Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

The Project of the Deep Well Drilling in the Pauzhetsky Geothermal Area

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Keywords: project, scientific drilling, transition zone, island arc, seismic stations, pilot industrial well, magma chamber, supercritical heat, geothermal power station.

ABSTRACT

The well of the Icelandic project RN-15/IDDP-2 in Reykjavik has reached supercritical geothermal conditions. The research and practical results of this project are of exceptional interest for similar projects in other volcanic regions. Kamchatka is one of the promising regions. Eichelberger J. and Kiryukhin A. proposed a scientific drilling project at the Mutnovsky volcano (Eichelberger and Kiryukhin, 2006). The implementation of this project is very difficult, since the well site is at a large absolute elevation. Often there is stormy weather and most of the year there is a thick cover of snow. Pauzhetsky hydrothermal-magmatic system in the Southern Kamchatka is the best variant for this project. This area is located in the transition zone from the Kuril island arc to the continent. Geology and hydrological-geothermal conditions are studied here in detail, using several dozens of geothermal wells. The maximum depth of one of them is ~1200 m. The maximum temperature of formation of hydrothermal minerals is ~330°C. The Ministry of Education and Science of the Russian Federation supported the project No. 14.W03.31.0033 "GEOPHYSICAL RESEARCH, MONITORING AND FORECAST OF THE DEVELOPMENT OF CATASTROPHIC GEODYNAMIC PROCESSES IN THE FAR EAST OF THE RUSSIAN FEDERATION" supported the grant and allocated funds for the installation of 75 seismic stations which will record information about deep activity under the Far Eastern volcanoes, including the volcanoes of the Pauzhetsky geothermal area. Its structure contains volcanoes with magmatic chambers in the Earth's crust. A pilot industrial well is planned to be drilled close to the extrusion into the zone of influence of a magma chamber in the upper crust. The supercritical heat transfer agent can be used to increase the capacity of the Pauzhetsky geothermal power station and for the transmission of electricity to Petropavlovsk-Kamchatsky.

1. INTRODUCTION

The success of the deep drilling project (IDDP) is important not only in exploring the possibilities, technology and economics of producing supercritical geothermal resources (Friðleifsson et al., 2018). Repeating such studies in other geothermal areas is also very interesting and useful. However, the main purpose of the next site of a similar study may be geological goals, such as problems of the formation of the granite layer of the earth's crust and the formation of hydrothermal ores. The Kuril-Kamchatka volcanic arc, a classical zone of modern subduction of the Pacific Ocean plate and the Asian-European continent, can be an alternative object of such deep drilling.

It is assumed that the Pauzhetsky geothermal area is a successful volcano-tectonic structure for the above purposes. The southern end of Kamchatka, where the Pauzhetsky geothermal area is located, represents the transition zone of the Kuril arc of active volcanoes into the East Kamchatka volcanic belt. It is characterized by the origin of the granite layer of the earth's crust, which is manifested in the development of acid volcanism associated with hydrothermal activity. Products of acidic volcanism and hydrothermal activity of the Pauzhetsky geothermal area are almost complete analogues of such manifestations on the Krafla volcano in Iceland, where wells are drilled in the zone of oceanic plate spreading. This suggests that the processes of subduction and spreading are similar. It is possible that such global tectono-magmatic structures are different stages in the evolution of mobile belts of the earth's crust and upper mantle.

Currently, a project is proposed for scientific drilling in Kamchatka on the Mutnovsky field (Eichelberger and Kiryukhin, 2006). The implementation of the Mutnovsky project can be very difficult, since the location of the well is at an absolute elevation of about 2000 m, where meteorological conditions in winter are supercritical (temperature <-20ºC, wind speed ~ 20-40 m/s, snow cover is more than 20 m.

The competitive area is the Pauzhetsky field of thermal waters, where climatic conditions are more favorable. The article "Long-lived volcanic centers of Kamchatka geothermal areas" presented at the Geothermal Congress 2020 (Belousov et al., 2020a) provides an overview of some of the studied geothermal areas of Kamchatka. One of the conclusions in this information is the assumption, on the example of the Banno-Paratunsky geothermal area, about the formation of extensive artesian thermal basins in areas of areal acid volcanism. Another article, also presented at the Geothermal Congress 2020, "Evolution of the Pauzhetsky geothermal area and acid volcanism" (Belousov et al., 2020b), is devoted to the origin and development of the Pauzhetsky geothermal area associated with extensive manifestations of acid volcanism in the middle-upper Pleistocene and Holocene. In order to achieve supercritical conditions, the attractive places for drilling a deep well are the roots of acidic lava-extrusive complexes. In the Pauzhetsky geothermal area, such a complex exists on the Thermal Volcano. Geology, magmatism and hydrogeothermal conditions are studied here in detail, including several dozens of geothermal wells. The maximum depth of one of them is ~ 1150 m. Maximum temperatures well above 200°C.

In Southern Kamchatka, including the Kambalny Ridge, studies are started using seismic tomography methods to study hydrothermal-magmatic systems and the relationship with the mantle structures of the Kuril-Kamchatka subduction zone.

