THE CYCLE

A Review of Whole Planet Coupling, Water's importance, The Organic Solar System's influence on Earth, and a Refined Mechanism for the Core Mantle Decoupling Event (Pole Shift).

By P.S.H.S, 2025.

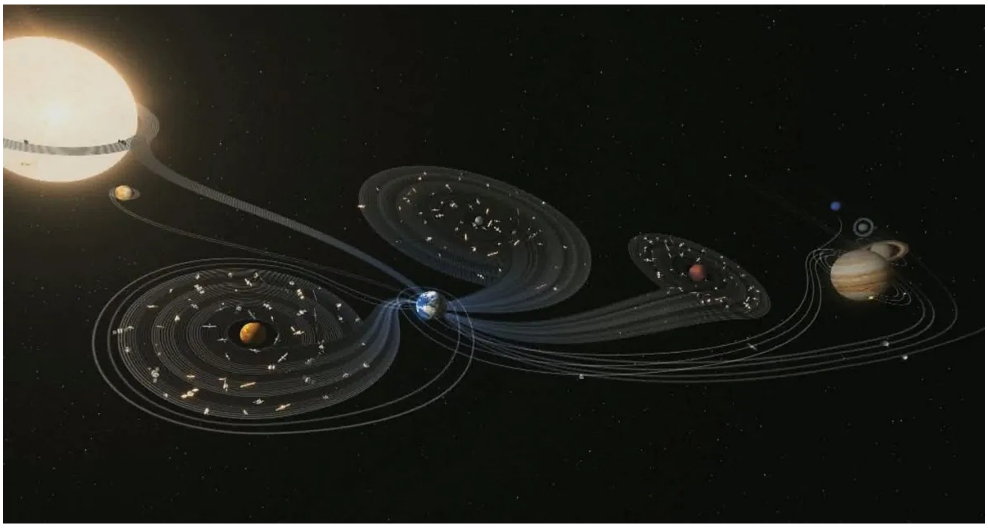
Introduction

Understanding the dynamic processes within Earth's interior is essential for deciphering the planet's geological past and anticipating its future evolution. Central to this endeavor is the core-mantle boundary (CMB), a critical interface where the liquid outer core meets the solid mantle, driving Earth's geodynamic engine. The newest widely accepted Core Mantle Decoupling Dzhanibekov Oscillation Theory (ECDO) posits that periodic decoupling of the core and mantle arises from shifts in the core's hexagonal packing, ultimately forming Large Low Shear Velocity Provinces (LLSVPs). **This theory's focus overlooks the intricate chemical and dynamic interactions in the context of Earth, that allow for decisive comprehension of the role of each component that may affect such an event. These articles aim at looking at the vast wealth of data as to allow the formulation of an integrated systemic view.**

Through an integrated review and analysis of geochemical and geophysical data, these series of articles are an attempt to provide a holistic mechanism propelled by the interplay of water and hydrogen in our planet to refine the specifics and plausibility of such an event.

It reveals that water, transported to the deep mantle through subduction, forms a series of wide-ranging reactions that may form the basis of mantle dynamics, triggering the formation of Ultra-Low Velocity Zones (ULVZs) and fueling hydrogen-driven mantle plumes that manifest as LLSVPs, volcanic activity, aid for core-mantle coupling, and surface expressions.

Beyond Earth's interior, I investigate how external cosmic factors, such as solar cycles, planetary alignments, and lunar tides, modulate these deep processes by exerting force upon water**.** These findings unveil **a synchronized cycle linking Earth's core and Space to its tectonic and atmospheric evolution**, offering new insights into historical geological shifts and future predictions.



This investigation covers a large span of information, and insofar will have the following chapters, published in parts:

PART 1. THE CORE

- The Composition of Earth’s Core
- Core-Mantle Interaction
- Ferric Oxide

PART 2. THE MANTLE

- The Earth’s Mantle
- Water and Hydrogen content in the Mantle
- Dissolved water weakens mantle minerals
- Interaction of Water in the Core-Mantle Boundary (CMB)
- Formation of ULVZs
- Approximate Order-of-Magnitude Calculation for Yearly FeO Mass Creation at the CMB
- The Large Low Shear Velocity Provinces (LLSVPs)

PART 3. THE DEGASSING

- The Pathways of Hydrogen
- Plume Creation
- Volcanic Degassing and VOC/H2O Balance
- Reaction Pathways, P-T Ranges, and Kinetic Constraints

PART 4. THE SURFACE

- Amagmatic Ghost Plumes: A Source of Liquid Water
- The Troposphere and Stratosphere’s Balance
- The Great Greenhouse Contradiction
- Hydrogen at the Atmosphere
- Solar Flares and Coronal Mass Ejections

PART 5. THE COSMOS

- The Influences Outside of the Earth
- The Influence of the Moon
- Solar Flares, Solar Sunspot Activity, and the 11 year Sun Cycle can be Predicted
- Planetary Alignment

