Natural (Gold) Hydrogen - Pipeline or Pipe Dream

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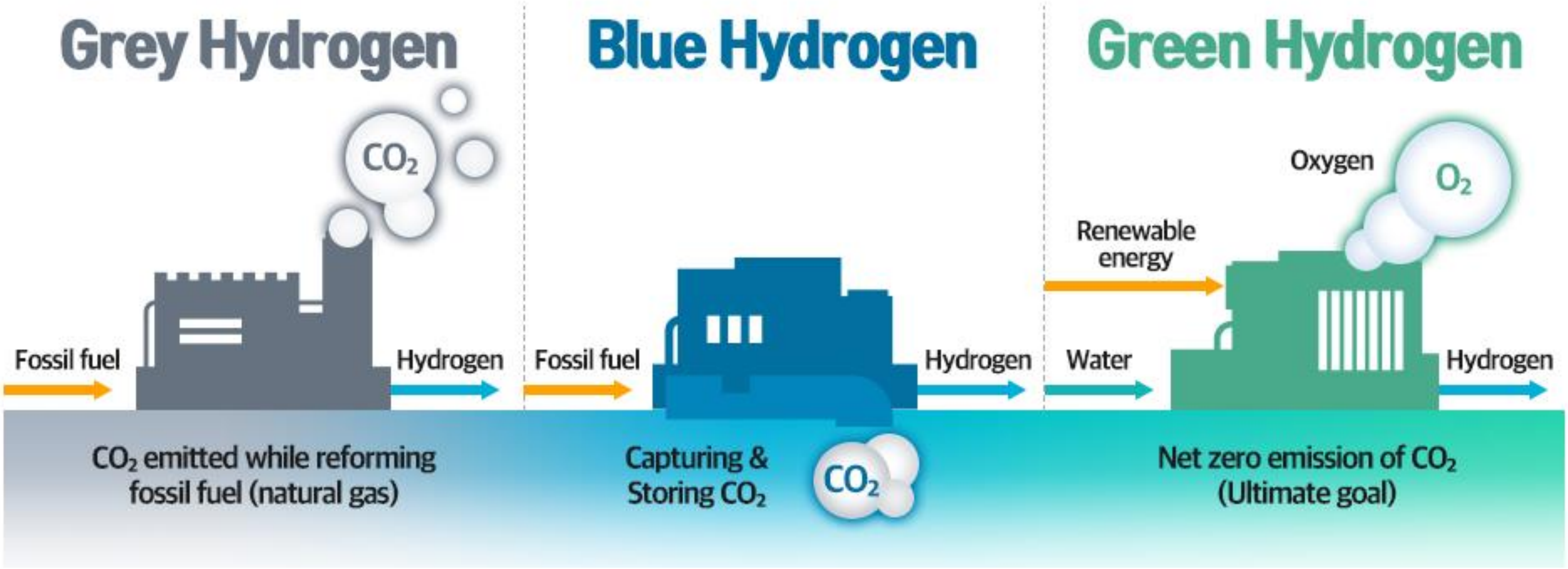
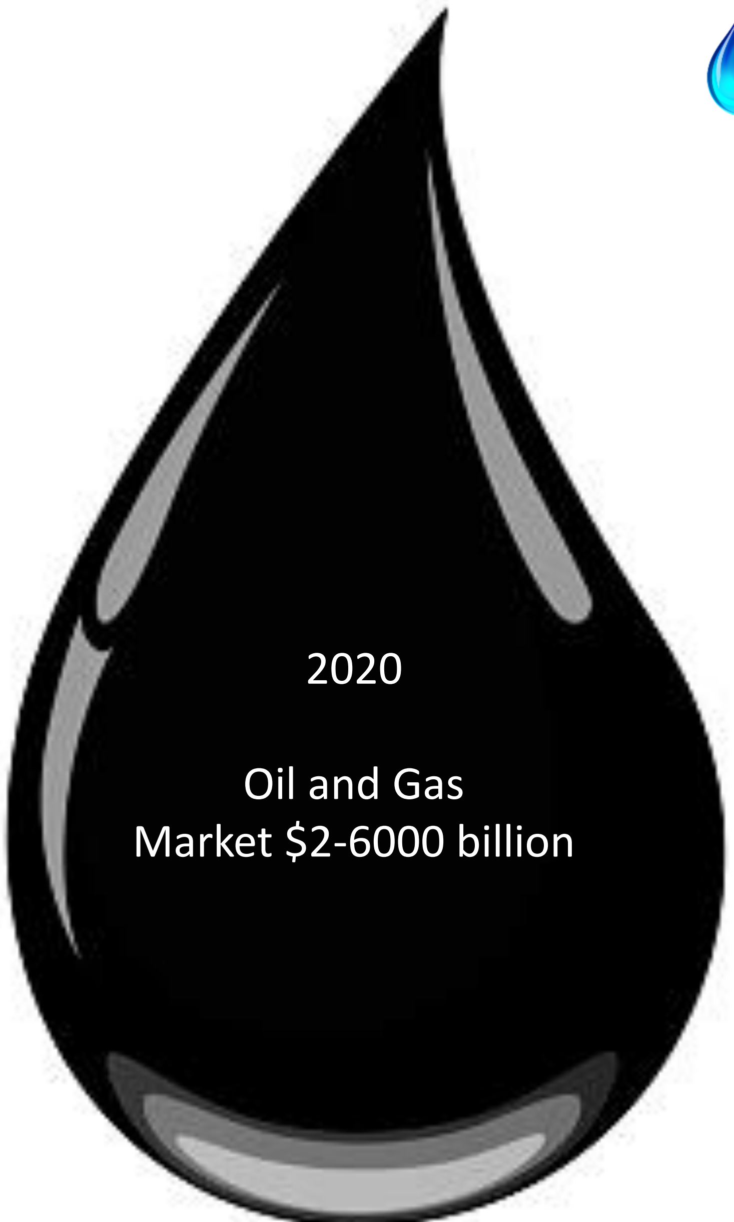
The colours of hydrogen



