ON THE GEOENERGETIC SIGNIFICANCE OF GEOCHEMICAL PROCESSES

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Abstract

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ON THE GEOENERGETIC SIGNIFICANCE OF GEOCHEMICAL PROCESSES

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In the course of the evolution of the Earth' s crust, the rocks composing it are constantly subjected to various physicochemical transformations having one or another energetic effect, the accounting of which may to some extent supplement the available information on the heat balance in different parts of the Earth' s crust. A correct assessment of the fundamental role of geochemical transformations in geoenergetics is also necessary because among geologists, despite the convincing criticism by D. S. Korzhinskii (^1), notions are still alive ([2-]4) according to which these transformations constitute the main driving force of deep-seated processes, transforming into heat the solar energy absorbed by the crystalline substance of the Earth during the weathering of aluminosilicates. In reality, however, the thermal effects of geochemical transformations cannot contradict the Le Chatelier principle, according to which reactions occurring under conditions of decreasing temperatures proceed with the release of heat, and vice versa.

The physicochemical changes in the substance of the Earth' s crust that take place at the stages of its transformation from bottom sediment to consolidated and recrystallized rocks of the deepest stages of metamorphism may be conventionally expressed by more or less simple chemical equations. This makes it possible, by determining the sign and quantitatively estimating the thermal effects of individual reactions, to characterize the energetic effect of geochemical processes.

The thermal effect of any geochemical reaction

$$\sum_i n_i M_i \to \sum_j n_j M_j$$

is described by the equation for the change in enthalpy

$$\Delta H^0_{298} = \sum_j n_j (H^0_{298})_j - \sum_i n_i (H^0_{298})_i,$$

where $(H^0_{298})_{i \text{ and } j}$ is the standard enthalpy of formation of the minerals.

Comparison of calculated reaction enthalpies under standard and natural temperature conditions has shown that the use of standard data makes it possible, with sufficient accuracy, to judge the magnitudes of the thermal effects of reactions occurring in the Earth' s crust at higher temperatures.

By this method the specific thermal effect of a number of hypergene, epigenetic, metamorphic, and metasomatic reactions has been estimated*. Knowing the mass of the rock being altered and the time over which the reaction takes place, it is easy to pass from the specific thermal effect to determining the amount of heat released through the realization of the process in one or another block of the Earth' s crust, i.e., to approach an estimate of the contribution of this process to the regional and planetary heat balance.

The averaged results of determining the thermal effects of the most important geochemical reactions and the amount of heat released or

* The values of the standard enthalpies were taken from the data of (ˆ5).

absorbed in the course of their realization under real conditions, are summarized in Table 1.

Among hypergene processes, oxidation reactions have the greatest specific thermal effect; under favorable conditions and at high rates of realization, they can create thermal anomalies similar to Yangan-Tau [(6)]. Widespread hypergene reactions of destruction of minerals and rocks, formed under conditions of elevated temperatures and pressures, proceed, as a rule, with the release of small amounts of heat. At the same time, the leaching of rock salt and certain other processes are endothermic in character.

Table 1

Thermal effect of geochemical processes

Stage of transformation of the substance of the Earth' s crust	Nature of the processes of physicochemical transformation of matter	Specific thermal effect of geochemical and metamorphic reactions, cal/g*	Amount of thermal energy released during realization of the process under real conditions, $cal/cm^2 \cdot s$
Hypergenesis	Oxidation		
Hypergenesis	Organic matter	−5000	$\leq -4 \cdot 10^{-5}$
Hypergenesis	Sulfides	−2000	$\leq -10^{-5}$
Hypergenesis	Decomposition of minerals, kaolinization	−(20—50)	-10^{-9}
Hypergenesis	Leaching		

Stage of transformation of the substance of the Earth' s crust	Nature of the processes of physicochemical transformation of matter	Specific thermal effect of geochemical and metamorphic reactions, cal/g*	Amount of thermal energy released during realization of the process under real conditions, cal/cm^2 • s
Hypergenesis	Limestones, gypsum	−(2—30)	-10^{-8}
Hypergenesis	Rock salt	+15	$+(3—4) \cdot 10^{-7}$
Epigenesis	Dissolution crystallization	±(2—30)	$\pm 10^{-9}$
Epigenesis	Hydration dehydration	±20	$\pm 10^{-9}$
Metamorphism	Regional progressive metamorphism	+(50—220)	$+(10^{-7} \div 10^{-6})$
Metamorphism	Contact progressive metamorphism		
Metamorphism	Siliceous limestones	+(50—160)	$+(10^{-7} \div 10^{-6})$
Metamorphism	Autometamorphism		
Metamorphism	Serpentinization	−(50—120)	-10^{-6}
Metamorphism	Crystallization of glasses	−(25—65)	-10^{-6}
Metamorphism	Metasomatism, greisenization	−500**(?)	-10^{-5}(?)
Metamorphism	Hydrothermal metamorphism (zeolitization, anorthitization, albitization, sericitization)	−(30—110)	-10^{-5}

