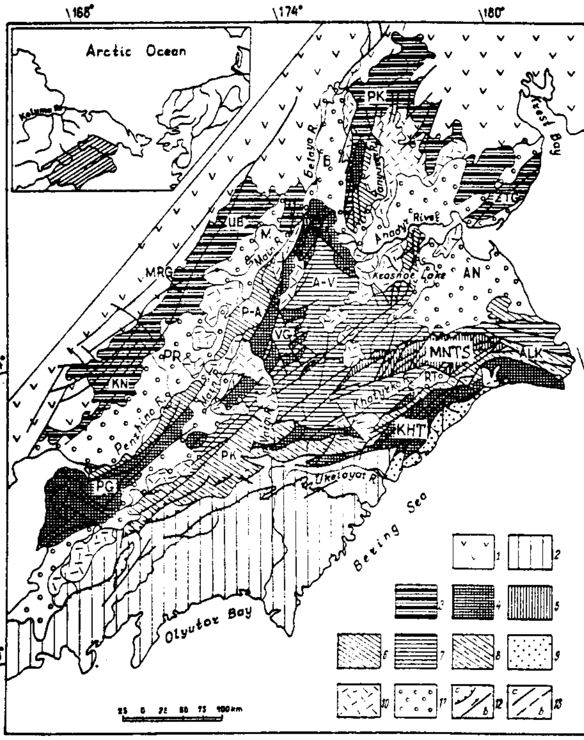

Fig.1. Simplified tectonic map of the Anadyr-Koryak Highlands. 1 - volcanic formations of the Okhotsk-Chukchi volcanic belt; 2 - the Olyutor zone; 3 - marginal island-arc uplifts: KN - Kondyrev, MRG - Murgal, UB - Ubienka River horst-anticline, PK - Pekulney, ZT - Zolotorskoe); 4 - thorough-going ophiolite polycyclic troughs (0_2-K_2): Penzhin-Pekulney (PG-PK) and Pikasvayam-Khatyrka (P-KHT); 5 - the Mainits median island arc (C_1-K_1); 6-9 - areas of widespread early molasse formations: 6 - Penzhin-Anadyr (P-A); 7 - Algan-Velikorechen block (A-V); 8 - Pikasvayam- Alkatvaam (PK-ALK); 9-11 - late orogenic structures: 9 - Nizhne-Khatyrka depression; 10 - late orogenic volcanic belts; 11 - Neogene-Pleistocene depressions (Anadyr - AN, Rytgyl - RT, Markov - M, UST- Belskaya - B, Parapolsky Dol - PR).

complexes of the sodium series are present in different tectonic environments (Ivanov, 1989). Fragmentary outcrops of Precambrian rocks include rare serpentinized ultramafic and gabbro bodies, such as in the Vaezsky Uplift, and plagiogranite dikes, such as those formed in the Iomraut nappe. An ophiolite rock sequence of Riphean-to-Vendian age is distinguished in late Precambrian rock paragenesis.

The geologic system under consideration is especially characterized by Phanerozoic magmatism confined to narrow linear troughs (Fig.1). These troughs developed in a continuous-discontinuous, discrete and polycyclic way within a single structure from the Ordovician to the Campanian. Each of these cycles was associated with noncompensated jasper-terrigenous-siliceous sedimentation and initial basalt volcanism and was terminated, except in the Senonian, by plutonogenic ultramafite-gabbro-plagiogranite magmatism.

There are two troughs of this kind: the Penzhin-Pekulney, in the west, extending for 1,000 km, and the Pikasvayam-Khatyrka, in the east, extending for 700 km. These troughs are separated by the Algan-Velikorechen block, which features a small manifestation of pre-Cenozoic magmatism (Fig.1).

Calcareous basalt and spilite were deposited in the southern Talov-Pekulney trough (TP) during Early-to-Middle Paleozoic (O_{2-1}), and explosion products of intermediate and, to a lesser extent, felsic composition were deposited there in the mid-Devonian. Deposits of andesite and trachyandesite began to occur in the Late Carboniferous. The northeastern Pikasvayam-Khatyrka trough features the most complete (D_2-T_2) and thick (more than 5,000 m) sedimentary-volcanic section of Paleozoic rocks in northeast Asia. The Pikasvayam-Khatyrka trough is characterized by extensive magmatism with volcanics making up 60 percent of the sequence, felsic-to-mafic developmental-type and contrasting rock composition with spilite and basalt making up 35 percent, and keratophyrews and felsic tuffs making up 25 percent.

