

Primordial hydrogen-helium degassing, an overlooked major energy source for internal terrestrial processes

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Abstract

The currently accepted theories concerning terrestrial processes are lacking in accounting for a source of internal energy which: (a) are quickly focused, e.g. earthquakes and volcanic eruptions; (b) are of very high density; (c) provide very high velocities of energy release; (d) have very high density of the energy transport and relatively small losses during transportation over long distances; (e) are quasi-constantly released and practically limitless. This energy release is always accompanied by H- and He-degassing. Solid solutions of H and He, and compounds of He with H, O, Si and metals were discovered in laboratory experiments of ultra-high PT-conditions; He-S, He-Cl, He-C, He-N structures can be deduced from their atomic structure and compositions of natural He-rich gases. Ultra-high PT-conditions exist in the Earth's interior; hence it seems most likely that some "exotic" compounds are present in the Earth's core and mantle.

During Earth's accretion, primordial hydrogen and helium were trapped and stored in the planet interior as H- and He- solutions and compounds, stable only under ultrahigh PT-conditions that were discovered in recent experiments. These are described step by step (for each PT-conditions): H- and He-trickling from the solid; convecting in the liquid core; flux-melting the solid mantle and generating gas-liquid (pyromagma) scavenging plums. H- and He-release from core solutions and incorporating in H-He and other chemical compounds and following gradual decomposition due to decompression are accompanied by

intense energy release. The practically infinite energy source for earthquakes will be the explosive chain reaction of the H- and He-compounds decomposition, triggered by decompression within the fault zone. Ongoing decompression within an upward moving hypocenter accompanied by additional release of energy will cause (a) decomposition of H- and He-compounds; (b) release of elemental H, O, C, N, Cl, F, Si, metals, etc., and (c) new detonation-induced synthesis of H₂O, SO₂, H₂SO₄, CO₂, H₂S, HCL, HF and other compounds. Thus the manifestations of volcanic eruptions are produced by ascending pyromagma, which melts the surrounding rocks and bores through them under the pressure and heat of continuous explosions (volcanic earthquakes).

³He serves as a unique measuring transformer correlative to the internal heat flow. Measurements and calculations lead to the conclusion that up to half of the present rate of heat flow from the Earth's surface is contributed by the above listed chain of H and He-related reactions. This is amount of energy five times greater than the energy loss involved in earthquake and volcanic activity.

Keywords: earthquakes, volcanic eruptions, energy sources, elastic strain, mechanism, physical, geochemistry, helium, hydrogen, compounds, degassing

1 Introduction: the currently accepted theories concerning terrestrial processes lack in accounting for a plausible energy source

1.1 Inadequacy of the traditionally accepted sources of energy

Terrestrial processes, like internal heat flux, hot spots, plate tectonics, earthquakes and volcanic eruptions, are explained by three major traditional sources of energy: decay of radioactive elements (U, Th and others); the heat from gravitational compression and differentiation; and the heat generated by impact of meteorites [1]. Obviously, these sources are dispersed, can not be focused, and, as we will try to demonstrate, are not the causes of most of the Earth's internal processes. The main problem with the present theory is that it cannot point a finger at any other energy source or on any other energy carrier. Thus, the recent estimates of the mean heat flow for all continents are 65 ± 1.6 mW/m², and for all the oceans 101 ± 2.2 mW/m² [2], yet the radioactive elements responsible for the heat supply are concentrated mostly in the "granite layer", present in continents and absent

in the oceans. The present rate of heat flow from the Earth's surface is evaluated at 4.43×10^{13} W (*ibid.*). In terms of energy, this outflow of heat is the most impressive of internal processes; the more spectacular energy loss involved in earthquake and volcanic activity is an order of magnitude less (about $2-3 \times 10^{12}$ W). Francis [3] and most of the researchers today suggest that all known energy sources of the Earth can supply only about half of its observed heat flow, and that there is a need for additional energy sources, probably primordial heat, left over from the Earth's accretion and core formation. According to variable calculations of the internal energy supplied by gravitational differentiation in the Earth's liquid core, its amount is barely adequate for generating the magnetic field of the Earth (even under condition that the coefficient of efficiency of this process is very high [4]). And – one of the most important factors - the energy flow from any one of the three above-stated traditional energy sources cannot be easily and quickly concentrated.

The proposed herein model of hydrogen and helium outgassing as a major source of terrestrial energy was reported since 2000 at four professional conferences (e.g., [5, 6]), and to the best of our knowledge, was not put forward previously by anybody else. It substitutes “the primordial hydride Earth” hypothesis of Larin [7], who suggested the dominantly metal-hydride Earth's core (unconvincingly, because of comparatively low density of the iron and nickel hydrides). Also, Larin's [7] hypothesis is unrelated to the problem of conservation of energy during Earth's accretion and of this energy release by degassing. We are using the discussed in many articles hypothesis on possible interrelation between earthquakes, and rise and fall of tide; thus the seismic activity on the moon was recorded only on its near-to-earth side, affected by lunar tides [8]. We are using also the discussed in Sect. 1.2.3 earthquake model of Ponomarev [9], but instead of his “hypothetical fluid” we introduce a real, energy-releasing phase-transfer of H- and He-compounds.

1.2 Related theories and difficulties in explanation

1.2.1 Generation of liquid magma and plutonic activity

The common opinion originating from geophysical observations is that in spite of high temperatures beneath the crust, the rocks there are mostly solid, and their melting points rise with increasing pressure. It is commonly assumed, that magma rises from the mantle and that its energy and energy contained in magma gases comprise the sole energy source for plutonic

processes. One of the most important thermal qualities of magmas, contributing to their stability, is the great contrast between their specific heat (roughly 0.3 cal/g) and their heat of fusion or crystallization (around 65 to 100 cal/g at atmospheric pressure). Consequently, about the same amount of heat is involved in crossing the melting interval as in raising or lowering the temperature of the mantle rock or liquid to about 300°C. Because of obvious reasons, among the three aforementioned traditional sources of internal energy of the Earth, only decay of radioactive elements could be useful for melting solid mantle into liquid magma. However, the concentrations of the principal radioactive elements in its rocks are too low to be taken into account (Table 1); so today there are no known heat sources inside the mantle.

| Isotope | Half life (10 ⁹ yr) | Heat production (cal / g*yr) | Abundance in mantle (ppm) | Annual heat production per gram of mantle (10 ⁻⁶ cal / g*yr) |
|-------------------|-----------------------------------|------------------------------------|---------------------------------|--|
| U ²³⁸ | 4.5 | .706 | .03-.13 | .02-.09 |
| Th ²³² | 13.9 | .202 | .12-.52 | .02-.04 |
| K ⁴⁰ | 1.3 | .211 | .05-.22 | .01-.05 |
| Σ | | | | .05-.18 |

Table 1: Contribution of the principal radioactive elements to the heat production of the mantle (from [10], table 3-1).

Ingenious mechanical models proposed for the mantle rock melting (friction heating, tectonic uplift) are inadequate [10]. The thermal model of flux-melting, whereby the melting temperature of the mantle rock would be lowered by the addition of volatiles from a source at greater depth, or of water from submerging rocks in the subduction zone [11], looks more interesting. However, the combined volatile contents of oceanic basalts are less than one percent of H₂O and CO₂, and are so much lower than the saturation content at mantle depth that it is doubtful whether the addition of these small quantities could account for the generation of large amounts of magma.

Thus among the phenomena that still require satisfactory explanations are the liquid states of the core-mantle boundary [12] and of the asthenosphere beneath the solid upper mantle, the sources of energy behind upwelling of mantle plumes in the solid mantle, the energy and forms of heat-convection which moves continental plates and produces seismicity by interaction be-

tween plate margins. There are difficulties in explanations of the energy source for melting sedimentary rocks (e.g., the process of granitization), and for generation of magma chambers in the Earth's crust, which include accommodation for greater volume by melting, pushing aside, and lifting up the enclosing rock. As is regularly stated in textbooks of geology, felsic or volatile-rich magmas of low density are capable of rising as cylindrical columns into crustal rocks that show little or no evidence of horizontal deformation. However, it is improbable that such rising would occur through a few kilometers of cold, ground-water-containing rock: either the layered rocks have to be themselves red-hot, of which there is no evidence, or else this magma has to be injected with explosive suddenness [13]. As shown by casting practice, melting, even with a continuous supply of the heat energy to the surrounding matter, would propagate at an average speed of about 1 mm/min or 500 m/year, much slower than the observed ascent of the volcanic magma.

The emplacement of a very large volume of magma can be enormously quick. Thus the November 1964 catastrophic eruption of the Shiveluch Volcano (Kamchatka Peninsula) was preceded, beginning a month prior to eruption, by a swarm of earthquakes in the crust, developed against a background of increased seismic activity in the upper mantle at depths of 105-120 km [14]. This was interpreted by the authors as evidence that the "replenishment" and enlargement of the crustal magma chamber had started from the magmatic "roots" zone in the upper mantle; so, the velocity of its magma uplift was more than 100 km/month. The enormously quick emplacement of the very large volume of magma with the simultaneous enlargement of the volcano's magma chamber and melting of its country rock would require a very high density of energy transfer.

1.2.2 Molten lava lakes

Halema'uma'u (Hawaii), the most famous among the long-living lakes of molten lava on Earth, was boiling in the crater of Kilauea from 1823 to 1924, finally disappearing during the Kilauea eruption. Its level fluctuated up and down, the boiling was sometimes more, sometimes less intensive; many people came to see this fire lake, even from Europe. Jaggar [15] and his co-workers measured the temperature of the lava lake surface (roughly 1140°C), and its depth, from 131 m to zero, when the lake was practically dry. No conduits, connecting the lava lake with the mantle were found, only fractures, but somehow it received its energy from the mantle. The same enigma was encountered by Tazieff [16], when the Nyiragongo Volcano in

Zair, Africa, emptied in 1977 the bowl of its crater simultaneously with a small earthquake, flooding during 25 minutes 2,000 hectares with 1,100°C hot basanite-lava pouring forth through fractures that suddenly opened in the lava lake. There were no fumaroles inside the crater, and no vertical conduit with convecting liquid magma in the empty crater, and not even a large but empty one. Tazieff's [17] calculations have shown that the amount of thermal energy radiated from its surface by the Nyiragongo lava lake flows were about 960 Mw in 1959 and 12,200 Mw in 1977 (power three times greater than that produced by the Chernobyl nuclear power-plant and equal to the power produced by all the power plants in Israel in 2004).

