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Evolution of the Pauzhetsky Geothermal Area and Acid Volcanism

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ABSTRACT

In the Pauzhetsky geothermal area, the development of the Earth's crust from the Pliocene to the present has been determined by long-lived volcanic centers in the mode of the island arc which was the northern extension of the Kuriles. Near their boundaries, facial transitions from basaltic lavas and pyroclastic rocks to coarse sediments are observed, which at a distance are replaced by increasingly shallow volcanomictic material. From the Upper Pliocene to the Middle Pleistocene, the area of distribution of the effusive basalt composition of the long-lived volcanic centers is sharply increased. A significant number of eruption channels are produced, through which lava and pyroclastics of various compositions were erupted, including ignimbrites, pumice and lava flows and andesite, dacite and rhyolite domes. Acid rocks are the products of magma chambers activity in the Earth's crust. This period is characterized by the expansion of the land area due to the appearance of central-type volcanoes with calderas in the conditions of a glacier of considerable thickness (hundreds of meters and first kilometers). In the Holocene, the number of eruption channels on the Ilyinsky and Zheltovsky long-lived volcanic centers is reduced to one and these volcanoes were transformed into central-type volcanoes. Koshelevsky, Kambalny and Dikii Greben Ridge long-lived volcanic centers have a linear-nested arrangement of eruption channels, the same as on the Vernadsky Ridge (Paramushir Island, the Kuril volcanic arc). It is assumed that such volcanic ranges inherit basaltic fissure structures similar to the fissure eruptions of Iceland and Hawaii. Acid magma chambers screened heat flows of the mantle basalt reservoirs, partially generated and retained heat which feeds the hydrothermal systems of the Pauzhetsky geothermal area, and increased the thickness of the granite layer of the Earth's crust. The granitization process led to the formation of the geological structure of the continental type in the southern tip of the Kamchatka Peninsula.

1. INTRODUCTION

Drilling of the first well the first well in the Pauzhetsky thermal field was drilled at the location of boiling sources. In accordance with the evolutionary hypothesis of Emmons (1924), it was assumed that the geothermal steam of the Pauzhetsky boiling sources is separated directly from the magma chamber. The test results of this well showed that the thermal field in the valley of the Pauzhetka River is a place for unloading a hydrothermal system located on the northwestern slope of the Kambalny volcanic ridge. Its structure is represented by a complex of several multi-channel volcanoes. They had magmatic chamber in the upper part of the earth's crust and were formed in an island volcanic arc. Some volcanoes with magma chambers in the crust were characterized by the presence of significant thermal fields with field of alter rocks. In middle Pleistocene, the Pauzhetsky region was covered by a ~ 1 km glacier. At this time, areal eruptions of melts and pyroclastic material of different composition from andesites to rhyolites occurred.

The Pauzhetsky hydrothermal system was formed, which is closely associated with manifestations of the acidic volcanism of the Kambalny Range. Genetic relationship of long-lived andesitic volcanic centers of the Kuril-Kamchatka island volcanic arc, extensive manifestations of acid volcanism and hydrothermal activity determined the evolution of the Pauzhetsky geothermal area.

Averev V.V. (1967) showed that in the areas of modern volcanism, the most typical is the association of the hydrothermal process with the phenomena of “acid volcanism”. He believed that the most powerful and high-temperature hydrothermal systems of New Zealand, the USA and Kamchatka are located in areas where pumice, ignimbrites and welded tuffs are extremely widely developed, as well as extrusion of dacites and rhyolites of upper quaternary age. Banwell (1963, 1964), using thermal power estimates for the Wairakei hydrothermal system, expressed the idea that in the magma chamber under this system, the melt undergoes convection. Heat enters from the mantle. The presence of acidic extrusions in the structure of the Pauzhetsky hydrothermal system and in the Valley of Geysers in Kamchatka testified to their close connection. Averev (1967) proposed the concept that acid volcanism and hydrothermal systems have one source of heat — andesite-basalt volcanism.

2. GEOLOGY OF PAUZHETSKY GEOTHERMAL DISTRICT

The Pauzhetsky geothermal area is located on the southern tip of the Kamchatka Peninsula, on the border of the West Kamchatka and Central Kamchatka structural-facies zones. Together with the volcanoes Zheltovsky, Ilinsky, Kambalny, Thermalny, Koshelevski and Mashkovtseva, it is part of the southern end of the East Kamchatka volcanic region. A relatively small area contains a wide range of sedimentary, volcanic-sedimentary and volcanic rocks - from basalts and andesites of modern volcanoes and ancient volcanoes to dacites, rhyodacytes and rhyolites of quaternary extrusions. The last stages of development of the region of the Middle Upper Pleistocene and Holocene were characterized by the formation of pyroclastics and effusive acid composition.

