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Technology of Developing a Man-Made Deposit of Rare Elements at High Temperatures

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Abstract: Today, it is critical to develop a technology of man-made deposit development at high temperatures to produce various valuable components. The study presents the results of research of a rhenium deposit at Kudriavy volcano expressed as the layout of geothermal fields on the top of the volcano and a deposit development process chart as well as new determination of a man-made deposit. The obtained results may further contribute to the development of the mining industry as well as to gaining valuable raw materials which could help various Russian industries develop.

Key words: Rhenium deposit, fumarole fields, development process, electrothermal destruction, mining, industry

INTRODUCTION

Development of deposits of rare elements is an important way for the development of a modern society which will contribute to emergence of new technologies but using them requires a special approach (Kaerbek and Kholodjakov, 2016; Kholodnyakov and Argimbayev, 2014).

Rhenium deposit is one of such deposits. This is an extremely rare metal. In natural deposits, tungsten-rhenium-molybdenum is the most common combination. Also, rhenium is contained in columbite (niobium), firestone, zircon and some rare-earth minerals. Rhenium is dispersed worldwide in negligible concentrations.

Rhenium is used in those industries where no other raw material can replace it. The main form of the application is numerous alloys. Due to its unique heat resistance, it is highly demanded in space technology, production of aircraft and missiles in the nuclear industry, where temperatures reach 3,000°C. Rhenium is also used for making special contact points. They have the property of self-cleaning in case of a short closing. Oxide is left on the surface of conventional metals which prevents the current from passing. Current also passes through rhenium alloys but it leaves no traces behind. Due to this fact, the contact points, made of this metal have a longer service life. Rhenium is used in nuclear medicine to diagnose and treat serious diseases. Rhenium-188 deserves special attention. Rhenium-187, the radioactive isotope is used to determine the age of rocks (Znamensky *et al*., 2005; Loganina *et al*., 2016; Pikalov *et al*., 2016).

The scope of use of rhenium is pretty wide and diverse. Due to its unique properties, this metal is highly demanded worldwide (Argimbaev and Kholodjakov, 2013, 2016; Sarma, 2012; Burmistrov *et al*., 2017).

Supply of this metal to industries is the critical task at the moment. The need for it may be reduced by formation of and involvement in the development of man-made deposits.

MATERIALS AND METHODS

The object of research is the rhenium deposit at Iturup island, Kudriavy volcano which can be attributed to a promising man-made deposit. This deposit is unique in its kind because rhenium, being a quite valuable metal is produced in the form of gas fumes on fumarole fields. In total, there are 6 fields like that on the volcano: “Rhenium” field, “Anhydrite” field, field-605, “Crack” field, “Saddle” field, “Dome” field and “Molybdenum” field. This mineral is formed and produced at geothermal fields at temperatures ranging from 300-900°C (rarely more than 1,000°C).

At the summit of Kudriavy volcano, the elements of four craters and explosion funnel of different age, structure and fumarole activity are highlighted by geological and morphological features.

Crater 1 is the largest (with the diameter of 260 m) and the oldest (it forms the bottom rock mass) one which is presented by the fragment of somma in the center of the summit part of Kudriavy volcano. Spatially it limits all high-temperature platforms of the Kudriavy volcano. Its somma is formed by interbedding of andesite-basalt and

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andesitic lavas and agglomerates, heavily modified by solfataric and fumarole activity. The remainder of the crater has been destroyed by later eruptions.

Crater 2 is laid over the first crater and is located in the Eastern part of the volcano. By its outlines, it is close to the correct circumference (with the diameter of 170 m on the top of the somma), opened to the East. Somma is formed by viscous andesitic lavas (average thickness) with inclusions and veinlets of cordierite glass. Andesitic extrusion is located inside the crater ("Hot Dome") which occupies more than half of the crater area. About 3 fumarole platforms with high-temperature gases coincide with it which received their own names (in brackets: area, m^2; medium/maximum temperature, °C): "Crack" (322; 528/750), "Dome" (980; 620/920;) "Saddle" (106; 566/723). The fourth platform "Field-605" (396; 586/784) coincides with the upper edge of the somma. The lower parts of relief are filled with crater and lacustrine sediments, formed by erosion (substantially wind erosion) of the surrounding hills and temporary streams, occurred due to the melting of snow and heavy downpours. Lowering to the West of the extrusion dome is heated enough (52°C at a depth of 5 cm). With the deepening of 1.5 m, the temperature rises up to 96°C and is accompanied by intensive emission of sulfurous gases. Perhaps, sandy and argillaceous sediments are a barrier for gas jets and form a casing, preventing the volcanic gas dispersal and directing its movement to "Rhenium Field". In other lowerings during pit sinking (up to 2 m), the rise of temperature was not recorded. Probably, these lowerings are the traces of major explosion funnels, formed around the "Hot Dome", similar to the funnel of October 1999 but later filled with tephra and sediments of water streams.

