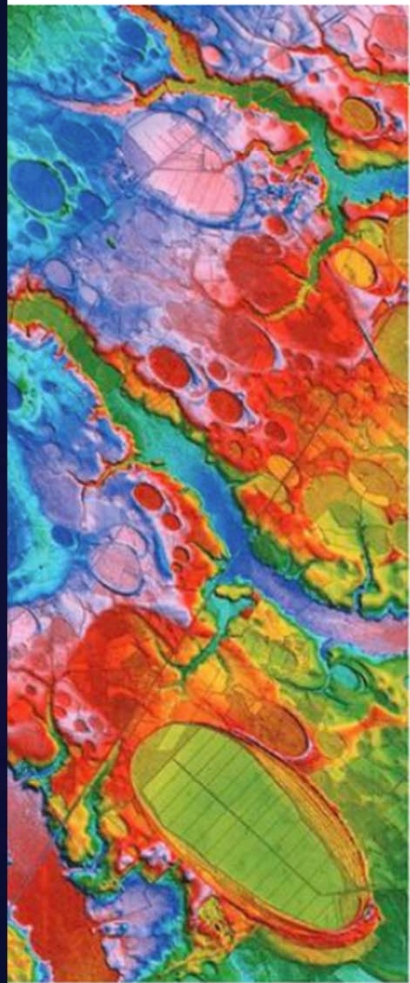
Exploration de l’hydrogène naturel : où en est la recherche ?

Grenoble H_2 Exploration Project
Laurent Truche, Frédéric Victor Donzé
Hugo Dutoit (PhD), Nicolas Lefeuvre (Post-Doc), Camille Dusséaux (Post-Doc), Dimitri Laurent (Post-Doc)

Native H_2 observatory: https://nativeh2project.osug.fr/

GEPhyX2024, Grenoble, 4 Juillet 2024



Hunt for natural hydrogen heats up

In 1859, Edwin Drake sank 20 meters of cast-iron pipe into the earth beneath Titusville, Pennsylvania, and struck oil, collecting it in a bathtub. The well kicked off the U.S. oil rush and changed the world. This year saw the start of another energy rush, this one based on hydrogen produced naturally within Earth. Unlike oil the gas could be a tonic, not a toxin, for the climate.

Historians might one day trace its birthplace to another unlikely town: Bourakebougou, Mali. In 2012, engineers unplugged a borehole there that had been cemented shut in 1987, after a careless cigarette sparked an explosion. The gases it spewed turned out to be 98% hydrogen. A generator was hooked up. Producing only water as exhaust, it supplied the village with its first electricity. Curiously, after a decade of withdrawals, gas pressures in the borehole have not decreased—a suggestion that a deep source is replenishing the hydrogen.

Inspired by the discovery, prospectors are now finding signs of significant hydrogen deposits on every continent save Antarctica. Venture capital is flowing to startups such as Koloma, which came out of stealth mode in July with $91 million in funding, including investments from Bill Gates's Breakthrough Energy Ventures. In September, the U.S. Geological Survey (USGS) launched a research consortium with support from Chevron and BP, and the Advanced Research Projects Agency-Energy began a $20 million natural hydrogen R&D program.

That Earth holds any hydrogen at all defies conventional geological wisdom. Because hydrogen is energy rich and reactive, researchers thought that in Earth's crust most of it would be eaten up by microbes or converted into other compounds. Its surprising existence in so many places has prompted speculation that it leaks up from Earth's core or is created as radioactive elements in the crust split water. But many researchers believe it is generated when water reacts with iron-rich minerals at high temperatures and pressures.

An unpublished USGS study suggests Earth may hold 1 trillion tons of hydrogen—enough to satisfy growing demand for hydrogen as a fuel and fertilizer ingredient for thousands of years. Some prospectors say extracting it could prove far cheaper than manufacturing "green hydrogen" with renewable electricity, an approach supported by billions of dollars in government subsidies. But the big question is whether Earth's hydrogen is concentrated in reservoirs that companies can tap economically. If it is, environmentalists may find themselves in the odd position of cheering the roughnecks on with cries of "drill, baby, drill!" *—Eric Hand*

Lidar maps of coastal North Carolina reveal kilometer-wide circular depressions that may encompass seeps of hydrogen.

Hydrogeninsight
Powered by RECHARGE

ANALYSIS | Will natural hydrogen extracted from the ground be the next global gold rush?

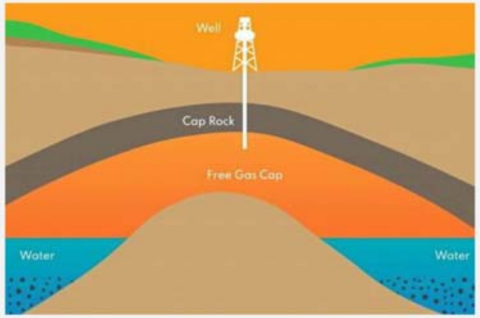
The existence of naturally occuring H2 has been known about, but not well understood, for centuries — but this could be about to change, writes Rystad Energy Hydrogen Research

7 November 2022 11:16 GMT *UPDATED 25 July 2023 9:38 GMT*
By Rystad Energy Hydrogen Research

'Significant concentrations' of natural hydrogen discovered in northeast France by local power and gas producer

FDE has submitted an application for an exclusive mining exploration permit in the Lorraine region in bid to assess commercial potential

16 May 2023 14:07 GMT *UPDATED 16 May 2023 14:33 GMT*
By Leigh Collins



Massive underground reservoir of natural hydrogen in Spain 'could deliver the cheapest H2 in the world'

Helios Aragón says it has access to giant resource of naturally occurring hydrogen in northern Spain but the country's anti-oil rules are standing in its way

6 April 2023 8:18 GMT *UPDATED 6 April 2023 8:18 GMT*
By Rachel Parkes

Natural hydrogen detected in 'multiple locations' in South Australia

First stage of soil gas testing has yielded promising results for Australian firm Gold Hydrogen ahead of initial drilling in October

25 July 2023 9:25 GMT *UPDATED 25 July 2023 9:36 GMT*
By Polly Martin

Gold Hydrogen detects 'elevated levels' of natural H2 from Australia's first exploration well

Brisbane-based company says it still needs to take uncontaminated downhole samples to confirm the exact purity of the hydrogen

19 October 2023 10:13 GMT *UPDATED 19 October 2023 10:18 GMT*
By Leigh Collins

US offers $20m in funding for technology to improve natural-hydrogen exploration and extraction

The Department of Energy is backing research into detecting and extracting hydrogen from subsurface stores or reduced iron minerals

8 September 2023 9:27 GMT *UPDATED 8 September 2023 9:27 GMT*
By Polly Martin

'It's on every continent' | Bill Gates-backed start-up drilling for natural hydrogen in the US

Secretive Koloma backed with $91m from investors, including Breakthrough Energy

20 July 2023 11:54 GMT *UPDATED 20 July 2023 12:15 GMT*
By Rachel Parkes

'Everything is speculative' | A boom in applications for natural hydrogen exploration in France is more about policy than reserves

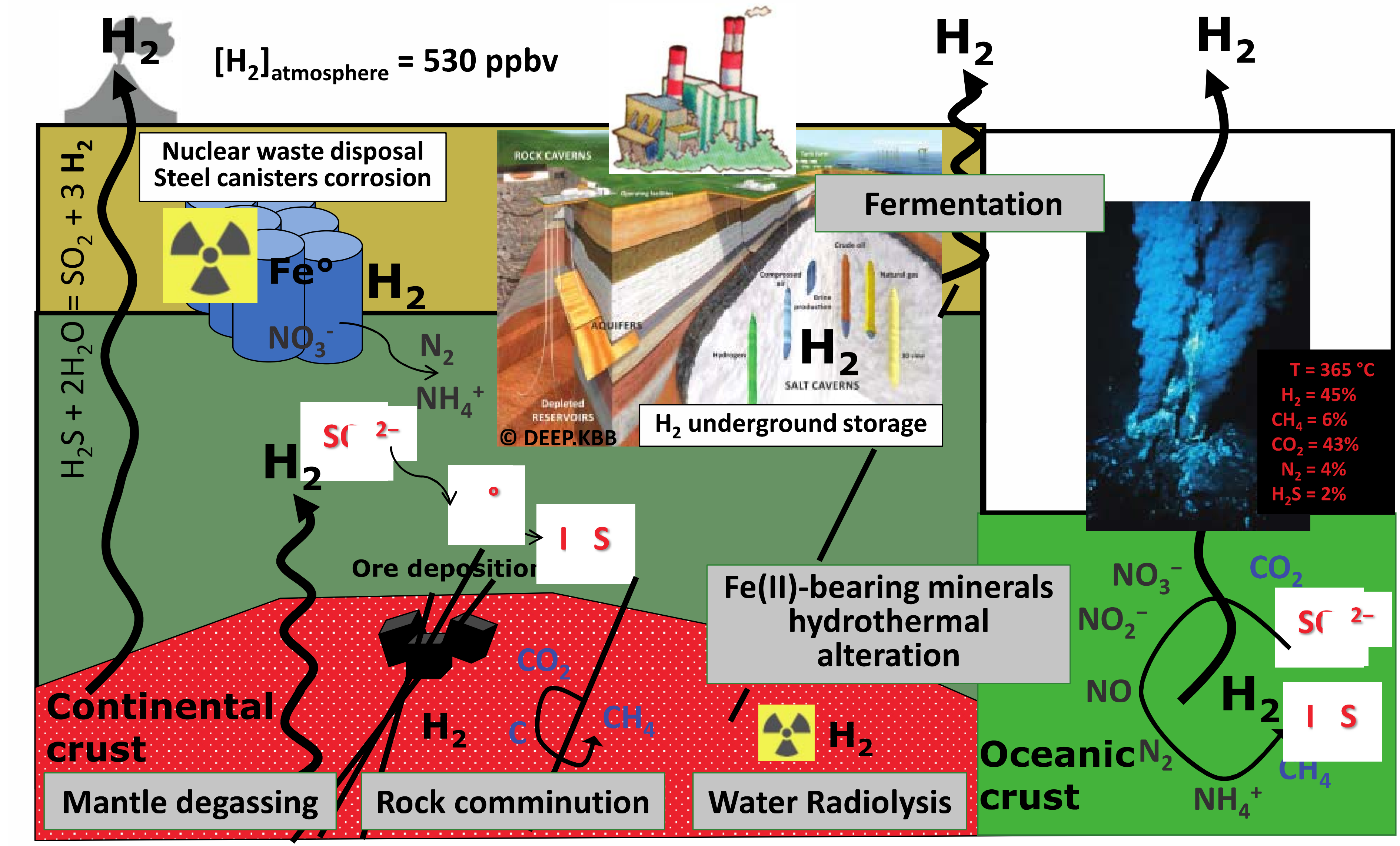
Naturally occurring H2 worldwide could meet anywhere from a quarter to five times of global demand based on estimates, but actual resources are yet to be proven

19 September 2023 10:25 GMT *UPDATED 19 September 2023 10:25 GMT*

By **Polly Martin**

H_2 SYSTEM

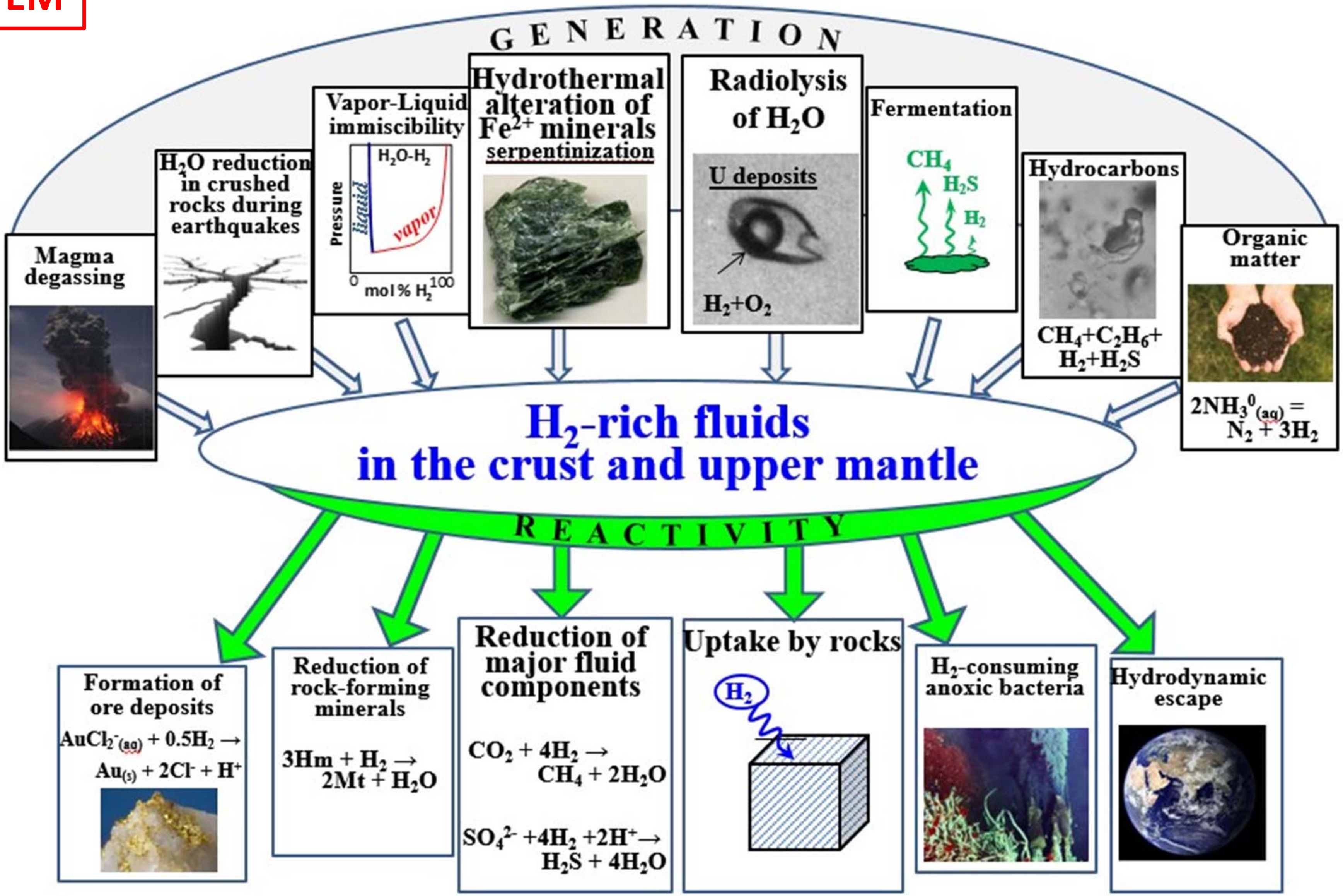
Hydrogen sources and sinks in the Earth's crust



