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Prospects of Geothermal Energy Use in the Kuril Islands

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ABSTRACT

The Kuril Islands have unique natural complexities that are of great importance for geopolitics and social economics of Russia **(Fig. 1)**. In Kuril Islands, power engineering suffers great difficulties operating due to challenges in fuel deliveries. At the same time, there are well-known geothermal manifestations and deposits in this area which might help solve the problem. The potential electric capacity is estimated to be 295 MW through 100 years of exploitation; explorations were done in all large islands of the Kuril ridge near the main built-up areas (Strategy…, 2001). The Northern Kuril deposit in Paramushir island (estimated to be 40 to 100 MW), Oceanic deposit in Iturup (60 MW) and Mendeleeva-Goryachiy Plyazh in Kunashir (60 MW) are first 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 evaluated and prospects of geothermal energy use in the regional economy are shown summarizing results of geological-geophysical studies and prospecting-exploring activities.

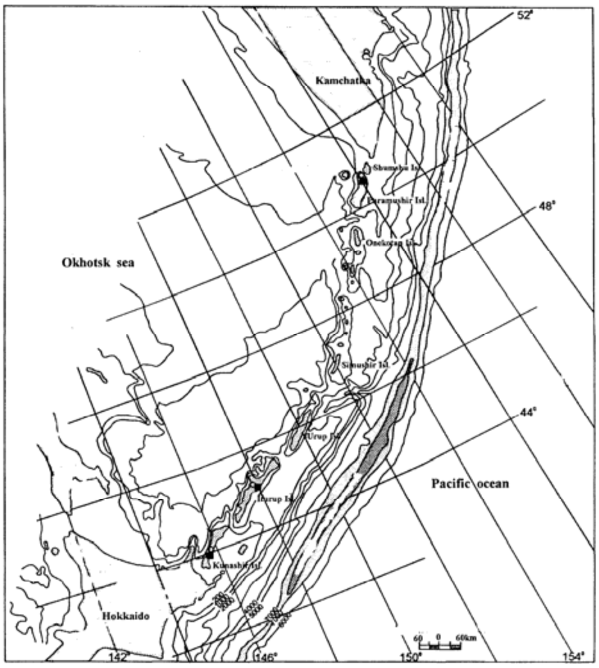

Figure 1: The physiographic map of Kuril insular arch

1. INTRODUCTION

On the basis of practical studies, new geological objects have been found in volcanoes, also found were hydrothermal systems of recent and ancient insular arches. These activities were done within the last years. These 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 allows processes such as interaction of hydrothermae with cold meteoric waters, subterranean boiling and steam and gas separation. During volcanic eruptions, great amount of atmospheric gases gets into depths 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 the system is composed mainly of loose rocks, this preconditions formation of voluminous magmatic rock bodies that 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 degassing of melts and, consequently, stable recharge of the system. Presence of sub-surface horizon of bicarbonaceous carbonated hydrothermae is typical for the hydrochemical structure of this type of 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 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 ores in the earth crust's 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 discovery of series of such hydrothermal-magmatic systems which are promising for regional economy use.

2. THE NORTHERN PARAMUSHIR HYDROTHERMAL-MAGMATIC SYSTEM AND NORTHERN KURIL GEOTHERMAL DEPOSIT

The interest in the study of Northern Paramushir hydrothermal-magmatic system is caused 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 structure. These are insular locations of the object under study (Paramushir island and the Great Kuril range) at the joining point 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). Interest is also due to 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. Plus the fact that recent volcanism manifestations are represented by the active volcano Ebeko and the Holocenic volcano Neozhydanny which is considered to be extinct adds to the interest.

Paramushir and Shumshu islands are the relatively more 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's northern part is composed by rocks of ages beginning from Upper Miocene-Pliocene up to recent one. The foundation consists of sedimentary rocks of the Paramushir complex. 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's upper part are represented by conglomerates, brecciae etc. lying eastward almost flat or at an angle of $5\text{-}10^0$. Their visible thickness is up to 500 m. The Neogene deposition section is crowned with 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. Oceanic suit thickness is evaluated to be 900-1000 m. Sills, dykes and subvolcanic formations of various shapes are associated with the Okhotsk and Oceanic suits volcanogenic rocks. 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 a close age with that of sills. Its thickness reaches few tens of meters. Subvolcanic bodies of Aerodromnoe Plateau type are of interest they are 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 ages beginning from 110 years up to 20 thousand years are widely represented there. Bilibina, Krasheninnikova, Bogdanovicha, Ebeko and other volcanoes are composed by young post-Glacial bipyroxene andesite lavas or andesite-basaltic ones. The volcanoes form the large 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. 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 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 negative excess density (Bernshtein et al., 1966).

