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Natural Hydrogen Precambrian crust

Detailed summary of the 2014 Nature paper

ORIGINAL PAPER AUTHORS

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READING GUIDE

Inside the paper

Observations, generation mechanisms and the global estimate.

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OVERVIEW

Overview

The 2014 Nature paper by Barbara Sherwood Lollar and colleagues argues that the ancient continental crust has been substantially underestimated as a source of hydrogen. Its scientific focus is the energy available to microbial life in the deep subsurface and the contribution of continental rocks to global geological hydrogen production.

The authors combine a worldwide compilation of hydrogen measurements with calculations for two generation mechanisms: radiolysis of water and hydration reactions involving iron-bearing rocks. Their central estimate is 36–227 billion moles of hydrogen per year from the Precambrian continental lithosphere, comparable in scale to published estimates for marine systems.

Why the continental contribution had been missed

Earlier assessments had extrapolated a regional estimate from South Africa and often treated radiolysis as the only relevant continental mechanism. The paper instead accounts for the large area of exposed and buried Precambrian crust, additional water held in mineral inclusions, and hydrogen-producing reactions in mafic and ultramafic rocks.

What the study adds

Hydrogen-rich fluids are not confined to ocean-floor hydrothermal environments. Measurements from continental sites, including the Canadian and Fennoscandian shields, show that ancient rocks can also host hydrogen-rich systems. The modelling places those observations within a broader estimate of geological production.

How to interpret the result

The headline range is a modelled production estimate, not a measurement of hydrogen delivered to the surface each year. The paper does not estimate commercial reserves, extraction costs or sustainable production from a particular well. This summary preserves that distinction and treats the work as a 2014 research contribution, not a current resource assessment.

Source: Main text, Nature 516, pp. 379–381; Table 2; online Methods. Headline range restated in billions of moles.

01 / MEASUREMENTS & INTERPRETATION

The evidence from continental sites

The study brings together more than 200 samples or boreholes, including 56 previously unpublished observations, across 32 sites worldwide. The Methods describe gas discharging from exploration boreholes at 19 Precambrian Shield sites in Canada, Finland and South Africa, with 13 additional sites included for comparison.

What was measured

Much of the gas was originally dissolved in saline groundwater within rock fractures and was released when boreholes depressurised those systems. Other observations came from seeps, historical records or fluid inclusions. Because dissolved concentrations were not consistently available across these sources, the compilation uses volume percent of the total gas phase.

Site	Maximum reported hydrogen	Interpretation
 Sudbury, Canada	57.8%	An observed site maximum, not an average reservoir grade.
 Timmins, Canada	12.7%	A historical observation in this 2014 compilation.
 Thompson, Canada	2.75%	Part of a geographically and chemically varied dataset.
 Red Lake, Canada	1.60%	An occurrence measurement, not a production rate.
 Outokumpu, Finland	12.8%	Evidence that hydrogen-rich systems occur outside Canada.
 Pori, Finland	30.4%	One of the high concentrations reported in Shield settings.

Why the maxima require care

Table 1 reports the highest hydrogen concentrations and hydrogen-to-helium ratios observed at each location. These should not be treated as representative field averages or assumed to describe one identical sample. At the same time, hydrogen consumption can lower the amount remaining relative to its original production.

The geographical spread establishes that continental hydrogen is not an isolated phenomenon. It does not establish the dimensions, connected volume or recoverability of a reservoir at any of these sites.

Source: Figure 1, p. 380; Table 1 and its notes, p. 381; Methods, supplied PDF p. 5. Selected values from Table 1.

02 / GEOCHEMICAL FOUNDATIONS

Two mechanisms for making hydrogen

The study estimates hydrogen generation through two processes with different controls. Both involve water, and both can supply chemical energy independently of sunlight to deep subsurface environments.



Mechanism	Process and controlling factors
Hydration reactions	Water reacts with iron-bearing minerals. Oxidation of reduced iron is coupled to hydrogen generation. Rock composition, reactive surfaces, water access and reaction progress control the result.
Radiolysis	Ionising radiation from naturally occurring radioactive elements splits water molecules. The amount and distribution of water, radioelement concentrations and rock volume influence hydrogen production.

Hydration and serpentinisation

The paper uses “serpentinisation” broadly for hydrogen-producing hydration and oxidation-reduction reactions in mafic and ultramafic rocks. It is not limited to one mineral reaction. Precambrian greenstone belts are particularly relevant because they contain substantial volumes of these rock types and can be many kilometres thick.

In the simplified reaction used for the calculations, three units of ferrous oxide in silicates react with water to produce magnetite and one unit of molecular hydrogen. This is a stoichiometric modelling relationship; actual production depends on how much of the potentially reactive iron is reached by water and reacts.

