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Earth's Hidden Ocean — The Ringwoodite Discovery That Rewrites Water's Origin Story

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Earth's Hidden Ocean — The Ringwoodite Discovery That Rewrites Water's Origin Story

> *The landmark 2014 discovery by geophysicists Brandon Schmandt and Steven Jacobsen — of a massive water reservoir trapped in ringwoodite minerals* **700 km below Earth's surface** *— has resurfaced in scientific discourse in 2026 as new seismic studies continue to validate their findings. The discovery, published in Science (June 2014), fundamentally challenges the long-held cometary delivery theory of Earth's water origin and has profound implications for understanding the deep water cycle.*

THE SCHMANDT-JACOBSEN STUDY: WHAT WAS DISCOVERED?

The Research Team

The study titled **"Dehydration melting at the top of the lower mantle"** was published in *Science* (Vol. 344, No. 6189, pp. 1265-1268) on **13 June 2014**. The research team comprised **Brandon Schmandt** (University of New Mexico), **Steven D. Jacobsen** (Northwestern University), **Thorsten W. Becker**

(University of Southern California), **Zhenxian Liu** (Carnegie Institution of Washington), and **Kenneth G. Dueker** (University of Wyoming).

The Core Finding

The team discovered that Earth's **mantle transition zone** (410-660 km depth) contains a vast reservoir of water — potentially **three times the volume of all surface oceans combined**. This water is not in liquid form. It exists as **hydroxyl groups (OH-)** trapped within the crystal structure of a high-pressure mineral called **ringwoodite**.

How They Proved It

The researchers used three independent lines of evidence:

- **USArray seismic data** — A network of **2,000 seismographs** deployed across the continental United States (part of NSF's EarthScope project) recorded seismic waves from over **500 earthquakes**. These waves **slowed down significantly** when passing through the transition zone, indicating the presence of hydrous (water-bearing) rock.
- **High-pressure laboratory experiments** — The team demonstrated that when hydrous ringwoodite transitions to denser minerals (bridgmanite and periclase) at the 660 km boundary, it releases water through a process called **dehydration melting**, producing intergranular melt.
- **Numerical modelling** — Computer simulations confirmed that downwelling mantle material crossing the 660 km discontinuity would undergo partial melting if the transition zone were hydrated.

WHAT IS RINGWOODITE?

Mineral Identity

Ringwoodite is a **high-pressure polymorph** (structural variant) of olivine, with the chemical formula **(Mg,Fe)2SiO4**. It belongs to the **spinel crystal structure** group, crystallising in the **isometric system** with space group **Fd3m**. In its structure, magnesium and silicon occupy octahedral and tetrahedral coordination sites with oxygen, respectively.

Water Storage Mechanism

Ringwoodite's remarkable property is its ability to incorporate **water as hydroxyl (OH-) defects** within its crystal lattice. Two hydroxide ions replace one magnesium ion and two oxide ions in a vacancy substitution mechanism. Laboratory studies show ringwoodite can store up to **2.6 wt% H2O** in its structure — an extraordinary capacity for a nominally anhydrous mineral.

Where It Forms

PROPERTY	DETAIL
Depth range	525-660 km below surface
Temperature	Above 1,600 degrees C
Pressure	18-23 GPa
Precursor mineral	Wadsleyite (which itself forms from olivine at 410 km)
Successor mineral	Bridgmanite + periclase (below 660 km)

The Diamond Evidence (Pearson, 2014)

Just months before the Schmandt-Jacobsen study, another landmark paper provided **direct physical proof**. In March 2014, **D.G. Pearson** and colleagues published in *Nature* the discovery of the **first terrestrial sample of ringwoodite** — found as a tiny inclusion inside a diamond from **Juina, Brazil**. The inclusion contained approximately **1.5 wt% water** as hydroxyl ions. This was groundbreaking because ringwoodite had previously been found only in **meteorites**, never in a sample originating from Earth's interior. The diamond had formed at approximately **525 km depth** in the transition zone, carrying the ringwoodite inclusion to the surface.