The main water-bearing horizons and complexes are formed in accordance with the territorial geology 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. 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 $5\text{-}15^0$ 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's upper part is recharged owing to atmospheric precipitation infiltration. To a great extent, the water-bearing complex is conditioned by high jointing of rocks that suddenly decreases at the depth. Therefore, two zones with different filtration properties are formed along the vertical line. The upper zone (up to 100 m) has filtration coefficient $\geq$ 6-8 m/day and the lower one has $\leq$ 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's lower part suffers difficulties with water exchange. The water increased mineralization, and relatively high quantity of Mg and Ca found can be explained by possible participation of "shore thermae" in their formation, described by similar hydrogeological conditions (Kononov and Tkachenko, 1974). The Northern Kuril geothermal resources are evaluated in 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. For the first case, the long-term evaluation of geothermal resources is given taking into account the coefficient of the natural thermal capacity increase.

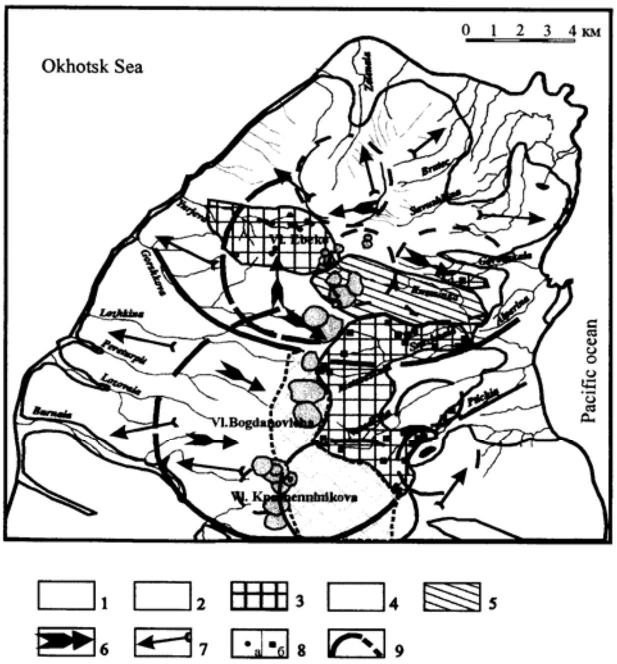

Figure 2: Hydrodynamic and morphotectonic map of the nothern end of the Paramushir Island (by E. Kalacheva, in edition by S. Rychagov). 1 – Ground Water discharge zone. 2 – Underground water feed zone. 3 – Discharge zone of deep water-bearing horizons. 4 – Suggested extension of discharge zone of deep 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.

At present, the Northern Paramushir hydrothermal system thermal capacity can be evaluated approximately on the basis of determining the surface thermal manifestations discharge (Sugrobov, 1976; Sugrobov, 1995). Heat discharge made by the system's eastern slope 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 discharged by surface thermal anomalies is identified with minimum use of 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 due to 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°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 evaluating 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 studied typical systems to be 2.5 km proceeding from the roof bedding at 0.5 km depth and the system 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 overall 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. This area calculation can have error of 30%. Temperature in the system bowels can be evaluated according to the measurement of temperature in wells (maximum temperature is 210°C) and calculation by geochemical gas thermometers (260-360°C). For approximate calculations of energy in the reservoir, temperature is assumed to be homogeneously 200°C. 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°C; 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):

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

in which T is the average temperature (°C) in the system bowels in the layer of 0.5 – 3.0 km (200°C), T_1 is the average annual air temperature (for the Northern Kuril Islands it is about 0°C) 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 $qR = 13.5 \pm 4.0x10^{18}$ 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 about 97.6 ± 29.3 MW.

The Northern Paramushir hydrothermal-magmatic system resources potential calculated in two ways shows building of geothermal electric PP with capacity from 15 up to 100 MW to be probable. At present, the electric capacity of the diesel electric PP in Northern Kurilsk city is 4.8 MW and thermal power of boiler-rooms is 16 Gcal/h. As for 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. These estimates can be used as guides for organisation of exploring works with a view to evaluate reserves as well as for operating drilling to get the necessary quantity of natural heat-transfer supplying Northern Kuril city's power.

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's central part. The basic data on this object are given previously (Rychagov, 1993) as well as in the materials of this conference. Not presenting all the actual data, 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.