Truche et al., 2020

H_2 SYSTEM

H_2: from Sources to Sinks



H_2 sources and sinks at global scale

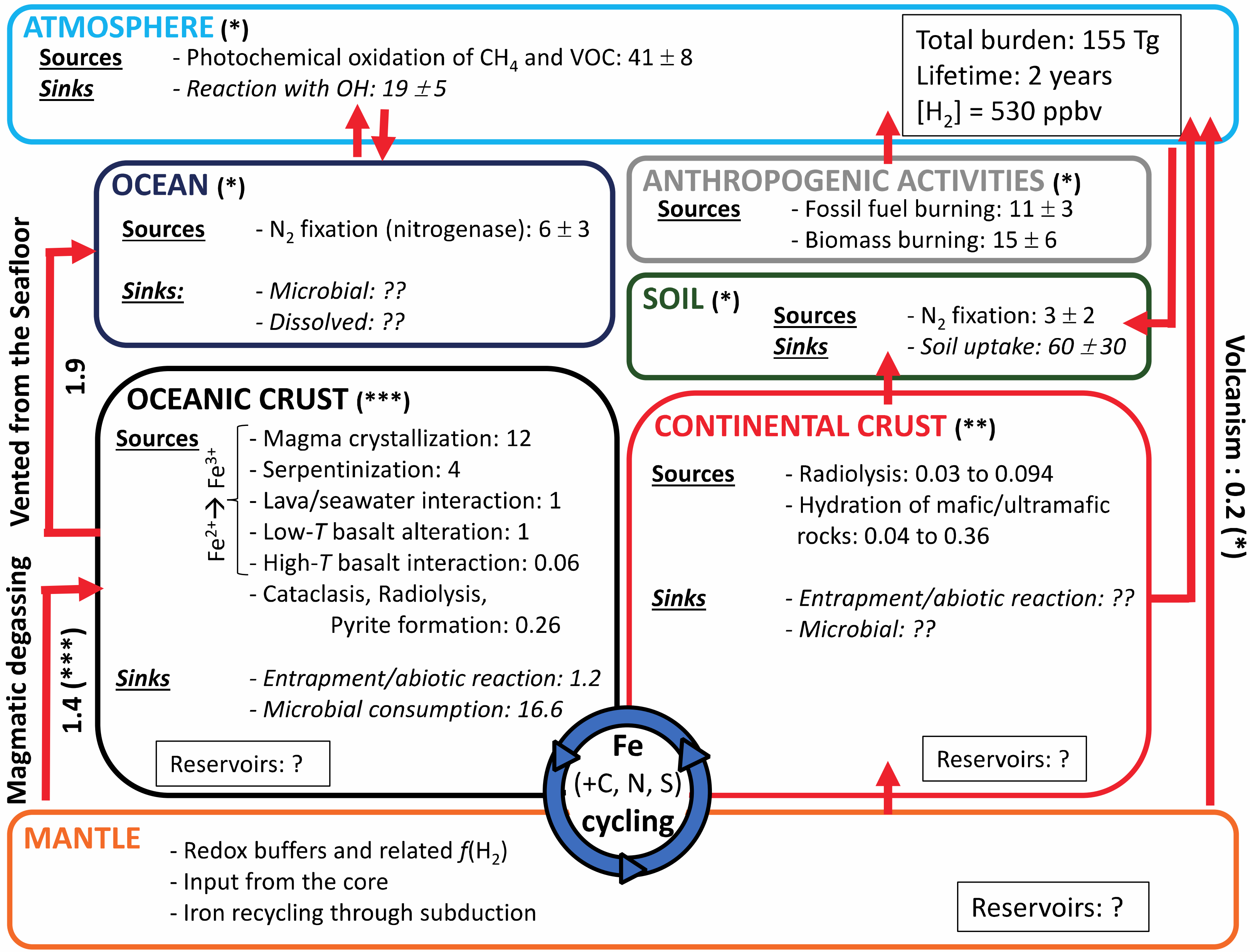
All numbers in Mt/yr

(Truche et al., 2020)

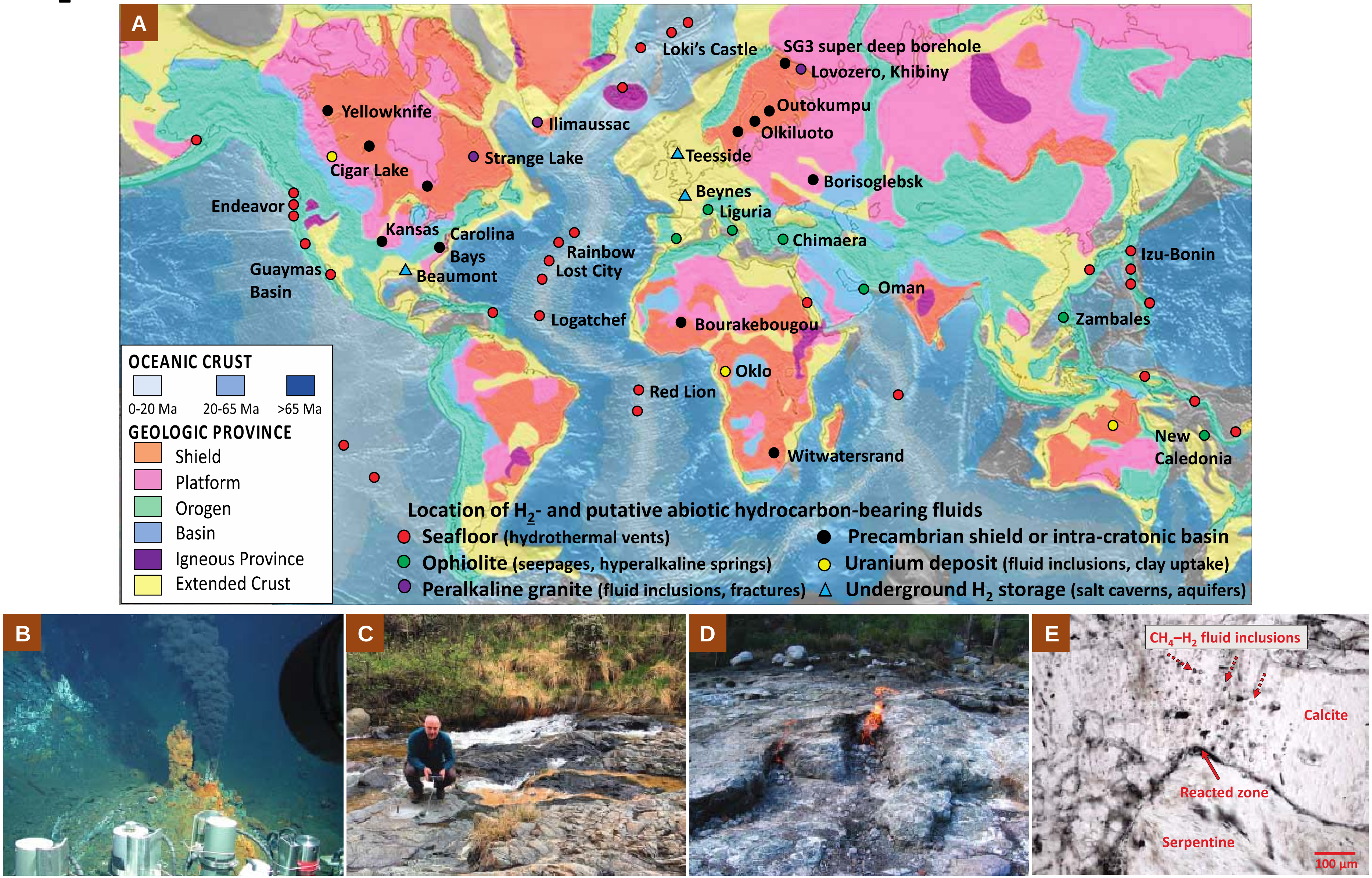
* Ehhalt and Rohrer (2009)
**Sherwood Lollar et al. (2014)
*** Worman et al (2015)

More recent studies like Klein et al (2020), Merdith et al (2020) end up with similar fluxes

Industial use/energy:
94 Mt/yr
IEA report (2022)



Native H_2 occurrence worldwide



1933

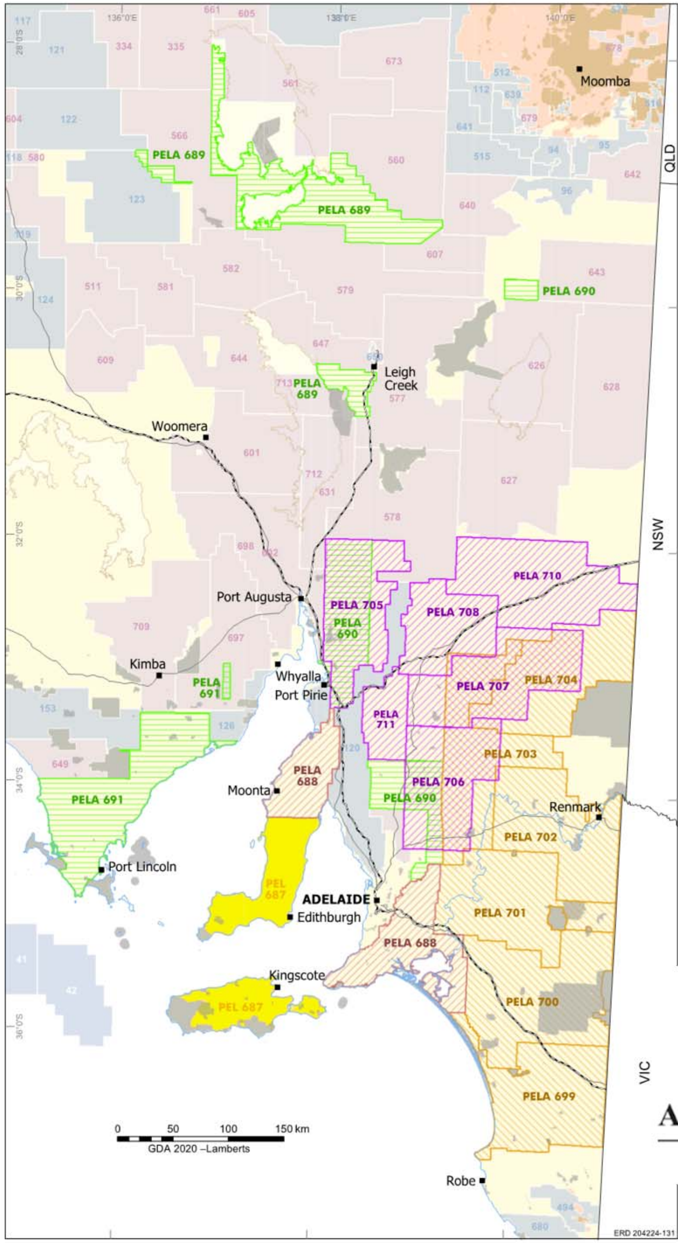
of fire travelling backwards and forwards between the bores
the sea. The Company was urged to obtain samples of the ga
the method of collection from the bailer was explained. Sa
were collected and alalysed by the Government Analyst, at a
when a depth of 615' had been reached. Boring was continue
more gas was reported. a further sample obtained from 950'

- 2 -

	I.	II.
Methane	2.6%	4.68%
Nitrogen (by difference)	36.0%	22.61%
Total	100.0	100.0

Boring operations ceased when a total depth of 961'4" was reached
and have not been resumed. Water level in this borehole was at a

Ward, L. K. (1933)



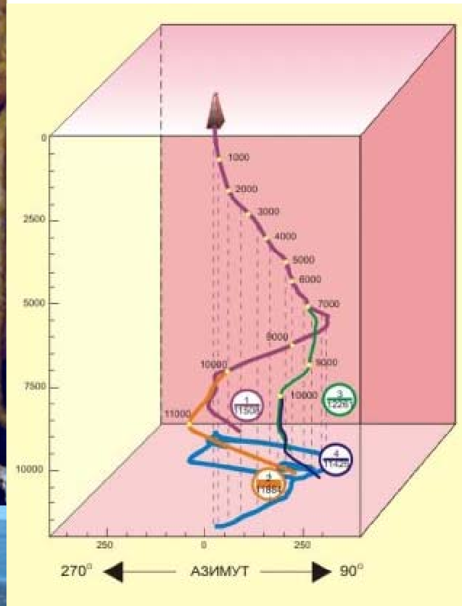
2022

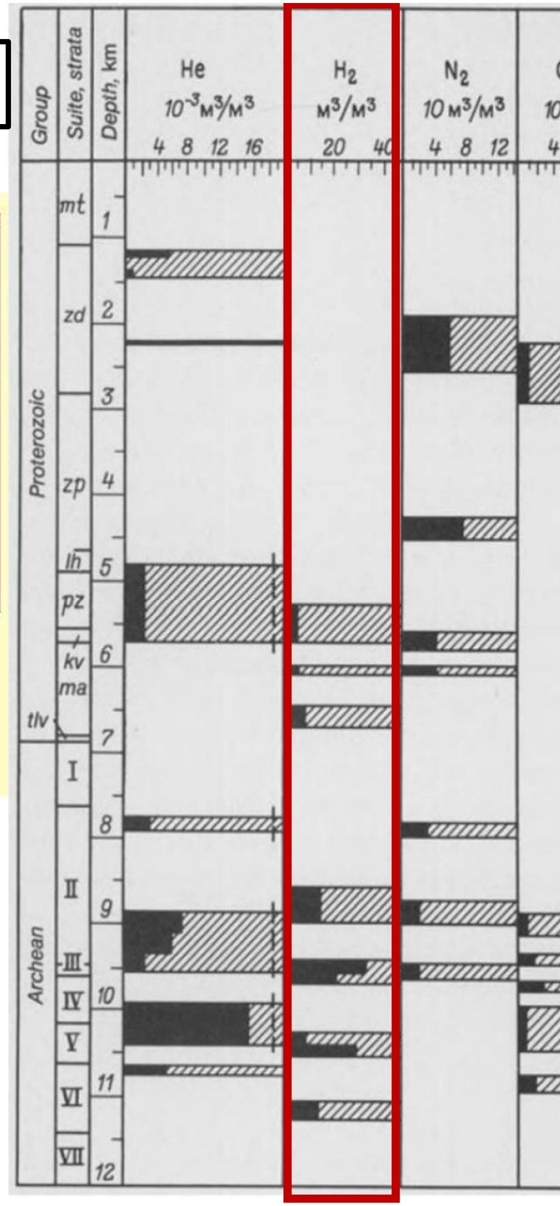
Australian Government
Geoscience Australia

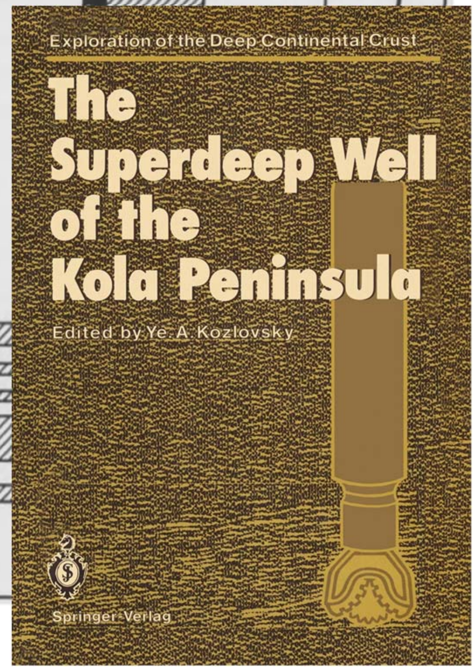
Kola super deep borehole (Zapoliarny, Russia)

H_2-bearing gas flowing out of the pipe

1983







Kozlovsky Y.A. (1987)

indicative of a substantial mantle He component. The δD-values of CH_4 and H_2 are −136 and −590‰, respectively, consistent with equilibration temperatures of 110–125°C. Carbon and He isotopic data could be consistent with derivation of the Zambales gas directly from a reduced mantle. However, phase equilibria and H isotope data indicate that the gas also could have been produced by reduction of water and carbon during low-temperature serpentinization of the ophiolite.