Noncontemporaneous fragments of Paleozoic volcanogenic-jasper-siliceous rock occur in olistilith found in Mesozoic strata and in fragmentary serpentinite melange throughout the Pikasvayam-Khatyrka zone. A gradual continent-to-ocean transition of volcanism took place from the mid-Ordovician to the Late Triassic: from the Penzhin-Pekulney trough during O_2-D_2 to the Pikasvayam-Khatyrka trough during D_3 -T_3. Felsic volcanism manifested itself widely through the Late Paleozoic and indicates an intense development of interior uplifts.

Paleozoic magmatism most commonly terminates with Late Triassic volcanism. The island arc conjugate to the Pikasvayam-Khatyrka trough was fully developed during Late Paleozoic (C_2-T_3). A fragment of this island arc is present in the basement of the inherited Mainits island arc of the Mesozoic. The base of the Paleozoic section (C_2-P_1) is composed of subalkalic and alkalic basalt; in the northeastern Kankaran Range, these are trachybasalt and trachyandesite of Late Triassic age. A southerly exposed submerged slope of the Paleozoic island arc is represented by a boninitoid rock assemblage associated with subalkalic basalt of the calc-alkalic series.

Volcanic rocks in Paleozoic sections include appreciable lava that has a high-sodium, low-alumina, and medioferrigenous composition and has a rhyolite-basalt of the calc-alkalic series with a well-differentiated basalt component (Fig.2A). The basalts are characterized by a bimodal distribution of low-potassium and moderate-potassium varieties: K_2O at 0.6 percent and 1.3-2.7 percent, respectively (Fig.2B and C).

No orogenic formations were found indicating the developmental failure of Paleozoic troughs. The evolution of these troughs terminated with the development of harzburgite, dunite-harzburgite, dunite-clinopyroxenite-gabbro, and gabbronorite complexes; these are represented in the northern Penzhin-Pekulney zone by the lherzolite complex, which contains a small amount plagiogranite assemblage. The presence of authentic plutonogenic ophiolites is evident only from the eastern Ekonai flank of the Pikasvayam-Khatyrka zone.

Developmental stages of polycyclic troughs took place from Late Jurassic to Early Cretaceous (Kimmeridgian to Hauterivian). At this time, island-arc systems were formed in a geodynamic environment of marginal seas adjacent to the troughs of a completed Paleozoic development stage. These island-arc systems were

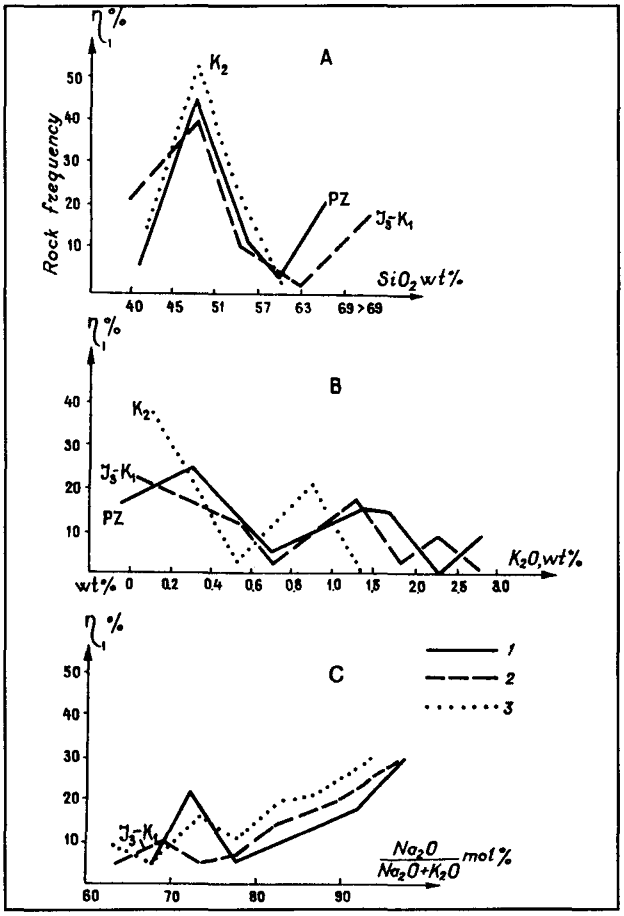

Fig.2. Histograms of distribution of silica: (A) potassium oxide, (B) potassium-to-alkali sum ratio, and (C) volcanic series of eugeosynclinal troughs: 1 - Paleozoic rhyolite-basalt; 2 - Upper Jurassic to Lower Cretaceous rhyolite-dacite-basalt; and 3 - Senonian (Campanian) andesite-basalt.

