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Discussion Forum

Experimental and theoretical data show that the main source of the earth's energy, which is the prime cause of endogenic and tectonic processes, is fusion reactions that take place in the planet's inner core, which consists of metal hydrides. The authors hypothesize that there exist deep-seated hydrogen fluids (plumes) that propagate from the earth's core and transfer to the surface the thermal energy of nuclear reactions. These hydrogen fluids, owing to the Earth's rotation and the Coriolis acceleration, spiral in the outer liquid electroconductive core of the earth, inducing the dipole magnetic field.

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Fusion Reactions As the Main Source of the Earth's Internal Energy

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For many millennia, people have observed with superstitious fear volcanic eruptions, earthquakes, and other menacing phenomena that come from the earth's interior. Naturally, the cause of these phenomena has been sought in religion and myths. Only at the end of the 18th century did P.-S. de Laplace propose a scientific explanation of the earth's internal energy on the basis of his hypothesis that the Earth had once been a liquid spheroid in a molten state. Then it was covered with a hard crust as it cooled down, and now it is gradually cooling down and generating heat. The famous physicists and meteorologists of the 18th century, J.-J. D'Ortous de Mairan, G. de Buffon, and J.S. Bailly, considered the earth's internal heat the main factor that affected climatic and meteorological phenomena. These ideas reigned in science until the beginning of the 19th century. It was the physicist and mathematician C. Fourier who proved that the heat that comes from the depths of the planet is insignificant compared to the energy received from the Sun and cannot be manifested in meteorological and climatic phenomena. However, the nature of this heat remained a mystery until the phenomenon of radioactive decay of a number of elements was discovered at the beginning of the 20th century, and, importantly, the earth's crust contained these elements. This discovery, finally, made it possible to find a clear physical explanation of the source of the earth's internal energy.

Many experimental research works performed over the past 100 years have made it possible to update the physicochemical parameters of the earth's inner volume. A number of the results of recent investigations agree poorly or do not agree at all with the accepted theory of the radioactive nature of the earth's internal energy. Therefore, it is necessary to return to this problem.

THE EARTH'S INTERNAL HEAT: ESTIMATIONS AND EXPERIMENTAL MEASUREMENTS

In order to analyze the observed geophysical and geological phenomena, it is crucial to know the nature and amount of energy that emanates from the Earth's interior regions. According to recent data, the temperature gradient (for several-kilometer depths) is $dT/dr = 0.025–0.03$ grad./m (i.e., the temperature grows, according to different estimates, by approximately 25–30°C with each kilometer deeper into the earth's crust). Obviously, the value of the heat flow through the entire surface of the earth will be

$$F = dT/dr\chi 4\pi R^2, \qquad (1)$$

where χ is the thermal conductivity of the earth's crust (for its upper layers, the value of the thermal conductivity coefficient for basalt is $\chi = 2$ J/(m s grad)), and $4\pi R^2$ is the area of the earth's surface.

The calculation yields a value of $F \approx (2.8–3.1) \times 10^{13}$ or 28–31 W, which is a theoretical and estimated value of the heat flow through the earth's surface. Naturally, practical experimentation is necessary to know the exact value. Such research has become possible relatively recently, beginning with 1939, when E. Bullard first measured the heat flow in South Africa and A. Benfield, in England. From 1956, such measurements started to be conducted under the sea as well. Currently, there are over 20000 measurement points across the globe, and the data obtained can be found in the global data catalog of the World Data Center for Solid Earth Physics [1]. However, as it turned out, it is hard to obtain experimentally the exact value of the integral heat flow. The point is that local heat flows from the planet's interior are assessed by drilling shallow wells and measuring the temperature coefficients

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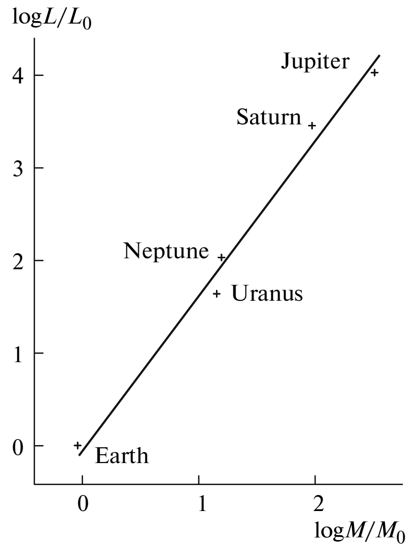

The luminosity–mass dependence diagram for the Earth and giant planets.

and thermal conductivity. The wells on the earth's surface are spaced heterogeneously. Simple averaging of all experimental data is a very rough way of obtaining approximate figures. In order to improve accuracy, it is necessary not only to sum up data but also to apply various corrections to them. Examples of such corrections can be the replacement of oceanic measurements with the prediction of theoretical cooling models; the addition of an arbitrary or theoretical amount of the hydrothermal heat flow that was measured well only in the ridge region; the elimination of the nonstationary effect from tectonic and magmatic events; and the exclusion of data from regions that were admittedly affected by hot spots.