THE MANTLE TRANSITION ZONE: EARTH'S HIDDEN WATER TANK

What Is the Transition Zone?

The mantle transition zone is the region between **410 km and 660 km depth**, sandwiched between the upper mantle and the lower mantle. It is defined by two sharp **seismic discontinuities** — boundaries where seismic wave velocities change abruptly due to **mineral phase transitions** (not compositional changes).

Mineral Phase Transitions in the Transition Zone

DEPTH	PHASE TRANSITION	SEISMIC EFFECT
410 km	Olivine transforms to **wadsleyite** (beta-phase)	Seismic velocity increases sharply
520 km	Wadsleyite transforms to **ringwoodite** (gamma-phase)	Moderate velocity increase
660 km	Ringwoodite dissociates into **bridgmanite + periclase**	Seismic velocity increases; negative Clapeyron slope

Why Water Accumulates Here

Both wadsleyite and ringwoodite can store **2-3 wt% water** as hydroxyl groups in their crystal structures — far more than the minerals above or below the transition zone. This creates a natural **"water trap"**: water carried downward by subducting slabs is absorbed by wadsleyite and ringwoodite, but when these minerals transform to bridgmanite below 660 km (which holds far less water), the excess water is released through dehydration melting. This mechanism effectively **traps water in the transition zone**, preventing it from sinking into the lower mantle.

Volume Estimate

If just **1%** of the rock mass in the transition zone contains water, the total volume would equal approximately **three times the water in all of Earth's surface oceans**. The transition zone is a shell **250 km thick** encircling the entire planet — a vast volume of rock capable of storing enormous quantities of water.

EARTH'S INTERNAL STRUCTURE: A COMPLETE OVERVIEW

Understanding the ringwoodite discovery requires knowledge of Earth's layered architecture. Earth's interior is divided into distinct layers based on **chemical composition** and **mechanical behaviour**.

Layers by Chemical Composition

LAYER	DEPTH RANGE	THICKNESS	PRIMARY COMPOSITION	DENSITY	TEMPERATURE
Crust (Oceanic)	0-5 km	~5 km	Basalt (Si, O, Fe, Mg)	3.0 g/cm3	Up to 200 degrees C
Crust (Continental)	0-70 km	~30-70 km	Granite (Si, Al, O)	2.7 g/cm3	Up to 400 degrees C
Upper Mantle	35-410 km	~375 km	Olivine, pyroxene (Mg, Fe silicates)	3.4 g/cm3	200-1,600 degrees C
Transition Zone	410-660 km	~250 km	Wadsleyite, ringwoodite	3.7-4.0 g/cm3	1,600-1,900 degrees C
Lower Mantle	660-2,900 km	~2,240 km	Bridgmanite, periclase	4.4-5.5 g/cm3	1,900-4,000 degrees C
Outer Core	2,900-5,100 km	~2,200 km	Liquid iron-nickel alloy	10-12 g/cm3	4,000-5,000 degrees C
Inner Core	5,100-6,371 km	~1,250 km	Solid iron-nickel alloy	12-13 g/cm3	5,000-6,000 degrees C

Major Seismic Discontinuities (UPSC-Critical)

DISCONTINUITY	DEPTH	SEPARATES	DISCOVERED BY
Conrad	~15-20 km	Upper crust (sial) and lower crust (sima)	V. Conrad (1925)
Mohorovicic (Moho)	5-70 km (avg. 35 km)	Crust and mantle	Andrija Mohorovicic (1909)
Repetti	~700 km	Upper mantle and lower mantle	Near the 660 km boundary
Gutenberg	~2,900 km	Mantle and outer core	Beno Gutenberg (1914)
Lehmann	~5,100 km	Outer core and inner core	Inge Lehmann (1936)

How We Know: Seismic Wave Behaviour

- **P-waves (Primary)** — Compressional waves; travel through **solids and liquids**; speed increases with density
- **S-waves (Secondary)** — Shear waves; travel through **solids only**; completely blocked by the liquid outer core
- **Shadow Zone** — S-waves create a shadow zone beyond **103 degrees** from the earthquake epicentre (proving the outer core is liquid); P-waves create a shadow zone between **103 degrees and 142 degrees** (due to refraction at the core-mantle boundary)

