PROSPECTS OF GEOTHERMAL ENERGY USE IN THE KURIL ISLANDS

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The Kuril Islands with their unique natural complex are of the greatest importance for geopolitics and social economics of Russia **(Fig. 1)**. Hitherto in the Kuril Islands power engineering operates owing to fuel deliveries and it suffers great difficulties in this connection. At the same time well-known geothermal manifestations and deposits the summary potential electric capacity of which is estimated to be 295 MW per 100 years of exploitation are located in all large islands of the Kuril ridge near the main built-up areas (Strategy…, 2001). The Northern Kuril deposit in Paramushir island (as per different data estimated to be from 40 up to 100 MW), Oceanic deposit in Iturup (60 MW) and Mendeleeva-Goryachiy Plyazh in Kunashir (60 MW) are first and foremost among them (Strategy, 2001; Belousov et al., 2002; Rychagov et al., 2004). Working models of some geothermal manifestations and deposits in the Kuril Islands are represented, their electric and thermal capacity potential is evaluated and prospects of geothermal energy use in the regional economy are shown on the basis of generalisation of results of geological-geophysical studies and prospecting-exploring activity.

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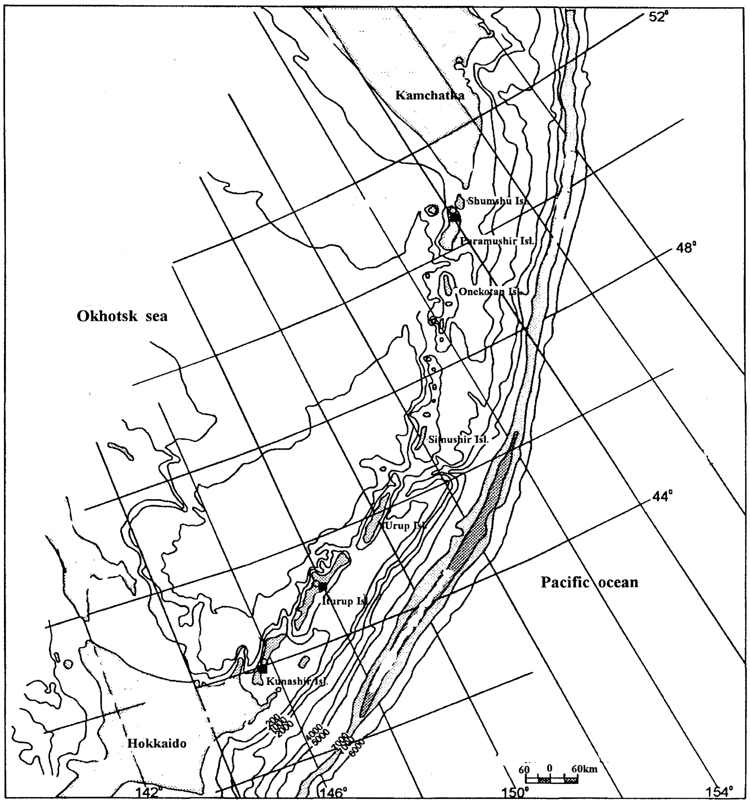

Figure 1: The physiographic map of Kuril insular arch and main geothermal deposits.

1. Introduction

On the basis of practical studies the new geological objects have been found in volcanoes and hydrothermal systems of recent and ancient insular arches within the last years. These ones are long-living ore-forming hydrothermal-magmatic convective systems in the area of transition from the oceanic crust to the continental earth's crust (Rychagov et al., 1999). Under insular arch conditions characterised as subareal ones the upper parts of hydrothermal-magmatic systems are located at the boundary of interaction of three geospheres: atmosphere, hydrosphere and lithosphere. This fact conditions such processes as interaction of hydrothermae with cold meteoric waters, subterranean boiling and steam and gas separation. During volcanic eruptions the great amount of atmospheric gases gets into the depth of several kilometres preconditioning the beginning of phreatic-magmatic and phreatic explosions (Oshawa et al., 2000) as well as activation of hydrothermal processes. Environments where dynamic alteration of thermodynamic parameters causing formation of mixed hydrothermae with different pH and Eh are formed in hydrothermal systems. Increased carbonic acid concentrations in the upper part of hydrothermal-magmatic systems of insular arch volcanism stage are conditioned by specific structural-geological processes. Since this part of systems is composed mainly by loose rocks preconditions for formation of voluminous magmatic rock bodies are created there. At the stage of insular arch volcanism the greater part of the abyssal high-temperature magmatic melt is localised in the long-living volcanic centre structure itself. Such hold-up of magmatic melts in the upper horizons of the earth's crust causes relatively proportional and gradual heat dispersion and continuos degasation of melts and, consequently, stable recharge of the system. Presence of sub-surface horizon of bicarbonaceous carbonated hydrothermae are typical for the hydrochemical structure of this type hydrothermal-magmatic systems. Intensive CO_2 release and extensive vaporisation cause formation of thick areas with sulphate-acid alterations as well as silicified rocks and deposition of great quantity of metals. These structure roots submerge into the depth of many kilometres and dozens of them – down to the primitive basaltic magma generation levels in the upper mantle. The hydrothermal cell "overbuilds" the magmatic convective one and therefore controls distribution of chemical elements including ore, alkaline and rare ones in the earth's crust upper horizons. Thus it is a self-isolating geological system. Just this property of systems predetermines large geothermal, epithermal ore, copper-porphyritic and other deposit formation in their bowels (Rychagov, 2003). The complex study of volcanoes and hydrothermal systems of the Kuril insular arch allowed to find the series of such hydrothermal-magmatic systems which are promising for the regional economy use.

