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Influence of silica deposition on a geothermal deposit, landscape and ecological situation (Case study: the South Kamchatka and the Northern Kuril Islands)

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ABSTRACT

Natural and artificial siliceous sinter deposits actively participate in alteration of argillized rocks and in precipitation of mineral salts on the surface of geothermal deposits. The formation of extensive mass of siliceous sediments, silification and hardening of rocks enhance water-confining and heat-insulating properties of rocks, which results in practically instant in geological time alteration of thermodynamic parameters in separate blocks of deposits and results in formation of additional solution boiling zones. It is obvious that natural and artificial sediments of silica in a certain manner alter landscape and ecological setting in geothermal deposits area.

1. INTRODUCTION

Geothermal processes greatly impact surrounding landscape processes in recent volcanism areas. Due to ascension of high-temperature mineralized deep-seated fluids, various types of hydrothermal solutions mixed with meteoric waters form and interact with rocks, biosphere and atmosphere. During development of geothermal deposits, anthropogenic activity also contributes to the formation of hypergenesis zone. Namely, discharge of hydrothermae from wells and separators onto the day surface substantially impacts environment, morphology and geochemistry of landscape. A detailed study of composition and structure of artificial mineral precipitates, rate of their precipitation, accumulation mechanisms and redistribution of ore and rare elements in them and in enclosing rocks significantly broadens knowledge about supergene processes initially formulated by A.E. Fersman (Fersman, 1939) and eventually followed up by many soviet, Russian and foreign geologists.

The typical hydrothermal solutions of present-day volcanism areas contain silicic acid in dissolved and colloid forms (Belousov et al., 1998; Chukhrov, 1955). When hydrotherms ascend to the surface and physical-chemical conditions at thermodynamic barriers change, a significant portion of dissolved silicic acid becomes colloidal and silica gel then solidifying into silica minerals (opal, tridymite, crystobalite, chalcedony, quartz) is formed. Silification of enclosing rocks and formation of thick (namely, over 1,000 m at the North-Kuril geothermal deposit) additional water-confining and heat-insulating horizons within the structure of a hydrothermal system are observed (Rychagov et al., 2002; Rychagov et al., 1994). This process is most dynamically manifested at the aquatic thermodynamic barrier. “Surplus” thermal water discharge on the landscape of the Pauzhetsky geothermal deposit during 40 years formed extended (≥ 500 м) and thick (up to 1.0 meter) mass of siliceous sediments ≥ n x 1000 m^3 in size. A study of ore elements distribution in them proved that the strata contained relatively high concentrations of Au – up to 0.1 ppm, Ag – 4 ppm, As - 40 ppm, Sb – 50 ppm along the whole length and across the whole vertical section (Koroleva et al., 1993). Moreover, maximum concentrations of elements in sediments are observed over a distance of first meters from wells and in the upper densest layers being formed directly in present-day water flow. Irregular distribution of elements depends upon many factors: macro- and microelement composition of solutions, velocity of water flow, physical-chemical properties of formed silica gel, petrophysical properties of siliceous sediments , zone sequence, participation of microorganisms in stratum formation (thermophilic blue-green algae and bacteria), etc. The lower layers of this bedded formation and substrate (peat), underlying the siliceous sediments, accumulate native mercury – up to n x 10 ppm.

2. RESULTS OF RESEARCHES

The Pauzhetsky hydrothermal system and a geothermal system of the same name (the South Kamchatka) were explored in the 1960-80s (Belousov, 1978; Structure…, 1993). Pauzhetsky Geothermal Power Plant with a capacity of 11 MW has been sustainably functioning since 1967. Several natural thermal fields are distinguished. Besides, artificial thermal anomalies are formed in some areas due to discharge of vapor and hydrothermae from wells and separators onto the day surface. These artificially-induced thermal anomalies are mainly characterized by formation of siliceous sinter deposits. At the Pauzhetsky geothermal deposit, the thickest and longest coats of siliceous sinter deposits have been formed due to discharge of hydrothermae from wells GK-3, R-106 and R-120 since the 1980s (Rychagov et al., 2006), **Figure 1**. Thermal waters

a

b

Figure 1: Formation of artificial silica sediments and thermophilic blue-green algae and bacteria on Pauzhetsky geothermal deposit, a – from thermal water of well R-120, b – well GK-3.

used for electricity and heat generation have chloride-sodium and rare-metal composition with a temperature of lower water-bearing horizon of 220 ^{0}C, and pH from 8 to 10 (Pauzhetsky…, 1965; Structure…, 1993). It is these waters that are discharged on the deposit's landscape. The waters discharged on the surface are acid and low-acid sulfate and hydrocarbonate-sulfate solutions with a wide cation composition **(Table 1)**. These solutions also participate in the formation of siliceous, sulfate and other deposits on the surface of thermal fields and artificial siliceous sinter deposits when waters are mixed with deep-seated hydrothermae.

