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THE KOSHELEVSKY VOLCANIC BLOCK AS A PROSPECTIVE SITE FOR THE DEVELOPMENT OF GEOTHERMAL POWER INDUSTRY ON THE SOUTH OF KAMCHATKA

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ABSTRACT

The Koshelevsky Hydrothermal-Magmatic System (complex volcanic block) was formed through evolution of a large outer magmatic chamber formed at the junction of the largest South-Kamchatka fault zones. The System is composed of seven volcanic structures of Lower Quaternary to Holocene age and of basic to acid rocks. In general, this system is a complex long-lived andesite volcano formed at the boundary of two huge blocks of the Earth's crust – the South-Kamchatka and North-Kuril segments of the Kuril-Kamchatka island arc. These huge blocks are divided by crust-cutting faults penetrated by a deep-earth (containing mantle components) metal-carrying fluid. The crust-penetrating character of faults is confirmed by gravimetric and seismologic, isotope-geochemical survey data as well as data demonstrating the existence of ascending fluxes of hydrocarbons including the heavy ones (C_5H_{12}, C_6H_{14}, C_7H_{12}, et al.).

The forecast resources of the Nizhne(Lower)-Koshelevsky geothermal field explored in 1975-1984 are estimated to yield 210 kg/sec of dry steam. Drilling to a depth of 1,500 meters proved the existence of a thick overheated steam reservoir the lowest boundary of which was not reached. This circumstance places this field among such large-scale vapor-dominated systems as the Geysers (USA), Larderello (Italy), Matsukawa (Japan) and Kamojang (Indonesia). On the surface, steam reservoir is manifested by a compact thermal anomaly sized 250 x 500 meters with a capacity of 25,000 kcal/sec. Capacity of the second largest thermal anomaly, Verkhne(Upper)-Koshelevsky is estimated 50,000 kcal/sec. Our findings confirm the availability of large steam reservoirs in the central part (in the inner caldera) and in separate geological blocks at the border of the Koshelevsky volcanic block and reveal a deep-earth origin of a convective heat flow. All this testifies to the earlier appraisal which stated the availability of geothermal resources on site feasible enough to construct power stations with a total capacity of more than 300 MW_e.

1. INTRODUCTION

The south Kamchatka has enormous geothermal resources. Hydrothermal-magmatic systems are the most promising sites for harnessing heat and electric energy in the Kuril-Kamchatka region. (Rychagov, 2005). They are associated with the largest on Kamchatka geothermal fields: the exploited Pauzhetsky and Mutnovsky and the explored Nizhne (Lower)-Koshelevsky one. Proven resources of these fields amount to 73 MW_e (Sugrobov et al., 2006), the forecast resources are estimated by us and other researchers to exceed 1000 MW_e. The development of geothermal power industry in the southern end of the Kamchatka peninsula is deemed strategically necessary in view of the shortage of power resources and unstable hydrocarbon fuel delivery to Kamchatka. The Pauzhetsky-Kambalny-Koshelevsky geothermal region is important owing to both fundamental research opportunities and potential power and heat supply to households and industry on the south Kamchatka.

2. GEOLOGICAL STRUCTURE OF THE REGION

The Pauzhetsky-Kambalny-Koshelevsky geothermal region is enclosed in the South-Kamchatka geothermal province (**Fig. 1**) (Rychagov et al., 2006_1). The region is identified