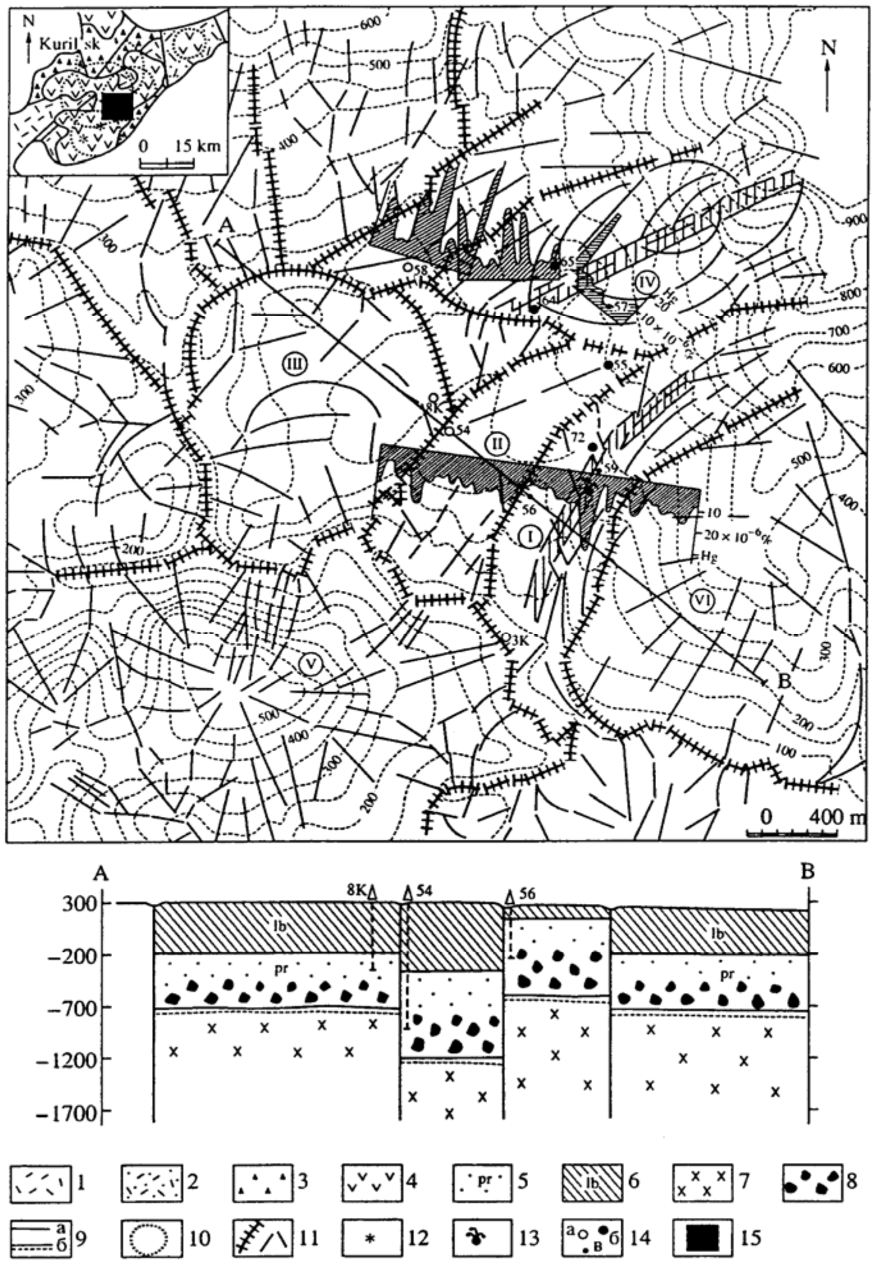

Figure 3: Scheme of the present-day tectonic structure of Baranskogo hydrothermal-magmatic system (Rychagov, 1993). 1-4 – Geological complexes (on the inset map based on Geologo-geofizicheskii atlas…, 1987): 1 – Middle Miocene-Pliocene volcanogenic silicic-diatomic, 2 – Middle Miocene-Pliocene volcanogenic (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.

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 average capacity. For the data on studying 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 gaseous-liquid inclusions in secondary minerals 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 by 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).

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 the 60’s. In 1963 V.V.Averyev and V.I.Belousov recommended manifestations of high-temperature hydrothermae in the area of Mendeleev volcano as the evidence 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. They 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, several wells up to 760 m deep were drilled (Dunichev and Riznich, 1968). The results of these studies remained 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 change in economic situation in our country. That is why the results of geological and geophysical research and drilling conducted in the 60’s 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)**.