There is no evidence for the common explanation that the energy supply of such a scale to the lava lakes comes by lava-magma convection, and it sounds improbable that lava can circulate through fractures or narrow channels between the surface and the mantle over a depth of many kilometers. The only possible heating source of comparable scale, which comes to our mind, is a giant stream of inflammable gas, like the one which erupted in 1906 from Vesuvius, in 1969-1970 and in 2001 from Etna, and many others.

It is commonly assumed that energy of magma and energy contained in magma gases comprise the sole energy source for plutonic processes, that magmas are both an energy-carrier and an energy source. Some researchers think differently: Markhinin ([18], p. 63) quoted from the book "Die Geschichte des Vesuvs" (by Alfaro and Friedlaender, who analyzed the 1906 eruption of Vesuvius, ref. there): "There aren't, and cannot be any exact gas-measurements, but it seems, in accordance with the diameter of the channel and the velocity of gas-extrusion that not only volume, but even the weight of the erupted gases must be many times greater than all the mass of tephra and lava".

There is plenty of evidence that great amounts of energy were invested in melting the country rock, which is not the energy of any magmas and not the energy contained in magma gases. Lavas of unusual composition, such as the carbonate lavas and tephra of the Oldoinyo Lengai Volcano in East Africa and the sulfur lavas of Siretoki-iow-san in Hokkaido, clearly show that the primary magma, by definition, mostly siliceous, is, at least in these cases, not an energy carrier, otherwise silica would be present in their eruption products.

1.2.3 Earthquakes and volcanic eruptions

Earthquakes and volcanic eruptions are described in most studies separately and explained differently. However, these events are related in space and

time: most earthquakes and volcanoes occur in deep-seated faults at plate boundaries, rifts, and transform faults (Fig. 1); earthquakes precede and accompany volcanic eruptions, but not every earthquake culminates in surface eruption. Before Reid [19] hypothesized his model of “earthquake as a result of rock displacement under accumulated elastic stress”, it was thought that earthquakes and volcanic eruptions are generated by the same power (e.g., Sir Charles Lyell [20], 1875; Charles Darwin [21], 1842-1846). Well-qualified and untroubled by any theories, eyewitnesses have clearly shown in their descriptions that underground explosions and surface eruptions of gases are an integral part of the observed earthquakes. The currently accepted dilatant-diffuse and avalanche fracturing earthquake theories are based on field observations of earthquake damage patterns. However, those relate only to solid material under atmospheric conditions, and do not account for the actual PT properties of the lower lithosphere and mantle matter, where very large number of earthquake hypocenters occurs. There exists also an unexplained detail: from the mechanical model point of view, earthquakes would be expected on compressional faults, but the vast majority of earthquakes occur on extensional faults, e.g., on subductional plate boundaries (Fig. 1), where faults are dominantly extensional [22].

Tectonic earthquakes, as determined by time-distance graphs, develop at a depth up to 700 km. Elastic stress can be accumulated only in the upper part of the lithosphere, which is less than 20 km thick. At greater depth the rock-temperature is higher than 1/3 of the rock’s melting temperature and the rock creeps (e.g. [23]). Thus, the earthquakes with foci deeper than 20 km are not explained by currently accepted theories. The focal depths of “volcanic” earthquakes are usually limited to 0-3 km, within the liquid magma chamber of a volcano, where no elastic stress can be accumulated. Even in the upper zone of the Earth’s crust, all experiments with the measurements of the pre-earthquake build-up of the strain were unproductive; it was shown that only a very small part of the elastic strain, about $10^3 - 10^4$ J/m³, is released during earthquake, much less than the average level ($10^6 - 10^7$ J/m³ [24]). The hypothesis of self-organized criticality in a lithosphere medium, which is in permanent supercritical stress condition (*ibid*), seems too rash, especially when speaking about plate boundaries: the loss of stress because of generation of fractures amounts to 90%. A medium in supercritical stress conditions behaves like a melt; for fractures to be kept open, the stress has to be less than critical, and in lithosphere fault-zones fractures are plentiful. A supercritical lithosphere medium would be energy saturated and not be able to absorb additional energy, meaning that even small waves would not fade; however, it absorbs even the waves of strong explosions.

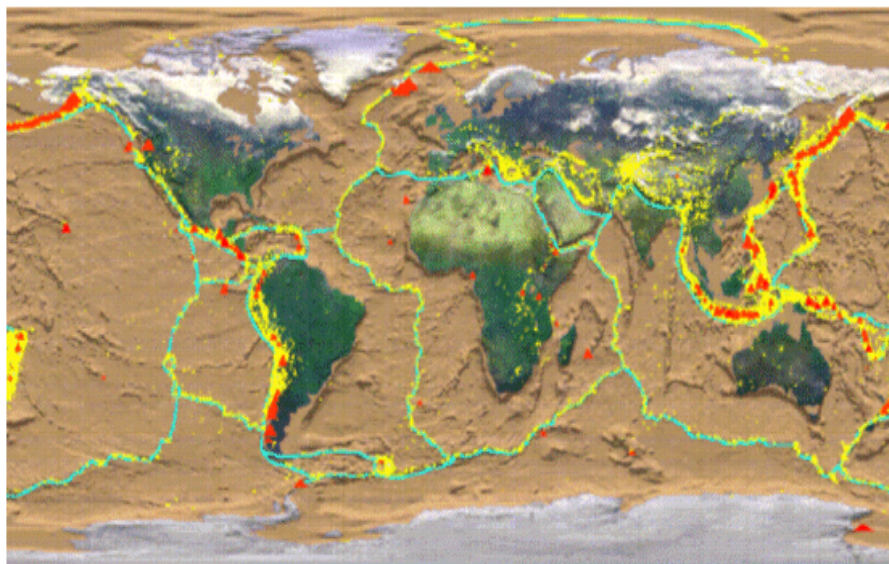


Figure 1: Computer-generated surface map of the planet Earth showing plate margins (blue lines), illustrating a good correlation of active volcanoes (red triangles) with earthquake epicenters (yellow dots). (Compiled after Internet data, mainly provided by USGS Smithsonian Institution sites and NOAA/NGDC).

Each increment on the Richter earthquake-magnitude scale corresponds roughly to a 30-fold increase in the amount of energy released ([1], p. 267). Gutenberg and Richter [25] place the number of earthquake per year above magnitude 7.0 at about 20, above 6.0 at about 100, above 5.0 at a little under 1,000, and that above 3.0 at about 50,000; we understand that Gutenberg-Richter relation is an energy law, which indicates some constant energy supply. The active earthquake-related processes sometimes persist up to several years, from foreshocks through the major shock to the last aftershock; sometimes there are several large shocks of a similar magnitude (e.g., the 1976 Gazli earthquakes, where two shocks with magnitude 7.0 and 7.3 were separated by only a five-week period [26]). With such a phenomenon, after discharge of energy by a major shock, a mechanism for a quick accumulation of energy for following shocks is badly needed. Rikitake [27] discovered that for most of the already published anecdotal reports of precursory phenomena, the logarithm of the precursor time was linearly related to the main shock magnitude. We suppose that with all the pessimism of the

modern seismology concerning the possibility of earthquake prediction, some monstrous energy must in some way be concentrated at a certain point, in a certain form, in a certain medium, and by some means triggered to explode.

Many of the geophysical and geochemical anomalies that are shared by both earthquake and volcanism, as well as the nature of their power sources are not fully understood. Among them are: (1) violent outgassing prior and during earthquakes [28, 29] and volcanic eruptions [30]; (2) anomalous infrared radiation reflecting heat release, which precedes also shallow earthquakes [31, 32]; (3) pre-earthquake radio and acoustic noise [33]; (4) diffuse glow and fireballs [28]; (5) upward migration of earthquake hypocenters [9]; (6) measurable transitory deformations of the earth's surface before an earthquake (*ibid.*) and volcanic eruptions [1]; (7) earthquake-related strain-cycling and mobilization of subsurface waters [34]. Correlation between earthquakes and earth's tides were shown by a number of researchers in numerous articles.

Partial explanation of these anomalies may be found in Ponomarev's Thermo-Gas-Dynamic (TGD) earthquake model [9]. According to this model, stored elastic energy and initial mechanic processes trigger earthquake in the hypocenter, this behaves as a "steam-boiler" that is filled with a hypothetical fluid discharged from magma under variable pressures and supercritical PT conditions. That hypothetical fluid explodes in a closed volume, causing destruction of the rocks at the hypocenter. There is a linear relationship between the amount of energy released and the volume of the hypocenter. Ponomarev's TGD model fails to explain: (a) the nature of this hypothetical fluid; (b) the source of energy that compensates a liquid-gas adiabatic cooling related to expansion; (c) the nature and source of energy indicated by extraordinary thermal, electrical and chemical phenomena.

1.3 Energy scale of great earthquakes and volcanic eruptions

Great earthquakes and volcanic eruptions release tremendous amount of highly focused energy. The kinetic and strain energy released by earthquakes, which are determined from seismic radiation, amounted, e.g., to 4.3×10^{16} J for the moderate 28/6/92 Landers earthquake (local magnitude $M_L = 6.8$) [35]. For comparison: energy released by explosion of 1×10^6 t. TNT (1 Mt) equals to 4.2×10^{22} erg, or 4.2×10^{15} J [36]. Thus the energy released during the Landers earthquake is equivalent to a 10 megaton H-bomb. Local magnitude correlates well with the Richter magnitude [35]. As mentioned above, each increment on the Richter scale corresponds roughly to a 30-fold increase in the amount of energy released. Consequently, the energy released in the Alaska earthquake of 1964 ($M_L = 8.6$) may be es-

estimated as 3×10^{19} J, equivalent to a monstrous explosion of a more than 1000 megaton bomb! The observed densities of energy released by earthquakes are very high and provide very high velocities of mechanical fracture propagation, similar to those of an explosion (in the case of the 1964 Alaska earthquake 3.5 km/sec [37]), close to the sound velocity in the lithosphere. Actually, it is greater than the limit of the velocity of fracture propagation, that is equal to half of the shear-wave speed [38], i.e., much less than the velocity of sound. There are still velocities greater than these that were generated by the Alaska earthquake; for example, Aprodov [39] noted that large granite boulders along the recent fault in Mongolia were neatly sliced by the earthquake, with their halves continuing to stand in an unstable position on both sides of the fault. Velocities which produce these effects are as great as velocities of explosions or even of detonations, which are an order of magnitude greater than those of sound.