2.1 Rocks of Paleogene-Neogene Age

The most ancient rocks in the southern end of the Kamchatka peninsula are volcanogenic-sedimentary rocks of Paleogene-Neogene age. Outcrops of these rocks on the surface are noted in the cliffs of the valley of Khakytsyn River (southern coast of the Kuril Lake), on average, the river. Etamink, in the eastern side of the basin, part of which is occupied by the Kuril Lake; at the northwestern foot of the ridge of Belyaev; in the sides of the Incanyush River, Waterfall stream, and further south along the Pacific

coast of this area. In addition, in the Pauzhetsky thermal field, two wells (at a depth of 800 and 1200 m), the lower part of which (550 m) represents the Neogene terrigenous sea sediments. The dating of these deposits was made in outcrops along the river Khakytsyn and the Pacific coast, where the fauna was found pelecipod. In other cases, the analogies were established according to lithologic-petrographic and structural-textural characteristics of rocks, as well as by occurrence conditions. In the outcrops in the area of the Kuril Lake and in the wells, the formations of the Neogene age are represented by sandstone, large-, medium- and fine-grained (greenish-gray, gray and dark gray). It is cemented with carbonate-chlorite-zeolite cement. The decrease in the grain size is observed in the east and southeast directions. The fragments in it are composed of dark-colored rock-forming minerals and basalts. Rocks changed hydrothermal processes of medium temperature propilization.