2. The Nothern Paramushir Hydrothermal-Magmatic system and Northern Kuril geothermal deposit

The interest in study of the Northern Paramushir hydrothermal-magmatic system is determined by the specific conditions of distribution, accumulation and dynamics of the regional surface and subsurface waters as well as by particular features of the system itself structure. These are insular location of the object under study (Paramushir island and the Great Kuril range) at the joint of the oceanic earth's crust with that of continental type, location in the large, complex and long-developing tectonic-magmatic structure of the Vernadskogo volcanic range, wide development of volcanogenic formations of rocks with well-collecting properties, presence of the heating source of the unknown nature and parameters in the system bowels at more than 2-3 km depth and the fact that recent volcanism manifestations are represented by the active volcano Ebeko and Holocenic volcano Neozhydanny considered to be extinct.

Paramushir and Shumshu islands are the relatively upstanding blocks of the earth's crust and they are considered as the southern extension of the Pribrezhny horst in South Kamchatka (Aprelkov, 1971). Paramushir island northern part is composed by rocks of the age beginning from Upper Miocene-Pliocene and up to Recent one. The foundation consists of sedimentary rocks of the Paramushir complex of suits. The most ancient rocks among those laid bare are represented by layered volcanomict sandstones, tuffs, tuff-gritstones and tuff-aleurolites (the Okhotsk suite, $N_1^3 – N_2^1$) with total thickens from 1400 up to 3000 m. Deposits in the Okhotsk suite section upper part are represented by conglomerates, brecciae et al. lying eastward almost aflat or at the angle $5\text{-}10^0$. Their visible thickness is up to 500 m. The Neogene deposition section is crowned with the oceanic suit Middle-Recent Pliocene formations ($N_2^{2\text{-}3}$) represented by volcanic brecciae in blocks, tuff conglomerates, tuff sandstones, tuffs and tuffites of the middle and basic compositions. The Oceanic suit thickness is evaluated to be 900-1000 m. Sills, dykes and subvolcanic formations of various shape are associated with the Okhotsk and Oceanic suits volcanogenic rocks or break them. Mayak mountain located in Northern Kurilsk city is composed by sills. The rocks are represented by dense, massive, dark-grey diabases of paleotypic habit. Breaking bodies in the form of dykes have the age close to that of sills and thickness reaching the first dozens of meters. Subvolcanic bodies of Aerodromnoe Plateau type are of interest as the possible analogues of recent intrusions recharging the

Northern Paramushir hydrothermal-magmatic system. Thick flows of andesite lavas occur on volcanogenic-sedimentary deposits of the Okhotsk and Oceanic suits. It has been determined that andesites are of Upper Pliocene age (Syvorotkin, Rusinova, 1989). The lava-pyroclastic deposits of basaltic composition supposedly being of Lower-Middle Pleistocene age are laid bare in the northern part of Paramushir island. The bipyroxene Interglacial andesites (Gorshkov, 1967) of the age beginning from 110 up to 20 thousand years are widely represented there. Bilibina, Krasheninnikova, Bogdanovicha, Ebeko et al. volcanoes are composed by young post-Glacial bipyroxene andesite lavas or andesite - basaltic ones. The volcanoes form the large extensive tectonic-magmatic structure in the bowels of which andesite-basaltic melt migrated over a long period of time. Ebeko volcano located in the northern part of Paramushir is active. As is known it erupted in 1793, 1895, 1934-38, 1967-71 and 1987-91 yy. (Melekestsev et al., 1993; Menyailov et al., 1992). The last eruptions were phreatic.

Abyssal seismic sounding showed that in this area the thickness of consolidated earth's crust is 20-25 km, the Mohorovičič surface occurs at 20-25 km depth, the granitic layer thickness is 2 km and loose deposition thickness is 1-2 km. The negative anomaly of gravity is found in the area of Ebeko volcano central cone. It can be explained by low density of rocks forming the vertical cylindrical body with oval section (~ 2 x 1 km). It is supposed that there is no large magmatic chamber directly under Ebeko volcano. The negative anomaly of gravity is explained by the foundation surface uplift in the form of arch having the negative excess density (Bernshtein et al., 1966).

The main water-bearing horizons and complexes are formed in accordance with the territorial geological (Belousov et al., 2002), **Fig. 2**. *The water-bearing complex of Pleistocene-Holocene age* is represented by andesites, andesite-basalts, their tuffs and brecciae, overlaying more than 80% of the territory. The water-bearing complex is a hydraulic system in which subsurface waters are contained in fissured volcanites enclosed among more massive and less flooded rocks. The high-discharge sources (up to 40-50 l/sec) are observed at effusion contacts with underlaying rocks, representing the bed outcrops extending up to 1 km distances. Single high-yield subsurface water discharges are localised in the tectonic deformations. Chloride-sulphate-carbonaceous waters with mineralization from 0,1 up to 0,3 g/l are predominant. The waters connected with the hydrothermally altered rock zones are characterised by sulphate-calcic composition, acid reaction and up to 2,9 g/l mineralization. The fumarolic thermae at the slopes of Ebeko and Neozhydanny recent volcanoes belong to this water-bearing complex. *Water-bearing* *complex of Pliocene age rocks* is represented by the Oceanic suit rocks forming the gentle monocline with western 5-15^0 dip. The rock mass main peculiarity is wide development of loose rocks. Headless waters confined to the crust of weathering as well as horizons of head pressure strata-fissure waters are developed within the complex boundary. The complex upper part is recharged owing to atmospheric precipitation infiltration. To the great extent the complex water-bearing is conditioned by high jointing of rocks that suddenly decrease at the depth.