The irregular mechanism of corrections leads to significant differences in data on the earth's total heat flow obtained by different teams of authors. Thus, according to D.L. Anderson's latest fundamental monograph on the earth [2], the absolute heat flow that comes through the earth's surface, as judged by the averaged experimental data, reaches 30 TW. However, some scientists believe this value is understated and, taking into account various corrections, assume that a more probable value of the integral flow is $F = 44.2 \pm 1$ TW [3]. In later studies [4], an even larger value was obtained for the integral flow, $F = 46 \pm 3$ TW. Taking into account the fact that the results of these very accurately performed studies agree within the limits of measurement errors, the heat flow issuing from the earth's surface may be assumed equal to $F = 45 \pm 1$ TW (10^{12} J/s, or 1.5×10^{21} J/yr). This energy is almost three orders of magnitude smaller than the energy received by the earth from the sun; therefore, it is possible to assume that the earth's inner heat does not affect our planet's climate directly. Nevertheless, the value of the heat flow issuing through the earth's surface is great. It exceeds by one-to-two orders of magnitude the total energy annually released during earthquakes and volcanic activity.

EXPERIMENTAL MEASUREMENTS OF THE EARTH'S INTERNAL HEAT

What can be the long-term source of such a giant energy? It was assumed 10–20 years ago that the main source of the earth's internal energy is the decay of long-lived radioactive isotopes, such as ^{238}U, ^{235}U, ^{232}Th, and ^{40}K, present in the rocks. However, a number of factors do not fit into this hypothesis. An approximate calculation of the energy released as a result of radioactive decay (if decay reactions occurred in the entire volume of the globe, including the core) yields a value of 2.3×10^{20} cal/yr or $9.63 \times 10^{20} \approx 1 \times 10^{21}$ J/yr. This value is not enough to explain the earth's total inner energy ($\approx 1.5 \times 10^{21}$ J/yr). Moreover, the estimated energy of radioactive decay is clearly overstated, because a trend has been revealed that the concentrations of radioactive elements in lithospheric rocks decrease from the upper layer of the earth's crust to the lower and upper parts of the mantle, and the effect of radioactivity in the core is probably absent. Note that V.I. Vernadsky wrote about it back in 1933, "On the basis of what we know about geological processes in the earth's crust, we have to assume that the rate of heat radiation of radioactive atoms decreases with depth faster than we observe it in the upper part of the earth's crust. This indicates that the amount of radioactive atoms decreases with depth" [5, p. 281].

Many facts favor the above conclusion, primarily, the so-called helium–heat flow paradox [2, p. 343]. The point is that, as U and Th decay, ^{4}He and antineutrinos, as well as heat, are generated. The observed ^{4}He flow from the mantle into the ocean is an order of magnitude smaller than the ^{4}He flow into the continental crust. Heat flows under the continents and under the oceans are approximately equal, which, in turn, created a sensation for geophysicists. This phenomenon can be explained if we assume that heat flows are mainly formed in the earth's deep layers, while the radioactivity of the earth itself depends on the radioactivity of the earth's crust, whose thickness under the oceans (4–7 km) is almost an order of magnitude smaller than that under the continents (30–50 km and more).

It has been established that short-term (years, decades, and centuries) catastrophic heat discharges from the earth's interior into the upper mantle, crust, atmosphere, and hydrosphere have occurred more than once during the earth's geological history, which disagrees with the hypothesis of the radiogenic nature of the earth's heat, since radioactive decay is a slow and monotonic process.