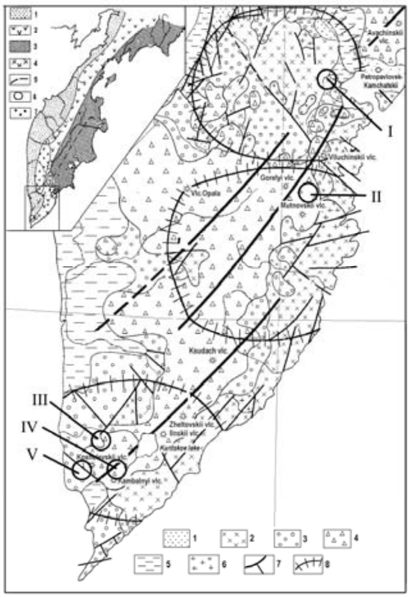

Figure 1: Geothermal Regions of South Kamchatka: the Structural Plan (Rychagov et al., 2006_1). Inset map: main structural areas of Kamchatka in Paleogene-Neogene time (made by G.M.Vlasov and V.V. Yarmolyuk in 1964): 1 – West-Kamchatka, 2 – Central Kamchatka, 3 – East-Kamchatka; 4 – Sredinny massif (Sredinny Ridge); 5 – boundary of the East-Kamchatka volcanic zone; 6 – geothermal regions; 7 – geothermal systems. Main map: 1 – Pre-Island-Arc-Stage rocks (Pre-Oligocene); 2 – Lower structural stage (Oligocene (?) – Middle Miocene); 3 – Middle stage (Middle Miocene– Pliocene); 4 – Upper stage – Quaternary volcanites; 5 – Quaternary and Pliocene - Quaternary (?) sedimentation masses of the upper structural stage of the internal area of the island arc; 6 – Large bodies of the quartz diorite complex; 7 – Faults; 8 – Boundary of geothermal areas, from North to South: Paratunsky, Mutnovsky-Zhirovsky and Pauzhetsky-Kabalny-Koshelevsky. Roman numbers indicate geothermal fields: I – Paratunsky, II – Mutnovsky, III – Pauzhetsky, V – Lower-Koshelevsky; and thermal manifestations of Kambalny Ridge (IV).

with the long-lived volcanic center – a large tectonic-magmatic structure of the southern end of the peninsula. The geological structure was developing from the early Oligocene to Holocene (The long-lived…, 1980). Rocks of the region are typical for an island arc complex and constitute three structural stages. The lower stage of Oligocene - middle Miocene age is composed of volcano-sedimentary rocks and hosts a complex of intrusive bodies having contrasted composition: from gabbro to plagiogranites. The middle stage of Miocene – Pliocene age is represented with sedimentary-volcanic strata of basic and intermediate composition. The upper stage reflects the Quaternary phase of the Kuril-Kamchatka arc evolution and is represented with andesites and their tuffs as well as basalts and rhyolites of Pleistocene-Holocene age (Geologic-geophysical…, 1987). The Pauzhetsky-Kambalny-Koshelevsky geothermal region includes three main geological structures governing its development, location of heat sources, hydrodynamics and the formation of separate geothermal fields: the Pauzhetsky hydrothermal-magmatic system, the Kambalny volcanic ridge (structural high) and the Koshelevsky hydrothermal-magmatic system (a complex volcanic massif).

3. HYDROTHERMAL_MAGMATIC SYSTEMS OF GEOTHERMAL AREA

The Pauzhetsky hydrothermal-magmatic system is located in the homonymous Quaternary volcanic-tectonic depression sized 20 x 25 km in plan view (Structure …, 1993). The eastern flank of the depression is complicated with structural high of the Kambalny volcanic ridge controlling three groups of present-day thermal fields (North-, Central- and South-Kambalny). From the south the structure is bridged by the active Kambalny volcano. The structural high represents a system of successively elevated blocks of rocks with amplitude growth towards the ridge axis. Total structural high amplitude is 1,000-1,200 meters based on analysis of the position of rocks in the Upper-Pauzhetsky sub-suite within the structure of the geothermal region (Structure…, 1993). The Koshelevsky volcanic massif was formed as a result of the evolution of a large peripheral magma chamber formed at the intersection of the South-Kamchatka regional fault zones (Vakin et al., 1976; Lebedev, Dekusar, 1980). The massif is composed of five volcano edifices **(Fig. 2)**, from Lower- Quaternary to Holocene in age and from basic to acid (mainly, intermediate) in rock composition. In general, this is a typical though complex andesitic volcano localized at the boundary of the South-Kamchatka and North-Kuril Island arc segments separated by crust-penetrating permeable faults to form large regional tectonic blocks. The crust-penetrating nature of the faults in this section of the South Kamchatka structure is interpreted on the basis of.geophysical data, outputs of isotope-geochemical studies, data on the existence of ascending hydrocarbon fluxes, including the heavy ones (The long-lived …, 1980; Pisareva, 1987). The volcanic massif is located over the long-lived (from Miocene-Pliocene to now) Koshelevsky hydrothermal-magmatic system which controls the formation of large geothermal deposits, igneous mineral resources (sulfur, secondary alunite quartzites, gypsum, gold-polymetallic ore occurrences), carbonate and alkali-metallic waters having balneological value.