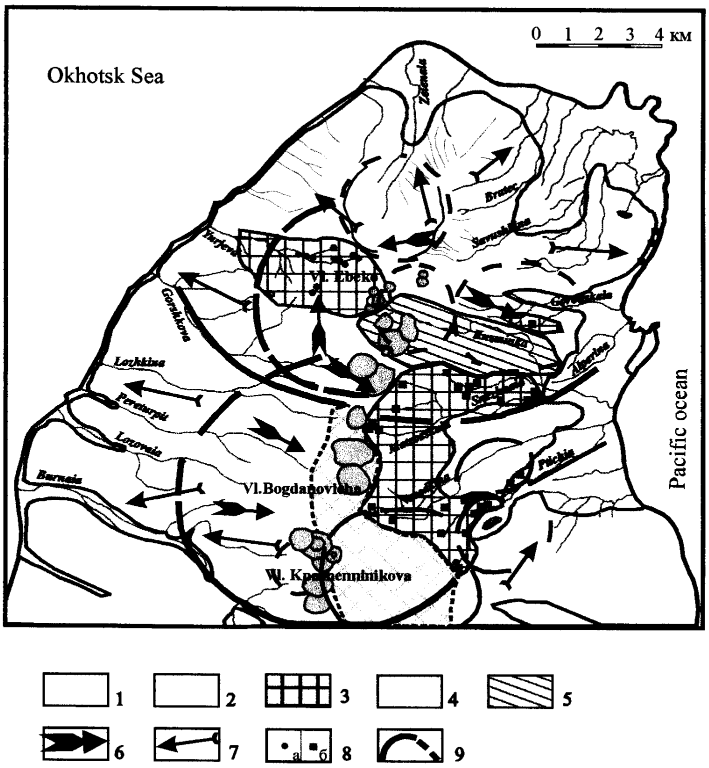

Figure 2: Hydrodinamic and morphotectonic map of the nothern end of the Paramushir Island (by E. Kalacheva, in edition by S. Rychagov). 1 – Ground Water discharge zone. 2 – Underground water feed zone. 3 – Discharge zone of deep water-bearing horizons. 4 – Suggested extension of discharge zone of deep water-bearing horizones. 5 – Undeground water pressure zone. 6 – Direction of undeground waters. 7 – Direction of ground waters. 8 – Sources: a – thermal, b – cold. 9 – Boundaries of morphotectonic blocks

Therefore two zones with different filtrational properties are distinguished along the vertical line. The upper zone (up to 100 m) has filtration coefficient $\geq$ 6-8 m/day and the lower one has that of $\leq$ 0,4 m/day. The spring discharges are not more than 1 l/sec. *The water-bearing complex of volcanogenic-sedimentary Miocene age rocks* is represented by the Okhotsk suit rocks. The complex depositions are characterised by great facies variability. Difference in jointing of rocks conditions layer after layer flooding of deposits and formation of fissure-strata pressure and non-pressure waters in them. Recharge is made owing to infiltration of atmospheric precipitation at the areas of rock outcrop to the day surface. The complex lower part suffers difficulties with water interchange. The water increased mineralization and relatively high quantity of Mg and Ca are explained by possible participation of “shore thermae” in their formation, described for the similar hydrogeological conditions (Kononov and Tkachenko, 1974).

The Northern Kuril deposit long-term geothermal resources are evaluated by two ways (Belousov et al., 2002): 1) according to natural heat discharge by the surface thermal manifestations; 2) according to the data on determination of thermal energy contained in mountain rocks saturated with the fluid. In the first case the long-term evaluation of geothermal resources is given taking into account the coefficient of the natural thermal capacity increase. At present the Northern Paramushir hydrothermal system thermal capacity can be evaluated approximately on the basis of determination of heat discharge by the surface thermal manifestations (Sugrobov, 1976; Sugrobov, 1995). Heat discharge made by the system eastern slope thermal manifestations is 10 850 - 14 300 kcal/sec. The quantity of heat discharged at the western slope is determined to be within the range 6 700 - 40 000 kcal/sec. The amount of heat discharge by the surface thermal anomalies is identified with the minimum geothermal resources. The coefficient values are determined through the comparison of operating reserves of the series of geothermal deposits with the thermal capacity of natural discharge of hydrothermae. For Kamchatka hydrothermal systems the coefficient of operating reserve increase varies from 3 to 7 in comparison with thermal capacity. The well water intake capacity increase can be explained by additional involvement of thermal waters during exploitation owing to the fluid flow from other horizons and removal of heat accumulated by the reservoir mountain rocks. If the capacity increase coefficient of the Northern Paramushir system is assumed to be 3 then the value of the long-term resources will be 43 000 kcal/sec that corresponds to 15 MW of electric capacity and 150 kg/s of water with 120-130^{o}C temperature.