https://newsroom.posco.com/en/posco-to-establish-hydrogen-production-capacity-of-5-million-tons/

Hydrogen – The race to a cheap/clean source



Hydrogen

2020

87 million tonnes

>96% of hydrogen from fossil fuels – most of this is 'Grey'

<0.1% hydrogen 'green'

requires a compound average annual growth rate (CAAGR) in clean hydrogen production of 66% between now and 2030, and 23% between 2030 and 2050

IEA: Net Zero by 2050 – A Roadmap

2050

538 million tonnes

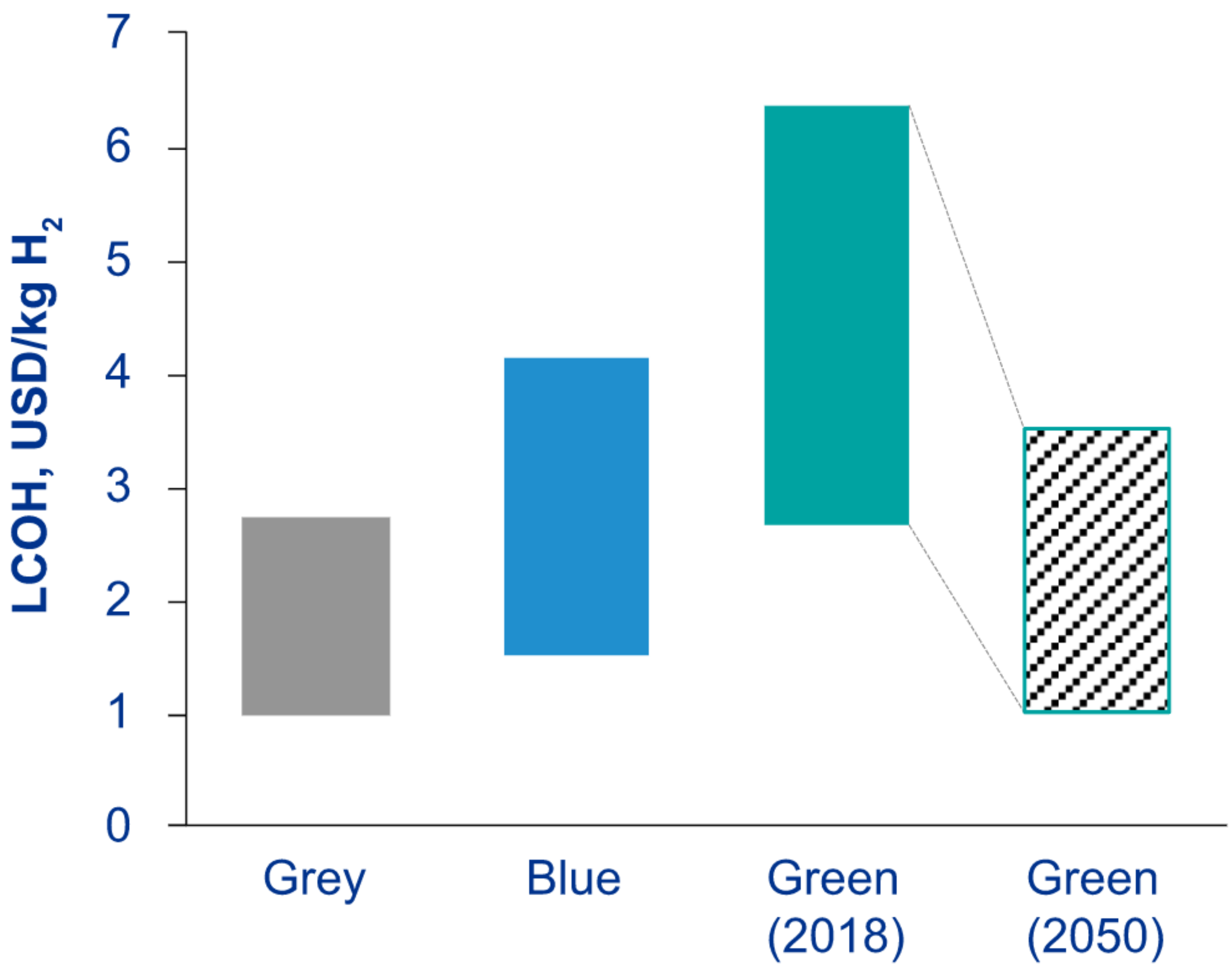
306 million tonnes Green

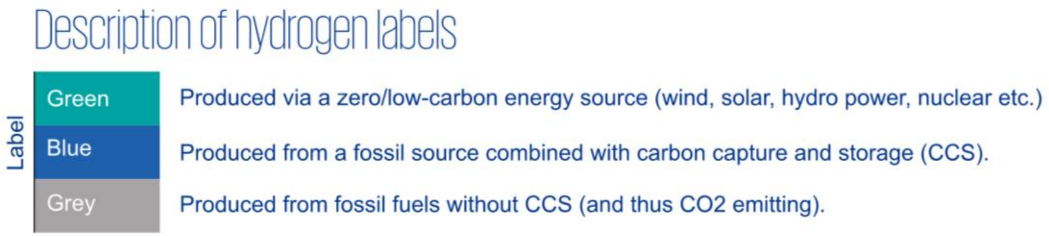
198 million tonnes Blue

+ other

Market $300-1000 billion

