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J. Marvin Herndon
Transdyne Corporation, California

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SOCIETY FOR SCIENCE AND EDUCATION

Origin of Earth's Magnetic Field, its Nature and Behavior, Geophysical Consequences, and Danger to Humanity: A Logical Progression of Discoveries Review

J. Marvin Herndon, Ph.D.
Transdyne Corporation, San Diego, CA 92131 USA

ABSTRACT

Albert Einstein was unsuccessful in attempting to understand the origin of Earth's magnetic field, which he considered to be one of the five most important unsolved problems in physics. Many who followed Einstein failed to understand the origin of the geomagnetic field because crucial prerequisite information was not available or was being systematically ignored by the geoscience community. Here I review the logical progression of discoveries from Earth's protoplanetary origin that led to my concept of a nuclear fission 'georeactor' at Earth's center, evidence of its existence, and the mechanism for generally maintaining stable operation over geological time scales and producing Earth's magnetic field. In the micro-gravity environment at Earth's center, uranium, mixed with reactor poisons from fission and decay products, forms the georeactor sub-shell, which is kept in motion by nuclear fission energy from uranium that settles-out forming the georeactor sub-core. The amount of nuclear fission energy produced in the sub-core reaches a steady state wherein the amount of fission energy produced balances the uranium precipitation and the energy transferred to the inner core heat-sink by convection. Sub-shell convection twisted by planetary rotation, I posited, produces the Earth's magnetic field by the dynamo concept first espoused by Elsasser. Occasionally, sub-shell convection is disrupted, for example, by surface trauma such as from a great meteor impact or by an intense outburst of charged particles from the sun, which can lead to a geomagnetic reversal or excursion. Such convection disruption may lead to an extra burst of nuclear fission energy which, by replacing the lost heat of protoplanetary compression energy, can trigger earthquakes and volcanic activity at Earth's surface. Eventually, the geomagnetic field will collapse with potentially devastating consequences for our highly-integrated, technology-based infrastructure. Humanity should approach that unknown time with eyes open and with a willingness to work together for common survival.

INTRODUCTION

From time to time a movie such as *The Core* releases which is based upon the premise that the collapsing geomagnetic field threatens humanity and must be fixed. Both the cause of the problem, its consequences, and the fix are pure fiction, but the threat is real.

The geomagnetic field serves as a deflector that shields humanity from the onslaught of the solar wind. Loss of that shielding will potentially have devastating consequences for our highly integrated, technology-based infrastructure. As abstracted from [1] and quoted from [2]:

> *"Widespread communications disruptions, GPS blackouts, satellite failures, loss of electrical power, loss of electric-transmission control, electrical equipment damage, fires, electrocution, environmental degradation, refrigeration disruptions, food shortages, starvation and concomitant anarchy, potable water shortages, financial systems shut-down, fuel delivery disruptions, loss of ozone and increased skin cancers, cardiac deaths, and dementia. This list is not exhaustive. It is likely that a geomagnetic field collapse would cause much hardship and suffering, and potentially reverse more than two centuries of technological infrastructure development."*

The time of the next partial or full collapse of the geomagnetic field is unknown, however, recent dip pole movements [3] and decreasing geomagnetic intensity [4, 5] suggest that it "might be sooner rather than later" [2]. If the geomagnetic field were to collapse now, Earth scientists would be without a clue as to what to do. That might seem like hyperbole, but it is not.

Albert Einstein [6], worked diligently, but unsuccessfully, to understand the origin of Earth's magnetic field, which he considered to be one of the five most important unsolved problems in physics [7]. Many before and after Einstein attempted to understand the origin of Earth's magnetic field, but failed. One reason for failure is that crucial prerequisite discoveries had not yet been made. Another reason for failure is that as crucial discoveries were being made, they were being systematically ignored by the scientific community that beginning in the 1970s had abrogated long-existing standards of science and become more cartel-like.

Absent understanding, confusion prevails and slows the progress of science. For example, recently published evidence points to activities on the sun provoking earthquakes [8-15] and volcanic eruptions [16, 17]. However, as noted by Novikov et al. [12], "*The main problem with this research is a lack of physical explanations of a mechanism of earthquake triggering by strong variations of space weather conditions*." With understanding, the mechanism becomes obvious [18].

The purpose of this review is to provide, without reliance upon false concepts, a step-by-step recitation of the logical progression that has led to current knowledge of the nature of the geomagnetic field, its origin, behavior, geophysical consequences, and potential dangers to humanity.

PROBLEMATIC UNDERSTANDING

In 1855, Michael Faraday [19] reported his discovery that an electric current, i.e., the flow of electric charges, produces a magnetic field. But how did this discovery connect to the production of Earth's magnetic field?

In 1939 and in subsequent investigations, Walter Elsasser provided an important insight by suggesting that the geomagnetic field was generated by a convection-driven dynamo mechanism in the Earth's fluid core [20-22]. A dynamo is a magnetic amplifier. Elsasser's idea is that convection motions coupled with planetary rotation would greatly amplify a small "seed" magnetic field. Elsasser [20-22] simply assumed that convection exists in the fluid core without any independent corroborating evidence. More than 80 years later no independent corroborating evidence has been discovered. However, Elsasser's dynamo is the only mechanism proposed that seemed to make sense. Countless individuals assumed it must be correct because the Earth *has* a magnetic field instead of asking "What's wrong with this picture?"

The Earth-core temperature of molten iron alloy is too high for the existence of permanent magnetization. What produces the "seed" magnetic field? That was left unspecified. But there are other problems that seriously call into question the idea that the geomagnetic field is generated within Earth's fluid core by Elsasser's convection-driven dynamo mechanism, most notably, the physical impossibility of sustained thermal convection in the fluid core as well as the driving energy source being unknown.

Convection is perhaps the most misunderstood natural process in Earth science. Hypothetical, computer-programmed convection models of Earth's fluid core [23-26] continue to be produced, although sustained fluid-core thermal convection has been shown to be physically impossible [27] and therefore necessitates a fundamentally different geoscience paradigm [2, 28-39].

In 1957, Subrahmanyan Chandrasekhar [40] described convection in the following, easy-to-understand way:

> *"The simplest example of thermally induced convection arises when a horizontal layer of fluid is heated from below and an adverse temperature gradient is maintained [i.e., bottom hotter than top]. The adjective 'adverse' is used to qualify the prevailing temperature gradient, since, on account of thermal expansion, the fluid at the bottom becomes lighter than the fluid at the top; and this is a top-heavy arrangement which is potentially unstable. Under these circumstances the fluid will try to redistribute itself to redress this weakness in its arrangement. This is how thermal convection originates: It represents the efforts of the fluid to restore to itself some degree of stability."*

Consider the example of a pot of water on the stovetop. Heat at the bottom causes the water to be slightly less heavy (less dense) than the water above. This is an unstable configuration. The heavier (more dense) water at the top falls by gravity displacing the lighter (less dense) water at the bottom. The *adverse temperature gradient*, *i.e.* the bottom being hotter than the top, is maintained by the cooling that occurs at the open water surface.

To the best of my knowledge, consequences of the *adverse temperature gradient*, described by Chandrasekhar [40] have not been explicitly considered in either solid-Earth or tropospheric convection calculations. Despite lengthy literature searches, I was unable to find quantification of the effect of adverse temperature gradient on convection efficiency. The following simple classroom-demonstration experiment, however, can provide critical insight for understanding how convection works and is applicable to a proper understanding of Earth-core convection [27], as well as to tropospheric convection in Earth's atmosphere [41].
As described recently [42]:

> *The convection classroom-demonstration experiment was conducted using a 4 liter beaked-beaker, nearly filled with distilled water to which celery seeds were added,*

and heated on a regulated hot plate. The celery seeds, dragged along by convective motions in the water, served as an indicator of convection. When stable convection was attained, a ceramic tile was placed atop the beaker to retard heat loss, thereby increasing the temperature at the top relative to that at the bottom, thus decreasing the adverse temperature gradient.

Figure 1, from [41], extracted from the video record [43, 44], shows dramatic reduction in convection after placing the tile atop the beaker. In only 60 seconds the number of celery seeds in motion, driven by convection, decreased markedly, demonstrating the principle that reducing the adverse temperature gradient decreases convection. That result is reasonable as zero adverse temperature gradient by definition is zero thermal convection.

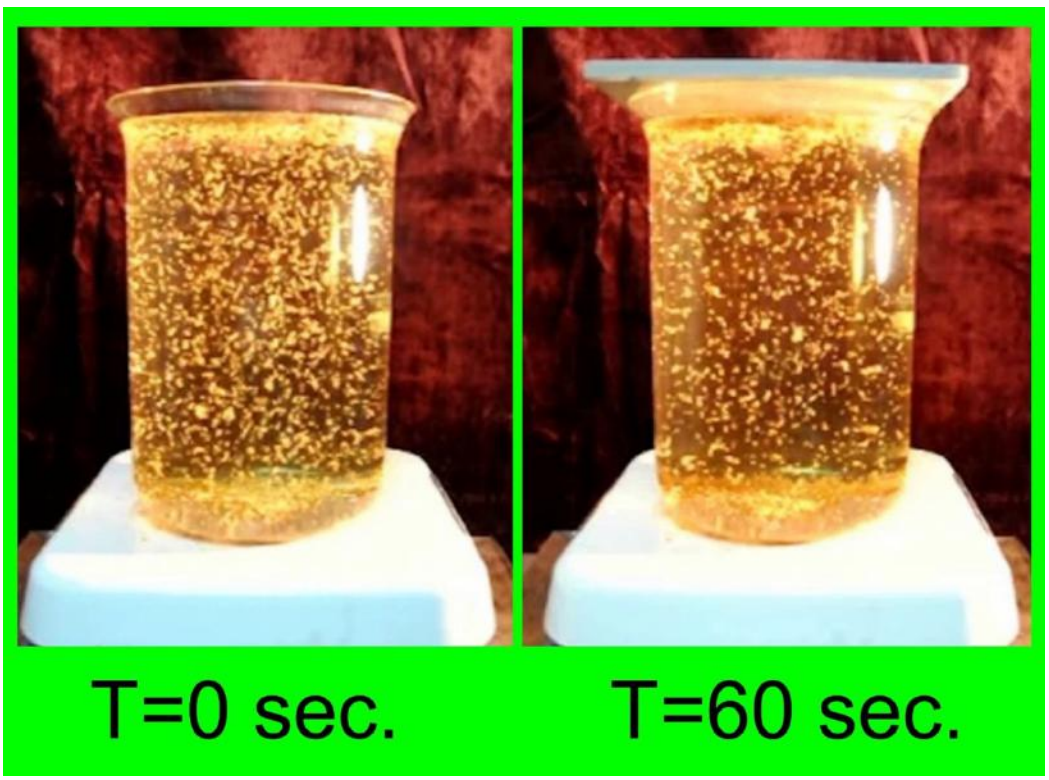

Figure 1. From [41]. A beaked-beaker of water on a regulated hot plate with celery seeds pulled along by the fluid convection motions. Placing a ceramic tile atop the beaker a moment after T=0 reduced heat-loss, effectively warming the upper solution's temperature, thus lowering the adverse temperature gradient, and reducing convection, indicated by the decreased number of celery seeds in motion at T=60 sec.

Convection in the fluid core is physically impossible for two reasons [27, 45].

First, for sustained convection, heat brought to the core-top must be quickly removed, a physical impossibility as the core is surrounded by an insulating silicate blanket, the mantle, that has significantly lower thermal conductivity, lower heat capacity, and greater viscosity than the Earth's core. This understanding is illustrated quite clearly in Figure 1. Such a fundamentally simple concept is rarely, if ever, incorporated in geodynamo computer models [25, 46, 47].

