**Khubaeva, Briantseva, Sim**

# ANALYSIS OF RECENT DEFORMATIONS IN NORTH-PARAMUSHIR GEOTHERMAL DISTRICT (THE KURIL ISLANDS, RUSSIA)

**Khubaeva O.R.[1], Briantseva G.V.[2], Sim L.A.[2]**

[1] Institute of volcanolgy and seismology FEB RAS, Petropavlovsk-Kamchatsky, Russia, E-mail: chubaeva@kcs.iks.ru
[2] Lomonosov State University, Moscow, Russia

**Keywords:** geothermal area, hydrothermal-magmatic system, modern deformation, tectonic

## Abstract

First analysis of recent tectonic deformations was done by an example of the North-Paramushir geothermal district and a homonymous hydrothermal-magmatic system. Main systems of lineaments and block structures which control activity of quaternary and modern volcanoes, hydrothermal springs and heat influx by heated waters, were identified. Additional data on possibility of discovery of a large geothermal deposit and ore mineralization were derived.

## Introduction

The Paramushir Island's tectonics, volcanism and geothermal resources have been in the focus of research and study for many decades (Gorshkov, 1967; Meleksetsev et al., 1993; Belousov et al., 2002). This is one of the most studied islands of the Kuril archipelago. However, a role played by extensional tectonics in the evolution of this district remains unclear. The issues related to extensional tectonics were addressed in the authors' earlier papers. The relation of lineaments, expressed in the relief, to regional network of extensional faults and to the earth's crust permeable zones controlling the locus of volcanic apparatuses and thermal water discharge zones at the northern end of the Paramushir Island was demonstrated (Khubaeva et al., 2005). The efficiency of paragenetic analysis of associated fault systems for an analysis of extensional fault kinematics was demonstrated in work (Sim, 1991). We identified the recent disjunctive dislocations expressed in the relief of the northern, modern volcanic, end of the island. We determined their kinematic types based on the paragenetic analysis of lineaments and demonstrated the relationship of geothermal processes with the recent fault tectonics of the island.

## A Summary of District Geomorphology

The Paramushir island is one the largest islands in the Greater Kuril chain (**Fig. 1).** The island stretches for over 100 km from the south-west to the north-east and is averagely from 20 to 25 km wide. An area of the island is 2042 km$^2$. The northern end of the island is formed by the Vernadsky Ridge shaped by the merged structures of quaternary volcanoes. The ridge extends in submeridional direction from Vetrenaya mountain in the north to Vernadsky mountain in the south and is totally 25 km long and averagely 10 km wide. The ridge watershed almost coincides with the island's centerline. The highest mountains are confined to the watershed. Vernadsky Mountain has a maximal elevation above ocean level (1,180 meters). Cross-section of the ridge is noticeably asymmetric. The slope facing Pacific is relatively low-angle (5-10$^0$ on the average) whereas the Okhotsk sea slope is more pronounced (15-20$^0$ on the average). The undersea slope from the eastern end of the island is flatter and wider than that of the western end. The dissected mountain relief of the Vernadsky ridge was formed owing to interaction of active tectonic-magmatic, volcanic, erosion and hydrothermal processes. At present, volcanic activity largely of explosive and phreatic character and gas-hydrothermal activity directly influencing present-day relief formation processes are continued in the northern and central parts of the ridge. The North-Paramushir geothermal district corresponds spatially to the Vernadsky Ridge. In terms of morphology, the axial part of the geothermal district is a successive submeridionally-oriented series of monogenetic and more complex quaternary volcanic apparatuses which build up the Vernadsky ridge watershed. The northern part of the geothermal district accommodates the North-Paramushir long-existing ore-forming hydrothermal-magmatic system (Belousov et al., 2002),

with which this paper deals.

## General geological description of North-Paramushir geothermal district and the homonymous hydrothermal-magmatic system

Much attention has been paid to thermal manifestations in the northern end of the Paramushir island since first general papers dedicated to the Kuril island arc hydrothermae (Gorshkov, 1967). A series of publications (Rychagov et al., 2002, 2004; Chudayev et al., 2003) have recently been dedicated to underpinning of genetic relation of hydrothermae to the magmatic feeding system of the Ebeko volcano and adjacent volcanic structures. Without going into detailed review of implications about relationship of hydrothermal systems as such and hydrothermal-magmatic systems, for the purpose of characterizing thermal manifestations the authors will hold to definition "hydrothermal-magmatic system" (Rychagov et al., 2002), because this definition, in our opinion, most completely reflects the relation of a hydrothermal process and magmatism.