conjugate pairs to troughs such as the Penzhin-Pekulney trough, the Murgal marginal island-arc uplifts, the Pikasvayam-Khatyrka trough, and the Mainits median island arc (Fig.1). Jasper-siliceous and siliceous-terrigenous sequences formed in these troughs during the Kimmeridgian and Hauterivian, respectively. The volcanic portion of the section is dominated by lava of a continuous and gradually differentiated rhyolite-dacite-andesite-basalt complex with high-sodium and calc-alkalic, and probably calcareous, series associations (Fig.2A). An ultramafic volcanic complex consisting of lava, pyroclastic, and subvolcanic rocks, formed in the northern Penzhin-Pekulney trough during Hauterivian (Markovsky et al., 1985; Bely et al., 1988), and a dike complex developed to the south, thus defining the continental crust boundary. There are no picritoids in the Pikasvayam-Khatyrka trough, and the section here is abundant in potassium-sodium and subalkalic basaltic rocks.

Both the Paleozoic and Late Jurassic-Early Cretaceous (Neocomian) developmental stages of geosynclinal troughs are characterized by a reduction in andesite (Fig.2A). The Neocomian stage terminates with rocks of an ophiolite plutonogenic series. Dunite-clinopyroxenite-gabbro and gabbronorite complexes predominate, and dunite-harzburgite and plagiogranite are less common (Fig.3). Major plagiogranite rock masses and serpentinite of numerous melanges make up an important part of the rocks of the Pikasvayam-Khatyrka trough.

The Murgal marginal island arc represents a chain of en echelon uplifts that overlie continental crust and extend for more than 750 km. These appear to be a projection of the Benioff zone onto modern structures and topography. Island arc rocks consist of Volgian-Berriasian lava and tephra of a high-sodium, calc-alkalic, andesite-basalt association and a Hauterivian potassium-sodium trachybasalt and trachyandesite-basalt complex (Fig.4). Termination of the development of the marginal island arc occurred with the intrusion of diorite-granodiorite-tonalite plutons, covering an area of up to 5,000 km^2, which, in combination with the previously mentioned gabbro complex, forms a gabbro-diorite-tonalite intrusive group (Fig.5).

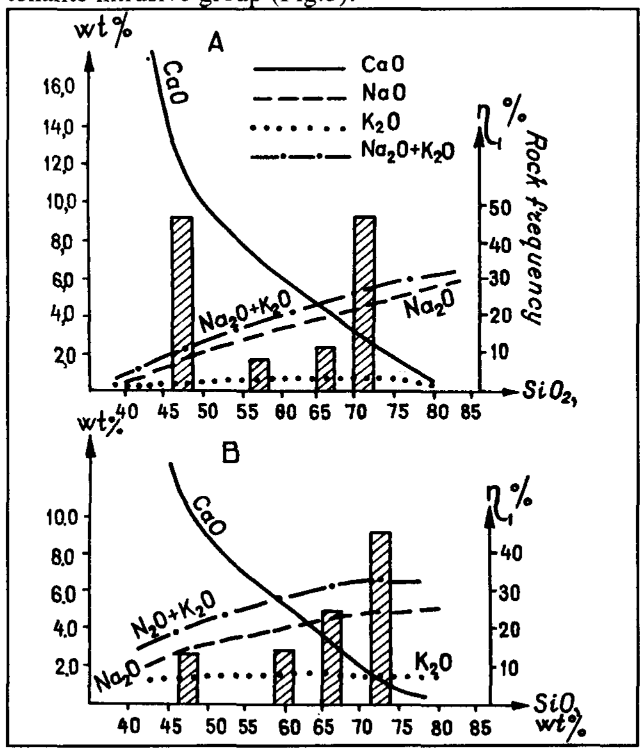

Fig.3. Statistical-petrochemical chart for (A) - contrasting ophiolite gabbro-granite series (J_3-K_1) and (B) - early orogenic gabbro-diorite-granodiorite-granite series (K_2sn_1). Graph A is from 260 analyses and graph B is from 117 analyses.

