

Low Energy Nuclear Synthesis in Earthquake, Volcanic Eruptions, and Genesis of Heavy Elements

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Abstract

1989 is the beginning of intensive research into the phenomena of cold nuclear fusion, renamed “The Low Energy Nuclear Synthesis Reactions” (LENR). Based on these results and the long-term research of earthquakes and volcanic activity, the authors of this article put forward a hypothesis about the mainly chemical nature of the energy released at earthquakes and volcanic eruptions with the participation of primordial hydrogen and helium: high mobility of hydrogen and oxidizers provide focusing and accumulation of the latent chemical energy, which is realized suddenly and instantaneously as explosions and initiate the earthquake and/or eruptions. The volcanic eruption is viewed therein as a special type of earthquake whereby the hypocenter rises to the earth’s surface. The authors proposed a new hypothesis that LENRs add significant energy to earthquakes and eruptions at the synthesis of elements lighter than iron, thus creating excess energy, which is partially used for the synthesis of heavier elements. The combination of the chemical and nuclear reactions transforms these centers of geophysical activity into giant reactors where the nuclear, chemical, and thermal transformation of mantle materials and the creation of primary deposits of heavy elements such as uranium, thorium, gold, etc. So, all chemical elements heavier than iron are not detected in the solar wind. These elements discovered on our planet could be (and probably were) created on planet Earth and not imported from explosive supernovae or far-off remote stars. To the best of our knowledge, this hypothesis has not been proposed until now.

Keywords

Low Energy Nuclear Synthesis Reactions” (LENR), Volcanos, Earthquakes, Ore-Deposits

1. Introduction

In 1985, Martin Fleischmann and Stanley Pons observed anomalous behaviors of an experimental electrochemical cell that included melting and partial vaporization of the palladium cathode, resulting in the electrolysis of the heavy water containing deuterium. In 1989, a hypothesis about cold nuclear fusion was published [1]. 1989 marked the beginning of intensive research into phenomena called “Low Energy Nuclear Synthesis Reactions” (LENR). By 2010, these LENR studies had resulted in the ability to synthesize nearly all of the known chemical elements, even the new trans-uranium, and proposed several hypotheses regarding the significant role of LENR in planetary cores, the source of the internal energy of Earth and giant planets.

More than 20 years ago, the authors of this article put forward a hypothesis regarding the energy released during earthquakes and volcanic eruptions that it is mainly chemical in nature, with the participation of primordial hydrogen and helium [2] [3]. The experimentally established and theoretically corroborated phenomenon of the conversion of trapped and stored during Earth’s accretion latent energy of primordial hydrogen and helium, released by degassing processes from the Earth’s core and lower mantle due to the decomposition of their compounds and interstitial solutions into a totality of different types of thermal, electromagnetic and chemical energies of active compounds that are responsible for the major terrestrial processes. The high mobility of hydrogen and oxidizers (oxygen, sulfur, and halogens) provides the focus and accumulation of their latent chemical energy, which is realized suddenly and instantaneously as an explosion that initiates earthquakes and/or eruptions. A volcanic eruption is viewed as a special type of earthquake whereby the hypocenter rises to the Earth’s surface; eruption may be accompanied by volcanic tremors, which are harmonic or inharmonic ground vibrations with durations lasting from minutes to months.

Examples of critical analyses were provided previously [2] [3]. Thus, the paradigm of earthquake explanation “by elastic rebound” is over 100 years old; it cannot provide short-term earthquake prediction (when, where, and how strong) and cannot explain all the accumulated facts. For example, it is known that the maximum amount of elastic energy accumulated in any material equals its critical fracturing energy. The authors calculated this critical energy for a block of high-quality structural steel, $600 * 100 * 20$ km, which is the approximate size of the block of faulted lithosphere rock in which the Alaska 1964, M 8.6 earthquake, or $5 * 10^{18}$ J, was generated. The steel block result ranged from $5 * 10^{14}$ to $3 * 10^{15}$ J [2]. Thus, the earthquake’s energy in the faulted country rock was several orders of magnitude greater than what is considered possible for structural steel. Its seismic velocities were close to sound velocities and higher than those of mechanical fracture propagation.

Volcanic eruptions are explained, even today, by magma-steam and phreatic explosions, which provide the maximum power at the beginning of the process. However, the great eruption of Tambora in 1815 released kinetic energies of 10^{20}

J, equivalent to an explosion of 24 billion tons of TNT, and generated pressures of a few tens of Giga-Pascal, too much for a steam explosion; it reached its maximum only after 7 months of continuous activity, and ultimately lasted 15 months [ibid., references there]. Thermal energy radiated by the boiling lava lake Nyiragongo (Zair) in 1977 was 12,200 MW (a power three times greater than that produced by the Chernobyl nuclear power plant reactor). The power supply for keeping the boiling lava lakes boiling is usually explained by buoyant lava circulation through deep channels, but when the 1977 earthquake emptied the Nyiragongo crater, Tazieff could not see any channels, liquid lava, or even fumaroles there [4] [5]. The average annual release of energy in earthquakes is roughly 10^{25} ergs (10^{18} J) [6]. The heat escaping Earth's interior is estimated at 46 ± 3 TW based on heat-flow measurements collected from twenty thousand boreholes distributed worldwide, corresponding to 1.451×10^{21} J/year [7] [8]. The well-known dramatic results of these phenomena are caused by huge amounts of energy release focusing on time and space. There are three possible ways for such a rapid energy release: hydrothermal, chemical or nuclear explosions.

Hydrothermal explosions contribute to geyser and volcanic activity [9]-[13], where the density of the realized energy is limited by pressure, temperature and volume of steam, and by the properties of the heater [10] [14]. The observed hydrothermal explosions release energy that is significantly below that of certain earthquakes and eruptions.

Nuclear or thermonuclear explosions (100 - 1000 MT TNT equivalent) release energies of 10^{17} - 10^{18} J. However, thermonuclear explosion is impossible in the Earth's interior because the nuclear explosion needs a very high concentration of enriched ^{235}U or ^{239}Pu , which is not present there in any significant concentrations. Natural uranium contains 99.3% of uranium isotope ^{238}U , which is fissionable but not fissile. The fissile ^{239}Pu and ^{233}U are produced in nuclear reactors from ^{238}U and from ^{232}Th . Dispersive distribution of the uranium and thorium in the lithosphere and mantle may be assumed from the data from geoneutrino spectroscopy [7] [8]. Seismic prints of nuclear, thermonuclear and chemical explosions are largely distinctive, which is the basis for the international monitoring system of nuclear tests. For years, this system has not detected any nuclear explosion that could be mistaken for a natural earthquake eruption or, conversely, mistake the natural earthquake for a nuclear explosion (<https://www.ctbto.org/our-work/international-monitoring-system>). The system has already proved its effectiveness, having detected all six of North Korea's declared nuclear tests between 2006 and 2017. Furthermore, it continuously identifies various phenomena, including earthquakes, volcanic eruptions, meteor strikes, and nonnuclear explosions, such as the blast that devastated Beirut in 2020.