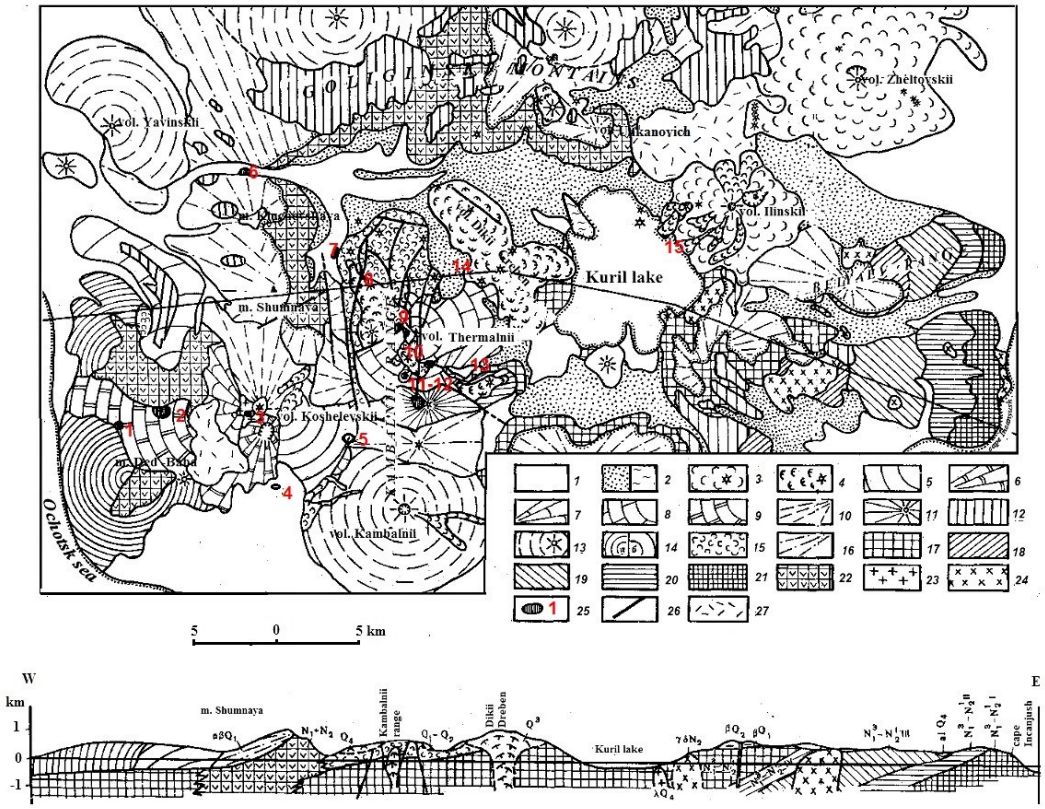

Figure 1: Schematic geological map of the Pauzhetsky geothermal area (Belousov, 1978). 1 - Q4 - Holocene-alluvial, proluvial and glacial deposits; 2 - Q4 - Holocene, pumice-caked tuffs of the Pulomynk Peninsula; 3 - Q4 - Holocene, basalts, andesite-basalts of active volcanoes; 4 - Q3 - Q4 - Upper Pleistocene-Holocene, dacite rhyolite extrusive domes and their lava flows; 5 - Q3 - Q4 - Upper Pleistocene-Holocene, andesites of the East Koshelevsky volcano; 6 - Q3 - Q4 - Upper Pleistocene-Holocene, andesite-basalts of the Central Koshelevsky volcano; 7 - Q3 - Upper Pleistocene, Valentine volcano andesites; 8 - Q3 - Upper Pleistocene, andesite-basalts of the Thermal volcano; 9 - Q2 - Q3 - Middle, Upper Pleistocene, andesites of the West Koshelevsky Volcano; 10 - Q2 - Middle Pleistocene, basalts of the Ancient Koshelevsky volcano; 11 - Q2 - Middle Pleistocene, andesite-basalts of the Kambalny Range; 12 - Q2 - Middle Pleistocene, ignimbrites and sintered tuffs of rhyodacite and rhyolite (Golygin horizon); 13 - Q1 + Q2 - lower, middle Pleistocene, basalts and andesite-basalts; 14 - Q1 - lower pleistocene. lava and tuffs of basalt (a) and andesite-basalt (6); 15 - N23 + Q2 - upper Pliocene-Middle Pleistocene, dacite tuffs (Pauzhetski formatin); 16 - N23 + Q1 - Upper Pliocene-Lower Pleistocene. Terrestrial tuff and lava deposits of ancient volcanoes; 17-21 - N13-N21 - Upper Miocene-Lower Pliocene. Marine sedimentary-volcanogenic deposits: V - formation of mainly conglomerates and sandstones, less often tuff crabs and basaltic lavas; IV - a formation of tuffs and lavas of basalts, tuff-conglomerates; III - formation of tuff-breccia and tuffs; II - a formation of coarse clastic tuffs and basalts lavas; I – a formation of sandstones, conglomerates, less often tuffs; 22 - N1 + N2 - unseparated, mainly volcanogenic, sediments; 23 - subvolcanic intrusion of dolerites of the Koshelevsky volcano; 24 - N2 - Pliocene, subvolcanic intrusions of diorites and diorite porphyrites; 25 - modern thermal fields and hydrothermally alter rocks (1- Sivuchinsky, 2 – Nizhne-Koshelevsky, 3 - Verkhne-Koshelevsky, 4 - Teplovsky, 5 - Medvezhy, 6 - Ozernovsky, 7 - Pauzhetsky, 8 – Vostochno-Pauzhetsky, 9 -10 – Severo-Kambalny, 11-12 – Juzhno-Kambalny, 13 – Vostochno--Kambalny, 14 - Vitaminy, 15 - Kurilsky; 26 — faults; 27 —Pleistocene-Holocene; loose deposits of various genesis.

The lower part of the Neogene volcanogenic-sedimentary complex is well represented on the Incanius Peninsula in cliffs of the eastern and southern part of the peninsula, in a flat (no more than 10 °) monocline, falling to the north-west. The upper half of the volcanogenic-sedimentary complex can be traced to east of the Kuril lake, where dominated by coarse clastic rocks and lava. Layered tuff-like sandstones and siltstones are of subordinate importance. For the whole complex, sharp facial variability along strike is characteristic. The apparent power of the entire complex is at least 1500 m.

Volcanic formations of the socles of the Shumnaya and Klyuchevskaya mountains correlate with the sedimentary terrigenous stratum of Neogene age (Aprelkov, 1961; Averev, Belousov et al., 1965). Pyroclastic rocks and basaltic lavas of the south-western part of the ridge Belyaev, Cape Incanyush and river basins on the Okhotsk coast have the same age.

The volcanogenic formations of Paleogene-Neogene age are sloughed by mountains and ridges, and are the remnants of extinct volcanoes. Some of them, like Belyaev Ridge, had several eruption centers. The maximum visible power of these formations varies from the first hundreds to 1000 m and more.

2.2 Quaternary Rocks

Tuff-sedimentary rocks of acid composition were found on the Kambalny Ridge, identified by S. Aprelkov in the Pauzhetsky suit (1961). Averev V.V. and Belousov V.I. (1965) considered that these rocks are Quaternary, and Aprelkov S.E. dated Upper Pliocene-Lower Pleistocene time. The upper horizons of the Pauzhetsky formation were dated to the Upper Pleistocene. The rocks of the Pauzhetsky Formation, which form the northern part of the Kambalny Range, where the Pauzhetsky deposit of thermal waters is located, date back to the Quaternary. The age of the remaining rocks of the southern end of the Kamchatka Peninsula was determined by their relationship with sections of the Pauzhetsk Formation, and sometimes with a Neogene sedimentary complex or lithologic-petrographic features (Belousov, 1978).

2.2.1 Pauzhetsky Formation (Pleistocene)

The full sections of the Pauzhetsky Formation are opened by wells drilled in the Pauzhetsky field and in the outcrops of the northern part of the Kambalny Range. The upper 450 m of the stratum is represented by tuffs (hyaloclastites) of dacites and rhyolites of various particle size distribution. In sections of wells, in the southeastern direction from the Pauzhetsk thermal springs, down to the eastern slope of the Kambalny ridge, coarse clastic tuffs prevail. In the northern direction, in the upper part of the sections, the thickness of fine-grained tuffs gradually increases to 100 m and more. Rocks of the Pauzhetsky Formation were encountered in the outcrops of the northern part of the Kambalny Range, in the cliffs of the r. Ozernaya, Vitaminny and Ulyanov lakes. Further north, in the southern parts of the Goliginsky Mountains, we have not found them on sedimentary Neogene rocks. It is assumed that the Pauzhetsky Formation in this direction is wedged out. In the eastern direction, it extends to the axial part of the Kambalny Range. Next, the Pauzhetsky formation facies passes into the tuff-conglomerate. Its distribution is limited to the eastern parts of the Kambalny Range. In the upstream of Pauzhetka River, starting from the Pauzhetsky field, formation, facially changing, is wedged out.

