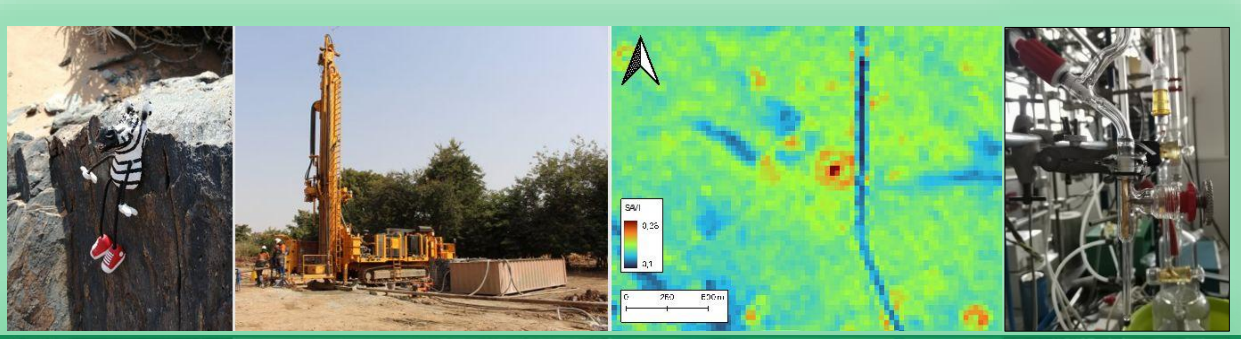


Dr Isabelle Moretti

The natural H_2 exploration started. Where ? By who ? Targeting which H_2 system ?

May - 2026 – Société Philomathique

Chance, pioneer works and research

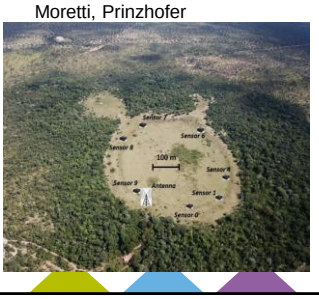
H_2 reserve discovery in Mali… looking for water

Mali: L'hydrogène de Bourakebougou fascine la communauté scientifique et fait la Une de La Tribune

H_2 emanation in Philippines
Deville & Prinzhofer

H_2 emanation in Russia, soil gas sampling, first description of fairy circles
Larin, Zgonnik, Prinzhofer, Deville

H_2 emanation in Brazil… first monitoring of a fairy circle
Moretti, Prinzhofer

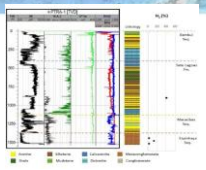


From research to industry: everything changed since 2019

Hydrogène naturel : une nouvelle découverte majeure dans le bassin minier en Lorraine ?

Well Hoarty NE3 in Geneva, Nebraska (HyTerra)
Production test stopped because of a broken pump

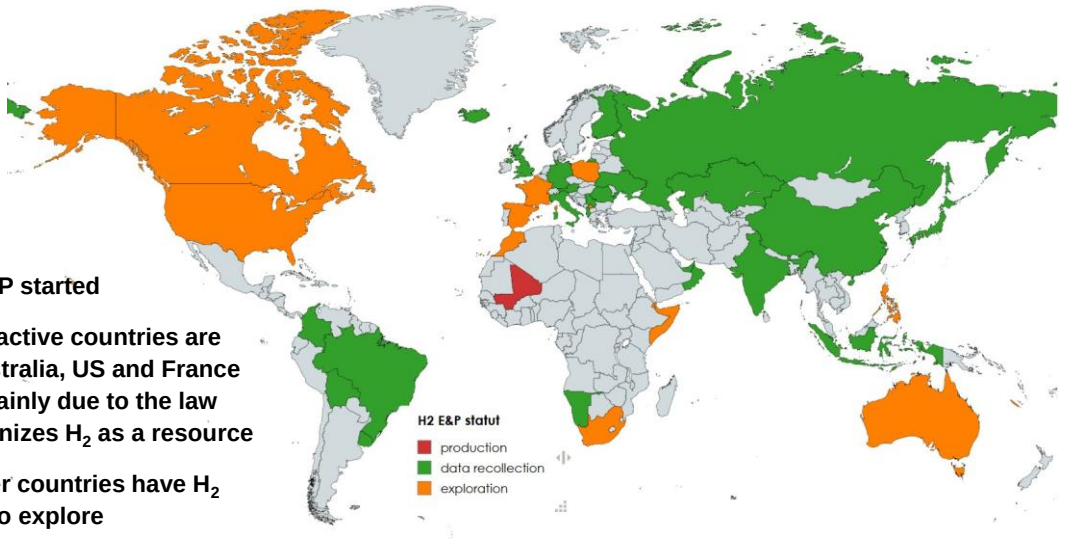
Hyterra, Kansas



Hydroma, Mali

Gold Hydrogen, South Australia

What is happening worldwide



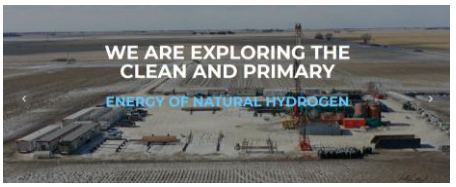
- The H_2 E&P started
- The most active countries are South Australia, US and France but it is mainly due to the law that recognizes H_2 as a resource
- Many other countries have H_2 potential to explore

Startups with investors… but noy only

Ex in USA, Koloma

Well funded by Breakthrough Energy (=Bill Gates foundation)

Confidential for long time and in the first page of the news paper since last July 2023.



NHE – Geneva project, Nebraska

Koloma cofounder and CTO Tom Darrah, left, COO Carrie Hudak, cofounder and CEO Pete Johnson, and cofounder and chief business officer Paul Harraka at the company's Denver office.

Nemaha project

2023: 70 10^6\$
2024: 240 10^6\$
2025: Koloma Announces International Expansion into Australia

More than 50 companies are now drilling or looking for acreage

February 18, 2025 – Koloma Inc., announced a USD $23.8 million raise to launch Koloma Australia Pty Ltd, marking the first of what the company projects to be many international exploration efforts and partnerships outside of the US.