2. GEOLOGY OF PAUZHETSKY GEOTHERMAL AREA

Pauzhetsky geothermal area is located at the southern end of the Kamchatka Peninsula. It is part of the southern end of the East Kamchatka volcanic region (Fig. 1).

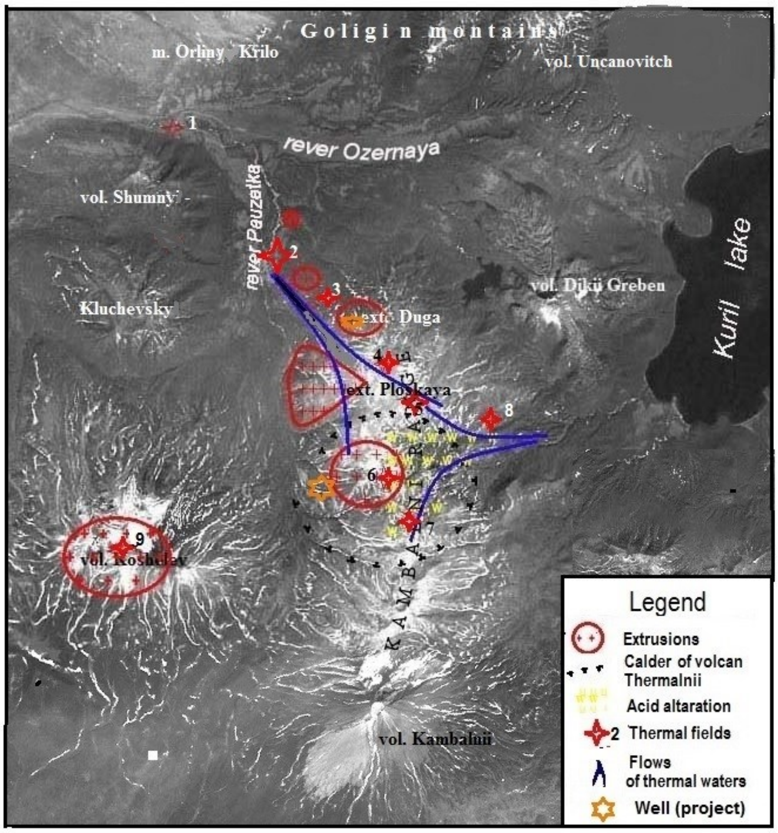

Figure 1: Satellite image of the Pauzhetsky geothermal region. The Kambalny volcano, Koshelevsky long-lived volcanic centers, the Thermalny volcano caldera, altered rocks and thermal fields: 1 - Ozernovsky, 2 - Pauzhetsky, 3 - East Pauzhetsky, 4-5 - North-Kambalny, 6-7 - South-Kambalny, 8 - East-Kambalny, 9 - Verkhne-Koshelevsky.

In a relatively small area, a wide range of sedimentary, tuff-sedimentary and volcanic rocks is presented - from basalts and andesites of modern volcanoes and paleovolcanoes to rhyodacites composing extrusive neoplasms. The last stages of the development of the Upper Quaternary and Holocene time zones were characterized by the massive formation of pyroclastics and effusive acid composition. Thermal manifestations are located at the northwestern foot of the Kambalny Range and in its axial part (Belousov et al., 2020b).

2.1 Rocks of the Pauzhetsky Geothermal Area

2.1.1 Rocks of the Paleogene-Neogene Age

The Paleogene-Neogene rocks, uncovered by drilling in the explored area of the Pauzhetsky field, are represented by a monotonic stratum of fine-grained sandstones of the Miocene age, occurring at a depth of 1050 m, with deep-sea marine mollusks. Higher along the section, volcanic sandstone of medium density, green color, medium-grained, is composed of fragments of basalts and andesites, plagioclase crystals, augite, carbonate-chlorite cement. Processes of secondary mineral formation are developed along the fragments. The chemical composition indicates the andesitic and basaltic composition of the parent rocks. Volcanogenic formations of Neogene age are represented by basaltic lavas and coarse-clastic pyroclastic sequences. These rocks have positive structures that are quite noticeable in the modern macrostructure of the area. In most cases, they have absolute marks - the first hundreds of meters. The mountains and small ridges composed of Paleogene-Neogene volcanic rocks represent the remnants of extinct volcanoes. Some of them, like the Belyaev Ridge, apparently had several eruption centers. The maximum visible power of these formations varies from the hundreds to 1000 m and more.

2.1.2 Quaternary Rocks

In the Quaternary, in the Pauzhetsky geothermal region, along with the subaerial andesite-basalt islands, volcanic structures were widely developed by volcanic formations. They are composed of tuff-sedimentary rocks (Pauzhetsky suite), welded tuffs + ignimbrites, lavas and extrusions of an acidic composition. Pauzhetsky suite lies on Neogene sandstones. It begins with tuff-conglomerates, which, in turn, overlap the lithocrystalline tuff of dacites. We unite these horizons into a single stratum. The lithocrystalline tuff of dacites has a light gray color. It is firmly cemented, massive, with a crystallocatlastic structure, composed of fragments of crystals of plagioclase, quartz, hornblende, augite. Fine-grained mass is cemented by secondary recycling. In it are scattered rare rounded fragments of basalts and andesites. Their sizes reach 4–5 cm. The thickness of lithocrystalline tuff has a total capacity of 270 m (190 m is welded tuff and 80 m is tuff-conglomerate).