The northern end of the island is composed of rocks, upper Miocene-Pliocene to Recent in age. The basal complex is composed of volcanogenic-sedimentary rocks of paramushir series – volcanomictic sandstones, tuffs, tuff-gravelites of okhotsk series, and also poorly sorted conglomerates, breccias, coarse-grained sandstones of ocean series. Deposits of Okhotsk and ocean series are intruded by dykes and sills up to first tens of meters thick, and by bigger subvolcanic bodies of andesite and andesite-basalt composition (Gorshkov, 1967; Fedorchenko et al., 1989). Deposits of Okhotsk and ocean series underlie upper Pliocene age andesite lavas forming plateau in the southern part of the north Paramushir. Of the most ancient effusives, lavas of basalt composition, presumably lower-middle Pleistocene in age, are exposed. Two-pyroxene andesites, named interglacial, are widely presented here. The formation of quaternary volcanites is associated with activities of several volcanoes and volcanic centers, located at the north of the island (Krasheninnikov, Bilibin, Bogdanovitch, Fersman and others). The formation of volcanoes took place on the axial part of large submeridionally elongated permeable zone (Meleksetsev et al., 1993). Continued inflow of magmatic andesite-basalt melts along the axial part towards the surface maintained a high activity level of the indicated volcanoes and ended up in the formation of the most recent volcanoes – Ebeko and Neozhidanny (Unexpected), whose structures are composed of post-glacial lavas of two pyroxene andesites and andesite-basalts. Spatially and genetically, the North-Paramushir hydrothermal-magmatic system is associated with the Ebeko volcano. At present, a high fumarolic activity is maintained (Belousov et al., 2002; Khubaeva et al., 2005). It is notable, that the majority of the Ebeko's eruptions are either phreatic or minor explosions (for example, explosive eruptions from the Middle crater, which took place from 4.10.1934 to the fall of 1935) (Meleksetsev et al., 1993).

According to data provided in paper (Khubaeva et al., 2005), the northern end of the island is characterized by the development of four systems of lineaments, expressed in relief, the strike of which corresponds to planetary set of lineaments: diagonal system – the north-eastern and north-western directions and orthogonal – sublatitudinal and submeridional. Distribution of lineaments is irregular, their proximity zones mark boundaries of volcanic structures and disjunctive nodes are confined to their central parts. This feature is most obvious within the Ebeko volcano structure.

## Research methodology

Identification of lineaments, presumably marking the recent extensional faults, was done according to N.P. Kostenko methodology (Korchuganova et al., 2001). It is presumed that lineaments reflect the existence of disjunctive faults in relief lithogenic base, upon which recent movements occur, or erosion processes worked currently passive faults, for one reason or another, being more exposed to degradation due to erosion factors, than adjacent sections. In particular, for identification of faults the most favorable are the sections which experience transtension and shear-fault when high fracturing and crushing zones are formed within rocks and discontinuance with a slip occurs. These sections are selectively exposed to fluvial processes, therefore in a number of cases development of a weak zone may be reflected in some part of drainage system even under cover of quaternary lava

deposits (Kostenko, Briantseva, 2004). Therewith, it was taken into account that not all lineaments can be unequivocally assigned to actual faults within extensive development of accumulative forms of volcanic relief (Kostenko et al., 1999). In such cases, it is necessary to conduct a combined geological-geophysical analysis of the area and each indicated lineament is subject to underpinning (Geophyzicheskiye…, 2006). An analysis of combined geological-geomorphologic profiles was conducted for specification of positions of faults, identified during map interpretation. Reconstruction of a type and kinematics of faults was performed using the structural-geomorphologic method (Sim, 1991). The method is based on recording of determinate mutual orientation of associated faults (fractures) in zones of dynamic effects of shear-faults. Two systems of orthogonal shear fractures are oriented at an angle $45^0 - \alpha$ (where $\alpha$ –angle of shear) towards compression axis, and a system of separations – perpendicular to axis of dilatation of stress field, which caused strike-slip fault. According to data on orientation of the indicated systems of associated fractures with respect to shear plane (See papers of M.V. Gzovsky, 1954-1975), compression axis is oriented towards shear plane: at an angle of $45^0$ in general case, and at an angle $60^0$ under additional stretching, and at an angle $30^0$ under additional compression. Thus, the methodology allows to restore a direction for axes of main normal stresses, which caused shear-fault, sign of shear-fault (left or right) and geodynamic setting of shear-fault formation (compression or dilatation). Because strike-slip shear-faults on research site were identified based on conventional fault interpretation, structural-geomorphologic method of stress field reconstruction serves as an additional, specifying the established fault kinematics. An analysis of focal mechanisms of earthquakes was done to confirm the established stress field (data from 2002.01.28 to 2004.12.18, 13 values) using wolf grid and O.I. Guschenko conic grid (Guschenko, 1979).