1986

1. Introduction

ation of sedimentary organic matter as a con-

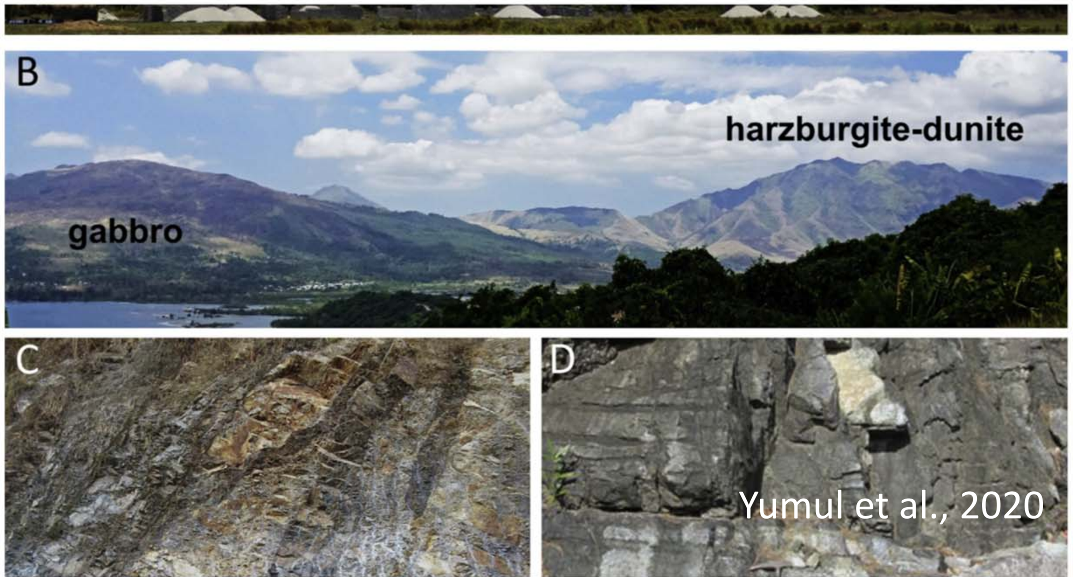
Laboratory: *[1]Scripps Institution of Oceanography; *[2]Argonne National Laboratory; *[3]Global Geochemistry Corp.; *[4]Department of Scientific and Industrial Research, New Zealand.

low concentrations of ethane and CO_2, its high $\delta^{13}C_{CH_4}$, and its high $^3He/^4He$ ratio. We therefore consider two possible abiogenic models for the origin of the gas, in which organic components may be present but are not predominant.

3.1.1. Mantle origin for the Zambales gas. The observed He isotopic composition of the Zam-

constraint in understanding the origin of the major components of the gas.

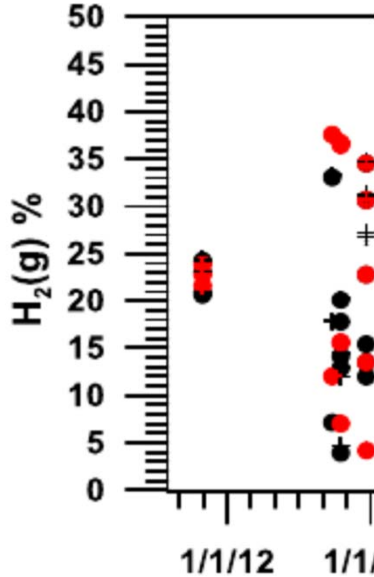
Craig and coworkers suggested the use of $CH_4/^3He$ vs. $^3He/^4He$ plots in constraining the origin of CH_4 in natural gas fields (e.g., Poreda et al., 1986; Craig and Horibe, 1988). In Fig. 2, we compare the CH_4 and He isotope abundances in the Zambales gas with similar data



The Chemistry of Hyperalkaline Springs in Serpentinizing Environments: 1. The Composition of Free Gases in New Caledonia Compared to Other Springs Worldwide

2021

Christophe Monnin[1], Mariann uéméneur[2], Roy P e[3], Julie Jeanpert[4], Pierre Maurizot[4], Cédric Boulart[5], Jean-Pierre Donval[6], and Bernard Pelletier



1991 - 2002

ELSEVIER

Chemical Geology 191 (2002) 345–359

CHEMICAL GEOLOGY
INCLUDING
ISOTOPE GEOSCIENCE

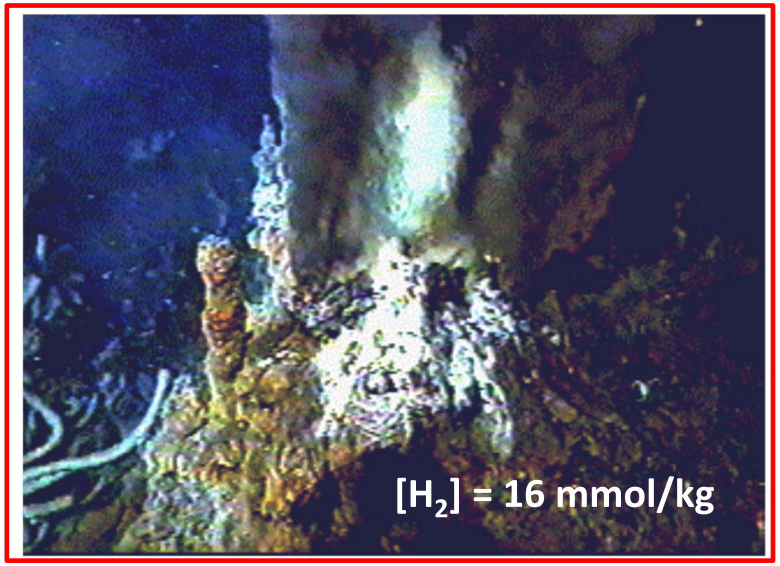
www.elsevier.com/locate/chemgeo

Geochemistry of high H_2 and CH_4 vent fluids issuing from ultramafic rocks at the Rainbow hydrothermal field (36j 14VN, MAR)

J.L. Charlou[a,*], J.P. Donval[a], Y. Fouquet[a], P. Jean-Baptiste[b], N. Holm[c]

[a]Département Géosciences Marines, IFREMER Centre de Brest, BP 70, 29280 Plouzané, France
[b]LSCE, CEA-CNRS UMR 1572, Centre d'études de Saclay, Gif sur Yvette, France
[c]Department of Geology and Geochemistry, Stockholm University, Sweden

Received 8 May 2001; accepted 17 June 2002



Rainbow : H_2 Flux = 2000 m^3/yr (180 kg/yr)
(Charlou et al., 2008)

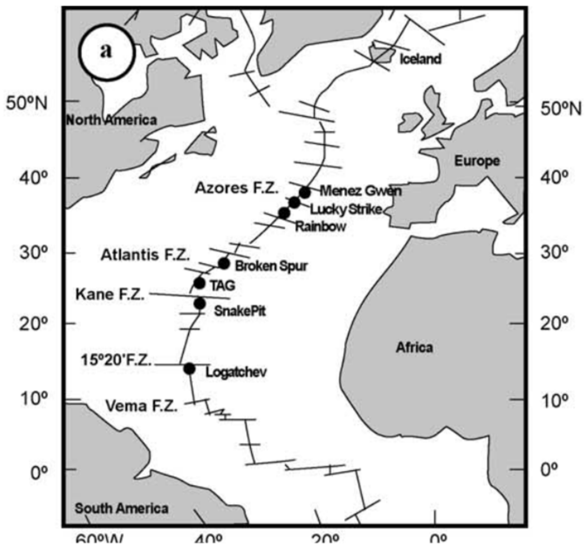
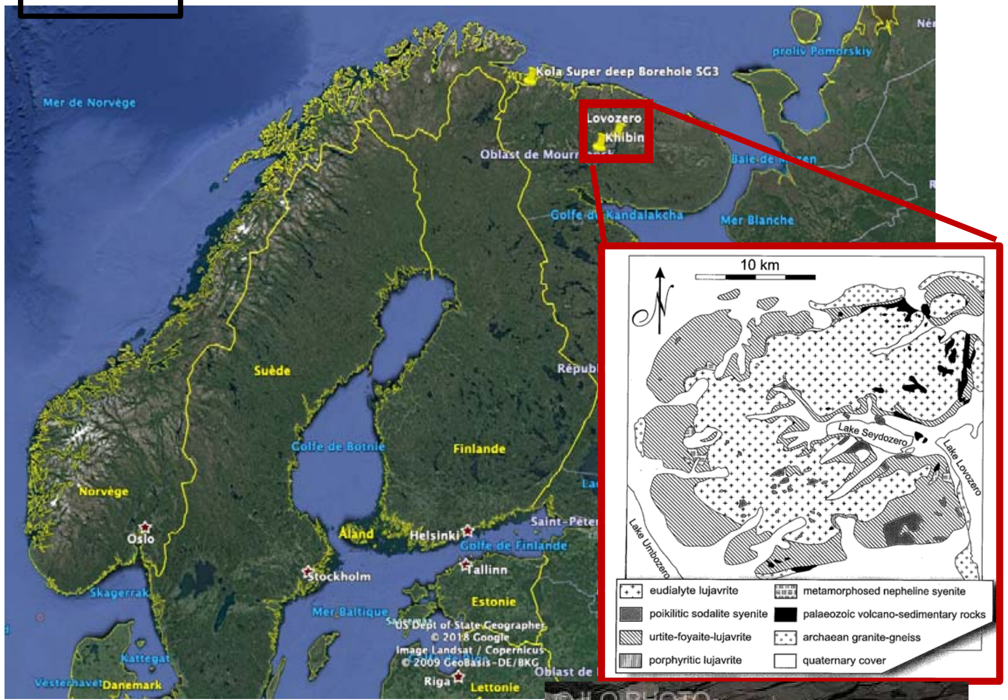


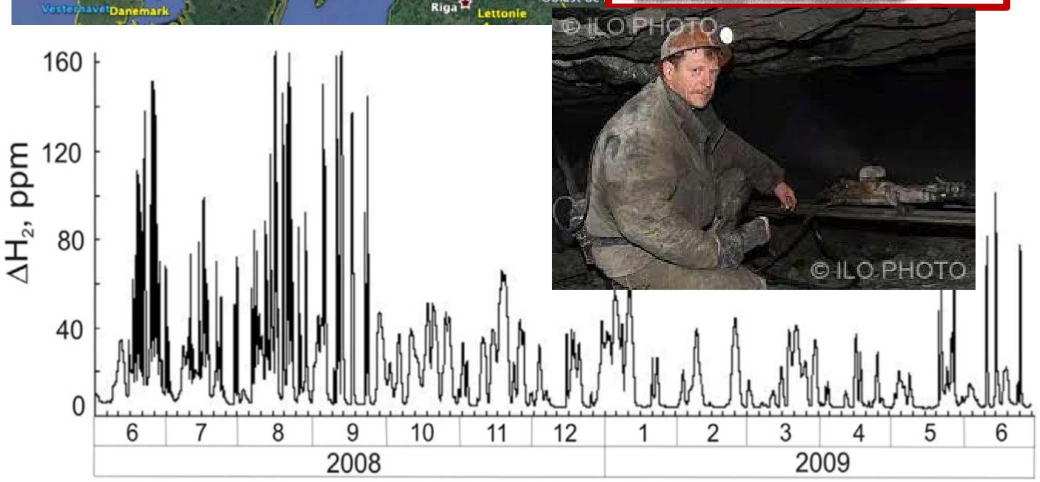
Table 3
Evolution of exit temperature, pH, chlorinity, gas endmembers and isotopic carbon in Rainbow vent fluids between 1997 and 2001

Cruise element	Flores[a] (July 1997)	Saldanha[b] (May 1998)	Cruise 42-Keldhysh[c] (October 1999)	Iris[d] (May 2001)
T (°C)	362	346–350	308	342
pH	2.8	2.5–3.0	–	2.9
Cl (mM)	750	740–750	753	750–760
H_2S (mM)	1.2	< 1.5	2.0–2.5	1.0–1.2
CO_2 (mM)	16	13–15	2.9–3.1	14–17
H_2 (mM)	16	10–12	13	11–13
CH_4 (mM)	2.5	1.7–2.0	2.2	1.8–2.5
$\delta^{13}C$-CH_4(PDB) ‰	– 15.8	– 16.0	– 13.0/ – 13.4	– 18.2
$\delta^{13}C$-CO_2(PDB) ‰	– 3.0	– 3.1	1/ – 4	– 3.1

1975

Evidences for H_2 and HCs occurrence in hydrothermal fluids from peralkaline intrusions



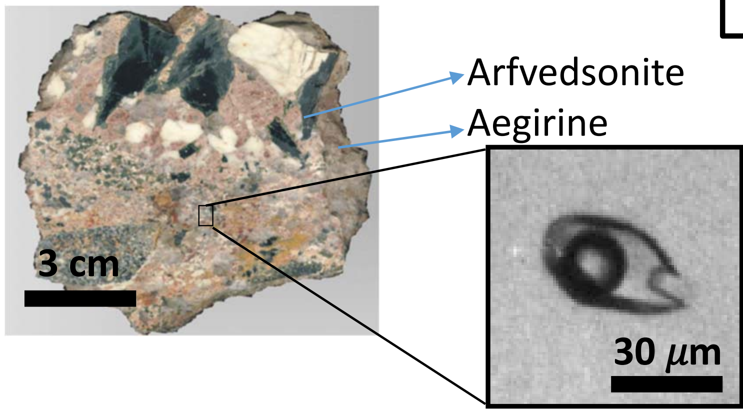


Nivin et al. (2016)

Strange Lake pluton (Canada)

H_2 + HCs (up to C6) bearing fluid inclusions

1997



Inorganic synthesis of hydrocarbons during alteration of peralkaline granite

Salvi and Williams-Jones (1997), Potter et al. (2013)

and Identification of Species

…iks and standardisation was achieved …nounts of known gas mixtures (avail- …rom Scott® Speciality Gases Co., …nto the gas chromatograph, except for …ected as saturated vapour at known …re. Blanks were run by crushing inclu- …rtz crystals and pure-silica rods, frag- …leaned exactly as would be regular

eliminated because N_2, as the carrie… Ar produces a signal with the inverse… extremely low fugacity at the conditi… study, and the detection limits of CO… µmoles). Moreover, as discussed be… most favourable conditions for its fo… >500°C and f_{O_2} < QFM), is unlike… >1% of the carbonic species. Figure 2… for analyses of a sample and a blan… rier gas.

Gas chromatography

$$3Na_3Fe^{II}{}_4Fe^{III}Si_8O_{22}(OH)_2\,_{(arfvedsonite)} + 2H_2O$$
$$=$$
$$9NaFe^{III}Si_2O_6\,_{(aegirine)} + 2Fe_3O_4\,_{(magnetite)} + 6SiO_2\,_{(quartz)} + 5H_2$$

1988

Radiolysis evidenced by H_2-O_2 and H_2-bearing fluid inclusions in three uranium deposits

JEAN DUBESSY[1], MAURICE PAGEL[1], JEAN-MICHEL BENY[2], HILBERT CHRISTENSEN[3], BERNARD HICKEL[4], CHARLES KOSZTOLANYI[1] and BERNARD POTY[1]

[1]Centre de Recherches sur la Géologie de l'Uranium et GS CNRS-CREGU, BP 23, 54501—Vandoeuvre-lès-Nancy, Cédex, France
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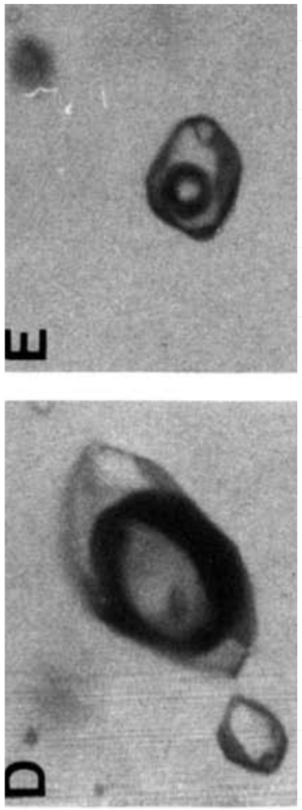
[3]Studsvik Energiteknik AB, Nuclear Division, Reactor Chemistry, S-61182 Nyköping, Sweden
[4]IRDI/DPC/SCM/4A 331. Centre d'Etudes Nucléaires de Saclay, 91191—Gif-sur-Yvette, Cédex, France

(*Received April* 16, 1987; *accepted in revised form February* 11, 1988)