The first researchers (Aprelkov, 1961) identified them as analogs of ignimbrites discovered by wells on the Wairakei hydrothermal system in New Zealand. Belousov V.I. (1978) showed that these tuffs were cemented by amorphous metacolloidal silica, zeolites, and hydromica of hydrothermal origin. The primary rock texture of this horizon was porous.

The full sections of the Pauzhetsky suite contain four horizons of tuff-conglomerates of various capacities. Fragments in them are represented by basalts and andesites. More thick horizons tuff-konglomeraty located in the lower part of the section. The maximum measured thickness of one of these horizons (the third from the top) is 140 m. The thickness of the rest (successively from top to bottom) is 10-30-80 m. A gradual decrease in the thickness of the horizons in the south-east direction is characteristic. At a distance of one kilometer, they are approximately halved. It is obvious that the demolition area for tuff-konglomeraty was in the place of the Shumny and Klyuchevsky mountains. During the period of their formation, they were active volcanoes.

Simultaneously with the tuff-sedimentary Pauzhetky suite, a lava-pyroclastic complex was formed: in the areas of the Shumny, Klyuchevsky mountains, Yavinsky ridge, Orliny Krilo, north-western part of the Belyaev Ridge, along rivers on the Okhotsk coast of the southern end of Kamchatka. The position and nature of changes in the capacity of the horizons of tuff-conglomerates in the section of the Pauzhetsky suite in the valley of the Pauzhetka River suggest that the lava-pyroclastic formations of basaltic and andesitic compositions in the mountains of Shumny and Klyuchevsky were formed in the Lower Pleistocene time.

In the axial part of the Kambalny ridge, the section of the Pauzhetsky suite is crowned with andesitic and basalt composite tuffs. In the area of Cherny Scaly and the Scalisty Pik, closely related volcanic rocks of mainly andesitic composition are developed. Some lava flows have an almond stone texture. In them the pores are filled with chalcedony. The thickness of these formations is, on average, 400–500 m: along the strike it changes dramatically. The section of volcanic rocks is characterized by complex re-interleaving of lavas and pyroclastics. Based on the relations of the Pauzhetsky suite with the Cherny Scaly volcano on the Kambalny ridge, the age of the latter should be defined as Upper Pleistocene.

In our opinion, late volcanic rocks of the southern part of the Kambalny Range, including the Kambalny volcano cone, are syngenetic with them. In the Upper Pliocene and, probably, several previously long-lived volcanic centers, such as the Koshelevsky, Kambalny, Ilinsky and Zheltovsky volcanoes, already existed. The volcanogenic rocks composing these macrostructures are represented by lavas and pyroclastic deposits of basalt, andesitic and rhyolite composition. At the final stages of development of these structures, in the Holocene period, outflows of basalt flow occurred, in some cases, the introduction of extrusive domes.

At the same time, mass eruptions of an acidic material occurred at the end of the Upper Pleistocene and in the Holocene. Volcanogenic macrostructures of the region appeared, such as the Dikyi Greben, extrusion of the Kambalny ridge rhyodacites and the Golyginsky mountains, pyroclastic flows (with horizons of ignimbrites and welded tuffs) in the Golyginsky mountains and on the eastern and southern sides of the depression of the Kuril Lake. In the same period in the Pauzhetsky geothermal region, the formation of pumice deposits and tuff-sedimentary rocks occurring between the valley of the Ozernaya River and northern boundary of the ridge Dikyi Greben.