The calculation of resources according to the heat accumulated in the block of mountain rocks within the estimated deposit boundary showed that their amount is greater as it is equivalent to 98 MW of electric capacity, the volumetric method of evaluation of the long-term resources is considered to be more reliable (Muffler, Cataldi, 1978). Application of this method provides for assessment of the thermal energy contained in fluid-saturated mountain rocks. For this it is necessary to determine the volume of the block of heated mountain rocks (the geothermal reservoir), their temperature and specific heat content. When determining the reservoir volume its height can be assumed (before the exploring data have been received) by analogy with the studied typical systems to be 2,5 km proceeding from the roof bedding at 0,5 km depth and the system basic depth of 3 km. The area is calculated according to distribution of surface thermal manifestations taking into account peculiar features of the geological structure and hydrogeological conditions existing there (Sugrobov, 1995). The distance from Ebeko volcano thermal fields up to the first high-temperature wells is 5,5 km. If the estimated united hydrotherm flow width is assumed to be equal to the distance between the geothermal wells П-1 и ГП-3 (about 1,8 km) then the reservoir area will be 10 km^2. The area calculation error is 30%. Temperature in the system bowels can be evaluated according to the measurement of temperature in wells (maximum temperature is 210^oC) and calculation as per geochemical gas thermometers (260-360^oC). For approximate calculations of energy in the reservoir temperature is assumed in the whole for the full volume = 200^oC. This corresponds to the average temperature of many hot-water systems. The specific heat of rocks saturated with water and steam is assumed to be 2,7 J/cm^{3o}C, the reservoir thermal energy extraction coefficient is 25% and the ratio of the reservoir thermal energy to efficient work is 0,057 for the reservoirs with average temperature of 200^oC; the coefficient of electric use for hot-water systems is 0,4 (Assessment…, 1979). The geothermal electric power plant expected capacity is calculated according to thermal energy of reservoirs (qR):

$$\mathbf{qR = VC\ (T\text{-}T_1),}$$

in which T is the average temperature (^oC) in the system bowels in the layer of 0,5 - 3,0 km (200^oC), T_1 – the average annual air temperature (for the Northern Kuril Islands it is about 0^oC) and C is the specific heat of fluid-saturated mountain rocks (2,7 J/cm$^{3)}$).

For the Northern Kuril deposit when $V = 25 \pm 7,5$ km^3 then $qR = 13,5 \pm 4,0 \times 10^{18}$ J.

When the ratio between efficient work and thermal energy of the reservoir is 0,057 the known thermal energy at the mouth of wells (Q) will be equal to $0,77 \pm 0,23 \times 10^{18}$J. The geothermal electric PP capacity is determined from the ratio $E = Q\ \eta/t$ in which η is the coefficient of transfer of the reservoir thermal energy into electric one (0,4), t is the time of the reservoir energy use during operation of PP (it is assumed 100 years). Therefore in the Northern Kuril deposit the geothermal electric PP capacity is 97,6 ± 29,3 MW.

Thus, in prospect the Northern Paramushir hydrothermal-magmatic system resources in the whole calculated by two ways are intended for building of geothermal electric PP with capacity from 15 up to 100 MW. At present the summary electric capacity of the diesel electric PP in Northern Kurilsk city is 4,8 MW and thermal power of boilerrooms is 16 Gcal/h. As per the near prospects the required electric power in Northern Kurilsk city is 8-15 MW and heat consumption is about 24 Gcal/h. Apparently, the estimated geothermal resources exceed the quantity of the existing and required thermal and electric capacity. Therefore they can be the reliable guiding line for organisation of exploring works with a view to evaluate reserves as well as for operating drilling to get the necessary quantity of the natural heat-transfer agent supplying Northern Kuril city power complex.

3. The Baranskogo Hydrothermal-Magmatic system and Oceanic geothermal deposit (Iturup Island)

The Baranskogo hydrothermal-magmatic system including the active volcano of the same name is the most studied one in the Kuril-Kamchatka region as a result of drilling wells at the Oceanic hermal deposit and conducting complex research works in Iturup island central part. The basic data on this object are given previously (Rychagov, 1993) as well as in the materials of this conference. Not to repeat all the actual data massive we briefly characterise the system and deposit. The Baranskogo hydrothermal-magmatic system is confined to the volcanic-tectonic structure formed within the Central Iturup circular megastructure boundary (the volcanogenic-ore centre). The system structure is in blocks **(Fig. 3)**. The main thermocontrolling structures are horsts. Their rocks differ with maximum permeability and intensive hydrothermal alterations from the rocks of subsided blocks and tectonic-magmatic uplifts. The Starozavodskoe Field and the Boiling River horsts are characterised by considerable heat discharge from the bowels of the hydrothermal-magmatic system: up to 71 000 kcal/sec of summary capacity. As per the data on study of metasomatites at present the enclosing volcanogenic and volcanogenic-sedimentary rocks are actively transformed due to influence of high-temperature hydrothermae (according to the data from thermal logging of wells solution temperatures are up to 300-320^{0}C and as per materials of study of gaseous-liquid inclusions in secondary minerals those are up to 470^{0}C). Recent thick (up to 200-250 m) liquid-steam transition areas are widely developed within the horst boundaries. There rocks are completely replaced my mineral associations such as quartz-adular, quartz-adular-wairakite and quartz-adular-prehnite-wairakite-epidote.