Crater 3 with the diameter of 80 m is located to the West from the first crater and laid over the somma of Crater 1 of Kudriavy volcano. Its formation is due to poor eruptive activity and introduction of small boss-shaped body of andesites, now fully recycled by high-temperature gas streams. Somma of Crater 3 practically has not survived and its location is reconstructed partially. There are three fumarole platforms in its western part (in brackets: area, m^2; medium/maximum temperature, °C): "Rhenium Field" (1,048; 481/620) has a size of approximately 50-20 m and is located on the steep inner slope of the old crater in the middle of the elongated summit. The walls of the crater are made of lava and pyroclastic formations, represented by olivine-pyroxene basaltic andesites. The rhenium field is constantly covered by clouds of dense fumes. Temperatures of fumaroles increase by 300 to 550-600°C from the Northwestern part to the Southeastern part of the field

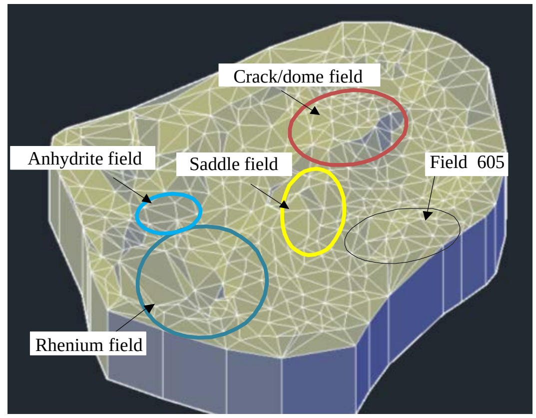

Fig. 1: Fields layout

where at night in some places, the red glow can be observed. Rocks at the fumarole field are heavily changed and covered with a crust, made primarily of sulphates and are impregnated by sulphur along its edges; "Anhydrite Field" (140; 280/360) (Fig. 1).

Crater 4 spatially limits the spread of low-temperature fumaroles and has the shape of an ellipse, open to the North. Three last lava flows in the Northern, Southern and Southwestern directions (top part) effused from it as well as andesite-basaltic slags were thrown, covering all formations of the Kudriavy volcano. Here also are several isolated areas with fumaroles, the gases of which mainly have the temperature of 98-120°C (up to 210°C) and deposit sulphur intensively. However, in some areas, the gas temperature exceeds the melting point of sulphur.

Crater 5 was formed by the eruption, occurred on October 7-8, 1999 which began as phreatic (according to Steinberg). Later, Znamensky reported on lava observed at the bottom of the crater during the second half of October. Crater 5 is the explosion funnel with the depth from 15-40 m with the diameter of top circumference of about 15 m and almost vertical walls. Funnel "cut off" the part of the crest of the Crater 2 and uncovered the part of the "Hot Dome" extrusion exocontact. The gases were ejected from a hole in the heated (to red glow) rocks at its bottom. Although, all high-temperature fumarole platforms are located within the radius of 200 m from the funnel, its explosion did not affect the mode of its degassing to an extent noticeable visually whereas the extinct one of fumarole-dacitic dome has intensified.

All rocks of the volcano are divided into three uneven-aged rock masses. The lower rock mass consists of numerous block lava flows of andesite-basalt and andesite composition, uncovered on the periphery of the volcano and separated from each other by breccia