2.1.3 Extrusion

At the Thermalny volcano and its periphery, young extrusive formations of rhyolite and andesite-dacite composition are widely developed. According to the description of Grib E.N. (Belousov, 1978), they date from the Upper Pleistocene and Holocene and occupy a significant part of the territory. Their sizes range from 0.01 to 8 km2. Small extrusions are dome-shaped. They are usually surrounded by tuff deposits, which fall to the sides of the dome and are broken by faults with small displacements. Extrusions of large sizes, such as Ploskaya, produce more significant disturbances when tuffs appear. The area of the dome is 4.7 km2. Two lava flows associated with the dome poured onto the tuffs of the Pauzhetsky suite. The total length of the streams is 2.5–3.0 km, thickness is from 30 to 150 m. In the structure of the dome, layering is observed, due to the texture of the rocks. The thickness of the interlayers is from 0.5 to 2.0-3.0 m. The course of the rhyodacite streakiness mainly follows the perimeter of the dome. The angles of incidence of the streakiness are steeply inclined towards the center of the dome (68-80°), while the angles of inclination gradually decrease towards the marginal parts, in the lower outcrops they are 5-10°. Pumice on the top of the dome lie horizontally. In the upper lava flow, the separation has an inclination angle of 40-60°, mostly towards the dome, at the bottom - the falling of lavas changes in the direction of the flow. The angles of incidence range from 17 to 76°. The highest content of phenocrysts of plagioclase and dark-colored minerals is observed in glassy and rough streakiness rhyodacites of the dome and massive thin-fluid dacites of the lower stream. In the fluid dacites that form the base of the dome and the upper lava flow, the number of phenocrysts decreases. Their lowest content is observed in pumice rhyodacitis. Among the phenocrysts, plagioclase prevails, which is in the form of three generations. The first generation includes phenocrysts 3.0-5.0 mm. These are zonal crystals with melted and corroded outer zones. The composition of the core is labrador-bitovnite with 60-70% An. Intermediate zones contain 45-58 and 30-40% An. Phenocrysts of the first generation are found in the lower lava flow at the base of the dome. In the plagioclase crystals of this generation there are two-phase glassy inclusions (glass + gas), combined (glass + gas + melted from the melt apatite crystal) and crystalline. They are distributed parallel to the growth faces, along the cleavage planes and along the boundaries of the zones. The shape of the inclusions is drop-shaped, shapeless, angular, tubular. When heated in crystalline inclusions in the temperature range 950-1015°C, gas bubbles were released. As the temperature increased, they combined into one or two large bubbles. At a temperature of 1340°C, the bubbles turned into points. Small drop-like inclusions of glass were subjected to homogenization at 1334°C. The obtained temperatures indicate the crystallization of plagioclase phenocrysts at a considerable depth from very water-poor magmas.

The second generation includes nonzonal crystals ranging in size from 1.0 to 2.5 mm with An 30-41%. The outer zones, they are also melted, but the surface is mostly clean. The second generation plagioclase is more characteristic for the facies of the dome and the upper stream and is found in insignificant amounts in the lower lava flow and at the base of the dome. The third generation of plagioclase includes microlithes 0.1-0.8 mm with An 24-28%.

In the extrusion of Ploskaya there is hornblende (up to 3.5%) and hypersthene (from single grains to 2.5%). The maximum content of hornblende is characteristic of glassy rhyodacites of the eastern part. Optical properties are distinguished by common and basaltic hornblendes. Porphyritic crystals of the hornblende are usually extended by the length of the axis along the fluidity. The phenocrysts of plagioclase are less subject to this regularity.

Chemical analyzes confirm the presence of two phases of eruptions. The first phase has a dacite composition and forms the base of the dome and the lower flow of lava. The second phase forms the dome itself and the upper lava flow and corresponds to the composition of the rhyodacite. Thus, extrusion Ploskaya is a multi-act formation. At an early stage of its development, a melt erupted, resulting in the formation of the basal part of the dome and the lower flow of lava. Subsequently, the dome increased due to more acidic lavas of rhyolite and rhyodacite composition. As extrusion increased, new portions of lava squeezed out the previous ones, as a result of this process, its dome rose upwards. Viscous material erupted through a relatively narrow channel, which contributed to the formation of concentric flow lines. In the deep sections of the southwestern extrusion, a bulbous dome shape is observed. The flattening of the upper part of the dome could be due to the subsidence of the cooled lava and the partial lowering of the erupted material back into the channel.

The complex interrelation of tuff-sedimentary rocks and extrusive bodies of acidic and basic composition, varying volume and non-simultaneous introduction, shows that the structure of the Thermal volcano is a complex volcano-tectonic uplift. After the formation of the dome in its eastern part, hornblende glassy rhyolite introduced, consisting of fresh glass with a low content of phenocrysts. Subsequently, the eastern part of the dome was elevated to 140 m from its original position. The existence of such uplift is evidenced by a zone of strongly crushed rocks. This fault can be traced along the entire northwestern slope of the Kambalny Range.

The complex interrelationships of tuff-sedimentary rocks and extruding bodies of acidic and basic composition of different volume and penetrating them, varying in volume and incompatible, suggest that the structure of the northern part of the Kambalny Range is a complex volcano-tectonic uplift. In the valley of the river Pauzhetka roof of the Pauzhetsky suite is located at an absolute elevation of 100 m. In the axial part of the Kambalny ridge, it is located at an altitude of 900-1000 m above sea level.

3. HYDROGEOTHERMAL CONDITIONS AND HYDROTHERMAL CHANGES IN THE ROCKS OF THE PAUZHETSKY HYDROTHERMAL SYSTEM

Information from hydrogeological, geothermal conditions and hydrothermal changes in rocks of the Pauzhetsky hydrothermal system is necessary to select the location of the drilling of a scientific deep well.

3.1 Hydrogeothermal Conditions

The conceptual model of the explored part of the Pauzhetsky hydrothermal-magmatic system is represented by two water-bearing complexes and several waterproof horizons. These complexes and horizons are represented by volcanogenic rocks that date from the Upper Miocene and Quaternary.