According to our research data (Rychagov et al., 1993) it is probable that the direct source of heat for the Oceanic geothermal deposit is a thick subvolcanic body of andesite-basaltic composition, apparently, connected to the peripheral magmatic chamber. It is supposed that the roof of the peripheral magmatic chamber under Baranskogo volcano is located at 3-5 km depth (Zlobin, 1989). The determined electric capacity of the deposit is 12 MW and potential one is ≥ 60 MW (Strategy…, 2001).

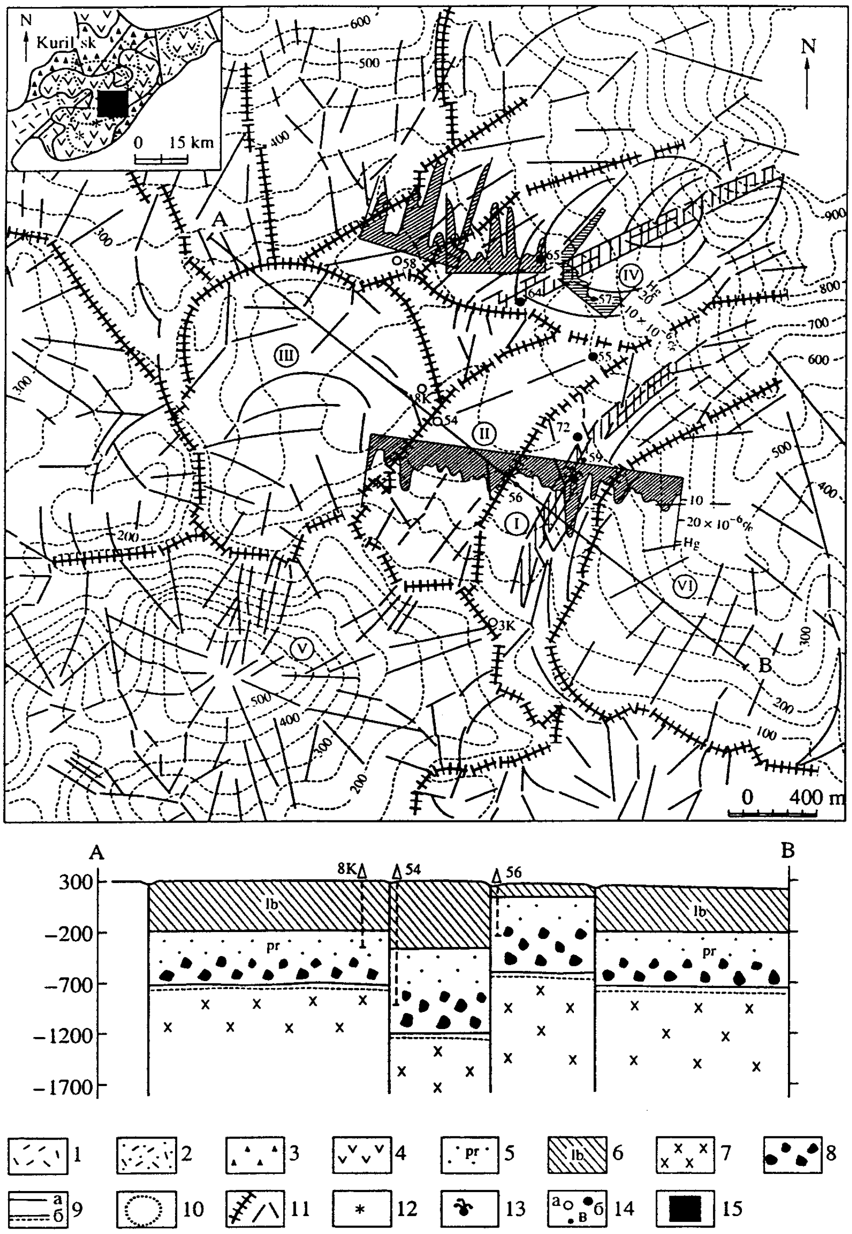

Figure 3: Scheme of the present-day tectonic structure of Baranskogo hydrothermal-magmatic system (Rychagov, 1993). 1-4 – Geological complexes (on the inset map based on Geologo-geofizicheskii atlas…, 1987): 1 – Middle Miocene-Pliocene volcanogenic silicic-diatomic, 2 – Middle Miocene-Pliocene volcanogenic (predominantly silicic) rocks, 3 – Middle Miocene-Pliocene andesibasaltic, 4 – Quaternary andesitic. 5 – The Parus Formation. 6 – The Lebedin Formation. 7 – Diorites. 8 – Intrusive tuffs (intrusive or automagmatic breccias). 9 – Contacts: a – lithological, b – intrusive. 10 – Volcano-tectonic structures. 11 – Faults and boundaries of tectonic blocks. 12 – Volcanoes. 13 – The Goluboe ozero hot spot. 14 – Boreholes: a – without ore and silicate pellets, б – with ore and silicate pellets, в – boreholes without representative samples. 15 – Figer area on the inset map. The axial parts of horsts and mercury geochemical profiles are hatched in different patterns.