The greatest volcanic eruptions are also much stronger than the most terrible man-made explosions. Among such eruptions the best studied is the Krakatau (Indonesia) explosion of 1883; when about half of the mountainous island disintegrated into very thin powder, was dispersed as volcanic ash over a territory of 800,000 km², and in part thrown into the stratosphere, to a height of 60-80 km [40]. “The two annihilated mountains were about 8 km long and 2-5 km wide. In their place a sea bottom depression 250-270 m deep developed. The volume of the blown-up material was about 18 km³; the initial velocities of the fragments were 600-2,000 m/sec. A special study of this eruption has shown that a significant part of this expelled mass had a velocity greater than 8 km/sec, and therefore could leave the Earth forever” (*ibid.*). For comparison, the initial velocities of the St. Helens, Bezymyanny and Sheveluch explosions were about 280-500 m/sec (*ibid.*); during the November 12, 1964 eruption of the Mt. Sheveluch volcanic blocks weighing more than 3,000 t were hurled to a distance of 12 km [41]. The most powerful H-bomb explosion (the Novaya Zemlya Islands, 1961, 50 megaton) was heard by some local inhabitants in the northern Urals Mts. and at the Pechora River, at a distance of 700-800 km (Gilat, unpubl.); for comparison, the 1883 Krakatau volcanic eruption (Indonesia) was heard at a distance of 4653 km [42]. Even larger by most measures was the 1815 Tambora eruption (*ibid.*); according to Hedervari [43], it released all together from 2.88×10^{26} to 1.4×10^{27} erg (or 1.4×10^{20} J). Vaganov et al. [40] estimated the volume of ash and fragments blown up by this eruption at about 100-150 km³, the horrific explosion energy at about 10^{20} J, equivalent to an explosion of 24,000 Mt (24,000,000,000 t) of TNT.

The most popular explanation of volcanic explosion today is the “champagne-bottle-cork-model”, where the strongest explosions occur at the opening stages of eruption, when some external factor (e.g., avalanche) lowers lithostatic pressure of the upper part of the volcano-mountain (“cork”); as a result, the water-vapor-bubbles accumulated in magma-chamber during the pre-eruption period instantly expand, and their increased pressure blasts the mountain top. Nevertheless, each volcano behaves in its own way. Thus, the monstrous eruption of Tambora in 1815 reached its maximum only after 7 months, and lasted in all for 15 months, whereas the incredible eruption of Krakatau in 1883 took 3 months to develop its greatest intensity [30]. Strong blasts do not always occur in a closed volume: e.g., Bezymianny erupted (1956) vertically before it unleashed a directed blast; Pinetubo produced major eruptions between June 12 and 15, 1991, prior to its culmination in ground-hugging surges of ash, monstrous runaway lava jets and the strongest earthquakes, which rocked Manila for hours and hours, sixty miles from the volcano. In this case the explosions came from the open chambers; volatiles or water-vapor could not have accumulated under any roof-rocks prior to eruption, and the common explanation that a cause for volcanic explosions is the pressure of water vapor and other volatiles contained in magma ascending in a closed volume (e.g., [1]) sounds improbable. Apparently there has to be a practically unlimited another source of internal energy, part of which can be focused.

2 Limit of mechanical energy accumulation in the lithosphere

The maximum level of the accumulated elastic energy depends on temperature, velocity of deformation, plasticity, and strength of the materials involved [44, 45]. As described above, the elastic stress cannot accumulate at a depth of more than 20 km. The maximum amount of energy (ME) accumulated in solid material is equal to or less than the critical energy of fracturing, because fracturing leads to decrease of the stored elastic energy. Critical density of the energy of deformation is a parameter that combines energy of deformation and resistance to breaking [45]. Not knowing the exact mechanical properties of the lithosphere rock, we will look for its upper limit, calculating the ME, in place of unknown faulted rock, for a block of high-quality structural steel 600 km x 100 km x 20 km in size (the possible size of the lithosphere block in which the Alaska 1964 earthquake was generated).

The estimated energy of mechanical failure (Q) depends on critical density of energy (W) and on maximal volume of the zone of plastic deformation, which is the apex radius of the main fracture (r) multiplied by the size of its plane (S): (Q = W x r x S). As is easily found in the ASM Handbook [46], experimental and calculated estimations of the resistance to fracturing for this type of steel are 2060 MJ/m³. For a block of 600 km x 100 km x 20 km, its maximal volume of the zone of plastic deformation (r x S) is:

$$1.96 \times 10^{-3} \times 72 \times 10^9 = 141 \times 10^6 \text{ m}^3.$$

The corresponding maximum of stored elastic energy (Q = W x r x S) is:

$$141 \times 10^6 \text{ m}^3 \times 2.06 \times 10^9 \text{ J/m}^3 = 29 \times 10^{16} \text{ J}.$$

It follows that upper limit of the mechanical energy that could be stored within a 600 km x 100 km x 20 km size block of the high-quality structural steel (less in the much weaker faulted rock!), is two orders (3x10¹⁹ J) of magnitude smaller than the energy of the 1964 Alaska earthquake. Therefore, there must have been another, non-mechanical source of energy.

3 Chemistry of volcanic gases

Manifestations of the latent chemical energy in earthquakes and plutonic processes have been noted at least since Ovid's *Metamorphoses*; Sir Charles Lyell [20] (*"Principles of Geology"*, 1875) thought that "The primary causes of the volcano and the earthquake are to a great extent the same, and connected with the development of heat and chemical action at various depths in the interior of the globe". To-day's paradigm assumes that energy of magma and energy contained in magma gases comprise the sole energy source for plutonic processes.

However, the common observation is that the total amounts of chemicals released to the atmosphere by volcanic activity is usually many-fold greater than that which could be contained in the extruded amounts of magma or fluids. Thus during the 1980 St. Helens eruption the amounts of CO₂ [47], and SO₂ [48] emitted were several times greater than those which could be released from degassing of ascended magma; isotopic data suggests that these gases and fumarole's waters were of mantle origin [49]. Analyses of fumarole's samples from the crater indicate that sulfur is released from the

magma mainly as H_2S and oxidizes to SO_2 as it cools in the plume. Correlation of non-periodic H_2 emissions with magmatic activities recorded during the same eruption suggests a magmatic origin of the H_2 [50].

A great deal of water is given off as steam in most eruptions – 15,000 tons a day by the Paricutin Volcano, Mexico, in 1945 – but how much of this is groundwater sucked into the volcanic system and nobody knows for sure how much came from the mantle, dissolved in the magma. Steam activity around most volcanoes is thought to be the result of discharge of ground waters which circulate to depths of 2 to 4 km, and heat up to temperatures that probably do not exceed 400°C . Deeper, hotter rocks are too impermeable for groundwater convection cells to penetrate. There is some uncertainty in a major part of the studies on volcanic gases regarding the origin of their constituents, such as carbon dioxide, sulfur dioxide, and chlorine, since the elements involved in these could have been derived from crustal rocks as well as being present to some extent in the original magma.

Nonetheless, mighty gas ejections from the volcano can continue during years without eruption of any solids or liquids, heating the vent-comprising rock, e.g., Mt. Etna's Bocka Nuovo crater in 1969-1970 [16]. Tazieff's team used rapid chromatographic techniques for the gas-analyses; perhaps the most remarkable feature in their results is the surprisingly small amounts of water in the gases of Mt. Etna: CO_2 was about 50 %, while H_2O was less than 40 % and fell as low as 3-4 % during short bursts of hot gas [51]. Even during quiescent periods, the plumbing system of the Mt. Etna volcano discharges about 200 t/day of gas containing helium with mantle-type isotopic composition; monitoring of gas manifestations located in the southern and eastern parts of the volcano has shown that the gas is sometimes carbon dioxide, and sometimes methane dominated [52]. The amount of CO_2 released is estimated to be around 25 Mt/year [53]. Up to today there are no theoretical explanations for the source of aggressive chemicals, such as HF, which cannot be stored in magma prior to eruption (in the laboratories it is stored in paraffin bottles), but are expelled in thousands tons (e.g., 0.2 million tons of HF were released during 1919 by "smoking furnaces" in the ignimbrites of the Valley of Ten Thousand Smokes [54]).

According to Markhinin [18] and Fedotov and Markhinin [55], all four sources of information on composition of volcanic gases (analyses of gas samples taken straight from the liquid lava, analyses of gases from fumaroles and of gases preserved in solidified lava and in a fresh tephra) show that the most important among them are H_2O , H_2 , CH_4 (and other hydrocarbons), O_2 , CO , CO_2 , COS , N_2 , NH_3 , Cl , H_2S , SO_2 , SO_3 , S , He , Ar , Xe , boric and arsenic acid, chlorides and fluorides of metals. Tens of compounds which are

usually defined as “organics” (e.g., amino-acids) were also identified in the very carefully collected “sterile” samples of fresh tephra from the erupting Tyatya and Tolbachik volcanoes (Kamchatka) (*ibid.*).