In the sections of wells and in the streams of the northwestern slope of the Kambalny Range, the 400-meter thick tuff-sedimentary sedimentary of the Pauzhetsky Formation is underlain by a horizon of lithocrystalline tuff of dacite composition. Previously, it was correlated with the horizon of caked tuffs of the Golygin Mountains (Averev and Belousov, 1965; Aprelkov, 1961). However, the lithological-petrographic characteristics, the chemical composition of these horizons of tuffs are different. In the wells and the Svetly stream, their cement is represented by amorphous silica, hydromica and chabazite (Belousov, 1978).

Among the deposits of the Pauzhetsky Formation are four horizons of tuff-conglomerates of various thicknesses. Fragments in them are represented by basalts and andesites. More thick horizons tuff-conglomerates 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. Obviously, the demolition area for tuff-conglomerates was located on the site of the Shumnaya and Klyuchevskaya mountains, which during the period of their formation were active volcanoes.

2.2.2 Volcanogenic Rocks of the Lower and Middle Pleistocene

Simultaneously with the tuffaceous-sedimentary Pauzhetsk Formation, a lava-pyroclastic complex was formed in the areas of the ancient volcanoes Shumnaya, Klyuchevskaya. Yavinsky ridge, Orlinoe Krilo, the north-western part of the Belyaev ridge, along the rivers of the Okhotsky coast (Fig. 1). The position and nature of changes in the thickness of the horizons of tuff-conglomerates in the section of the Pauzhetsky Formation in the valley of the Pauzhetka River suggest that lava-pyroclastic formations of basalts and andesites of the Shumnogo and Klyuchevskogo volcanoes formed in the lower Pleistocene. In the northwestern part of the Belyaev Ridge, the section of the lower Pleistocene formation consists of two horizons. Here, this complex of rocks lies on Neogene volcanic sandstones. In the area of the rivers of the Okhotsk coast, the volcanogenic complex of the Lower Pleistocene is also represented.

2.2.3 Ignimbrites and Tuffs of the Middle Pleistocene

Extensive fields of ignimbrite (golygin horizon) are located on the periphery of the Pauetskaya volcano-tectonic structure. (Fig. 1) (Aprelkov, 1961). Aprelkov S.E. determined the age of ignimbrites by their stratigraphic position, Pliocene. Averev V.V. and Belousov V.I. dated their age middle Pleistocene. Using the Ar-Ar method, Leonov V.L. and others estimate their age as the middle Pleistocene (Leonov et al., 2008). This ignimbrite horizon was compared with the lithocrystalline tuff of dacites in deep wells. Belousov V.I. (1978) determined that the correlation of these rocks is not possible due to their different origin.

2.2.4 Upper Pleistocene and Holocene Volcanogenic Formations

In the axial part of the Kambalny ridge, the rocks of the Pauzhetsky Formation are covered with andesite and basalt tuff-conglomerates. In the area of the Thermalny volcano (Black Rocks) and the peak of Scalisty, closely related volcanic rocks are mainly of andesitic composition. The thickness of these formations is on average 400–500 m. The rocks of the Thermalny volcano are dated to the Upper Pleistocene. It is assumed that late volcanogenic rocks of the southern part of the Kambalny Range and the Kambalny volcano simultaneously formed with them.

At the same time, many eruptions of an acidic material occurred at the end of the Upper Pleistocene and Holocene. In the caldera of the Dikyi Greben volcano, a lava-extrusive complex was formed, extrusions of the Kambalny ridge and the Golygin mountains. In the same period in the Pauzhetsky geothermal region, the formation of pumiceous deposits and tuff-sedimentary rocks occurring between the valley of the Ozernaya River and northern boundary of the Dikyi Greben.

Some additional information about the structure of the Pauzhetsky geothermal area is provided by the analysis of geophysical data, in particular maps of aeromagnetic anomalies (Averev, Belousov, 1965). On the map, the buildings of andesite-basaltic volcanoes are clearly distinguished by one of the positive anomalies of high order. The same anomalous values of the magnetization of rocks are characteristic of the Dikyi Greben. The high order of the anomaly above it does not correspond to the acidic composition of the rocks composing the upper part of its construction. Karpov and Yarotsky (Averyev, Belousov, 1965) interpreting these aeromagnetic data showed that the roof of the body that caused the positive anomaly is at a depth of 700-800 m. The values of the magnetic anomaly over this volcano are similar to the values of such anomalies above the Zheltovsky and Ilinsky, folded rocks of andesite-basalt composition. Negative anomalies on the Kuril Lake are associated with negative relief and possibly the presence of an extrusive-intrusive body naked on the Island of Sergze Alaida and Cape Tugumink.

2.3 Conditions for the Formation of the Rocks of Pauzhetsky Geothermal Area

All rocks of this region can be divided into two interrelated complexes: volcanogenic and volcanogenic-sedimentary. A characteristic feature of the Pauzhetsky volcanogenic complex, in our opinion, is the strict localization of igneous rocks within the geothermal area. In sections near the boundaries of their distribution, it is possible to observe facial transitions from basaltic lavas to rough sediments, which at a distance are replaced by ever more small clastic volcanogenic material (Fig. 2).