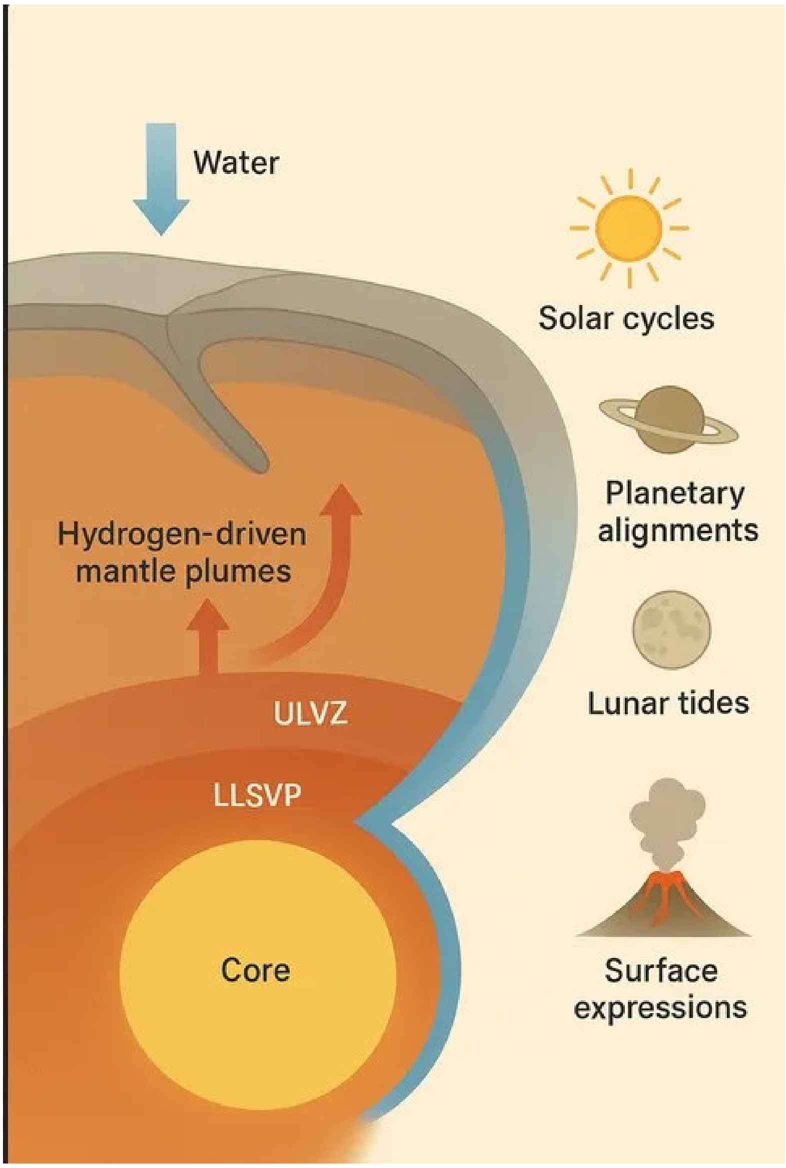
PART 6. THE CYCLE

- Under evidence, what does it take for the CMB Event to Happen

- A Geomagnetic Weakening?
- Comets and Meteors

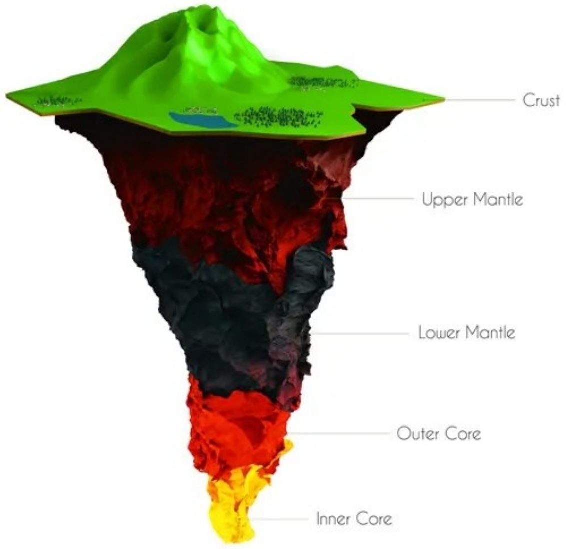
To improve reading accesibility of this work, with aid of *ChatGPT,* I’ve included in the start of each section a layman’s terms synthesis paragraph in italic text, **so that any reader can quickly understand what each section is about.** That is the extent of aid used by AI. Sources are attached to the text of the article.

This is a comprehensive investigation of up to date literature and evidence. Any conclusions that may have been reached are supported by available data.



PART 1, THE CORE

The Composition of Earth’s Core - A review



Imagine the Earth’s center as a giant ball of iron and nickel metal, but when researchers “listen” to it with seismic (earthquake) waves, it sounds about 5–10% lighter than pure iron and nickel should be, like finding your bag of sugar is mysteriously missing a few spoonfuls. To fix that mystery “missing weight,” studies suggest bits of lighter ingredients like silicon, hydrogen, oxygen, carbon, or sulfur got mixed in. Silicon and hydrogen are top suspects because the early Earth had lots of water and rocks, and when molten iron met water in a deep magma ocean, it grabbed hydrogen (and some oxygen and silicon) into the core. Over time, this created a lighter, oxygen-rich layer at the core-mantle boundary, which may explain big events in Earth’s history, like massive oxygen releases and even the rise of life’s oxygen in the atmosphere.

The Earth’s core is believed to be primarily composed of an Fe-Ni alloy. However, seismic observations show that the density of the core (both liquid outer core and solid inner core) is lower than that of pure iron or Fe-Ni alloy at the relevant pressure and temperature conditions *[Source 1]* *[2]*. This is known as the “density deficit”. To explain this density deficit, it is generally accepted that the core contains light impurities or light elements alloyed with the iron and nickel. The specific identity and relative amounts of these light elements are still debated, due to mismatch in seismic data, sound velocities and density compared with the Fe-Ni theory.

“*The Earth’s core is believed to primarily consist of Fe-Ni alloy according to cosmochemical and geochemical constraints (Badro et al., 2015; McDonough & Sun, 1995). However, the seismologically-constrained density of the Earth’s core, such as one from the preliminary reference Earth model (PREM) (Dziewonski & Anderson, 1981), is 5%–10% lower than that of Fe and Fe-Ni alloy at the pressure and temperature (P-T) conditions expected to the core (Dewaele et al., 2006; Fei et al., 2016; Sakai et al., 2014), which is known as the density deficit (Birch, 1952). Extensive experimental and geochemical studies have proposed different light elements to explain such a density deficit, including silicon (Si), sulfur (S), oxygen (O), carbon (C), and hydrogen (H) (Hirose et al., 2021). Among them, Si and H are important candidates due to their abundances in the Earth system (McDonough & Sun, 1995) and their high solubilities in Fe metal at high P-T (Badding et al., 1991; Fischer et al., 2013; Fu et al., 2022, 2023).*”

Candidate light elements proposed by experimental and geochemical studies include Silicon (Si), Sulfur (S), Oxygen (O), Carbon (C), and Hydrogen (H). Silicon (Si) and Hydrogen (H) are considered important candidates due to their abundances in the Earth system and their high solubilities in Fe metal at high pressures and temperatures. Geochemistry, metal-silicate partitioning experiments, and isotope fractionation experiments support Si as the dominant light element. Carbon (C) might also **have been** present in the core in the past due to its abundance in primitive chondritic meteorites and its siderophile nature during metal-silicate differentiation.

Recent planet formation theories suggest that **a large amount of water** could have been delivered to the growing Earth.

"*Since Birch reported the density deficit and velocity excess of the Earth's outer core with respect to pure iron (Fe), light elements in the core have long been explored but still remain controversial. Recent planet formation theories suggested that a large amount of water could have been delivered to the growing Earth. The chemical reaction of water with Fe metals in a magma ocean led to the incorporation of hydrogen (H) along with silicon (Si) and oxygen (O) into the core6–9. While O is least partitioned into solid Fe and should therefore be negligible in the inner core10–12, both Si and H could be present in both the outer and inner core. Indeed, measurements of the density and sound velocity of solid Fe and Fe alloys supported that Si and H are important impurity elements in the inner core. Recent theoretical calculations suggested that the Earth's solid inner core is an hexagonal close packed Fe60Si4H1–15 alloy, depending on the temperature at the inner core boundary (ICB), TICB = 5500–6500 K.* "

The chemical reaction of water with Fe metals in a magma ocean could lead to the incorporation of H, along with Si and O, into the core, causing the great Oxidation event.

"*Hydrous minerals in subducted crust can transport large amounts of water into Earth's deep mantle. Our laboratory experiments revealed the surprising pressure-induced chemistry that, when water meets iron at the core–mantle boundary, they react to form an interlayer with an extremely oxygen-rich form of iron, iron dioxide, together with iron hydride. Hydrogen in the layer will escape upon further heating and rise to the crust, sustaining the water cycle. With water supplied by the subducting slabs meeting the nearly inexhaustible iron source in the core, an oxygen-rich layer would cumulate and thicken, leading to major global consequences in our planet. The seismic signature of the D'' layer may echo the chemical complexity of this layer. Over the course of geological time, the enormous oxygen reservoir accumulating between the mantle and core may have eventually reached a critical eruption point. Very large-scale oxygen eruptions could possibly cause major activities in the mantle convection and leave evidence such as the rifting of supercontinents and the Great Oxidation Event.* "

Regarding the inner core:

The Earth's solid inner core is mostly iron packed in a hexagonal close-packed structure, but it's a little "lightened" by small amounts of other elements, mainly about 1.6–3 weight % in silicon and 0.15–0.6 weight % in hydrogen. These silicon and hydrogen levels can explain why the core's density is about 4% lower than pure iron and why seismic waves travel through it more slowly. There's a trade-off between Si and H: if you put in more silicon, you need less hydrogen, and vice versa, and while some models push silicon up to ~4.7 wt% or hydrogen to ~1.4 wt%,

oxygen and carbon barely get into solid iron under those extreme pressures, so they are seen as not important in the inner core.

The solid inner core is primarily hexagonal close-packed (hcp) Fe containing some light elements. However, based on combining new data with existing datasets, models suggest the inner core likely contains around 1.6%–3% silicon and 0.15%–0.6% hydrogen by weight.