Hydrogen – The race to a cheap/clean source





[The hydrogen trajectory - KPMG Global (home.kpmg)]

COST is critical

Natural (Gold) Hydrogen

Chimera, Turkey

INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 43 (2018) 19315–19326

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journal homepage: www.elsevier.com/locate/he

Discovery of a large accumulation of natural hydrogen in Bourakebougou (Mali)

Alain Prinzhofer [a,*], *Cheick Sidy Tahara Cissé* [b], *Aliou Boubacar Diallo* [b]

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[b] PETROMA, Mali

Estimated - $1/Kg H_2

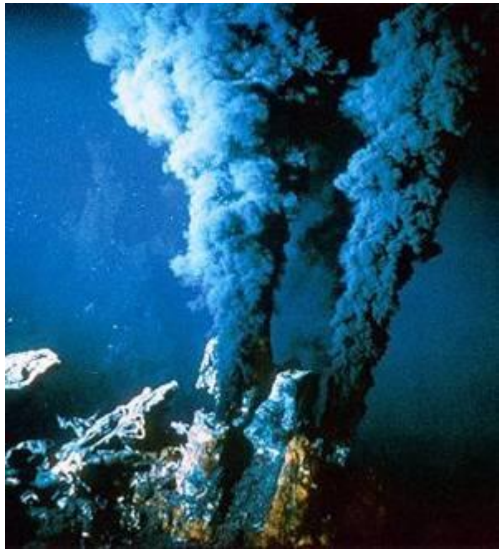
Hydrogen (and helium) generated in the crust