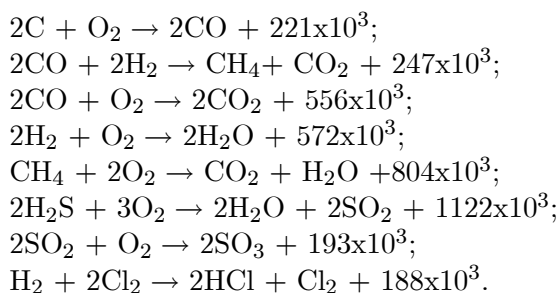
The quite surprising composition of dry gases and vapor-condensate samples taken from the hot liquid lavas during the eruption of one of the Kamchatka volcanoes (Table 2), allows for a few preliminary conclusions: (1) the many-fold difference between minimal and maximal contents of major gases shows that Tazieff’s conclusion about strong variations in compositions of erupted gases also holds in the case of gases contained in lava; (2) the condensate from the samples of the liquid lava gases is a very acid sodium-chloride brine with dominant Al-Zn-Cu cations (Al, Zn, Cu >>> Ca, Fe, Mg); its composition does not indicate any relationship with the composition of lavas containing these gases; (3) the composition of gases in liquid lavas is unstable and offers quite a few possibilities for exothermal chemical reactions which could supply heat to lava and keep it liquid; (4) the most important: the erupting lavas and at least some of erupting gases came from different sources in the mantle.

| Dry gases | Minimal concentration | Maximal concentration | Dry gases | Minimal concentration | Maximal concentration |
|---|------------------------------------|--------------------------|-------------------------|-------------------------------------|--------------------------------------|
| H ₂ | 0.002 % | 25.5 % | CH ₄ | 10 ⁻⁵ % | 0.56 % |
| O ₂ | 0.6 % | 19.7 % | N ₂ | 38.6 % | 83.4 % |
| He+Ne | 0.02 % | 0.17 % | CO ₂ | 0.2 % | 41.0 % |
| CO | 0.0 % | 0.6 % | H ₂ S | 0.003 % | 0.008 % |
| HF | 0.005 % | 0.06 % | HCl | 0.05 % | 0.07 % |
| SO ₂ | 0.002 % | 0.006 % | | | |
| Vapor-condensate from the same samples, average composition (ppm) pH = 0.66-0.85 | | | | | |
| Anions and acid: | | Cl ⁻ - 23.800 | F ⁻ - 2560 | SO ₄ ⁻² - 220 | H ₂ SO ₄ -1327 |
| Cations: | NH ₄ ⁺ - 6.2 | Na ⁺ - 720 | Al ⁺³ - 251 | Zn ⁺² - 190 | Cu ⁺² - 93 |
| | Ca ⁺² - 68 | Fe ⁺² - 37.5 | Mg ⁺² - 18.3 | Cd ⁺² - 25 | K ⁺ - 2.6 |
| | Li ⁺ - 1.5 | Pb ⁺² - 1.4 | Mn ⁺² - 1.2 | Sn ⁺² - 0.05 | Ag ⁺ - 0.001 |

Table 2: Composition of dry gases separated from water vapor (~90 % of the gas volume) by condensation, taken from the hot (1.000⁰C ± 65⁰C) liquid lavas during the 1975-1976 Tolbachik volcano fissure eruption (from [18], p.48).

4 Volcanic gases as energy carriers

It is common knowledge that under certain conditions chemical reactions between some of the gases begin as combustion and develop as a chain-reaction culminating in explosion. Active particles – free atoms and radicals – in the course of that chain-development react with molecules of the initial gases, forming end-products and new active centers. The mixture of oxygen and hydrogen explodes when hydrogen concentrations vary between 6 and 95% (volume). When even small amounts of water vapor are present, explosion occurs at a temperature of about 600⁰C; the water is a catalyst accelerating explosive reactions thousand-fold. These and similar reactions, typical for explosive mixtures, generate a great amount of energy. Here are some examples (J/mol):



The 1815 Tambora eruption blew out (among ash and other chemicals) about 52×10^6 t of sulfuric acid [56], whose synthesis from primary elements could produce energy equivalent to 96 megatons of TNT. The synthesis of 50×10^6 t of water from a hydrogen-oxygen mixture (“detonating gas”) could produce the energy equivalent to 150 megatons of TNT. According to Vaganov *et al.* [40], analyses of gases from fresh lavas of Kamchatka volcanoes made by I.I. Glustchenko show that primary explosive gases uncontaminated by meteoric water and air (H_2 , Cl_2 , CO , OH , F_2 , Br_2 , H_2S , CH_4) comprise 10 to 70% of total volcanic gases.

Volcanic activity practically always begins from “tectonic” earthquakes, and is accompanied by “volcanic” earthquakes. Earthquakes associated with volcanic activity come in great swarms (volcanic tremor): e.g., at the beginning of the Mount St. Helens eruption (1980) more than 2400 earthquakes with local magnitudes greater than 2.4 and up to 4.0, were recorded by the local seismic network [57, figs. 3-5]. Their seismic records show obvious

differences in earthquake signatures. “Tectonic” earthquakes have impulsive P- and S-phases and a wide range of frequency components, and depths limited to 0-10 km. “Volcanic” earthquakes have hypocenters limited to 0-3 km in depth within or close below the liquid magma chamber of a volcano, where no elastic stress can be accumulated, and are characterized by emergent P-phases, undistinguishable S-phases and mostly low frequencies that range from 1 to 5 Hz.

McNutt [58] compiled a lot of data which define an empirical relation between tremor amplitude and eruption explosivity: as the tremor amplitude increases, the explosivity increases. To our and others experience, volcanic eruptions sound like a train of explosions and the earth trembles, like during an earthquake; when closely observed, they look like a chain of TNT-explosions, the solids and liquids fly from their centers like in explosions; they smell like explosions - so, maybe - they really are chemical explosions which produce volcanic earthquakes?

5 Properties of the thought-for energy source

The weakness of the present paradigm related to plutonic processes, is not only in its postulate that only magma and its contents are responsible for all the energy supply for plutonic processes. Mechanical models for the magma generation and its transportation without energy supply basically remain the famous models of *perpetum mobile* and also don't work. The model proposed herein provides another and immensely more powerful source than magma of highly energized mantle gases.

Observing the worst of earthquakes, which triggered volcanic eruptions in three volcanoes in Chile, Charles Darwin [21] concluded: “From the intimate and complicated manner in which the elevatory and eruptive forces were shown to be connected during this train of phenomena, we may confidently come to the conclusion, that the forces which slowly and by little starts uplift continents, and those which at successive periods pour forth volcanic matter from open orifices, are identical”. A century and a half later - analyzing the modern geological observations – we came to the same conclusion. So, what are the properties of these forces?

Evidently, these forces: (1) are tremendous and quasi-constantly discharged; (2) can be quickly concentrated and focused; (3) have very high velocities of energy released, which must be equal to or higher than crack

propagation velocities, otherwise the crack will stop; (4) provide increasing intensity of the energy released during earthquakes and volcanic eruptions; (5) provide fast accumulation of energy between shocks and eruptions; (6) have very high density of the energy transport and relatively small losses during transportation over long distances; (7) supply to the lithosphere highly energized gases for igneous processes, and concentrate minor and trace elements for ore-forming hydrothermal solutions; (8) as discussed later, correlate with ^3He outflow.

Nuclear processes are independent of external conditions (at existing conditions on Earth) and cannot respond to their changes with intensity of energy liberation or absorption. All processes of stress-accumulation, deformation, and fracturing are irreversible, have a very long relaxation period and do not provide the observed short-time cyclic sequence of the energy release and accumulation causing foreshocks and/or aftershocks. "Pressure of the gases contained in magma" cannot provide the adequate energy, pressures and velocities observed, nor even the amounts and chemistry of the observed erupting gases.

A comparison between limits of intensity of the energy flows accessible by convection, thermo-conductivity or by transfer of the latent energy of chemical compounds, shows that the latter is the most favorable. For example, the heat of water formation is 285.83 kJ/mole, i.e., generation of 0.5 mole of water (from 1 g of hydrogen and 8 g of oxygen) releases the amount of energy equal to the specific melting energy of 1 kg of quartz, or to the amount of heat required to raise the temperature of 1 kg of quartz to 200⁰C. This example of a small mass of material with a large energy capacity easily transferred is very important, because the hydrodynamic losses increase with the square of mass flow.

A common observation is that earthquakes and volcanic eruptions are accompanied by a mighty outflow of mantle helium, hydrogen, and other gases. This co-occurrence suggests that these elements may have bearing on the sought-for energy source. Remarkable correlations between mantle helium-3 concentrations and internal heat flows, found by many researchers in seafloor hydrothermal flows since 1970s (e.g. [29], pp. 234-235, and numerous subsequent articles, e.g. [59]), may be another direct indication for this connection.

6 Accumulation, transformation, and release of energy within the planet Earth: primordial hydrogen and helium as its most abundant and most important agents

6.1 H- and He-abundance within Earth's interior

Hydrogen and helium are the most abundant elements of space, comprising 98-99% of its matter. Of the helium isotopes the light ^3He is produced mainly by nuclear fusion (not attainable under conditions of Earth's interior), whereas the heavy ^4He is produced mainly by the radioactive decay of uranium. The $^3\text{He}/^4\text{He}$ ratio in continental subsurface material is 10^{-7} - 10^{-8} , and in atmospheric air 1.4×10^{-6} . It is much larger in the volcanic emanations at oceanic ridges (1.2×10^{-5}) and Hawaiian volcanic exhalations (4.5×10^{-5}), suggesting even lighter composition of helium in the mantle, closer to the ratio of the solar wind (4.6×10^{-4}), which indicates its primordial origin [60].

The alternative suggestion of the ^3He being produced by a deep-Earth nuclear fission reactor was made by Hollenbach and Herndon [61, 62] based on numerical simulation, by analogy with natural fission reactors that have operated during 10^5 - 10^6 years at Oklo, Gabon, 2 billion years ago [63]. However, it is difficult to accept this suggestion because no fission or decay products (e.g., isotope ^{10}Be) were detected in oceanic basalts or anywhere else coming from the sources deep inside the Earth. Unfortunately, this suggestion also lacks theoretical grounds for existence of water in the Earth's core (water acts as a regulator of the fission reaction).

According to present-day models, during accretion the greatest part of the tremendous kinetic energy of impacting bodies and planetesimals was transformed to heat that caused melting of a large part of the planet matter, gravitational differentiation and core segregation at about 4.50 Ga ago. Accretional processes are likely to have provoked efficient degassing, and many researches suggest, on the bases of isotopic studies, that only about 5% of initial gases were retained inside the Earth. Towards the end of accretion, gas loss from the mantle continued via fractional degassing of convecting melts, thus the upper mantle was quickly depleted, and the lower mantle started to behave as a near-closed system at about 150 m.y. after the beginning of accretion (e.g., [64]). The two-layer mantle model is attested to by a much more dispersed $^4\text{He}/^3\text{He}$ isotopic ratio measured in Oceanic Island Basalts (OIB), up to as low as 25,000 in the Loihi Seamount, Hawaii

[65]. By comparison, the very stable $^4\text{He}/^3\text{He}$ ratios with the mean value of about 88,000 were measured in Mid-Oceanic Ridge Basalts (MORB), where the source of MORB is degassed and the signature of radiogenic helium is very strong (*ibid.*). Based on the Loihi ratios, Allegre et al. [66] suggested $^4\text{He}/^3\text{He} = 5,200$ at the formation of the Earth, which is in agreement with the value of 6670 measured in gas-rich meteorites, but significantly higher than the 2500 value for solar helium.