"The Earth's inner core is believed to be made up of solid iron and nickel alloys, but there are also some lighter elements alloyed in. We studied how silicon and hydrogen affect the density and sound wave velocity of the iron alloys in the inner core. We combine our new data with existing datasets to create a model that shows that the inner core likely contains around 1.6%–3% silicon and 0.15%–0.6% hydrogen. These amounts can explain the density and sound velocity of the inner core as observed through seismic measurements. "

There is a large trade-off between the estimated Si and H contents needed to match seismic data; for instance, higher Si content would mean lower required H content and vice versa. Other postulates suggest that the maximum estimated Si content is approximately 4.7 wt% and maximum H content is approximately 1.43 wt%.

Oxygen (O) is considered highly incompatible with solid Fe metal, so only a trace amount of O may exist in the inner core. **Carbon (C)** is also unlikely to be an important impurity element in the inner core due to its low solid-hcp / liquid partitioning coefficient.

"Discussion : Crystallization of hcp Fe–Si–H at Earth's inner core.

The solid inner core of our planet consists of hcp Fe containing some light elements; the inner core density deficit with respect to pure Fe has been estimated to be about 4%. While the least amounts of O and C are incorporated into solid Fe in the inner core. Si, H and S are known to form solid solution with Fe to some extent, and likely present in the solid core. Nevertheless, interactions among Si, H and S atoms in hcp Fe could be strong and affect their simultaneous solubilities as well as solid–liquid partitioning. Indeed, the liquid immiscibility, a typical consequence of the strong interaction, has been observed between Fe–H and Fe–S liquids to > 100 GPa50. "

"*Recent ab initio simulations performed by Refs.17 and 51 emphasized the presence of C and/or H in the solid inner core, in order to account for not only the density but the low P- and S-wave velocities observed. As mentioned above, C is unlikely to be an important impurity element in the inner core because of its low DC (solid-hcp/ liquid) ~ 0.122; otherwise the liquid core should be enriched in C, which is not compatible with its density and velocity observations . Alternatively the inner core alloy may be H-bearing hcp Fe60Si4H1–15 when TICB ranges from 5500 to 6500 K (more H is necessary for lower TICB).* "

Hydrogen here is *particularly emphasized* as necessary to account for the low P- and S-wave velocities observed in the inner core, in addition to density, but the study is behind a paywall.

Regarding the outer core:

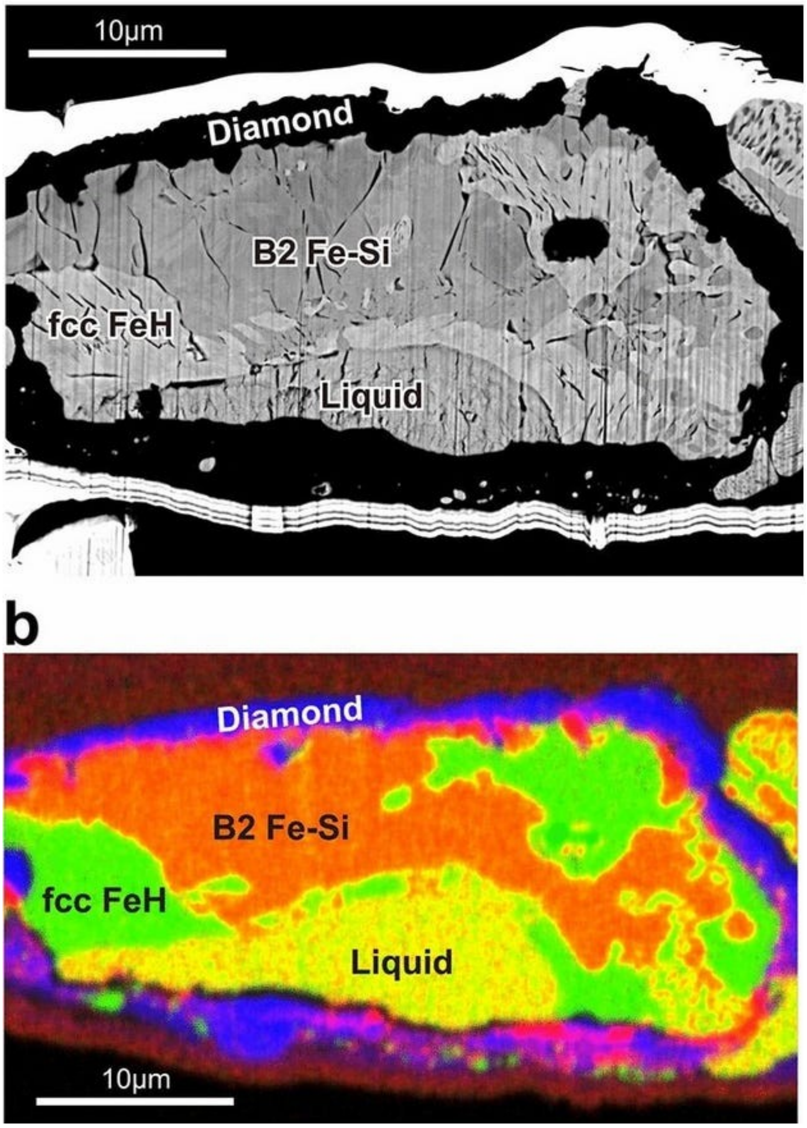
Recent studies show that Earth's liquid outer core has about 2–3.6% silicon by weight, and experiments tell us that silicon and hydrogen basically go into the solid inner core almost as much as they stay in the liquid outer core (their "preference numbers" are near one), so they can't explain why the outer core is lighter than the inner core. To make up the density difference, we need another light element that really hates being part of iron; oxygen fits the bill: it stays

almost entirely in the liquid, is barely found in the growing solid inner core, and so its presence in the outer core is what makes that layer less dense than the inner core.

Recent models considering both geochemical and geophysical constraints (Badro et al., 2015) suggest that the outer core contains 2–3.6 wt% Si.

Experimental measurements indicate relatively high solid/liquid partition coefficients for Si (DSi = 0.94(4)) and H (DH = 0.70(12)) between hexagonal close-packed (hcp) Fe and the coexisting liquid. These values, being close to 1.0, imply that the concentrations of Si and H do not differ significantly between the outer and inner core. This relatively small difference in Si and H concentrations between the outer and inner core requires the inclusion of other light elements in the outer core to explain the observed density contrast between the outer and inner core. Oxygen (O) is identified as a key candidate for this role, as it is least partitioned into solid Fe compared to S and Si, and is expected to be negligible or exist only in trace amounts in the solid inner core due to its high incompatibility with solid Fe metal. The presence of Oxygen in the liquid outer core, which is largely excluded from the solid inner core during crystallization, is thus crucial to account for the density difference between the outer and inner core.

The outer core liquid may include 1.7–4.4 wt% O, along with Si and H, depending on the inner core boundary (ICB) temperature. The reduction of the Fe-FeO miscibility gap with increasing pressure is *expected* to significantly affect core differentiation mechanisms, controlling oxygen partitioning.



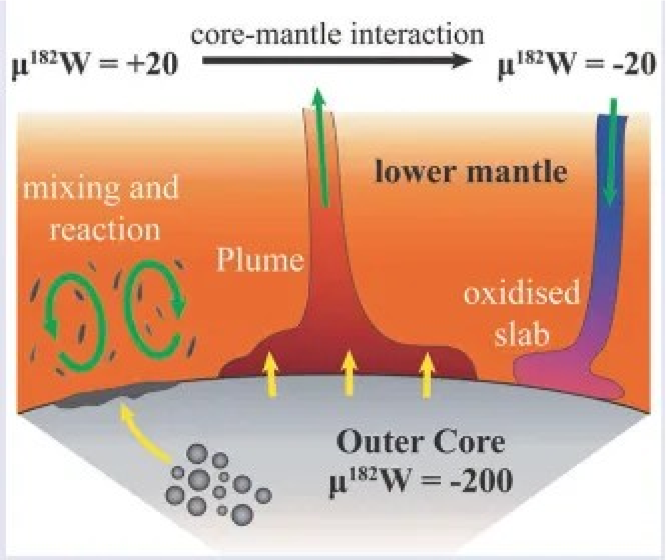
From the study "Melting phase relations in Fe–Si–H at high pressure and implications for Earth's inner core crystallization". Coexisting Fe–Si–H liquid and solid fcc FeH and B2 Fe–Si phases at 48 GPa and 2100 K in run #4 using Fe–Si and CnH2n+2 paraffin as starting materials. (a) Back-scattered electron image and (b) combined X-ray elemental map of Fe (green) + Si (red) + C (blue). Bubbles and cracks in (a) indicate that hydrogen was present in liquid and solids at high pressure and escaped during decompression.