- **Hydrogen from two sources:**

1) Reaction between iron-rich rocks and water

Serpentinization (= hydration)

$$3Fe_2SiO_4 + 2H_2O = 2Fe_3O_4 + 3SiO_2(aq) + 2H_2$$



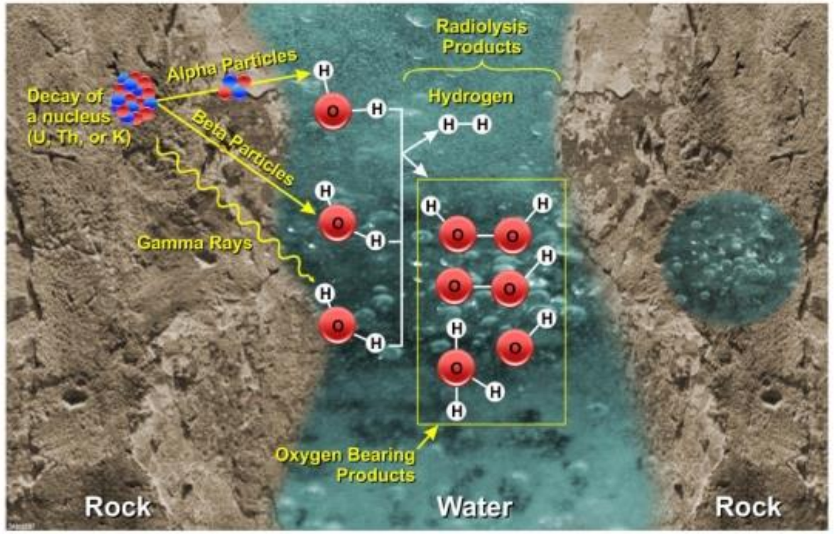
First identified in the 1960's and seen in ocean crust hydrothermal systems in the 1970's