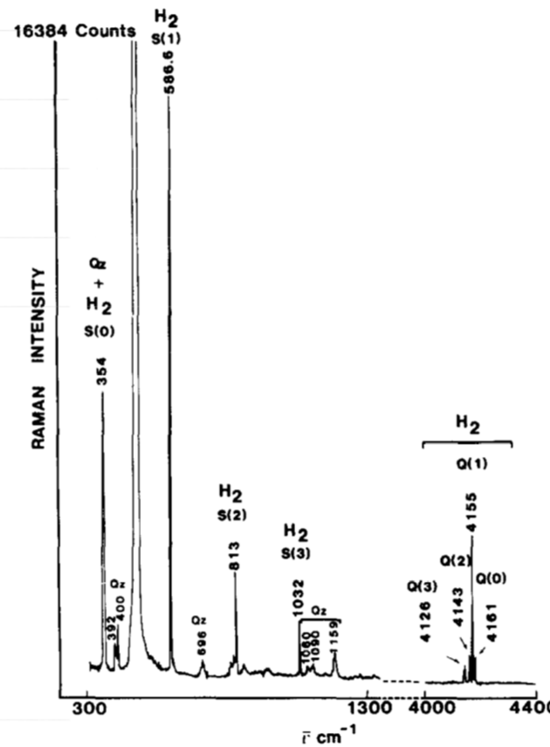
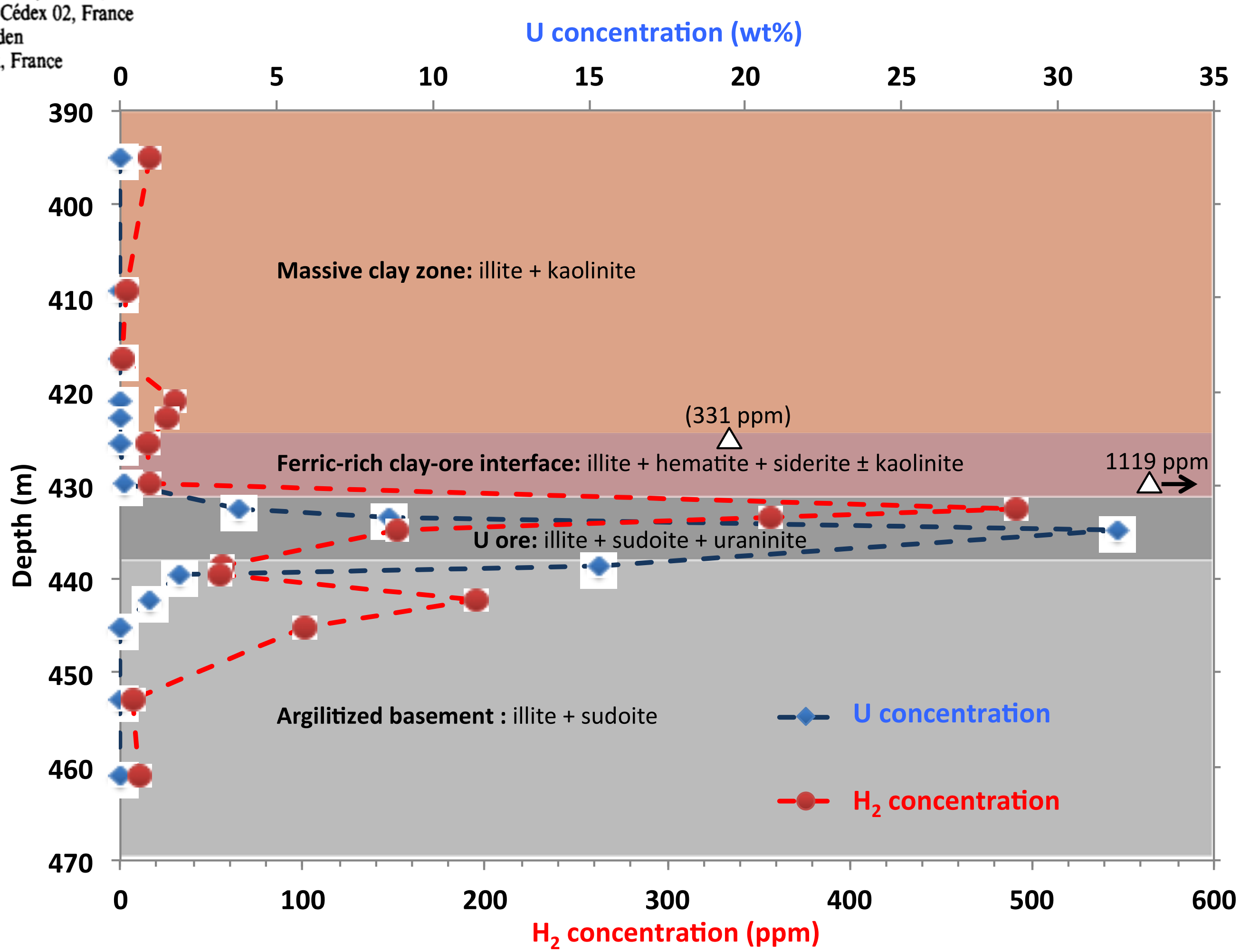


FIG. 3. Rotational and vibrational-rotational Raman bands of H_2 in a $L + V$ inclusion from sample 2894 (Oklo).

Clay minerals trap hydrogen in the Earth's crust: Evidence from the Cigar Lake uranium deposit, Athabasca

Laurent Truche [a,b,*], Gilles Joubert [c], Maxime Dargent [b], Pierre Martz [b], Michel Cathelineau [b], Thomas Rigaudier [d], David Quirt [e]

2018



H_2 emission in active fault systems

Mechanoradical H_2 generation process:
- Friction expose fresh silicate surfaces
- Silicate radicals react with water to produce H_2 and silanol groups

$$2(\equiv Si\cdot) + 2\,H_2O \rightarrow 2(\equiv SiOH) + H_2$$

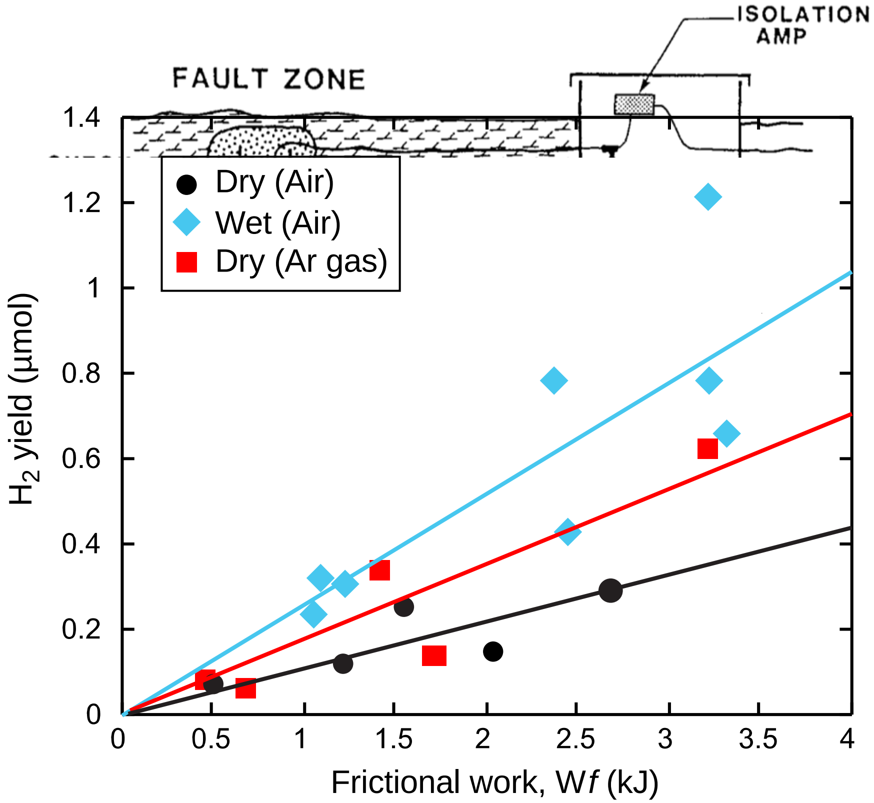
378 Motoaki Sato, A. J. Sutton and K. A. McGee PAGEOPH,

1984

3. Monitoring method

The H_2 monitoring system is schematically shown in Fig. 2. A 1.5-m deep hole was dug outside the northern wall of the winery. A polyvinyl-chloride (PVC) pipe, which is about 6 cm in diameter, 1.5 m long, and perforated at the lower one-third of the length, was placed in the hole. The lower one-third of the hole outside of the PVC pipe was then filled with coarse sand, and the remainder with soil. An H_2 sensor was placed at the bottom of the pipe and the interior of the pipe was filled with sand. Soil gases may move relatively freely into and through the pipe under this arrangement.

Sato et al., 1984



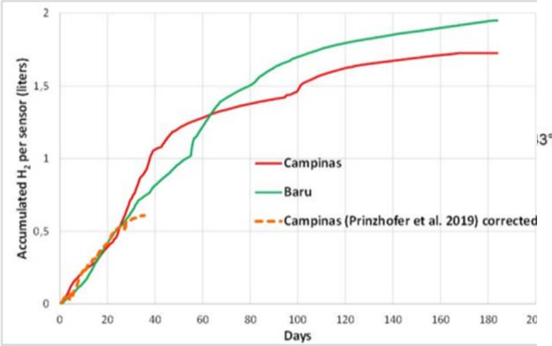
2011

Hirose et al., 2011

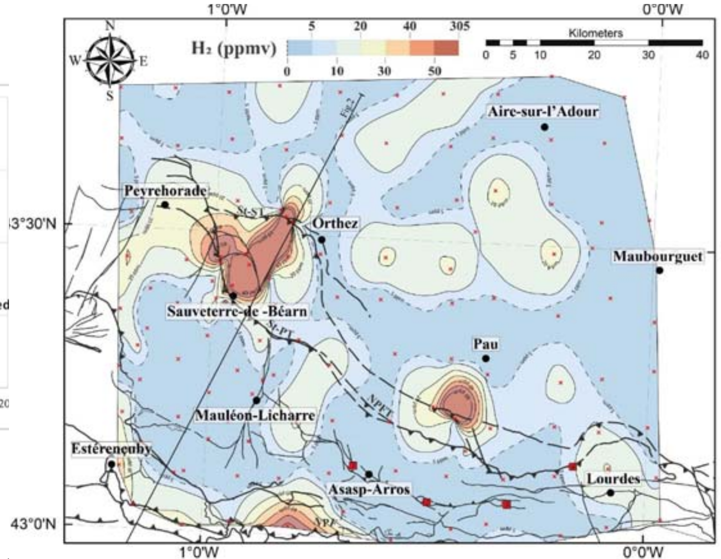
EXPLORATION

Recent Exploration activities worldwide: few examples

Brazil: ENGIE, UPPA, Geo4U



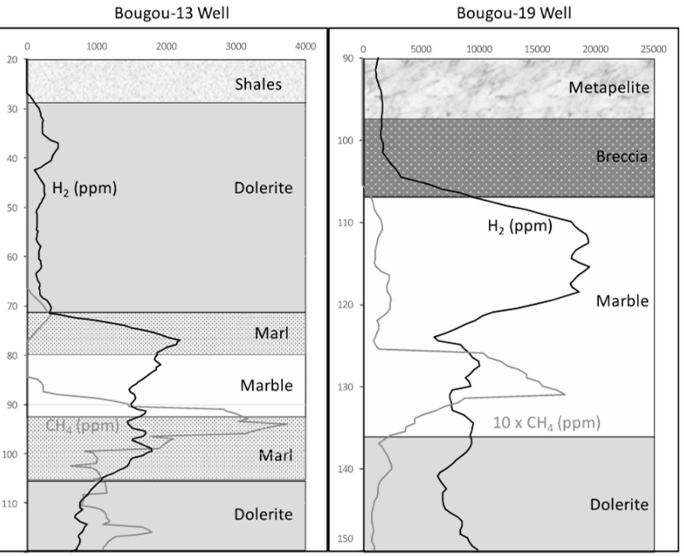
Moretti et al., 2020



France: BRGM, 45-8Energy, ISTerre, CVA, ENGIE

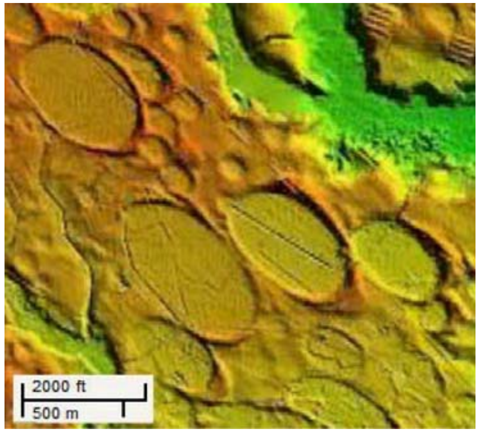
Lefeuvre et al., 2021, 2022

Mali: HYDROMA, IFPEN, TOTAL



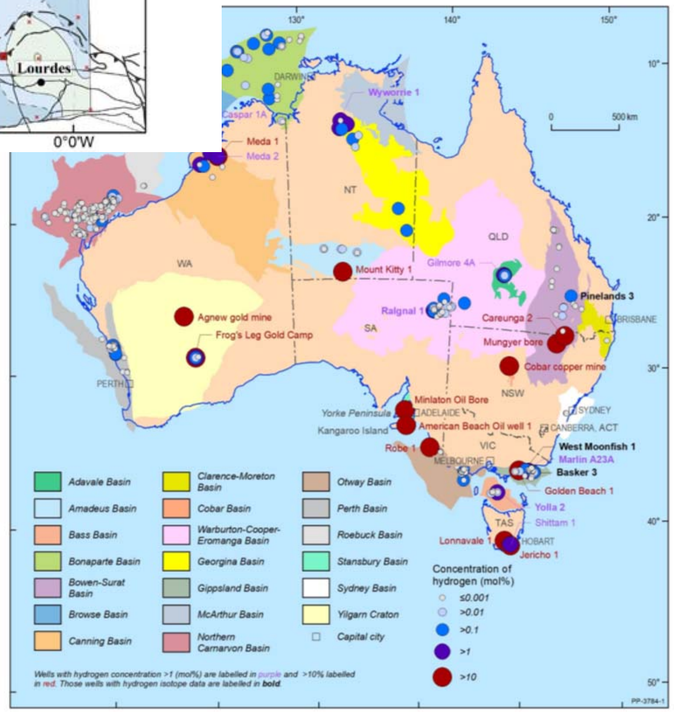
Prinzhofer et al. 2018

USA: USGS, NH2E



Zgonnik et al. 2015

Australia: GA, CSRIO, GoldH2, H2EX



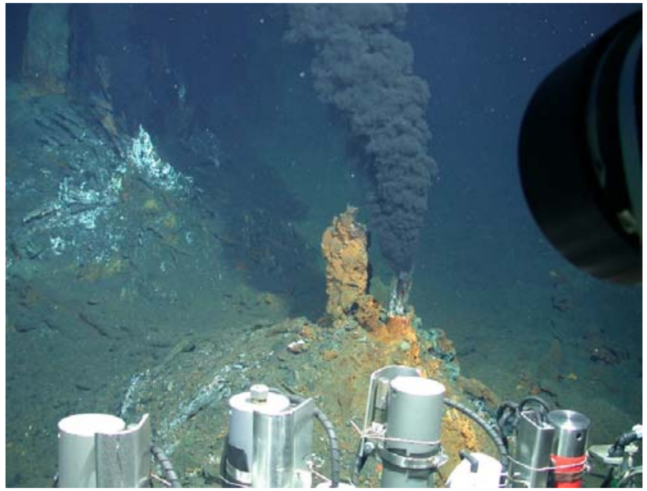
Boreham et al., 2022

H_2 outgassing rates at local scale

Robust methodology
(accumulation chamber, water-displacement method)

Haylain pool, Oman: **150 kg/yr**
200 m² (Leong et al 2023)

Chimaera, Turkey: **3540 kg/yr**
2000 m² (Etiope 2023)



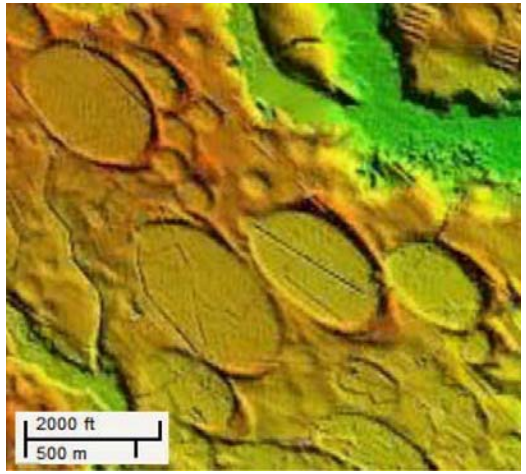
Rainbow vent, MOR: **180 kg/yr**
(Charlou et al 2008)