For the purpose of study of present-day geothermal processes, there were studied parameters of heat efflux: water temperature was measured in rivers and brooks, which together with water flow rate enables us to take into account hidden and localized thermal water discharge to estimate a total heat efflux within each water catchment area. When mapping heat field of hidden thermal water discharge centers the following formula was used: $Q \cdot t^oC : S = J$ kcal/km$^2$-c, where Q – water flow rate (l/sec); $t^oC$ – brook temperature; S – water catchment area; J- heat efflux in kcal /km$^2$-c. Values were mapped topographically (Aver'ev, 1966).

## Research results

The island has infolded block structure. The structure of disjunctive tectonics in the northern end of the island is governed by paragenetic relations of linear and circle faults. Two main systems of linear faults were identified during the topographic map interpretation: NW and NE strikes and main submeridional zone consisting of a system of proximity faults NNE. Submeridional zone is divided by faults of NW strike, which have left-handed shear-fault component. These data are evidenced by earlier works (V.L. Leonov, an oral communication; Khubaeva et al., 2005). Besides, faults of sublatitudinal strike were identified. The system of linear faults represents a combination of NW and NE strike shear-faults, as well as gaping faults of submeridional strike. Additionally, a normal fault component is identified for shear-faults.

The most important circle structures are radial-concentric structure of the Vetrovoy volcano and the system of radial first of the Kozirevsk volcanic-tectonic structure. Regional faults are a conjugated system of submeridionally oriented normal faults and gaping faults (formed in dilatation conditions), left-handed shear-faults of north-east strike and right-handed shear-faults of north-west strike. The formation of such a conjugated system may be a consequence caused by submeridional compression forces with flat or subhorizontal orientation of compression and dilatation vectors, which meets the existing tectonic knowledge about Circum Pacific global zone of latitudinal displacement. This character of stress field was confirmed by the analysis of focal mechanisms of earthquakes using wolf grid. Consequently, common stress field was determined to have compression axis 205∠30 and dilatation axis 116∠0. Diagonal system of shear-faults does not contradict such present-day stress field. The analysis of focal mechanisms of earthquakes gives

important information not only on kinematics of disjunctives, but also allows to make tectonic-physical generalizations about alteration of stress condition of environment at depth of the North-Paramushir hydrothermal-magmatic system. Positively, the absence of local seismicity monitoring network and usage of data from the regional network of seismic stations with a modest accuracy of determination of earthquake hypocenters makes us regard such results (while analyzing an area of ~ 400 ÷ 500 $km^2$) as ancillary information. Right-handed strike-slip fault restricts Levashov's horst form NW, which also conforms to sublatitudinal compression of the region. Intrusions, volcanic cones, both extinct and active, and hydrothermal manifestations are confined to submeridional zone of faults and to sections where this zone intersects NW and NE strike faults.

The Ebeko volcano is confined to the intersection of the main submeridional zone with one of NW strike fault. However, there is a high probability that present-day volcanism is related to large NE strike fault which interprets right-handed shear-fault. The NW wing of this shear-fault interprets a fault which spatially conforms to the Yur'ev River and which is an extension of the fault to which the Ebeko volcano is restricted. The modern activity at the junction of opposite direction shear-faults (WNW- Yur'ev and NW - Ebeko) can be explained by their position in relation to the axis of common modern dilatation which is close to normal. In addition, this area of daylight surface accommodates only two groups of thermal springs and they are both confined to the fault indicated above. Hydrothermal springs and a set of volcanoes are restricted to sublatitudinal faults which may happen to be gaping faults within stress field with submeridional compression. Quaternary volcanism is confined to faults of this type (Spinks et al., 2005). A system of sublatitudinal graben-like trenches is interpreted along the island's eastern coast (along the Levashov river, the Nasedkin river, the Ptich'ya river), whose orientation conforms to submeridional dilatation.