* The minus sign characterizes an exothermic process; the plus sign, an endothermic one.
** According to [9].

At the stage of epigenesis, geochemical transformations are characterized by the local development of a number of reversible processes (dissolution—crystallization, hydration—dehydration). Depending on the shift of equilibrium in one direction or another, these processes have small exothermic as well as endothermic effects.

Metamorphic processes, which lead to the deepest transformations of rocks, require significant amounts of energy for their realization. A study of 20 metamorphic reactions (mainly links of progressive metamorphism of siliceous limestones) for all distinguished metamorphic facies showed that their thermal effect varies from +50 to +220 cal/g, averaging +125 cal/g. With a duration of regional metamorphism of 10^6—10^7 years, and of contact metamorphism of 10^4—10^5 years, the time-averaged thermal effect of regional metamorphism of a kilometer-thick rock sequence or of contact transformations in a layer 100 m thick should amount to $(0.1 \div 1.0) \cdot 10^{-6}$ cal/cm$^2 \cdot$ s, i.e., heat absorption in these processes may be commensurate with the magnitude of the conductive flux of deep heat.

Autometamorphic transformations of cooling magmatic rocks are accompanied by the release of heat. Thus, the average value of exothermi-

···of the thermal effect of serpentinization reactions is 75 cal/g. The involvement in this process of a mass of ultrabasic rocks with a volume of 1 km^3 will lead to the release of $2.3 \cdot 10^{17}$ cal of heat. Some researchers ([7]) believe that this process may be responsible for the established increase in heat flow on mid-ocean ridges. The process of crystallization of glasses that are part of ignimbrites and other effusive rocks is also exothermic and autometamorphic.

The majority of metasomatic processes (skarn formation, greisenization ([8])), which begin against the background of a rise in geoisotherms serving as the impetus for the development of these processes, are also characterized by a total exothermic effect; subsequently they proceed under conditions of decreasing temperatures and the introduction of acidic, and then alkaline, solutions. The specific thermal effects of these processes may be very large (up to 500 cal/g ([9])?), but the comparatively limited areas over which they develop do not allow them to exert a substantial influence on the regional thermal regime of the subsurface.

A considerable exothermic effect is also characteristic of the processes of hydrothermal metamorphism ([10]) taking place in the near-surface zone. In this zone, ascending hydrothermal solutions are influenced by the surrounding rocks and, in striving to counteract the decrease in temperature, metasomatically replace magmatic minerals by hydrothermal ones. On average, the specific thermal effect of such reactions (anorthitization, albitization, sericitization, zeolitization) is 50-80 cal/g. At the Pauzhetka deposit, the amount of heat released as a result of hydrothermal metamorphism processes ($2.4 \cdot 10^{-5}$ cal/cm$^2 \cdot$ sec) amounts to 20% of the observed thermal power. This value is close to A. J. Ellis' s data ([11]) on heat release during hydrothermal alteration of rocks in the Wairakei area.

Considering the specific thermal effects of various geochemical reactions, one may conclude that, for the most part (with the exception of oxidation processes), they have one and the same order of magnitude and are commensurable with one another. The geoenergetic effect of various natural reactions, however, is determined by the rate of their realization, which is very small and is perceptible only on the scale of geological time.

Thus, the energetic effect of the overwhelming majority of geochemical processes is considerably less than the conductive heat flow ([12]), and they cannot be the principal source of deep heat. Exceptions are individual local processes that create a stressed thermal regime in the places where they occur. In general, however, geochemical processes lead only to the transformation of internal terrestrial energy from one form into another and to its redistribution among different zones of the Earth. These processes in fact do not change the planet-wide ratio between the input and expenditure of deep energy, thus occupying a position between its primary sources and modes of expenditure; but in the geoenergetic balance of individual areas they may act as significant components of it.

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