Second, due to compression from the weight above, the bottom of the fluid core is 23% denser than the core-top. The small decrease in core-bottom density from thermal expansion (< 1%) is insufficient to make the core top-heavy as required for convection [40].

Growth of the inner core is frequently assumed to power the geodynamo [48, 49], however, there is no independent evidence that the inner core has been growing over geological time.

More than 80 years has elapsed since Elsasser [20] published his geodynamo concept. It was certainly a very good idea, but not applicable to the Earth's fluid core. Why have I been able to advance the geodynamo concept, but geoscientists have not? The best way to answer that question is to describe the discovery-steps I made in a logical progression of understanding, many which were ignored by a geoscience community that either fails to read the scientific literature or fails to adhere to sound scientific standards.

How can virtually the entire scientific community be wrong, not only about geomagnetic field generation, but about much of the foundation of geophysics, geology, and even astrophysics? Recently, I published a book [50] that is available on most amazon.com platforms entitled *Paradigm Shifts: A Primer for Students, Teachers, Scientists and the Curious* (Figure 2). To my knowledge it is the only book that teaches how to make important discoveries, as well as being a no-nonsense guide through advances in the geosciences and astrophysics.

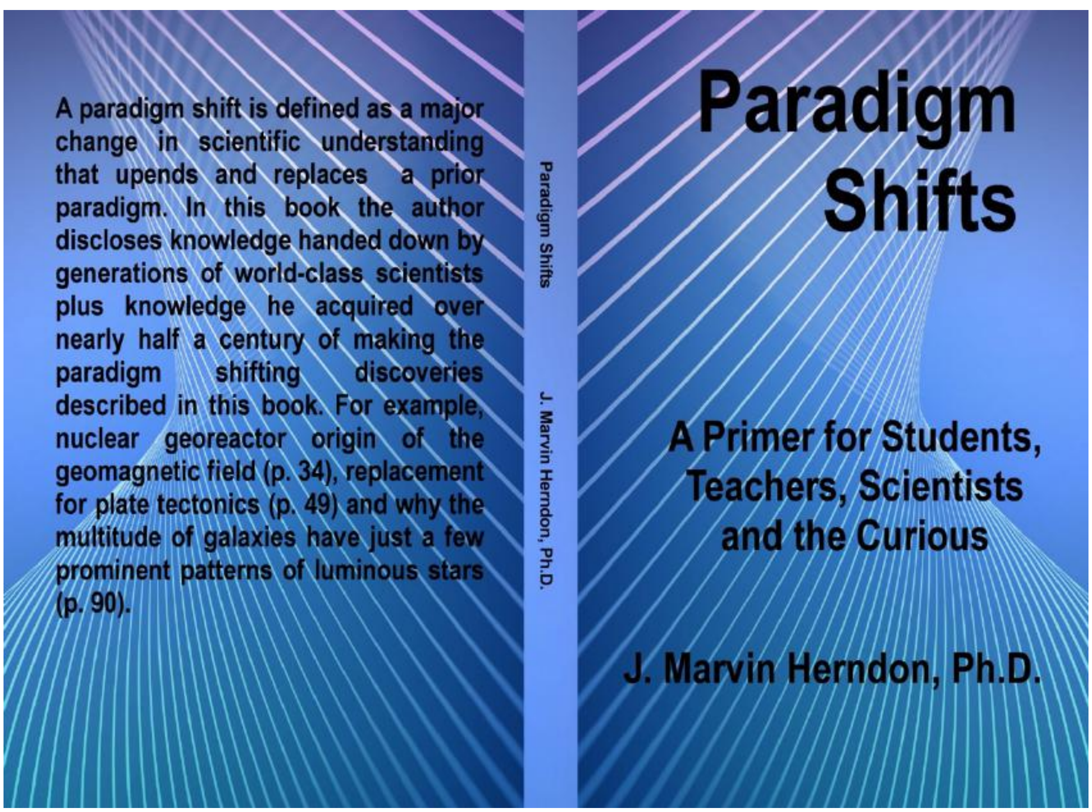

Figure 2. Recently published book available at several Amazon.com platforms.

In the following, I describe from a first-person perspective the logical progression of understanding from fundamental considerations to the latest advances related to the geomagnetic field.

METEORITES AND PLANETARY FORMATION

Numerous studies during the 20th Century connected in fundamental ways meteorites and planetary formation processes. The matter of Earth, Moon, meteorites, and presumably the other planetary bodies in our Solar System formed from well-mixed common primordial matter, as indicated by the identical isotopic ratios of their elements, except for minor differences, see inset Figure 3. The chemical element ratios of that primordial matter is indicated by the similarity of corresponding elemental ratios in the photosphere of the sun and in groups of meteorites called chondrites (Figure 3) [51].

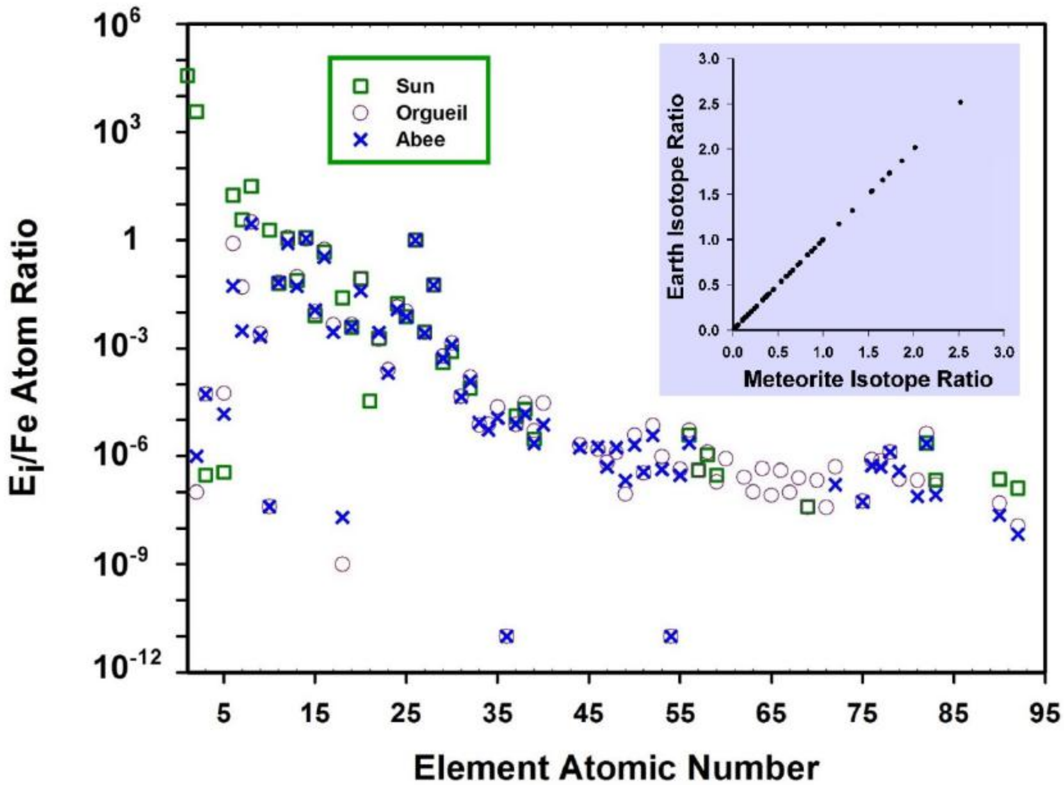

Figure 3. Comparison of relative element atom-abundances, normalized to iron, in the sun and in the Orgueil carbonaceous chondrite and in the Abee enstatite chondrite. From [51]. Inset shows the similarity between isotope ratios from meteorites and Earth.

There are three groups of chondrite meteorites that have more-or-less similar compositions:

- Carbonaceous chondrites, e.g. Orgueil
- Enstatite chondrites, e.g. Abee
- Ordinary chondrites, the most common type

The rare, primitive carbonaceous chondrites are highly oxidized, i.e. virtually all of their elements are combined with oxygen. Their minerals are characteristic of a low temperature environment and even contain water of extraterrestrial origin. From thermodynamic considerations their components are consistent with parent matter that condensed at low pressures and low temperatures from an atmosphere of solar composition [51]. Earth could not have formed from carbonaceous matter like the Orgueil meteorite as it contains no iron metal to form the core.

The Abee enstatite chondrite, on the other hand, has copious amounts of iron metal. However, the rarity of enstatite chondrites and their highly-reduced "oxygen starved" minerals were not understood before 1976 and, consequently, were not considered representative of Earth-formation material.

The ordinary chondrites, however, being the most abundant of the chondrites and possessing iron metal were assumed to be similar to the Earth. Since the 1940s, Earth has widely been thought to be similar to an ordinary chondrite meteorite. However, in 1978 I showed that ordinary chondrite minerals were inconsistent with condensation from a gas of solar composition, but were consistent with re-evaporated condensed matter after separation from solar gases [52].

In the 1970s, I studied enstatite chondrites, especially the Abee meteorite. At the time the highly reduced "oxygen starved" state of enstatite meteorites was a great mystery. It was a mystery because solar matter has sufficient oxygen to combine with all of the condensable elements, such as evident in the Orgueil carbonaceous chondrite. Understanding was the key to solving that mystery.

In a hot gas having the composition of the photosphere of the sun, ideally, iron metal condenses when the partial pressure of iron gas exceeds the vapor pressure of iron metal. Consequently, at higher pressures, iron metal condenses at higher temperatures. The availability of oxygen, however, is controlled by the pressure-independent reaction

$$\mathbf{H_2 + \frac{1}{2}O_2 = H_2O}$$

which at higher temperatures becomes more reducing [53].

Indeed, at higher pressures liquid iron metal (including the elements that dissolve in it) is the most refractory condensate, condensing at higher temperatures than oxides. The published conclusion is that the parent matter of enstatite chondrites could have obtained the highly reduced oxidation state by condensing from solar matter at high pressures, provided the condensate was isolated from reaction with the gases at low temperatures [53].

In 1944, Arnold Eucken [54] published a scientific article entitled "Physikalisch-chemische Betrachtungen ueber die frueheste Entwicklungsgeschichte der Erde" which translates as "Physico-Chemical Considerations about the Earliest Development History of the Earth". From thermodynamic considerations, Eucken investigated condensation from primordial matter, namely, a gas of the composition of the sun's photosphere at pressures from 1 to 10^4 atm. Eucken showed that the first primordial condensate from a cooling gas of solar composition at high-pressures would be molten iron at high temperatures, followed at lower temperatures by silicate minerals, and, if condensation were complete, at still lower temperatures, by gases and ices as evident in Jupiter.

From these thermodynamic considerations, Eucken [54] proposed Earth's formation progressed from within a giant gaseous protoplanet that began with liquid iron metal raining out to form Earth's core, followed by the condensation of minerals that formed its mantle. Without realizing beforehand, in 1976 Hans E. Suess and I [53] confirmed the thermodynamic considerations that Eucken [54] had published in 1944. The next step in the logical progression of understanding would be connecting an enstatite chondrite, like the Abee meteorite, to Earth's interior.

SHADOW ZONE MYSTERY

In 1906, Oldham discovered Earth's iron metal core whose boundary lies about half way to the planet's center [55] (Figure 4). By 1930, its dimensions were well established and the core was found to be liquid [56]. A simple picture of Earth's interior emerged: An iron alloy core surrounded by a silicate-rock mantle and topped with a very thin crust (discovered by Mohorovičić in 1909 [57]). But something was missing. Earthquake waves from a large New Zealand earthquake, instead of being shadowed by the core, were actually observed at the surface in the shadow zone. This posed a great geoscience mystery.