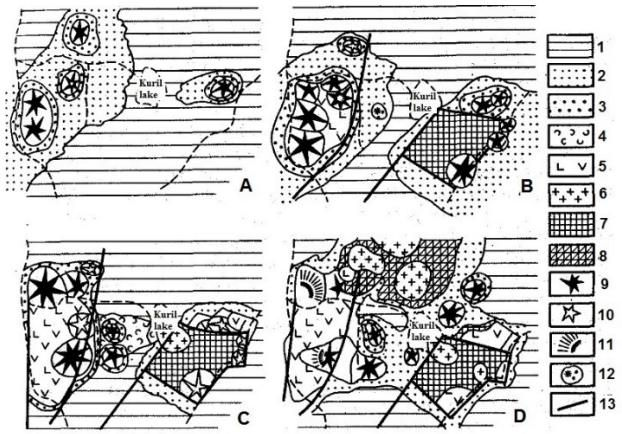

Figure 2: Stages of development of the Pauzhetsky geothermal area in the south of Kamchatka (Belousov, 1978). A-Paleogene-Neogene stage; B - Pliocene stage; C - Upper Pliocene - Lower Pleistocene stage; D - Pleistocene stage; 1- fine and small-clastic facies; 2 - mid-clastic facies; 3 - coarse clastic facies; 4 - depositions of the Pauzhetsk Formation; 5 - uplift zone formed due to the accumulation of lava-pyroclastic material of andesite-basalt volcanoes; 6 - areas of acid volcanism; 7 - zone of Paleogene-Neogene elevation; 8 - zone of the Middle Pleistocene uplift, synchronous with the manifestations of acid volcanism in the Golygin mountains; 9 - active volcanoes; 10 - extinct volcanoes; 11 - volcanoes erupting in subaerial conditions; 12 - underwater volcanoes; 13 - main faults

In the Upper Pliocene - Lower Pleistocene, the area of distribution of effusive formations increases with a moderate speed due to the increase of eruption centers on the main volcanoes of the region. This period is characterized by the expansion of land area as a result of the connection of islands of the island arc. Faults appear between them, limiting large blocks of previously formed volcanic structures. Between volcanic islands remain intermontane depressions, which are filled with coarser clastic sediments. The seabed rises due to excessive compensation of the subsidence of the deep parts of volcanic islands. Geophysical studies have confirmed the existence of the Pauzhetsky depression (Balesta and others, 1974). Within the limits of the depression, a conducting heterogeneity is surely distinguished, which can be interpreted as a crust magmatic chamber (at depths from 5 to 10 km) or as fluid enrichment of horizons at depths of several kilometers.

In the middle-upper Pleistocene and Holocene occurred formation of large volumes of effusive-extrusive and pyroclastic rocks of acidic composition (from dacite to rhyolite), prevalent in a large part of the Pauzhetsky geothermal area (Fig. 1). In the southern part of the Kambalny Range there are a number of volcanic apparatuses, of which the most active is currently the Kambalny volcano. In the Holocene, the number of eruption centers decreases, especially in the area of the Ilinsky and Zheltovsky volcanoes. Until recently, the Koshelevsky and Kambalny volcanic centers are characterized by several eruption centers (Structure of the hydrothermal system, 1993).

3. ACID VOLCANISM IN PAUZHETSKY GEOTHERMAL REGION

In the edifices of the andesite volcanoes of the Pauzhetsky geothermal area, Miocene and early Pliocene small intrusive body of dolerite and hornblende diorite porphyry are located (Dolgozhivuschyi centr ..., 1980; Structure ..., 1993). It is assumed that in the Miocene-Pliocene they were shallow magmatic chambers of these volcanoes. These intrusions are located in tuff and volcanogenic-sedimentary strata modified by medium-temperature hydrothermal solutions (~ 200-300ºC). Hydrothermal minerals of the propylitic facies, quartz, carbonate, clays and others are presented. On these volcanoes there are zones of acid changes with the

quartz-opal-alunite complex of secondary minerals, which is characteristic both for the crater lakes of modern Kuril arc volcanoes and for surface sulfuric acid changes.

In the evolution of the Pauzhetsky geothermal region, products of acid volcanism are widespread, starting from the middle Pleistocene. They are represented by ignimbrites of the Golygin horizon, pyroclastic sequences of the Pauzhetsky Formation, and extrusive-lava complexes.

3.1 Ignimbrites

The ignimbrites of the Pauzhetsky geothermal region were studied in more detail by Aprelkov S.E. (1961). Because of their areal distribution on the Golygin mountains, they were distinguished into a marking Golygin horizon. It was assumed that they were formed in the Pliocene-Pleistocene. Aprelkov S.E. (1961) ignimbrites of the Golygin mountains correlated with litocrystalline tuffs of the dacites of the Pauzhetsky deposit of thermal waters. According to the description of Aprelkov S.E. ignimbrites cover the rocks of the Miocene-Pliocene andesite-basaltic volcanoes. The total area of ignimbrite distribution is about 80 km^2, the volume is about 10 km^3. The distance between the extreme points of their development is 30-35 km. In the southwest, the horizon is highly eroded. Some of its fragments in the form of narrow elongated strips, bounded by ledges, have been preserved on the watersheds of the rivers.