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nomenon of the conversion of trapped and stored during Earth's accretion latent energy of primordial hydrogen and helium, released by degassing processes from the Earth's core and lower mantle due to the decomposition of their compounds and interstitial solutions into a totality of different types of thermal, electromagnetic and chemical energies of active compounds that are responsible for the major terrestrial processes. The high mobility of hydrogen and oxidizers (oxygen, sulfur, and halogens) provides the focus and accumulation of their latent chemical energy, which is realized suddenly and instantaneously as an explosion that initiates earthquakes and/or eruptions. A volcanic eruption is viewed as a special type of earthquake whereby the hypocenter rises to the Earth's surface; eruption may be accompanied by volcanic tremors, which are harmonic or inharmonic ground vibrations with durations lasting from minutes to months.

In view of the above, the most likely mechanism of the onset of an earthquake or eruption is a chemical explosion, or detonation [2] [3] [15] [16] that begins from the foreshocks and allows accumulation and fast release of a huge quantity of energy. There is latent energy of the chemically active substances that are realized at degassing and phase transition processes which are accompanied by thermal and electrochemical processes. The galvanic and thermal currents create a geomagnetic field [17]. The decomposition of solid and liquid solutions, dissociation, and chemical transformation of mantle rocks leads to the formation of an explosive mixture of hydrogen and/or methane (in the lithosphere) with oxygen or other oxidizers.

The proposed hypothesis herein demonstrates the possible impact of the LENRs on endogenic processes in earthquake hypocenters and in volcanic chamber centers with maximum density energy release. In these centers, chemical and nuclear reactions reinforce each other; LENR releases additional energy to synthesize helium and other chemical elements up to iron. This new hypothesis expands our understanding of the physics and chemistry of earthquakes and volcanic eruption processes and explains the formation of primary volcanogenic, magmatic-hydrothermal, and other related deposits of many chemical elements, including economic deposits of uranium, thorium, REE, gold, and others.

2. Chemical Explosions Associated with Earthquakes and Volcanic Eruptions

The probability of explosion is determined by the following conditions: Availability of fuel (hydrogen or methane in the Earth's interior), availability of oxidants (oxygen, sulfur, chlorine, fluorine, etc.), mixing of fuel and oxidant for the formation of flammable and explosive composition, and existence of the ignition source or self-ignition conditions [18] [19].

The availability of fuel and oxidants is determined by their high concentrations in space and in the solar wind continuously bombarding Earth [20]-[22]. It is apparent that all chemical elements of solar wind (see **Table 1**) participated in accretion and formation of Earth including hydrogen, carbon, oxygen and sulfur. It

appears that most of the primordial hydrogen, helium, and oxygen were captured during Earth's accretion [2] [3] [22]-[24] [26] [27]. Solar wind bombarding and Earth's degassing processes are accompanied by formation in its nebula of the chromophores HHe^+n , H_2He^+n , and He^+n clusters that likely promoted capture and absorption of helium and hydrogen [23]-[25]. The abundance and chemical activity of hydrogen, oxygen and carbon resulted in their capture and absorption by the earth's atmosphere, hydrosphere, lithosphere and mantle. Also possible is hydrogen incorporation into Earth's core [26], which may contribute to deep Earth's geodynamics [22] [27]. Formation of hydrocarbon compounds at upper mantle thermobaric conditions is also possible [28].

Table 1. Abundance of the chemical elements in solar corona and wind [20].

Element	Element Number	Space, Solar wind, ppm
Hydrogen	1	739,000
Helium	2	240,000
Oxygen	8	10,400
Carbon	6	4600
Neon	10	1340
Iron	26	1090
Nitrogen	7	960
Silicon	14	650
Magnesium	12	580
Sulfur	16	440

There is an oxygen cycle and long-term exchange of oxygen and oxygenated species between deep earth, mantle, and exosphere [29], where oxygen acts simultaneously as a catalyst in Earth's interior [30]. It is well known that "99% of the gas molecules emitted during a volcanic eruption are water vapor (H_2O), carbon dioxide (CO_2), and sulfur dioxide (SO_2); all these compounds result from exothermic reactions. The remaining 1% is comprised of small amounts of hydrogen sulfide, carbon monoxide, hydrogen chloride, hydrogen fluoride, helium, and other minor gas species" [USGS, <https://www.usgs.gov/faqs/what-gases-are-emitted-ki-lauea-and-other-active-volcanoes>]. During 2014-2015, the eruptive period of the Nakadake crater, Aso volcano in Japan, the ratio of the gas's $\text{H}_2\text{O}/\text{SO}_2$ increased from 30 to >60 [31], demonstrating that the reactions of hydrogen and oxygen are major source components of the chemical energy realized in Earth's interior during eruptions and earthquakes.

Thus, it is clear that hydrogen and oxygen are available in all layers of the earth. Lithosphere contains flammable hydrogen and methane—explosive hydrogen compound (see Table 2). Volcanic eruptions are often observed as a stream of natural explosions (sudden, rapid releases of energy that produce potentially damaging

pressures), fires, or deflagrations (flame speed is lower than the speed of sound, which is approximately equal to 335 m/sec at atmospheric pressure) and detonation (an explosion where the flame speed is greater than the speed of sound) [33] [34]. Explosion or detonation is possible when there is 1) availability of the reactive composition of the gaseous mixtures, 2) the critical initiation energy, 3) the existence of a critical radius of the pores or gaseous bubble, which corresponds to the blast wave produced by the initiator and to the Chapman-Jouguet (CJ) detonation. All these conditions were essentially based on the Zel'dovich-von Neumann Döring (ZND) model of detonation waves [33]-[35].

Table 2. Properties of hydrogen and methane [19].

Name	Dimension	Hydrogen	Methane
Molecular mass	g/mol	2.016	16.043
Boiling temperature	K	20	111
Liquid density	g/ml	71	422
Limits of flammability in air	Vol %	4 - 75	5.3 - 17
Explosion limits in air	Vol %	18.3 - 59	6.3 - 13.5
Minimum spontaneous ignition pressure	Bar	~41	~100
Minimum ignition energy	J	0.02	0.29
Flame temperature in air	K	2318	2148
Autoignition temperature	K	858	813

Note that methane is a highly flammable and explosive component of mine gas [32].