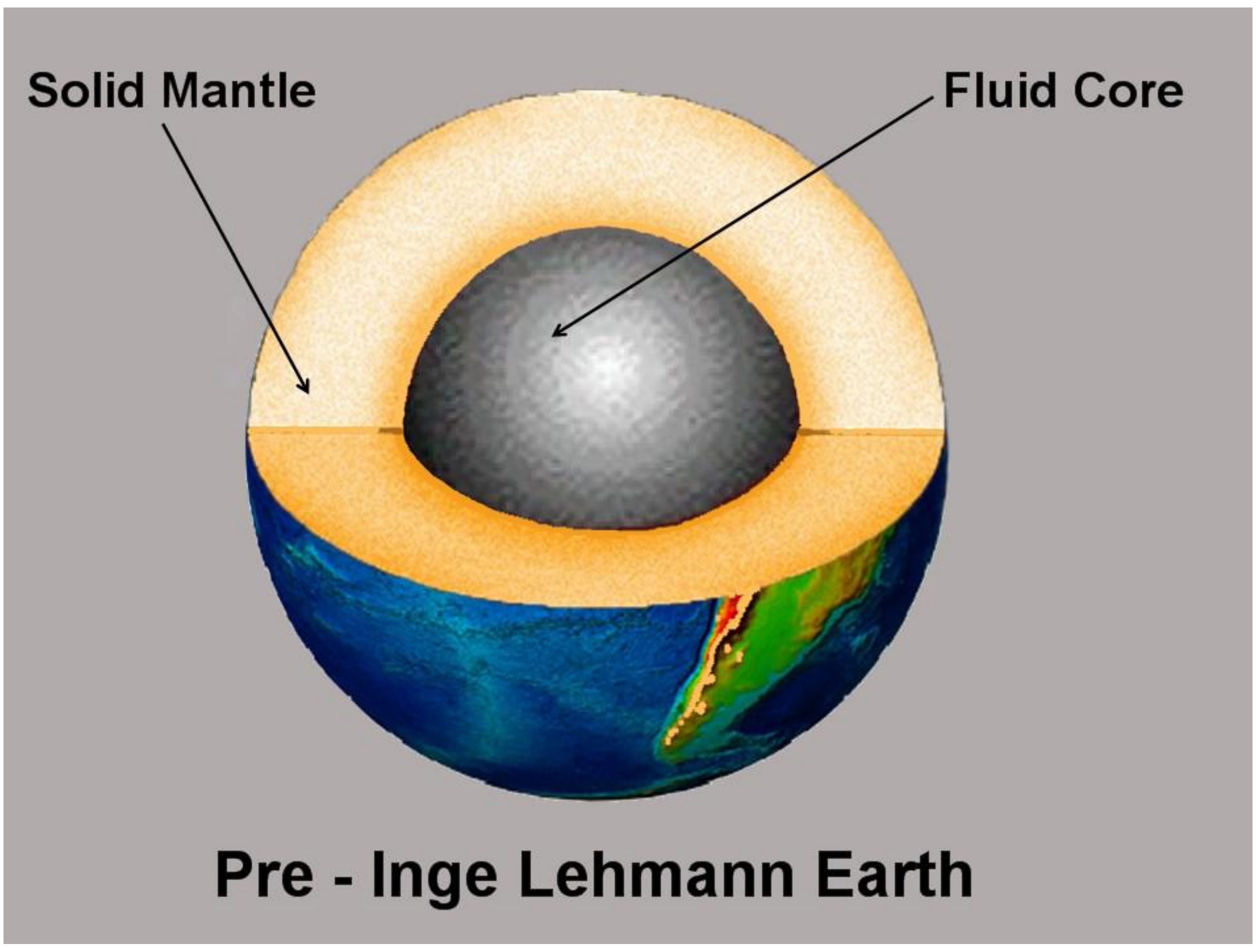

Figure 4. The simple picture of Earth's interior as understood in 1930.

In 1936, the Danish seismologist, Inge Lehmann, solved this great mystery by correctly deducing that within the fluid core there must be a solid inner core that would reflect earthquake waves into the shadow zone, thus explaining seismic observations [58]. Figure 5 shows her discovery diagram. Lehmann's reasoning was of such great precision that her inner core concept was accepted as fact even though confirmatory evidence was not available until the 1960s.

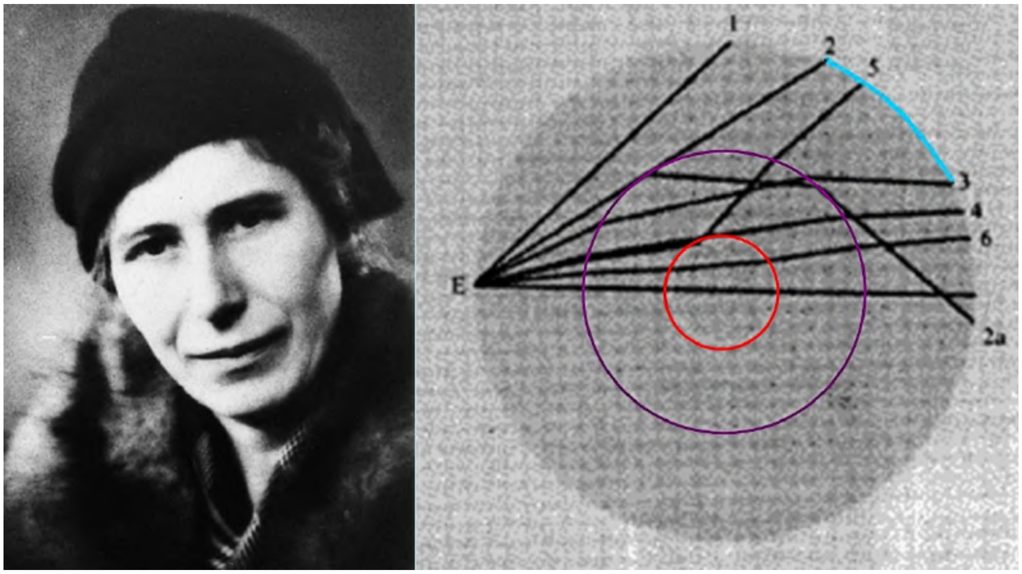

Figure 5. Photograph of Inge Lehmann (1888-1993) and a drawing from [58] illustrating her discovery of the inner core. I colorized that drawing for clarity. The shadow zone is indicated in blue.

Studies of Earth's rotation and earthquake waves can provide information on the distribution of mass-layers within the planet. The chemical composition of those layers, however, must be deduced from studies of meteorites. In the 1930s and 1940s, Earth was thought to resemble an ordinary chondrite meteorite, called ordinary because of their great abundance. If heated sufficiently in the laboratory, the elements of an ordinary chondrite separate into two components, an iron alloy beneath silicate-rock, a configuration reminiscent of Earth's then understood composition (Figure 4) before Lehmann's inner core discovery [58].

In ordinary chondrite meteorites, nickel is *always* found alloyed with iron metal; all of the elements heavier than iron and nickel, even combined together, could not comprise a mass as great as the inner core. So what is the composition of the inner core? In 1940 Birch [59] thought he had the answer. Birch *assumed*, without corroborating evidence, that the inner core is iron metal in the process of solidifying (freezing) from the liquid iron-alloy core (like an ice cube in a glass of ice-water). If Birch were correct, one could determine the temperature at the inner core boundary by measuring the solidification temperature of iron at the respective pressure. That is what Li et al. [60] did in 2020 and which has been done by many since the 1940s, but the basis is a fatally-flawed assumption.

For the first 39 years Birch and other geoscientists had no reason to believe the inner core composition was other than partially frozen iron (or nickel-iron) metal.

When Birch [59] and others imagined that Earth resembled an ordinary chondrite meteorite, they ignored a different possibility, an enstatite chondrite, one of the much less common chondrite meteorites whose matter had formed under oxygen-starving conditions and even contained some minerals not found on Earth's surface. Because of their rarity and seemingly inexplicable oxygen-starved minerals, enstatite chondrites were simply ignored as candidates for Earth's interior composition.

While investigating enstatite chondrite meteorites in the 1970s, I spent hours studying photomicrographs by world class petrologists, such as those of Paul Ramdohr [61-63]. One thing that caught my attention was the occurrence of the mineral named perryite, a compound of nickel and silicon.

In the highly reduced enstatite meteorites, nickel silicide occurs both as lamellar exsolutions from silicon-bearing iron metal [61, 63-66] and as more massive forms intimately associated with metal and iron sulfide in certain enstatite chondrites [62, 67]. It occurred to me that, even in this iron-rich environment, circumstances had prevailed that were appropriate in nature for silicon to combine with nickel and separate it from iron metal. I realized that, if Earth's core initially contained silicon, nickel silicide could precipitate and settle beneath the less dense fluid iron alloy core, forming the inner core with precisely the mass observed.

In 1979, I published a contradiction [68] to the 39 year old inner core idea (Figure 6).

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The nickel silicide inner core of the Earth

BY J. M. HERNDON

Department of Chemistry, University of California, San Diego, La Jolla, California 92093, *U.S.A.*

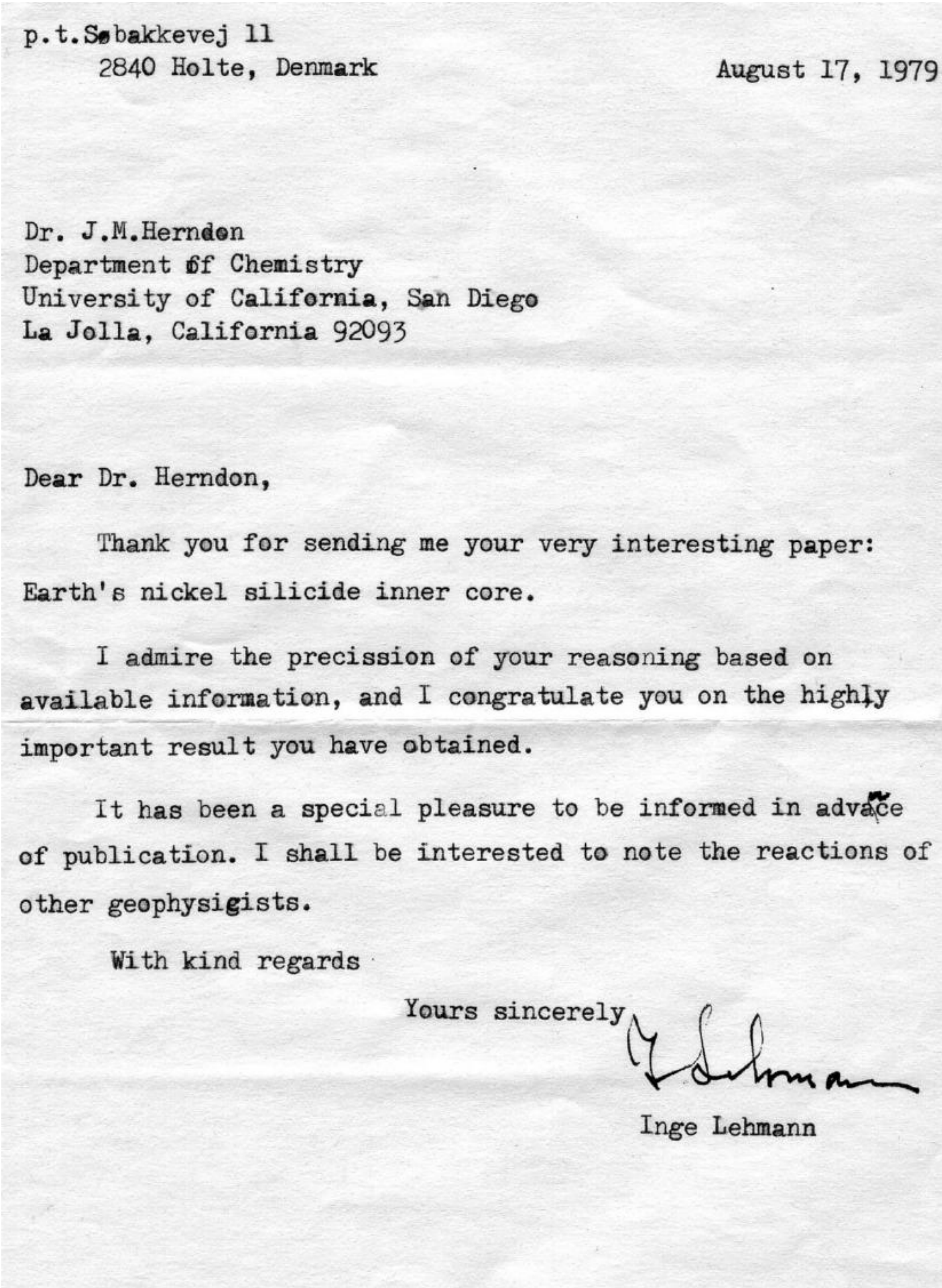
(*Communicated by H. C. Urey, For.Mem.R.S. – Received* 27 *November* 1978 – *Revised* 19 *April* 1979)