The Earth's atmosphere contains 1.2×10^9 moles of ^3He ; the classical observation of He escape to space provides relatively small residence time of helium in the atmosphere ($\sim 10^6$ years). Using three main tools: mass balance equations, the concept of mean age of outgassing, and the systematic use of the absolute amount and isotopic composition of all rare gases, Allegre et al. [66] came to the conclusion that half of the Earth's mantle is 99% outgassed and calculated the helium concentrations ($^3\text{He} = 1.8 \times 10^{-9}$ cc/g, and $^4\text{He} = 4.5 \times 10^{-5}$ cc/g) and amounts ($^3\text{He} = 2.1 \times 10^{14}$ moles, and $^4\text{He} = 5.3 \times 10^{18}$ moles) in the lower mantle, where supposedly $^4\text{He}/^3\text{He} = 25,000$. The helium flow from the lower mantle calculated by them is 5.5×10^7 moles/year of ^4He , and 2,200 moles/year of ^3He ; an additional part of ^4He flux is accounted for by degassing of radiogenic helium from the crust. The opinion of many researchers in this field is that the upper mantle is heated from below and not from within (*ibid.*).

Hence, the assumption that Earth is still left with enormous quantities of hydrogen and helium is justified by the still continuous large-scale flux of these gases from the Earth's interior into outer space; the remaining questions are what is their specific energy and in what form are these gases stored and transported.

6.2 H- and He-activity and latent energy

Both elements are abundant and would have had to be highly active during Earth's accretional and differentiation periods, in accordance with the Law of Mass Action. The very basic Le Chatelier principle predicts that when stress is applied to a mixture in an equilibrium state, the equilibrium will shift to relieve the stress. Stresses include changes in temperature, pressure or concentrations of species in the mixture. Thus increasing concentration of a reactive drives the reaction forward. Thus the ultrahigh PT-conditions during accretion enhance the progress of endothermic reactions of formation of H- and He-compounds and solid solutions, which provide efficient cooling and produce end-products more compact than the reactive.

By Prigogine's theorem, which describes the natural way from chaos to

order for any level of matter creation, the energy and mass flows provide interaction of any open thermodynamic system with the environment; steady evolution of any such system requires a minimum rate of entropy generation [68]. The minimum of Gibbs energy is a natural condition of stability of any open stationary system; it causes minimum dissipative losses.

Thus, the endothermic processes (proposed herein) of transformation, transportation, and accumulation of accretion energy and its substances, during the Earth's accretion and differentiation periods would be accompanied by minimal losses, and correspondingly by minimal heating of the interior. The cooling effect provided by these processes prevented reverse evaporation of the accreted mass. The energy spent on endothermic transformation of H and He elements into compounds and solutions is subsequently liberated during the exothermal decomposition of these compounds (Sect. 7).

The chemical potential (free energy) of any gas in solution is calculated as follows [70]:

$$\mu_H = \frac{1}{2}\mu_0 + \frac{RT}{2} \ln \frac{P}{P_0} = \bar{H}_H - T\bar{S}_H \quad (1)$$

where:

- μ_H is partial free energy of gas in solution, J·mole⁻¹;
- μ_0 is the standard free energy of gas at pressure P_0 , J·mole⁻¹;
- R is the gas constant, J mol⁻¹K⁻¹;
- P is the equilibrium pressure of gas at temperature T , bar;
- P_0 is the equilibrium pressure of gas at temperature $T=273.15$ K, bar.
- H_H is the partial enthalpy of gas in solution, J·mole⁻¹;
- S_H is the partial entropy of gas in solution, J·mole⁻¹K⁻¹;
- T is the absolute temperature, K.

Inasmuch as the solubility of gas under isothermal conditions increases with pressure [69], concentration of a gas in solution is a function of pressure

$$c = A \cdot \sqrt{P} \quad (2)$$

where: c is concentration of solution, mol*L⁻¹, A is constant, mol*L⁻¹ * Pa^{-0.5}, and P is pressure, Pa.

Estimation of the specific energy stored in helium and hydrogen under ultrahigh PT-conditions of Earth's interior was made using equation (1); the results are presented in Table 3. Based on the evaluation of the hydrogen constituent of volcanic emanation, atmospheric air and of its escape flux into space, Voytov [71] gave a conservative estimate of the hydrogen flux from

| Depth (km) | Pressure (Gpa) | Temperature (K) | Specific energy (J/mole) | |
|------------|----------------|-----------------|--------------------------|----------|
| | | | Helium | Hydrogen |
| 0 | 0 | 300 | 12480 | 8652 |
| 10 | 0.3 | 500 | 20800 | 14420 |
| 100 | 3.4 | 1800 | 74880 | 51912 |
| 500 | 18 | 2000 | 83200 | 57680 |
| 1000 | 40 | 2500 | 104000 | 72100 |
| 2000 | 88 | 3500 | 145600 | 100940 |
| 3000 | 160 | 5500 | 228800 | 158620 |
| 4000 | 238 | 5800 | 241280 | 167272 |
| 5000 | 321 | 6000 | 249600 | 173040 |
| 6000 | 358 | 6200 | 257920 | 178808 |

Table 3: Specific stored energy of the He- and H- solutions in Earth’s interior

Earth’s interior as 6×10^{12} g/y; based on assuming it came from the depth of 1,000 km, the amount of its liberated energy can be estimated as 2.163×10^{17} J/y (Table 3). This agrees with the recent estimate of global earthquake energy, which is about 10^{17} – 10^{18} J/y [8]. Actually, the hydrogen outflow is greater: Voytov’s (*ibid*) estimate does not take into account the great stores of clathrate (methane hydrate, e.g. [72]) and the massive outflow of methane and other hydrocarbons from tectonically-active zones discovered in the 1980s (Voytov, private communication, 2003).

We assume that hydrogen and helium are stored in and transported from Earth’s core and mantle in the forms that were observed in the experiments under similarly ultrahigh PT-conditions and described below.

6.3 H- and He-compounds under ultra-high PT-conditions: experimental data

6.3.1 Hydrogen and helium solid solutions

Experiments under ultra-high PT conditions have shown that under conditions prevailing at the Earth’s core a large quantity of hydrogen and helium can be stored in solution (in accordance with equation (2)). Spherical He-bubbles 1-2 nm in diameter have been found entrapped in constructional iron and nickel by means of transmission electron microscopy [73]. Entrapped hydrogen was found near or around the helium bubbles, aggregating with these bubbles due to their positive tensile stresses. The energy of interaction

between hydrogen and helium in the bubbles is 0.7-0.9 eV/atom [74]. The trapping energy of hydrogen atoms within different defects is about 0.03-0.1 eV for interstitials, 0.25-0.31 eV for dislocations and 0.4-0.5 eV for vacancies.

6.3.2 Helium compounds

Helium is an inert gas under atmospheric conditions, but at temperatures higher than 1000 K and pressures higher than 14 GPa compounds of He-H, He-O, He-Si, and He-metals were observed (e.g., [75–77]). He-S, He-Cl, He-C and He-N structures can be deduced from their atomic structure and composition of natural He-rich gases [29]. Decomposition of H and H compounds releases large amounts of energy (more than 2 kkal/g-mol for the He-H system, estimated from published data [74, 78], and from standard energy conversion factors). ^3He has a spin 1/2 (the spin of ^4He is 0), therefore ^3He is more active, by a factor of almost four orders of magnitude, in interacting with other elements under the ultrahigh PT conditions. The estimation of the stored energy made in the previous section is supported by data in recent studies of ^3He gas endothermic formation of solutions in solids and liquids. For example, Saunders et al. [79] described a chemical shift of the helium nucleus, demonstrating a high binding energy of helium with surrounding matter. This shift was observed experimentally and the potential barrier of solution formation was estimated as maximum 10eV, which corresponds to 230.5kcal per g-mol. This amount of stored energy is in excess of the heat of water formation from hydrogen and oxygen (68.3 kcal per g-mol).

6.3.3 Hydrogen compounds

A solution of 138.2 cm³ of hydrogen in 100 g of iron only increases the alpha-iron lattice constant from 0.28590 to 0.28612 nm [80]. The dissolution energies of hydrogen in liquid iron and nickel at the temperature of melting are 15.18 kcal/mole and 8600 kcal/mole, respectively [81], increasing sharply with rising temperature. Increase of pressure increases their stability. Na and K at standard conditions absorb 126-135 cm³ of hydrogen per 1 cm³ (*ibid.*). The H₂-H₂O binary system forms at high pressure a novel 1:1 type of clathrate, where H₂O and H₂ form two interlocking networks, both with a diamond structure, stable up to at least 30 GPa [78]. Single-crystal X-ray diffraction studies of the H₂-CH₄ system under similar pressure revealed four different solid compounds with molar ratios of 1:2, 1:1, 2:1 and 4:1 (stable to at least 30 GPa, *ibid.*). The conclusion is that

at high pressures the “gas-ice” compounds are ubiquitous. This data supports the hypothesis proposed by Gold [82] of the existence of an enormous reservoir of methane, deeper within the Earth than any organic deposits. This data also suggests that at least part of the immense methane resources discovered by ocean drilling in the oceanic crust (e.g., [83]), and of methane hydrate in the oceanic sediments (e.g., [72]), the amount of which (2×10^3 to 4×10^6 Gt) greatly exceeds that in other reservoirs of the global carbon cycle (*ibid.*), are mantle derived. Although commercial extraction of this methane is still not a practical procedure (see [84]), the geochemical implications of these reservoirs are considerable.