Diagram (See Fig. 1) shows that two heat anomalies are restricted to the Ptich'ya river's graben: the first one is up-river and conforms to the junction of two faults (heat efflux at river is 30,967 кcal/км$^2$sec), the second is in the river's estuary and belongs to the sector of local dilatations resulted from opposite direction shear-faults (heat efflux is 10306 кcal/км$^2$sec). This area possibly accommodates a zone of lateral flow (spreading) of thermal waters. In the west of the island only one graben-like trench of the same strike is interpreted. These trenches indirectly testify to a tendency of uparching of the island, whose convex part faces the east. In the northern end of the area, submeridionally directed systems of dykes and corresponding proximity zones of necks were mapped. These intrusive and extrusive bodies, as well as submeridional zone of faults, including extinct volcanoes testify to alteration of modern stress field as compared to Neogene.

Thermal springs and fumaroles are presumably associated to the system of faults being radial with respect to the Vetrovoy volcano vent. At the same time, highest-temperature springs are located within the section of submeridional permeable zone where the Ebeko volcano vent is localized. Spiral-shaped in plan zone of development of opalites is associated with the Kozerevsky volcano spatially and possibly genetically which testifies to active circulation of thermal water epithermal depth facies in not so remote past**.** Currently, thermal water discharge in local areas occurs within this volcanic structure. Spatial distribution of cold and warm (up to 10-12$^0$C) springs convinces us in the fact that their circulation is connected with linear subvertical permeable zones of fault origin. Thus, prospect of localization of axial zone of ascending thermal water flow is associated with near-vent part of the upper-Pleistocene Vetrovoy volcano. The absence of thermal manifestations at this section is possibly related to the fact that here, in thick erosion zone of the volcano caldera, a large amount of meteoric waters accumulates and this leads to their mixing with deep-seated waters and active cooling of upper horizons of a geothermal reservoir. It was shown earlier that the North-Paramushir hydrothermal-magmatic system was promising not only in terms of geothermal deposit formation, but was also promising for epithermal Au-Ag, mesothermal polymetallic and, possibly, Cu-porphyry mineralization (Rychagov et al., 2002, 2004). The combined geologic-structural research we conducted confirmed that the North-Paramushir system belongs to such structures of volcanic island arcs, in which John Hedenquist (Hedenquist, 1987) and Jim Lowless (Lowless, an oral communication) demonstrated a possibility of close to simultaneous formation of geological

environments with various ore-geochemical setting.

## Conclusions

1. Based on structural-geomorphologic research conducted on site of the North-Paramushir hydrothermal-magmatic system, an original graph of the recent fault tectonics was made, a conjugated system of lineaments was identified which includes submeridional gaping fault and diagonal faults. Graben-like trenches the formation of which may be associated with vertical block slips were identified along the eastern coastline.
2. Activity of volcanoes, thermal springs and convective heat efflux are determined by modern activity of faults. The Ebeko volcano, thermal springs and main heat efflux are restricted to sectors of local dilatation what was specified by means of field studies.
3. Continuation of structural-geomorphologic works will facilitate specification of prospects of the North-Paramushir hydrothermal-magmatic system in terms of finding in its interior not only geothermal but a number of ore deposits, which, in our opinion, may be positioned as follows: Au-Ag epithermal – in blocks at the structure periphery, mesothermal polymetallic and Cu-porphyry mineralization – at deep levels in the central part of the system.

**Acknowledgements to:** S.N. Rychagov for scientific guidance and practical help during the preparation of the paper; I.F. Delemen and V.I. Belousov for discussion of basic aspects of the work; I.V. Meleksetsev for scientific consultations during the research; L.V. Kotenko and T.A. Kotenko for assistance in field works and for providing some factual material.
**Work was completed with grant support:** FEB RAS №№ 05-III-Г-08-146, 05-III-E-08-029, 06-III –B-08-371, 06-III-A-08-332; НШ-2294-2003.5; Russian Fund of Fundamental Research № 06-05-64689a.