From observations of nature the suggestion is made that the inner core of the Earth consists not of nickel–iron metal but of nickel silicide.

Contemporary understanding of the physical state and chemical composition of the interior of the Earth is derived primarily from interpretations of seismological measurements and from inferences drawn from observations of meteorites. Seismological investigations by Oldham (1906), Gutenberg (1914) and others helped to establish the idea that a fluid core extends to approximately one half the radius of the Earth. The existence of a small, apparently solid inner core at the centre of the Earth was recognized by Lehmann (1936) from interpretations of

Figure 6. From [68].

Figure 7 is the image of a complimentary letter I received from Inge Lehmann in which she expressed interest in the responses of other geophysicists. Now, four decades later I review those responses.



p.t.Søbakkevej 11
2840 Holte, Denmark

August 17, 1979

Dr. J.M.Herndon
Department of Chemistry
University of California, San Diego
La Jolla, California 92093

Dear Dr. Herndon,

Thank you for sending me your very interesting paper: Earth's nickel silicide inner core.

I admire the precission of your reasoning based on available information, and I congratulate you on the highly important result you have obtained.

It has been a special pleasure to be informed in advance of publication. I shall be interested to note the reactions of other geophysigists.

With kind regards

Yours sincerely

Inge Lehmann

Figure 7. Letter from Inge Lehmann to the author.

While awaiting publication of my nickel silicide inner core concept [68], I imagined that there would be debate and discussion, and worried that geoscientists with well-funded laboratories would pick up the ball and run with it, leaving me in their dust. Instead there was silence. It was as if the paper had never been published. That work was ignored and has been ignored for four decades, as evidenced, for example, by Li et al.'s 2020 paper [60] and He et al.'s 2022 paper [69]. Moreover, my NASA grant, which had funded the work, was not renewed for no good reason. I was "excommunicated" and without that grant my university position evaporated.

The problem with NASA and some other government science-funding agencies is that they fail to take into account the human-nature response to new ideas.

In 1623, Galileo, one of the greatest scientists of the millennium, precisely characterized human response to new ideas in a letter written to Don Virginio Cesarini (translated by Stillman Drake) [70]:

> *"I have never understood, Your Excellency, why it is that every one of the studies I have published in order to please or to serve other people has aroused in some men a certain perverse urge to detract, steal, or depreciate that modicum of merit which I thought I had earned, if not for my work, at least for its intention. In my Starry Messenger there were revealed many new and marvelous discoveries in the heavens that should have gratified all lovers of true science; yet scarcely had it been printed when men sprang up everywhere who envied the praises belonging to the discoveries there revealed. Some, merely to contradict what I had said, did not scruple to cast doubt upon things they had seen with their own eyes again and again....How many men attacked my Letters on Sunspots, and under what disguises! The material contained therein ought to have opened the mind's eye much room for admirable speculation; instead it met with scorn and derision. Many people disbelieved it or failed to appreciate it. Others, not wanting to agree with my ideas, advanced ridiculous and impossible opinions against me; and some, overwhelmed and convinced by my arguments, attempted to rob me of that glory which was mine, pretending not to have seen my writings and trying to represent themselves as the original discoverers of these impressive marvels....I have said nothing of certain unpublished private discussions, demonstrations, and propositions of mine which have been impugned or called worthless....Long experience has taught me this about the status of mankind with regard to matters requiring thought: the less people know and understand about them, the more positively they attempt to argue concerning them, while on the other hand to know and understand a multitude of things renders men cautious in passing judgment upon anything new."*

Scientists should tell the truth and describe completely the extant state-of-the-art. That is what genuine scientists do. And there is good reason. When an important new contradiction arises, members of the scientific community should try to refute the contradiction on a sound scientific basis. If unable to do so, they should cite the concept in subsequent relevant publications. That way others may learn and possibly advance the science.

Science tends to progress in logical steps. If a contradiction were correct, but is ignored, progress is impeded. That is what happened to my nickel silicide inner core concept, and it doomed the geophysics community to be trapped in a logical *cul-d-sac*, unable to progress to the next scientific discovery. That left the way clear for me to make one discovery after another, after another, etc.

EARTH'S DEEP INTERIOR

In 1952, Birch [71] provided a lengthy discussion of the importance of meteorites and lamented on the difficulty of determining which of the many diverse meteorites are a match for Earth's composition. I discovered how to circumvent that difficulty by relating mass ratios of mineralogically determined parts of meteorites to parts of the Earth determined by seismology and moment of inertia considerations [72].

Consider first the weight percent of iron alloy in enstatite chondrites and in ordinary chondrites compared to the weight percent of Earth's iron alloy core, as shown in Figure 8, left. Clearly, only enstatite chondrites have a sufficient proportion of iron alloy to constitute Earth's core.

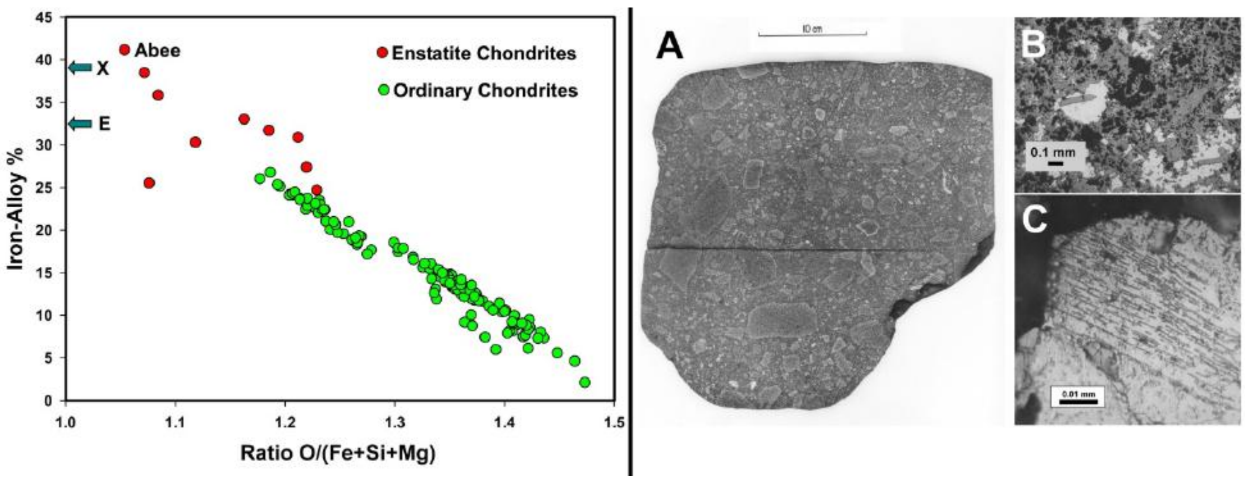


Figure 8. Left: Comparison of the mass percent of iron alloy in various chondrite meteorites to that of the Earth as a whole (E) and the endo-Earth (X) (lower mantle plus core [72]); Right: (A) Nearly complete slice of the Abee enstatite chondrite. (B) Micrograph showing its enstatite crystals surrounded by previously molten iron metal. (C) Micrograph showing platelets of iron carbide in its metal [73, 74].

Enstatite chondrites, containing some strange minerals such as osbornite, titanium nitride [75], are unique in having formed under oxygen-starving, highly-reducing conditions. They are the most highly reduced, i.e., least oxidized, naturally occurring mineral assemblage known. As a consequence, their major silicate, enstatite, $MgSiO_3$, is nearly devoid of oxidized iron. Moreover, their iron metal contains silicon [76].

On June 9, 1952 the Abee enstatite chondrite fell to ground in Alberta, Canada [77]. A single mass was recovered five days later from a wheat field. Figure 8A shows a nearly complete slice of the roughly basketball-size, 107 kg Abee enstatite chondrite. Abee has been described as an explosion breccia because of its angular fragments [78], but its morphology is quite unique. Peripheries of some of the angular components are shiny, enriched in iron metal that was clearly molten. Figure 8B, is a micrograph showing crystals of the major silicate-mineral, enstatite ($MgSiO_3$), embayed (surrounded) by iron metal which was liquid at a time when the mineral crystal was solid. Figure 8C is a micrograph of the iron metal, etched with acid that reveals platelets of *pearlite*, iron carbide, indicative of relatively rapid cooling. M. Lea Rudee and I in 1978 [73] and 1981 [74] published the results of metallurgical experiments that showed during its formation Abee last cooled from 700°C to 25°C in ten hours.

Before 1976, no one understood how the oxygen-starved (highly reduced) parent matter of an enstatite chondrite could have formed from primordial matter with the composition of the sun's photosphere. In 1976, Herndon and Suess [53] showed that condensates at high-temperatures and high-pressures would be oxygen-starved, like the Abee parent matter, provided that such condensate was isolated from reaction with the gas at lower temperatures.

Follow this logical progression which I first considered in 1980 [72]: If the inner core is indeed nickel silicide, then the core must be like the alloy portion of the Abee enstatite chondrite meteorite, which means that Earth's core should be surrounded by a silicate-rock shell like Abee's enstatite silicate ($MgSiO_3$). Multiplying the mass of Earth's core times Abee's silicate to alloy ratio [79] yielded the mass of the silicate shell that must surround the core. I found that the radius of that silicate shell corresponds within 1% to the location of the seismic boundary that separates the lower mantle from the upper mantle [80]. Thus, the ratios of mass for the internal shells of the Earth (inner core, total core, lower mantle) should match those of the Abee enstatite chondrite meteorite, and they do, as shown in Table 1 from [27].

Later, I realized that calcium and magnesium, additional elements in the core with high affinities for oxygen, would combine with sulfur to form calcium sulfide (CaS) and magnesium sulfide (MgS), respectively, and float to the top of the core. These components also can be connected with parts of Earth by mass ratios, as shown in Table 1. For details see [27].