7 Induced chain of reactions of hydrogen-helium-degassing as a main source of energy of internal terrestrial processes

7.1 Transformations of energy of primordial H- and He-compounds in terrestrial processes

Some of the pathways of helium and hydrogen from Earth’s interior to the atmosphere may be traced now using available experimental data. The basic process of energy release is a chain of induced chemical reactions at the local instabilities of PT conditions (steps), bringing distinctly dominant exothermic processes of outgassing and decomposition of unstable structures, and secondary conjugated endothermic processes, forming other compounds that will be stable at given conditions. Below we indicate the basic steps by which the stored energy is released by a degassing process, based on the similarity of Earth’s interior PT conditions to those in the laboratories where He- and H- compounds have been studied. It is suggested that primordial H and He accumulated the excess energy during Earth’s accretion by endothermal formation of solutions in solids and liquids, chemical and van der Waals compounds.

7.2 Deduced solutions and bubbles in the solid core

He and H can form solid solutions, and possibly form sub-lattice bubbles of helium-hydrogen in Fe-Ni inside the Earth’s solid core. H-He-bindings and the high solubility of both elements in metals make possible the above suggested high (and stable) concentration of both elements in the core. The binding energy of He-H 0.71 eV, according to conversion factors for energy

equivalents, corresponds to 8232 K, more than in the center of Earth, so the H-He binding will be stable even there.

This hypothesis substitutes “the primordial hydride Earth” hypothesis of Larin [7], who suggested the dominantly metal-hydride Earth’s core, which is not convincing due to the comparatively low density of the iron hydride (6,440 g/cm³) and nickel hydrides (7,040 g/cm³ for NiH₂ and 7,370 g/cm³ for NiH). The Earth-core density, calculated from acoustic data for atmospheric PT conditions, is about 10% less than 7,860 g/cm³, the density of iron near the melting point. By comparison, the density of iron saturated with dissolved hydrogen (138.2 cm³ of hydrogen per 100 g of iron) has a density lower than that of iron by only 0.2%, and 8,963 g/cm³ is the density of both nickel and hydrogen-saturated nickel. There is, probably, less hydride.

7.3 Self-organized convectonal structure of the liquid core

Both hydrogen and helium have densities lower than those of the surrounding medium; this difference and differences of the pressures in the core and on the core-mantle boundary provide trickles and concentrated flows of buoyant bubbles, which cannot be distributed uniformly in a certainly heterogenic (in chemical composition, structure, temperature, stress produced by the Earth’s-tide) medium; elevating bubbles quickly become hotter than the surrounding matter because of the temperature gradient and grow in volume; hydrogen and helium are the only gases which do not cool adiabatically (Joule-Thomson effect). The flow-pressure of elevating matter will compliment the descending movement of heavier iron-nickel matter to the hard-core’s zone of crystallization, forming a convectonal structure.

Gravitational differentiation, by common opinion the most powerful among all possible processes, is barely adequate for generating the dynamo which produces the magnetic field of the Earth (3.6x10⁹-10¹¹ w, [85]). Allegre et al. [66] concluded that the half of the mantle closest to the Earth’s-surface is already depleted by light gases (see Sect. 6.1); let us suppose that all of the flux of primordial hydrogen (6x10¹² g/y), conservatively estimated by Voytov [71], comes from a depth of 5,000 km (some 150 km above the liquid core–hard core boundary). Using results of calculation of the specific energy stored in hydrogen (Table 3), we can estimate that the energy it would release on its way from the 5,000 km to the 3,000 km-depth (close to the core-mantle boundary) will be:

$$14,420 \text{ J/mole} \times 3 \times 10^{12} \text{ mole/y} = 43,260 \times 10^{12} = 4.3 \times 10^{16} \text{ J/y.}$$

This energy generates power (1 year corresponds to 3.1557×10^7 seconds) of

$$4.3 \times 10^{16} \text{ J/y} : 3.1557 \times 10^7 \text{ sec.} = 1.34 \times 10^9 \text{ w.}$$

The energy supplied by He flow will be negligible (2×10^4 w). Anyhow, this energy of rising in the liquid core hydrogen is an essential addition to the energy produced by gravitational differentiation because most of it is the mechanical energy of convection, essentially the mass transfer.

7.4 Scavenging diapirs in the Earth's mantle, hot spots and continental drift

Concentrated flux of hotter-than-mantle hydrogen and helium from the core will generate liquid magma by a process of volatile flux-melting, and warm the wall-rocks, producing a “heat-focusing” effect. Their mixture with liquid magma, less dense than the surrounding medium (condition of Rayleigh-Taylor instability), will initiate its rise. In accordance with Bailey's [11] model, this rise may precede volatile fluxing and “heat-focusing”, where the action of helium and hydrogen is especially effective, because these two gases do not cool adiabatically under decompression. Thus the adiabatic cooling resulting from decompression of rising mix is less than the estimated temperature gradients, and gases transfer heat. The volume of flux-melting has to be limited by influx of volatiles and their energy: increased temperature is accompanied by increase of local pressures, which, in its turn, rises the specific temperature of melting and causes local solidification. The gas-magma mix rises as a diapir or plume, melting overlying rock and moving upward, at the beginning in an accelerating rate, and then with a quasi-constant velocity. The diapir would tend to produce and then follow pre-heated channels in which it would be strongly focused. The local increases in discharge of energy and heat, together with the fluxing and de-compacting action of volatile components, would cause local fusion at seismic discontinuities.

In accordance with the results of the experiments (Sect. 6.3), it is expected that part of the gas-magma-mix energy in the mantle will be accumulated by endothermic formation of solutions, endohedral clusters, and chemical and van der Waals compounds in solids and liquids. Eutectic melting along boundaries of structural elements causes selective solution of solid components and gas migration between solid and liquid phases; it also causes mass transfer of solids from the summits of the growing fractures to their openings. Harris [86] discovered a strong tendency of magma melt to

scavenge incompatible elements from the Si-Mg-Al-Ca-K-Na mantle-rocks through which it passed, i.e., elements that are strongly fractionated into the liquid tend to be carried in the liquid and to accumulate in increasing concentrations. Taking into account this nature of the magma melt, and the fact that ^3He is four orders of magnitude more active than ^4He in interacting with other elements (under ultrahigh PT conditions), it would not be too rash to assume that the gas-magma mix, and first of all its ^3He , while rising through the mantle, will scavenge the minor and trace elements (O, S, C, N, Cl, F, metals, etc) dispersed in it, forming He-H, He-O, He-C, He-S, He-N, He-metals and other compounds; thus those elements can be concentrated and transferred to the lithosphere, for their future role as volcanic gases and ore-forming hydrothermal solutions.

At the depths where temperatures are less than 800 K and 500 K, (Table 3), formation of methane and ethane, respectively (as probably formed on Jovian Planets), as well as reactions of He-compounds with water, becomes possible [70]. Some of the above-mentioned reactions result in the release of elemental hydrogen and oxygen. The combination of endothermic reactions (decomposition of crystal hydrates, oxides and hydro-oxides), and overwhelming exothermic reactions (decomposition of He- and H-compounds, formation of water, acids, halogenous salts, sulfur hydride, and oxides of carbon, nitrogen and sulfur) allows an energy transfer not only by a hot diapir or density current, but also along the deep-seated faults into the future earthquake hypocenter.

In the scheme suggested herein, major border zones of the mantle blocks act as conduits for ascending material. Equilibrium between pressure of the moving medium and resistance of the system will result in quasi-constant discharges of magma and accordant resonance structures in the asthenosphere and the upper mantle, thus conveying the plates of lithosphere away from the spreading ridges. Diapirs, rising through the mantle at the minor zone-intersections would create the hot spots. The main mass of the mantle interacts with the conveying zones by means of heat- and mass-transfer. Thus, in the zones of subduction, which are usually characterized by anomalously high heat flows, cooler plates would attract the ascending flow of melts enriched in the H- and He-compounds. The high gradients of temperature would cause hydrothermal redistribution in electrolytes and secondary heat flows, which would effectively melt the subsiding lithospheric blocks and redistribute them, possibly, somewhere within the asthenosphere.

We do not see any direct indications for any regular sinking of any great mass of cooler matter through the solid mantle, which is necessary for organized convection. As we see, all types of plate boundaries are character-

ized by intensive heat flows generating sub-vertical to sub-horizontal low-velocity zones (as described by the surge tectonics theory, i.e., [87]), and all of them, including subduction boundaries with related volcanism, are better explained by ascent of the H- He-related gas-magma mixes. The basic sameness of different plate boundaries is illustrated sometimes by their transformation mutual in the lithosphere. Thus the East Pacific subduction zone of South America transforms northward to the spreading zone of the East Pacific Rise, then to the transform of San Andreas and subduction zones father northward and westward; similar transformations occur in the southern part of the West Pacific Subduction Zone southward through the great Alpine strike-slip fault of New Zealand's Southern Island to the spreading zones father south. A slowly moving zone of crystallization of the Earth's hard core changes the distribution of gases and heat between rising conduits, thus influencing the magnetic field of the Earth and the continental drift; on the other hand, the comparative stability of the main blocks of the mantle provides a certain stability in the relationship between blocks of the lithosphere and zones of circulation.

7.5 Zone of earthquakes; decompression in the fault zone triggering explosive reactions

Most earthquakes and volcanic eruptions are sited on the plate boundaries, rifts, and transform faults (Fig. 1), where maximal focal depth of the earthquake hypocenters and eruptions producing kimberlite pipes is about 680 km. We assume that from this depth upward mantle matter behaves as a brittle solid or as a liquid, like salt or asphalt, depending on temperature, and on the type and velocity of pressure applied. The proposed model of the primordial hydrogen-helium-induced earthquakes includes the following (Fig. 2):

1. Decompression in a fault zone by external factors (such as the accumulated influence of tidal waves causing fatigue fracturing of the matter) causes (in accordance with Le Chatelier's principle) explosive decomposition of H- and He-compounds (minor earthquake).

2. As mentioned previously, H and He are the only gases that do not cool upon expansion; heat-producing explosions compensate the fall in temperature by adiabatic expansion of other gases and vapor dissolved in magma. Intruding into rocks, H and He effectively weaken the rock microstructure [88]. High-pressured mantle gases and fluids generated during this stage inflate and weaken any accessible faults, thus reducing static friction across its walls [28, 89].