An earthquake is an underground explosion whose intensity depends on the depth (from a few kilometers or tenths of kilometers to hundreds of kilometers) of the foreshock hypocenter (explosion center) and the quantity of the detonated explosive. One can hear a far-off “boom” and perhaps feel a weak concussion. The next foreshock (or main shock) will occur at a lesser depth. Sailors have compared it with the sound of a far-off artillery cannonade. If the hypocenter is close by, one will feel the hot wind and an air blast and will see a growing dust cloud growing and closing in on the view of the disaster: View of smashed and falling buildings, formation of rupturing and closing of these faults; there is a lot of injured and buried people. Similar to the surface earthquake explosion would be the chamber explosion of the volcanic eruption. Chemical explosions are the trigger, the first step of earthquakes and eruptions [2] [3] [15] [16]. The chemical explosions release the energy, which: a) can be easily focused; b) is of very high density; c) offers very high velocities of energy release; d) may be transported with high density and relatively small losses over long distances. Such chemical sources of energy in the mantle may be quasi-constantly discharged and practically limitless [2].

Growth of temperature increases the range of the explosive mixture from (4 - 75) to (1 - 90)% mole fractions of hydrogen at 25°C and at 400°C, correspondingly [36]. Formation of the reactive composition of the gaseous mixtures (i) requires

fuel and oxidant gas mobility, which increases with temperature and decreases with pressure [37]. The concentration and mobility of hydrogen depend on pressure, temperature, and the presence of helium and other noble gases [38]-[42]. Hydrogen, water, and noble gasses change mantle rocks' conductivity, diffusion permeability, viscosity, and P-T phase boundaries [41] [43]-[49]. Many experimental and theoretical works have been devoted to studying the possible phase transformations of mantle materials with depth.

Unfortunately, these works mainly focus on equilibrium processes, and static phase diagrams do not consider the principally dynamic nature of all the phenomena. Among other processes, solar and moon tides create pressure expansion waves in the mantle; their speed decreases linearly with increasing depth, from more than 460 m/sec on the equatorial surface to 405 m/sec at a depth of 800 km. The prerequisite for explosions triggering earthquakes and eruptions is the creation of the detonation cells and the accumulation of the explosive gas mixtures within. The dynamic embrittlement leading to the formation of microcracks and cracks at the passing of tidal waves is likely the basic route of this process. The phenomenon of dynamic embrittlement is well-known [50]-[54]. It is a non-monotonic function of temperature and depends on pressure and loading rate that is accompanied by the adsorption/desorption of hydrogen and other substances on the grain boundary. The dynamic embrittlement of mantle rocks enriched by hydrogen, oxygen, and noble gases requires future study. Consider that tidal waves are triggers of earthquakes and eruptions [55] [56]. Changes in the pressure, temperature, composition, and structure of mantle materials with depth lead to changes in physico-mechanical properties that are reflected by seismic wave velocity, as illustrated in **Figure 1**.

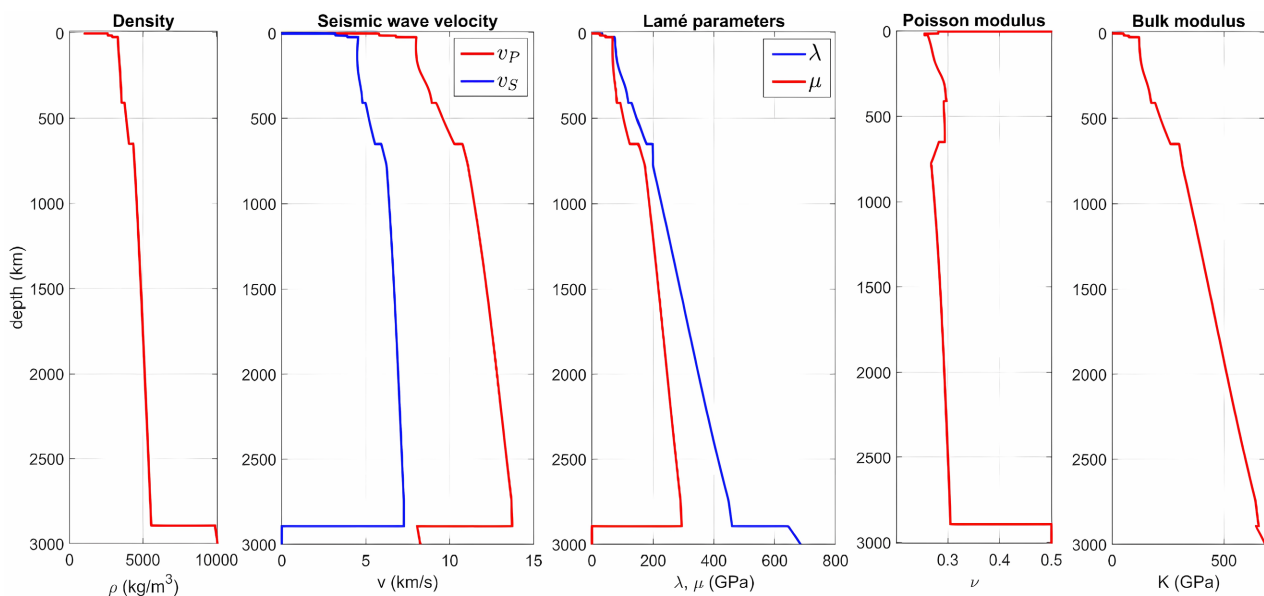


Figure 1. Average physical properties derived from seismic waves velocity as a function of depth in the crust and in the mantle. Seismic waves velocity data from (B. Kustowski, G. Ekström, A. Dziewoński, Anisotropic shear-wave velocity structure of the earth's mantle: A global model. *J. Geophys. Res. Solid Earth* 113, 6 (2008)), STW105 reference model (2008) [57].