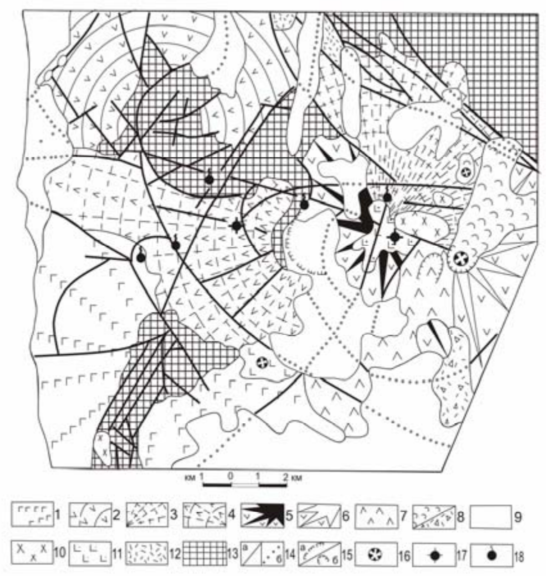

Figure 2. Geological plan of the Koshelevsky volcanic massif (Vakin et al., 1976; in authors modernization).1, 2 – Lower-Quaternary volcanoes: 1 –Ded i Baba (Grandfather and Grandmother), 2 – Tret'ya Rechka (The Third River); 3-8 – effusive and pyroclastic formations of Koshelevsky massif: 3 – Drevniy Volcano (Ancient), 4 – Zapadniy (Western), 5 – 1545 Volcano , 6 – Vostochniy(Eastern) , 7 – Tsentralniy (Central), 8 – formations of the Active crater, a – lava flows, б – deposits of directional explosion; 9 – loose deposits of different age and genesis ; 10 – extrusions of Holocene age; 11 – subvolcanic intrusions of dolerites; 12 – volcanic-sedimentary deposits of the Pauzhetsky suite; 13 – Pre-Quaternary effusive; 14 – discontinuous faults, a – identified, b – presumed; 15 – calderas (a) and erosion craters and explosion funnels (b); 16 – effusive and cinder cones; 17 – main thermal anomalies (the Upper-Koshelevsky confined to subvolcanic intrusion of dolerites and Lower-Koshelevsky – in the center); 18 – hot springs.

4. MAIN GEOTHERMAL DEPOSITS ON SOUTH KAMCHATKA

The Pauzhetsky geothermal deposit is one of the most studied sites of this kind on Kamchatka (Belousov, 1978; Structure…, 1993). The site installed capacity is 11 MW_e, a forecast capacity $\geq$ 60 MW_e calculated for 100 year long exploitation (Strategy…, 2001). The site hosts a number of surface thermal anomalies which had existed before the beginning of exploitation. Interpretation of data from deep drilling established that the geological structure of these parts of the deposit represents Quaternary structural highs that govern the movement of ascending local fluxes of chloride-sodium thermal waters and long-evolved liquid-vapor transition zones (Zhatnuyev et al., 1991). Owing to active tectonic-magmatic and hydrothermal processes, the hydrothermal-metasomatic quartz-adularia breccias confining complex geochemical anomalies (Au, Ag, As, B, K, Li, Rb) and gold-sulfide mineralization are formed under the thermal fields. Accordingly, zones of ascending hydrothermae at the Pauzhetsky deposit host the formation of both geothermal anomalies and hydrothermally-altered rocks and mineralization. The Kambalny volcanic ridge includes several thermal fields each of which is distinguished by geological and morphological structure. As a rule, thermal fields are localized in ring structures having a diameter over 500-600 meters and representing craters of a Middle-Upper-Quaternary andesitic volcano (**Fig. 3**). Vent facies rocks (agglomerate tuffs and breccias) and intermediate extrusions outcrop on the boundaries of the structures. Thermal waters discharging on this site are distinguished by high grades of Au and low ratios of $^{87}Sr/^{86}Sr$ which indicates that there is a deep seated fluid participating in the formation of thermal waters. We presume that there exists a direct connection of geothermal anomalies of the Kambalny volcanic ridge to the volcano's peripheral magma chamber and to separate subvolcanic bodies of basic-intermediate composition (Structure…, 1993).