Radiolysis and helium as a companion tracer

Uranium and thorium decay contribute to both radiogenic helium-4 and water radiolysis. Potassium contributes to radiolysis but does not produce helium-4. The authors use modelled hydrogen-to-helium production relationships to connect radioactive-element inventories with hydrogen generation.

Helium is chemically inert, while hydrogen can be consumed by microbes and chemical reactions. Their relationship therefore offers information about production and loss, but a measured ratio is not a direct reading of the amount of hydrogen available for extraction.

Source: Main text, pp. 379–380, equation 1; Methods, supplied PDF pp. 5–6.

03 / METHODS & ASSUMPTIONS

How the radiolysis estimate is built

The authors replace a simple regional extrapolation with a calculation based on helium production, water-filled porosity and the extent of Precambrian crust. Two forms of subsurface water are considered separately: water in fractures and water trapped as fluid inclusions in minerals.

Water-filled fractures

The model assumes fracture porosity declines with depth. Average values are approximately 0.96% in the upper 10 kilometres and 0.12% between 10 and 20 kilometres. These values are used to calculate hydrogen-to-helium production ratios for the upper and middle crust, then scale hydrogen production to the Precambrian portion of the continents.

The resulting fracture-water estimate is approximately 16 billion moles of hydrogen per year. This is a calculated generation rate within the relevant rock and water system, not a measured atmospheric flux or a rate of withdrawal from wells.

Water in mineral inclusions

Fractures are not the only water-containing spaces exposed to radiation. The paper assumes an additional fluid-inclusion volume equivalent to at least 1% water-filled porosity. Including this component adds approximately 31 billion moles per year, bringing the radiolysis estimate to approximately 47 billion moles per year.

	Component	Estimated radiolytic production
	Fracture water	16 billion moles of hydrogen per year.
	Fluid inclusions	An additional 31 billion moles per year.
	Combined estimate	47 billion moles per year, with both components included.

Sensitivity to the amount of water

Porosity is a major assumption. Higher values within published ranges for crystalline rocks would increase calculated production. The authors describe their adopted assumptions as conservative, but the calculation does not determine how readily hydrogen in isolated inclusions enters connected fractures or a producible accumulation.

Source: Main text, p. 379; Table 2, p. 381; Methods, "Radiolytic H₂ estimates for Precambrian continents," supplied PDF p. 5.

04 / METHODS & ASSUMPTIONS

How the hydration estimate is built

The hydration calculation begins with the area and composition of Precambrian crust, estimates the amount of reactive iron in a chosen rock volume, and then introduces a timescale to express hydrogen production per year.

	Assumption	Treatment in the study
	Geographic extent	Exposed and buried Precambrian crust covers approximately 72% of continental surface area in the geological compilation used.
	Depth considered	A 5-kilometre interval is used for hydration, linked to the estimated habitable zone—not a proposed drilling depth.
	Rock composition	About 25% of Proterozoic and 50% of Archean crust is treated as mafic or ultramafic. The calculation uses 10% FeO and a rock density of 3,000 kg/m ³ .
	Reaction completeness	Both complete reaction and a lower-efficiency case are assessed. In the latter, the reacted fraction decreases by a factor of two in each successive kilometre.
	Time	Rock ages provide a first approximation where natural reaction rates and histories are poorly constrained.

From a rock inventory to an annual estimate

With complete reaction, the calculation yields approximately 78–180 billion moles per year. The depth-dependent, lower-efficiency case reduces that range to approximately 20–40 billion moles per year. Table 2 combines the lower and upper boundaries as 20–180 billion moles per year for hydration.

The significance of the timescale

Hydration occurs episodically as fractures develop, fluids move and fresh mineral surfaces become available. Averaging potential production over the full age of a rock is not a measurement of its present reaction rate. The authors use this long timescale to construct conservative estimates, while acknowledging limited information on natural reaction zones and rates.

Alternative calculations using erosion or laboratory results are discussed as checks. The paper also notes the difficulty of extrapolating laboratory behaviour to natural rocks with different temperatures, alteration histories and water access.

Source: Main text, pp. 380–381; Methods, supplied PDF pp. 6–7; Extended Data Tables 1–2, supplied PDF pp. 8–9.

05 / RESULTS & COMPARISON

The production estimates in context

Table 2 reports the continental estimates alongside several published marine estimates. The key conclusion is a comparison of scale: ancient continental rocks may be a major contributor to geological hydrogen production, rather than a negligible counterpart to oceanic systems.

	Component	Billion moles of hydrogen per year	Basis
	Precambrian radiolysis	16–47	Fracture-water estimate, extending to include fluid inclusions.
	Precambrian hydration	20–180	Lower and upper modelling boundaries for water-rock reactions.
	Combined continental estimate	36–227	Sum of the two components; the range stated in the abstract.