Precious Metals as Core Components and Tracers

The Earth's core, comprising a liquid outer core and a solid inner core, is widely considered to be a significant reservoir for various elements, including what are often referred to as precious or noble metals. Precious metals, particularly ruthenium (Ru), are highly concentrated in the metallic core and are extremely depleted in the silicate mantle. This is because highly siderophile elements (iron-loving, HSEs), like Ru, were almost entirely removed from the mantle and preferentially partitioned into the core during Earth's main accretion phase. Similarly, tungsten (W) is a moderately siderophile element that also preferentially partitioned into the Earth's core during its segregation. The core is estimated to contain about 90% of Earth's total W, and tungsten is much more abundant in the metallic core compared to the mantle. The presence of gold (Au) and platinoids in the core, with some suggestions of their escape from it, is also discussed in some models, linking their origin to early Earth differentiation processes.

Tungsten (W) Isotopes

The short-lived 182W system is a strong tracer for core-mantle interaction. Since hafnium (Hf) is a lithophile (silicate-loving) element and W is siderophile (iron-loving), W preferentially entered the core, leaving the mantle depleted in W but enriched in Hf. This differentiation means the W-rich core has a W ratio approximately 200 parts per million (ppm) lower than the mantle.



Ocean island basalts (OIBs), believed to originate from deep mantle plumes, exhibit anomalous (unradiogenic) tungsten isotope ratios. This signature, observed in basalts from locations like Hawaii and Réunion Island, is diagnostic of a core contribution to their mantle sources. The anti-correlation between negative W and high He signatures in OIBs further strengthens the argument for direct core-mantle interaction.

One such basalt formation.

“Traditionally, the high 3He/4He signature has been attributed to an undegassed reservoir in the deep mantle. Additional processes needed to obtain low 182W/184W often entail unobserved ancillary geochemical effects. It has been suggested, however, that the core feeds the lower mantle with primordial helium, obviating the need for an undegassed mantle reservoir. Independently, the tungsten-rich core has been suggested to impart the plume source with anomalous tungsten isotope signatures. We advance the idea that isotopic diffusion may simultaneously transport both tungsten and helium across the core–mantle boundary, with the striking implication that diffusion can naturally account for the observed isotopic trend. By modeling the long-term isotopic evolution of mantle domains, we demonstrate that this mechanism can account for more than sufficient isotopic ratios in plume-source material, which, after dynamical transport to the Earth’s surface, are consistent with the present-day mantle W-He isotopic heterogeneities. No undegassed mantle reservoir is required, bearing significance on early Earth conditions such as the extent of magma oceans. “

Ruthenium (Ru) Isotopes

Recent research on mass-independent Ru isotope variations indicate that the core and mantle possess different Ru isotopic compositions. This difference may arise because the Earth’s mantle’s Ru composition is predominantly a result of late-accreted material (a “late veneer” of chondritic material added after core formation ceased), which was compositionally distinct from Earth’s main building blocks that formed the core.

Hawaiian basalts show higher Ru than the ambient mantle. When combined with their unradiogenic W isotope ratios, this is a clear diagnostic of a core contribution to their mantle sources - the earth’s core is currently considered the most viable source to explain the coupled positive Ru and negative W values observed in OIBs.

“*The incorporation of core material derived from an s-process-enriched late impactor, stranded in the mantle, could hypothetically explain the coupled isotope systematics of Hawaiian OIBs. Yet, the last impactors incorporated into Earth’s mantle as part of the late veneer, that are more likely to* *contribute to the OIB source, are required to have ε100Ru to lower the 100Ru > 0 composition of the Eoarchean mantle to the present day mantle value (ε100Ru ≈ 0) and, therefore, do not have an appropriate composition. As such, the Earth's core is at present the most viable source to explain the combined origin of positive ε100Ru and negative μ182W values observed in OIBs.*"

Helium (He) Isotopes:

The Earth's core is also proposed to be a reservoir of primordial helium. This primordial helium, with its high He signature, can migrate to the deep mantle via diffusive equilibration. This mechanism could explain the observed high He ratios in OIBs, potentially *removing* the necessity to invoke an undegassed, primitive mantle reservoir that has survived the entire history of Earth's convection and magma ocean stages.

These elements were found in extruding igneous *surface* provinces of the planet today. The distinct isotopic compositions of these elements in mantle-derived rocks provide compelling evidence for *core-mantle interaction* and the core's role as a reservoir, given the lack of deposits in the mantle.

Core-Mantle Interaction pathways

Components can exit the Earth's core primarily through interactions occurring at the Core-Mantle Boundary (CMB). Several potential mechanisms are here described:

Diffusive Isotopic Exchange and Migration:

Diffusive isotopic exchange at the CMB is a plausible mechanism for core-mantle interaction. This process involves the exchange of tungsten isotopes across the boundary. The core is much more abundant in tungsten, allowing it to continuously supply the lower mantle with tungsten characterized by a specific isotopic signature (μ182W = -220).

This process is suggested to simultaneously transport both tungsten and helium across the core-mantle boundary (CMB). Tungsten self-diffusion in the lower mantle is thought to be efficient enough to allow for this isotopic exchange. Given that tungsten is much more abundant in the metallic core, the core can continuously supply the lower mantle with its characteristic 182W/184W signature. This diffusive exchange can naturally account for the observed 182W – 3He - 4He anti-correlation in OIBs.

The studies I have found so far seem to imply the ideas that Primordial helium and neon may migrate from the core to the deep mantle via diffusive equilibration, and that noble gases partition similarly between liquid metal and solid silicate, which is relevant for diffusive transport across the CMB, generating a large disequilibrium at the CMB in helium concentration, induced by mantle hydrogen degassing, which may drive core-mantle diffusion. The core may act as a reservoir of both tungsten and helium isotopes, fed to the lower mantle via isotopic diffusion, potentially explaining their signatures in mantle plumes.