Table 1. Fundamental mass ratio comparison between the endo-Earth (lower mantle plus core) and the Abee enstatite chondrite. Above a depth of 600 km seismic data [81] indicate data layers suggestive of veneer, possibly formed by the late addition of more oxidized chondritic and cometary matter, whose compositions cannot be specified at this time

Fundamental Earth Ratio	Earth Ratio Value	Abee Ratio Value
lower mantle mass to total core mass	1.49	1.43
inner core mass to total core mass	0.052	theoretical 0.052 if Ni_3Si 0.057 if Ni_2Si
inner core mass to lower mantle **+** total core mass	0.021	0.021
D′′ mass to total core mass	0.09*	0.11**
ULVZ† of D′′ CaS mass to total core mass	0.012****	0.012**

***Calculated assuming average thickness of 200 km. ** = avg. of Abee, Indarch, and Adhi-Kot enstatite chondrites. D′′ is the "seismically rough" region between the fluid core and lower mantle. ULVZ *** is the "Ultra Low Velocity Zone" of D′′. ****Calculated assuming average thickness of 28 km. Data from references [79, 82, 83].**

SOLAR SYSTEM FORMATION

The first hypothesis on the origin of the sun and planets was advanced in 1755 by Kant [84] and was modified four decades later by Laplace [85]. Early in the 20th Century, Laplace's nebula hypothesis was replaced by the Chamberlain-Moulton [86] hypothesis which held that a passing star pulled matter from the sun which condensed into large proto-planets and small planetesimals. Although the passing star idea fell out of favor, the nomenclature of proto-planets and planetesimals remained. Generally, concepts of planetary formation fall into two categories that involve either (1) condensation from an atmosphere of solar composition at high pressures, hundreds to thousands of atmospheres (atm.) or (2) condensation at very low pressures, <0.0001 atm.

The protoplanetary theory attracted scientific attention in the 1940s and 1950s [54, 87, 88], but was abandoned and ignored by phenomenological computer-model makers in the early 1960s who, inspired by Cameron [89], attempted to explain Earth's compositions and dynamics solely on the basis of the planetesimal theory, an activity which has continued to the present [90, 91] all the while ignoring published contradictions [92-95].

The mass ratio data shown in Table 1, displayed graphically in the left portion of Figure 9, connect the components of the inner 82% of Earth to a particular enstatite chondrite whose parent matter Eucken [54] and Suess and I [53] connected to high pressure condensation from a cooling gas of solar composition, thus validating in the main protoplanetary formation of Earth [96]. The observation of oxidized iron in the surface and upper mantle is indicative of a less abundant planetesimal component.

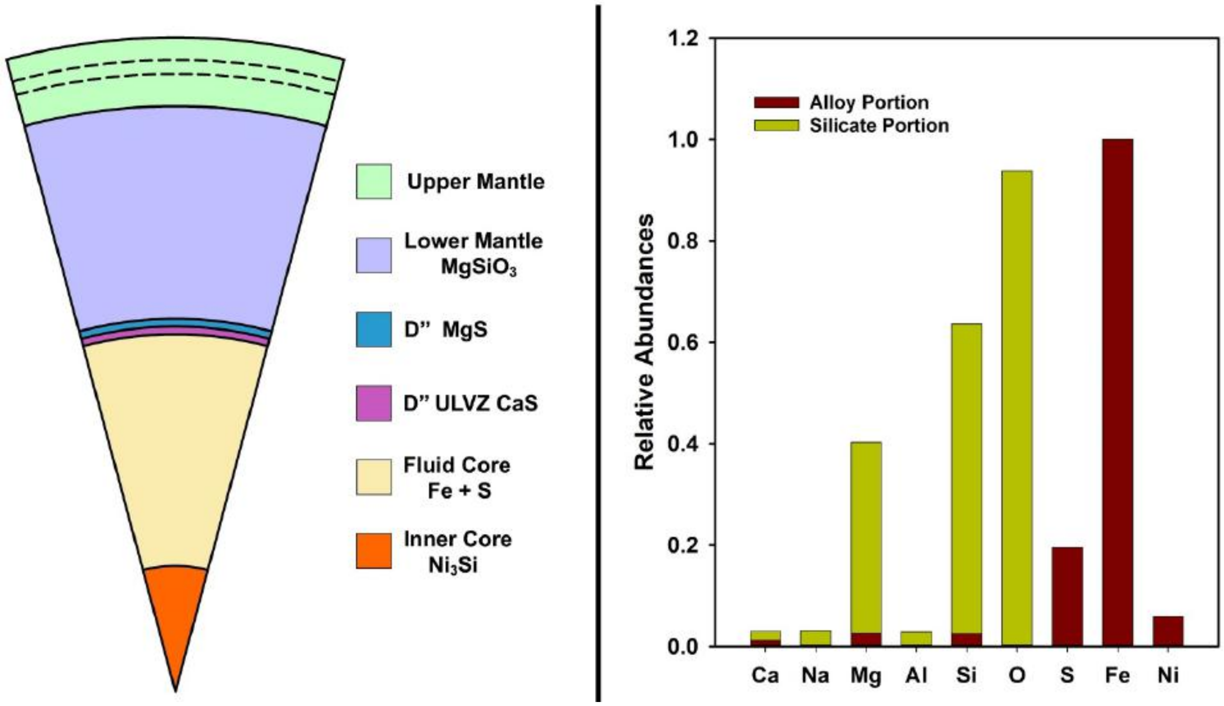


Figure 9. Left: The composition of the endo-Earth (core plus lower mantle) from the data referenced in Table 1. Right: Relative proportion of major and minor elements originally in Earth's core deduced from their occurrence in the Abee enstatite chondrite.

EVIDENCE FROM MERCURY AND MARS

The left portion of Figure 10 shows two rimless pits on Mars located to the northwest of Ascraeus Mons. The pits are 180 and 310 meters in diameter. The associated wispy, dark material appears to have blown out of the pits. Although the Martian pits are considerably larger and far fewer than the pits on Mercury discovered by the Project Messenger mission [97], I suspect that they may be of similar origin, namely the result of hydrogen geysers [98].

Molten iron, which dissolves copious amounts of hydrogen [99], is the first major condensate during protoplanetary formation [53, 54]. Eventually, when the planetary core solidifies, the hydrogen is exsolved and rushes to the surface. Along the way the hydrogen reduces iron sulfide to iron metal, which is blown out and deposited at the surface. On Mercury, which is devoid of atmospheric winds, the iron is deposited around the pits and remains in its reduced state (Figure 10, right). On Mars, presumably the iron is blown downwind and becomes oxidized. In each case, the validity of this concept can be tested by determining whether the deposited material is iron metal and iron oxide, respectively.

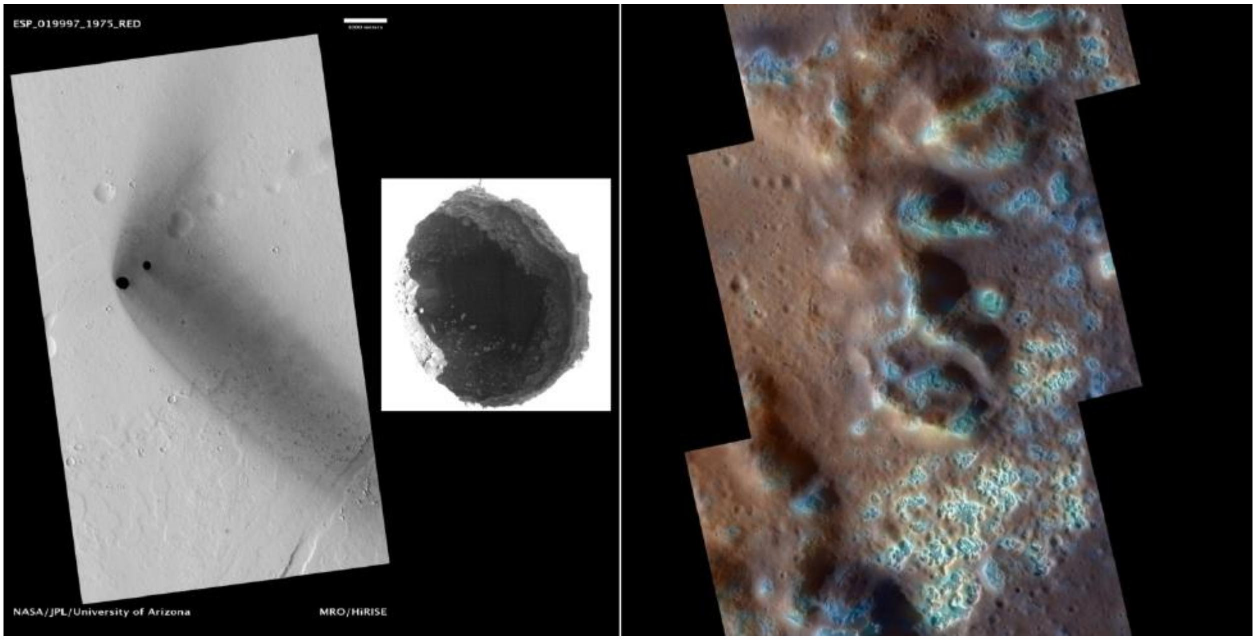


Figure 10. Left: Dark rimless pits NW of Ascraeus Mons on planet Mars. Inset: Close up of rimless pit. From [100]; Right: Pits surrounded by shiny material on planet Mercury. From [97].

EARTH CORE PRECIPITATES

The distribution of Earth-core precipitates is shown in Table 1 and in the left portion of Figure 9.

What happens as this alloy begins to cool? It helps to think like a metallurgist here instead of like a geologist. Some elements, such as sulfur, really like to be dissolve in molten iron and they will tend to want to stay dissolved as long as possible. But some elements are incompatible, particularly those that greatly prefer oxygen. Incompatible elements, like calcium and magnesium, will seek a way to escape the iron alloy, and they find it by combining with sulfur. Both calcium sulfide (CaS) and magnesium sulfide (MgS) form solids at temperatures that are well above the melting point of iron. Both are less dense than the iron alloy and will tend to float atop it.

I have suggested that calcium sulfide (CaS) and magnesium sulfide (MgS), which precipitated from the Earth's core and floated to its top, are the cause of the seismic "roughness" at the core-mantle boundary [29, 31, 32, 101]. There is an industrial process that is really quite similar. To remove sulfur from high-quality steel, magnesium or calcium is injected into the molten iron to combine with the sulfur at a high temperature and float to the surface [102-104].

Similarly, as I suggested based upon observations of enstatite meteorites [68], silicon combines with nickel to form nickel silicide which is more dense than the iron alloy and settles by gravity to form Earth's inner core.

The elements shown, in the right portion of Figure 9, comprise about 98% of the chondrite mass. One of the lesser abundant trace elements, uranium, is of particular importance. In 1982, Murrell and Burnett [105] discovered that uranium resides entirely in the alloy portion of the

Abee enstatite chondrite. This means that uranium, initially present in the Earth's fluid core, precipitated and migrated to the center of our planet.

INSIGHT FROM THE GIANT PLANETS

As astronomers first discovered in the late 1960s, three of the giant gaseous planets, Jupiter, Saturn, and Neptune radiate into space approximately twice the energy they receive from the sun and display prominent turbulence [106, 107] (Figure 11). The explanation proffered by NASA-funded scientists was that the energy is gravitational [108]. It did not make sense to me that Jupiter should still be collapsing after 4.5 billion years. Reflecting on the problem in 1991, I realized that Jupiter has all the ingredients for a planetocentric nuclear fission reactor. I applied Fermi's nuclear reactor theory [109] to demonstrate the feasibility that the internal energy production driving atmospheric turbulence in the giant planets is produced by planetocentric nuclear fission reactors. My scientific paper on the subject was published by *Naturwissenschaften* in 1992 [28].