Reading the units

The original headline range is $0.36\text{--}2.27 \times 10^{11}$ moles per year. Expressing it as 36–227 billion moles per year changes only the notation. A mole is a measure of the amount of a substance; these numbers describe estimated hydrogen generation, not the energy delivered by a commercial project.

Comparison with marine systems

The ocean-crust estimates listed in Table 2 include 80–130, 190 and 200 billion moles per year from different studies; the slow-spreading-ridge estimate is 167 billion. Another basaltic ocean-crust estimate is 450 ± 300 billion moles per year. These are alternative or differently scoped assessments, not independent quantities to add together.

The authors conclude that including the continental contribution could roughly double estimates based on marine systems alone. This is their interpretation of global geological production from these processes, not a doubling of proven reserves or a forecast for the hydrogen industry.

The scope of the calculation

The reported continental total combines radiolysis calculations for the upper and middle crust with hydration estimates over 5 kilometres. It is not one uniformly sampled global layer. Volcanic, mantle-derived and microbial hydrogen sources are excluded from Table 2.

Source: Abstract, p. 379; Table 2 and concluding paragraphs, p. 381; online Methods. Values converted from units of 10^{11} mol/year to billion mol/year.

06 / SIGNIFICANCE & LIMITATIONS

What the findings establish

A larger geological energy source for deep life

The paper's principal contribution is to geochemistry and the deep biosphere. Ancient continental rocks can generate hydrogen through more than one mechanism, providing a potentially important energy source for subsurface microbial communities. Continental environments therefore belong alongside marine systems in assessments of this energy supply.

Why the Canadian Shield matters in the study

Canadian measurements form part of the empirical dataset, and the Canadian Shield is one example of the old continental terrains included in the geological scaling. Hydrogen-rich observations and the abundance of suitable rock types support the broader scientific argument. The paper does not rank Canadian exploration prospects or assess any NorthLight property.

Production is not the same as accumulation or recovery

A rock can generate hydrogen without retaining it in a connected reservoir. The amount remaining can be reduced by microbial consumption and reactions producing other compounds. The figure caption explicitly recognises these sinks when interpreting measured concentrations and hydrogen-to-helium ratios.

The calculations do not determine reservoir size, gas purity over a whole field, flow to a well or economically recoverable quantities. Nor does generation over geological time demonstrate replenishment at the rate of commercial extraction. These distinctions are necessary when considering the study in an energy-exploration context.

What remains uncertain

Results depend on geological scaling, water-filled porosity, the amount and accessibility of reactive rock, reaction completeness and the timescale used. The observations span different sampling settings and report site maxima, while the annual totals are model outputs. The authors' description of conservative assumptions does not turn the resulting range into a statistical confidence interval.

The enduring finding is that Precambrian continental hydrogen production should not be overlooked. The study supplies a scientific foundation for further investigation; it does not itself establish a commercially exploitable hydrogen resource.

Source: Figure 1 caption, p. 380; Table 1 notes, Table 2 and conclusions, p. 381; Methods, supplied PDF pp. 5–7. Commercial distinctions clarify the scope of the study.

APPENDIX / GLOSSARY & SOURCE GUIDE

Source guide and terminology

	Concept	Meaning in this summary
	Precambrian	The very long interval of Earth history before the Cambrian; includes the Archean and Proterozoic terrains modelled here.
	Mafic / ultramafic	Rock categories rich in iron- and magnesium-bearing minerals relevant to hydrogen-producing reactions.
	Radiolysis	Splitting of water molecules by ionising radiation, producing hydrogen among the reaction products.
	Production rate / flux	Generation per unit time / movement across a boundary per unit time. The paper stresses that these are not interchangeable.
	Fluid inclusion	A small volume of fluid trapped within a mineral, distinct from water in connected fractures.
	Porosity	The fraction of a rock's volume occupied by pores or voids; the model focuses on water-containing space.

Original publication

Sherwood Lollar, B., Onstott, T. C., Lacrampe-Couloume, G. & Ballentine, C. J. (2014). The contribution of the Precambrian continental lithosphere to global H₂ production. *Nature* 516, 379–382. DOI: 10.1038/nature14017.

[Read the complete paper on Barbara's research website \(free PDF\).](#)

Where to find the supporting material

Main argument and radiolysis: journal p. 379. Global observations: Figure 1, p. 380, and Table 1, p. 381. Production estimates and conclusions: Table 2 and text, p. 381. Author contributions: p. 382. Detailed Methods: supplied PDF pp. 5–7. Extended Data Tables 1–2: supplied PDF pp. 8–9.

This is an independently written NorthLight summary of the supplied 2014 paper, including its Methods and Extended Data Tables. The separate source-data spreadsheet was not supplied and has not been independently reanalysed. Numerical checks refer to the published tables and calculations.

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