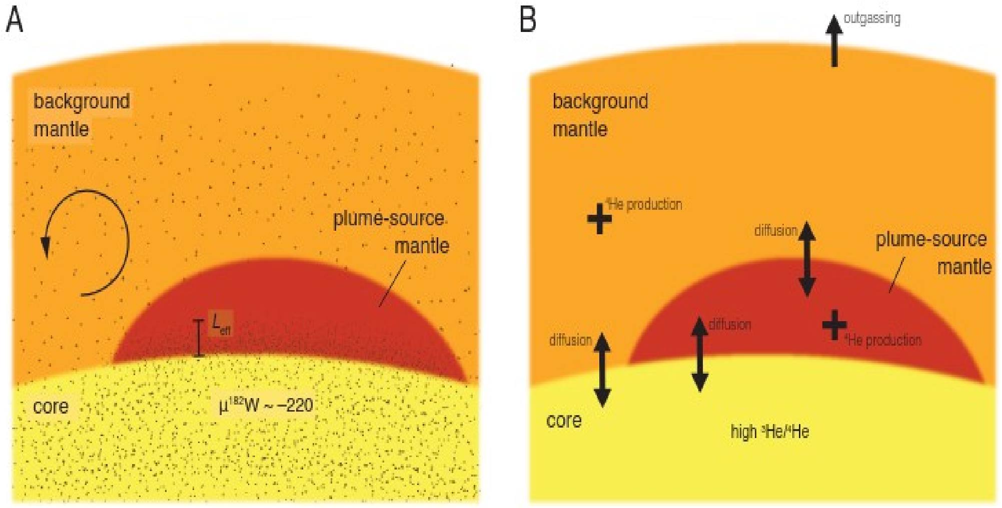


Fig. 1. Conceptual model for (*A*) tungsten and (*B*) helium evolution. (*A*) The core μ^{182}W signature diffuses into mobile background mantle material with a CMB lifetime of 100 Ma, after which mixing with the overlying mantle occurs. Simultaneously, diffusion occurs between the core and a plume-source mantle reservoir, where material is static and the core μ^{182}W signature builds up over ~4 Ga. (*B*) The background mantle concentration in ^{3}He and ^{4}He is governed primarily by diffusion across the CMB (driven by the CMB concentration gradient), outgassing at the surface (proportional to a time-invariant mantle processing rate *r*), and radiogenic production of ^{4}He. A plume-source mantle reservoir above the CMB is not subject to outgassing, but it is subject to diffusion across the boundary with the overlying background mantle.

Si-Mg-Fe Oxide Ex solution:

Core-mantle interaction could be a consequence of Si-Mg-Fe oxide ex-solutions from the core. **These oxides (like FeO) can efficiently incorporate tungsten into their structure without accompanying highly siderophile elements.**

Ex solutions are expected to form due to simple secular core cooling, as the solubility of oxides in liquid iron decreases with decreasing temperature. Crystallization of the inner core likely increases oxygen concentrations in the outer liquid core, leading to increased Si-Mg-Fe oxide precipitation. More oxidizing conditions in the outer core decrease tungsten's affinity for liquid metal, inducing its extraction from the core and incorporation into the mantle via these oxides.

Tungsten seems to be enriched in FeO-rich regions of quenched metal alloys, whereas HSEs generally show oxygen-avoiding behavior. This process could increase HSE concentrations in the plume mantle source by a smaller, harder-to-detect margin (3–40%). This exsolution mechanism is also consistent with the observation that oxygen is not easily incorporated into solid iron during inner core crystallization, potentially leading to increased oxygen concentrations in the outer liquid core and promoting oxide precipitation.

Bulk Core Entrainment:

The simplest model involves the direct addition of bulk core material to a lower mantle source. To explain the W and Ru isotope variability in OIBs, less than 0.25% of a bulk core component would be required. However, this model faces the challenge that such entrainment should significantly increase the concentration of HSEs in OIBs, **which is not consistently observed**.

Compositional Convection and Buoyant Fluid Release:

Compositional convection *can* drive core dynamics. This can involve a phase change in the liquid where a density gradient develops or the dissolution of an incompatible element due to solubility changes. As the inner core crystallizes from below, it releases buoyant light element-rich fluid into the surrounding liquid iron, driving compositional convection in the outer core. This process could effectively transfer lighter elements from the crystallizing inner core into the outer core. A hydrogen-enriched layer in the topmost outer core could be sourced from deeply subducted water interacting at the CMB. This compositional difference can create a stratified layer at the top of the outer core.

Hydrogen degassing from the core has been suggested to account for core expansion by reducing hydrogen concentration, and this degassing **might require a rise in temperature.** Vigorous hydrogen degassing must have been a consequence of core heating and pressure elevation caused by an increased flux of **ambient proton hydrogen (like those caused by solar flares), at least early in Earth's history**. The flow of hydrogen from the core is described as uninterrupted, potentially forming numerous jets by the time it reaches the mantle.

Iron-Water Exchange:

Iron-water exchange at the CMB can lead to hydrogen and oxygen being simultaneously incorporated into the outer core, along with FeO enrichment in the mantle. This reaction mechanism is considered dynamic.

Mass balance calculations suggest this exchange, even if forming ultra-low velocity zones (ULVZs), might not significantly affect the composition of the whole outer core, but a **thin, stable layer at the topmost outer core** could see increases in oxygen and hydrogen by a few percent. This incorporation of hydrogen offers a plausible explanation for the formation of a low-velocity layer in the outermost core. The chemical exchange reactions involve the Fe–Si–O–H system in the CMB region.

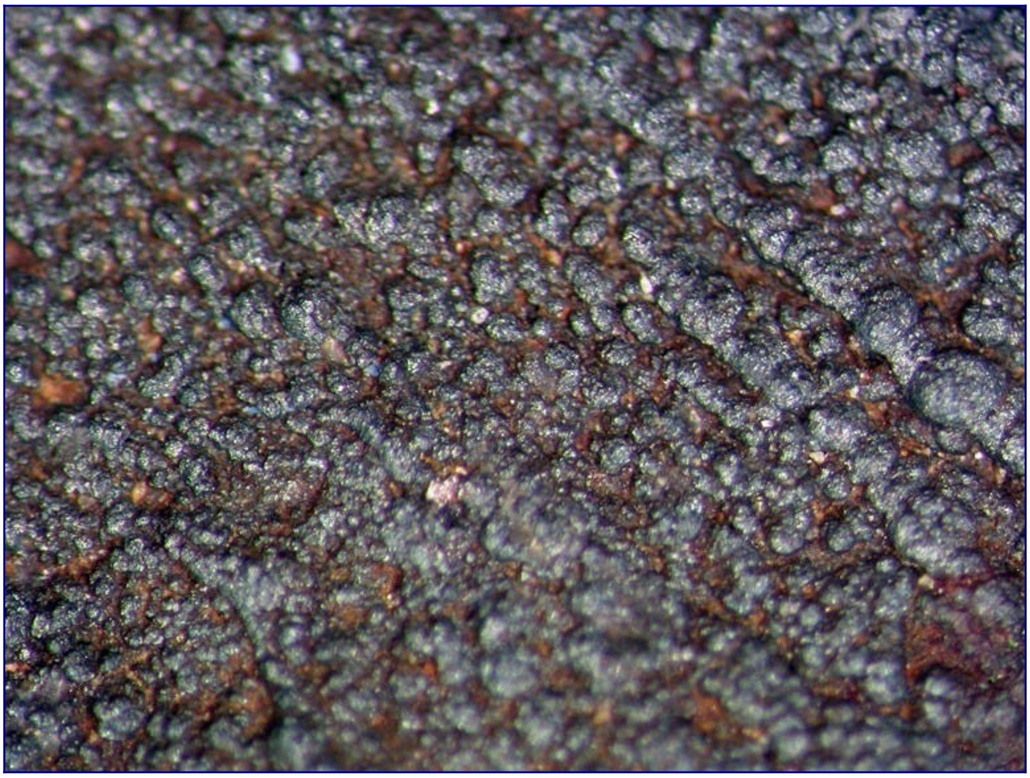
What is Ferric Oxide (FeO) ?

FeO is just iron and oxygen stuck together in a one-to-one ratio ("iron monoxide"), and it's everywhere in the rocky parts of planets like Earth. In the mantle, FeO helps determine at what temperatures and pressures rocks melt and crystallize, which in turn shapes how a planet's interior cools and evolves. Deep down, where pressures and temperatures get so extreme, FeO changes from being an electrical insulator (like a ceramic) into a metal (able to carry electricity) and even helps shuttle heat and light elements (like oxygen and water) between Earth's core and mantle. Because of these properties, its melting point, its ability to flip from insulator to metal, and its chemical reactivity, FeO is a key ingredient in models of how planets form, what their insides look like, and how they behave over geological time.