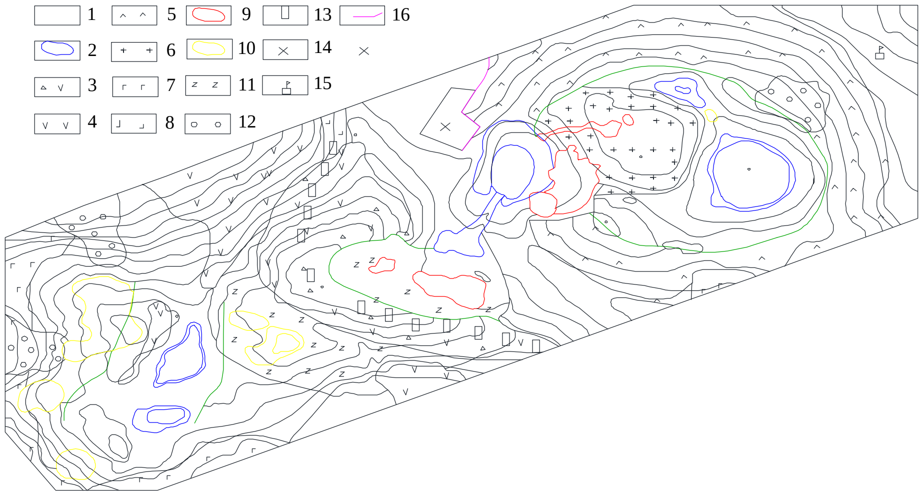

Fig. 2: The geological pattern of the apex part of the Kudriavy volcano: 1-2 - present sediments including diluvial; 1) Crater and lacustrine sediments; 2) 3-6-Holocene volcanic formations including slags and agglomerates; 3) Lava and agglomerates; 4) Crater 4; covering lava; 5) The extrusive dome; 6) Crater 2, andesites; 7) Andesite-basalts; 8) Crater 1; 9-high-temperature fumarole platforms; 10) Areas of spread of low-temperature fumaroles; 11) argillization zones; 12) Areas of spread of ingrained sulfur ores; 13) Edge of the craters; 14) Geological facial and boundaries; 15) Upper field camp; 16) Edges of steep side hills and 17) Japanese sulphur mine

covers. The effusion of lava flows occurred mainly in the Westerly direction; the Eastward spread of lava was limited by construction of the rhyolitic dome and Srednyi volcano. The surface of lava flows is covered with prostrate shrub, alder, birch, especially, at elevations <350 m. After formation of this rock mass, Kudriavy volcano, apparently was relatively inactive. Talus breccia was formed on the Southern and Northern side-hills with the layers of tuffs and organics. We described the section of the sediments at the bottom of this lower rock mass in a dry log between the extrusion body and the lava flow of the last eruption on the Northern side hill of Kudriavy volcano.

The lens, formed by the interlaying of loams with peat bogs, lays on the Southern side hill of Kudriavy volcano. There are 5 interlayers of peat bogs with a capacity of 3-4 cm. The radiocarbon age of the second peat bog is 4.450±100 years. Therefore, the age of the lower complex of the Kudriavy volcano may exceed 5,000 years (Fig. 2).

RESULTS AND DISCUSSION

Given the various complexities, associated with mining and geological conditions, climate, high temperatures and many other factors, we have proposed the technology of development which includes: preliminary layer-by-layer ripping by the electroheat installation as well as re-ripping by the ripper at a given depth, after the rock mass excavation, the operating equipment is replaced by a capacity, allowing to lay the absorber along the entire area with the purpose of saturation with useful component (Argimbayev *et al*., 2016; Argimbaev and Alexandrovich, 2016; Filatov *et al*., 2015; Gavrishev *et al*., 2016; Argimbaev, 2016) (Fig. 3).

The development technology is that an artificial rock mass of absorbent material is formed after the extraction of the overburden rocks using special extraction-and-loading equipment which will hold inside the rhenium particles with fumarole gases. This artificial rock mass is mined and the new material laying is made. In this way, the man-made deposit is created.

Currently, there are many definitions which characterize the man-made deposit and all of them have the common feature-accumulation of mineral raw materials or minerals formed in the course of various productions.

All definitions of man-made deposit do not take into account the fact of the valueless addition of useful properties to the material. Given this fact, it is possible to make a new definition.

Man-made deposit is a deposit, created or formed as a result of the development of the technology is the result of various production technologies, containing raw materials with included or added useful components, properties as well as being valuable.

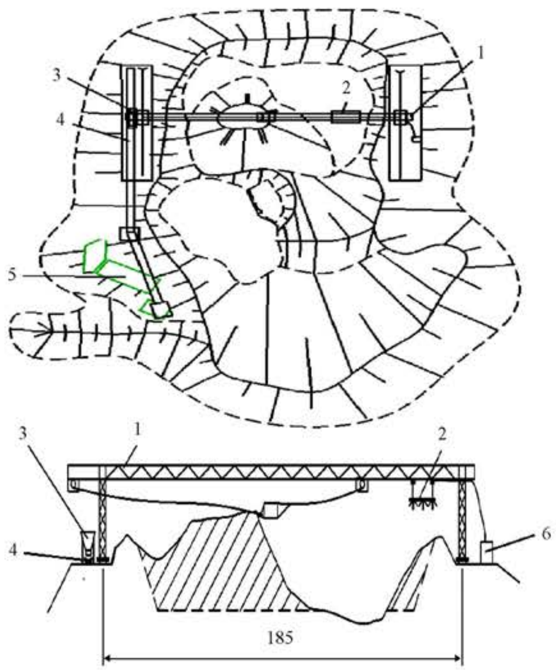

Fig. 3: The process diagram of development of the mineral deposit using new extraction-and-loading equipment: 1: Upgraded scraper with overhead electroheat installation; 2: Electroheat installation; 3: Mobile bunker; 4: Conveyor; 5: Working site with rock re-handling and 6: Power generator

