THERMAL POWER OF HYDROTHERMAL SYSTEMS AND ACTIVE VOLCANOES

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Abstract

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THERMAL POWER OF HYDROTHERMAL SYSTEMS AND ACTIVE VOLCANOES

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The thermal effect of active volcanism and hydrothermal systems existing in regions of present-day intensive volcanic activity is realized mainly through convective heat transfer. Molecular thermal conductivity is of strictly subordinate importance. The motion of a deep-seated heat carrier is determined by the structure of the enclosing medium. It is advisable to consider the heat flow of a hydrothermal system together with elements of the geological structure that are in paragenetic connection with the source of deep heat.

The development of volcano-tectonic depressions, and of ring-shaped caldera subsidence structures in plan, is the result of processes apparently initiated by large stocks of upper-mantle material and magmatic chambers intruded into the Earth' s crust.

Table 1

Location of thermal anomaly	Total thermal power, 10^3 kcal/sec	Area, km^2	Specific heat flow, $kcal/km^2 \cdot sec$
B. Semyachik, Kamchatka	75	85	880
Uzon–Geyzernaya, Kamchatka	139	160	870
Taupo–Wairakei–Waiotapu, New Zealand	770 [10]	1100 [8]	700
Beppu, Japan	19 [10]	25 [12]	760
Torfajökull, Iceland	500 [10]	700 [6,9]	700

Location of thermal anomaly	Total thermal power, 10^3 kcal/sec	Area, km^2	Specific heat flow, $kcal/km^2 \cdot sec$
Hengill, Iceland	55–80 [10]	80 [6,9]	700–1000
Ahuachapán, Salvador	80 [5]	80 [7]	1000

As a rough approximation, we shall assume that the area of the ring structure (caldera) corresponds to the area of the generation center of deep heat; that is, we shall assume a vertical arrangement of weakened zones of tectonic faults associated with the formation of the given structure. Then the total natural thermal power of a number of local thermal manifestations located within the ring structure, referred to its area, may be regarded as an energy characteristic of the generation center. It is assumed here that the hydrothermal system is in a regime of quasi-stationary heat flow.

Table 1 compares the specific heat flows of several hydrothermal systems; by the area of a thermal anomaly is meant the area distinguished as a structural geological unit.

The data in the table show that for young thermal anomalies, whose lifetime amounts to tens and the first hundreds of thousands of years, the power of heat supply is practically the same and on average equals 800 $kcal/km^2 \cdot sec$. As the activity of the heat-generation center dies down, the specific thermal power of the thermal anomaly correspondingly decreases.

Thus, for example, for the Nalachevo thermal anomaly (Kamchatka), which has existed for about 10^7 years, the thermal power is about 10 $kcal/km^2 \cdot s$, i.e., it is of the same order of magnitude as the regional heat flow.

Let us now compare the specific power of hydrothermal systems with the average power of active volcanic edifices, making use of the fact that the main share of the energy of volcanic eruptions (80–95%) is accounted for by the heat carried by eruption products ([11]).

The age of the cone of the active Karymsky volcano (eastern Kamchatka), determined by the radiocarbon method, is about 7000 years (communication from B. V. Ivanov). The volume of the cone is 3.35 km^3. Let us take the average density of the material composing the cone as 2.4 g/cm^3, and the heat content of volcanic products as 360 cal/g. The cone is situated in a caldera whose area is 20 km^2. The explosivity coefficient for the volcanoes of Kamchatka is 50–60% ([3]); however, a considerable part of the pyroclastic material falls on the cone. It may be assumed that during formation of the cone, from 20 to 40% of the solid material was ejected beyond the caldera as a result of explosive eruptions. After calculation we obtain that the average thermal power of Karymsky volcano, referred to the area of its caldera, is 750–1000 kcal/km$^2 \cdot$ s.

The specific thermal power for Krenitsyn Peak, located in the Tao-Rusyr caldera, Onekotan Island, ranges from 520 to 700 kcal/km$^2 \cdot$ s. (The area of the caldera is 42 km^2, the volume of the cone 4.4 km^3, and its age 7000 years ([2]).)

The area of the volcano-tectonic depression of the Khukhaitup–Ostraya volcanoes (Sredinny Range, Kamchatka) is 1500 km^2, and the volume of basalts erupted over the last $1.5 \cdot 10^4$ years is 600 km^3. For the Sedankinsky volcanic region of the Sredinny Range, the area of the depression is 1000 km^2, the volume of basalts 250 km^3, and the time of formation of the volcanic edifices 10^4 years ([1]).

Taking the average density of the erupted rocks as 2.5 g/cm^3, and their heat content as 400 cal/g, we obtain an average thermal power, referred to the areas of the Khukhaitup–Ostraya and Sedankinsky depressions, of 850 and 800 kcal/km$^2 \cdot$ s, respectively.

A calculation of the total area occupied by 28 active volcanoes of Kamchatka gives $4 \cdot 10^3$ km^2. Taking the specific power of active volcanism to be 800 kcal/km$^2 \cdot$ s, we obtain the average intensity of losses of deep heat for the entire zone of active volcanism of Kamchatka through volcanic edifices as $3.2 \cdot 10^6$ kcal/s. This value, in order of magnitude, agrees with the result obtained in ([5]), $5.4 \cdot 10^6$ kcal/s.

A comparison of the data presented makes it possible to conclude that, in an energetic sense, modern hydrothermal systems in regions of active volcanism and the active volcanic edifices of central volcanoes are equivalent, despite the extraordinary diversity of forms in which volcanic activity is manifested.

The close values of specific thermal power for modern hydrothermal systems and volcanic edifices indicate the commonality of the processes underlying volcanic activity.

The established magnitude of the specific power of active volcanism makes it possible to make quantitative estimates of certain volcanic phenomena.

Paroxysmal eruptions of Shiveluch volcano (Kamchatka) occurred in the Holocene, on average, once every 150 years, and during each eruption 10^9–10^{10} tons of material were ejected ([4]). Taking a heat-flow value of 800 kcal/km$^2 \cdot$ s, we obtain an area of the heat-generation focus of 400 km^2, which corresponds to a magmatic body 22 km in diameter. The validity of this estimate will be shown by geophysical measurements, if such are carried out in the future.

Avachinsky volcano: the diameter of the magma chamber, determined by geophysical methods, is 6 km; the area of the horizontal projection of the chamber is 30 km^2. With a specific power of 800 kcal/km$^2 \cdot$ sec, we obtain a heat flux supplying the volcano of 24,000 kcal/sec. Through the fumaroles of the crater, 18,000 kcal/sec is discharged [5]. Consequently, about 6000 kcal/sec accumulates in the volcano. The last eruption of the volcano occurred in 1945. It may be expected that the thermal effect of a future eruption, if it occurs, for example, in 1970, will amount to $5 \cdot 10^{12}$ kcal ($2 \cdot 10^{23}$ ergs). Such a thermal effect corresponds to the effusion of a lava flow 3 km long, 150 m wide, and 10 m thick.

Proceeding from an average specific thermal power of 800 kcal/km$^2 \cdot$ sec, it is also possible to predict in advance the magnitude of the natural thermal discharge of some hydrothermal systems. For example, for the Golovnin caldera on Kunashir Island, calculations give a heat flux on the order of $10\,000 \pm 2000$ kcal/sec (caldera area 12 km^2). The results of actual measurements in the Golovnin caldera, which will be carried out in the near future, will be the subject of a subsequent communication.

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Note: Figure translations are in progress. See original paper for figures.