4. The Mendeleeva-Goryachiy Plyazh Hydrothermal-Magmatic System and the Geothermal Deposit of the Same Name (Kunashir Island)

The Goryachiy Plyazh-Mendeleeva hydrothermal (hydrothermal-magmatic) system was actively studied in 60-es years. In 1963 V.V.Averyev and V.I.Belousov recommended manifestations of high-temperature hydrothermae in the area of Mendeleev volcano as the object for drilling hydrothermal wells in order to let steam-water mixture or dry steam come to the surface and then use them for development of the fuel and energy complex of Southern Kurilsk city and the central and southern parts of Kunashir island. In 1963 the staff of PGO «Sakhalingeology» carried out geophysical and electrical exploring works confirmed the supposition of V.I.Belousov and T.P.Kirsanova that there is a lateral flow of steam-hydrothermae structurally confined to Mendeleeva volcano north-eastern slope. In 1964-67 yy several wells up to 760 m deep were drilled (Dunichev and Riznich, 1968). The results of these studies remained the fundamental for the understanding of geothermal processes and models of the Goryachiy Plyazh geothermal deposit as well as geothermal manifestations associated with Mendeleeva volcano activity. From 1992 it was planned to begin the new stage of exploring-prospecting works with a view to enlarge the deposit reserves and build a geothermal electric PP but these works were prevented by the economy situation change in our country. That is why the results of geological and geophysical research and drilling conducted in 60-es years remain the most complete till present. Herein the actual data from these studies as well as the interpretation of Mendeleeva-Goryachiy Plyazh geothermal deposit and .hydrothermal-magmatic system structure are given.

Within the geothermal deposit boundary the explored area is composed by volcanogenic rocks, tuffs prevailing over lavas **(Fig. 4)**. Pleistocene-Holocene deluvial-eluvial deposits overlay the lava-pyroclastic strata of Neogene age that is the analogues of the Iturup and Utyosnaya suits (Sergeev, 1976). The strata is divided into three complexes: 1 – lower (layered tuffs, tuffites and aleurolites of andesite composition), 2 – middle (pumice tuffs and lavas of dacite composition) and 3 – upper (tuffs, lavas of basaltic composition and tuff diatomites). The age of the lower and middle complexes is evaluated to be Upper Miocene – Middle Pliocene and the age of the upper one – Upper Pliocene. The complex rock thickness varies from 160 up to 440 m. The allochthonous pumice tuffs and tuffites with fauna are laid bare in the explored area central part. They dip almost horizontally and have parallel bedding formed by interchange of aleurolite and pumice layers. Agglomerate, psephitic and pumice tuffs as well as layered allochthonous tuffs

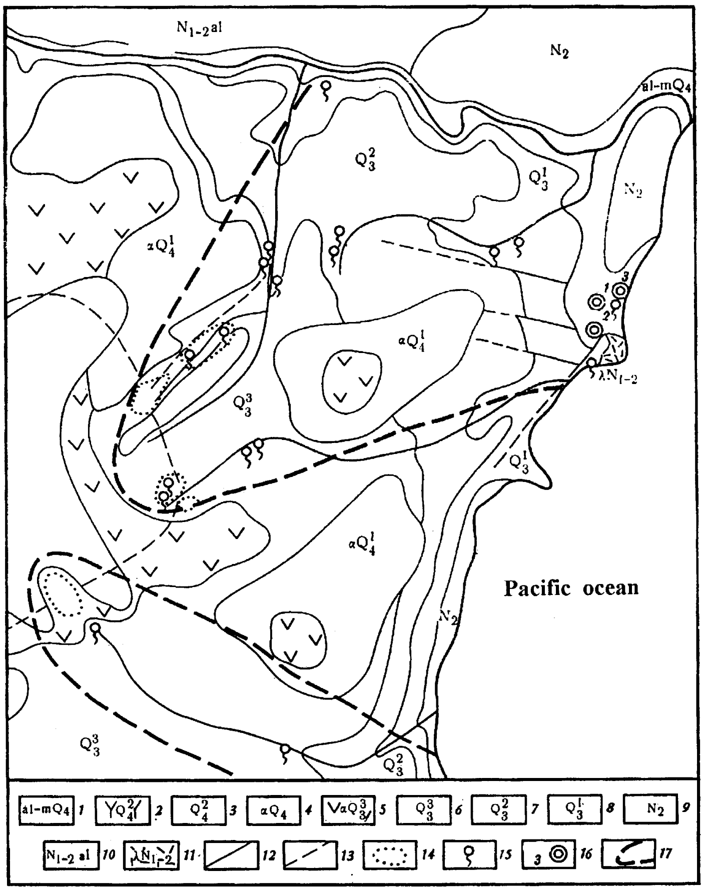

Figure 4: The geological scheme of geothermal deposit Goryachiy Plyazh (Dunichev and Riznich, 1968). 1 – Alluvial and marine deposits. 2 – Extrusive dacite. 3 – Pyroclastic deposits. 4 – Deluvium-proluvium deposits. 5 – Andesite and andesite-basalt of upper complex. 6 – Pyroclastic rocks of upper complex. 7 – Pyroclastic rocks of middle complex. 8 – Pyroclastic rocks of lower complex. 9 – Agglomerate basaltic tuffs. 10 – Dacite tuffs. 11 – Extrusive liparite. 12 – Faults, real. 13 – Faults, assumed. 14 – Solfataria field. 15 – Thermal springs. 16 – Drill holes. 17 – The boundaries of thermal area.

with tuff diatomites are laid bare in the complex upper part. Such kind of structure is the evidence of subcontinental conditions of lava deposition and pyroclastics of volcanoes erupted basaltic and andesite material at the final stage of the volcanogenic strata formation.