H_2 sources: mainly H_2O

- Fe oxidation with geothermal hot fluids
- Serpentinization
- Hydrothermal context but basic
- Granite peralkaline
- Volcanic
- Radiolysis
- Mechanoradical
- Open question: NH_3
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$$2\,FeO + H_2O = Fe_2O_3 + H_2$$

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$$2\,FeS_{(pyrrhotite)} + H_2O = FeS_{2_{(pyrite)}} + FeO + H_2$$

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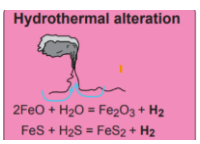
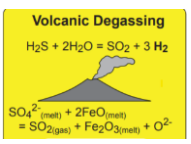
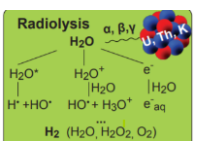
$$H_2S + 2\,H_2O = SO_2 + 3\,H_2$$

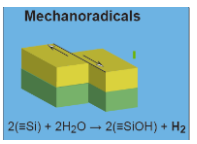
H_2O + α, β, γ

H_2O + …



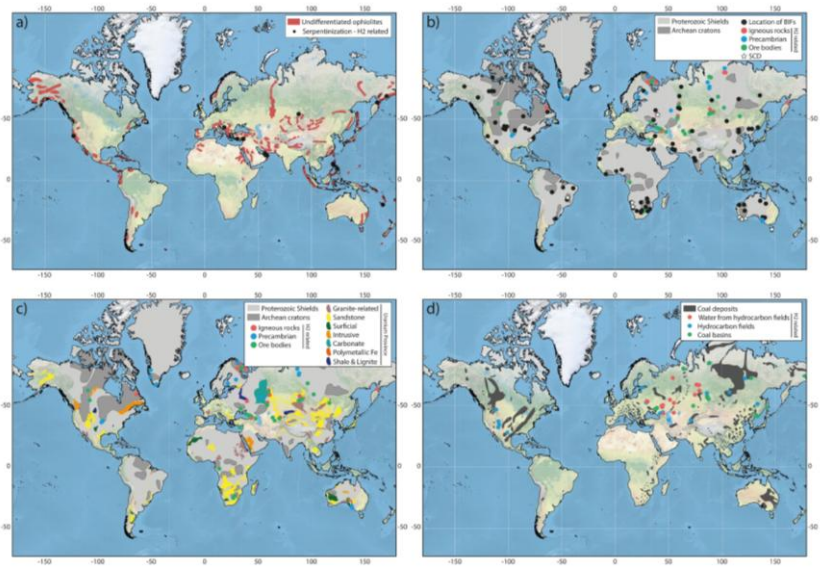






Modified from Klein et al., 2020 Elements, Vol. 16, pp. 19–24

4 types of generating rocks



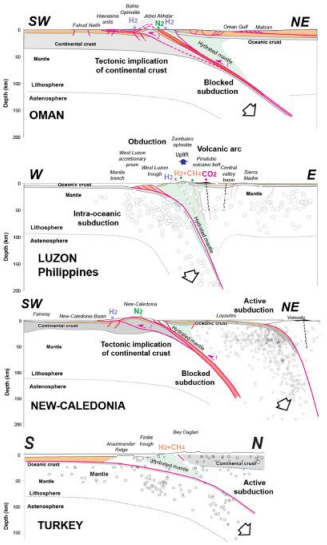
Lévy et al., 2023, Natural H2 exploration: tools and workflows to characterize a play, STET, doi.org/10.2516/stet/2023021

H2_GR1

- Ophiolite context
- The gas is often a mixture H_2, CH_4, N_2
- Serpentinisation at low temperature: High pH and carbonatation
- Capture of atmospheric CO_2

Oman

Indonesia, 2024, courtesy of Indra Sanjaya.

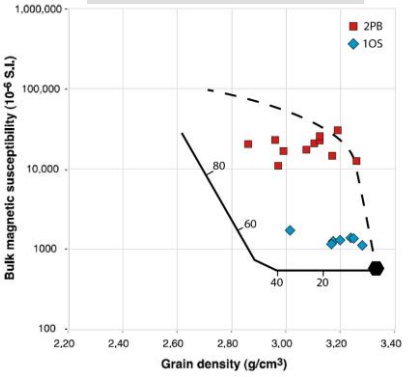


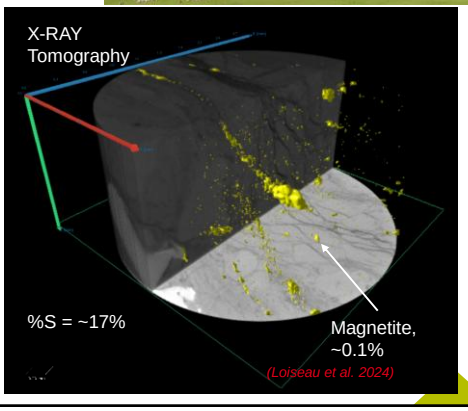
Vaquand et al., 2018.

H2_GR1

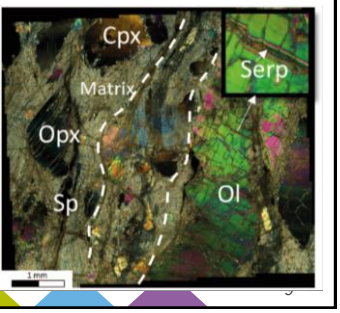
- Oceanic lithospheres are not homogeneous
- The serpentinization process is heterogenous
- Tools are still missing to evaluate bulk remaining H_2 potential

Using only density is not a good proxy for serpentinisation rate





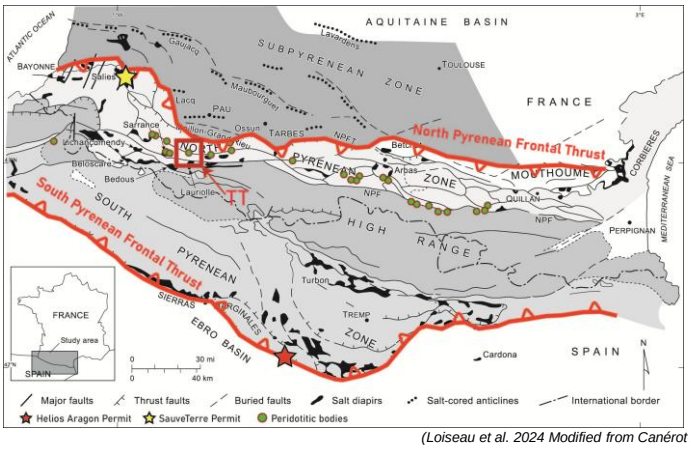
The outcrop is just ~ 1km long but the serpentinisation ranges from 3% to 62%



30/05/2026

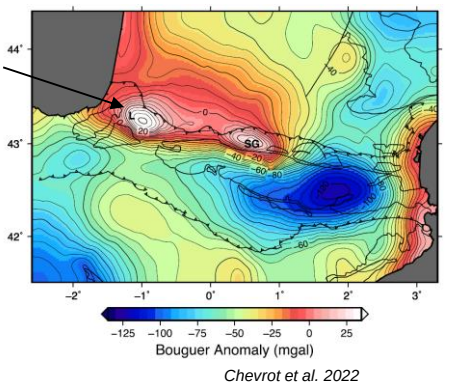
Pyrenees : Geological context :

hyperextension (~110Ma)
followed by collision (~83Ma)



(Loiseau et al. 2024 Modified from Canérot 2005)