The Mainits median island arc, which extends for more than 200 km, is inherited from the Paleozoic structure. The base of the island arc is composed of high-sodium subalkalic and, to a lesser extent, alkalic and high-alumina basalt ranging in age from Kimmeridgian to Early Tithonian. Up-section, there is a sedimentary-pyroclastic sequence and calc-alkalic series lavas of dacite-andesite-basalt composition with an increased alkalinity, silicity, and magnesium content of potassium-sodium range. The section terminates with an andesite-basalt complex. A boninitoid complex of probable Hauterivian age is found in the northeastern

Murgal island arc (Gelman et al., 1988; Zlobin et al., 1989). The plutonogenic group of post-Hauterivian age includes intrusions of dunite-clinopyroxenite-gabbro, gabbronorite, and plagiogranite complexes.

The Late Jurassic-Neocomian development stage of the Anadyr-Koryak geosystem terminated with an orogenic cycle featuring widespread and complete sedimentary and magmatic formations, which differs from situation during the Paleozoic stage. The orogenic interval is different in this region; lower molasse ranges in age from Late Albian in the Penzhin trough to Maastrichtian in the eastern highlands.

Orogenic processes in the Penzhin-Pekulney and Pikasvayam-Khatyrka troughs were contemporaneous with local rejuvenation associated with the development of sedimentary-siliceous-volcanic formations of Campanian age. The volcanic portion of the section includes a high-sodium andesite-basalt complex with an andesite content of 25 percent and a content of undifferentiated basalts of 65 percent. There are also felsic ash tuffs with a potassium content of 2.6-3.6 percent (Fig.2A). Basaltic rocks are characterized by a bimodal distribution of potassium (Fig.2B) and coeval calcareous, subalkalic, high-alumina, high-sodium, and potassium-sodium basalt, much like rocks of the Paleozoic and Neocomian stages.

Early orogenic formations include a rare pre-Danian sedimentary-volcanic molasse with sodium basalt flows and a widespread, continuous and complete intrusive group of small bodies such as dikes and stocks of gabbro, diorite-granodiorite-granite, and syenite-monzodiorite-diorite.

The late orogenic stage began in the Late Senonian with the development of alkalic gabbro rock complexes, including teschenites and crinanites. These subsheet bodies and dikes are found in a coal-bearing molasse of the Rarytkin Range and the Upper Senonian rocks in the vicinity of Navarin Cape.

The late orogenic stage (Eocene to Early Miocene) was characterized by the formation of independent belts of volcanic structures that developed, to some extent, contemporaneously in different geodynamic environments. The Penzhin-Algan volcanic belt is located within the Penzhin trough and formed coincidently with the closing trough. The Krasnoozersk-Opukh belt follows the lineament and cuts across major structures of the Anadyr-Koryak geosystem (Fig.6). Different geodynamic environments, under which these volcanic belts were formed, also manifested themselves in distinctive belt structures and compositions. The Penzhin-Algan belt is dominated by basalt-andesite rocks, which make up plutonic and volcanic domes. The Krasnoozersk-Opukh belt represents a chain of volcanic depressions and consists of a rhyolite-dacite complex including a younger contrasting rhyolite basalt rock sequence and a terminal rhyodacite-rhyolite ignimbrite sequence of potassium-sodium and potassium rocks. Rock complexes of the volcanic belt belong to a hypersthene series in the calc-alkalic range and are characterized by a felsic-to-mafic development-type, a greater abundance of pyroclastic material, and potassium in alkalites up-section (Fig.7). These contemporaneous volcanic belts were formed in different tectonic settings and are composed of rocks of a single hypersthene series, which is manifested