There may be a thin, sloppy layer of iron oxide (FeO) right where the solid rock of the Earth's mantle meets the liquid iron core, and this layer "wires up" the two like an electrical bridge. Because it conducts electricity so well, it lets the moving molten core tug on the solid mantle with electromagnetic forces, which can tweak how fast our planet spins and even wobble its rotation axis (changing the length of a day or causing tiny nods in Earth's tilt). The conductivity of FeO depends on how its internal defects arrange themselves, and at the super-hot, high-pressure conditions down there it shifts between ordered and disordered defect patterns, right at the temperatures estimated for the core–mantle boundary. Those shifts mean some patches conduct better than others, helping explain why we see "ultra-low velocity zones" in seismic data (areas where waves slow dramatically because FeO-rich pockets scatter them). In short, a patchy,

highly conductive FeO layer at the core–mantle boundary can electrically link mantle and core motions and account for odd rotation quirks and weird seismic hotspots.

Wüstite, or Fe1-xO, is an iron Monoxide. It is recognized for its prominent role in controlling the properties of rocky planetary bodies.



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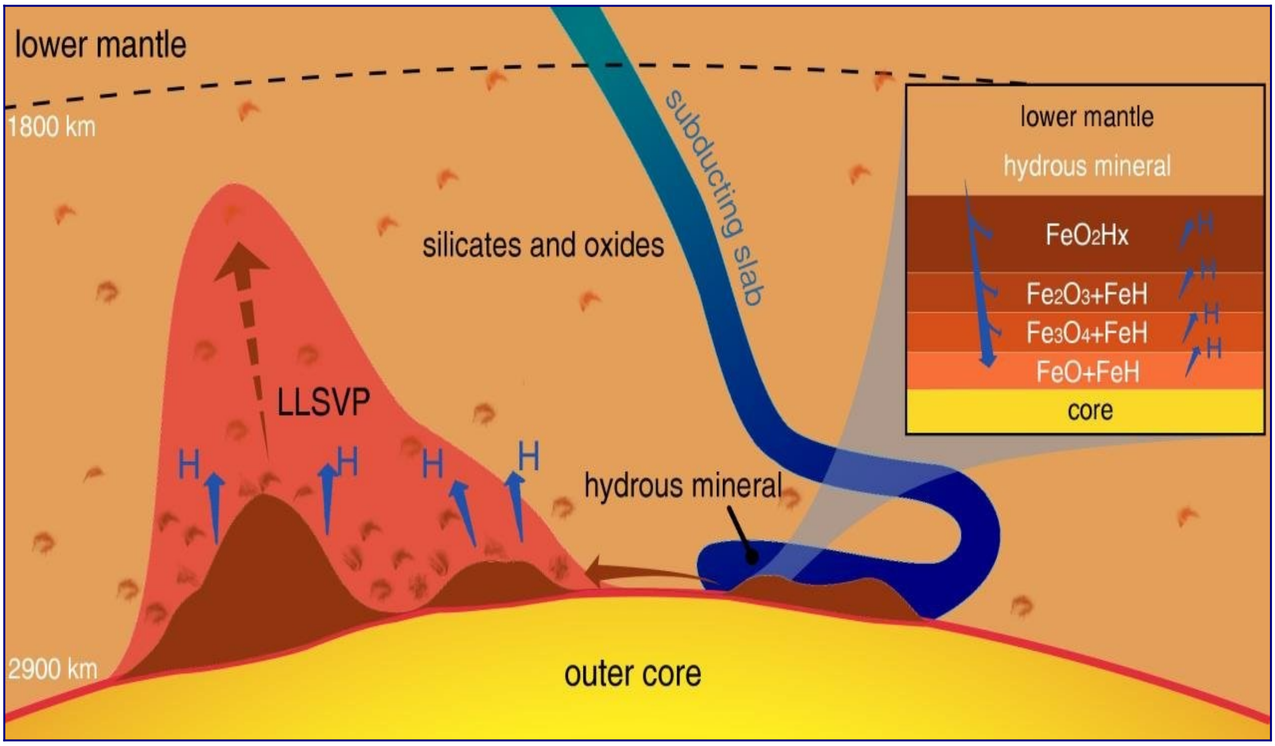
“Wüstite (Fe1-xO) has long been recognized for its prominent role in controlling the properties and evolution of Earth and other rocky planetary bodies1–4. In particular, FeO represents an end-member component in Earth’s major mineralogical systems, with its melting point being an essential parameter for constructing planetary interior models. In the FeO-MgO-SiO2 system of the mantle, the melting curve of FeO controls crystallization sequences of Earth’s primordial magma ocean The Fe-FeO system has been extensively studied to assess the viability of oxygen as a major light element in Earth’s outer core. FeO has further been implicated in chemical and heat exchanges between the core and mantle, as well as in the deep mantle water cycle over geologic time. “

FeO is a **main component of mantle rock.** It represents an **end-member component in Earth’s major mineralogical systems**, such as the FeO-MgO-SiO2 system in the mantle.



In the Fe-O-H system, FeO is a key compound involved in reactions, such as the reaction between iron and water which can produce FeO alongside iron hydride (FeH). Furthermore, starting compositions for reactions in the Fe-O-H ternary system can include FeO.

- FeO is the iron endmember of ferropericlase (Mg,Fe)O, which is the second most common mineral in Earth's lower mantle, as has been studied in chemical transition models.
- Wüstite (Fe1-xO) is known for its **iron defects,** consisting of Fe^{2+} vacancies and interstitial Fe^{3+} atoms.
- Stoichiometric FeO can occur as a **metastable intermediate** during the decomposition of wüstite when samples prepared above 1000 °C are annealed at 225 °C. - *German study, use a translator.*

At 136 GPa, the melting temperature is constrained to 4140 ± 110K. This relatively high melting temperature at core-mantle boundary (CMB) pressures supports the viability of solid FeO-rich structures at the base of the mantle.

Under ambient conditions, FeO is typically described as a Mott or charge-transfer insulator, thus its use in MOSFETs.

However, investigations reveal that FeO **undergoes a significant transition in its electrical properties under the high pressures and temperatures found within the Earth's interior.** Experimental measurements using a laser-heated diamond-anvil cell have shown that rock-salt (B1) structured FeO metallizes at around 70 GPa and 1900 K.