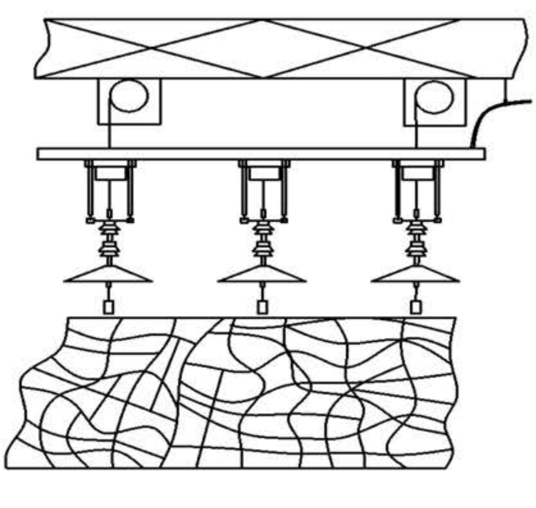

Fig. 4: Operating body of the electroheat installation

A complex of extraction and ripper equipment includes two connected kinematic scraper winches and electroheat installation (Fig. 4).

Winches are installed on the overhead crane, moving along the wide gauge rails with their location on opposite sides of the volcano. Winches are equipped with a scrapper bucket with the capacity of 2-4 m^3 and if necessary with a ripper. Its simultaneous movement is done in opposite directions. The winch design enables receiving and unloading the excavated rock mass into a mobile bunker, located on the side slope of the volcano.

The electrothermal method of destruction of rocks is based on creating an uneven temperature distribution in its volume. As a result, a solid operating body, destroying the rock is created. Various energy sources can be used: super-high-frequency radiation, high and utility frequency current, infrared radiation and corpuscular rays (Fig. 5).

The electric methods of destruction of rocks can be classified by the aggregate state of the operating body into the electrothermal, electrodynamic and combined ones. The feature of favorably distinguishing installation, using the electrical method of destruction is the ease of the actuating device through which the energy is supplied to the rock.

In all described methods, the destruction of rocks occurs due to the inside creation of temperature differences by the solid operating body. An operating body gives up some of its heat to the surrounding rocks and the atmosphere. Energy losses are proportional to the time. As a result, the energy intensity of the destruction process should be the more, the more time of the destruction, that is, the lower the performance.

The process of destruction can be analyzed by consideration of the term reflecting the energy costs to form the new surface:

$$Pt = A_p + \int_{T_0}^{T_K} m_1 \cdot C_{v_1} \cdot dT + q_1 \cdot m_1 + \int_{v}^{t} \lambda_1 \cdot S_1 \cdot \frac{dT_1}{dR} \cdot dt + \omega_1 + \omega_2 + \omega_3 \quad (1)$$

Where:

- Pt = Energy supplied from the source
- A_p = Work on formation of the new surface
- $\int_{T_0}^{T_K} m_1 \cdot C_{v_1} \cdot dT$ = Energy for heating of the operating body
- q_i, m_i = Energy for phase transitions
- $\int_{v}^{t} \lambda_1 \cdot S_1 \cdot \frac{dT_1}{dR} \cdot dt$ = Energy transmitted by the operating body to the surrounding rock due to thermal conductivity
- ω_1 = Energy for heating of the operating body
- ω_2 = Energy transmitted by the operating body to the atmosphere
- ω_3 = Energy, lost by the operating body due to loss of its mass
- m_1 = Mass of the operating body