Outliers:
the "fairy circles"
mystery

Capinas, Brazil **: 256 t/yr ; 220000 m²**
(Moretti et al 2021)

Measurements, methodologies and computations are uncertain (McMahon et al., 2023)

Carolina Bays, USA : **58 t/yr; 480000 m²**
(Zgonnik et al 2015)



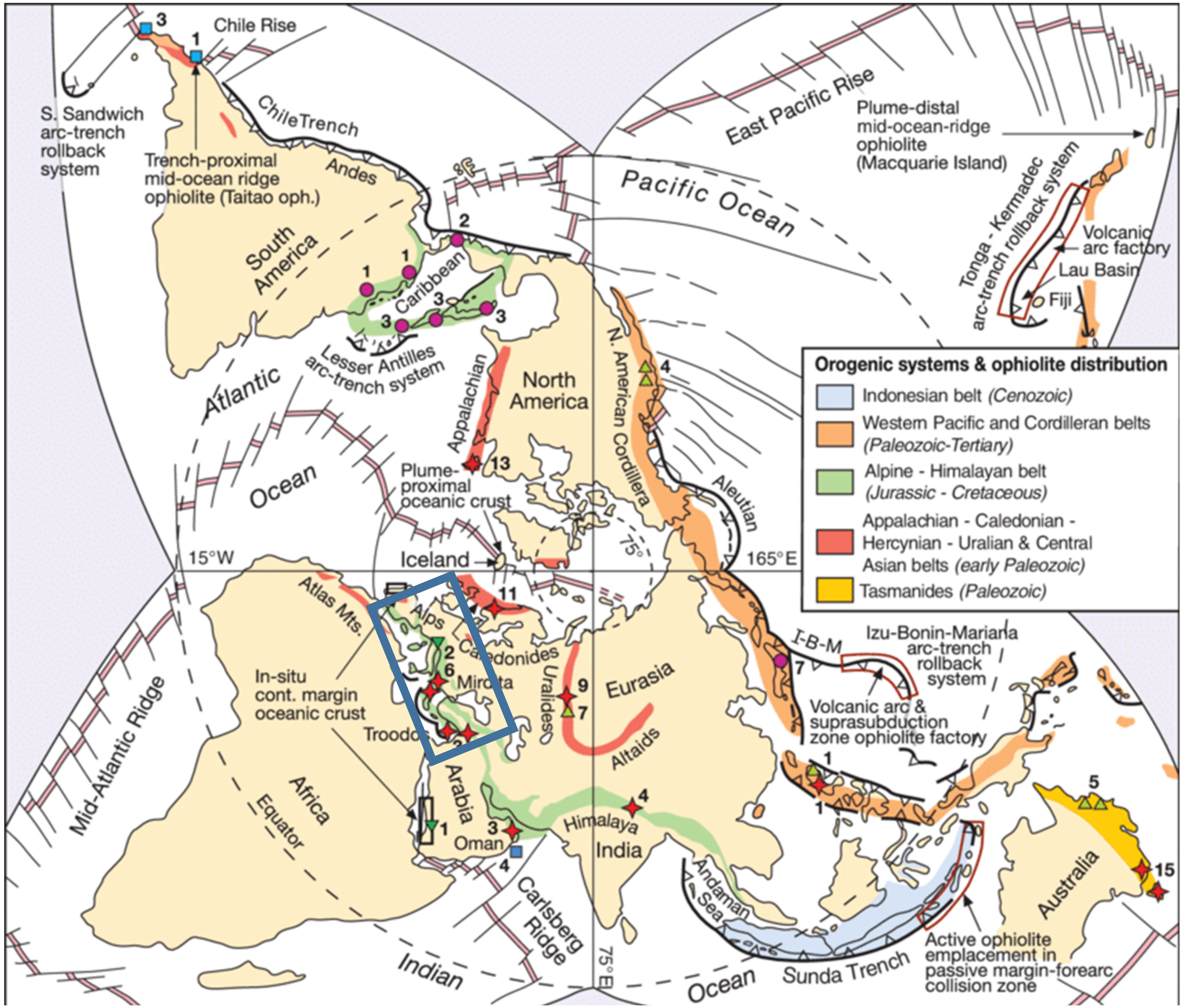
Hydrogen reservoirs in ophiolites

L. Truche, F-V Donzé, E. Goskolli, B. Muceku, C. Loisy,
C. Monnin, H. Dutoit, A. Cerepi

The exemple of the Bulqizë chromium mine (Albania)

UGA Université Grenoble Alpes
ISTerre
Géosciences Environnement Toulouse
EPOC
AK3N
Polytechnic University of Tirana UPT Albania
cnrs

Ophiolites: the only place on the continent where H_2-rich gas can be found at the surface

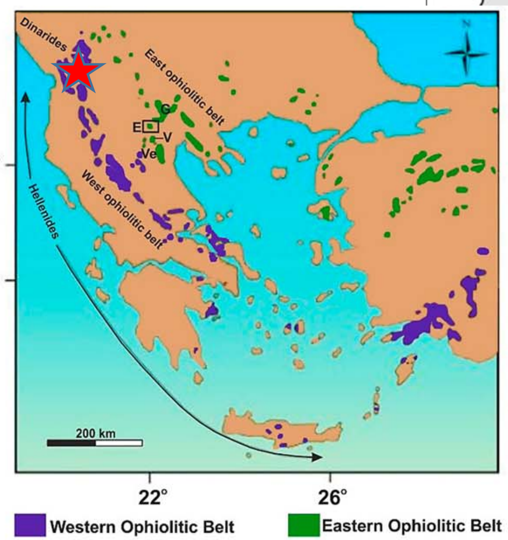


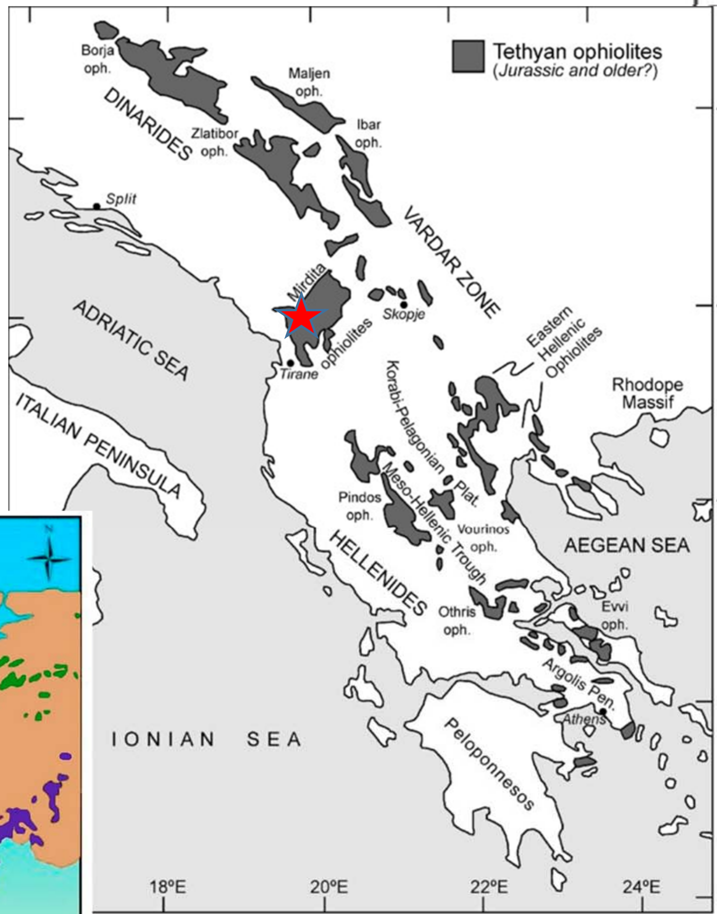
The Giant East – Mediterranean supra-subduction zone ophiolite belt > 3000 km long

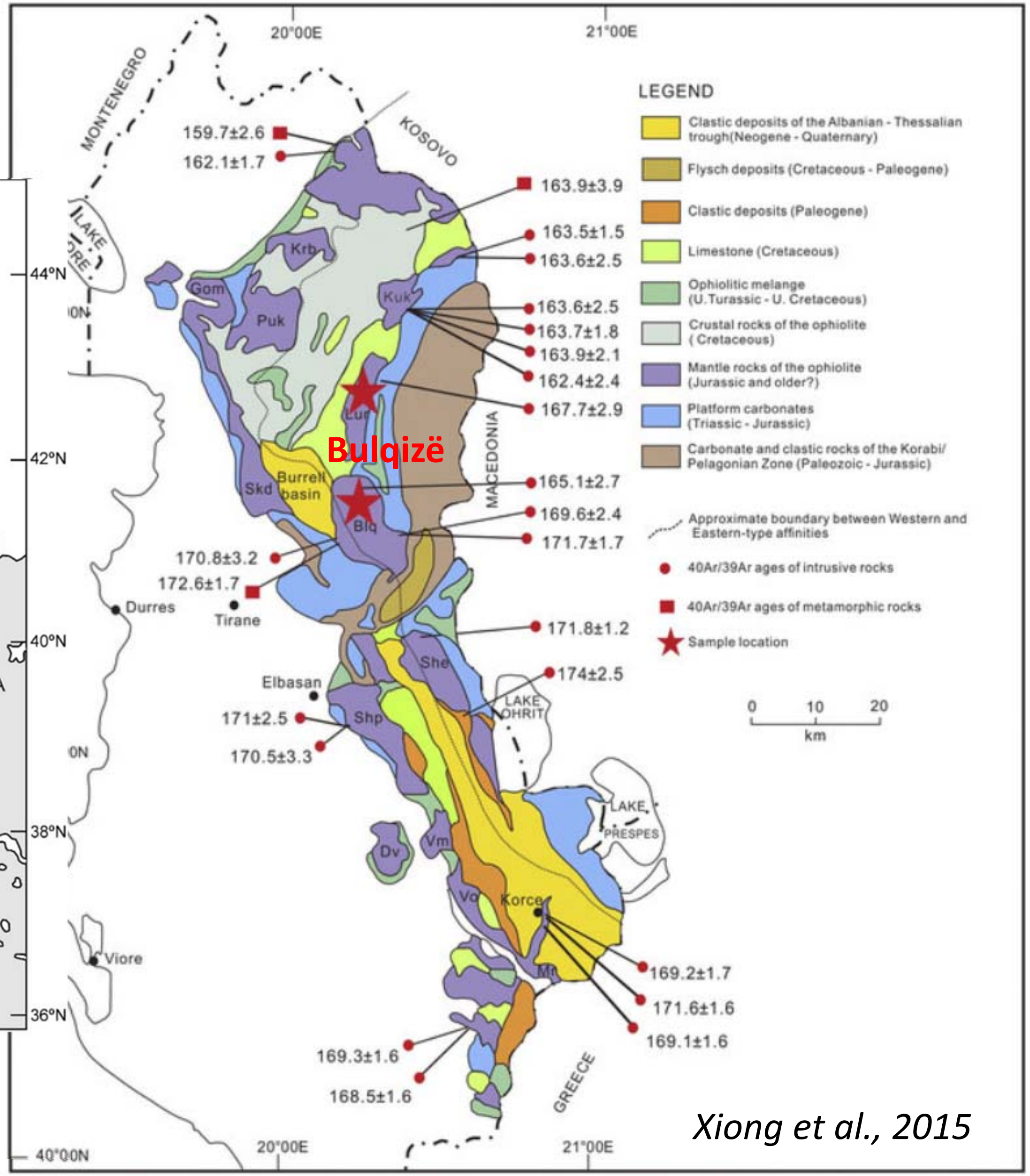
Dilek et al., 2014

Ophiolite in Albania: Bulqizë mine, chromium ore

Mirdita – Bulqizë Ophiolite

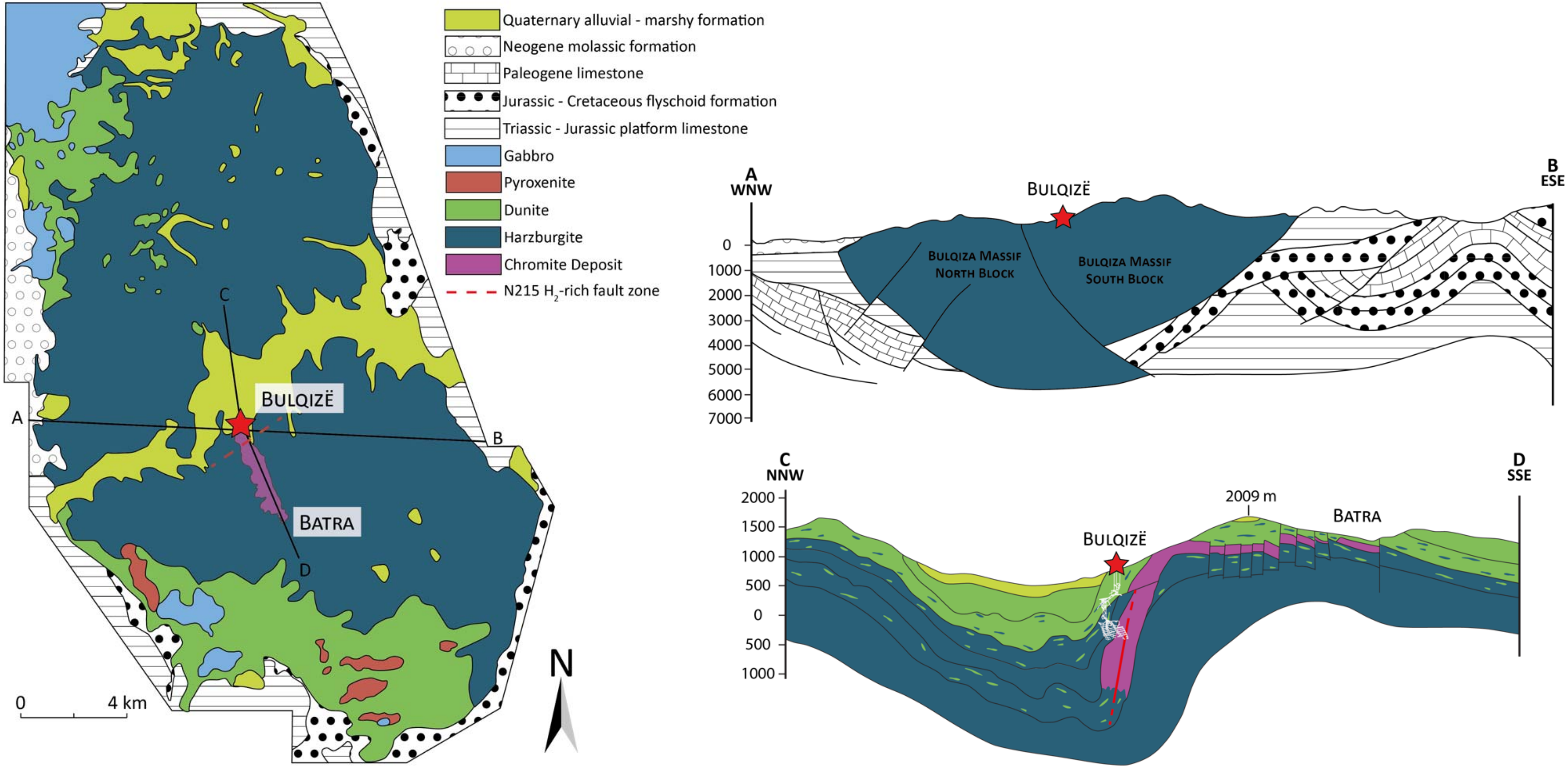




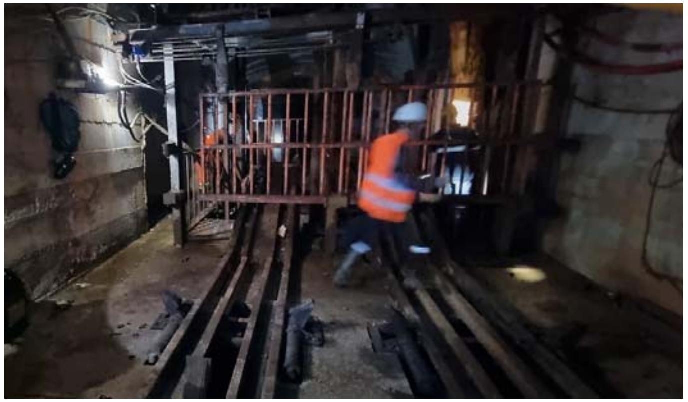


Xiong et al., 2015

Bulqizë mine: chromite ore, AlbChrome Ltd. mining company



Bulqizë mine: chromite ore, AlbChrome Ltd. mining company



2017, L19

Three missing after gas blast at Albania's Bulqize mine - report

Author
Marina Mikhaylova

Published
Feb 06, 2017 14:55 EEST
TIRANA

Author: Ray Forster. Licence: Creative Commons.