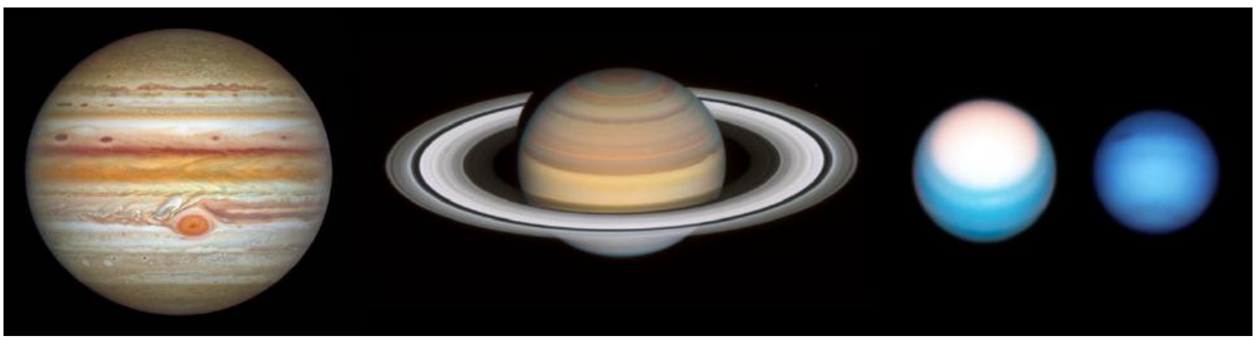


Figure 11. NASA images of the giant planets. Left to right: Jupiter, Saturn, Uranus, Neptune. Not to scale. Note their turbulent features.

Initially, I thought that hydrogen would be necessary to slow neutrons for the nuclear fission chain reaction, but quickly realized that hydrogen was not at all necessary. A fast neutron reactor does not require a moderator, such as hydrogen, to slow neutrons. That opened the possibility of central nuclear fission reactors inside Earth, other planets and large moons.

NUCLEAR FISSION GEOREACTOR AT EARTH'S CENTER

In 1993, I applied Fermi's nuclear reactor theory to demonstrate the feasibility of a nuclear fission "georeactor" at Earth's center [29], followed by further advances in 1994 [30] and 1996 [31]. Figure 12 is a schematic representation of Earth's georeactor.

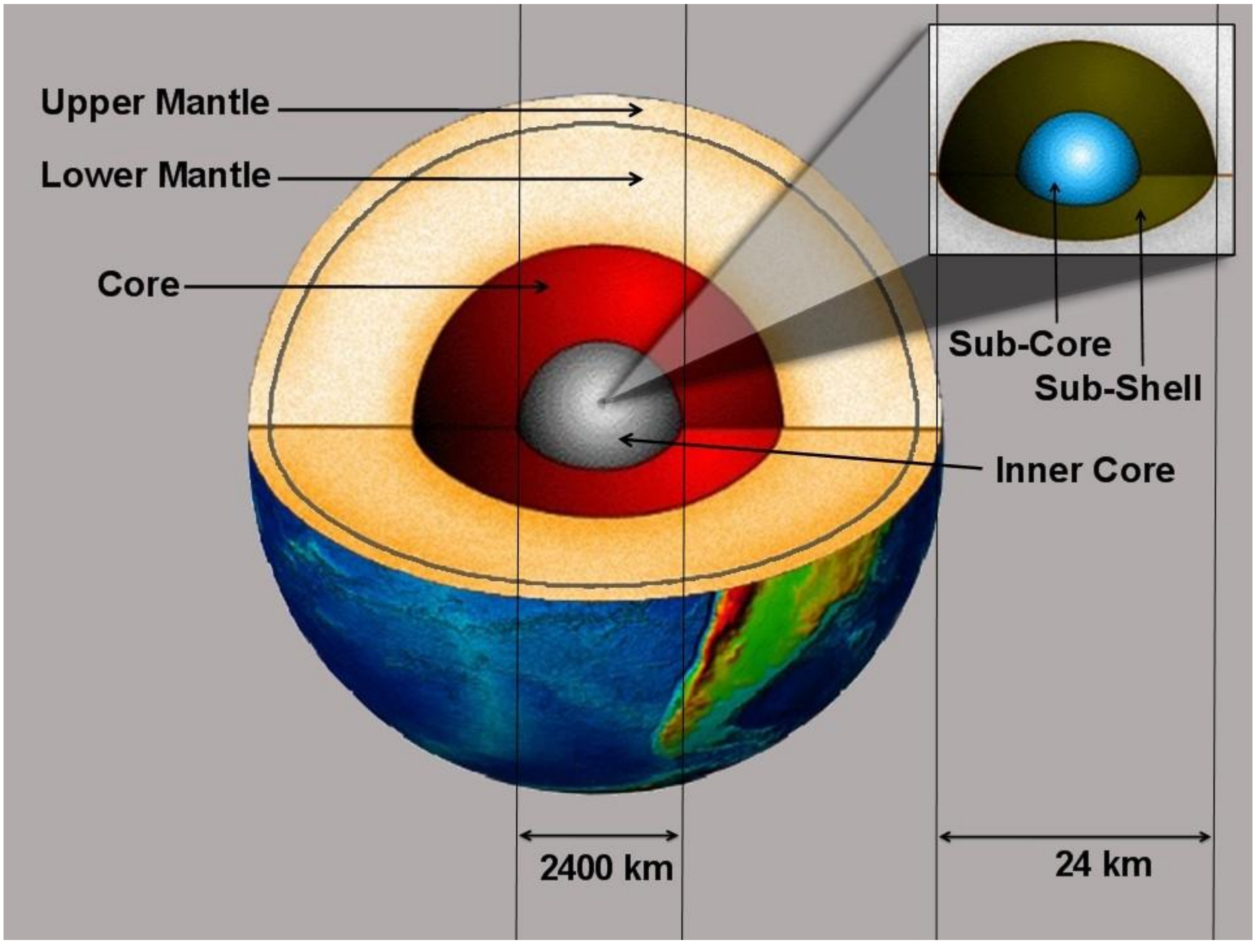


Figure 12. Earth's nuclear fission georeactor (inset) shown in relation to the major parts of Earth. The georeactor at the center is one ten-millionth the mass of Earth's fluid core. The georeactor sub-shell, consisting of nuclear fuel, radioactive decay and fission products, is a liquid or slurry, situated between the nuclear-fission heat source and inner-core heat sink, which assures stable convection that is necessary for sustained geomagnetic field production by convection-driven dynamo action in the georeactor sub-shell [31, 35, 36]. From [2].

Further advances came from nuclear georeactor numerical simulations, made using the SAS2 analysis sequence contained in the SCALE Code Package from Oak Ridge National Laboratory [110] that was developed over a period of three decades and extensively validated against isotopic analyses of commercial reactor fuels [111-115]. Dan Hollenbach graciously modified the computer program to operate over geological time scales and also to remove fission fragments, which are reactor poisons. In the georeactor fission fragments, with about half the mass and atomic number, are removed naturally by gravitational layering based upon density. The Oak Ridge calculations demonstrated (1) that the georeactor could operate over geological time scales as a fast neutron breeder reactor [116] and (2), significantly, would produce helium in precisely the range of compositions observed in deep-source lavas [34].

EVIDENCE OF GEOREACTOR EXISTANCE

Numerical simulations of georeactor operation, conducted at Oak Ridge National Laboratory, provide compelling evidence for georeactor existence: Georeactor helium fission products matched quite precisely the $^3He/^4He$ ratios, relative to air, observed in oceanic basalt as shown in Figure 13. Note in that figure the progressive rise in $^3He/^4He$ ratios over time as uranium fuel is consumed by nuclear fission and radioactive decay. The high $^3He/^4He$ ratios observed in samples from 'hotspots' are consistent with the sharp increases observed from georeactor simulations as the uranium fuel becomes depleted and ^4He diminishes.

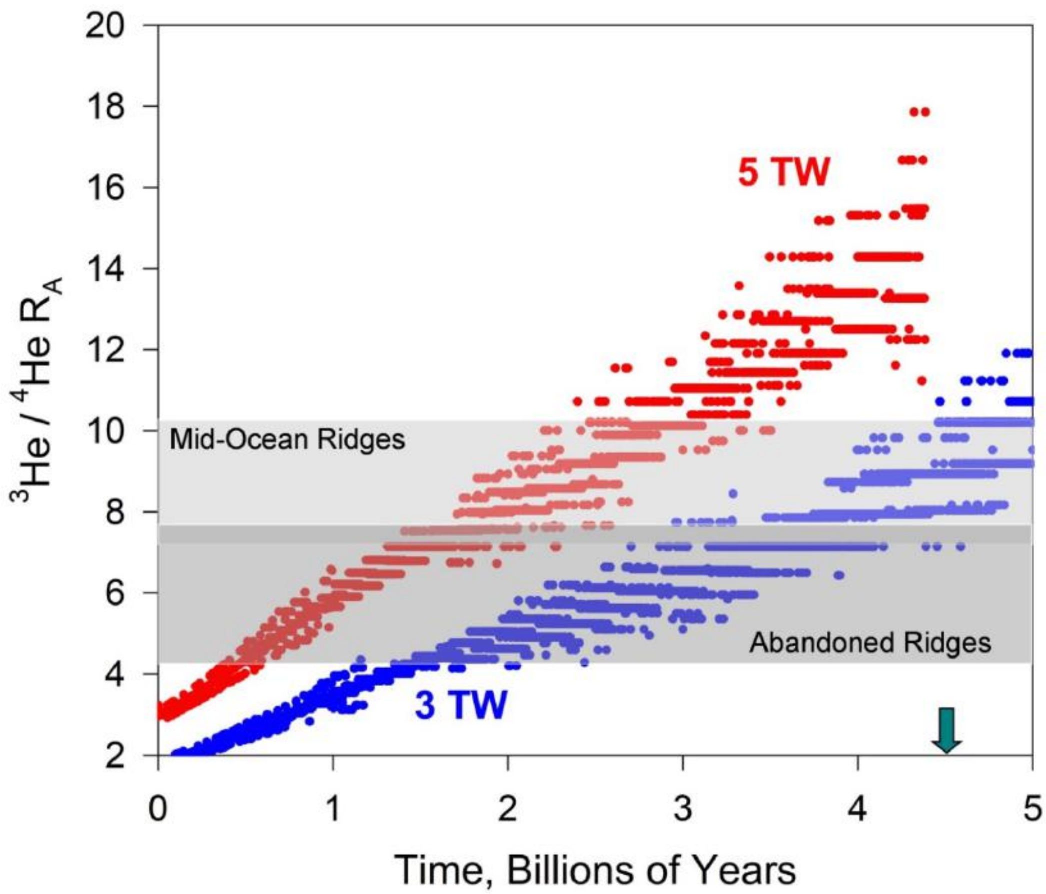


Figure 13. Fission product ratio $^3He/^4He$, relative to that of air, R_A, from nuclear georeactor numerical calculations at 5 terawatts, TW, (upper) and 3 TW (lower) power levels [34]. The band for measured values from mid-oceanic ridge basalts is indicated by the solid lines. The age of the Earth is marked by the arrow. Note the distribution of calculated values at 4.5 billion years, the approximate age of the Earth. The increasing values are the consequence of uranium fuel burn-up. Icelandic deep-Earth basalts present values that range as high as 50 times the atmospheric value [117].