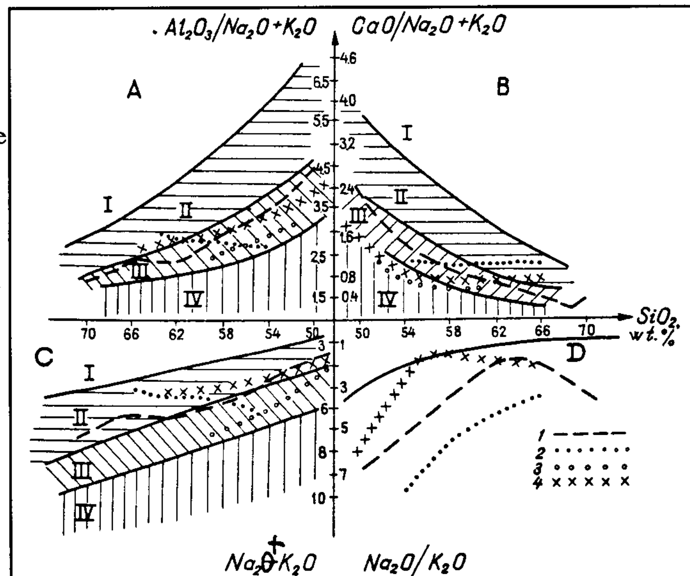

Fig. 4. The rock petrochemical chart of the andesite-basalt complex of the Murgal marginal island arc. Areas of rock-type distribution: I - calcareous, II - calc-alkalic, III - subalkalic, IV - alkalic; Variety curves: 1 - subalkalic rocks, 2 - Berriasian (basalts, less common andesite, dacites), 3 - Early Valanginian (andesites, andesite-basalts), 4 - Hauterivian complex of dacite lavas, ignimbrites, andesites, trachyandesites, and trachybasalts.

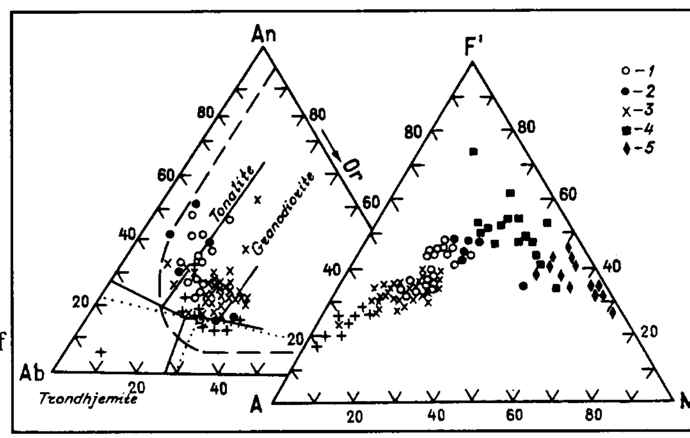

Fig.5 Petrochemistry of the Zolotogorsky gabbro-tonalite-granodiorite series. The rock normal composition diagrams for Ab-An-Or and AFM=A (Na_2O+K_2O) - F (FeO') - M (MgO) complexes. 1 - quartz diorites, 2 - diorites, 3 - granodiorites, 4 - gabbro, 5 - gabbroid cumulates.

in their metallogenic properties.

The history of magmatism in the northern Koryak region terminates with a deuterorogenic complex of subalkalic olivine basalts and ankaramites at Navarin Cape. Here, they are represented by lavas, lava breccia, and scoria-like basalt featuring distinct vent cones. Lavas of the Navarin complex are abundant with different ultramafic rock fragments varying in composition from olivinite to plagioclase-bearing lherzolite (Zanyukov et al., 1976; Fedorov et al., 1990).

CONCLUSIONS

(1) The continent-to-ocean transition zone of the northwestern Pacific is characterized by the presence of

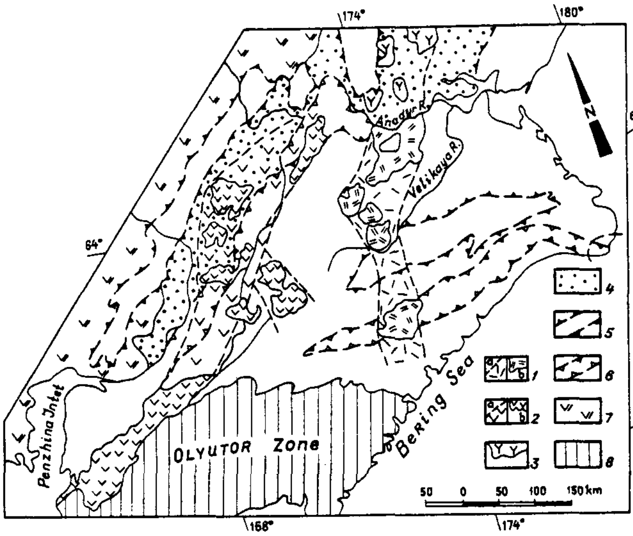

Fig.6. Location map of late orogenic volcanic belts of the Koryak Highlands. 1 - the Krasnoozersk-Opukh volcanic belt, a - b - volcanic structures; 2 - the Penzhin-Algan volcanic belt, a - b - volcanic structures; 3 - areas of volcanites conditionally assigned to the late orogenic stage; 4 - undifferentiated deposits (P-O). Major structures of the Anadyr-Koryak geosystem: 5 - marginal and median island arcs; 6 - ophiolite troughs of a through occurrence (for their names and ages see Fig.1); 7 - the Okhotsk-Chukchi volcanic belt (non-differentiated); 8 - the Olyutor zone.