February 6 (SeeNews) - A gas blast injured three workers in Albania's Bulqize chrome mine on Saturday, whereas three others were still missing 24 hours after the explosion, according to local media reports.

Rescue teams we continuing the search for the three missing workers, public broadcaster RTSH said on Sunday.

Both the wounded and the missing workers are Chinese citizens, employees of Wenzhou Mining company which is digging an additional well to extend the mine's lifespan, according to RTSH.

The wounded workers were hospitalised. Their injuries were not life-threatening, RTSH said.

2011

BASIC MATERIALS OCTOBER 18, 2011 / 1:11 PM / UPDATED 12 YEARS AGO

Albanian miner dies in chrome mine blast

By Reuters Staff 2 MIN READ

TIRANA, Oct 18 (Reuters) - An Albanian miner died and two out of seven wounded are fighting for their lives on Tuesday after the explosion of a pocket of hydrogen at the Bulqiza chrome mine managed by Austria's DCM DECOmetal .

2023, L17

KRONIKE

Explosions in the mine, three miners were injured in Bulqiza

Shkruar nga Pamfleti

An explosion occurred in a mine in Bulqiza.

As a result, three miners were injured, while the cause is suspected to be from the gas explosion.

According to sources, the injured miners suffered severe third-degree burns. As a result, they headed to Tirana for more specialized treatment.

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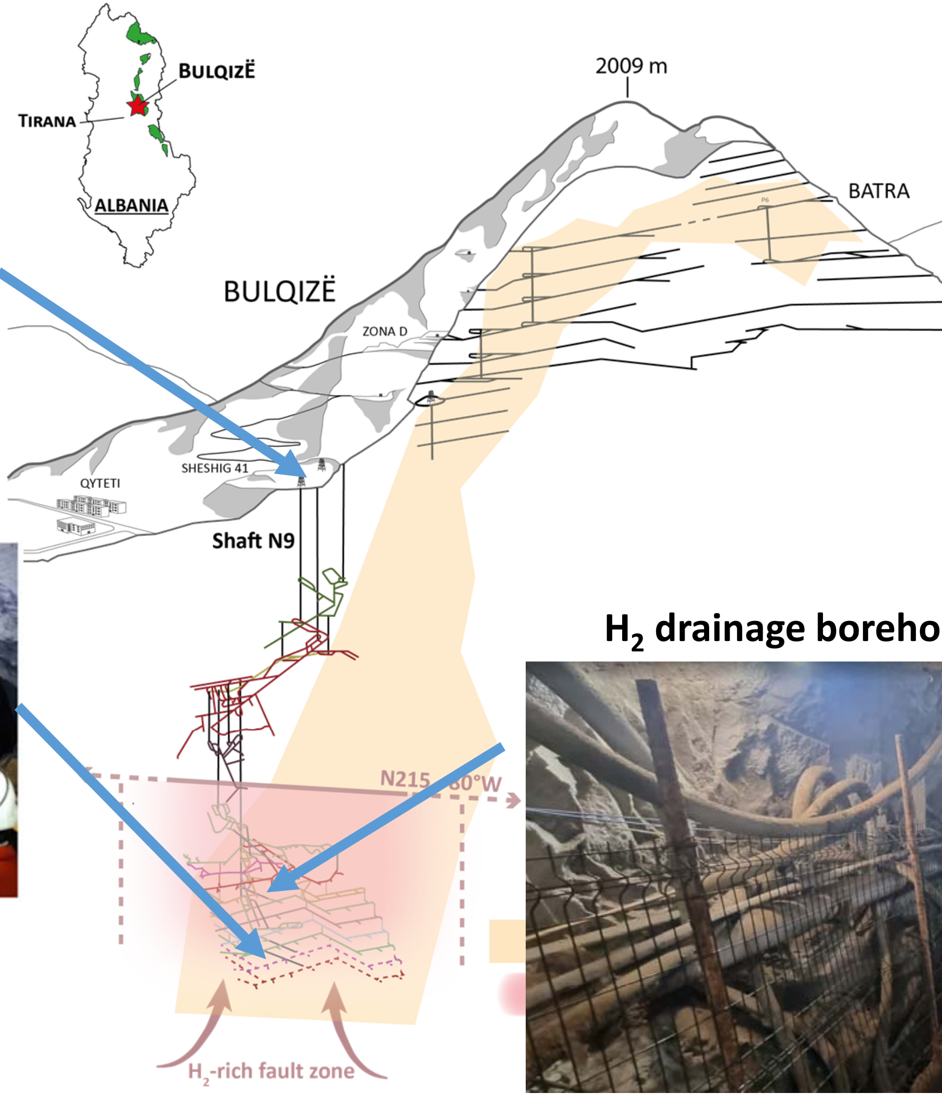
Schematic 3D view of Bulqizë underground chromite mine. The entrance of the mine is at an altitude of 840 m above mean sea level and the deepest level is at -180 m.

Entrance (+840 m amsl)

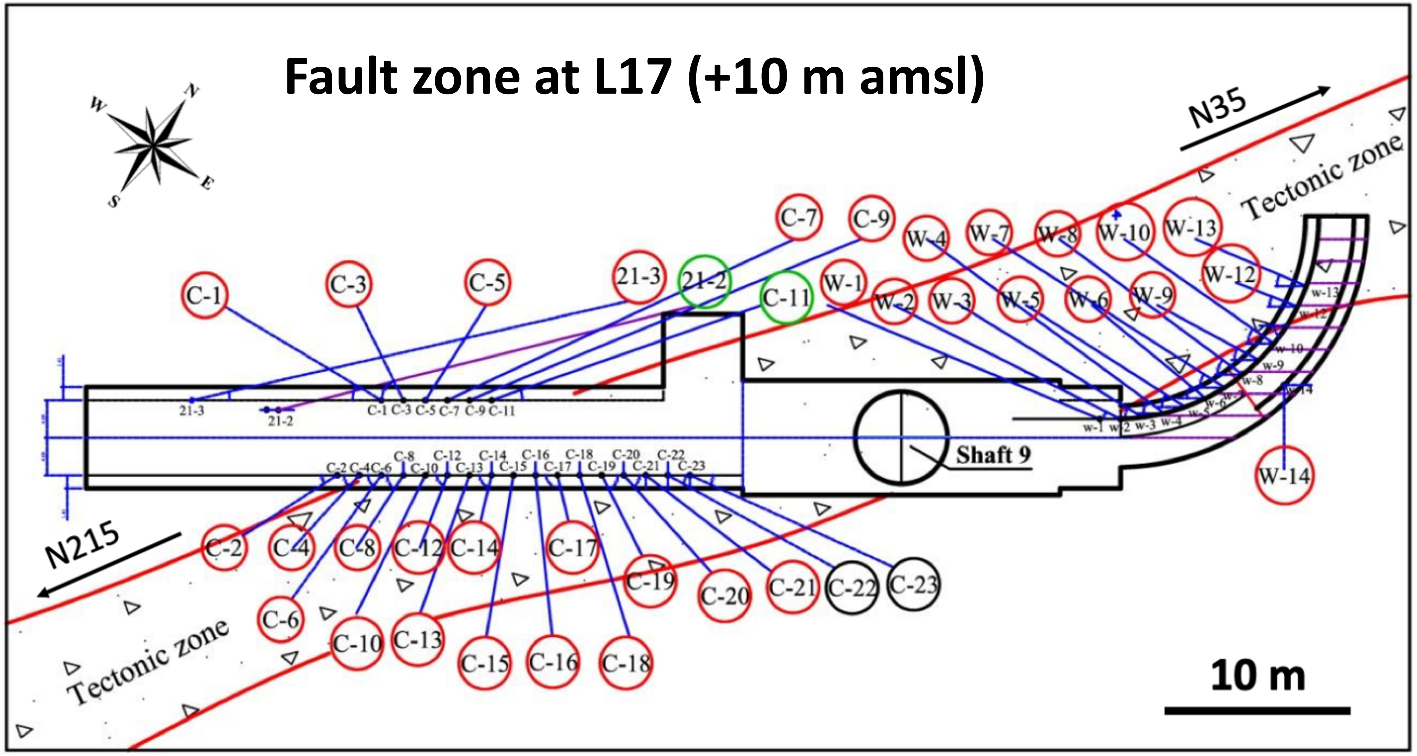
The jacuzzi at L19 (-110 m bmsl)

> 1 km below the surface



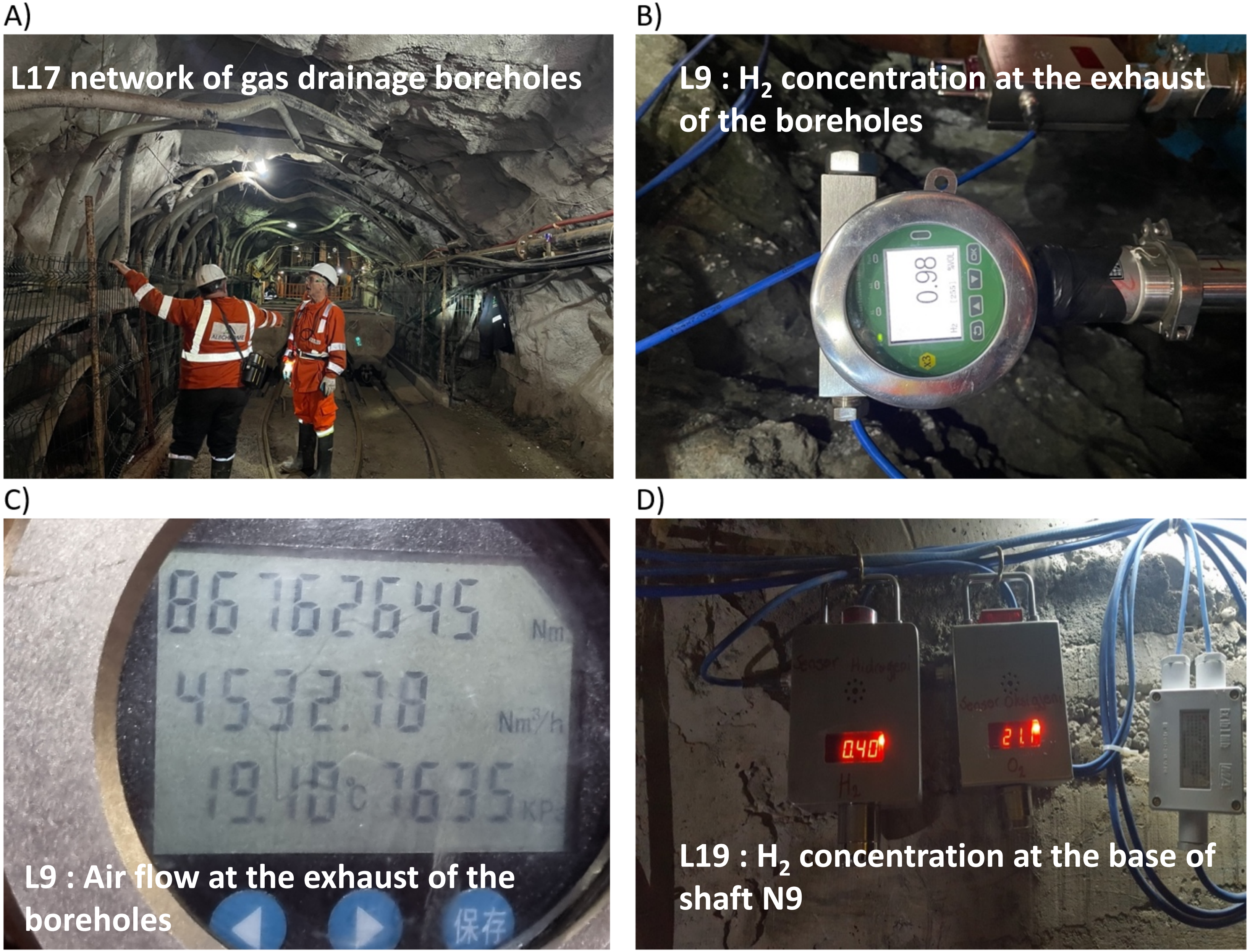
Batra deposit

H_2 drainage boreholes at L17



One geotechnic well closed:
P = 20 bar
(leaking, no casing)

Vented at L9



1.2 vol % as measured by GC-TCD

Air flow rate through the boreholes 4532 Nm^3/hrs

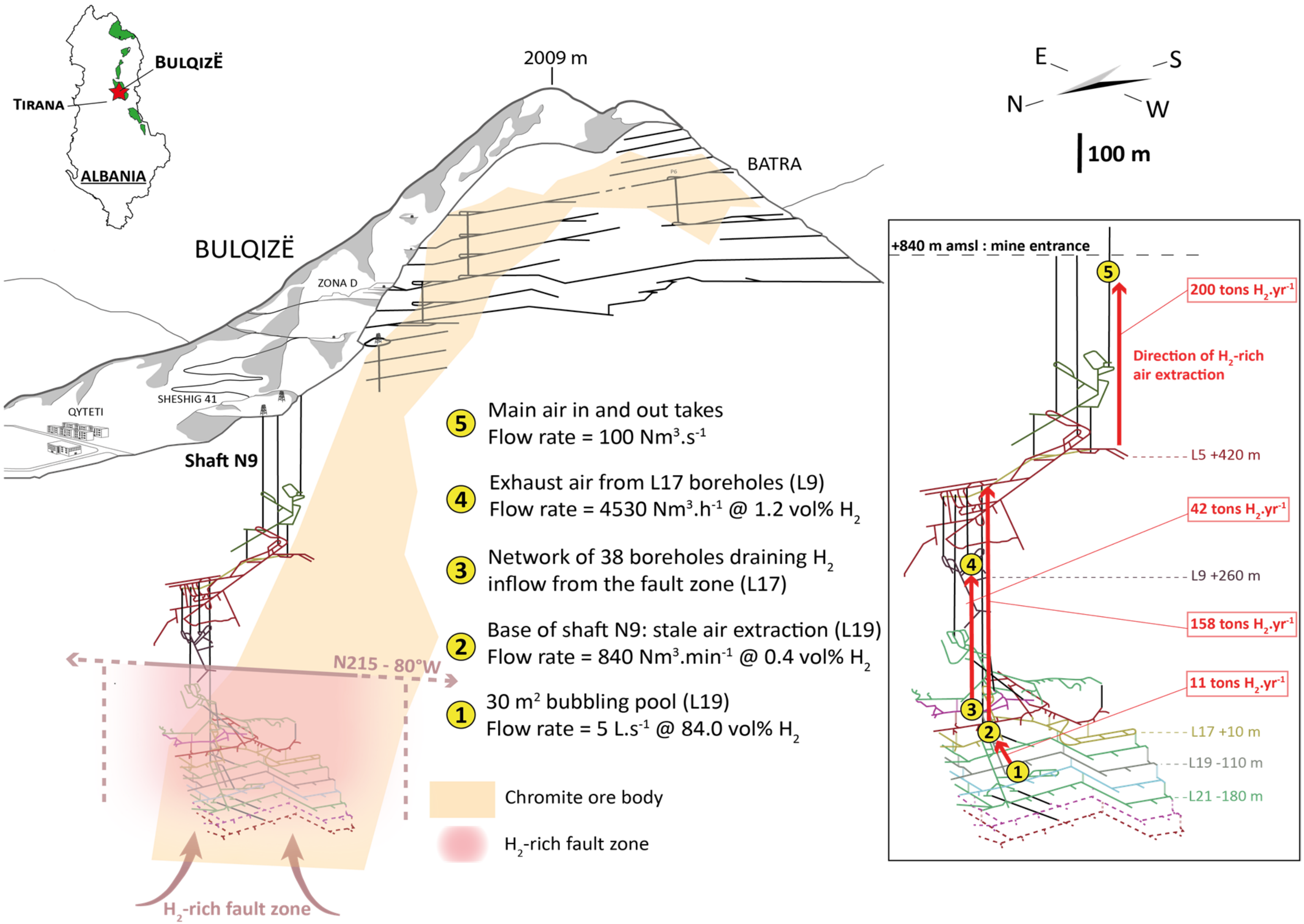
L19 ventilation at the base of shaft N9:
- 840 Nm^3/min
- 0.4 vol% H_2 in the stall air

Composition of the gas samples collected in the mine as measured by GC-TCD.