Recently, 15 universities from the United States, Western Europe, and Japan conducted a fundamental work on experimentally measuring the size of the heat flow from the earth's interior to the atmosphere [6], caused by the decay of radioactive isotopes, in particular, uranium, thorium, and potassium, inside the planet. The size of the radioactive decay was determined by accurate measurements of the geoneutrino flow using the Kamioka Liquid Scintillator Antineutrino Detector (Japan) and the available data obtained with the Borexino detector (Italy). It has been revealed that the radioactive decay of ^{238}Uand ^{232}Th in total contributes 20 TW to the earth's heat flow. Neutrinos emitted due to the ^{40}K decay were below the sensitivity limit of this experiment, but, as is known, their contribution is no more than 4 TW. Thus, the total energy of radioactive decay is about half of the earth's total heat flow, which was assumed at 44.2 TW. The authors of this work explained the result obtained on the assumption that the initial reserve of the earth's heat had not yet been depleted.

We cannot agree with this conclusion for the following reasons. First of all, the authors underestimate the earth's internal energy. It is obvious that the heat flow that comes through the planet's surface is far from being all the energy generated by the earth. In order to assess its full energy, it is necessary to determine the energy required to maintain the magnetic field. Otherwise, the field that has existed for at least 3.5 billion years without a regeneration source will disappear relatively quickly (within several tens of thousands of years). There is a great uncertainty in assessing the energy necessary to maintain the earth's magnetic field. Currently, the value of the magnetic field of the earth's core is measured more or less confidently [7], while, in order to calculate the energy, we need the value of the relative magnetic permeability $\mu/\mu o$, and its value changes from 1 (as the magnetic force lines go outside of the globe) to 100 (for the earth's inner iron core). Consequently, if various $\mu/\mu o$ values are used, the estimated energy of the magnetic field can be within 1.7–170 TW. Let us conventionally assume an average value of 85 TW. In this case, the earth's full energy equals the sum of the energy emitted by the earth through the surface (45 TW) and the energy necessary to maintain the magnetic field (85 TW), i.e., 130 TW. According to the above experimental study [6], radioactivity yields only 24 TW.

Other sources of the earth's internal energy are possible. At different times, various hypotheses were used to explain the energy generated by the planet: planetary differentiation, the Moon's tide-generating force, chemical segregation, heat generation in the liquid core by internal and external friction that manifests itself as liquid layers with different viscosities rotating relative to one another, and the space sources of energy predetermined by the effects of galactic processes on the Earth. Anderson's monograph [2] shows that only about 10 TW of energy can be attributed to nonradioactive sources, such as cooling and core differentiation, mantle compression (compaction), tidal friction, etc. This results in a significant discrepancy: 34 TW are generated inside the earth, while 130 TW are spent. In addition, there are serious grounds to doubt that the earth's primary energy reserve can ensure the necessary additional energy. It is easy to calculate the loss of planetary energy. The main heat-emitting layer that prevents the earth from cooling (kind of a "jacket") is the earth's crust. For the rock formations of which the earth consists, the temperature distribution in the interiors of large cosmic bodies at (radial) distance Δl is determined using a dimensional ratio [8, 127],

$$\Delta t \sim (\Delta l)^2/\chi, \qquad (2)$$

where Δt is the time interval during which temperatures equalize at the body's points at distance Δl; $\chi = \kappa/c_p\rho$ is the coefficient of thermal conductivity (m^2/s); κ is the coefficient of thermal conductivity (J m^{-1} s^{-1} K^{-1}); c_p is the specific heat capacity at a constant pressure (J g^{-1} K^{-1}); and ρ is density (g/m^3).

On average, for the earth's crust under the continents, we may assume that $\Delta l \approx 40 \times 10^3$ m and $\chi \approx 5 \times 10^{-7}$ m^2/s (the value typical of rock formations), then, using formula (2), we will obtain the time of the full cooling of the earth's crust, $\Delta t \approx 1 \times 10^8$ years. This is significantly smaller than the time of the earth's existence (4.5×10^9 years). However, we should note that under the oceans, which occupy 71% of the globe's area, the thickness of the earth's crust is almost an order of magnitude smaller; consequently, value Δt will be smaller by two orders of magnitude. We may state that the time of the earth's cooling, owing to the heat loss because of the thermal conductivity of the earth's crust, is measured to be just 10–20 million years. As for the mantle, its thermal conductivity is much larger than that of the earth's crust; therefore, it does not affect substantially the time of the earth's cooling. At present, many studies show that convective gas–hydrogen flows in the mantle, rather than thermal conductivity, play the main role in heat transfer from the core to the crust [9]. Naturally, these processes should be supported by a constant source of energy that emanates from the core, and this source cannot be the initial reserve of the earth's energy. It follows from the above that neither the crust as the earth's main heat-insulating layer nor the mantle could have preserved the initial reserve of the earth's energy for even 100 million years. Consequently, the core's temperature should have decreased significantly, but, according to recent studies, the temperature of the earth's inner core is higher by approximately 1000 K than was previously assumed, being 6230 ± 500 K [10].