Artificial siliceous sinter deposits have stratified structure: the upper 10 cm thick layer is composed of hard "geyserites"; lower down the section, deposits comprise non-homogenous loose or hard bands, include lenses of sand and redeposited dust of geyserites, buried remnants of wood and plants, films of thermophilic microorganism communities (**Figure 2)**. Chemical composition of deposits is not homogenous either both on the strike and in vertical sections **(Table 2)**. Upper layers are noted for higher concentrations of Au, but at large all the strata contain Au, Ag, B and other elements an order higher than the baseline values for hydrothermally-altered rocks of the area.

Figure 2: Layered structure of siliceous sediments. Thickness of layers makes from 0.5 to 10 centimeters. Dense layers alternate with friable.

Distribution of mercury in siliceous sinter deposits is of interest. In general, Hg content does not exceed baseline values for rocks: 0.1 - 0.3 x 10^{-6} % (Rychagov, Stepanov, 1994). But Hg forms high concentrations in deposits directly at the hydrothermal water outflow from wells. A tendency for concentrations to decrease is observed from upper to lower layers and along the strike of the strata **(Table 3)**. Separate relatively high concentrations of Hg in lower layers and at a distance from well can be connected with the presence of an organic matter participating in mercury sorption. For instance, high sorption properties of a peat bed underlying the strata were earlier demonstrated by an example of the full cross-section of siliceous sinter deposits from well R-120 to a depth of 0.9 (Rychagov et al., 2009).

3. CONCLUSION

In this way, vapor and hydrothermal water discharges on the surface of Pauzhetsky, Mutnovsky, Lower-Koshelevsky and other high temperature geothermal deposits of Kamchatka cause precipitation of deposits of opal-tridymite-crystobalite-chalcedony composition (artificial "geyserites"), which fill temporary or constant waterways. A thickness of deposits amount to 1.0 meter, a length - 600-700 m and 5-10 m wide on the average and with a precipitation rate within a range of 2 to 4 cm/year. These deposits are distinctive complex geochemical barriers due to the fact that Au, Ag, Hg, and rare earth metals transported by deep-seated waters towards the surface accumulate and unevenly distribute within them and underlying substrate (Structure…, 1993). Artificial siliceous sinter deposits also participate in alteration of argillized rocks and in precipitation of mineral salts on the surface of geothermal deposits. Formation of extensive strata of these deposits and hardening of rocks occurring in the hypergenesis zone strengthens their water-confining and heat-insulating properties which may lead to alteration of thermodynamic parameters in separate segments of a deposit and to formation of additional solution boiling zones. It obvious that artificial deposits of silica somewhat influence landscape and, at large, formation of the hypergenesis zone of geothermal deposits. Natural silicification of rocks occurring due to precipitation of silica gel in porous volcanogenic-sedimentary rocks in thick boiling zones causes hardening of rocks above zones of ascending fluid fluxes (the central parts of vapor-dominated geothermal deposits) and eventually causes isolation of separate blocks and geothermal reservoirs. Such processes have been confirmed according to the data from exploration and deep drilling at the North-Kurile geothermal deposit (the Paramushir Island).

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Table 1. Chemical composition of thermal waters of Pauzhetsky geothermal deposit

Parameters	VTF-1/05	VhTF-1/05	VhTF-2/05	NTF-1/05	R-121/05	R-103/05
1	2	3	4	5	6	7
pH field	4.6	3.7	3.7	9.4	9.1	9.0
Eh field	152	384	162	-304	-197	-217
T ^{0}C	94.9	83.5	93.1	96.4	91.0	95.0
pH laboratory	5.10	3.75	4.65	7.86	7.30	8.40
Components	Contents, mg/l					
Na^+	14.1	20.00	13.70	76.50	684.2	812.2
K^+	6.60	8.80	2.50	7.20	82.5	109.4
Ca^{2+}	16.03	80.16	4.81	6.41	124.2	104.2
Mg^{2+}	2.43	30.38	21.88	0.36	60.6	17.0
Al^{3+}	0.00	0.00	0.00	0.00	0.7	0.00
Fe^{2+}	0.00	0.15	0.00	0.00	0.00	0.00
Fe^{3+}	0.00	0.00	0.00	0.00	0.00	0.00
NH_4^+	5.40	72.00	120.00	1.70	1.0	0.5
H^+	0.00	0.18	0.00	0.00	0.00	0.00
Sum of cations	***44.56***	***211.52***	***162.89***	***92.18***	***953.2***	***1043.3***
Cl^-	3.55	2.84	3.55	46.09	1436.1	1602.8
SO_4^{2-}	85.49	576.36	21.13	46.11	96.0	76.8
HSO_4^-	0.00	21.53	0.00	0.00	0.00	0.00
HCO_3^-	13.42	0.00	561.36	133.02	42.7	58.6
F^-	0.00	0.00	0.00	0.00	1.7	0.00
Sum of anions	***102.46***	***600.73***	***586.03***	***225.21***	***1576.5***	***1738.2***
H_3BO_3	0.00	2.23	1.11	6.7	163.2	189.2
H_4SiO_4 solut.	144.5	189.50	62.50	190.00	145.0	114.0
H_4SiO_4 colloid.	0.00	16.50	1.00	46.00	250.0	324.4
Mineralization	**291.52**	**1020.48**	**813.53**	**560.09**	**3087.90**	**3409.10**