Figure 3. The Kambalny volcanic ridge. The present-day Kambalny volcano is in the background. In the center – the South-Kamchatka Central Field localized in a round crater 600-800 meters in diameter. The structure is surrounded by extrusive bodies of andesites and andesidacites. Picture by S. Rychagov.

The Lower-Koshelevsky geothermal field was explored in 1975-1984. Its forecast resources are estimated to have 210 kg/sec of dry steam or 90 MW of electric power capacity (Pisareva, 1987). Drilling to a depth of 1,500 meters demonstrated that the main feature of the deposit was the existence of a thick overheated steam reservoir the lowest boundary of which was not distinguished **(Fig. 4)**. This circumstance places this field among such large-scale vapor-dominated systems as the Geysers (USA), Larderello (Italy), Matsukawa (Japan) and Kamojang (Indonesia). (Truesdell, White, 1973; White et al., 1971). At the surface, the steam reservoir is manifested by a compact though powerful thermal anomaly sized 250 x 500 meters with a capacity of 25,000 kcal/sec. (Vakin et al., 1976). The field has captured additional attention since the discovery of high contents of methane and heavy hydrocarbons including C_5H_{12}, C_6H_{14}, C_7H_{12} in its thermal waters (Lebedev, Dekusar, 1980; Pozdeev, Nazhalova, 2008). CH_4 contents in vapor-gas mixture found in Well P-3 several years after drilling was within a range of 37-67 vol. %. We assume there is hydrodynamic connection between the Lower-Koshelevsky geothermal deposit and the Upper-Koshelevsky thermal anomaly with an estimated capacity of 50,000 kcal/sec (Vakin et al., 1976). In all, the site is one of the most promising ones on the south Kamchatka in terms of scientific and practical studies of geothermal and related mineral resources.

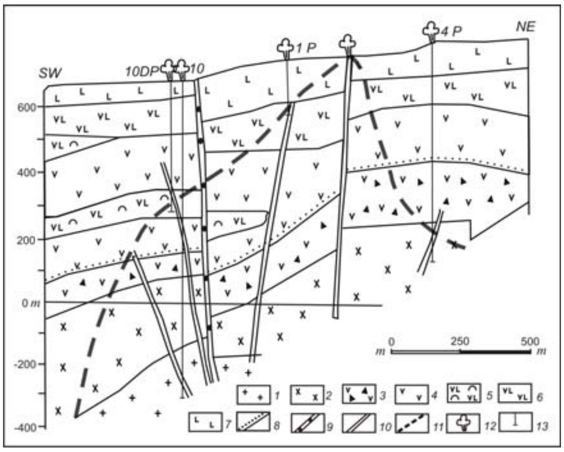

Figure 4. Geological section of the Lower-Koshelevsky geothermal field, based on paper of (Pisareva, 1987) and geological exploration data, revised and expanded. 1 – diorites; 2 – diorite pophyrites; 3 – subintrusive xenobreccias; 4 – Lower-Quaternary andesites; 5 –tuffs of andesibasalts; 6 – Middle-Quaternary lavas of andesibasalts; 7 – Middle-Upper-Quaternary lavas of andesidacites; 8 – the upper boundary of the subvolcanic complex; 9 – discontinuous tectonic faults filled with hydrothermal formations; 10 – open faults; 11- the upper boundary of steam; 12 – steam manifestations from wells and natural outlets; 13 – geothermal wells.