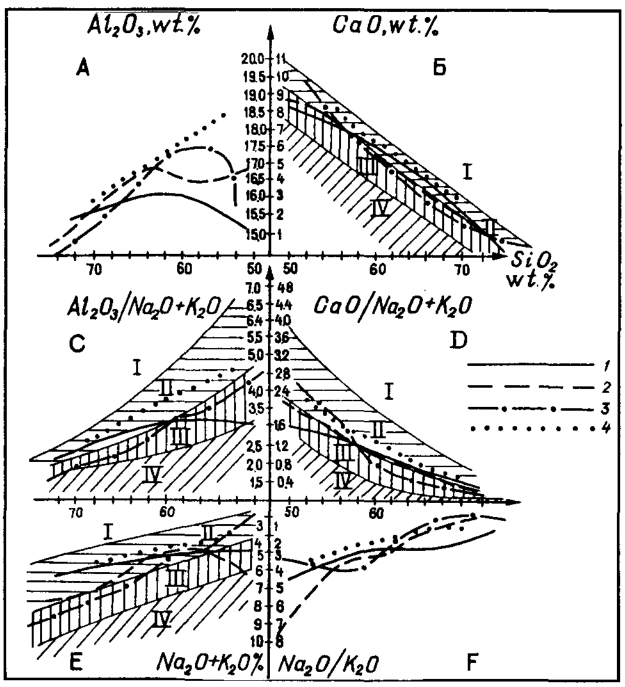

Fig.7. The rock petrochemical chart for the Cenozoic late-orogenic volcanic complexes of the Koryak Highlands. Areas of distribution of the petrochemical series: I - calcareous, II - calc-alkalic, III - subalkalic, IV - alkalic. Variety curves: 1 - basalt-andesite complex of the Penzhin-Anadyr volcanic belt, 2 - rhyolite-dacite complex, 3 - rhyolite-basalt complex of the Krasnoozersk-Opukh volcanic belt, 4 - basalt series of the Okhotsk-Chukchi volcanic belt.

different types of magmatic rocks of different ages (Archean to Pleistocene) that grade into one another, and provide evidence of the spatial and temporal evolution of the region's deep crust.

(2) Magmatic processes manifest themselves in linear ophiolite troughs, which developed in a continuous-discontinuous manner from the mid-Ordovician to the Senonian. Development of these structures may possibly be traced as far back as the Riphean to Vendian.

In fact, all cycles of initial volcanism are characterized by the occurrence of coeval calc-alkalic, calcareous (tholeiite), subalkalic, and alkalic basalts of a high-sodium series, which are common for ophiolite rock assemblages.

(3) Plutonogenic ophiolite complexes of an ultramafite-gabbro-plagiogranite series are rarely manifested within these troughs. These complexes feature different rock groups that vary in their relations within particular cycles and structures. The existence of Upper Precambrian ophiolites is possible.

(4) Within the continent-to-ocean transition zone, the magmatic events are characterized by the absence or sharp reduction of andesite in geosynclinal sections during the Senonian, which is characteristic of this region. This fact may indicate that these toughs (rifts?) developed in continental or subcontinental crust.

(5) Sections of the Murgal median island arc system begin with Paleozoic and Late Mesozoic subalkalic and alkalic basalt. This island-arc-like developmental model has not been previously described, except for the Kamchatka Region, and is a unique characteristic of the northwestern Pacific.

The Murgal marginal island arc and the chain of marginal uplifts, including the Pekulney and Zolotogorsky uplifts, are characterized by a gabbro-tonalite-granodiorite rock series that formed simultaneously with plutogenic ophiolites of these troughs during Late Jurassic to Neocomian time.

(6) During the late orogenic stage, ophiolite development in the Anadyr-Koryak geosystem was replaced by significant granitic rock associations of volcanic facies, which indicates quite new qualities of the deep crust. Two types of magmatic processes, femic (ophiolite) and granitoid (volcanogenic), produce double-type metallogeny in the region that is a combination of Cr, Au, and platinoid minerals from one side, and Sn, Sb, Au-Ag, and Cu-Mo from the other.

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