On Golygin Mountains and on the watershed of the Pervaya Rechky, the ignimbrites were observed in the form of prismatic pillars. The largest covers of ignimbrites are developed on the Golygin mountains, their small fields are common in the western and southern limits of the Pauzhetsk volcanotectonic depression.

The eruptions of large masses of ignimbrites occurred from many small eruptive channels located along the cracks. In some cases, they poured out of the crack itself along its entire length. Emissions to air and long-range air transport are not observed, but plastic flow and accumulation near obstacles, which are currently absent, are characteristic. The eruption of ignimbrite flows during glaciation in the Middle Pleistocene suggests that glaciers were such obstacles. The absence of part of the same streams in the river valleys may indicate that during their distribution in these places the valleys were filled with glaciers.

3.2 Pumice

In the Pauzhetsky geothermal area, eruptions of acid volcanism began in the Holocene around the Kuril Lake. A significant part of the southern tip of Kamchatka was covered with pumice deposits of both volcanoes of the central type and areal volcanoes. Thickness of pumice horizons reaches 100-110 m and more. The total area of pumice covers is 320-350 km^2, and the volume is 22-25 km^3. There are several pumice centers of high power. The Holocene age of pumice of Kuril Lake is 8350-8400 ± 200 years old (GIN-728, GIN-1060) (Dolgozhivuschyi Centr, 1980). Small pumice horizons are dated to the Middle and Late Holocene.

One of the largest centers of acid volcanism of the Pauzhetsk depression is the Dikyi Greben volcano. It has an andesite-basalt structure with an explosive caldera (3 x 6 km), which houses a lava-extrusion complex (Fig. 3).

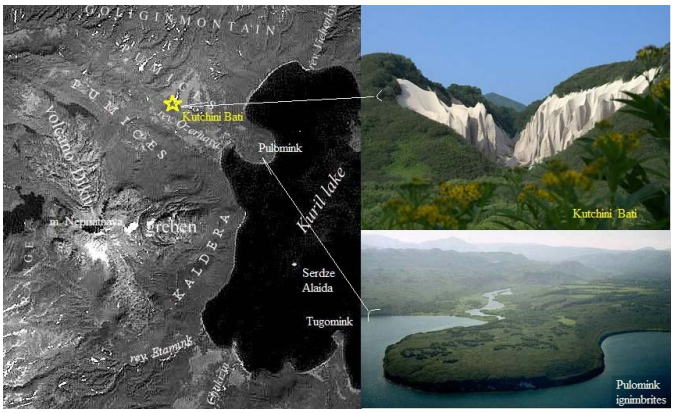

Figure 3: Space image. Showing the volcano Dikyi Greben, pumice deposits Kuthiny Baty and ignimbrites of the Polumynk peninsula.

The bulk of pumice is in the valley of the Ozernaya River. They formed a dam with a height of 240 m as a result of which the level of the Kuril Lake rose (Fig. 4) (Belousov, Belousova, 1990).

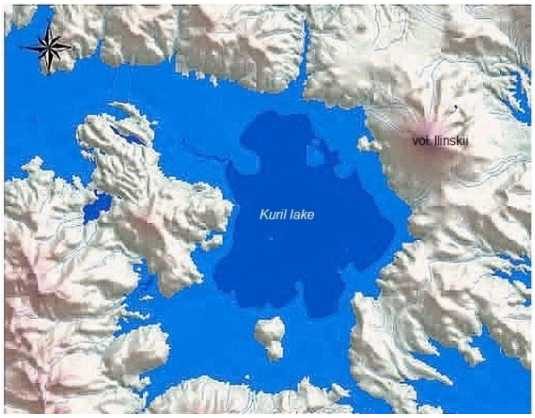

Figure 4: The boundaries of the Kuril Lake when the water level in it rises to 240 m (the modern water area of the reservoir is highlighted in blue). (Bugayev and others, 2009).

Pumice streams were "cold." The maximum thickness of the streams is observed on the outcrop of Kuthiny Baty and very quickly decreases to the foot of the Golygin Mountains. Pumices in the valley of the Ozernaya River have rhyodacite and rhyolite composition, and in the valley of the Khakytsin river pumice are similar to this. The joint finding of the pumice valley of the Ozernaya River and the lava-extrusive complex of the Dikyi Greben volcano suggests their genetic interconnection.

A large pumice field begins from the Ilinsky volcano and extends along the Belyaev ridge. Its area is ~ 120km^2, and the volume is 10-11 km^3. Pumice consists of several layers, among which there are ignimbrite horizons and scoria interlayers, whose thickness increases to the summit caldera (4-5 km in diameter) of the Ilinsky volcano.