THE LIKELIHOOD OF FUSION REACTIONS IN THE EARTH'S CORE

Therefore, a powerful source of stable energy must exist in the earth's core. This source can only be the energy of thermonuclear fusion. The question arises, can fusion reactions occur in the earth's core as likely happens in the interiors of giant planets? Fusion reactions need at least two conditions: first, hydrogen should be present in the earth's core in large amounts, which contradicts the prevailing theory of the iron core, and second, superhigh temperatures and pressures should be present, which also disagrees with the generally accepted ideas.

Let us consider these issues in detail. At present, there is no question that hydrogen was the main type of substance from which all cosmic objects originated, including the Earth as part of the Sun's once "dropped" shell. As the proto-Earth was formed, hydrogen should have been the main construction material (≈60 at %). Then gravitational compaction happened: the spherical diameter decreased, and, consequently, the angular rate of rotation increased quickly. According to the traditional concepts of the Earth's origin, free hydrogen is absent on our planet, because, due to its high volatility, it should have dissipated into outer space at the earliest stages of the Earth's formation. However, this disagrees with real facts. Geologists established long ago that hydrogen-containing gases and free hydrogen itself constantly escape the earth's interior. Consequently, a hydrogen source should exist somewhere in the depths of our planet. Probably, a substantial part of it as a lighter component should accumulate in the center of the planet (the inner core) owing to separation (the centrifugal separation effect) and then form various chemical compounds with metals and hydrides during cooling [11, 12]. The outer core has a lower density and temperature; therefore, we may assume that it consists mainly of metals that contain hydrogen as a solution and that have a significantly lower density (even if they contain as much hydrogen as hydrides). Note the following experimental fact. Metals (primarily, iron) at high temperatures and pressures have a universal capability to dissolve gases, primarily, hydrogen. At pressures over 10^5 bar, metals with dissolved hydrogen become plastic and have a high electroconductivity. Hydrogen dissolution in metals can be seen as the formation of a fully ionized hydrogen plasma in a metal volume. In this case, the earth's outer core should be liquid, which is proved by the attenuation of s waves as they pass through it. At the same time, judging by seismography data, it is assumed that the earth's inner core is solid.

Fusion reactions are possible only when the substance is in an extreme state, i.e., a state with an anomalously high concentration of energy. Astrophysicists G.A. Gamov (1938) and H.A. Bethe (1939) were the first to justify theoretically the possibility of such reactions at ultrahigh temperatures; however, in 1940 W.A. Wildhack showed the principal possibility of fusion reactions at low and ultralow temperatures but at a very high density of the substance. The thermonuclear reactions of this type were singled out as a special class of pycnonuclear reactions. In order to run a reaction like this, it is necessary that the reacting nuclei quantum-mechanically overcome the Coulomb barrier caused by the electrostatic repulsion of nuclei. The pycnonuclear reactions differ from the thermonuclear reactions in that the Coulomb barrier in them is overcome with zero motions of nuclei, while in thermonuclear reactions it happens with the thermal motion of nuclei. Ya.B. Zel'dovich made a simple and illustrative model analysis of the rate of a pycnonuclear reaction [13]. He showed that fusion reactions can occur in a subbarrier manner even in cold hydrogen compressed to a density of 10^4 g/cm^3 and smaller (for the $p + D$, $p + T$, $D + D$, $D + T$ reactions). In the typical conditions, the coefficient of transmission through the barrier is extremely small, and pycnonuclear reactions run very slowly at low pressures. However, they can be decisive at a high density of the substance, since the rate of subbarrier transmission grows quickly as the density increases. The Chinese astrophysicist Wang Hong-Zhang [14] calculated the corrections necessary to calculate the rate of a proton–proton nuclear reaction for mean temperatures ($10^3 < T < 10^5$ K) and high plasma densities and concluded that they are possible not only in the cores of giant planets but also in the Earth's core. Wang Hong-Zhang's luminosity–mass dependence diagram for giant planets and the Earth may serve as indirect proof.

This diagram is similar to the stellar one; i.e., there is a clear linear dependence of the luminosity logarithm on the mass logarithm. This situation can have only one explanation: the energy is formed as the result of nuclear reactions, during which the rate of energy generation increases exponentially as the temperature and pressure grow. The fact that the earth's luminosity index falls on the same straight line as the luminosity of giant planets allows us to state that the main mechanism of the earth's internal energy is nuclear reactions as well.