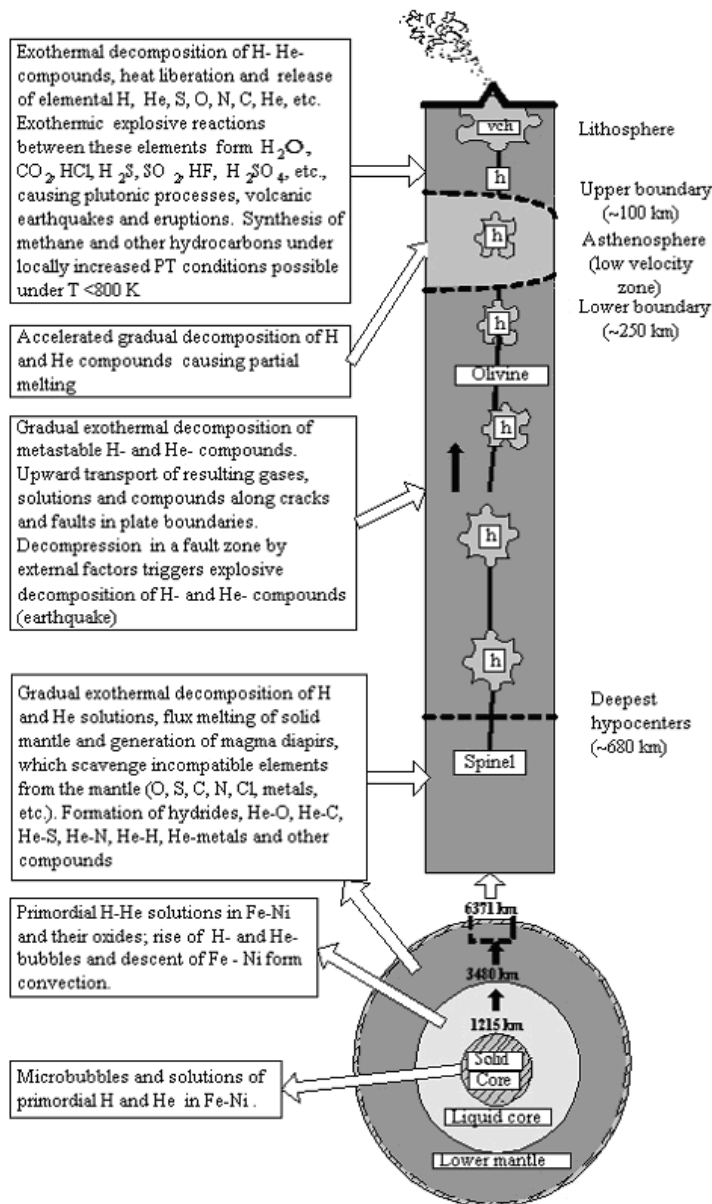


Figure 2: Suggested states and phase transforms of hydrogen and helium degassing from the Earth's interior. h - earthquake hypocenters; vch - volcanic chamber. Volcanic eruption is considered as a special case of earthquakes whereby hypocenters ascend to the earth's surface.

3. If the pressure rise in the potential earthquake hypocenter is not strong enough for further rock destruction, the pressure balance will be restored and the He-liberation process will stop; some of the hot chamber energy will be stored by means of endothermal reactions.

4. If the explosion of He-compounds destroys the initial hypocenter, causing fall of the pressure, further explosions of newly supplied H and He-compounds will proceed, moving upward through the main shock of earthquake to the aftershocks. High-temperature ($>100^{\circ}$ C) brines from deep-sited aquifers are pushed up through the fault zone and, when rising to a spot of stress release (in the upper 300 m of the rock sequence), instantly become steam, with a corresponding volume increase of up to 1,700 times, causing phreatic explosions and - under a wide-range of explosional pressure changes from very high to vacuum - spontaneous combustion of any inflammable volatiles (a possible reason for part of the earthquake-produced fires [90, 91]). An earthquake generated by chemical explosion, contrary to the mechanical quake, can produce all the features and physicochemical anomalies described in the Sect. 1.2.3. It can explain also some of the processes related to human activity: for example, a man-made shock (e.g., nuclear explosion) may produce fracturing and partial decompression in the lithosphere, triggering decomposition of H- and He-compounds, liberating latent energy and consequent earthquakes in months following. This is a possible reason for the general similarity of seismograms of earthquake and underground nuclear explosions (UNE), of the clustering of aftershocks after UNE, and occurrence of aftershocks demonstrating energy release in excess of the energy triggering UNE [92].

7.6 Plutonic activity and volcanic eruptions; phase transformation as the quickest possible process of energy transfer.

We assume that He, H and other elements released during exothermal decomposition of their compounds (O, H, S, C, Cl, F, metals, etc.) will participate in a sequence of exothermal chain reactions of synthesis in between, producing water, salts, and typical volcanic chemicals, including some very active (e.g., HF, H₂SO₄); these reactions release vast amounts of energy, generating volcanic eruption or earthquakes, which are basically the same process.

In special cases, where hypocenters a few hundred kilometers deep explode on intersections of major faults, extrusions of gas-magma-mix can blast straight up to the brittle crust, fracturing it to the Earth's surface,

causing decompression and opening a conduit for a stream of super-heated foaming pyromagma. With falling pressure, the pyromagma will be continuously supplied by chains of explosions of H- and He-compounds and complementing explosive reactions of synthesis, which enlarge the conduit as follows.

With falling pressure, hydrogen and helium become gaseous, their mobility sharply increases; quasi-stable flow of liquid magma changes to principally unstable bubbling and cavitating stream of gas-magma-mix characterized by pulsation and great variations in its discharge even under the same pressure differences. A close analogy to this process is the high-velocity pulsating water steam streaming through the cooling-pipes system of a nuclear reactor, where it may cause formation of local low-pressure zones (relative vacuum, the effect of “ejection”, described by the Bernoulli equation), as well as hydrodynamic cavitation and conforming shock waves; we have to note that the medium in any natural system is less homogenous than artificial cooling liquids.

Another feature: mantle-rock temperatures are close to their melting temperature (Sect. 1); if an earthquake opens fractures for gas-magma flow, hydrodynamic cavitation of the streaming foaming pyromagma, explosive reactions of decomposition and synthesis, and conforming shocks may produce tixotropic changes (drastic fall of the medium viscosity under critical deformation) from solid to liquid in wall-rocks of the mantle, enlarging the conduit and generating additional thrusting magma. Thus pyromagma and highly energized gases bore-up through the plastic rock of the upper mantle and the brittle rocks of the lithosphere. Super-heated liquids of the lower aquifers ahead of them will be thrust, bubbling and cavitating, to the surface, and exploded in stress-relief spots. The magma-water-gas exploding flow (“volcanic tremor”) described above would also produce a pumping effect, which assists in raising the explosive mix. This would be the quickest and most effective mechanism for the magma rise through the plastic and brittle rocks of the lithosphere, perfectly capable of generating breccia-pipes and diatremes.

If the rocks of the crust do not disintegrate from the initial blasts, a concentrated stream of volatiles, resulting from a weakened earthquake hypocenter, may generate a hot density current or diapir, melting through the mantle and slowly intruding into the brittle core. Hot gas flow through fractures and zones of weakness heats the rocks mobilizes and concentrates low-melting of components. He-compounds are stable only at temperatures higher than 1000 K and pressures higher than 14 GPa, i.e., they are not stable in the lithosphere; therefore, in case of slow and long-term decomposition,

their liberated energy and resulting gases would cause plutonic activity, i.e. melting of country rock and forming reservoirs of magma, where consequent fractionation, gravitational differentiation and scavenging of minor and rare elements may take place. This energy and the volatiles would preserve the high temperature and fluidity of the magma in colder surrounding rocks. The majority of atomic elements, liberated as a result of He- and H- compound decomposition, would participate in exothermic reactions, producing different minerals and typical “volcanic chemicals” (HCl, HF, H₂SO₄, SO₂, CH₄, CO₂, H₂O, Na-Cl, K-Cl and Mg-Cl brines, methane and heavier hydrocarbons), some of them stored, some reacting with country rock and producing secondary mineralizations, some migrating upward into a sedimentary sequence [93], generating abnormally high pressures typical to hydrocarbon environments. Methane, hydrogen, and mantle helium found by many researchers in great quantities in volcanic ejections and in hydrothermal fluids related to mid-oceanic ridges (with the characteristic ³He/⁴He of 8.4 times of that of the atmospheric ratio and CH₄/³He = 2.6x10⁶), are quite similar from one region to another, suggesting a non-biogenic origin of methane in these fluids (e.g., [94]).

Any additional decompression in the fault zone will cause aftershocks, whose hypocenters rise closer and closer to surface. Magma melts and volatiles, independent of magma in their amounts and composition, generate an air-lift-like mechanism producing a vertical rising column of foaming pyromagma, magma, or independent gas flow; innumerable detonating blasts of exothermal reactions (“volcanic earthquakes” and “volcanic tremor”) generate shock waves, expel the gases charged by chemical energy, heat and melt older lava and surrounding rocks, thus producing volcanic chambers of liquid magma. Finally, overwhelming pressure of accumulated gas explosions causes volcanic eruption, decompression, and increased exhaust of latent-energy-charged pyromagma and gases from the mantle. Thus, in contrast to a “tectonic earthquake”, all processes become frighteningly perceptible and chemicals testable, as in the case of surface explosion of a nuclear bomb (in contrast to its underground explosion).

We think that the differences between types and scales of earthquakes and volcanic eruptions depend mainly on the supply of He-H-compounds, depth and locality of triggering explosions, local strength of the lithosphere and conductivity of the conduit-system; we think that the events of a particular eruption depend also on the time-span of its preparation, and on the availability and composition of the mantle gases. We think that the physical properties of lavas depend mainly on the amount and composition of gases energized by the latent chemical energy that they contain.