The wells tap high-temperature hydrothermae ($\geq 150^0$C) with neutral and alkalescent reaction of chloride, sulphate and hydrocarbonaceous compositions. Violent hydrothermal alterations are observed in rocks of these three complexes. It is characteristic of them that green cryptocrystalline and scaly minerals of montmorrilonite-hydromica-hydrochlorite-celadonite group giving green colour to rocks are widely developed. Together with them zeolites: mordenite, analcime and laumontite are found everywhere. The adular is widely developed here. It is associated with quartz, laumontite, calcite, apatite and sphene. The textural characteristics of rocks considerably influence upon intensity of secondary minerogenesis. Alteration intensity is maximum in tuffs with large-size fragments (up to 50%) and it is minimum in those with fine fragments and in tuffites (up to 10%). The tuff and tuffite cement or the main mass of lavas often transform into silicificated areas in the composition of which montmorillonite, hydromicas and pyrit are observed. Quartz, smectite-illite, calcite, epidote, apatite and sphene replace rock along cement in dacite tuffs. Epidote conduct is noteworthy. In well № 7 epidote is in paragenesis with heulandite. In veins it associates with quartz, heulandite and desmine. As there are no reliable data on heat-transfer agent temperatures in wells the evaluation of temperatures as per mineral geothermometers is of great importance. Our and other research experience shows that such evaluation can be rather exact – up to several ^{0}C.

In general, the determined complex of secondary minerals is typical for temperatures reaching 150-160^{0}C. The exception is epidote and its associations with some other minerals which in the given sections can be related to middle temperature ones (≥ 200^{0}C). If epidote is found in the form of single fine crystals this fact points at values ≤ 200^{0}C. Epidote stable high quantity in well № 7 located on the oceanic shore and epidote paragenesis with heulandite are the probable evidence of presence of hydrothermae with temperature ≥ 200^{0}C. In cases when it is often met with laumontites or lower-temperature zeolites (analcime and mordenite) there can be supposed that temperatures of hydrothermae are < 200^{0}C. Heat contents of the steam-water mixture have been measured in the lower part of well №7 section. The received value is 159 kcal/kg that corresponds with the average hydrothermal temperature 160^{0}C in the pumping interval. However, in this well the pumping interval corresponds to the depths from 67 down to 405 m, i.e. it is located considerably higher than the area where epidote and heulandite accumulation in veins is observed. It means that in this well at the depth more than 550 m the heat-transfer agent temperatures are ≥ 200^{0}C. Judging by paragenesis of secondary minerals there are temperatures of hydrothermae up to 150^{0}C in well №3. Admittedly there should be inversion of temperatures in the near-face part of the well as the termination of the lateral flow of hydrothermal solutions is located there.

Lower temperature complexes of secondary minerals are characteristic of the wells drilled along the shore. Probably, this is the result of sea water infiltration through rocks. The fact of their inflow into the lateral flow bowels is confirmed by experimental pumping during which there was noted the increase of mineralization of hydrothermae released from wells. Nevertheless, sea water infiltration is inconsiderable. The rock strata is highly water-resisting owing to its primary composition (fine-fragmental ashy and aleurite tuffs) as well as to the shower of cryptocrystalline and metacolloid quartz in the rock pore space and along fissures. Violent processes of secondary minerogenesis are especially characteristic of the section upper parts. The area of hydrotherma boiling up is formed there. It is confirmed by the great quantity of calcite which, as it is well-known, precipitates during carbonaceous balance upset when carbonic-acid gas is discharged from hydrothermae. In this connection we consider that thickness of the vaporisation area in the chamber of the Mendeleeva-Goryachiy Plyazh hydrothermal-magmatic system lateral flow discharge is many hundreds of meters. In order to determine thickness of hydrotherma boiling areas there should be considered the depth of calcite expansion in sections. Calcite is developed in the Goryachiy Plyazh geothermal deposit rocks at depths of ≥ 700 м and there is great amount of free carbon dioxide in the chemical composition of hydrothermae. Besides, the process of silica deposition in pores and fissures is intensified during carbon dioxide discharge. This complies with sudden temperature fall in these areas and decrease of silica solubility in hydrothermae. Rapid decrease of the well discharges during experimental releases can be explained by intensive formation of calcite and silica minerals as the permeability coefficient diminishes in water inflow areas.

Intense hydrothermal alterations were observed in wells № 2 and 2a which tapped the large meridional fault confirmed by active steam discharge from them. Tuff cement is completely modified into montmorillonite, hydromicae, zeolites and calcite. Secondary argillo-zeolitic cement with calcite is formed in rocks. Besides, fragments of plagioclase crystals are completely replaced with adular and lomontite as well as adular, albite and quartz at the depth of 250 m. Hydrochlorite, calcite and calcite + hydrochlorite are developed along pyroxene. Potassium oxide quantity suddenly increases as well as that of sodium oxide falls at the depths lower than 155 m. All these facts confirm that high-temperature hydrothermae circulate in this section and thick areas of liquid-steam transition are formed there. Anhydride is noted almost in all sections at considerable depths. To our opinion this mineral origin is associated with deep infiltration of surface sulphate waters possibly formed in the lateral flow upper part closer to the place of its generation under the temperature ≥ 200^0C. In spite of high-temperature regime of the lateral flow of the Mendeleeva-Goryachiy Plyazh hydrotherma-magmatic system neither hot springs of the correspondent composition nor thermal fields or steam jets indicate this flow on the surface. This fact additionally confirms that the system high-temperature lateral flow is well-isolated even in the zones of fractures. First of all the gas-hydrochemical composition of hydrothermae as well as secondary minerogenesis processes contribute to this.