Mantle wedge

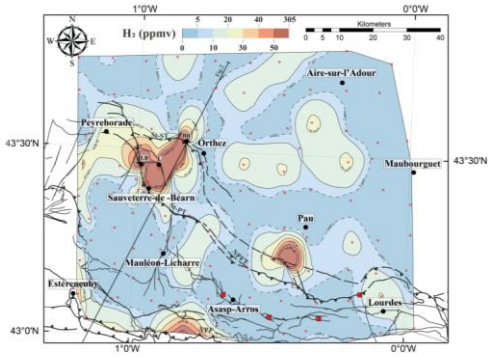


Chevrot et al. 2022

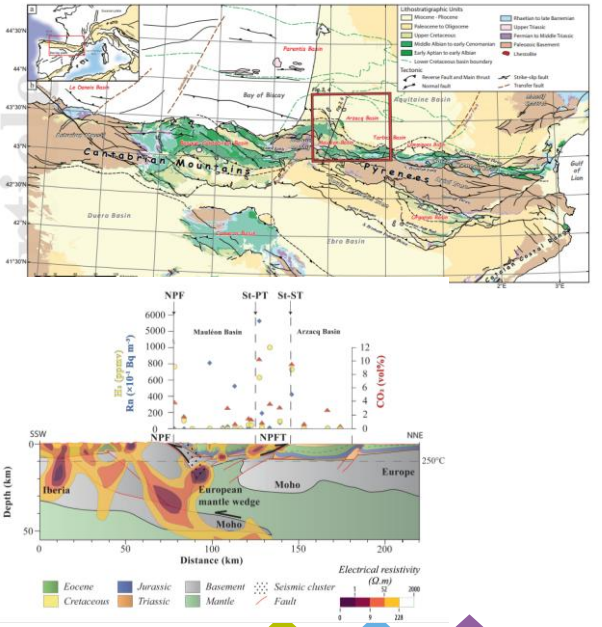
- 40 mantle bodies (green circles)
- H_2 exploration permits near Frontal Thrusts Helios Aragon (in Spain), SauveTerre (TBH2), Grand Rieu (45-8/Engie)…

In the Pyrenees

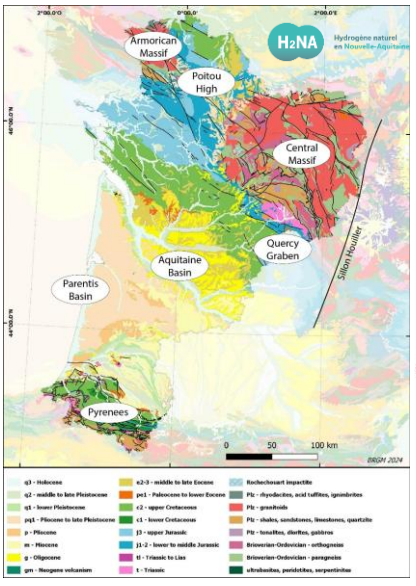
- Presence of mantle rocks at shallow depth < 10 km
- Most of these hot spots are located along the North Pyrenean Frontal Thrust and other related faults rooted in the mantle body



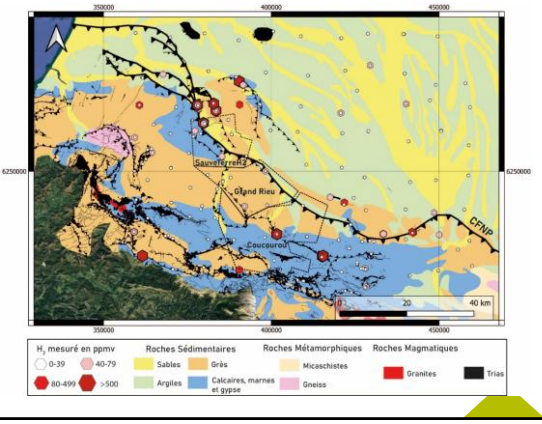
Lefeuvre et al., 2021 Native H2 exploration in the western Pyrenean foothills doi: 10.1029/2021GC009917.



South West: 4 permits in the Pyrenees+ 1 near Bordeaux



- Source: Mantle wedge and H2 flow from this ongoing serpentinization area
- Potential seal: Triassic salt
- Companies: 3 startups (TBH2, 45-8 and Mantle 8) and one huge international energy supplier (Engie)



Grand Rieu, 2nd block

45-8 energy storengy

H_2 sources: mainly H_2O

- Fe oxidation with geothermal hot fluids — $2\,FeO + H_2O = Fe_2O_3 + H_2$
- Serpentinization — $3\,Fe_2SiO_4 + 2\,H_2O = Fe_3O_4 + 3\,SiO_2 + 2H_2$
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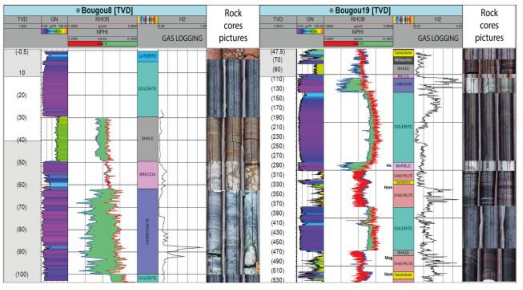
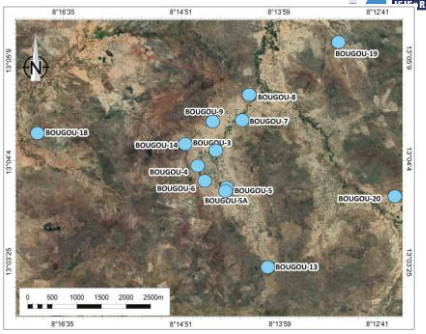
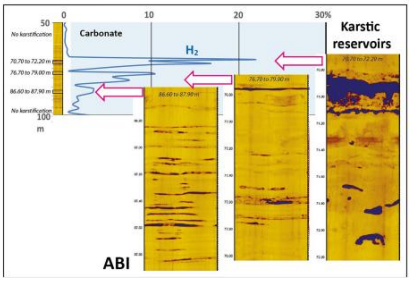
- Volcanic — $H_2S + 2\,H_2O = SO_2 + 3\,H_2$
- Radiolysis — $H_2O + \alpha, \beta, \gamma$
- Mechanoradical — $H_2O + \ldots$
- Open question: NH_3
- Late maturation of Organic matter

Mali: The pioneers

- Production since 12 years
- Various reservoirs (4, karst and sandstones, up to 12% of porosity)
- Various seals (Dolerite but also shale)
- Presence of BIF in this Neoproterozoic series