A decrease in the rate of tidal waves and changes in the physicochemical properties of the mantle rocks with depth limits determines the maximum possible depth of earthquake hypocentres that corresponds to all known observations [58]. Above the mantle transition zone, increases in pressure and temperature with depth expand the boundaries of explosive gaseous composition, thus increasing the possibility for explosion (earthquake, eruption) [36]. The unique role of hydrogen and helium in planetary formation and their dynamics has been described [2] [3] [15] [22]-[25] [27] [59] [60]. The helium-hydride dispersion in space and planetary nebulae has been discovered recently. The transition zone is distinguished by a high-water content [61]. The water content increases in the mantle transition zone [61]. Helium and other noble gases improve the mobility of hydrogen and oxygen [47] [48] [62]-[64]. These gasses and water act as a work body that increases the efficiency and power of explosions [65] [66]. The immiscibility of hydrogen with water in the upper mantle at a pressure of more than 2 GPa leads to the local occurrence of immiscible H₂-rich fluids that may be responsible for the formation of explosive mixtures [64] [67]. The existence of water in the mantle enables physicochemical and electrochemical processes, including hydrous magma [68], and most likely evolve into earth's hydrogen-oxygen cycle [29] [30] [69] [70]. Note that spontaneous combustion has been observed at room temperature in micro-bubbles of 5 - 20 microns hydrogen-oxygen mixtures at atmospheric pressure instead of the existing water—extremely effective cooler [71] [72]. These sizes are less substantial than the typical grains and pores in rocks [73] [74]. So, explosions of the porous rocks containing hydrogen-oxygen and methane-oxygen gas mixtures are the most probable origins of earthquakes due to the widespread presence of hydrogen, methane, and oxygen in the earth's interior [28] [75] [76].

Several brief conclusions of this part are presented as follows:

- Compositions and conditions in the upper mantle and lithosphere provide the chemical chain reactions that cause the explosions that are at least the trigger of, as well as the important energy source of earthquakes; hydrogen and methane are most likely the major fuels (or reactants) of these explosions or detonations; oxygen and sulfur are major oxidants;
- Helium plays a significant role in hydrogen transport and distribution through the formation and decay of helium-hydrogen compounds;
- Helium and argon increase the deformability and elasticity of silicate rocks, accelerate diffusion, and improve the transformation of the chemical energy into seismic (mechanical) energy by acting as a working fluid–gas, which expands at heating and contracts at the front of shock/blast waves, expanding after they pass.
- The minimal radius of pores or cracks in earthquake hypocentres may be associated with increased temperature and pressure with depth, which increases the critical rate of brittle cracks and seismic waves. As the hypocentres' radius increases, so does the linear speed of tidal waves. The combined action of these factors leads to the possibility of microcrack generation and pore openings

necessary for creating detonation cells with explosive gas mixtures at depths of less than 700 - 750 km (see data in **Figure 2**).

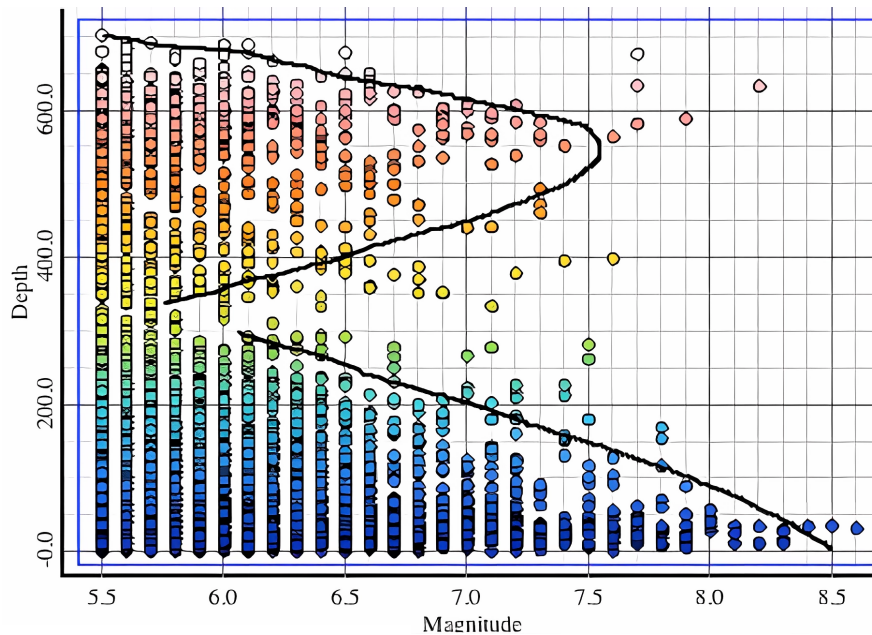


Figure 2. Distribution of earthquakes by magnitude and depth.

(http://app.earth-observer.org/data/basemaps/images/global/Earthquakes_512/EarthquakesGt5Depths_512/EarthquakesGt5Depths_512.html).

3. Necessity of LENRs on Earth for the Internal Energy Balance

The heat escaping Earth's interior is estimated at 46 ± 3 terawatts based on heat-flow measurements collected from twenty thousand boreholes distributed worldwide. Earth's internal energy budget includes both non-radiogenic and radiogenic components (**Table 3**).

Table 3. Non-radiogenic components of the Earth's energy budget [77].

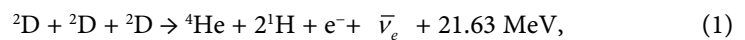
Name of Process	Energy, TW
Mantle differentiation	0.6
Thermal contraction	2.1
Earthquake-induced gravitational energy	2
Radiated seismic energy	0.3
Tidal friction	1 - 2

There are two types of radiogenic sources of energy decay of the radioactive isotopes and low-energy nuclear synthesis reactions (LENR) of elements lighter than iron ($z = 26$).

Geoneutrino spectroscopy enabled the estimation of the following decay im-

pact: ^{238}U - 8TW, ^{235}U - 0.3TW, ^{232}Th - 8TW, and 40K - 4TW [8]. Thus, the total heat flow of the nuclear decay and the non-radiogenic sources is 20 ± 0.5 TW.

There is a reason to look into LENR as the additional source of Earth's internal energy over the billions of years of heat generation, creation, and maintenance of geomagnetic field and lithospheric plate motion [78]-[83]. The discovery and research of low-energy nuclear fusion reactions (LENR) [1] [84]-[87] have led to proposed hypotheses regarding LENRs as major sources of Earth's and other planets' internal energies. The possible occurrences of LENR in the earth's core and in gaseous giant planets could be the result of conditions (high pressures and temperature) that lead to electron degeneracy and the possibility of three-body nuclear fusion of deuterium [81] [82]:



where: $\bar{\nu}_e$ is an antineutrino.

Magma can be described as a warm dense matter (WDM) [83]. Warm dense matter is an exotic state that is characterized by such high density and temperature that Coulomb coupling correlations, thermal excitations, and fermionic exchange effects are equally significant [88]. The WDM state of magma may result from thermo-hydraulic shocks resulting in explosions and gaseous bubble collapse [89]-[92]. These thermo-hydraulic shocks create conditions for LENR based on muon-catalyzed fusion (μCF) [83] [93].