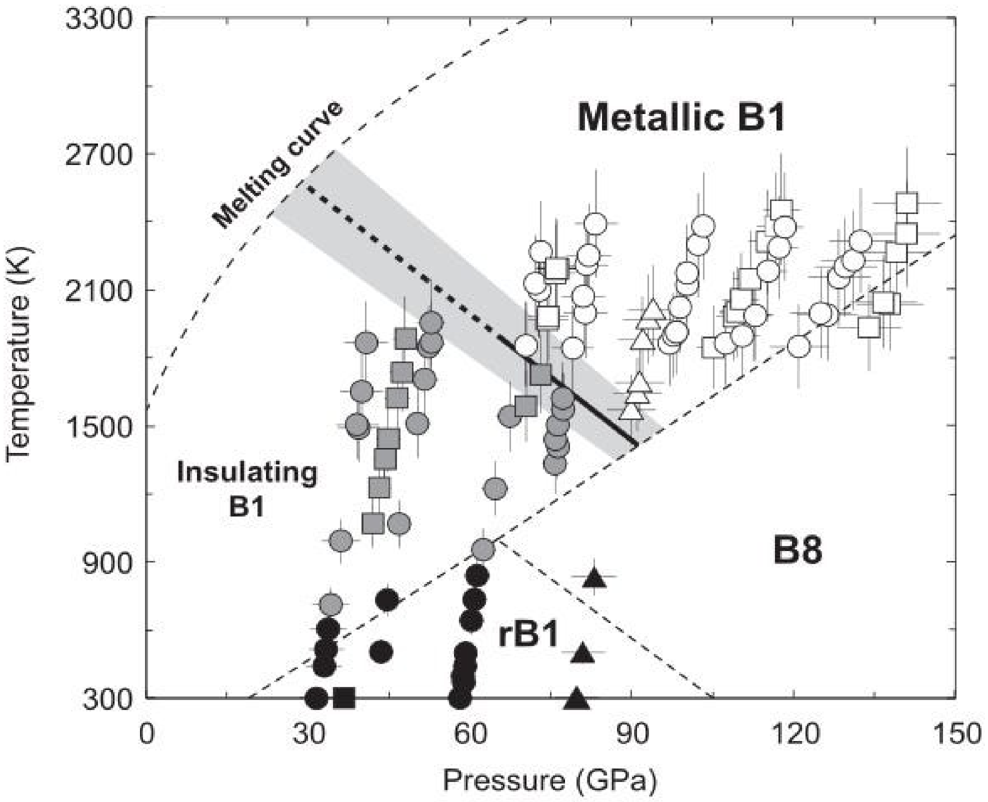


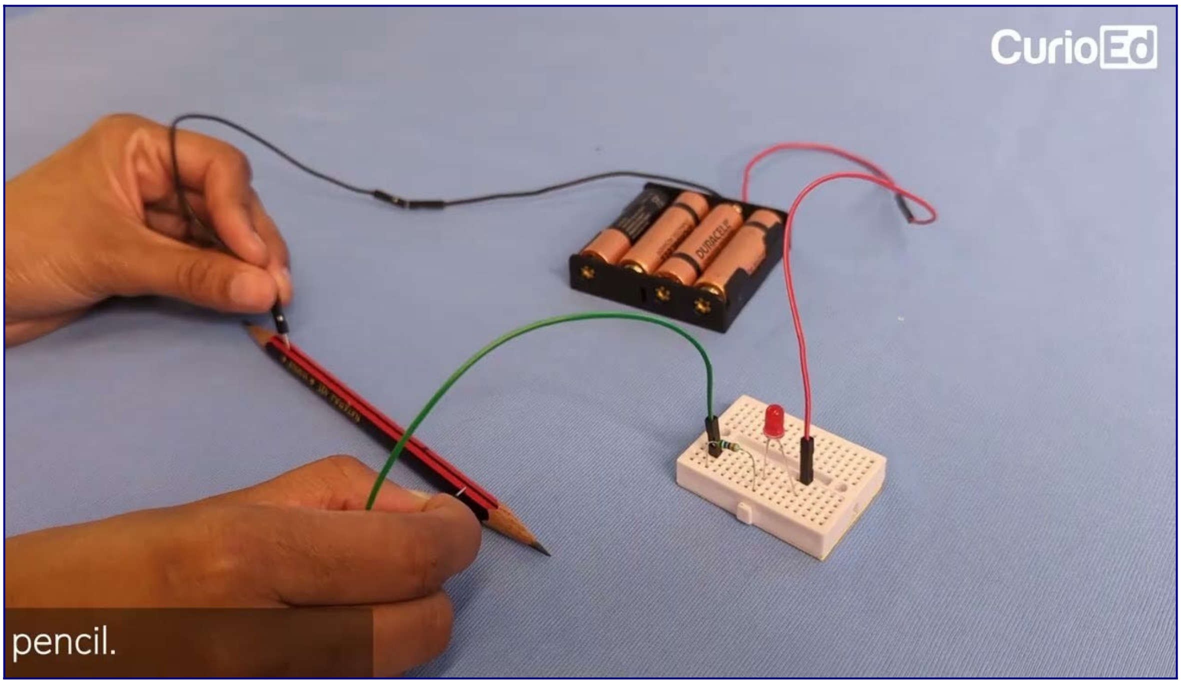
FIG. 1. Phase diagram of FeO. Stabilities of rB1, insulating B1, and metallic B1 phases are represented by solid, gray solid and open symbols, respectively. Circles, squares and triangles indicate each set of experiments (runs1–3). A metal-insulator transition boundary shown as bold line is determined from present data, and linearly extrapolated to the melting condition (broken bold line). The estimated uncertainty in location of the transition is shown by gray band. The melting curve and the phase boundaries of FeO shown as broken lines are from previous studies [1,7,35].

Other studies also suggest this transition occurs in the B1 structure at high pressure between 30 and 80 GPa. This transition happens without a structural phase transition in the solid state, i.e, it does not change form.

In the liquid state, the insulator-to-metal transition appears to be related to structural changes. In liquid FeO, the insulator-to-metal transition could likely be occurring around 40 GPa. This transition in the liquid state is correlated with a strong shortening of the Fe-Fe bond length, particularly pronounced between ambient pressure and ~40 GPa. This change in the liquid's compressibility regime happens at a pressure corresponding to the same observed insulator-to-metal transition pressure range in solid B1 FeO.

The metallization of FeO at high pressure and temperature is fundamentally related to electronic properties. It is related to a spin crossover or magnetic collapse transition. At high temperatures and pressures, electrons in FeO can fluctuate between a magnetic state (where they are tied to atoms) and a nonmagnetic state (where they are detached and move freely like in a metal). While the spin crossover and the insulator-to-metal transition are related, there might be a decorrelation between them, particularly at high temperatures.

At the pressure and temperature conditions estimated for the Core-Mantle Boundary (CMB), solid FeO and iron-rich (Mg,Fe)O can exhibit high electrical conductivity and metallic-like behavior, which would theoretically allow it to generate an electromagnet-based torque upon the mantle. The electrical conductivity of metallic B1 FeO in both observed experimental and theoretical evidence has been measured to be around 9.0 × 10^4 S/m at 135 GPa and 3700 K, conditions corresponding to the CMB region. This level of conductivity is **significantly higher than that of typical natural mantle materials.** **Graphite** (used in pencil leads) clocks in around 10^4 to 10^5 S/m, so it's actually in the same range as graphite in conductivity.