They form the upper part of a closed thermal artesian basin located in a volcano-tectonic depression between andesitic stratovolcanoes and volcanic ridges. The explored part of the thermal artesian basin has a reservoir structure and lies almost horizontally on a site of about 2 km and a width of 2.5 km. Its thickness, measured in wells, is about 500 m in the range from -5 to -500 m below sea level. In the central part of this section, the water-bearing complex is supplied through a system of canals with a deep coolant from a lower-lying aquifer. The upper aquifer complex is characterized by both porous and fractured-vein convective circulation. The volume of fissure space is 0.28 of the total volume of the aquifer complex. 99% of its natural thermal discharge was carried out by boiling sources, steam jets and floating soils on the Pauzhetsky field - 63 MW.

3.2 Hydrothermal Alteration of Rocks of the Pauzhetsky Hydrothermal System

3.2.1 Hydrothermal Alteration with Neutral Chloride Waters (propylitization)

The main routes of movement of hydrothermal solutions in the depths of the Pauzhetsky system at the stage of low-temperature propitization are marked by the intensive development of hydrothermal metasomatic lomonite (zeolite propitilization). A sharp decrease in the filtration rate and flow rates of hydrotherms (in reservoirs) causes a change of lomonite paragenesis to calcite and hydromica.

The products of medium temperature propitization (epidote indicator) are occasionally manifested in the most permeable rocks. Chlorite-smectite and illite-smectite mixed-layer formations are widespread in modified propylites. Of particular interest is the formation in the stratum of zeolitic and, less commonly, propylitic quartz-adular, wairakit-prehnite-epidote-quartz-adular, and epidote-quartz-adular associations.

The areas of silicification are composed of aggregates of fine-crystalline chalcedony and mosaic quartz, to which small diamond-shaped adular crystals are confined. In the upper (25-80 m) and lower (125-150 m) silicification subzones, the superimposed nature of quartz-adular metasomatites on zeolite propylites is more pronounced. There is a wide development of quartz-adular metasomatites at various depths. Metasomatites are formed in open faults, cracks and in intensely fractured areas. The power of zones is from tens of meters to centimeters.

3.2.2 Acid Changes

The rhyolites of the thermal extrusion of the apical part in the center of the caldera of the Thermalny volcano are altered to opalits with a small amount of alunite. The altered rocks form the southern, most elevated part of the extrusion and are represented by coarse gravel and chippings. In some places, it is possible to observe the primary morphology of extrusion, which in the upper part is represented as a fan of pillars. Opal rocks form the slopes of the upper streams discharging into the south-western part of the

Kuril Lake. The upper part of the section of the altered rocks was processed into mudstones, which included a large proportion of kaolinite. They are colored brown with iron hydroxides. The thickness of the sections is measured by the first meters. The lower horizons of rocks are characterized by a lesser degree of argilization, and they gradually turn into brown massive opalits with an admixture of clay minerals and alunite. Deeper, they are replaced by basalts subjected to low-temperature chloritization (propylites). In the deepest sections, unchanged basalts are observed. The maximum thickness of the altered rocks is 30–40 m. The volume of rocks treated with solutions is significant and, as can be seen from the descriptions, covers not only extrusion, but also enclosing its rocks. The extensive section of hydrothermal rocks suggests that acid leaching occurred at a distance of two to three kilometers from the source of solution generation. In this regard, we believe that the hydrothermal solutions were formed at the site of extrusion and formed flows of groundwater, filtered on the eastern slope of the Kambalny ridge. A glacier moraine has survived here, the feeding area of which was located in the center of the extrusive dome. Morena covers pumice deposits dating back to 7000-8000 years in the Pauzhetsk geothermal area, determined by the radiocarbon method. There are no fragments of altered rocks in the moraine. Currently, the upper part of the moraine is located at higher hypsometric elevations than the bottom of the circus. It is assumed that this is due to the greater rate of destruction and removal of hydrothermally altered rocks under the influence of temporary and permanent watercourses.

4. DISCUSSION

The geological history of the Pauzhetsky geothermal region begins with a finely detrital volcanogenic-sedimentary complex of rocks of the Middle Miocene, which were formed in marine conditions, and underwater eruptions of lava flows and hyaloclastites mainly of basalt composition. Numerous small intrusions (dykes and sills) are also observed in these sequences. These rocks were subjected to hydrothermal changes of the type of propitization with extensive deposition of amorphous silica, quartz and sulphide mineralization. The result of such changes is the formation of massive sulfide deposits (Pirajno, 2009). The presence of marine mollusks with thin-walled shells indicates a significant depth of the sea at a distance from volcanoes. Middle Miocene volcanoes are characterized by episodic eruptions, which is probably due to the absence of volcanoes with long-acting magmatic channels. It is assumed that they were analogues of modern oceanic volcanic islands.

At the end of the Middle Miocene, intrusions of diorite porphyrites were introduced, which testify to the formation of embryos of andesitic magma chambers in the upper part of the volcanic system. This process was controlled by the thermal energy of redox reactions generated by injections of basalt melts in the strata of silicified rocks with deposits of massive and dispersed sulphides formed by submarine hydrothermal systems (Belousov et al., 2017). Appearance of an additional source of heat in the volcanic magmatic system causes the formation of a melt. Its parameters support heat balance and the corresponding mode of volcanic eruptions (Belousov and Belousova, 2018). The interaction of igneous melts with the meteoric waters of the host rocks of the upper crustal horizons leads to the formation of long-lived volcanic centers. Their formation and activity is controlled by hydrothermal-magmatic systems (Belousov et al., 2020a).