4. Centers of Geodynamics Are Most Favorable for LENRs

Results of the theoretical and experimental studies of LENR reactions in solids and melts [94]-[102] have allowed researchers to propose several hypotheses, despite the fact that no satisfactory physical theory exists for low-energy nuclear reactions.

A Tokyo University group studied protons and tritons from the $d(d,p)t$ reaction in liquid In, Sn, Pb and Bi during $D + 3$ molecular deuterium beam bombardment of $15 < E < 60$ keV and $D(d,p)T$ reactions in various solid metals at bombarding energies between 2.5 and 25 keV; they also studied $^6\text{Li}(d,\alpha)^4\text{He}$ reactions in Pd and Au at bombarding energies between 30 and 75 keV. The goals of these studies were the experimental measurement of the screening energy and its influence on LENR rate [96]-[98].

LENR experiments also demonstrated a row of nuclear reactions that lead to creation or transformation of elements. For example, LENR experiments with deuterium in metals allowed the detection of: Sc, Ti, V, Ag, Cd, In, P, Cl, Br, Ge, As, Kr, Sr, Y, Ru, Xe, which were found in Pd. Moreover, the special type of electrical discharge between electrodes led to the appearance and accumulation in the water of a number of chemical elements, from Li to Pb, including deuterium and tritium [101].

The multi-nuclear nature and the "cooperative colliding process" hypothesis are supported indirectly by the results of the study of the catalytic action of neu-

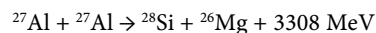
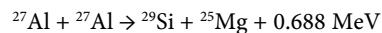
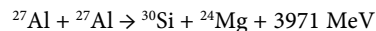
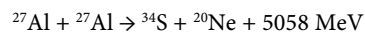
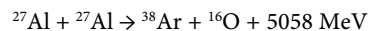
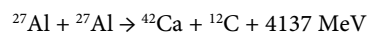
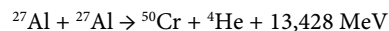
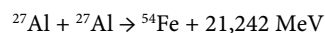
trino and antineutrino [101].

The observed LENR rate cannot be explained by conductive electron screening alone and needs to consider the environments surrounding the nuclei; thus, the authors proposed the hypothesis of multinuclear “cooperative colliding process” bombardment [96]-[98].

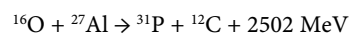
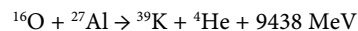
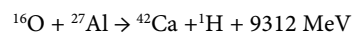
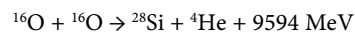
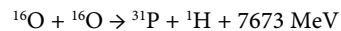
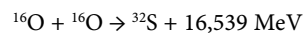
The cooperative character of the processes demanding for nuclear synthesis (LENR) is supported by [86] [87] [99] [103] [104] (see **Table 4**). This suggestion has been influenced indirectly by low-energy neutrino catalytic activity in LENR [101]. “Unlike many other hypotheses, the hypothesis that low-energy neutrinos participate in nuclear transformations allows us to explain many features of LENR:

- The appearance of a large variety of nuclides not only in “fuel”, but also in the surrounding matter;
- The necessity to heat or otherwise provide energy to matter particles;
- The need for a sufficiently dense environment;
- The lack (or very low intensity) of hard nuclear radiation;
- It is important to note that there is no “Coulomb barrier problem” in nuclear transformations involving neutrinos.” [101].

Table 4. Possible nuclear reactions in corundum (Al_2O_3) [101].



Additional nuclides can arise from interactions of two oxygen nuclei and nuclei of oxygen and aluminum:



The known results of LENR studies in solid melts and electrolytes indicate the possibility of synthesis of all elements in mantle conditions, while in the core containing mainly iron and nickel, and a single possible source of nuclear energy is hydrogen isotopes (see above).

Synthesis of the heavy and superheavy elements under laboratory conditions is a striking example of LENR that is principally different from those of the explosion of a supernova (Figure 3). According to existing theories, uranium and other heavy elements have a mainly cosmic origin, as suggested by studies of the compositions of solar wind meteorites and micrometeorites [106]-[109], and this is reflected in NASA's periodic table. Supernova explosions are accompanied by heavy-element synthesis and these elements' enrichment of meteorites and cosmic dust. Different stars' conditions favor the synthesis of different elements inserted into the atmosphere, hydrosphere, and lithosphere via bombardment by meteorites and heavy particles [110]. Modern researchers suggest that chemical elements are formed by nucleosynthesis in the cosmos and during the evolution of stars, as shown in Figure 4.

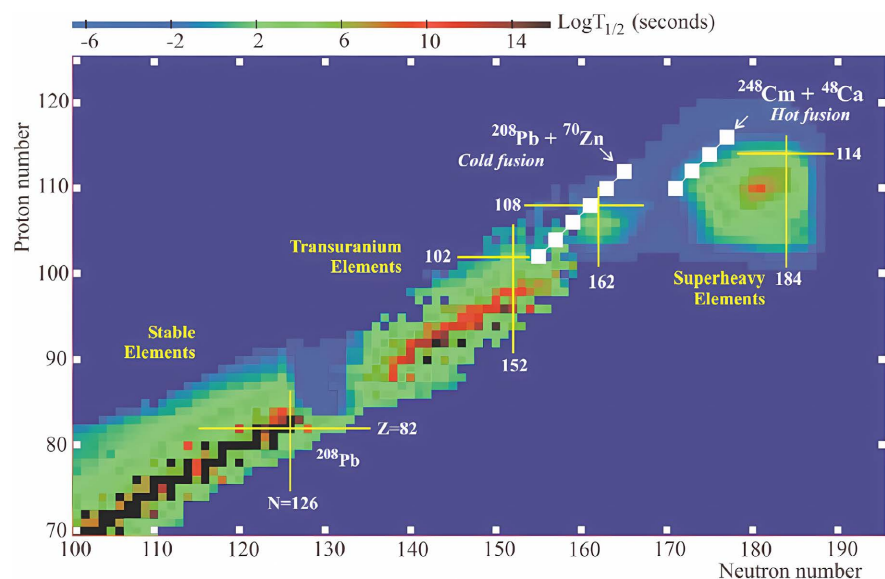


Figure 3. Chart of the nuclides, the domain of the heavy and superheavy elements [105]. White squares show the chains of the sequential α -decay of nuclei of element 112 produced in the cold-fusion reaction $^{208}\text{Pb} + ^{70}\text{Zn} \rightarrow ^{277}\text{112} + n$ and element 116 produced in the hot fusion reaction $^{248}\text{Cm} + ^{48}\text{Ca} \rightarrow ^{293}\text{116} + 3n$. Eight extra neutrons would increase the half-life of $^{277}\text{112}$ by four or five orders of magnitude [105].