7.7 Helium-3 as a unique measuring device (transformer) correlative to the internal heat flow

As noted in Sect. 4, the remarkable correlations between mantle helium concentrations and internal heat flows were found by many researchers in seafloor hydrothermal fluids already in the 1970s (e.g., [29], pp. 234-235). Hydrothermal vents jetting out water at close to their boiling point temperature ($350^{\circ} - 400^{\circ}\text{C}$ depending on their depth-related pressure) supply the oceans enormous masses of iron, manganese, silica, lithium, rubidium, etc., and deposit Cyprus-type sulfide ore containing great resources of zinc, copper, cobalt, lead, cadmium, silver, and gold. The hydrothermal activity in the spreading zones is comparatively uniform and, according to theory dominating today [95], the great part of the fluxes of the various elements are injected into, or removed from the ocean, by cold oceanic water circulating through submarine ridge crests and reacting with hot basalts. However, the isotopic data as well as the confirming $^3\text{He}/\text{heat}$ ratio, show that the substantial enrichment of CO_2 in the hydrothermal solutions is of a mantle origin ($\delta^{13}\text{C} = -6\text{‰}$); the ^{18}O in exhausting fluids, $+1.6\text{‰}$, reflects basalt equilibrium, confirming the previous results for dredged rocks and ophiolites; the dissolved strontium is essentially the same as in the basalts (0.703), balancing the river input (>0.712) and maintaining the oceanic value at 0.709 (*ibid.*). It seems that all the various elements injected into the ocean are scavenged and imported from the mantle by gas-magma diapirs either directly from the juvenile mantle flow or through the intermediary help of the oceanic water leaching oceanic basalts. As we tried to show in Sect. 7.4, the birth- and rise-related processes of diapirs and their energy are of physicochemical origin where the role of primordial hydrogen and helium is dominant and ^3He is an indicator. In the 1990s the $^3\text{He}/\text{heat}$ correlation became a standard tool for quantification of geothermal heat flux from mid-ocean ridges; however, no mechanism was proposed explaining this correlation.

With one neutron and two protons in its nucleus, a ^3He atom is less massive than a ^4He atom, which has an extra neutron. ^3He zero point motion is greater than that of ^4He , ^3He atom dropped at very low temperature onto the surface of bulk helium-4 floats showing off some remarkable quantum properties, which include particle-in-a-box quantum states and a staircase of magnetization [96]. These are not the lattice magnetic properties of solid metals or minerals, which are functions of the crystal structure and depend on PT-conditions, existing at temperature lower than Curie temperature.

The magnetic properties of atoms and molecules are primarily dependent

on the spin of electrons in a substance. Electrons can spin in one of two opposite directions and any two electrons in the same orbit are constrained to spin in opposite directions. A spinning electron behaves as a small magnet and will produce magnetic field while orbiting the nucleus of an atom. The opposing spins of two electrons on an orbit results in a net zero magnetic moment. The nuclear magnetic moment depends on the nuclear spin. The rules for determining the net spin of a nucleus are: (1) if the number of neutrons and the number of protons are both even, then the nucleus has no spin; (2) if the number of neutrons plus the number of protons is odd, then the nucleus has a half-integer spin (i.e. $1/2$, $3/2$, $5/2$); (3) if the number of neutrons and the number of protons are both odd, then the nucleus has an integer spin (i.e. 1, 2, 3). ^3He has a nuclear spin/quantum no.: $1/2$ (nuclear spin of ^4He is 0) and magnetic properties, therefore it interferes with electric and magnetic fields under any PT-conditions existing in Earth's interior.

Chemical reactions and cracking of crystalloids are accompanied by thermo-galvanic, thermo- and piezo-electric phenomena and by corresponding magnetic fields. The natural concentration of these fields takes place on the surfaces of phase boundaries or boundaries of electro-magnetic discontinuities. Consequently, unlike ^4He , ^3He is characterized by a very high surface activity and is educed out of pores and fractures produced by mechanical processes accompanying exothermal reactions of dissociation of H- and He-compounds. Thus ^3He may work similarly to a transformer in electrical measuring gauges; its coefficient of transformation would be the ratio of ^3He flow to amounts of reagents (^4He , H and elements scavenged by magma-diapirs from the mantle) multiplied by specific energies of physicochemical reactions and transformations, described above in the Sections 3, 6 and 7.2-7.6.

The total heat flow produced by these can be estimated, according to the data summarized by Jean-Baptiste et al. ([59], table 2), as follows.

The ^3He /heat ratio in vent fluids of various hydrothermal sites ranges from 4.3 to 47.0 (10^{-18} mol/J); thus the lowest ratio of 4.3 corresponds to 2.326×10^{17} J/mole of ^3He . Multiplying it by 2,200 mole/year, the ^3He -flow from the lower mantle estimated by Allegre et al. [66], we obtain 5.12×10^{20} J/year, which is equal to half of the present rate of heat flow from the Earth's surface (see Sect. 1.1), and is five times larger than the energy loss involved in earthquake and volcanic activity. These data may be considered as the direct proof of participation of helium in the heat-producing processes, and an indirect support for the hypotheses proposed herein.

8 Conclusions and possible research avenues

We think that the proposed model for conservation of energy during Earth's accretion by the endothermal formation of H and He solid solutions and compounds and its release by degassing and accompanying exothermal reactions described herein, is a main source of tremendous energy for terrestrial dynamics. This mass-transfer-related energy, in contrast to energy from traditional sources (Sect. 1), generates convection in the Earth's liquid core; it produces liquid magma in the mantle and supplies energy to rising diapirs and plumes; it can be easily transferred along major faults, quickly concentrated, and produces very high velocities of energy release and all the geophysical and geochemical anomalies typical of earthquakes. The proposed chain of reactions supplies highly energized mantle gases to the lithosphere, where they melt the asthenosphere and the upper mantle, bore conduits and chambers for generated magma by melting and explosions, rise through the brittle rocks and provide the energy for igneous activity and volcanic eruptions with all their manifestations.

The model is supported by undeniable facts, namely: (1) continuous tremendous degassing of primordial hydrogen and helium from Earth's interior; (2) very high energy-capacity of H- and He-compounds, some of which have already been studied in laboratories under ultra-high PT-conditions similar to those of the Earth's interior; (3) good correlation between the mantle helium- and the internal heat flow. It is based on published and accepted geological data, on the most basic geological theories, which include plate tectonics and surge tectonics theories, and on the universal physico-chemical laws.

The comprehensive model proposed herein may help to find solutions to practically all enigmas and questions related to the lack of plausible energy source for the main terrestrial processes (Sect. 1). It also provides a clue to the origin of abiogenic hydrocarbons (mostly methane) which are produced in parallel to volcanic and plutonic processes by reactions of elemental products of decomposition of He- and H- compounds, and cause the abnormally high pressures typical to the mantle-related hydrocarbon environments.

Release of primordial energy of the He- and H-compounds through a sequence of dominantly exothermal transformations (phase-transfer) is the quickest and most efficient process of energy transfer. These processes are bound to be responsible for the temperature of Earth's surface, which stays in the range comfortable for life-existence in spite of the approximately two-thirds increase of energy flow from the sun. This increase is balanced by the slow decrease of energy release by primordial He- and H- degassing and by

radioactive decay.

Because of universality of the physicochemical laws and of the helium and hydrogen abundance in space, the processes described herein are also universal and are bound to work on any planet in the solar system and elsewhere. Thus the H-He-degassing hypothesis may also offer a better understanding of volcanic and seismic activity on the moon, which has had similar volcanism and moonquakes, but only on its near-to-earth side and which usually occurred at a fixed phase of the lunar tidal cycle [8]. The far side of the moon lacks seismic activity and large, lava-filled basins (“seas”), volcanoes and scarp-like faults. The absence of extensive lava spreads on its far side may also be related to the tidal forces exerted by the Earth on the moon (only on its near-to-earth side), triggering quakes and eruptions, between three and four aeons ago. The cessation of volcanic activity on the moon, and the relatively low energy represented by moonquakes ($2 \cdot 10^{13}$ ergs per year, compared to $10^{24} - 10^{25}$ ergs per year by earthquakes [8]), may be indicative of the final stages of He- and H-degassing of the moon. Its degassing must be several orders of magnitude quicker, and its primary resources smaller than in the case of Earth.

The hypotheses proposed herein appear to be objectively testable. For example: it was thought that observations of the direction of the initial movements on the seismograms would give a very simple method of distinguishing between underground explosions and earthquakes due to elastic rebound; this is not so, most records of both of them show similar signatures [67]. This conspicuous similarity provokes the same question that we are dealing with in this study: may be all of them are underground explosions, cumulatively chaining up to one minute long in a great earthquake or single and concentrated into few milliseconds in atomic blast? Than, we have to find (and record for comparison) the evident case of purely mechanical elastic rebound? May be seismograms recording earthquake-shock on the millisecond scale will bring some enlightenment?

We suppose that for “any small earthquake...cascading into a large event” [97] some monstrous energy must in some way be concentrated at a certain point, in a certain form, in a certain medium, and by some means triggered to explode. The question arises, whether these energy concentrations of planetary scale do somehow manifest themselves before a major eruption? A pressure increase at earthquake hypocenters may, in theory, be monitored by the correlation of primary and secondary wave propagation in “seismic gap” areas.

If a shallow “tectonic” earthquake is akin to an unsuccessful volcanic eruption, there is a chance that in its epicenter some typical volcanic chemi-

cals could be found, which broke through the overlying strata to the surface. The detection of CO, CO₂, SO₂, HCl and temperature estimation of the emanating gases can be made by means of remote sensing similarly to detection of volcanic gases [98], close to the real time of the earthquake eruption. Entrapment of resulting reactive volatiles and mineralizations confined in country rock can be studied by drilling in a shallow earthquake-hypocenter.

Stoichiometry of earthquake/volcanic processes can be studied in a search for influx of energy latent in chemical compounds. The temperature generated by partial melting and ascending magma should decline in accordance with its loss of heat to the surrounding matter; the temperature regime and possible thermal anomalies can be studied using drillholes in the periphery of an active volcano. The changes of geophysical fields together with the succession of characteristic geochemical processes at the hypocenter or magma chamber may also be monitored, thus providing a method for short-term prediction of earthquakes and volcanic eruptions: this was done, in part, but with a great success, by the USGS volcanologists, during the Pinatubo eruption of 1991.

This work was initiated in order to explain the driving force behind earthquakes and volcanism; soon it became clear that the physicochemical energy source suggested herein is universal, i.e., it may participate in any terrestrial process, filling holes in the theories concerning evolving Earth. The hypotheses proposed herein do not presume to give a full solution to all the topics that we discussed; however, they may provide a base for constructive discussion.

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