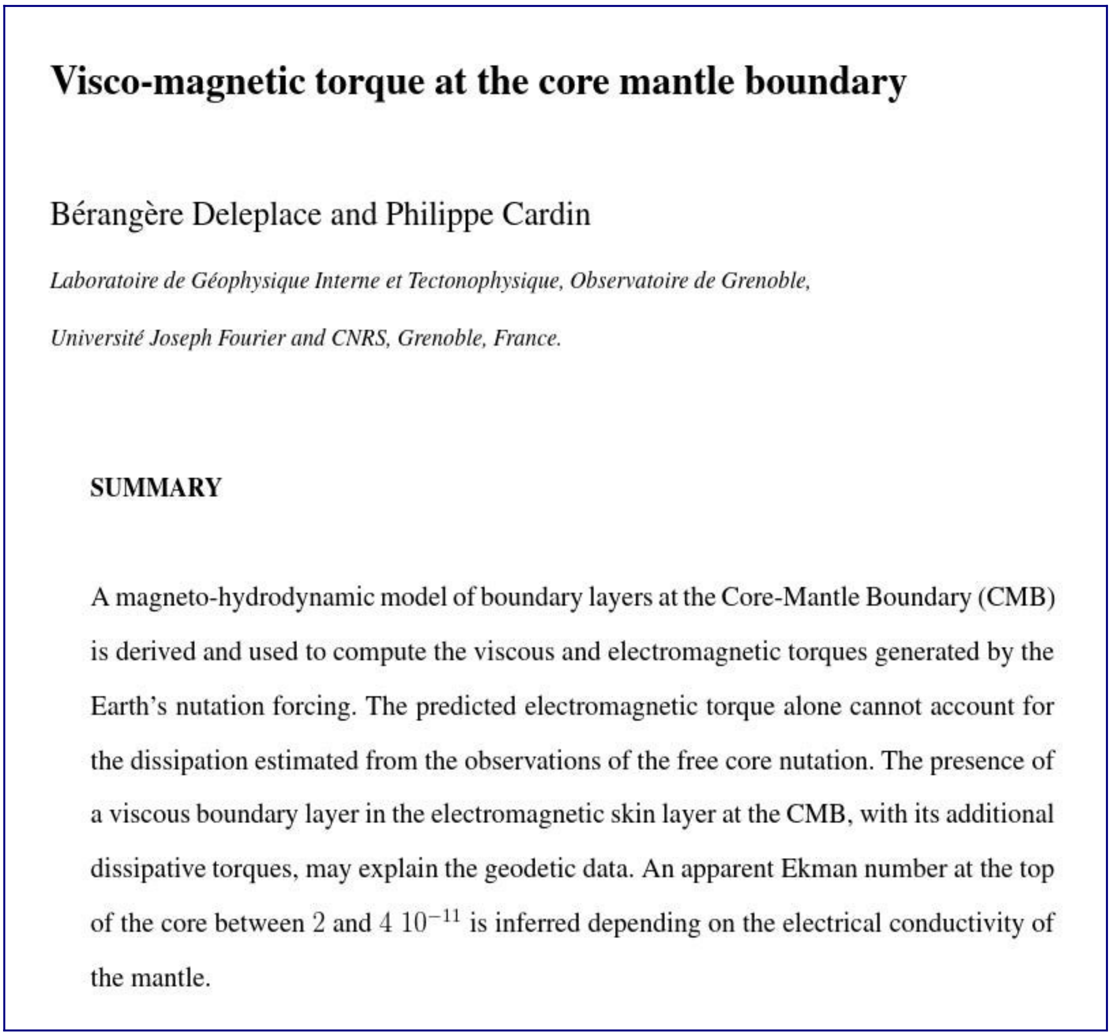


The newest examination of these characteristics of FeO along with its strength as of October 2025, can be found here.

"Iron (Fe) is a primary constituent of terrestrial planetary cores, yet its rheological properties under extreme conditions remain uncertain. Here we present direct measurements of Fe strength at 310-430 GPa pressures and 3700-5800 K temperatures, obtained using Rayleigh-Taylor (RT) instability experiments at the National Ignition Facility. Single-crystal α-Fe samples with [001] and [111] orientations are shock-ramp compressed past the α-ε transition along paths approaching Earth's inner core conditions. We find that ε-Fe derived from [001] α-Fe is consistently stronger (11-20 GPa), than that from [111] α-Fe (8-18 GPa), contrary to the trend at ambient conditions. Large-scale molecular dynamics simulations reproduce these values and attribute this anisotropy to microstructural evolution during the phase transition and subsequent ε-phase plasticity. Ripple growth analysis further constrains viscosities of 100-170 Pa·s under the driven conditions. Our results provide new experimental benchmarks for Fe rheology at inner-core conditions, with implications for seismic anisotropy and the geodynamo."

Highly conductive FeO at the CMB region has important implications:

- Highly conductive FeO at the CMB can enhance electromagnetic interaction between the solid mantle and the liquid core. That is, **improve core mantle coupling.**
- This enhanced EM interaction could potentially **explain observed anomalies in Earth's rotation, including variations in the length of day and nutations of Earth's rotation axis**. The existence of a non-zero mantle electrical conductivity is a precondition for the presence of currents and EM coupling torques on the mantle. Geophysical models studying EM coupling often assume conductive layers near the CMB, sometimes approximated as thin shells with significant conductivity. A conductance of approximately 10^8 S may be necessary to explain phase shifts in observed nutation and precession, and the magnitude of the EM torque is sufficient, especially if high conductivity is concentrated toward the CMB, requiring a conductance of 10^8 S to explain changes in the length of day. **That the FeO layer is heterogenous and viscous is highly relevant.**



Visco-magnetic torque at the core mantle boundary

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SUMMARY

A magneto-hydrodynamic model of boundary layers at the Core-Mantle Boundary (CMB) is derived and used to compute the viscous and electromagnetic torques generated by the Earth's nutation forcing. The predicted electromagnetic torque alone cannot account for the dissipation estimated from the observations of the free core nutation. The presence of a viscous boundary layer in the electromagnetic skin layer at the CMB, with its additional dissipative torques, may explain the geodetic data. An apparent Ekman number at the top of the core between 2 and 4 10^{-11} is inferred depending on the electrical conductivity of the mantle.

- A defect order-disorder transition in FeO has been observed up to lowermost mantle pressures, several hundred Kelvin below melting. The structure of iron defects strongly influences properties like conductivity. The temperature of this transition at CMB pressure (~3550 K) **closely aligns with recent CMB temperature estimates**, suggesting that temperature variations at the mantle base could lead to strong variations in physical properties, including conductivity, potentially explaining observations of patchy ULVZs (explored later). **Metallic FeO-rich structures and interaction with water have been suggested to explain ULVZs, enigmatic regions of extremely reduced seismic wave**

speeds dispersed across Earth’s heterogeneous mantle base. The diminished seismic wave velocities observed in FeO-rich mantle minerals quantitatively align with those of ULVZs.

Where does this FeO come from and how does it get to the CMB? Is there evidence for the presence of this FeO? What are the consequences of water and is it good or bad?… Will be explored in the next article of this series, ***PART 2. THE MANTLE.***

Conclusions

This information presented in Part 1 establishes a foundation for understanding the chemical and physical architecture of Earth's core and its capacity for dynamic interaction with the mantle above. Several critical findings emerge from this comprehensive review:

First, the Earth's core, long conceptualized as a simple Fe-Ni system has been revealed to be a chemically complex system. The persistent density deficit, approximately 5-10% lighter than pure iron, cannot be resolved by iron and nickel alone. Instead, this deficit points to the incorporation of multiple light elements, with silicon and hydrogen emerging as primary candidates alongside smaller contributions from oxygen, sulfur, and carbon. Particularly significant is hydrogen's role: at concentrations between 0.15-0.6 wt% in the inner core, hydrogen is necessary to account for observed seismic wave velocities, suggesting that **water's chemical interaction with molten iron in Earth’s history fundamentally shaped the core's composition.**

Second, the core functions not as an inert repository but as an active geochemical reservoir. The isotopic signatures of tungsten, ruthenium, and helium preserved in ocean island basalts and mantle plumes provide unambiguous evidence that **core material continuously exchanges with the deeper mantle** through multiple possible mechanisms: diffusive isotopic exchange, oxide exsolution, and compositional convection. These pathways bypass the traditional view of a perfectly isolated core, implying instead a system fundamentally coupled to mantle dynamics and surface processes.

Third, ferric oxide (FeO) emerges as a pivotal interface compound at the core-mantle boundary. Its metallization under CMB conditions (>70 GPa, >1900 K) endows it with **electrical conductivity comparable to graphite, creating a thin, highly conductive layer capable of generating electromagnetic coupling between the spinning liquid core and the solid mantle.** This electromagnetic "bridge" offers a testable mechanism for explaining anomalies in Earth's rotation, length-of-day variations, and nutation patterns, observations that have lacked adequate physical explanation within conventional geodynamic models.

These findings collectively suggest that Earth's interior operates as an integrated chemodynamic system, where the core's composition, the mantle's structure, and the planet's rotational behavior are not independent phenomena but interconnected expressions of a single underlying process. Water, transported into the deep mantle via subduction and reacting at the core-mantle boundary, seems to be a central driver of this coupling, bridging the inaccessible depths with observable surface phenomena.

Part 1 thus provides the prerequisite understanding necessary for the subsequent investigation into the mantle's role, the pathways of hydrogen degassing, surface expressions, and the cosmic forcing factors that collectively will be shown to orchestrate what this work terms "the cycle”, a synchronized coupling of Earth's interior, exterior, and cosmic environment that may illuminate both past geological upheavals and future planetary evolution.

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