The presence of fusion reactions in the earth's inner core, which consists of metal hydrides, is proved indirectly by the distribution of the concentration of helium isotopes. It was revealed that the ^{3}He/^{4}He ratio in the earth's mantle is stable and 1000 times larger than in the earth's crust [15]. This effect is clear in the light of processes in the inner core when a certain amount of isotope ^{3}He is formed during proton–proton reactions. Note that ^{3}He cannot be the "primary helium" that comprised the planet's substance 4.5 billion years ago, since, in this case, the earth's maximal temperature during its formation should not have exceeded 800–1000 K, which is clearly unreal. The $^3He/^4He$ ratio in the earth's crust decreases sharply because ^3He mixes with isotope ^4He, which is formed during the radioactive decay of U and Th. Then helium gets into the earth's atmosphere and vanishes into outer space through crust fractures and volcanoes.

Let us calculate specific energy release W (i.e., the amount of energy formed as the result of a nuclear reaction in a volume unit during a time unit) of the earth's inner core. The full internal energy of the earth (net of the energy of radioactive decay) is estimated at about 100 TW (1×10^{14} W), and the radius of the earth's inner core is 1221 km. Hence, the specific energy release is $W \approx 1.3 \times 10^{-5}$ W/m^3 = 0.013 mW/m^3. This is a very small energy release, much smaller than the energy release of the human body ($\approx$100 W/m^3). In other words, the rate of nuclear fusion is extremely small, which is logical to assume taking into account the low temperature of the earth's inner core. The significant energy released inside the inner core is expressed simply by its large size (the volume, $\approx 7.6 \times 10^9$ km^3).

Note also the following circumstance. The pressure in the center of the earth is $\approx 3 \times 10^6$ bar. This is a static pressure, but we have to take into account that approximately 100 large earthquakes occur annually, generating longitudinal elastic waves. Longitudinal waves create local density increases, passing through the substance in antinodal points. Thus, the pressure of a longitudinal wave in the antinodal points can increase by orders of magnitude; if we speak about the earth's core, the pressure at local points can reach 10^7–10^8 bar and more during the transmission of longitudinal (seismic) waves. Naturally, the density of the substance in these points increases sharply, and we may assume that they are the centers of thermonuclear reactions. The earth's inner core sort of "boils," and local thermonuclear reactions occur periodically in various places. Let us call this process "quasi-thermonuclear."

In places where local foci of thermonuclear reactions occur, the temperature should increase sharply. The hydrides decompose; hydrogen transfers from the hydride-ion form to proton gas; and, consequently, a large amount of hydrogen is released. The pressure in this zone increases sharply, and the flows of a hydrogen plasma are squeezed outside of the core. There can be no chain thermonuclear reaction because the heat excess leaves for external spheres (deep fluid plumes) together with heat-transferring hydrogen, and the temperature drops. Owing to the earth's rotation and the presence of the Coriolis acceleration, hydrogen (more precisely, proton gas) flows in spirals in the outer liquid core, which has a high electroconductivity. These spirals form a solenoid (a kind of induction coil) and, consequently, a dipole magnetic field of the earth. A characteristic property of plasma flows (filaments) is instability in space and time; therefore, we should expect that the poles of the earth's magnetic field would experience a certain chaotic movement.

* * *

The verity of a theory about the earth's origin is verified by its conformity with global phenomena that are well studied today. This is primarily the heat flow from the earth's surface, degassing, and the presence of an external magnetic field. The classical theory of the earth's structure (the core of iron, and the mantle of silicate) cannot explain all these phenomena. The heat flow manifestly exceeds the theoretical limits. The magnetic fields, although capable of originating under the convective motions of the substance in the iron core, are unable to create a dipole field, because they need a solenoid for this. The huge gas–hydrogen fluids that outflow from the earth turn out to be totally unexplainable.

The proposed hypothesis [16] of the thermonuclear nature of the earth's heat flow agrees well with the known experimental facts and opens up new ways of studying not only our planet but also other planets of the solar system. Thus, according to the accepted concept, only planets with a sufficiently fast rotation and possible thermonuclear reactions in their core can have a dipole magnetic field. Neither Mercury, nor Venus, nor Mars, nor the Moon meets these conditions: they all lack magnetic fields. The hydrogen reserves (as hydrides) in the Earth's core are not endless either. When they are depleted, naturally, the thermonuclear reactions will stop, and the magnetic field will "switch off"; tectonic activity will stop; and the planet will enter the stage of passive aging.