Thermal structures, sometimes called mantle plumes, beneath the Hawaiian Islands and Iceland, two high $^3He/^4He$ hot-spots, as imaged by seismic tomography [118, 119], extend to the interface of the core and lower mantle, further reinforcing their georeactor-heat origin. The high $^3He/^4He$ ratios measured in 'hotspot' lavas appear to be the signature of 'recent' georeactor-produced heat and helium, where 'recent' may extend several hundred million years into the past. Notably, Mjelde and Faleide [120] discovered a periodicity and synchronicity through the Cenozoic in lava outpourings from Iceland and the Hawaiian Islands, 'hotspots' on opposite sides of the globe, that Mjelde et al. [121] suggest may arise from variable georeactor heat-production.

As early as 1930, it seemed that energy mysteriously disappeared during the process of radioactive beta decay. To preserve the idea that energy is neither created nor destroyed, 'invisible' particles were postulated to be the agents responsible for carrying energy away unseen. Finally, in 1956 these 'invisible' antineutrinos from the Hanford nuclear reactor were detected experimentally [122].

As early as the 1960s, there was discussion of antineutrinos being produced during the decay of radioactive elements in the Earth. In 1998, Raghavan et al. [123] were instrumental in demonstrating the feasibility of their detection. In 2002, Raghavan [124] authored a paper, entitled "Detecting a Nuclear Fission Reactor at the Center of the Earth" wherein he showed that antineutrinos resulting from nuclear fission products would have a different energy spectrum than those resulting from the natural radioactive decay of uranium and thorium. Raghavan's 2002 paper stimulated intense interest worldwide, especially with groups in Italy, Japan and Russia. Russian scientists [125] expressed well the importance: "Herndon's idea about georeactor located at the center of the Earth, if validated, will open a new era in planetary physics".

The georeactor is too small to be presently resolved from seismic data. Oceanic basalt helium data, however, provide strong evidence for the georeactor's existence [34, 126] and antineutrino measurements have not refuted its existence [127, 128]. The two currently operational deep-Earth antineutrino detectors, at Kamioka, Japan [129] and at Grand Sasso, Italy [130], to date have not only failed to refute georeactor nuclear fission, but at a 95% confidence level, have measured georeactor energy production of 3.7 and 2.4 terawatts, respectively. Notably, the energy production levels used in the Oak Ridge National Laboratory georeactor calculations, indicated in Figure 10, ranged from 3 to 5 terawatts [34]. These antineutrino measurements provide the second independent, compelling evidence of the existence of Earth's nuclear georeactor.

When I first demonstrated the feasibility of a nuclear fission reactor at Earth's center [29], I thought of it solely as a means to power the mechanism that produces the geomagnetic field. Later, I realized that the georeactor itself is the production mechanism for Earth's magnetic field, and is also a crucial component in the geophysical system that drives major geodynamic activity.

EARTH'S MAGNETIC FIELD

If Earth's magnetic field is generated by a convection-driven dynamo, a magnetic amplifier, as suggested by Elsasser [20], it is produced by the georeactor [35, 37], not in the Earth's fluid core where convection is physically impossible [27].

The two-component planetocentric georeactor is one ten-millionth the mass of Earth's fluid core (Figure 14). The liquid or slurry georeactor sub-shell consists of nuclear fuel and nuclear fission and decay products. The sub-shell is situated between the sub-core nuclear-fission heat source and inner-core heat sink. That configuration in this micro-gravity environment assures stable convection that is necessary for sustained geomagnetic field production by convection-driven dynamo action in the georeactor sub-shell [31, 35, 36].

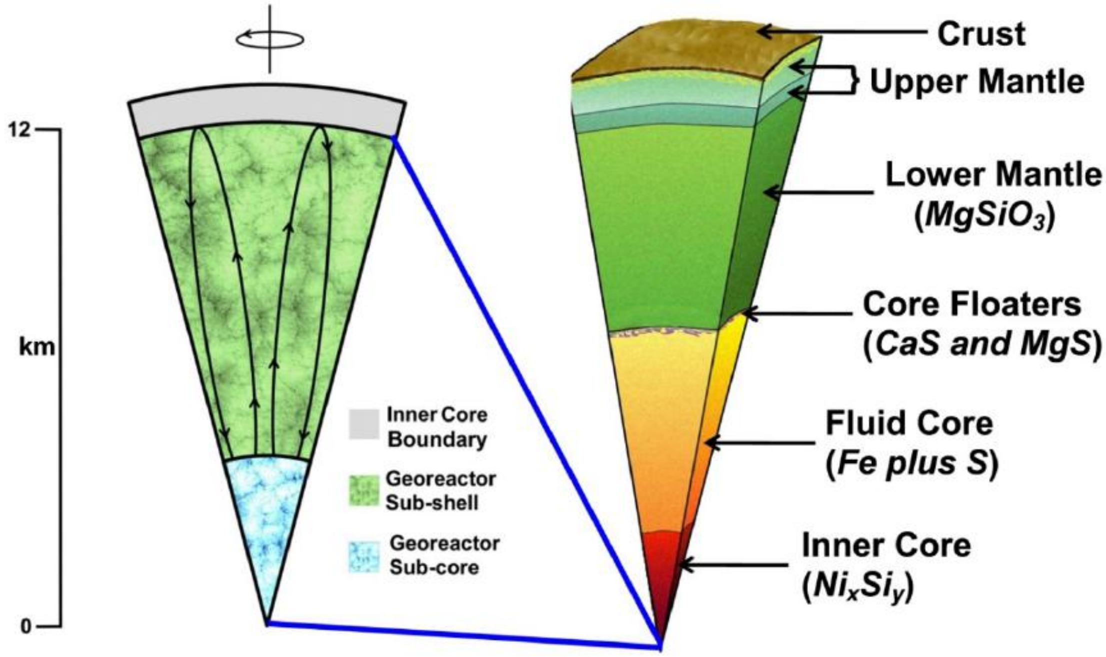


Figure 14. Schematic representation of Earth's nuclear fission georeactor with planetary rotation and fluid motions indicated separately; their resultant motion is not shown. Also shown are major portions of the Earth's interior from [45] based on [29-31, 34, 35, 37, 116, 131, 132] and on the fundamental mass ratio relationships shown in Table 1.

Generation of magnetic fields in planets and large moons [36, 37, 100, 133] are consequences of their formation commonality described by the following steps: Protoplanetary condensation at high temperatures and pressures leads to highly reduced iron alloy core-material containing uranium. The incompatable uranium precipitates and settles to the center. In that micro-gravity environment, the uranium forms the two-component nuclear reactor. Nuclear fission in the central reactor sub-core produces convection in the charged particle rich nuclear waste sub-shell. Sub-shell convection coupled with rotation acts as a magnetic amplifier (dynamo) that amplifies to a grand magnitude an ambient magnetic field generated by the motion of charged particles from radioactive decay.

GEOREACTOR STABILITY AND INSTABILITY

There are periods when the geomagnetic field has maintained the same polarity for periods longer than 20 million years [134, 135], but reversals and excursions are commonplace over Earth's geological history. Understanding the factors responsible for georeactor stability is crucial for understanding the factors that lead to georeactor instability.

The two-component structure of the georeactor provides a natural means of self-regulation. The georeactor sub-shell consists of uranium and radioactive waste, namely, fission fragments and nuclear decay products which are reactor poisons. Hypothetically, if, in the microgravity region near Earth's center, the sub-shell components were of uniform density, the reactor poisons would consume a sufficient quantity of neutrons to prevent sustained nuclear fission. Uranium, the densest substance settles out and engages in nuclear fission, which disrupts the georeactor assembly. Eventually a steady state is reached wherein the amount of fission energy produced balances the uranium precipitation and the energy transferred to the inner core by convection [136], illustrated in Figure 15.

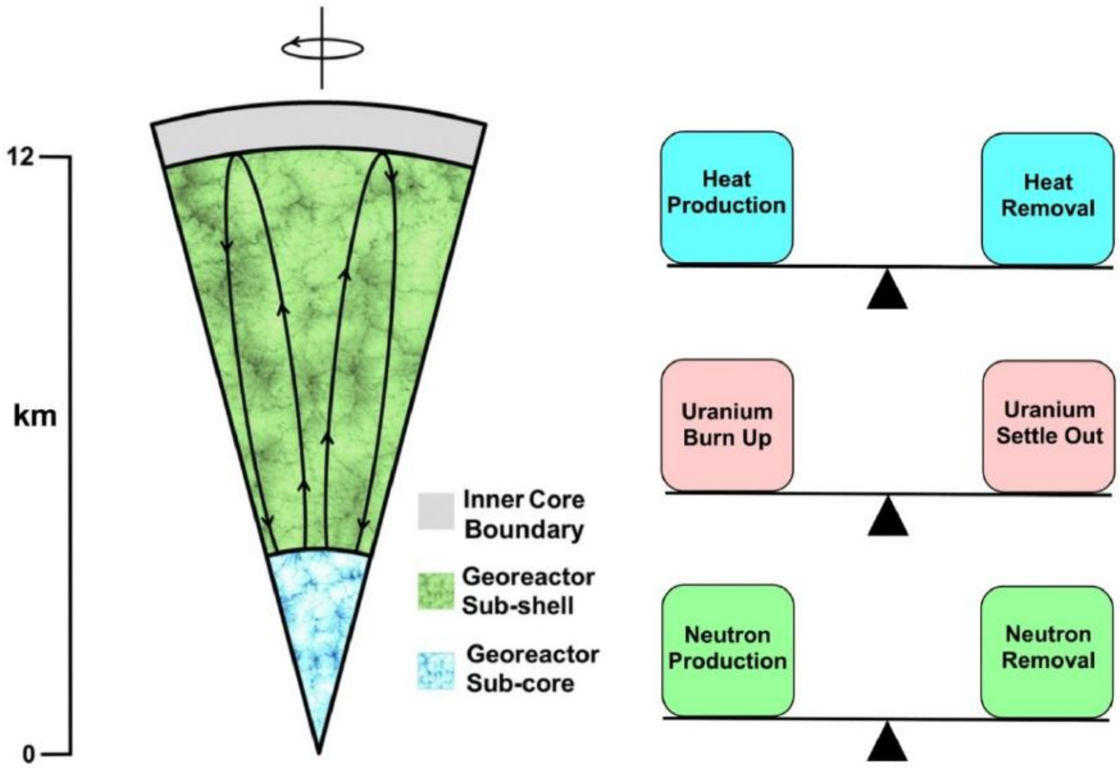


Figure 15. Schematic representation of Earth's georeactor, not to scale, with non-resultant planetary and fluid motions indicated separately (left) and (right) representations of the balances that must be maintained for stable georeactor operation. From [136].

The geomagnetic field, I posited, is produced by sustained convection in the radioactive waste sub-shell [28, 30, 31, 34, 35, 37, 50, 137]. The geomagnetic field has been stable, without reversals, for periods longer than 20 million years [134, 138], although more frequent polarity reversals and excursions occur, as shown in Figure 16.