5. SOME WORK DETAILS ON KOSHELEVSKY HYDROTHERMAL-MAGMATIC SYSTEM

In recent years, scientists of Institute of Volcanology and Seismology FED RAS have been increasingly involved in additional studies of geothermal and related resources of the Pauzhetsky-Kambalny-Koshelevsky geothermal region, primarily the Koshelevsky hydrothermal-magmatic system in order to generate its complex geological-geochemical model. New data on composition, transport conditions, mixture and sources of thermal waters have been derived. The surface of the Pauzhetsky and Lower-Koshelevsky geothermal deposits hosts the formation of acid and low-acid sulfate waters of mixed cationic composition (Ca-Na-Mg-K) and hydrocarbonate-sulfate ammonium waters **(Table 1)**. Mineralization of surface formation waters seldom exceeds 1 g/l. The waters of the geothermal region are characterized by alkali-metal and alkali-earth specialization.

Deep-seated waters are typical alkali-metal boric chloride-sodium ones with mineralization of ≥ 3 - 5 g/l (Sample R-121/05, table 1) or alkali-earth hydrocarbonate-calcium (Sample NK-1/06, Table 1). The latter type of solutions characterizes water mixture zone at a depth of over 500-1000 meters within the structure of the Lower-Koshelevsky reservoir. All the water types - deep-seated, mixed and surface – are characterized by high concentrations of silicic acid partially presented in the colloidal form. Colloidal silicic acid and silica gel play an important role in formation of deposits ("geyserites") on the surface of thermal fields and in saturation of the stratum of argillized metasomatites with silica minerals (Rychagov et al., 2006_2). These processes lead to rock consolidation and creation of the additional upper water-confining layer within structure of hydrothermal systems. Thermal waters discharged at the surface of the Kambalny ridge and the Lower-Koshelevsky thermal anomaly are formed with

Table 1. Chemical composition of thermal and other natural waters formed in the Pauzhetsky-Kambalny-Koshelevsky geothermal area

Parameters	№№ of water samples									
	VTF-1/05	VhTF-1/05	NTF-1/05	SKTF-1/05	YKTF-1/05	R-121/05	GK-3/05	R-108/05	NK-10/06	NK-1/06
1	2	3	4	5	6	7	8	9	10	11
pH field	4.6	3.7	9.4	5.7	7.4	9.1	8.8	8.8	4.3	10.2
Eh field	152	384	-304	243	-194	-197	-225	-180	63	37
T ^{0}C	94.9	83.5	96.4	14.9	85.0	91.0	92.8	96.8	77.8	69.5
pH laboratory	5.1	3.75	7.86	7.3	6.4	7.3	7.95	7.7	3.15	7.95
Components	Contents, mg/l									
Na^+	14.1	20.00	76.50	3.30	15.7	684.2	701.2	707.9	39.10	28.50
K^+	6.60	8.80	7.20	0.20	6.5	82.5	81.1	69.8	1.00	10.50
Ca^{2+}	16.03	80.16	6.41	0.20	91.8	124.2	82.2	107.2	44.49	56.11
Mg^{2+}	2.43	30.38	0.36	0.00	28.9	60.6	9.7	60.6	7.90	11.91
Al^{3+}	0.00	0.00	0.00	0.00	0.00	0.7	0.00	0.53	0.90	0.00
Fe^{2+}	0.00	0.15	0.00	0.15	0.00	0.00	0.00	0.00	1.76	0.00
Fe^{3+}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.03	0.00
NH_4^+	5.40	72.00	1.70	0.00	84.0	1.0	0.8	0.7	0.20	0.00
H^+	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum of cations	*44.56*	*211.52*	*92.18*	*3.85*	*226.9*	*953.2*	*875.0*	*946.7*	108.38	107.02
Cl^-	3.55	2.84	46.09	1.42	2.1	1436.1	1390.0	1418.4	2.84	8.15
SO_4^{2-}	85.49	576.36	46.11	1.44	500.6	96.0	92.2	96.0	268.97	48.03
HSO_4^-	0.00	21.53	0.00	0.00	0.00	0.00	0.00	0.00	10.67	0.00
HCO_3^-	13.42	0.00	133.02	14.64	76.9	42.7	48.8	43.9	0.00	214.78
F^-	0.00	0.00	0.00	0.00	0.24	1.7	0.00	1.6	0.27	0.00
Sum of anions	*102.46*	*600.73*	*225.21*	*17.50*	*579.84*	*1576.5*	*1531.0*	*1559.9*	282.75	270.96
H_3BO_3	0.00	2.23	6.7	0.00	0.00	163.2	150.2	163.8	2.78	0.6
H_4SiO_4 solut.	144.5	189.50	190.00	0.00	110.0	145.0	155.0	150.0	86.00	153.00
H_4SiO_4 colloid.	0.00	16.50	46.00	0.00	3.0	250.0	320.0	276.0	30.00	75.00
Mineralization	***291.52***	***1020.48***	***560.09***	***21.35***	***922.04***	***3087.90***	***3031.2***	***3096.4***	***509.90***	***606.58***
Sr, mg/l	0.32	1.88	0.1	0.16	0.74	0.39	0.42	0.58	1.05	1.05
$^{87}Sr / ^{86}Sr$	0.705210 ± 0.000019	0.704134 ± 0.000014	0.704982 ± 0.000011	0.703522 ± 0.000015	0.703302 ± 0.000012	0.703490 ± 0.000013	0.703448 ± 0.000013	0.703427 ± 0.000016	0.703906 ± 0.000015	0.703417 ± 0.000011