Pumices around the Kuril Lake and in the Pauzhetsky volcanotectonic depression are characterized by complex petrographic and chemical compositions. They lie on pumice pebbles, deposited in lakes. The pumice stratum consists of several streams of different lengths, thickness and chemical composition, the facies of which vary along the Ozernaya valley. Pumice streams erupted from many channels, but mainly from the summit craters (calderas) of the Ilinsky and Zheltovsky volcanoes.

3.3 Acid Volcanogenic-Sedimentary Deposits of the Pauzhetsky Depression (Pauzhetsky Formation)

The well-studied volcanogenic-sedimentary complex of acid rocks of the northern part of the Kambalny Range is known as the Pauzhetsky Formation. Different rocks are involved in its structure, the sedimentary origin of which is beyond doubt. The Pauzhetsky Formation is underlain by the horizon of dacitic lithocrystalline tuff, at the base of which is a stratum of alternating layers of tuff breccias and lavas of andesites and andesite-basalts. The thickness of the lava flows is 0.5-5.0 m (Structure ... 1993). The space between the debris is filled with lithocrystalline tuff similar to the above located tuffs. The total thickness of this layer is 80 m. This tuff, in appearance, is very similar to ignimbrites. Aprelkov S.E. (1961) correlated them with the ignimbrites of the Golygin Mountains (the Golygin horizon). Since these rocks are at different absolute heights (- ~ 400 m and + 500 m), it was assumed that the Pauzhetskaya depression is a graben (Averyev, Svyatlovsky, 1961). The degree of hydrothermal changes of these tuffs is 3-5% of the rock mass. Under the microscope, the rock consists of 50% of the crystals and their fragments, consisting of quartz, plagioclase, hornblende, augite, and fragments of lava andesite and andesite-basalt, cemented by colorless transparent amorphous mineral. Most of the fragments of crystals are angular. In the phenocrysts of quartz and plagioclase there are numerous fluid inclusions. Quartz is often corroded. Age of Lower Pleistocene.

According to Belousov V.I. (1978) these tuffs, formed on the slope of a subaerial Thermalny volcano, served as the aquifer of the hydrothermal system of this volcano, in which silica gel deposition and silicification occurred as a result of interaction with seawater (Belousov, Belousova, 2019).

The lithocrystalline tuff is covered with sediments of the Pauzhetsky Formatin, which dates from the middle and upper Pleistocene. It is composed of volcanic-sedimentary rocks that were deposited in the Pauzhetskaya volcanotectonic depression. Rocks are represented mainly by pumice and ash tuffs (hyaloclastites) of dacitic, rhyodacitic and rhyolitic, which alternate near the surrounding volcanoes with horizons of tuff-conglomerates, whose thickness rapidly decreases as they move away from them. It is assumed that the rocks of the Pauzhetskaya suite are products of underwater eruptions of acid melts.

3.4 Extrusions of Acid Melts in the Pauzhetsky Geothermal Area

The eruption of ignimbrites, pumice, and volcanic-sedimentary deposits of the Pauzhetsky Formation was often accompanied with the formation of extrusive domes. Some of them had small flows of considerable thickness. Rhyodacitic lava flows are rarely found; their thickness is measured by several meters. Such lavas are observed on the western slope of the Kambalny Range on the South Kambalny thermal field.

Acid extrusions are conventionally divided into two types. Extrusions of the first type are located in the craters or calderas of long-lived volcanic centers (Zheltovsky, Ilinsky, Unkanovich, Koshelevsky, Thermalny and paleovolcan Shumny-Klyuchevskoy). As a rule, these extrusive domes have or have had thermal manifestations with extensive fields of acid alteration. The rocks of these extrusions were andesitic and more acidic. It is assumed that the formation of such acidic waters, participated glaciers, snowfields or thick fogs, characteristic of island volcanic arcs. Extrusions of another type are characterized by almost no surface thermal manifestations. The most significant of these are extrusions of the Thermalny volcano (Ploskaya and Duga) and the lava-extrusive complex of the Dikyi Greben volcano. It is assumed that the extrusions of the first type have a conical shape and the acidic waters

of the condensate type form an impermeable cover on them (cap-rock). This cover significantly reduces underground meteoric discharge into the extrusion and it long time is hot. Extrusions of the second type have the shape of an inverted cone, as a result of which the underground flow of meteoric waters in them increases significantly. It cools the extrusion to a greater depth, as established on Log Valley, where the temperature at a depth of 2.5-3 km ~ 100ºC (Fischer et al., 2003).

Thermalny volcano is described in the article by Belousov and others (2020).

The extrusions of Dikyi Greben volcano is a multiphase lava-extrusion complex, in the formation of which pumice is involved. The geological structure of the Dikyi Greben is a combination of different types of volcanism. The composition of the rocks ranges from andesites to rhyodacites. The heterogeneous composition of phenocrysts in the rocks of the lava-extrusion complex of the Dikyi Greben volcano suggests that they were formed from magmas formed as a result of the mixing of acid and basalt melts. It is assumed that the high magnetization of the building of the volcano, shown by aeromagnetic studies, is due both to the lava-pyroclastic volcanic mass and to the formational basaltic intrusions underlying most of the lava-extrusive complex.