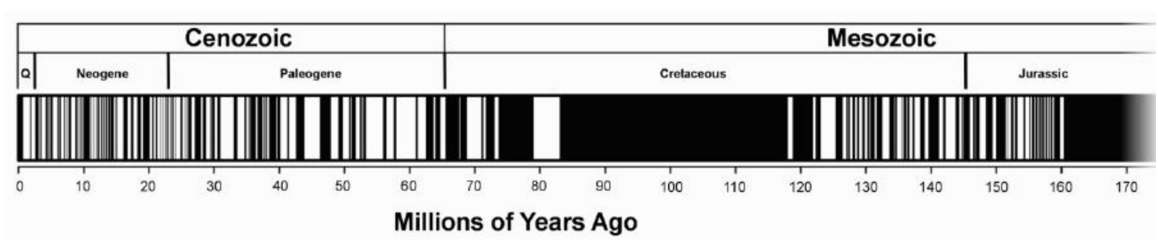


Figure 16. Geomagnetic polarity since the middle Jurassic. Dark areas denote periods where the polarity matches today's polarity, while light areas denote periods where that polarity is reversed. Based upon published data [139, 140]. From [2].

Major intensity and/or directional variability in the geomagnetic field can be reasonably attributed to disrupted convection in the georeactor sub-shell [136].

As the georeactor mass is only about one ten-millionth the mass of Earth's core, major trauma at Earth's surface by a large meteor impact or major surface geophysical event could in principle disrupt sub-shell convection.

Disruption of georeactor sub-shell convection could also result by energy from changes in the solar wind transferred via the geomagnetic field into the georeactor by Faraday's law of electromagnetic induction [19]. A simple apparatus, illustrated schematically in Figure 17, demonstrates the principle of electromagnetic induction.

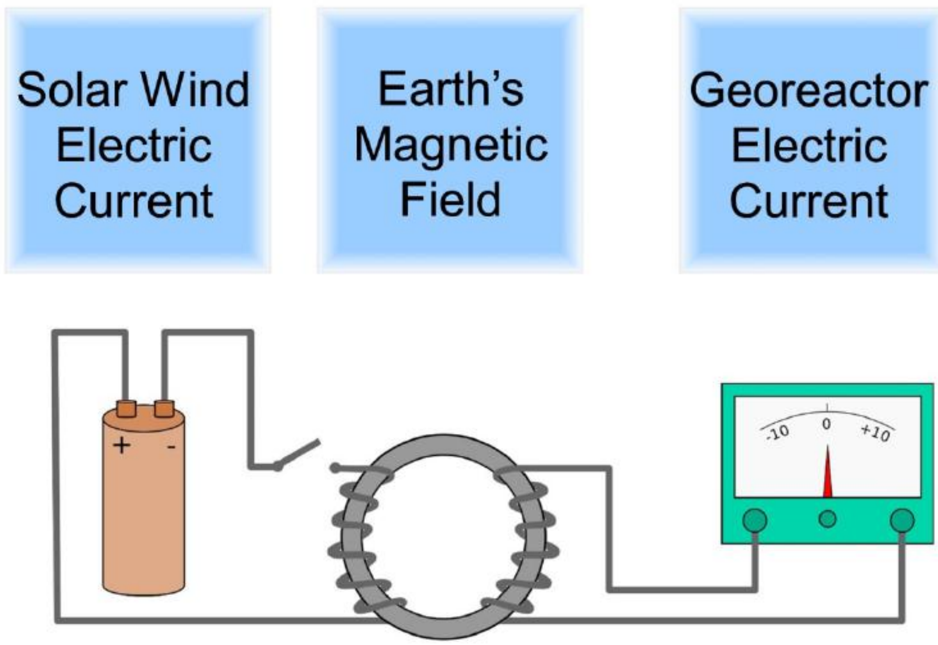


Figure 17. Schematic diagram of an apparatus for demonstrating the principle of electromagnetic induction and their corresponding components in nature. From [136].

When the switch in Figure 17 is closed, the galvanometer displays only a momentary pulse. When the switch is opened, the galvanometer displays a momentary pulse in the opposite direction. Only a *changing* electrical current can be transferred through electromagnetic induction. The blue boxes in this figure illustrate components in nature that correspond to the schematic electrical components indicated [136].

The solar wind comprises an electrical current of charged particles that stream from the sun. *If the solar wind were constant, no electrical current would be induced into the georeactor.* Exceptionally large changes in the solar wind or in the ring current of charged particles trapped in Earth's magnetosphere or in the cosmic ray flux, however, will cause electrical current to be induced into the georeactor sub-shell producing ohmic heating, diminishing sub-shell convection, and potentially leading to geomagnetic field collapse with concomitant magnetic excursion or reversal [136].

Diminishment of georeactor sub-shell convection may result in a spike of georeactor nuclear fission energy output due to additional uranium settling-out, even if not sufficient to cause a magnetic reversal or excursion [136].

GEOREACTOR AGEING AND DEMISE

The Oak Ridge National Laboratory georeactor simulation data, from [34], shown in Figure 13, displays a progressively upward trend. That upward trend in the $^3He/^4He$ relative ratio is the consequence of diminished ^4He production over time resulting from uranium fuel consumption by nuclear fission. Observation of high $^3He/^4He$ ratios relative to atmospheric helium, as high as 50 in Icelandic basalt [117], suggests the georeactor is in its final stages of life [34], but the specific time-frame is yet unknown.

Figure 18 presents a record of recent magnetic polarity reversals. The last polarity reversal event occurred about 786,000 years ago and may have occurred during a time span as short as 13±6 years [141], a time-frame consistent with other observations of rapid geomagnetic reversals [142, 143].

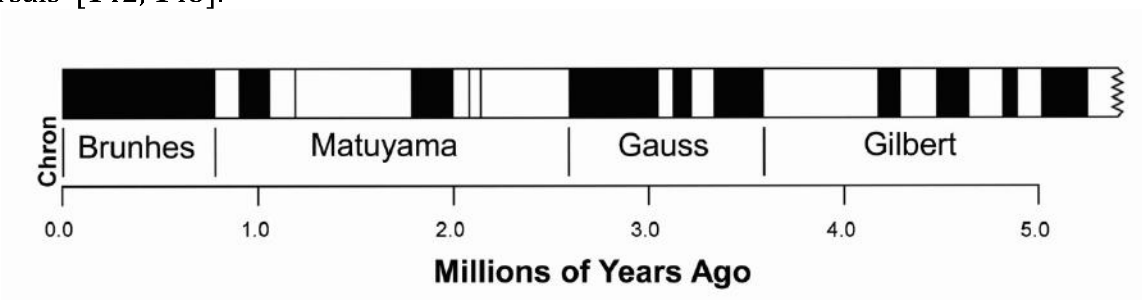


Figure 18. Recent geomagnetic polarity from rock-magnetism investigations. Dark areas denote periods where the polarity matches today's polarity, while light areas denote periods where that polarity is reversed. Based upon an image by the U. S. Geological Survey. Reproduced from [2].

No one knows when the next georeactor sub-shell convection collapse will occur. Recent movements of the North Magnetic Dip Pole [3] might imply weakening sub-shell convection, possibly portending collapse in the not too distant future [2].

MECHANISM OF SOLAR ACTIVITY TRIGGERING EARTHQUAKES AND VOLCANOES

The nuclear fission georeactor energy serves three major functions:

- Geomagnetic field production,
- Source of heat channeled to hotspots, such as Hawaii and Iceland, and
- Replacing the lost heat of protoplanetary compression.

The gases and ices of Earth's complete protoplanetary condensation as a Jupiter-like gas giant amounted to about 300 Earth-masses. This massive weight compressed the rocky portion to about two-thirds of Earth's present diameter and emplaced within it the tremendous energy of protoplanetary compression. After being stripped of its gases and ices by the violent solar wind produced during thermonuclear ignition of the sun, over time Earth began to decompress. Whole-Earth Decompression Dynamics describes the geological and geophysical consequences of Earth's decompression [34, 131, 144-146].

The stored energy of protoplanetary compression is the primary energy source for Earth's decompression. However, for decompression to progress without cooling and impeding decompression, the lost heat of compression must be supplied by georeactor nuclear fission. In addition to doing work against gravity, the stored energy of protoplanetary compression heats the base of the crust by a process known as *mantle decompression thermal tsunami* [147].

Decompression beginning within Earth's mantle propagates outward like a wave through silicates of decreasing density until it reaches the rigid crust where compression and compression-heating takes place. That compression-heating is the heat source for the geothermal gradient as well as for other surface phenomena including shallow-source volcanoes.

The mechanism for changes in solar weather triggering earthquakes and volcanoes is as a multi-stage amplifier. A change in the charged particle flux impinging the Earth's magnetic field induces electric current into the georeactor. That induced electric current causes ohmic heating in the sub-shell that disrupts convection. The disrupted sub-shell convection causes extra uranium to settle-out, which causes a burst of nuclear fission energy. That extra burst of nuclear fission energy replaces some of the lost heat of protoplanetary compression, which causes a burst in whole-Earth decompression. That burst in whole-Earth decompression results in a burst of heat emplaced at the base of the crust and/or Earth's surface experiencing a bit of decompression-driven movement, the extent of which is a function of the degree of sub-shell convection disruption [18].

This mechanism is applicable to solar weather triggering earthquakes and volcanoes as well as posing an explanation for the sometimes observed geomagnetic reversals associated with major geophysical events, such as basalt lava floods [148, 149].

GEOPHYSICAL CONSEQUENCES OF SUB-SHELL CONVECTION COLLAPSE

During georeactor formation there must have existed a brief period of chaotic nuclear fission activity before a steady state was reached wherein the amount of fission energy produced balances the uranium precipitation and the energy transferred to the inner core by convection. A similar situation may arise during each sub-shell convection collapse. Over Earth's lifespan, georeactor fuel has been decreasing due to nuclear fission and natural radioactive decay. Consequently, the amount of potential flare-up upon collapse of georeactor sub-shell convection will not be nearly as great as in earlier times. The amount of surface-effects from whole-Earth decompression will certainly be much less than in earlier times.

Volcanic regions heated directly by georeactor produced heat, characterized by high $^3He/^4He$ ratios, may expect increased eruptions during sub-shell collapse. These include the East African Rift System, Hawaiian Islands, Iceland, and Yellowstone among others [150]. Of particularly grave concern is whether a major pulse in georeactor energy might trigger eruption of the Yellowstone potential-super-volcano [151-154] whose georeactor-supplied heat is strongly indicated by high $^3He/^4He$ ratios [155, 156].

At some yet-unknown point in time, inevitably, georeactor uranium fuel will have sufficiently diminished so as to be unable to sustain nuclear fission chain reactions, thus marking the permanent demise of the georeactor and the geomagnetic field [34]. Humanity would be well-advised to approach that unknown time with eyes open and with a willingness to work together for common survival.

CONCLUSIONS

This review is different in that it discloses a specific logical progression of understanding that has led the author to the concept of planetary nuclear fission reactors and to the origin of planetary magnetic fields. Anyone who wishes can follow the step-by-step logical progression of understanding and recognize the veracity of fundamental developments and new insights on the origin of Earth's magnetic field, and much more.

Over my scientific lifetime of fifty years, I have witnessed the progressive failure of scientists either to read relevant scientific literature or to follow sound scientific principles, for example modeling physically-impossible Earth core convection. Scientists and their parent institutions have an intrinsic responsibility to tell the truth to the taxpayers who fund their work and to humanity in general. Attempting to suppress and/or ignore contradictory scientific publications is no different than lying and deceiving. Thirty years have elapsed since my first publication on the concept of planetary nuclear fission reactors, but to my knowledge no NASA-funded scientist has acknowledged that concept even though there is great relevance [28-30, 36, 95, 100, 146].

The potential collapse of the geomagnetic field, along with the concomitant consequences of georeactor sub-shell convection collapse, have very serious implications for all humanity. Instead of pretending that the georeactor does not exist, the geoscience community should expend its efforts on learning more about it, especially to ascertain the georeactor's near-term behavior and the state of its nuclear health.

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