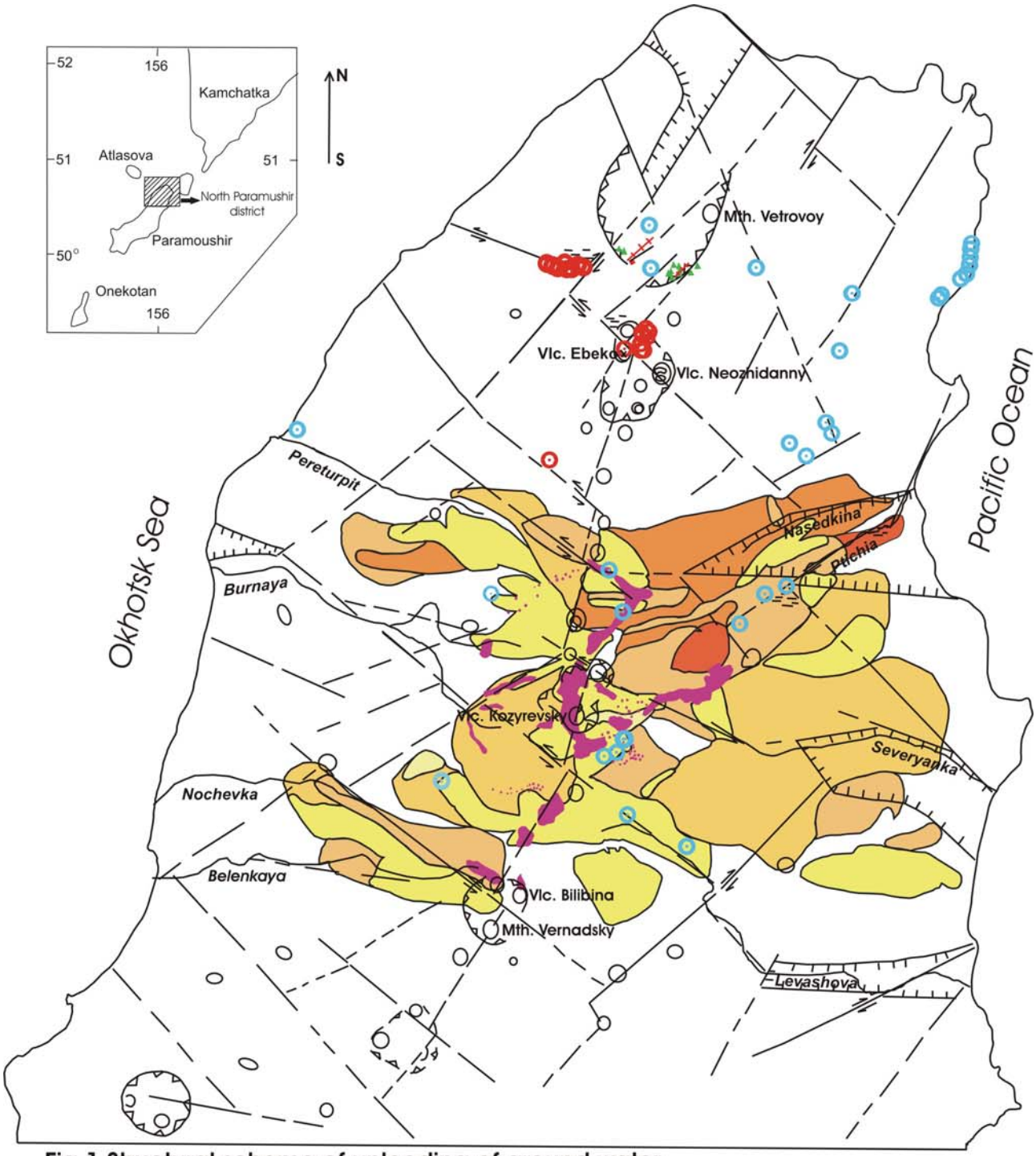


**Fig.1 Structural scheme of unlooding of ground water in the Northen part of Paramushir island**

1. Prospective fouls a) more sure б) less sure
2. Displacement
3. Graben depression
4. Volcanic constructions a) active б) not active
5. Caldera border
6. Sector of local strains
7. Sourses a) thermal б) cold
8. a) Neck б) Dike
9. Border of opalite distribution