2) Radiation splitting water molecules

Radiolysis

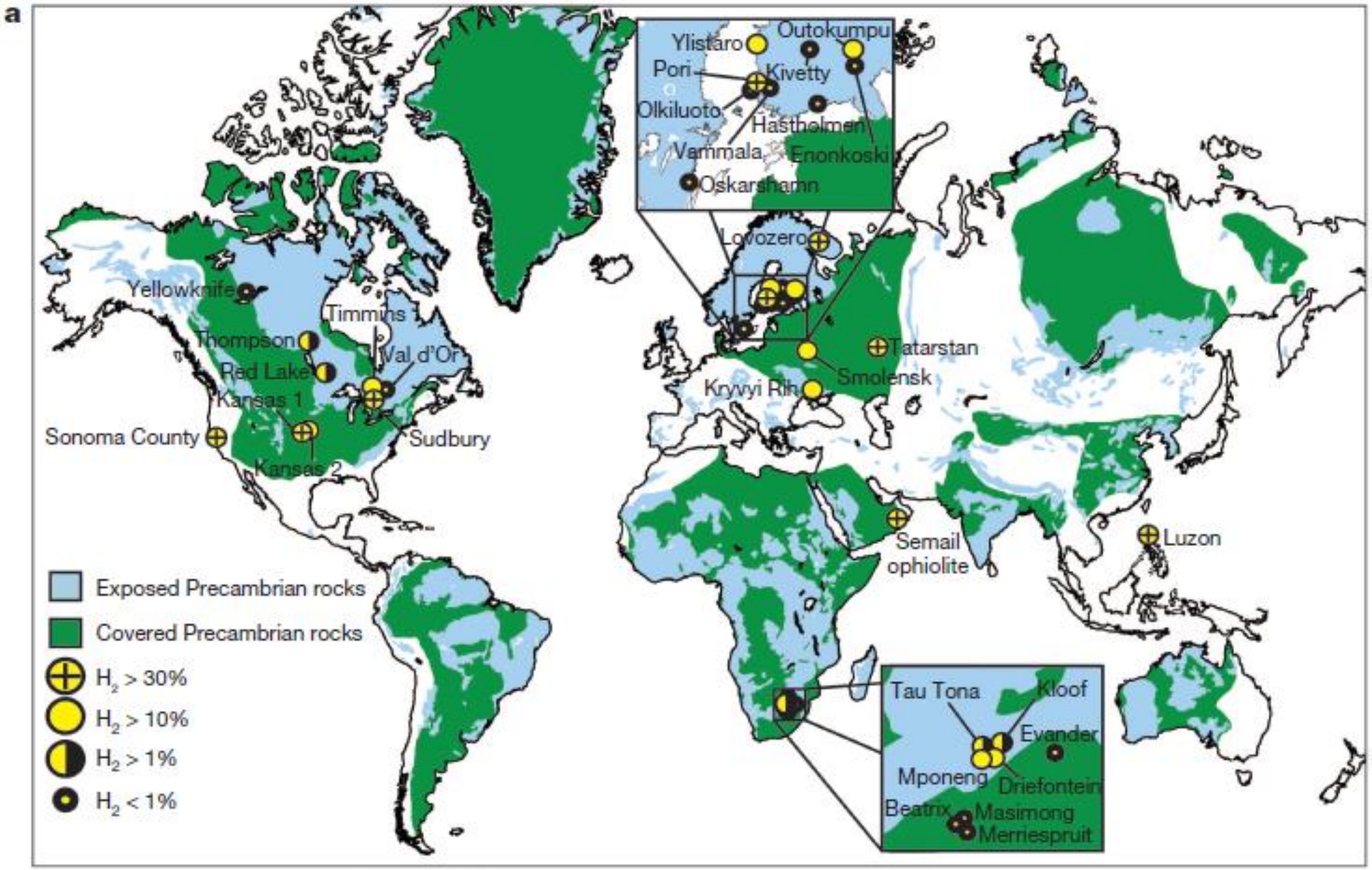
$$H_2O \xrightarrow[\text{from U, Th, K}]{\text{Ionising radiation}} e^-, HO, H, HO_2, H_3O^+, H_2O_2, H_2$$

(linking helium and hydrogen)



https://www.centauri-dreams.org/2021/07/02/radiolytic-h2-powering-subsurface-biospheres/