The constant decay rate of isotopes forms the basis for the radiometric scale used in geology to estimate the age of rocks and deposits. The known equation for rock dating is as follows:

$$t = \frac{1}{\lambda} \ln \left(1 + \frac{D}{P} \right) \quad (1)$$

where: t is the age of the rock or mineral specimen;

D is the number of atoms of the daughter product today;

P is the number of atoms of the parent isotope today;

λ is the appropriate decay constant, which for each parent isotope is related to its half-life:

$$t^{1/2} = \frac{\ln 2}{\lambda}$$

The Decay constant is equal to $1.45 \times 10^{-10} \text{ yr}^{-1}$ for U-238.

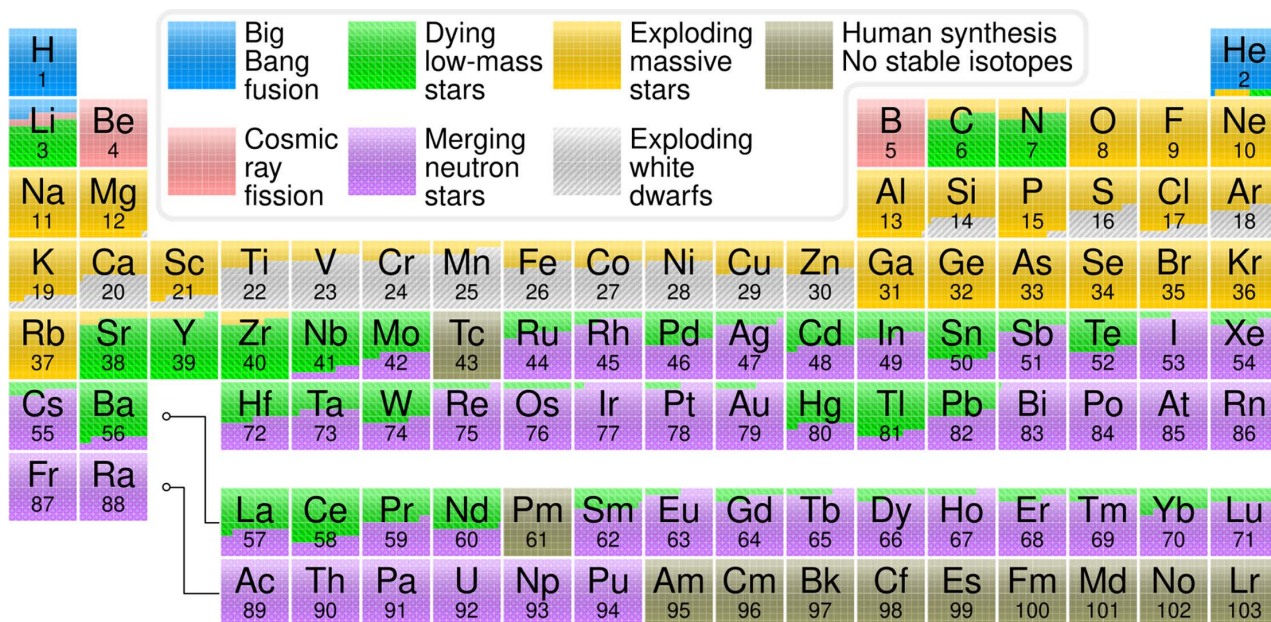


Figure 4. A periodic table showing the origins of the elements in the Solar System, based on data by Jennifer Johnson at Ohio State University. The percentages of each element's origins are represented by squares (out of a hundred) to make it easier to estimate proportions; hovering over the SVG image gives precise figures as tooltips. Elements above the lawrencium are not included. Johnson's explanation cautions, "We still don't know everything...". The image is NASA's Astronomy Picture of the Day 2020-08-09, 2017-10-24 and 2023-01-08 (https://commons.wikimedia.org/wiki/File:Nucleosynthesis_periodic_table.svg).

Influence of the chemical polarization [138] on nuclear process kinetics needs a combination of different isotopes and techniques for precise timing of rocks and deposits.

The radiometric scales also use the medium- and short-life isotope relationships among different isotopes, and chemical and activation analysis of different daughter products as shown in **Table 5**. This technology allowed us to estimate age of the meteorites [112]-[119]. Moreover, such analysis detects and proves the existence of nucleosynthesis in meteorites and asteroids [120]-[122].

Table 5. Various isotopes used for geophysical dating [110] [111].

Parent Isotope	Stable Daughter Product	Currently Accepted Half-Life Values
Uranium-238	Lead-206	4.5 billion years
Uranium-235	Lead-207	704 million years
Thorium-232	Lead-208	14.0 billion years
Rubidium-87	Strontium-87	48.8 billion years
Potassium-40	Argon-40	1.25 billion years
Samarium-147	Neodymium-143	106 billion years

5. Possibility of Planetary Origin of the Heavy Elements

Radiometric dating indicates a “young” age for most of the uranium and rare earth deposits and meteorites [123] [124].

The age of the Gneiss formation from the Karelian area of eastern Finland is 2.7 Ga [125], old Granite Transvaal, South Africa is 3.2 Ga, and Morton Gneiss from southwestern Minnesota is 3.6 Ga [126]. Radiometric dating is based on the analysis of concentrations of short-life and long-life isotopes and their decay products. For example, the four isotope systems (Rb-Sr, Sm-Nd, U-Pb, and Re-Os), when applied to Fe-sulphides and CaSiO_3 inclusions within 13 sub-lithospheric diamonds from Juína (Brazil) and Kankan (Guinea) give broadly overlapping crystallization ages ranging from around 450 to 650 million years ago [127]. “The South Faizuly manganese deposit was formed in the following four consecutive stages: 1) Sedimentation and diagenesis of ore-bearing sediments in the Middle Devonian period (395 - 349 million years ago), 2) Metagenesis of Mn-bearing rocks in the Middle Devonian-Early Carboniferous period, 3) Hydrothermal-metasomatic stringer ore mineralization during tectonic deformation of volcano-sedimentary rocks in the Middle Carboniferous-Permian period (about 300 million years ago), and 4) Supergene alteration and partial denudation of the deposit in the Mesozoic-Quaternary period (about 250 - 66 million years ago)” [128].

The chemical and isotopic analysis of rock samples from uranium deposits does not correspond to their extraterrestrial origin.