The hydrogen fluids that originate in the core are the source of the earth's endogenous heat energy, which exceeds many times the total energy of radioactive decay. These flows, which transfer most of the heat energy to the planet's surface, favor the formation of plumes of viscous and solid substances. The role of plumes in endogenic processes has been studied by many authors; in particular, it is reflected in numerous publications of the associates of the Laboratory of Petrology and Ore Genesis at the Institute of the Earth's Crust, RAS Siberian Branch [17]. The ideas of degassing and outflow of huge masses of substance from the interior to the upper horizons of the lithosphere and beyond underlie all geological concepts of the development of the Earth as a cosmic body. Since a deep fluid is a universal heat transfer agent, the traces of its effect on the formations of the earth's crust and upper mantle are recorded unambiguously, manifesting themselves as magnetism and volcanism, granitization, metamorphism, etc. Rising hydrogen fluids sort of washed carbon from deep geospheres, transferring it to the uppermost shells of the lithosphere. The manifestation of this trend led to the growth of the general concentration of carbon in the planet's sedimentary mantle and water basins that cover the earth; as a result, various compounds formed, from carbonate formations to coal and hydrocarbon splashes.

The new ideas of the thermonuclear nature of the earth's internal energy allow us to update the existing concepts of the origin of hydrocarbons (oil and natural gas). At present, it is assumed that hydrocarbons are products of decomposition of the remains of living organisms. However, back in the 1950s and 1960s, some Soviet (N.A. Kudryavtsev, V.B. Porfir'ev, G.N. Dolenko, and others) and foreign (the British scientist F. Hoyle and others) geologists raised doubts that this was the only right hypothesis and thought possible the theory of an inorganic (abiogenic) origin of oil. The new hypothesis, although winning no support at the VI (1963), VII (1967), and VIII (1971) international oil congresses, gained support among many practical geologists, because it agreed well with exploration data [18, 19]. However, within the prevailing concept of the earth's structure, the authors of the theory of the inorganic origin of oil were unable to explain where hydrogen came from, without which this theory was invalid. Even cosmic ideas of the "original cosmic origin of hydrocarbons," "that primordial hydrocarbons were initially (?!) buried and mothballed in the earth's interior," etc., were drawn to this end [18, p. 171].

The very possibility of inorganic synthesis of hydrocarbons was proved long ago; now we only have to find out whether the origin of natural gas affects its composition. Thanks to the work conducted at the Sobolev Institute of Geology and Mineralogy, RAS Siberian Branch [20], it was possible to develop a method of determining the source of carbon within natural gas. It turned out that, when using biogenic (limestone, calcium carbonate) and abiogenic (graphite) sources of carbon, a mixture of hydrocarbons that corresponded to the composition of the hydrocarbon part of natural gas was obtained after the compression and heating of reagents (adding iron and water) to pressures and temperatures that corresponded to the conditions of the earth's upper mantle. This proves that, in principle, two equal sources of hydrocarbons may exist.

However, there are differences as well. The sources of biogenic carbon are limited in volume and should somehow be tied to the geographical distribution of ancient flora and fauna. The sources of abiogenic carbon that have originated and originate owing to the discharge of carbon into the upper layers of the mantle and lithosphere by gas–hydrogen flows are practically unlimited. Definitely, if hydrogen from the deep zones of the planet is degassed, the hydrogenation will always take place as hydrogen hits formations enriched with carbon to form oil-bearing layers and natural gas deposits. Consequently, oil and gas are being formed now and will be formed until the hydrogen reserves in the earth's core run out and thermonuclear reactions stop.

Hydrogen that comes from the core can also find a way out in its free form. Cases of hydrogen effluence, which usually occur under cataclysms, were known in the past. The main obstacle to hydrogen exiting from the earth's depths is the crust, which consists of solid and practically impermeable rocks. The exception is cracks and faults through which gas leaks out slowly. In addition, neither can we exclude sudden discharges of large amounts of hydrogen during earthquakes and volcanic eruptions. This is more likely in the oceans, where the earth's crust is almost an order of magnitude thinner than under the continents.

Humankind is facing the complex problem of learning to extract pure hydrogen from land (oceanic) depths for industrial purposes. However, these are the problems of the new geology and new methods of prospecting and extracting pure hydrogen—a universal and environmentally friendly fuel.

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