Sampling Location	**Concentration (vol%)**			
	H_2	**CH_4**	**N_2**	**O_2**
Bubbling pool, L19	84.0	13.2	1.7	<10 ppmv
Ambient air, base of shaft N9, L19	0.40	0.05	78.1	20.8
Exhaust air from boreholes, L9	1.20	0.15	79.9	18.7

L 19

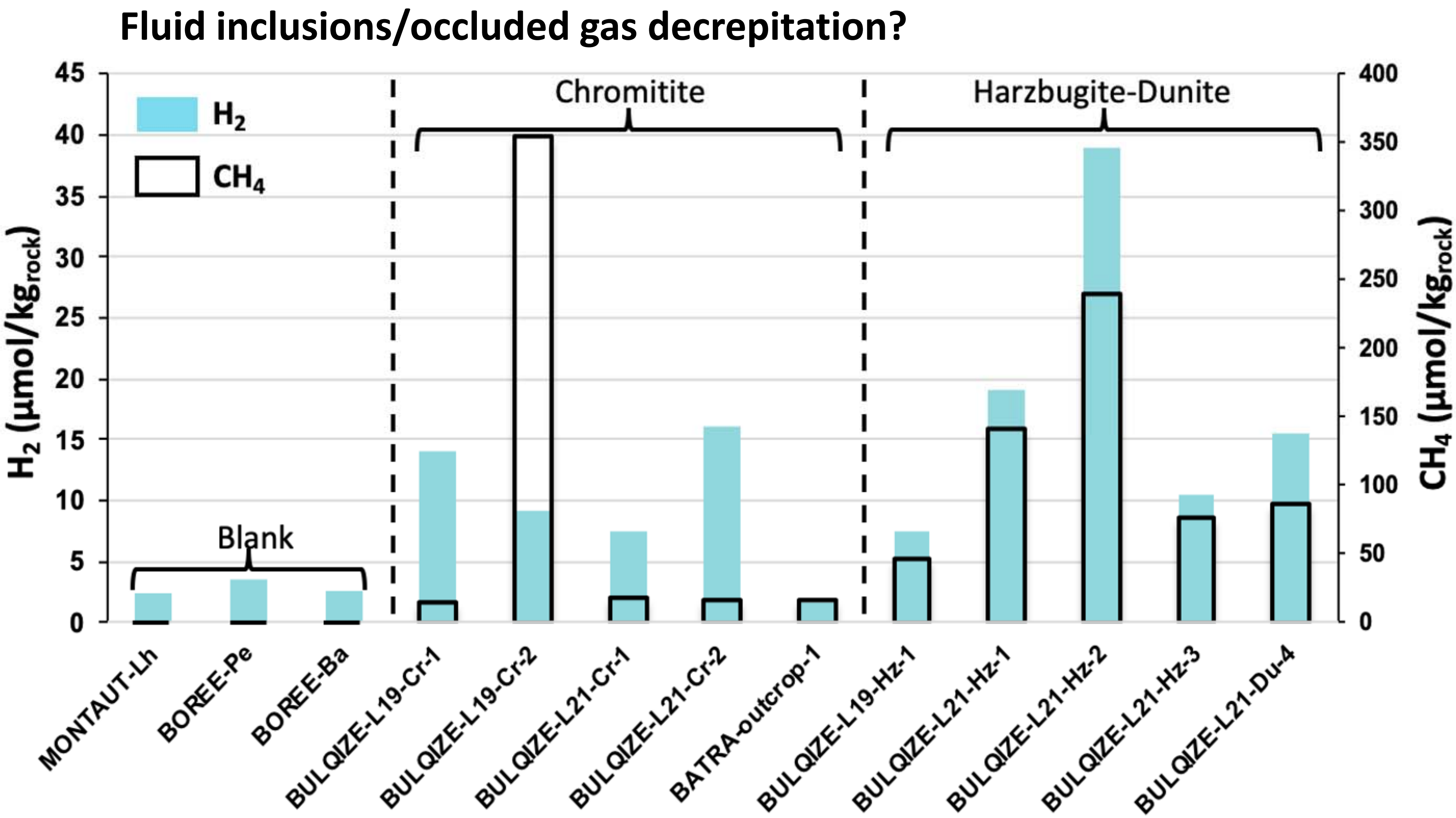
Schematic 3D view of Bulqizë underground chromite mine + locations of the measurements.



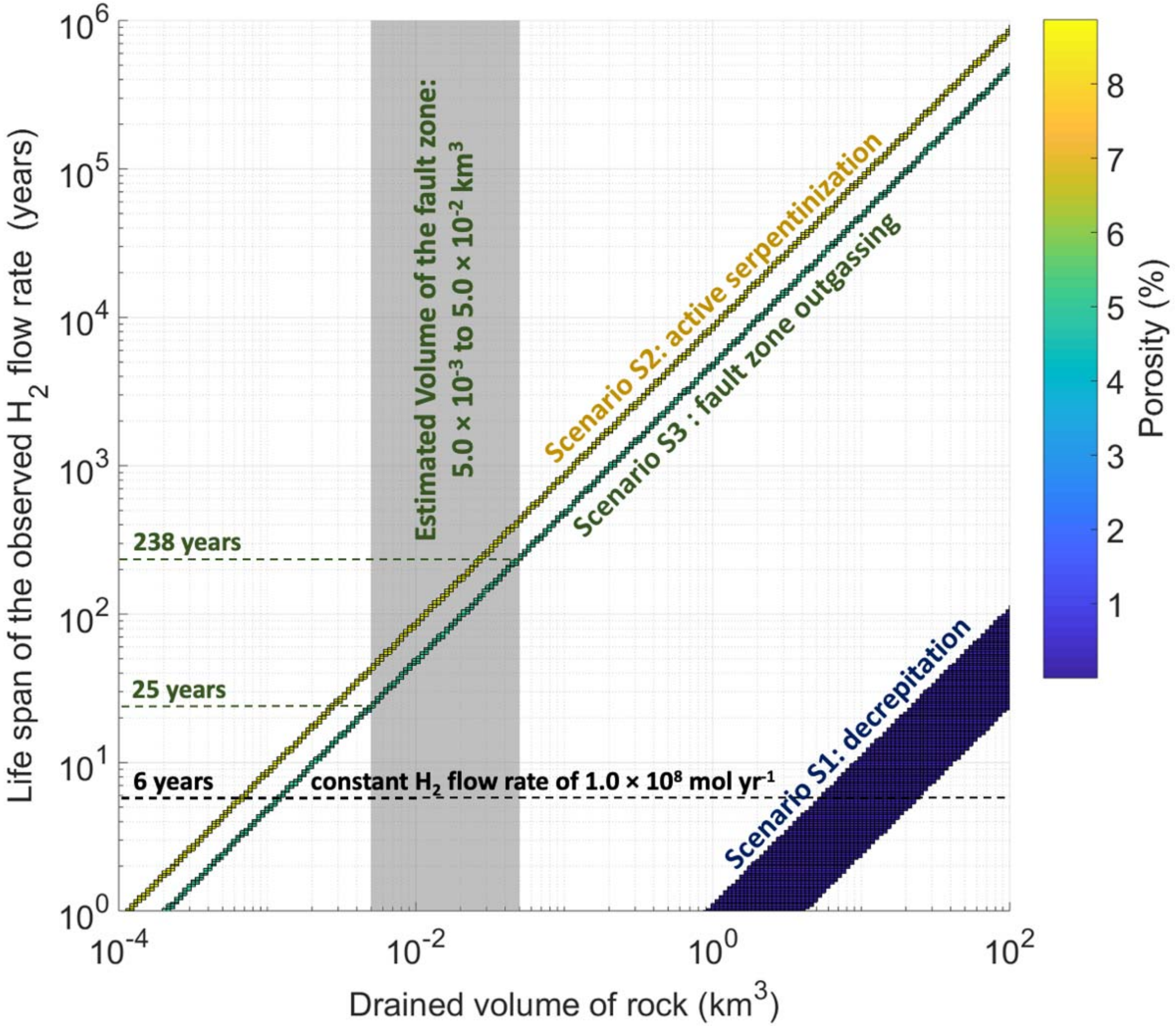
1.0×10^8 mol yr^{-1}

What could support this flux of 200 tons of H_2 per year?
(constant over 6 years)

1) **Fluid inclusion/occluded gas decrepitation?**
2) **Active and pervasive serpentinization ?**
3) **A deep reservoir perforated by the mine's galleries?**



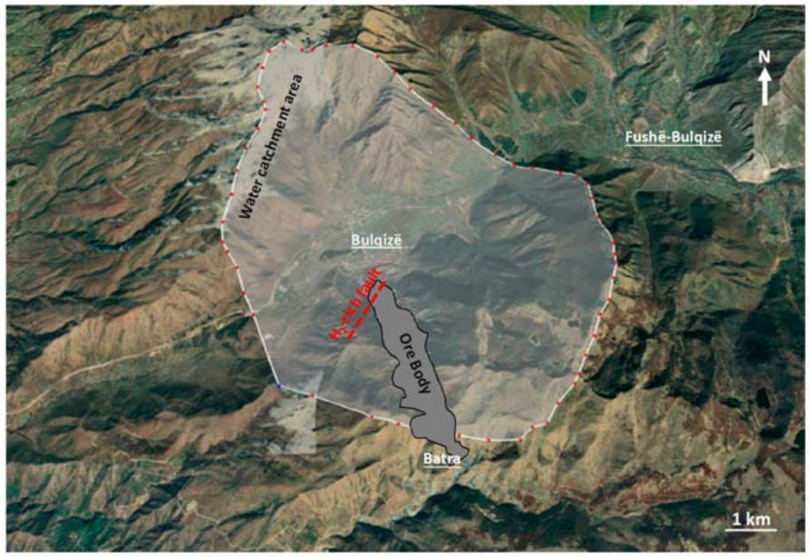
- **7 to 38 ×10^{-6} mol kg_{rock}^{-1}** in the bulk harzburgite, dunite and chromitite rock samples collected in the deepest levels of the mine.



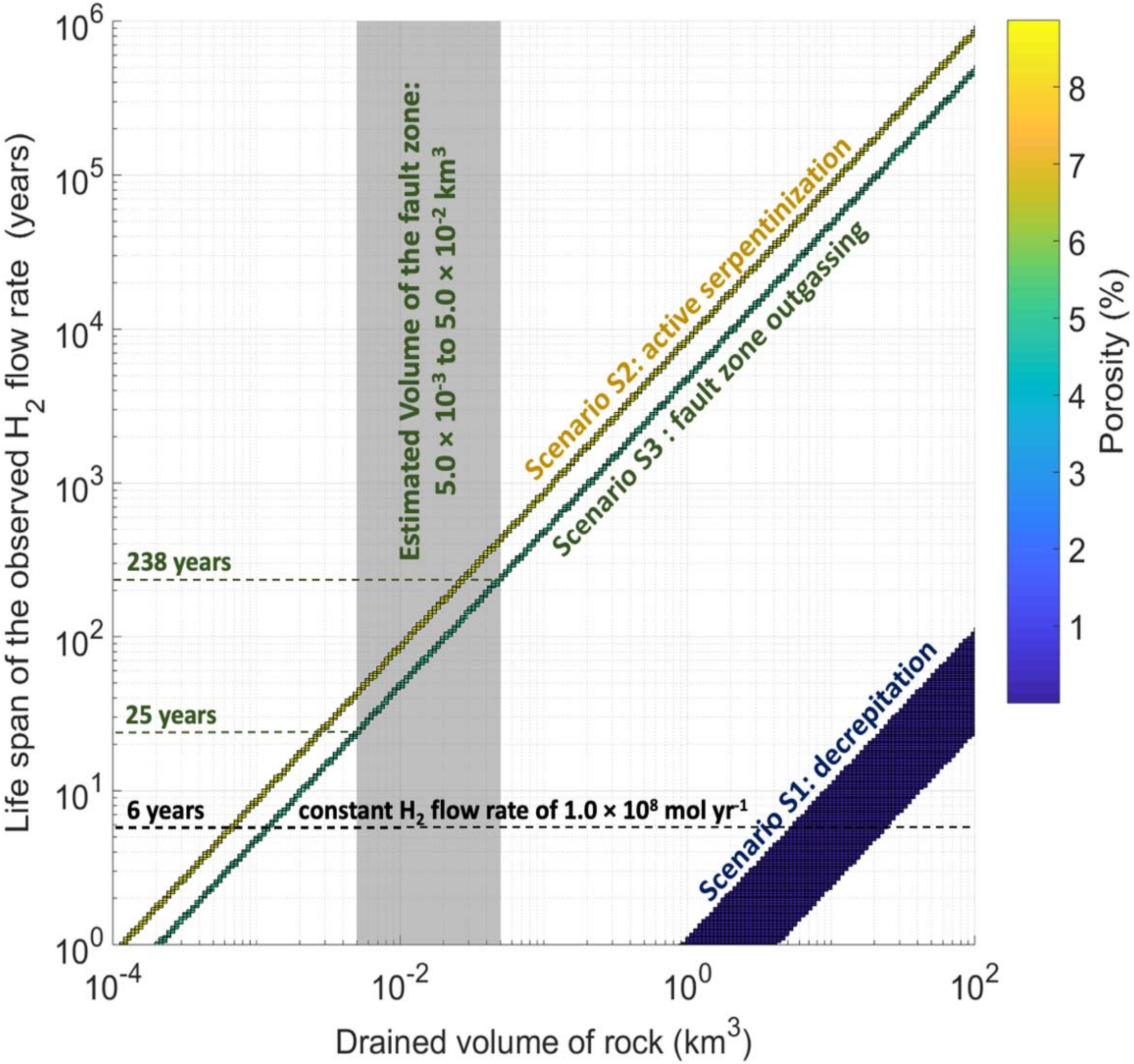
Active and pervasive serpentinization?