The note. Determination of full chemical composition of water was carried out in the Analytical Center of Institute of Volcanology and Seismology FED RAS (O.V. Shulga), contents of Sr – in Institute of Geochemistry, Siberian Branch of RAS (G.P. Sandimirova). Samples №№ 2-6 – the waters discharging on modern thermal fields (VTF – Vostochno(East-)-Pauzhetsky, VhTF – Verhne(Upper-)-Pauzhetsky, NTF – Nizhne(Lower-)-Pauzhetsky, SKTF – Severo(North-)-Kambalny, YKTF – Yuzno(South-)-Kambalny thermal fields); Samples №№ 7-9 – thermal waters from wells drilled in various blocks of Pauzhetsky geothermal deposit; Sample № 9, 10 – thermal water of Nizhne (Lower-) -Koshelevsky geothermal deposit formed on thermal field (10) and at deep horizons (11).

participation of deep-seated fluids which is confirmed by low values of $^{87}Sr/^{86}Sr$ (Table 1) and high grades of Au, alkali and rare earth metals.

Natural heat discharge at the surface is localized within two thermal anomalies – the Lower- and Upper-Koshelevsky (see data on their sizes and capacity above). Inner structures of the thermal anomalies have gone through substantial changes over the past decades since last geological-geothermic exploration, namely shape, location, boundaries and other attributes of explosion funnels, thermal lakes, and water and mud pots, even the general outline of geothermal fields. Maximal temperatures of steam on the surface amount to 120-127^{0}C for the Lower- and 150^{0}C for the Upper-Koshelevsky anomalies. Silicious-sulfide crusts with high grades of Au and Hg are deposited on high-temperature fumarole vents. Within the Upper-Koshelevsky thermal anomaly, colloidal silica precipitates and forms chalcedony brush-like crystals with elevated Au concentrations (up to 0.1 g/t) and other ore elements in places where hydrothermae are discharged with a temperature of 50-75^{0}C. Colloidal silica plays a big role in the formation of altered rocks and hydrothermal clays in the Lower-Koshelevsky thermal anomaly. These facts, the diversity of mineral precipitates, high concentrations of carbon dioxide and acid volcanic gases and things say for the existence of a deep-seated magmatic feeding source for vapor-hydrothermae. Probably, there is an even larger overheated steam reservoir under the one discovered earlier based on geological exploration data from the Lower-Koshelevsky thermal anomaly area.

6. CONCLUSION

The Koshelevsky Hydrothermal-Magmatic System was formed at the connection of the South-Kamchatka and North-Kuril geological structures (megablocks of the Earth's Crust) and is confined to junction of deep-seated crust-penetrating faults. This condition determines great outlooks of this system for prospecting and exploration of geothermal reservoirs of various types, primarily vapor-dominated ones. The development of geothermal power industry on the south of the Kamchatka peninsula will inevitably stimulate interest to other rich mineral resources of volcanic origin (pumice-stone, native sulfur, gypsum, alunite quartzites, gold-silver and polymetallic ore manifestations), recreational resources, tourism development.

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