**Heat Fluks (kcal/km$^2$s)**

1 2 3 4 5 6

1. More then 10 000
2. 4000 - 10 000
3. 1000 - 4 000
4. 300 - 1000
5. 0 - 300
6. 0,001 - 0,1

## References


1. Aver'ev V.V. *Gidrotermalny protsess*…(Hydrothermal Process in Volcanic Regions and its Relation to Magmatic activity )// Sovremennniy Vulkanizm. M.: Nauka, 1966. pp. 118-128.
2. Belousov V.I., Rychagov S.N., Sugrobov V.M. *Severo-Paramushirskaya*…(The North-Paramushir Hydrothermal-Magmatic System: Geological Structure, Conceptual Model, Geothermal Resources// Vulkanologiya i Seismologiya, 2002. № 1. pp. 34-50.
3. *Geofizicheskiye i geomorfologicheskiye*…(Geophysical and Geomorphologic Seismicity Risk Factors when Constructing in Present-Day Volcanism Regions) / Anosov G.I., Delemen I.F., Konstantinova T.G. et al. Vladivostok: DalNauka, 2006. 140 p.
4. Gorshkov G.S. Vulkanism Kurilskoy… (Volcanism of the Kuril Island Arc). M.: Nauka, 1967. 288 p.
5. Gushenko O.I. *Rekonstruktsiya polia…* (Reconstruction of Megaregional Tectonic Stresses of Seismic Regions of Eurasia ) // Stress and Deformation Fields in Lithosphere. M.: Nauka, 1979. pp. 26-51.
6. Kostenko N.P., Briantseva G.V. *K probleme…* (On Issue of Structural-Geomorphologic Interpretation in Closed Space Environments) // Bulletin of Moscow University. Series 4. Geology. №4. 2004. pp.34-38.
7. Kostenko N.P, Panina L.V., Briantseva G.V. *Structurnaya-Geomorfologischeskaya…* (Structural-Geomorphologic Confinement of Active and Pleistocene Volcanoes) // Theses of Report at XXXI Tectonic Meeting. M.: MSU, 1999. pp. 327-329.
8. Korchuganova N.I., Kostenko N.P., Mezhelovsky N.N. *Neotektonicheskiye metodi…* (Neotectonic Methods of Mineral Exploration. M., 2001. 212 p. (MNR RF geomap. MSGA).
9. Meleksetsev I.V., Dvigalo V.N., Kiryanov V.Yu. et al. *Vulkan Ebeko…* (The Ebeko Volcano (the Kuril Islands): History of Eruptive Activity and Future Volcanic Hazard) // Vulkanologiya i Seismologiya, 1993. № 3 pp. 69-81.
10. Rychagov S.N., Belousov V.I., Glavatskikh S.F. et al. *Severo-Paramushirskaya*…( The North-Paramushir Hydrothermal-Magmatic System: Characteristics of Deep Geologic Cross-Section and A Model for Modern Mineral and Ore Formation in Its Interior) // Vulkanologiya i Seismologiya, 2002. № 4. pp. 1-19.
11. Rychagov S.N., Pushkarev V.G., Belousov V.I. et al. *Severo-Kurilskoye…*(The North-Kuril Geothermal Manifestation: Geological Structure and Utilization Prospects // Vulkanologiya i Seismologiya, 2004. № 2. pp. 56-72.
12. Sim L.A. *Izucheniye tectonicheskikh*…(Study of Tectonic Stresses by Geological Indicators (Methodology, Results, Recommendations) // Izv. VUZov, Geologiya i razvedka, 1991, №10. pp. 3-27.
13. Suchkov V.E. *Energiya oledeneniya…* (Activity Index of the Paramushir's Glaciers (the Kuril Islands) // Proceedings of Glaciological Studies, issue 87. pp. 196 – 200.
14. Fedorchenko V.I., Abdurakhmanov A.I., Rodionova R.I. *Vulkanizm Kurilskoy…*(Volcanism of the Kuril Island Arc: Geology and Petrogenesis.) M.: Nauka, 1989. 238 p.
15. Khubaeva O.R., Shulga O.V., Kotenko L.K., Kotenko T.A. *Mofostructura i otsenka…*(Morphostructure and Assessment of Heat Influx in the Northern End of the Paramushir Island) // Geothermal and Mineral Resources of Modern Volcanism Areas (Proceedings of International Field Kuril-Kamchatka Workshop, 16 July – 6 August 2005). Petropavlovsk-Kamchatsky: "OTTISK", 2005. pp. 181 – 194.
16. Chudaev O.V., Chudaeva V.A. et al. *Sostav i usloviya…*(Composition and Conditions of Formation of Modern Hydrothermal Systems of the Far East.) Vladivostok: DalNauka, 2003.
17. Spinks K.D., Acocella V., Cole J.W., Basset K.N. Structural control of volcanism and caldera development in the transtensional Taupo Volcanic Zone, New Zealand // Journal of Volcanology and Geothermal Research, 144 (2005). Pp. 7-22.
18. Hedenquist J.W. Mineralisation associated with volcanic-related hydrothermal systems in the Circum-Pacific basin // Transactions of Forearth Circum-Pacific Energy and Mineral Resources Conference. Singapore. Am. Ass. Pet. Geol., 1987. Pp. 513-524.