The planetary exothermic low-energy nuclear synthesis of relatively light elements ($Z \leq 26$) may take place in either solid or liquid (melt) phase and does not need the high temperature required for synthesis in gas plasma [86] [87] (both from NASA), and as demonstrated in all LENR studies. These exothermic processes may be catalyzed by solar neutrinos and geoneutrinos, electric discharges (piezo, triboelectricity, and thermo-galvanic currents), and radiation, as described above. LENR processes may have been dominant at high-temperature conditions during the first billion years of the Earth’s history; the oldest rocks ever found (3.9 - 3.5 billion years old) belong to the Archean epoch and their composition is similar to that of the rocks from the base of the continental core. All of these rocks, at the end of this epoch and at the beginning of the Proterozoic era (2500 to 538.8 million years ago) underwent intensive deformation, metamorphism, granitic intrusions, mountain building, and are enriched in iron and heavy elements. Later, the endothermic LENR synthesis of heavy elements was (and is) possible at excess density of the released energy produced by impulse processes with high energy focusing. The maximum probability of such phenomena occurring exists in the hypocentres of earthquakes, volcanic chambers, mantle plumes, and on phase boundaries.

The hypothesis proposed herein is that the balance of the radiogenic components of Earth’s internal energy should include exothermic reactions of decay and LENR synthesis of the light elements ($Z \leq 26$), as well as the endothermic synthesis of heavy elements, including REE, noble metals, uranium, and thorium. The rich chemical composition of the mantle, in contrast to that of the solid core, creates

conditions for nuclear reactions: Synthesis or transformation of different elements—their stable and/or unstable isotopes. The “young” age of the radioactive isotopes, the cosmic distance between Earth and Supernova, and the distribution of the deposits of the heavy elements are a natural basis for the proposed hypothesis. The combination of the radiometric scale with petrographic and geochemical analysis is necessary for precise timing. The geoneutrino spectroscopy provides an estimated distribution of uranium, thorium, and potassium between the core-mantle and lithosphere, and the observed distribution indirectly supports our hypothesis. The uranium-lead cornerstone chronology of the meteorites and earth rocks allows for indirectly estimated impact of explosive supernova in uranium content in the Solar system. Age of the oldest meteorites is close to Earth and the ratio of uranium-lead would be significantly less than in Earth’s rocks, especially since these elements are kept in meteorites all their lifetime. The small ratio (see **Table 6**) reflects the young age of meteorites and lessens the probability of low-energy nuclear synthesis in meteorite rocks. In any event, this uranium is not a product of explosive supernovae or other star systems.

Table 6. Abundance [109] and calculated (Equation (1)) age of elements.

Source	Uranium, ppm	Lead (Pb), ppm	Ratio U/Pb	Calculated Age, Ma
Meteorites	0.008	2.470	0.003	19.45
Primitive mantle	0.021	0.185	0.113	695.2
Continental crust	1.400	12.600	0.111	683.5

We suggest, therefore, that primary and secondary uranium and thorium deposits occur as clusters within geologically permissive zones, mainly in the vicinities of large deep-seated faults, especially in earthquake hypocenters and volcanic eruption chambers localized in different parts of paleo-volcanos (Geology and Geochemistry of Uranium and Thorium Deposits, 2015). This is correct for uranium, thorium, and rare-earth elements (REE) (see **Figure 5**) and for Mo, W, Cu, Ag, Au, Zn, Pb, Sn, Hg, As, and S, whose deposits have been found in volcanogenic structures [129]-[137]. Volcanogenic systems are centers of plutonic activity, characterized by elevated structural and physicochemical openness conjugated in time with the ore-bearing processes. These factors promote the formation of different types of ore deposits: Exhalative, volcanogenic-hydrothermal, and volcanogenic-sedimentary, as they are related to varied and rich ore complexes. The physicochemical processes creating earthquakes and volcanic eruptions [2] [3] [15] also create favorable conditions for the increased rate of LENR synthesis of relatively light elements (number < 26 Fe) and provide lots of energy for the synthesis of heavy elements, U-Th-REE and possibly trans-uranium elements.

The initial step of the earthquake is a chemical explosion, the shock waves of which create high-voltage piezoelectricity in silicate rock and are accompanied by chemical polarization of nuclei and electrons that creates intranuclear resonance and “cooperative colliding process” (multinuclear oscillations) which may increase

LENR rates by 10 - 20 orders of magnitude [96]-[98] [100] [101]. Shock waves contribute proximity, which may increase LENR rates by 80 orders of magnitude [100]. The chemical explosions' electrical discharge and breakthroughs of the gas-magma stream through fractured and porous rocks create compression-decompression waves and cavitation [90]; this may lead to muon formation and muon catalysis of low-energy fusion reactions according to the hypothesis proposed in 2020 [83]. The creation of local overheating of the solutions and melts leads to the appearance of galvanic and thermoelectricity electrical discharges, which are capable of causing hydrogenation and nuclear fusion (LENR) in the solid and liquid phases.