In the Middle Miocene, the Pauzhetsky geothermal region was the northern part of the Kuril arc of volcanic islands. They were long-lived volcanic centers with hydrothermal-magmatic systems characteristic of island arcs (Henly and Ellis, 1983). Such a geothermal system is characterized by the presence of an ascending flow of high-temperature fluids. It is determined by fumaroles, hydrothermal change of rocks and suspended aquifer horizons (overwater) heated by water vapor. The analogue of such systems is the hydrothermal-magmatic system of the Ebeko volcano, the Kurile Arc (Fig. 2) (Khubaeva, 2019).

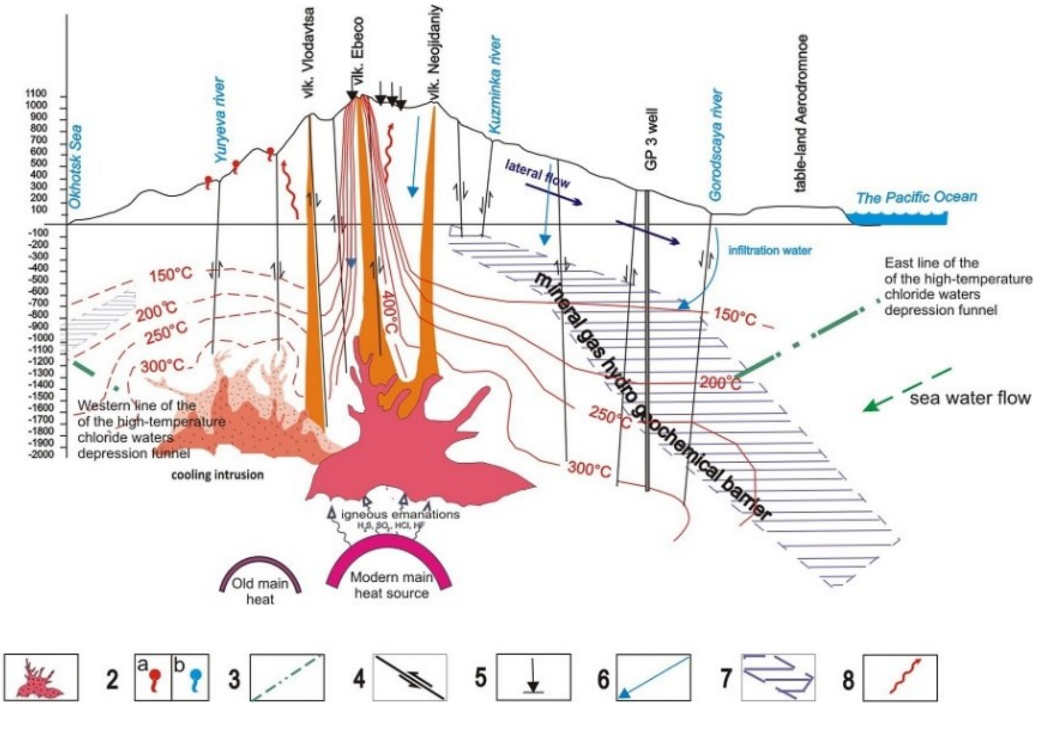

Figure 2: Scheme of the Deep Structure of the Hydrothermal-Magmatic System of Ebeko Volcano. 1. Magmatic Chanel, 2. Thermal Sourses A) Hot B) Cold, 3. Line Of High Temperature Chloride Waters Depression Funnel, 4. Fault Zone, 5. Fumarols, 6. Infiltration Waters, 7. Mineral Gas-Hydro- Geothermal Barrier, 8. Upflow (Khubaeva, 2019).

The evolution of the andesitic volcanoes of the Pauzhetsky geothermal region in the Upper Miocene-Pliocene was accompanied by an increase in the magma chamber due to the involvement of Kuroko-type sulfide concentrations, which were formed in their structure (Sato, 1973). This led to more regular eruptions of andesitic magmas, accelerating the growth of volcanic structures in the form of ridges and cones. In the intermontane depression (Pauzhetsky volcano-tectonic depression) a thermal artesian basin was located, in which heat was unloaded due to convection and boiling of thermal waters. This artesian basin is heated by heat emitted by oxidation-reduction reactions such as the burning of sulphides and carbon in the bowels of volcanoes. They were deposited in the process of their evolution by black smokers. At the same time with melts and magmatic fluids, significant amounts of condensable (SO_2, H_2S) and non-condensable (CO_2, H_2 CH_4 and others) gases are released. It is assumed that HCl is formed near the magma chambers as a result of hydration of chloride brines and seawater (Kazahaja and Shinohara, 1991). As a result of the condensation of these gases in the groundwater flows of volcanoes, ultra-acidic (pH <2, if HCl is condensed) and acidic (SO_2 is condensed) thermal waters are formed. Ultra-acidic hydrothermal solutions completely leach metal cations, and therefore andesites and more acidic rocks turn into opals. Acid waters transform these rocks into clays, which form water-impermeable cap-rock. Such conditions most often occur if the volcanoes are covered with glaciers, which also, like the covers of the mudstones, play the role of "cap-rock". Non-condensable gases accumulate under the "cap-rock" and the temperature rises — high-temperature hydrothermal systems of the Koshelev type are formed (Belousov, 1978). Some andesite volcanoes of the Pauzhetsky geothermal area (Koshelevsky, Termalny, Klyuchevsy-Shumny and Unkanovitch) belong to this type.