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 and S.V. Sergeeva). Samples №№ 2-5 – the waters discharging on modern thermal fields (VTF – Vostochno(East-)-Pauzhetsky, VhTF – Verhne(Upper-)-Pauzhetsky, NTF – Nizhne(Lower-)-Pauzhetsky thermal fields); Samples №№ 6,7 – thermal waters from wells drilled in various blocks of Pauzhetsky geothermal deposit.

Table 2. Chemical composition of artificial silica deposition (well R-120, Pauzhetsky geothermal deposit)

Chemical components	R-120 /05-1a	R-120 /05-1b	R-120 /05-1c	R-120 /05-3a	R-120 /05-3b	R-120 /05-3c	R-120 /05-4	R-120 /05-5
	Distance from well, m							
	50	50	50	150	150	150	200	250
	Deep, cm							
	25-40	15-25	0-15	20-25	5-20	0-5	0-10	0-10
	Contents, %							
SiO_2	81,44	87,60	80,06	86,58	86,70	86,72	79,75	86,70
TiO_2	0,17	0,02	0,14	0,002	0,003	0,001	0,14	0,02
Al_2O_3	4,29	1,52	5,09	0,94	1,08	1,90	3,55	1,47
Fe_2O_3	1,11	0,0	0,0	0,0	0,0	0,0	0,0	0,0
FeO	1,15	0,88	1,52	1,15	0,66	0,60	1,52	0,50
MnO	0,16	0,15	0,15	0,14	0,15	0,14	0,14	0,14
MgO	0,67	0,08	0,52	0,05	0,05	0,06	0,33	0,09
CaO	1,51	0,62	1,62	0,42	0,61	0,59	1,30	0,59
Na_2O	0,73	0,56	0,94	0,27	0,59	0,50	0,84	0,62
K_2O	0,38	0,24	0,59	0,12	0,14	0,28	0,33	0,24
H_2O^-	2,98	3,32	3,03	4,55	4,12	3,68	4,42	3,34
loss	5,43	4,78	5,91	5,51	5,56	5,45	7,44	6,53
Total	100,02	99,77	99,57	99,74	99,66	99,93	99,79	100,25
Au, g/t	0,026	0,062	0,057	0,0034	0,0057	0,042	0,024	0,008
Ag, 10^{-3}%	0,4	0,4	0,3	0,015	0,04	0,2	0,2	0,05
B, %	0,2	0,3	0,15	0,8	0,5	0,2	0,3	0,5

The note. Definition of full chemical silica deposition compound is executed in Analytical Center of Institute of Volcanology and Seismology FED RAS, analyst V.V. Dunin-Barkovskaya; Au, Ag and B – in Institute of Geochemistry SD RAS, analysts G.I. Scherbakova and N.E. Smolaynskay

Table 3. The distribution of mercury in silica deposition (well R-120, Pauzhetsky geothermal deposit)

Samples number	R-120-1/04-1	R-120-1/04-2	R-120-1/04-3	R-120-1/04-4	R-120-2/04-1	R-120-3/04-1	R-120-4/04-1	R-120-4/04-2
Distance from well, m	20	20	20	20	70	120	170	170
Depth, cm	0-5	5-15	15-25	25-30	0-5	0-5	0-5	5-20
Hg, n x 10^{-7} %	**420,0**	**110,0**	**53,0**	**14,0**	**19,0**	**3,6**	**5,2**	**79,0**

The note. Definition of Hg is executed in Analytical Center of Institute of Volcanology and Seismology FED RAS. Analyst Dr. I.I. Stepanov.