Thus, the data on high-temperature regime of the lateral flow of hydrothermae in the Mendeleeva-Goryachiy Plyazh hydrothermal-magmatic system shore area allow the supposition that it is very extended in the shelf zone up to the oceanic slope. The shelf geological sections received from the geophysical data permit to make such reconstruction. However, the hydrothermal metamorphism processes taking place there differ with considerable intensity and they have the definite trend leading to permeability decrease of water-enclosing horizons and their transformation into the waterproof strata – the screens isolating the geothermal heat-transfer agent and contributing to preservation of high temperatures in the hydrothermal system bowels. Geological prospecting works enlarged the geothermal deposit western boundary up to the Kisly creek. This allows receiving in this area not less than 200 kg/sec of the steam-water mixture (Dunichev, 1973). Such heat-transfer agent discharge is enough for building a geothermal electric PP that will completely satisfy power and heat demands of all the populated areas and industrial enterprises of Kunashir island. The potential electric capacity of the Mendeleeva-Goryachiy Plyazh geothermal deposit is evaluated to be ≥ 60 MW per 100 years of exploitation (Strategy ..., 2001). When carrying out works on this geothermal area preparation for pre-prospecting and drilling of exploring and operating wells it is necessary to pay special attention to research of secondary mineral associations which are the exact indicators of temperatures and conditions of steam-hydrothermae.

5. Conclusion

Thus, the new geological objects, namely the long-living (from thousands up to hundreds of thousands years) ore-forming hydrothermal-magmatic convective systems of insular arches are found in the recent hydrothermal systems due to development of the conceptual models of epithermal ore and geothermal deposits and on the basis of the materials received during drilling deep and abyssal wells. These transcrustal draining systems control transfer of thermal energy, melts, gases, hydrothermal solutions and chemical elements from the upper mantle level to the near-surface horizons of the earth's crust. According as the systems develop intratelluric flows, melts, magmatic gases and hydrothermal fluids interact with enclosing rocks as well as sea, subsurface and meteoric waters and actively influence upon reconstruction of the geological structure of the systems thereby assisting in the anomalous thermal flow isolation. This isolation process is self-controlled as a result of silica and other secondary element deposition around the hydrothermal-magmatic column. This fact conditions formation of geothermal, epithermal ore, porphyritic and other deposits in the upper parts of the earth's crust. On the basis of the abyssal seismic radiation data analyses as well as study of the composition and isotopy of volcanic gases, structural constructions and other materials it is determined that these geological structure roots submerge to the depth of many dozens of kilometres reaching the upper mantle. The mantle is the basic heat-generator determining the volcanic insular arch development. Peripheral magmatic chambers and getting colder subvolcanic bodies of andesite-basaltic composition as well as small intrusions of diorites and gabbro-diorites are the direct source of heat and the ore, alkaline and rare chemical elements in the hydrothermal-magmatic system structure. The calculations showed that this thermal energy quantity is not enough for supplying all the totality of intrusive, volcanic, gas-hydrothermal and other processes going on in these areas of the earth's crust. The other source of heat and chemical elements can be exothermal chemical reactions such as "burning" of sulphides, sulphur and several newly-formed minerals up to their complete oxidation producing great quantity of heat. Such additional source of heat is practically renewed during the evolution of the system newest stage and it can provide for the considerable part of the hydrothermal-magmatic system power consumption. Thus, long-living ore-forming hydrothermal-magmatic convective systems not only control heat-mass flows in the ocean-continent transition zone but also generate energy and substance. The hydrothermal-magmatic system geological structure is a hierarchic system of mountain rock blocks having circular, oval-circular and another form. At the each hierarchic level the geological space is organised as follows. The blocks of rocks with contrast physical-mechanical, petrological, mineralogical-geochemical et al. properties alternate along the lateralis and in the vertical sections. The peculiar block-mosaic geological structure made of the relatively monolithic (rigid, dense and impermeable) and deconsolidated areas. The last ones are the most permeable for the hydrothermal-magmatic fluid flows. As a rule, the uprising flows of steam-hydrothermae and gases are confined to the central parts of hydrotherma-magmatic systems and they are localised in the axial zones as well as along the boundaries of relatively uplifted isometric-circular blocks of rock. Meteoric waters and "worked off" hydrothermal solutions are filtered from top to bottom along fissures and cool off rocks in the subsided blocks. Thus, the series of less-sized convective cells is formed within the hydrothermal-magmatic system boundary. Each cell encloses the uplifted (hot and permeable) block of rocks as well as subsided (cooled and monolithic) one. Such structure determines dynamics of gas and water flows in the geothermal reservoir.

Three such systems are found and studied in the Kuril Islands. These are the Mendeleeva-Goryachiy Plyazh system (Kunashir island), Baranskogo system (Iturup island) and Northern Paramushir system (Paramushir island). The hydrothermal-magmatic systems include large geothermal deposits located directly near the main populated areas such as Southern Kurilsk, Kurilsk and Northern Kurilsk cities. The potential electric capacity of each deposit is more than 60 MW per 100 years of exploitation. The creation of technology of complex use of the power and mineral resources of these geological objects as well as pre-exploring and building the geothermal electric PP have the great perspective for the advancing social and economic development of the Kuril region and the whole Russian Far East.

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