Vast fields of hydrothermally altered rocks, deposits of a crater lake on the Shumny and Klyuchevsky volcanoes, opal rocks, replaced at a depth by propilitic rocks, confirm this conclusion. On other andesitic volcanoes, such characteristics are found in much smaller volumes. It is assumed that the volume of metamorphic rocks involved in the formation of magma chambers in various long-lived volcanic centers is different. Therefore, some of them are characterized by high thermal capacity and longer activity.

Alkaline chloride high-temperature solutions produce propylitic changes, migrating into the water-bearing complex. When cooled or interacting with the surrounding sea water, siliceous and other hydrothermal, mainly silicate minerals are deposited in the pores. Such an example is the lithocrystalline tuffs of the dalcites of the Kambalny Range.

In the Pauzhetsky geothermal region in the Middle Pleistocene, thickness glaciers (700–900 m in the Kambalny Range, extrusion of the Duga and Ploskaya) covered the Pauzhetsky volcano-tectonic depression, in which the thermal artesian basin was located (fig. 3) (Braytseva et al., 1968).

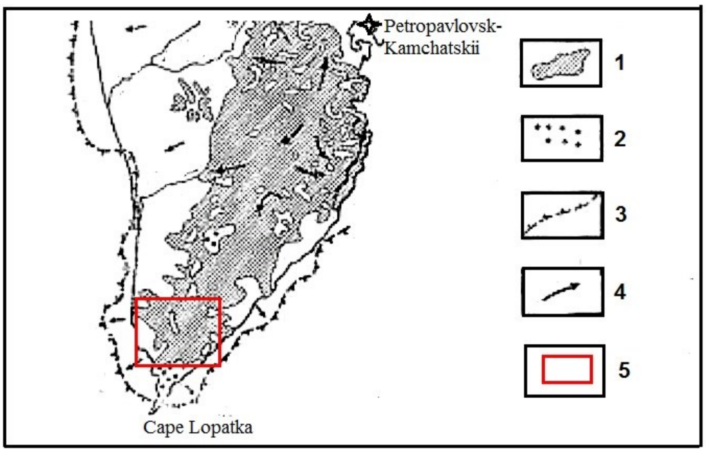

Figure 3: Scheme of the Upper Pleistocene glaciation of Southern Kamchatka (taken from Braytseva et al., 1968). 1-glaciers of the II phase of the upper Pleistocene glaciation; 2 - snowfields; 3 - boundaries of the distribution of glaciers of the first phase of the glaciation of the Upper Pleistocene; 4 - the direction of movement of the glaciers; 5 - Pauzhetsky geothermal area.

Glaciers limited groundwater flow and heat loss. As a result, high-temperature conditions were formed in its depths and an increase in CO_2 concentration occurred. Degassing and boiling of high-temperature waters led to the formation of a thick layer of silicified rocks and its heating, as in the Banno-Paratunsky geothermal area. (Belousov et al., 2020a). Volcanoes were areas of glacier feeding that flowed into the Pauzhetsky depression, put pressure on the plastic strata with lenses of melts. It is assumed that in this way some extrusion could have been formed. It is possible that sometimes this process was combined with the introduction of mantle melts, since the main plagioclases, hornblende and pyroxenes are found in the composition of the rhyodacite of extrusion Ploskaya. These minerals are characteristic of basalts and metamorphic rocks of a sheeted dike complex in Iceland (Friðleifsson et al, 2018). In the zone of extrusion contacts with host rocks, due to numerous faults (Belousov, 1978), CO_2 degassing occurs, resulting in disturbed carbonate equilibrium in thermal waters and loss of calcium. This leads to the transformation of Ca-silica gel into H-silica gel and the deposition of adsorbed metals in the cracks. Koroleva G.P. and others (1993) showed that geyserites deposited from the thermal waters of the Pauzhetsky hydrothermal system contain gold with significant concentrations. According to the analysis of 63 samples of geyserites deposited on the mouths of operating wells and at natural hydrothermal outlets, the average Au content in them is 33.5 mg/t, Ag - 242 mg/t, As - 21 g/t, Sb - 20 g/t. The maximum content of Au and Ag is set in the geyserite of well GK-3 - 420 mg/t and 20 g/t, respectively, and the content of As and Sb - 600 g/t in a sample of silica gel in RE-1. It is possible that on the periphery of the arc extrusion, where intensive degassing of CO_2 takes place, modern gold mineralization occurs.