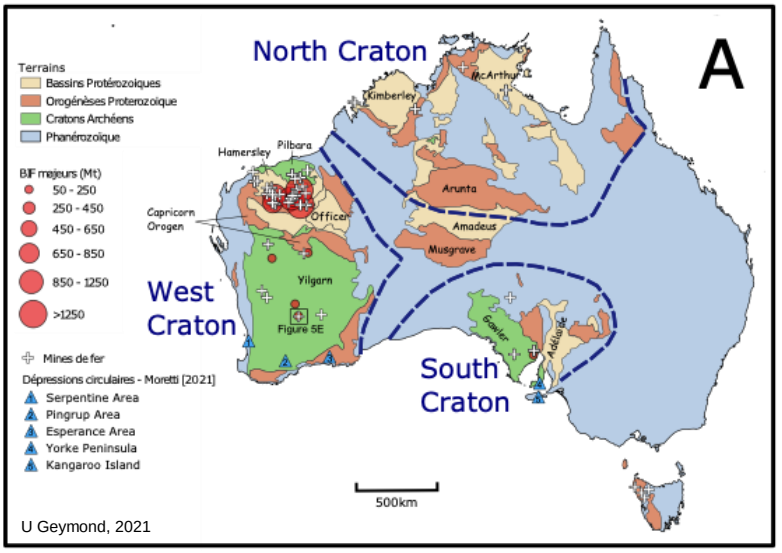






Maiga O., et al.. (2023) Characterization of the spontaneously recharging natural hydrogen reservoirs of Bourakebougou in Mali, Sci. Rep. 13, 1, 11876. https://doi.org/10.1038/s41598-023-38977-y

Australian Cratons & Banded Iron Formation



U Geymond, 2021

Fe content, Fe2+ / Fe3+

Work done in collaboration with the CSIRO, Perth

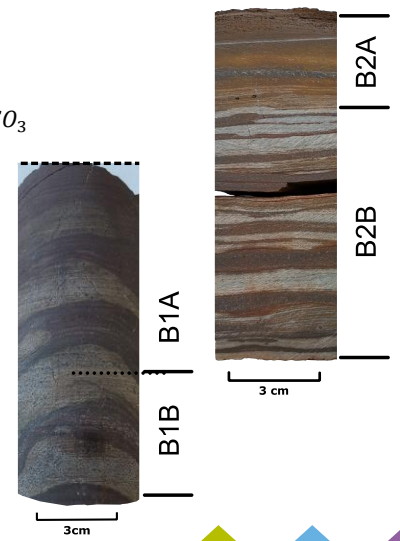
Hématite et (ou) magnétite → $Fe_2^{3+}O_3$, $Fe^{2+}Fe_2^{3+}O_4$

Silice et (ou) carbonate de fer avec magnétite disséminée → Ex: Sidérite: $Fe^{2+}CO_3$

- Rich cores are altered (Fe3+)
- But many BIF still contain Fe2+

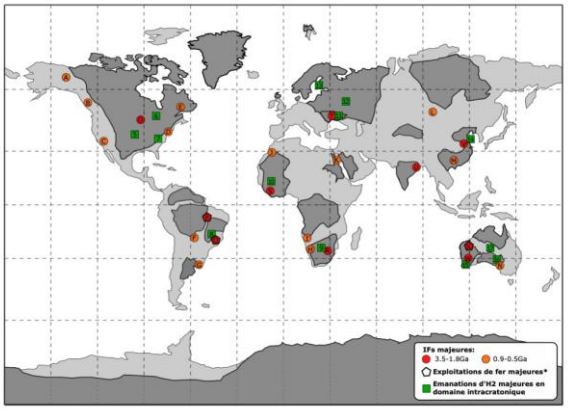
Sample	Iron Speciation—Mössbauer Spectroscopy (%)								Iron Content ICP-OES (wt%)
	Hematite	Goethite *	Ferrihydrite	Magnetite		Silicate			
	Fe^{3+}	Fe^{3+}	Fe^{3+}	Fe^{3+}_{octa}	$Fe^{2.5+}_{octa}$	Fe^{3+}	Fe^{2+}	Fe^{3+}/Fe_{tot}	Fe_{tot}
B1A	43	10	23	10	8	N.D.	6	0.90	11.78
B1B	76	10	N.D.	6	7	N.D.	<3	0.96	15.12
B1C	34	N.D.	3	24	39	N.D.	N.D.	0.81	56.83
B1D	30	N.D.	13	19	33	N.D.	5	0.79	14.08
B2A	18	78	N.D.	<3	<3	<3	N.D.	1.00	42.57
B2B	35	56	N.D.	4	3	<3	N.D.	0.99	28.95
B3A	18	50	N.D.	14	13	5	N.D.	0.94	27.01
B3B	13	43	N.D.	18	19	7	N.D.	0.91	36.87
B3C	56	N.D.	N.D.	25	19	N.D.	N.D.	0.91	41.70

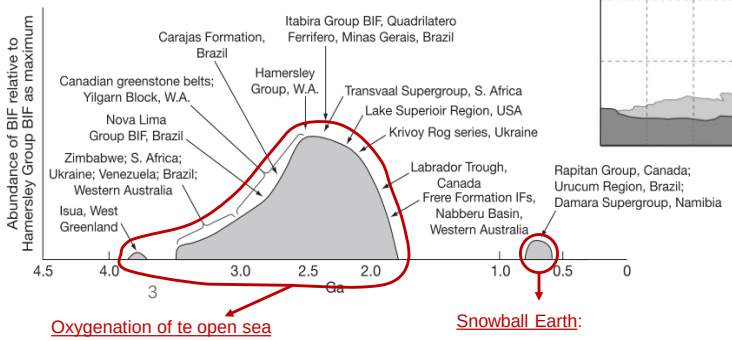
* goethite (α-FeOOH) + lepidocrocite (γ-FeOOH). N.D.: Not Detected.



Geymond, U. et al.. 2022. Can weathering of Banded Iron Formations generate natural hydrogen? Evidences from Australia, Brazil and South Africa. **Minerals**, 12, 163. https://doi.org/10.3390/min12020163

BIFs age and abundance





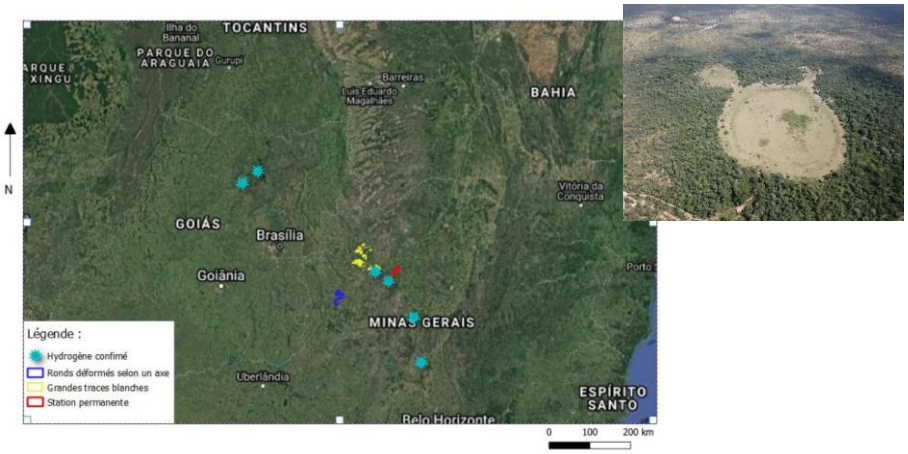
Oxygenation of te open sea

Snowball Earth:

Ramanaidou (2014)

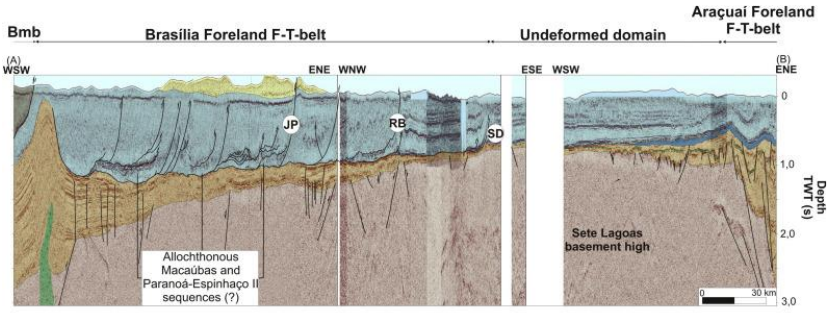
Brazil, Mina Gerais

- H_2 emanations have been measured in various places (Geo4U in collaboration with ENGIE)
- Statistic on the geometry of the fairy circles has been carried out in 3 zones including Sao Romao



Moretti, I., et al. 2021. Hydrogen emanations in intracratonic areas: new guide lines for early exploration basin screening. . Geosciences, https://doi.org/10.3390/ geosciences11030145

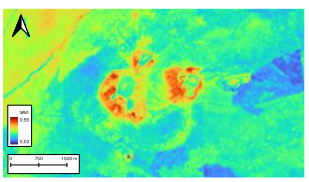
San Francisco Basin

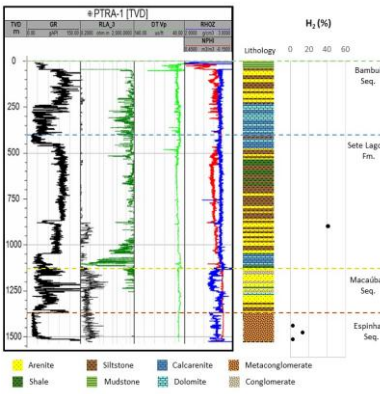


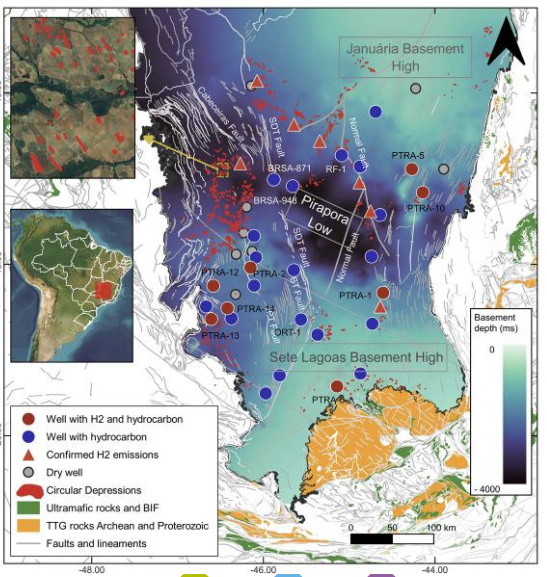
BIF banded Iron Formation
Quadrilatère de fer

São Francisco Basin: many indices and many H_2 generating rocks

- Old well with H_2, up to 40%
- Many SCD's
- Bif (archean and neoproterozoic)
- Intrusion (ultramafic, kimberlites…) linked with strong magnetic anomalies



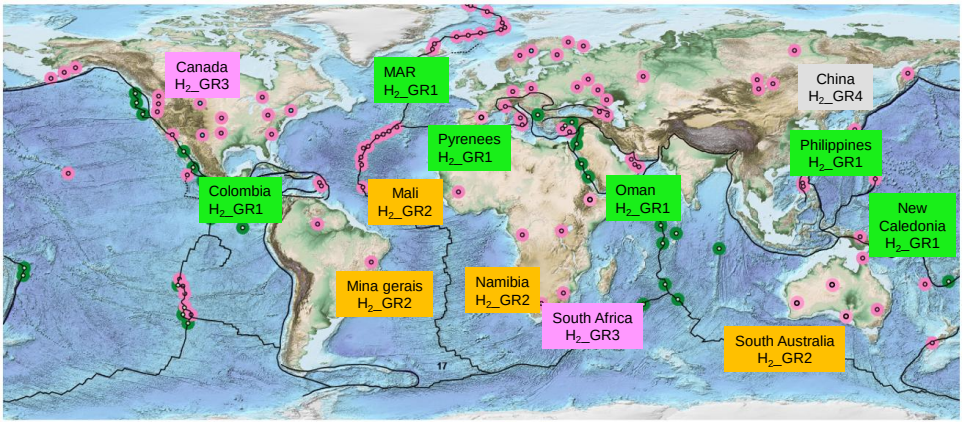




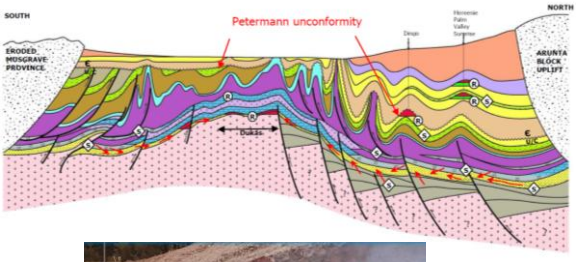
H_2_GR1: H_2 from serpentinization of mantellic and oceanic rock

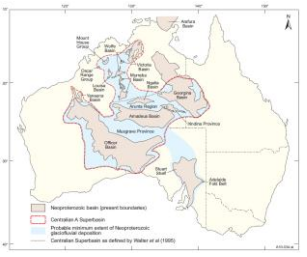
H_2_GR2 : H_2 and Iron rich sedimentary rocks and intrusive

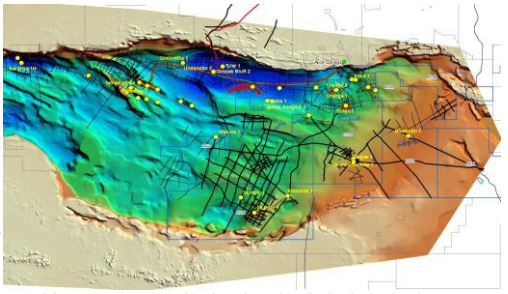
H_2_GR3: H_2 from radiolysis



Prospective Provinces : He & H_2







Mt Kitty 1 - gas: 9% Helium 11.5% H_2

Discovery done by Santos, 3 new wells will be drilled in 2023

- Others companies are targeting these blends
  - USA: **Desert Mountain**
  - Australia: **Santos**
  - Europe: **45-8**

Johns, D.; Menpes, A.; Walshe, P.; Bache, F. Exploration of a Sub-Salt Play in the Southern Amadeus Basin, Central Austra-lia—Searching for Big Gas in Proterozoic Réservoirs; Seapex Presentation; Seapex: Singapore, 2017.