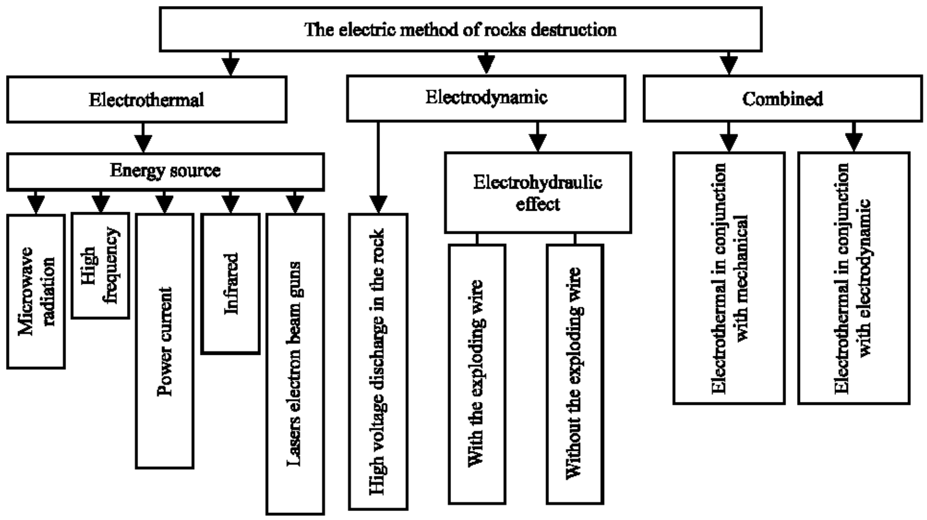

Fig. 5: Classification of electrical methods of destruction of rocks

C_{vi} = Heat capacity of the operating body, averaged by aggregate states
S_1 = The inner surface of the operating body
λ_1 = Ratio of thermal conductivity of rocks
q_1 = Specific heat of phase transitions
dT_1/dR = Gradient of temperature in the rock

It can be seen from the above expression that reduction of the energy intensity of destruction and increase of its efficiency ratio can be done by reducing the volume of the operating body, hence, its mass and the side surface as well as by the reduction of the time of energy input into it. It should be noted that the energy transmitted to the rock due to thermal conductivity used for heating of the operating body and transmitted from it to the atmosphere can be reduced almost to zero and the energy used for heating of the operating body and phase transitions should be maintained at a certain level because the pressure put by the operating body upon the rock is proportional to the energy put thereupon. Reduction of the operating body's mass will reduce its surface which is a component of the rock surface. Therefore, if we want the force generated by the operating body not to change, it is necessary to increase its temperature. This can be done by concentrating the energy in the limited volume of the rock, using high-voltage discharge. Other methods of destruction of rocks by highly concentrated energy flows (such as electron beam or laser destruction) do not provide sufficient temperatures to destruct large amounts of rocks within microsecond periods.

Creating conditions for destruction of rocks within small periods of time causes from the technological point of view, two positive effects at once: reduced energy intensity by reducing losses and increased productivity by reducing the destruction time. The temperature of rocks in the volcano crater is close to the temperature range of destruction. This allows providing an insight into what electric method will be the most efficient one.

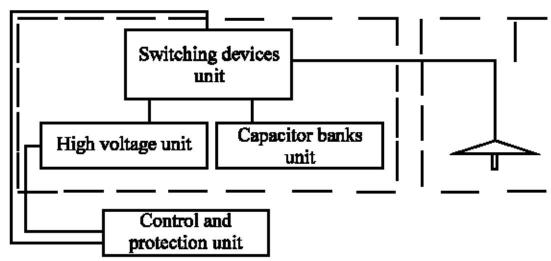

Fig. 6: The flowchart of installation of the electric rock destruction method

Therefore, the circuit diagram of the installation of rocks destruction should consist of high-voltage power circuits, control and protection circuits (Fig. 6).

High-voltage circuit of the installation includes the high-voltage transformer, rectifier, capacitor bank, switching devices and the actuating device. Low voltage circuit is the circuit diagram which provides automatic and operator control mode. The installation is equipped with the block system which prevents overloads of the electrical equipment and means of protection of the staff from possible flying of small pieces of rock.

Rock crushing units using the utility frequency current are simple in design and cheap. Voltage, at which a breakdown takes place, depends on the conditions of experience, rock properties and characteristics of voltage source.

Study of efficiency of the electrical method requires research of the breakdown in rocks of large thicknesses in the electric field with the frequency of 50 Hz at this rhenium deposit; current-voltage characteristics of rocks of large thicknesses; dependence of the breakdown voltage on the distance between electrodes on the resistance of the rocks as well as on the time of the breakdown and its dispersion.

CONCLUSION

The study of rhenium deposit at the Kudriavy volcano found the areas with the highest fumarole activity. The layout of these areas on the volcano has been modeled based on the data of underground surveying which contributed to the emergence of the new technology of development of unconventional deposit under the conditions of high temperatures using electrothermal destruction of rocks, new extraction and loading equipment which, unlike traditional ones can withstand high temperatures, sometimes exceeding 1,000°C. Electrothermal destruction of rocks under such conditions will be functioning quite well as the temperature of the rocks on the fumarole fields is close to the destruction range. A new definition of a man-made deposit was proposed, the technology of open development of the man-made deposit located on the volcano was developed. These results will allow the Russian Federation to get own rare-earth metals and new alloys which would give us the chance to enter a new stage of development of modern society in general and will be the basis for the Russian mining industry to make some progress.

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