THE GREAT WATER ORIGIN DEBATE: COMETS VS. INTERNAL OUTGASSING

The ringwoodite discovery reignited one of geology's oldest questions: **where did Earth's water come from?**

Theory 1: Extraterrestrial Delivery (Cometary/Asteroid Hypothesis)

The traditional theory holds that Earth's water arrived from space during the **Late Heavy Bombardment (LHB)**, approximately **4.1-3.8 billion years ago**, when water-rich asteroids and comets bombarded the early Earth.

Evidence supporting this theory:

- The **deuterium-to-hydrogen (D/H) ratio** in carbonaceous chondrite asteroids closely matches Earth's ocean water
- Models of early solar system dynamics (the **Nice Model**) predict large-scale delivery of volatile-rich material from the outer solar system

Problems with this theory:

- Most comets have **D/H ratios significantly different** from Earth's oceans (2-3 times higher)
- The volume of water in Earth's oceans is difficult to explain through impacts alone
- Recent measurements of Comet 103P/Hartley 2 (by NASA's EPOXI mission) showed a D/H ratio matching Earth's oceans, complicating the picture

Theory 2: Internal Outgassing (Endogenous Origin)

The ringwoodite findings strongly support the alternative theory that Earth's water originated **from within the planet itself** and was released to the surface through **volcanic outgassing** over billions of years.

Evidence supporting this theory:

- The Schmandt-Jacobsen study proves that the mantle can store **three times the surface ocean volume** of water
- Dehydration melting at the 660 km boundary provides a mechanism for water to **migrate upward** from the transition zone
- Volcanic emissions today still release significant amounts of **water vapour (H2O)**, suggesting ongoing degassing
- The Earth accreted from materials in the inner solar system that already contained hydrous minerals

The Emerging Consensus

Most geoscientists now favour a **hybrid model**: Earth's water likely came from **both** sources — initial water was trapped in the planet during accretion (stored in minerals like ringwoodite) and subsequently supplemented by asteroid/comet delivery. The ringwoodite reservoir may act as a **buffer**, regulating the amount of surface water over geological timescales by absorbing and releasing water through the deep water cycle.

INDIA CONNECTION: DEEP OCEAN MISSION AND SAMUDRAYAAN

Deep Ocean Mission (DOM)

India's **Deep Ocean Mission**, approved by the Union Cabinet in **June 2021** with a budget of **Rs 4,077 crore** for five years, is India's most ambitious programme to explore the deep ocean. The **Union Budget 2025-26** allocated **Rs 600 crore** for the mission. The mission is implemented by the **Ministry of Earth Sciences (MoES)** through the **National Institute of Ocean Technology (NIOT)**, Chennai.

Matsya 6000 (Samudrayaan)

PARAMETER	DETAIL
Vehicle	Matsya 6000 — self-propelled manned submersible
Target depth	6,000 metres
Crew capacity	3 persons
Operational endurance	12 hours (normal); 96 hours (emergency)
First test dive (500 m)	Planned by mid-2026
Full-depth test (6,000 m)	Planned by 2027
Implementing agency	NIOT, Chennai under MoES
Global position	India will be the 6th country to achieve crewed deep-sea exploration

Why It Matters

While the ringwoodite discovery concerns the **mantle** (hundreds of kilometres deep — far beyond any submersible), the Deep Ocean Mission reflects India's growing capability in **understanding Earth's interior and ocean floor**. The oceanic crust at mid-ocean ridges is where **mantle material surfaces** — studying these regions can provide insights into mantle composition, hydrothermal venting (which releases mantle-trapped water), and plate tectonic processes that drive the deep water cycle.

UPSC RELEVANCE

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Interior of the Earth, seismic waves and discontinuities, mantle transition zone, ringwoodite mineral, Deep Ocean Mission, Samudrayaan/Matsya 6000.

MAINS GS-1:

Physical Geography — Interior of the Earth, distribution of oceans and continents, origin of Earth's hydrosphere.