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- Volcanic
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H_2O + α, β, γ

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Modified from Klein et al., 2020 Elements, Vol. 16, pp. 19–24

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H_2_GR3: H_2 from radiolysis

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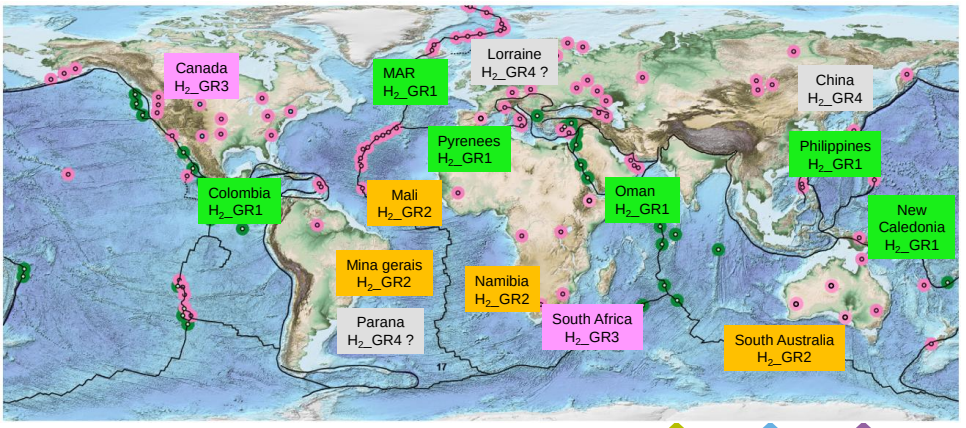


Hongkong

Towngas 煤氣 160 ANNIVERSARY

Gas supply mains consisting of 24-km of pipelines were connected to 500 street lamps and selected buildings.

City lighting set up in 1862-1864 in this British colony

Town Gas Characteristics

Chemical Composition

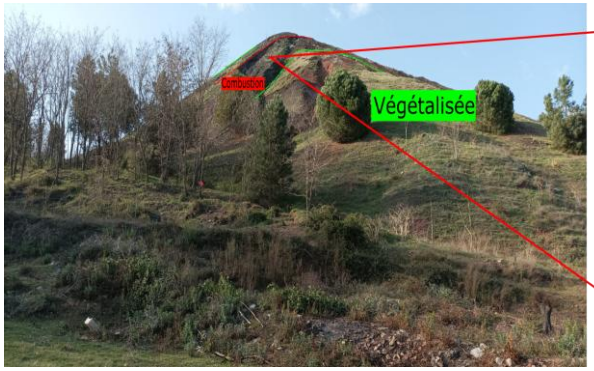
Carbon Dioxide	16.3% – 19.9%
Carbon Monoxide	1.0% – 3.1%
Methane	28.2% – 30.7%
Hydrogen	46.3% – 51.8%
Nitrogen and Oxygen	0% – 3.3%

Physical Properties

Calorific Value	17.27 MJ/m3
Specific Gravity	0.52
Wobbe Index	24
Weaver Flame Speed	35

- https://www.towngas.com/en/About-Us/Hong-Kong-Gas-Business/Gas-Production

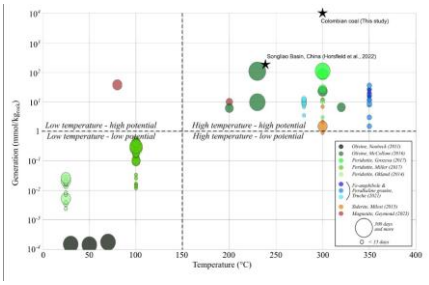
H2 and coal: the coal slag heap emits H2

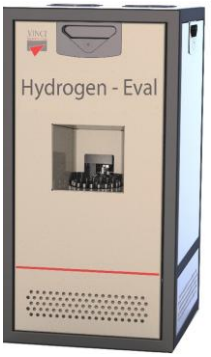


Composés	Cœur du terril
CH_4	0,2 %
CO_2	7,8%
O_2	12,3%
H_2	>>>>>
CO	52 ppm
H_2S	520
Balance	79,8 %

Video curtesy of D Lévy

Provinces prospective: Late maturation of source rocks (Thermogenic H_2)





Moretti et al., 2024

Huge estimated Ressource :

For immature samples :
H_2 yield = ¼ of the TOC in %

Geoscience Australia, Fm Tachawara : 850 tcf (2.12 Gt)
GFZ & **China University of Mining and Technology** Songliao Basin, China : 1819 tcf (4.6 Gt)

=> Global resources (based on the shale estimation already done for the shale gas) : 32 000 tcf
i.e. 6.4 10^{11} t (about 8500 yr of the current world H_2 consumption)

Horsfield et al., 2022, Molecular hydrogen from organic sources in the deep Songliao Basin, P.R. China
Mahlstedt et al; 2022, Molecular hydrogen from organic sources in geological systems, https://doi.org/10.1016/j.jngse.2022.104704
Moretti I.*, et al.,* 2024 The H_2 potential of the Colombian coals in natural conditions. IJHE, https://doi.org/10.1016/j.ijhydene.2024.06.225

AFRICA¶

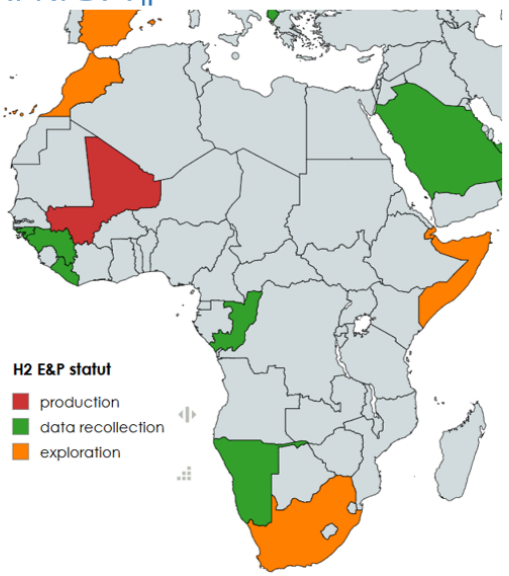


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FIGURE 3: NATURAL HYDROGEN EXPLORATION STATUS IN AFRICA BY MID-2025. RED: PRODUCTION; ORANGE: EXPLORATION: GREEN: RESEARCH¶