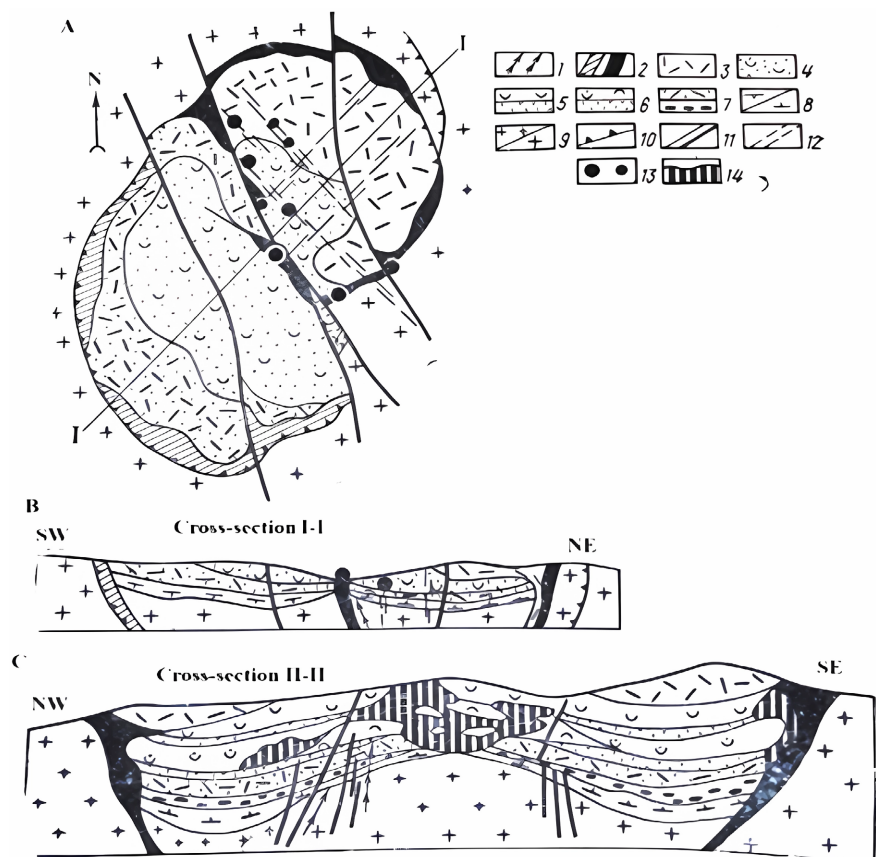


Figure 5. Geological situation and peculiarities of the structure of the ore-bearing fields of the volcanic caldera ([129], Fig. 50, translated from Russian by A. Gilat); (A) Schematic geological map of the caldera's ore-bearing deposits; (B) Geological cross-sections I-I; (C) Geological cross-sections II-II. Legend: 1. Youngest dykes of acidic and alkaline composition; 2. Late subvolcanic rhyolite intrusions; 3. Mostly baked tuff, ignimbrite, and breccias of the upper rhyolite group; 4. Undivided volcanic-sedimentary rocks of the Middle sequence; 5. Baked rhyolite tuff, tuffs-breccias, and tuff-sandstone of the Upper sequence; 6. Various tuffs rhyolite, tuffits, breccias, and tuffs sandstones of the Middle sequence; 7. Ignimbrite and baked rhyolite tuff, sandstone, and conglomerate of the Lower sequence; 8. Dacite, andesite, tuff andesite and andesite-basalt of the Lower sequence; 9. Variscan and Caledonian granitites and relicts of their roof, crystalline schist and gneiss; 10-11: Faults; 10. Ring-like and Bow-like; 11. Linear cutting-through; 12. Blind fault zones of the basement; 13. Uranium economic deposits and ore-manifestations; 14. Uranium ore projections on the cross-sections.

Thermal and acoustic fluctuations, galvanic currents and piezoelectricity, and formation of the shock and blast waves in hypocenters of earthquake and volcanic magma chambers [2] [3] [15] create the most favorable conditions for LENRs. Chemical polarization probably contributes additional acceleration in LENRs as well [138]. The summary release of chemical and nuclear energy from light element synthesis creates conditions for heavy element synthesis, including rare metals and uranium, and transuranic synthesis that corresponds to Le Chatelier's principle and allows absorption of some of the excess energy. The increased ratio of He3/He4 and the increased concentration of tritium in volcanoes [139]-[142] confirm the activity of the nuclear reactions. From known data, it is safe to assume that natural isotopes and radioactive contaminants catalyze LENRs, which is indirectly suggested by the increased tritium concentrations in nuclear testing sites [143]-[146]. As such, we propose herein a hypothesis regarding the maximum acceleration of LENRs in the hypocenters of earthquakes and eruption chambers, which increases energy of these phenomena, and regarding possibility of limiting the summary energy release due to low-energy synthesis of the elements ($Z \leq 26$ Fe). Note that (a) LENRs of elements ($Z \geq 26$ Fe) are the most efficient method of absorption energy in ultra-high PT conditions of detonation, and (b) this hypothesis explains the genesis of the common primary deposits of U-Th REE ores.

The theory of LENR participation in earthquakes and volcanic eruptions and a satisfactory hypothesis of the creation of uranium ores have not been proposed until now.

The hypotheses proposed herein are based on the universal physical-chemical laws, e.g., La Chatelain's principle, which (unless proved otherwise) must work under any conditions, including the ultra-high PT conditions prevailing during Earth's accretion, and based on geological observation; the hypotheses are supported by the results of recent experiments under ultra-high PT-conditions, which can be duplicated in any suitable laboratory including the laboratory of Nature.

The huge transportation time of heavy elements from supernovas to the Earth and the close relationship of volcanoes and uranium-thorium economic deposits indirectly confirm the proposed hypothesis. Following Ockham's razor principle, we declare that chemical elements originated on our planet rather than having been imported from far-off remote stars.

The absence of uranium and thorium in Earth's core and the "young" age of uranium in meteorites and the mantle make the theory of an extraterrestrial origin of uranium, thorium, and rare earth elements quite doubtful. Moreover, the age of many uranium deposits is less than one billion years (1 Ga), whereas the age of the most ancient rocks, determined by the same isotopic method, from 2 to 3.6 Ga, is comparable with the age of Earth itself. This fact indirectly supports our hypothesis regarding the formation of these heavy elements by LENRs in the Earth's upper mantle and even its core. To the best of our knowledge, the theory of LENR participation in earthquakes and volcanic eruptions and the satisfactory

hypothesis that uranium and other heavy elements originated within Earth (**Figure 4**) itself has not been proposed until now.

6. Conclusions

Based on the published results of numerous experiments on LENRs, Terez [78] [79] and Fukuhara [81] [82] concluded that LENR is the only apparent source of energy that allows one to compensate for the difference between observed heat flow from Earth and the total power of known non-radiogenic processes and radioactive isotope decay energy. The authors of this article, based on long-term research of earthquakes and volcanic activity [2] [3], put forward a new unconventional hypothesis about the accelerated LENRs in hypocenters of earthquakes and volcanic chambers due to specific conditions in centers of geophysical activity. In these centers, the chemical reactions also cause the chemical polarization of electrons and nuclei, culminating in explosions, increasing pressure and temperature, shock waves, phase transitions, tribo-piezo, and galvanic electricity. LENR's contribute significant energy to these phenomena through the synthesis of elements lighter than iron. Moreover, authors propose that part of the released energy as the existence of practically all chemical elements in mantle materials creates conditions favorable for LENRs synthesis of elements heavier than iron, leading to the formation of primary deposits of uranium, thorium, rare earth elements, noble metals, which are undetected in the solar wind.

The huge transportation time of heavy elements from supernovas to the Earth and the close relationship of volcanoes and uranium-thorium economic deposits (**Figure 5**) indirectly confirm the proposed hypothesis. Following Ockham's razor principle, we declare that chemical elements originated on our planet rather than being imported from far-off remote stars.

The absence of uranium and thorium in Earth's core and the "young" age of uranium in meteorites and the mantle make the theory of an extraterrestrial origin of uranium, thorium, and rare earth elements quite doubtful. Moreover, the age of many uranium deposits is less than one billion years (1 Ga). In contrast, the age of the most ancient rocks, determined by the same isotopic method, from 2 to 3.6 Ga, is comparable with the age of Earth itself (4.6 Ga). This fact indirectly supports our hypothesis regarding the formation of these heavy elements by LENRs in the Earth's upper mantle and core.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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