Such a process of formation of gold-bearing veins is assumed for the Banny ore field, located on contact with the extrusion of the Sunduk. (Belousov et al., 2020a). Similar processes are assumed to occur in the Berlin hydrothermal system in El Salvador, where hydrothermal solutions recovered by geothermal wells deposit amorphous silica and sulfide complexes with high concentrations of gold (Raymond et. al., 2005).

Dacite and rhyolite extrusion Ploskaya contain a larger amount of potassium (up to 4-5%). They are distinguished by high viscosity of the penetrating melt, since they form dome-shaped formations that spread weakly along the slope. This feature may characterize the degree of heating of the melt. With a high content of potassium, the softening temperature of the rock is very low and amounts to 700-800°C. This suggests a higher temperature of dacites and rhyolites on the southwestern slope of Thermal volcano near the South Kambalny thermal field. In them, the potassium content does not exceed 1.2%. These lava flows with a thickness of 2-3 m were very fluid, which apparently is a function of temperature. Data on the migration of alkali metals in igneous melts towards lower temperatures are also given for basalt flows of the Tolbachik eruption (Belousov and Belousova, 2016). It is assumed that these data can be used when choosing a drilling site.

5. SELECTION OF DRILLING PLACES FOR WELLS ON THE VOLCANO THERMALNY

The well number 1 is proposed to lay at the sole of extrusion Duga (Fig. 4). In the 70s of the twentieth century, a well over 600 m was drilled here. It entered the fracture and its drilling stopped as there was a powerful release of steam-water mixture. Tests on it were not carried out. However, around it, the deposits of colloidal silica (geyserite) lasted more than 10 years. As a result, we believe that the high-temperature waters were oversaturated with silica and had a temperature of about 350ºC and rose from a depth of ~ 2 km, where CO_2 degassing began. It is assumed that at this depth there is a cooling apophysis from the roots of extrusion Ploskaya, located next to the extrusion of the Duga. In Plosky extrusion rhyodacite has hornblende, which could be captured from the host rocks, this, by analogy with the data from the Icelandic project RN-15/IDDP-2, may indicate the presence the shield of the dikes horizon and supercritical temperatures.

Drilling this well can be of theoretical importance for obtaining information about the formation of gold vein deposits in carbon hydrothermal-magmatic systems (Belousov and Belousova, 2019).

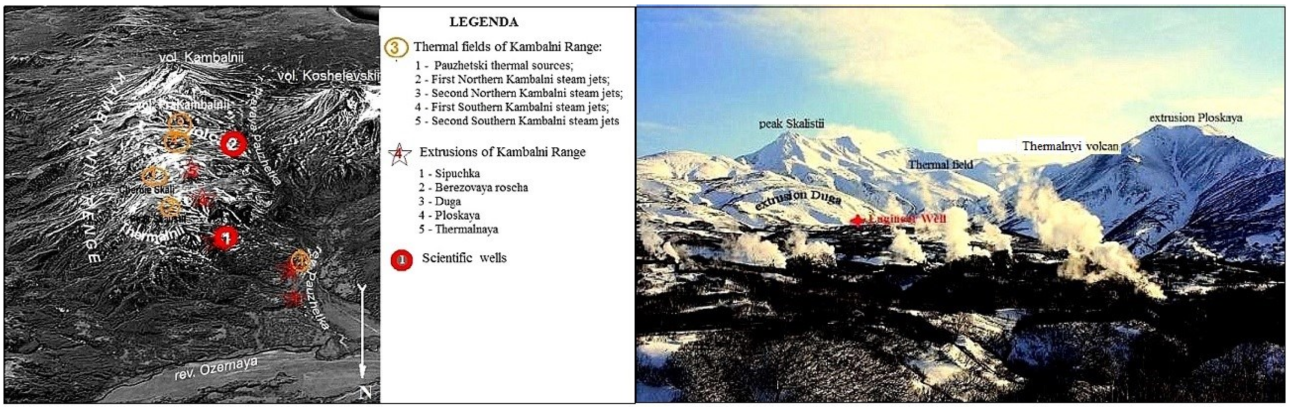

Figure 4: Shows the drilling sites of the projected wells.

The well number 2 is offered as a backup. The place of its drilling is at some distance from the Pauzhetsky geothermal power station, which complicates the rational use of supercritical coolant due to transportation problems. However, this place is located near the supposed magma source of the Thermalny volcano. His presence is indicated by the South-Kambalny thermal fields and the Opal rocks of the Thermalny extrusion.

6. CONCLUSION

The proposed review of geological, hydrogeological and geothermal data from the Pauzhetsky geothermal area shows a high degree of its knowledge. Additional research is expected to be supported by the project No. 14. W03.31.0033 "GEOPHYSICAL RESEARCH, MONITORING AND FORECAST OF THE DEVELOPMENT OF CATASTROPHIC GEODYNAMIC PROCESSES OF THE RUSSIAN FEDERATION" will clarify this data.

The authors hope that this project will interest the world geothermal society and it will be included in the system of international geothermal projects.

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