- → One country is producing H_2: Mali.¶
- → In four countries the exploration is active: Morocco, Djibouti, South Africa, Soudan.¶
- → Data have been published about the Namibian and East African Rift potential¶

Asia and Oceania¶

¶

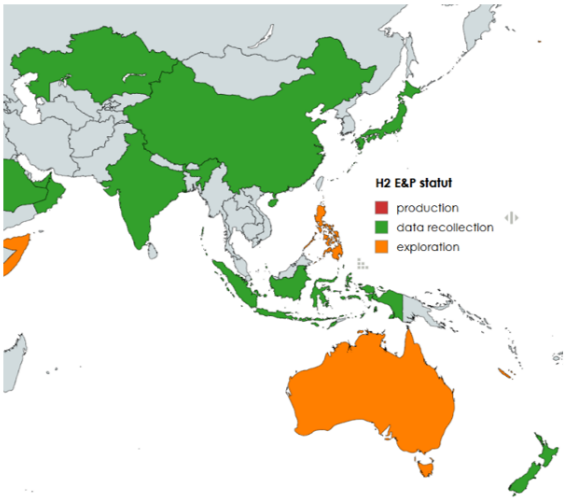
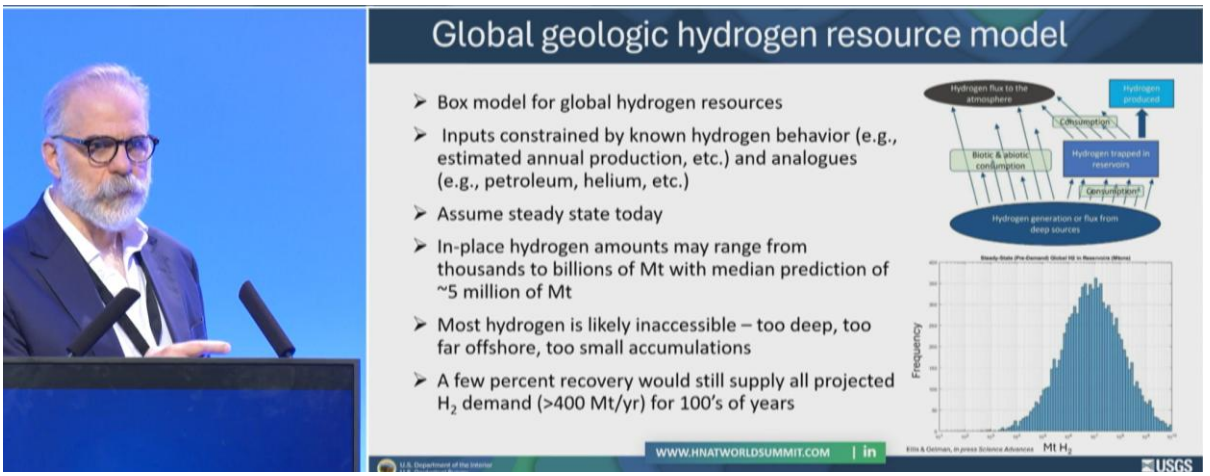


FIG 6: ACTIVITY IN ASIA AND OCEANIA BY MID 2025¶

- → Exploration is active in Australia and Philippines¶
- → Data has been published in Indonesia and in China¶
- → In Kazakhstan the government founded large projects to evaluate the country potential.¶
- → Literature shows that the topic is becoming hot in India¶

Resources / Reserves

G Ellis, USGS, HNAT-2024



USGS estimation: between 1000 y 10^9 Mt of H_2, P50: 5 10^6 Mt
Reserves for more than100 yr even with a low recovery factor and a strong increase of consumption x 4 (100Mt/yr in 2024)

What is happening worldwide

This first forum has been an **opportunity** for all stakeholders to showcase their **latest products & services**, build partnerships, establish and grow business relationships, raise financing, assemble teams… 750 attendees

Second edition took place in June 2022, 3nd in Perth Nov 2023 4nd in Paris 25-26th Nov 2024, we are currently organizing the 6th one.

AAPG included the topic in their International meetings of 2022 (ICE- April Cartagena-Colombia; May Budapest-Hungria), special AAPG about natural H2 in south America in December 2022; now all the AAPG or EAGE global event includes natural H2 in the program.

Side event at the COP 26 organized by the Glasgow Uni

AIE: creation of a Task dedicated to natural H_2 (confirmed in march 2024, n°49)

Earth2: Initiative to federate the European ecosystem of H_2 in subsurface

www.hnatworldsummit.com

2024: Involvement of the NOC

- In south America: Ecopetrol, Petrobras
- In the Middle East: Adhnoc, RakGas, SaudiAramco
- In Asia: Sinopec, Petronas

Natural Hydrogen in the northern Semail Ophiolite: A case study in the Emirate of Ras Al Khaimah, UAE

Gabriel Pasquet [a,*], Keanu Loiseau [a], Mohamed Diatta [a], Giacomo Firpo [b], Paul Swire [b], Andrew Amey [b], Thibaut Burckhart [b], Isabelle Moretti [a]

[a] Laboratoire des Fluides complexes et de leurs Réservoirs (LFCR), UMR 5150, IPRA, Université de Pau et des Pays de l'Adour, Avenue de l'Université, 64000 Pau, France
[b] RAK Gas, Ras Al Khaimah, United Arab Emirates

First downhole sampling of a natural hydrogen reservoir in Colombia

Cesar Patiño[1], Dariusz Strąpoć[2]*, Oscar Torres[3], Oliver Mullins[4], Ulises Bustos[5], Oscar Bermudez[6], Albeiro López[6], Maria Trujillo[7] and Hans Morales[7]

[1] Ecopetrol, Technical Development Center, Bogota, Colombia, [2]SLB, Well Construction Measurements, Clamart, France, [3]SLB, Well Construction Measurements, Bogota, Colombia, [4]SLB, Well Services, Houston, United States, [5]SLB, Reservoir Performance, Houston, United States, [6]Ecopetrol, Reservoir Engineering, Bogota, Colombia, [7]Ecopetrol, Exploration, Bogota, Colombia

Natural H_2 Transfer in Soil: Insights Measurements at Varying Depths

Cesar Patino [1], Dora Piedrahita [2], Elkin Colorado [2], Katherine Ari

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[2] Expro, Calle 11099-25, Oficina 801, Bogotá ... elkin.colorado@expro.com (E.C.)
[3] LFCR-UPPA, Rue de L'Université, 64012 Pa...
[4] Correspondence: isabelle.moretti@univ-pau...