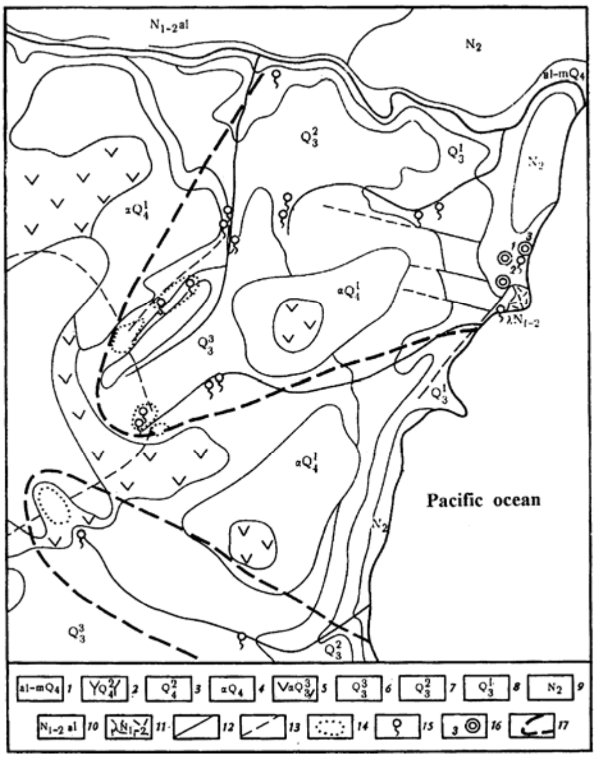

Figure 4: The geological scheme of geothermal deposit Goryachiy Plyazh (Dunichev and Riznich, 1968). 1 – Alluvial and marine deposits. 2 – Extrusive dacite. 3 – Pyroclastic deposits. 4 – Deluvium-proluvium deposits. 5 – Andesite and andesite-basalt of upper complex. 6 – Pyroclastic rocks of upper complex. 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.

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’s central part. They dip almost horizontally and have parallel bedding formed by interchanging of aleurolite and pumice layers. Agglomerate, psephitic and pumice tuffs as well as layered allochthonous tuffs with tuff diatomites are laid bare in the complex upper part. Such kind of structure is 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 (≥ 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 this, zeolites, mordenite, analcime and laumontite are found widely. The adular is also widely developed here. It is associated with quartz, laumontite, calcite, apatite and sphene. The textural characteristics of rocks considerably influence the intensity of secondary minerogenesis. Alteration intensity is largest in tuffs with large-size fragments (up to 50%) and it is least 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, the composition of which are observed to be montmorillonite, hydromicas and pyrit. Quartz, smectite-illite, calcite, epidote, apatite and sphene replace rock along cement in dacite tuffs. Epidote's conduct is noteworthy. In well № 7 epidote is in paragenesis with heulandite. It is associated with quartz, heulandite and desmine. As there are no reliable data on heat-transfer temperatures in wells the evaluation of temperatures by using mineral geothermometers is of great importance. Our and other's research experience shows that such evaluation can be rather accurate 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 ($\geq 200^0$C). If epidote is found in the form of single fine crystals, this fact points at values $\leq 200^0$C. Epidote 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 $\geq 200^0$C. In cases when it is often met with laumontites or lower-temperature zeolites (analcime and mordenite) it can be supposed that temperatures are $< 200^0$C. Heat contents of the steam-water mixture have been measured in the lower part of well №7 section. The measured value is 159 kcal/kg, this 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 depths more than 550 m, the heat-transfer agent's temperatures are $\geq 200^0$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. This is confirmed by experimental pumping during which it was noted that there is increase in 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's 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, the depth of calcite expansion in sections should be considered. Calcite is developed in the Goryachiy Plyazh geothermal deposit rocks at depths of $\geq$ 700 м and there is great amount of free carbon dioxide in the chemical composition of hydrothermae. Furthermore, the process of silica deposition in pores and fissures is intensified during carbon dioxide discharge. This corresponds 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 marked by active steam discharge. Tuff cement is completely modified into montmorillonite, hydromicae, zeolites and calcite. Secondary argillo-zeolitic cement with calcite is formed in rocks. Furthermore, 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 while 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. In 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 $\geq 200^0$C. Inspite 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. 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 well-extended from 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 $\geq$ 60 MW during 100 years of exploitation (Strategy ..., 2001). When carrying out works on this geothermal area, preparation for pre-prospecting and drilling of exploration and producing 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

New geological objects, namely old (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. 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 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 subvolcanic bodies of andesite-basaltic composition as well as small intrusions of diorites and gabbro-diorites are the direct source of heat, 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 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 combustion of sulphides, sulphur and several newly-formed minerals to their complete oxidation state producing great quantity of heat. Such additional source of heat is practically renewed during the evolution of the system's newest stage and it can provide for a considerable part of the hydrothermal-magmatic system's 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. The hydrothermal-magmatic system geological structure is a hierarchic system of mountain rock blocks having circular, oval-circular and another form. At each hierarchical level, the geological space is organised as follows: The blocks of rocks with contrast physical-mechanical, petrological, mineralogical-geochemical properties alternate along the lateral 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) ones. Such structure determines the 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 in 100 years of exploitation. The creation of technology for utilization of power and mineral resources from these geological objects as well as pre-exploring and building the geothermal electric PP have great potential for advancing social and economic development of the Kuril region and the whole Russian Far East.

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