MAINS GS-3:

Science and Technology — developments and their applications in everyday life; awareness in the fields of Space and Deep Ocean exploration.

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RINGWOODITE — CORE DATA:

Chemical formula: (Mg,Fe)2SiO4 — high-pressure polymorph of olivine

Crystal system: Isometric (spinel structure), space group Fd3m

Depth of formation: 525-660 km (mantle transition zone)

Water storage capacity: up to 2.6 wt% H2O as hydroxyl (OH-) groups

First terrestrial sample: Found in a diamond from Juina, Brazil (Pearson et al., *Nature*, March 2014)

Water content in natural sample: approximately 1.5 wt%

SCHMANDT-JACOBSEN STUDY (2014):

Title: “Dehydration melting at the top of the lower mantle”

Published: *Science*, Vol. 344, No. 6189, 13 June 2014

Lead authors: Brandon Schmandt (Univ. of New Mexico) and Steven D. Jacobsen (Northwestern Univ.)

Key method: USArray — network of 2,000 seismographs across the USA (part of NSF’s EarthScope project)

Data: Seismic waves from 500+ earthquakes slowed in the transition zone, indicating hydrous rock

Estimated water volume: Equivalent to three times all surface oceans

MANTLE TRANSITION ZONE:

Depth: 410-660 km below Earth’s surface

Thickness: approximately 250 km

Key minerals: Wadsleyite (410-520 km) and ringwoodite (520-660 km)

Both can store 2-3 wt% water as hydroxyl defects

410 km discontinuity: Olivine to wadsleyite transformation (Clapeyron slope: +4.0 MPa/K)

660 km discontinuity: Ringwoodite to bridgmanite + periclase (Clapeyron slope: -1 to -3 MPa/K)

SEISMIC DISCONTINUITIES (UPSC PRELIMS):

Conrad: 15-20 km — separates upper crust (sial) from lower crust (sima)

Mohorovicic (Moho): 5-70 km (avg. 35 km) — separates crust from mantle (discovered 1909)

Gutenberg: 2,900 km — separates mantle from outer core (discovered 1914)

Lehmann: 5,100 km — separates outer core from inner core (discovered 1936)

SEISMIC WAVE SHADOW ZONES:

- S-wave shadow zone: Beyond 103 degrees from epicentre (proves outer core is liquid)
- P-wave shadow zone: Between 103 degrees and 142 degrees (refraction at core-mantle boundary)

EARTH'S WATER ORIGIN DEBATE:

- Cometary/asteroid delivery: Late Heavy Bombardment, 4.1-3.8 billion years ago
- D/H ratio of carbonaceous chondrite asteroids matches Earth's oceans
- Most comets have D/H ratios 2-3 times higher than Earth's oceans
- Internal outgassing: Water trapped in mantle minerals released via volcanic degassing
- Current consensus: Hybrid model — both sources contributed

INDIA'S DEEP OCEAN MISSION:

- Approved: June 2021; Budget: Rs 4,077 crore (5 years)
- Union Budget 2025-26 allocation: Rs 600 crore
- Implementing agency: NIOT, Chennai under Ministry of Earth Sciences
- Matsya 6000: Manned submersible, target depth 6,000 m, crew of 3
- First shallow dive (500 m): Planned mid-2026
- India will be the 6th country to achieve crewed deep-sea exploration

OTHER RELEVANT FACTS:

- Earth's total radius: 6,371 km
- Mantle thickness: approximately 2,900 km (largest layer by volume)
- Outer core: 2,200 km thick; liquid iron-nickel; generates Earth's magnetic field
- Inner core: 1,250 km radius; solid iron-nickel; temperature 5,000-6,000 degrees C
- USArray/EarthScope project: Funded by NSF; observational period ended September 2021
- Olivine is the most abundant mineral in the upper mantle (above 410 km)
- Bridgmanite (Mg-silicate perovskite) is the most abundant mineral in the lower mantle

Sources: Science — Schmandt et al. 2014, Nature — Pearson et al. 2014, Northwestern University News, PIB — Deep Ocean Mission, Smithsonian Science

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