Subsurface hydrogen generation: Natural sources conversion technologies

Jian Hou[a,*], Wei Wei[a], Ziyuan Qi[a], Mohammad Alotaibi[b]

[a] Beijing Research Center, Aramco Asia, Beijing, 100102, China
[b] EXPEC Advanced Research Center, Saudi Aramco, Dhahran, 31311, Saudi Arabia

Helium and natural hydrogen in the Bohai Bay Basin, China: Occurrence, resources, and exploration prospect

Yongbo Wei [a,b], Quanyou Liu [c,*], Dongya Zhu ... Xiaoqi Wu [d], Pengpeng Li [c], Xiaowei Huang [c]

[a] State Key Laboratory of Deep Petroleum Intelligent Exploration and Develop... China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] Institute of Energy, School of Earth and Space Sciences, Peking University, B...
[d] Petroleum Exploration and Production Research Institute, SINOPEC, Beijing ...
[e] State Key Laboratory of Earthquake Dynamics, Institute of Geology, China E...

Integrated geochemical identification of natural hydrogen sources

Quanyou Liu [a,b,*], Xiaoqi Wu [c], Xiaowei Huang [a], Di Zhu [d], Qingqiang Meng [c], Dongya Zhu [c], Huiyuan Xu [c], Jiayi Liu [c], Pengpeng Li [a], Zheng Zhou [e], Kaiqiang Zhang [a], Zhijun Jin [a,c,*]

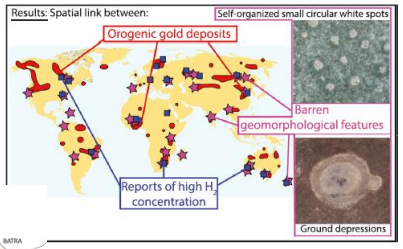
[a] Institute of Energy, Peking University, Beijing 100871, China
[b] Northwest Institute of Eco-Environment and Resource, Chinese Academy of Sciences, Lanzhou 730000, China
[c] Petroleum Exploration & Production Research Institute, SINOPEC, Beijing 102206, China
[d] Key Laboratory for Biomass Gasification Technology of Shandong Province, Energy Research Institute, Qilu University of Technology (Shandong Academy of Sciences), Jinan 250014, China
[e] Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ, UK

H_2 / Mines, 2025: the Mining companies start looking for H2

- Gold mines
- Chromite
- Iron
- Coal
- Uranium

Barren ground depressions, natural H_2 and orogenic gold deposits: Spatial link and geochemical model

Benjamin Malvoisin *, Fabrice Brunet

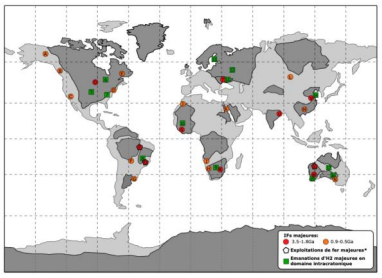


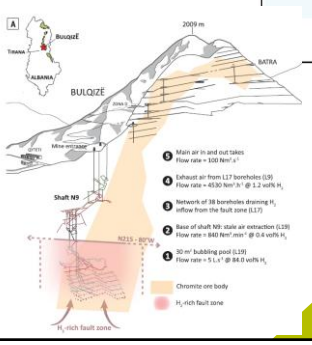
A deep reservoir for hydrogen drives intense degassing in the Bulqizë ophiolite

Laurent Truche[1]*, Frédéric-Victor Donzé[1], Edmond Goskolli[2], Bardhyl Muceku[3], Corinne Loisy[4], Christophe Monnin[5], Hugo Dutoit[1], Adrian Cerepi[4]

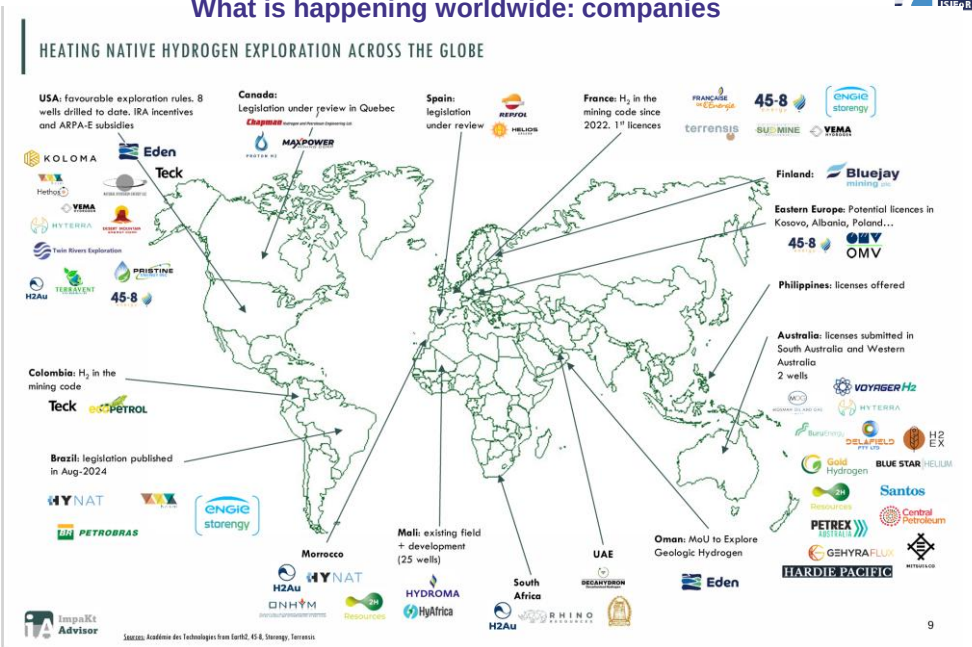
Can Weathering of Banded Iron Formations Generate Natural Hydrogen? Evidence from Australia, Brazil and South Africa

Ugo Geymond [1], Erick Ramanaidou [2], Dan Lévy [1], Abderrahim Ouaya [3] and Isabelle Moretti [1,*]





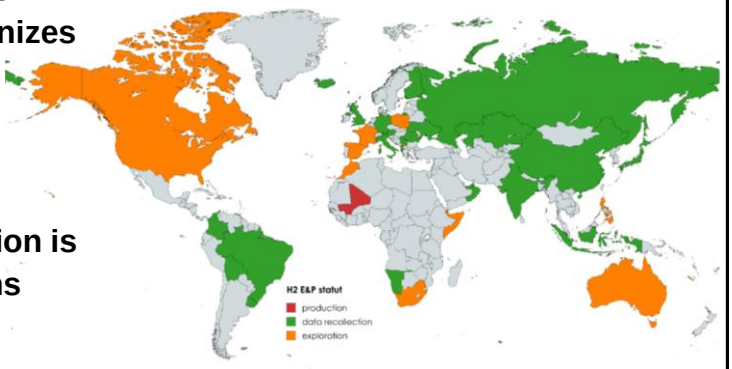
What is happening worldwide: companies



Take home messages

- The H_2 E&P started
- The most active countries are South Australia, US and France but it is mainly due to the law that recognizes H_2 as a resource
- Many other countries have H_2 potential to explore
- Hight temperature serpentinization is just one of the potential reactions

Thanks for your attention



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