An increased concentration of carbon dioxide during the introduction of melt into the water basin (sea, lake of melt water of glaciers) led to its swelling with the formation of pumice (Belousov, Ivanov, 1967; Belousov, Belousova, 2018.) This process is known for the production of penosilicate (Ivanov, Pavlov, https://findpatent.ru/patent/252/2524585.html). The high elevating power of water saturated with pumice fragments could contribute to the migration of relics of the lithocrystalline clastic horizon, with the result that in the pumice strata there are caked tuffs on the island Pomolink and Ilinsky pumice. Glacial cover pressure intensified the process of acid melt eruption. The high temperatures of the volcanic magmatic system and its saturation with carbon dioxide stimulated magma inflow under the siliceous horizon and its rise. This process occurred unevenly controlled by the eruptive channels through which the mantle melts flowed, drainage abnormal heat fluxes from the upper mantle levels. The evolution of the extrusion of Dikyi Greben volcano took place against the background of the evolution of the Pauzhetsky depression, bounded by the andesite-basalt volcanoes of the Kuril-Kamchatka island arc.

4. DISCUSSION

The geological positions of the Pauzhetsky geothermal area are controlled by the relatively young volcanic-tectonic structure of the transition of the Kuril island arc to South Kamchatka. By the nature of geodynamic processes, it is divided into three sections: east, central and western. The evolution of the Pauzhetsky geothermal area took place in the central area under the conditions of Pliocene-Quaternary volcanism activity.

The geological structure of the Pauzhetsky geothermal area was formed almost exclusively by volcanic processes in subaerial conditions, which were largely controlled by climatic conditions. Modern and historical climate changes have and have had a significant impact on the fluctuations of the water regime, both in the marine area of the region and in the underground hydrosphere. The interaction of surface water and products of magmatism manifested itself in the formation of relief, including high mountains, and therefore the migration of the snow line and the accumulation of solid perennial meteor precipitations changed. It is obvious that such structures had a significant impact on the temperature regime in the depths of volcanic structures and the underground hydrosphere.

In Kamchatka there were four glaciations of the Pleistocene age (Bryitseva et al., 1968). The main centers of glaciation were the mountain buildings of the peninsula. The glaciers of the Upper Pleistocene descended to sea level.

In the Middle Pleistocene in the Pauzhetsky geothermal region there was a simultaneous development of powerful glaciers with a thickness of ~ 1000 m and manifestations of areal acidic volcanism.

It is assumed that glaciers had a significant impact on the formation of volcanic structures. Almost all volcanoes of the preglacial time region (volcanic islands) in the presence of ice covers were subjected to strong explosive eruptions and the formation of flows of ignimbrites. Currently, ignimbrites are located mainly on the watersheds. The power of such flows increases with distance from the eruption channel. A stream of ignimbrites, having a modern thickness on the slope of the Unkanovich volcano, at the Orlinje Krilo volcano here reaches the first hundreds of meters. The pumice-ash Pauzhetsky Formatin, forming the northern part of the Thermalny volcano on the Kambalny ridge, was formed in a water basin. It is assumed that it was located under the ice, whose thickness reached ~ 600 meters. Flat plate extrusion (Ar-Ar age, 0.235 ± 0.041 million years) (Leonov and others, 2008) was introduced into the final stage of formation in the deposits of the Pauzhetsky Formation. In the Holocene, there were eruptions of high silicate melts saturated with carbon dioxide, forming foam, through numerous channels. The products of these eruptions have been deposited in the form of thick pumice strata in the river valleys near the eruption channels or on the slopes and foothills of andesite-basalt island volcanoes. Starting from the Middle Pleistocene, and up to the present, there has been a general rise in the area of manifestations of acid volcanism. It is assumed that as a result of metamorphism (silicification) of rocks in the zones of inflow of deep heat and its accumulation, both under glaciers and under these water-gas-impermeable strata, the crust is granitized.

Thus, the evolution of the Pauzhetsky geothermal area under the conditions of accumulation of internal energy is manifested in an increase in heat resources, an increase in the energy of coolants in the upper crust, and an increase in the prospects for its use.

5. CONCLUSION

1 - the evolution of the Pauzhetsky geothermal area at the final stage is characterized by extensive manifestations of areal acid volcanism that occurred during the Pleistocene glaciations.

2 - accumulation of a part of the anomalous stream and carbon dioxide is caused both by the cover of glaciers and by the metamorphic strata of hydrothermal systems over the dispersed streams of these streams.

3 - temperature increase in heat accumulation zones is accompanied by partial melting of the host rocks, their rise under the load of glaciers, injection of mantle melts caused by the release of carbon dioxide through the magmatic system.

4 - the general rise of the Pauzhetsky geothermal region is accompanied by an increase in the rate of expansion of the East Kamchatka volcanic zone as a result of the sliding of the upper blocks of the earth's crust over hot plastic horizons.

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