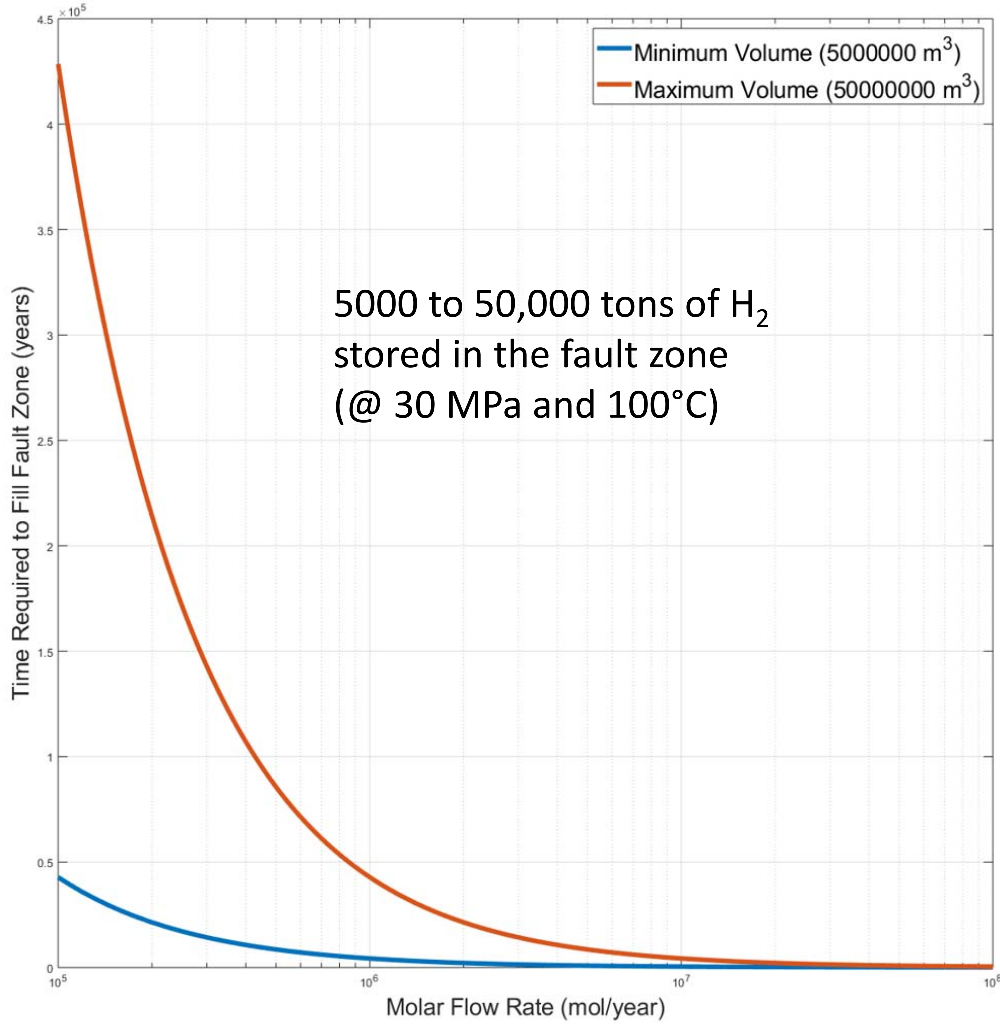
A similar conclusion can be reached by considering a maximum mine drainage volume of 135 km^3, corresponding to the effective rainwater catchment area of the mine of 45 km^2 , and a rock thickness of 3 km.

→ The whole drainage volume should have been fully serpentinized after solely 13.5 Ma



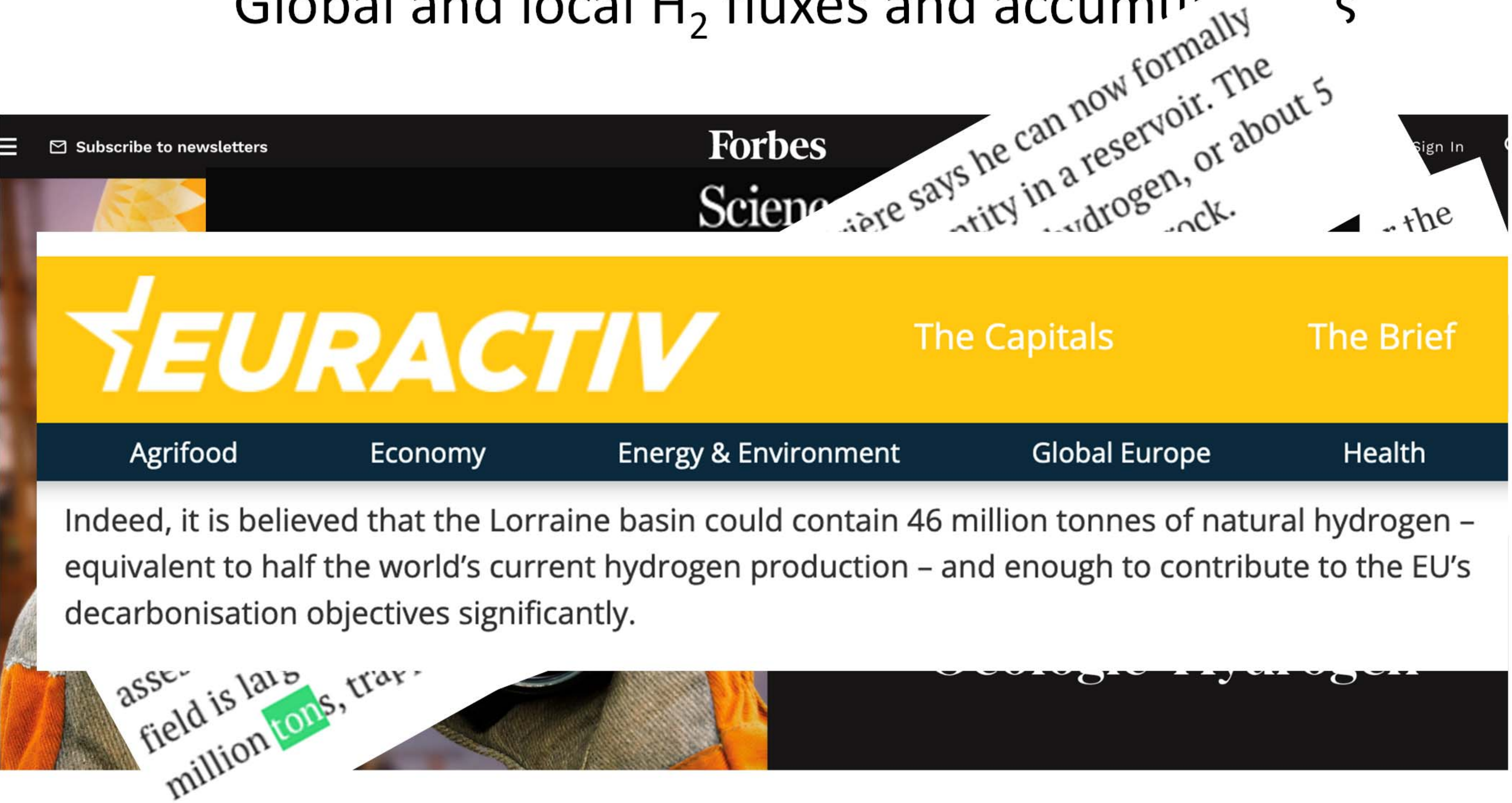
A deep reservoir perforated by the mine's galleries?





5000 to 50,000 tons of H_2 stored in the fault zone (@ 30 MPa and 100°C)

Global and local H_2 fluxes and accumu s



Global accumulation/buried
(and not reserves)
→ 150 x10^6 Mt
→ 10 x10^6 Mt

Local estimates
Bourakebougou: 5 Mt
Lorraine: 40 Mt

Natural Gas proven RESERVES

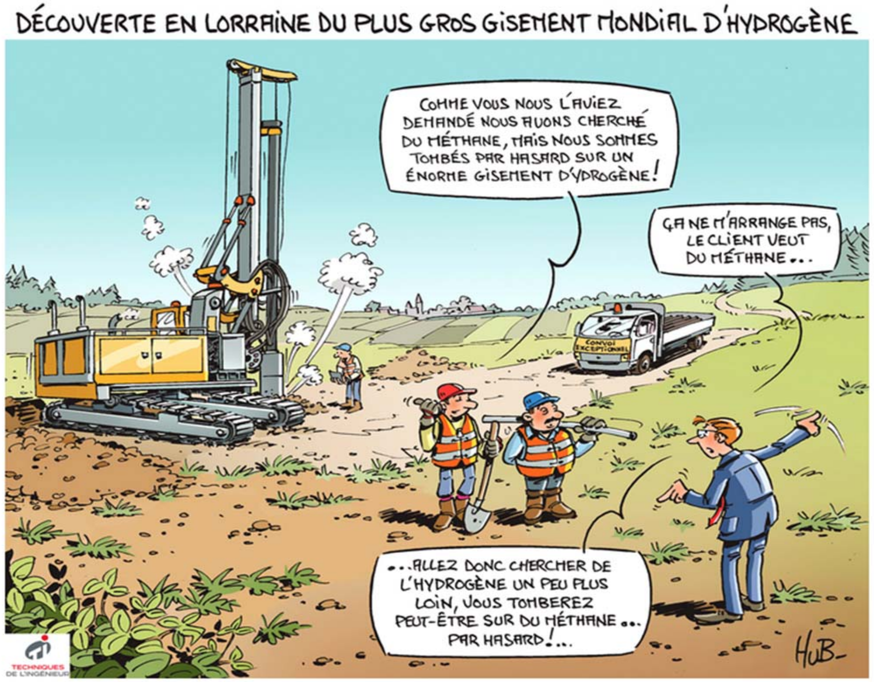
7,257 Tcf
→ 28000 x10^6 Mt

Some recent statements ("it is believed", "we speculate")….
no access to data and computation methods, no possible verification at this point in time
→ It may be true, it may be wrong. On ne sait pas!

Local accumulation

CNRS NEWS
Making sense of science

A gigantic hydrogen deposit in northeast France?



Scientific overstatements

→ The gas is dissolved – but concentration expressed as if it was free gas (20 vol%, infact only 1 ppm of H_2 dissolved)
→ The aquifer is within a coal basin – but the source of H2 is supposed to be siderite alteration
→ There is now gas flow out of the well
→ Methane is the dominant molecule in the gas mixture – but it is not mentioned
→ The reserve are estimated to be 46 Mt – but we don't know how the researchers come to this conclusion

One has to be very careful in making the conclusion jump from **locally encountered concentrations** to the presence of potentially **recoverable resources of geologic H_2 whether as a flux or a stock**

Is geologic H_2 renewable?

GEOSCIENTIST

Bourakébougo (Denis Briere, Chapman Petroleum Engineering Ltd., Canada). However, it was only in 2012 that Hydroma Inc. began drilling and testing for hydrogen in a controlled environment and discovered that the gas emitted by the reservoir was 98% hydrogen. Over the ten-day production test, reservoir pressure was largely maintained, implying that the source is renewable. The reservoir pressure has now been maintained for nine years and this supply of

Critically, natural hydrogen may be not only clean, but also renewable. It takes millions of years for buried and compressed organic deposits to turn into oil and gas. By contrast, natural hydrogen is always being made afresh, when underground water reacts with iron minerals at elevated temperatures and pressures. In the decade since

WIKIPEDIA
The Free Encyclopedia

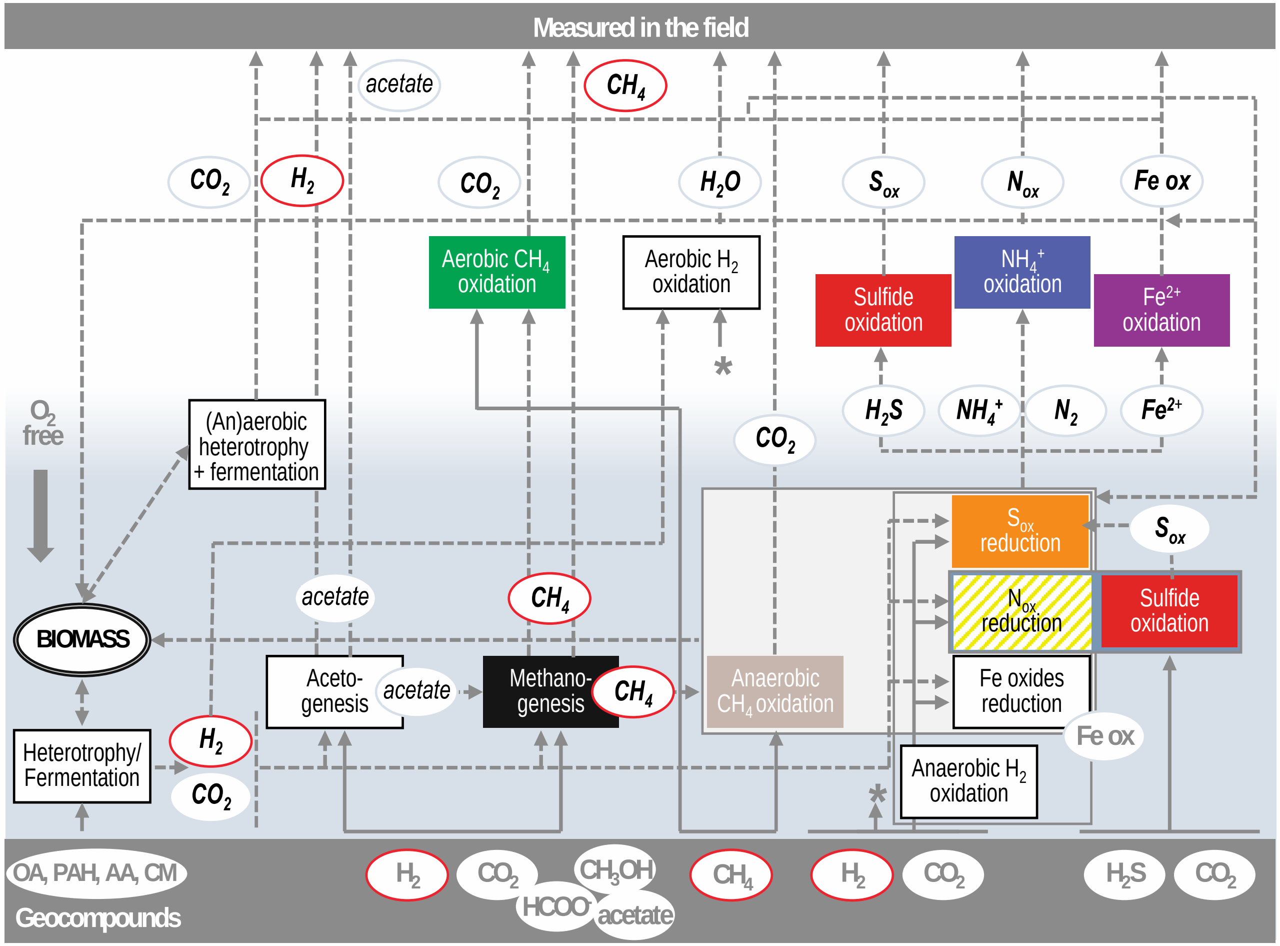
Natural hydrogen (known as **white hydrogen or gold hydrogen**), is naturally occurring[1] molecular hydrogen on or in Earth[2] (as opposed to hydrogen produced in the laboratory or in industry). The name white hydrogen distinguishes it from green hydrogen, which is produced from renewable energy sources from the electrolysis of water, and from grey, brown or black hydrogen, which is obtained from fossil sources.[3] Natural hydrogen may be renewable, non-polluting and allows for lower cost operation compared to industrial hydrogen.[4] Natural hydrogen has been identified in many source rocks in areas beyond the sedimentary basins where oil companies typically operate.[5][6]

Sustainability?

Potential impact on deep-seated microbial ecosystems relying on H_2 as an energy source

The subsurface is not a lifeless desert

→ The subsurface accounts for about 90% of the biomass in two domains of life, Archaea and Bacteria, and 15% of the total for the biosphere



Diversity of the metabolic pathways that function in the cycling of H_2 and CH_4 in (deep) microbial ecosystems.

(Menez, 2020)

Summary

1) There are significant inconsistencies between what can be found in the news and in scientific articles in terms of H_2 accumulations and fluxes.

As for hydrocarbon gas seepages, defining the level of H_2 concentration or flux at the surface that can indicate a potentially economic H_2 resource is misleading

2) Fluxes measured on diffusive emission sites are controversial and must be considered with caution

3) Geologic H_2 is not renewable. The tiny surface fluxes documented so-far may be equally explained by active serpentinization or by deep reservoirs degassing.

If economic accumulations do exist, they may represent a fossil stock compared to our consumption

4) In the perspective of geologic H_2 exploitation, the environmental degradation on deep ecosystems must be assessed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