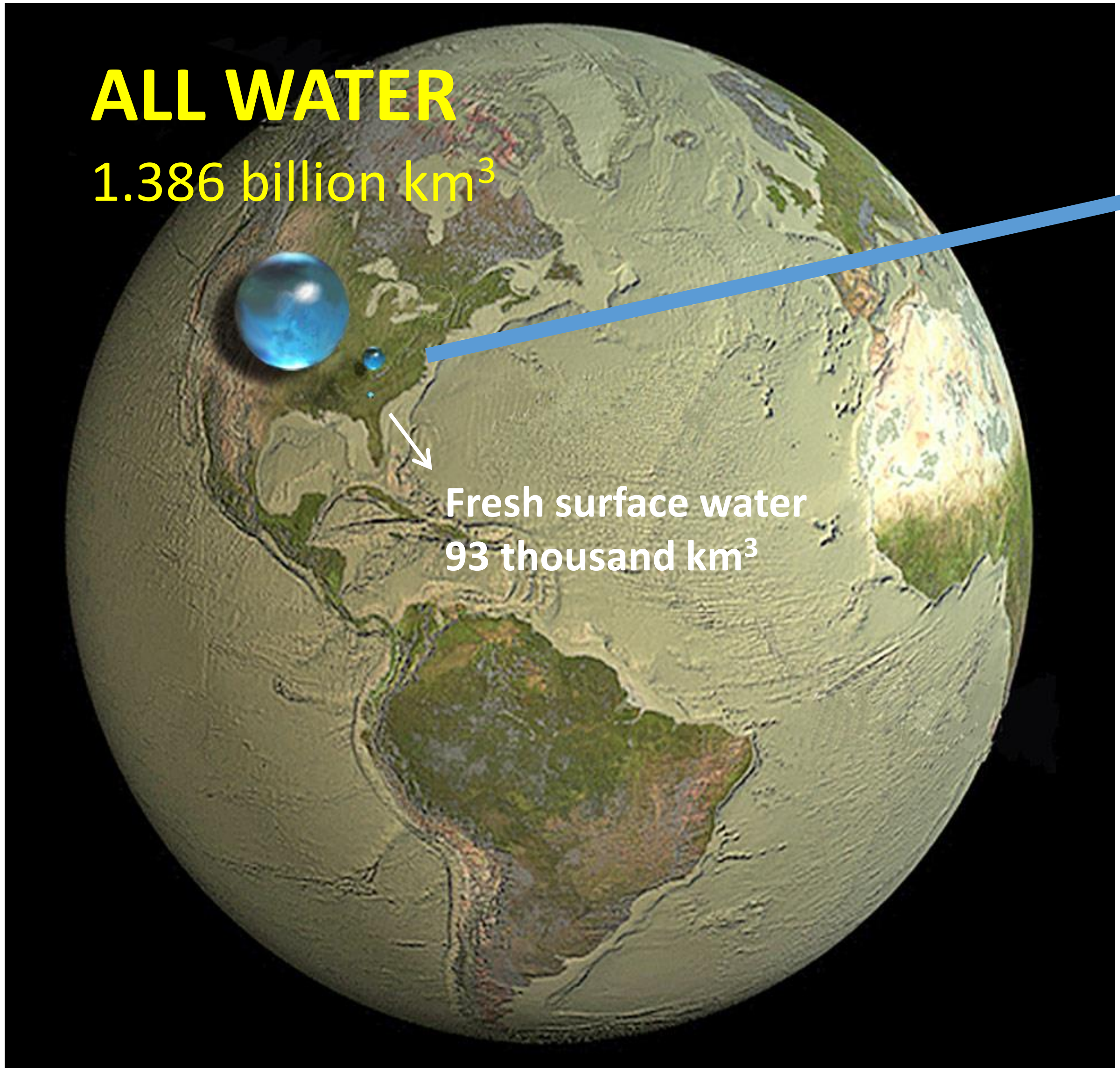
Old continental crust is Ferrous-rich



- Precambrian (>541Ma) continental crust
- Exposed (blue) and buried (green) = >70% of continental crust surface area

Sherwood Lollar et al., 2014

… and also contains water



Fresh ground water

~ 10.6 million km^3

Precambrian (saline) water

~ 11 million km^3

http://water.usgs.gov/edu/gallery/global-water-volume.html

Gold hydrogen - generation rate is known

*

LETTER

doi:10.1038/nature14017

The contribution of the Precambrian continental lithosphere to global H_2 production

Barbara Sherwood Lollar[1], T. C. Onstott[2], G. Lacrampe-Couloume[1] & C. J. Ballentine[3]

Table 2 | Estimates of H_2 production from water–rock reactions

System	H_2 production (10^{11} mol yr^{-1})	Reference
Ocean crust	0.8 to 1.3	Ref. 7
Ocean crust	1.9	Ref. 6
Ocean crust	2.0	Ref. 9
Slow-spreading ridges	1.67	Ref. 8
Basaltic ocean crust	4.5 ± 3.0	Ref. 5
Continental Precambrian radiolysis	0.16 to 0.47	This study
Continental Precambrian hydration reactions	0.2 to 1.8	This study

The table shows global estimates of H_2 production from water–rock alteration reactions (in units of 10^{11} mol yr^{-1}) from marine lithosphere and H_2 production estimates from radiolysis and hydration of mafic/ultramafic rocks from Precambrian continental lithosphere derived in this study. Estimates made using conservative assumptions. For details of all calculations see Methods. Volcanic, mantle-derived or microbial sources of H_2 are not incorporated.

- **The hydrogen production rate of the Precambrian crust is only recently known**
- **~30% of the production via radiolysis**
- **Average age of Continental Crust ~2Ga**

Sherwood Lollar et al., 2014

Continental hydrogen generated in 1Ga

- Continental H_2 generation rate = 0.36–2.27x10^{11} moles H_2/year
    - (up to 500,000 tons/year)

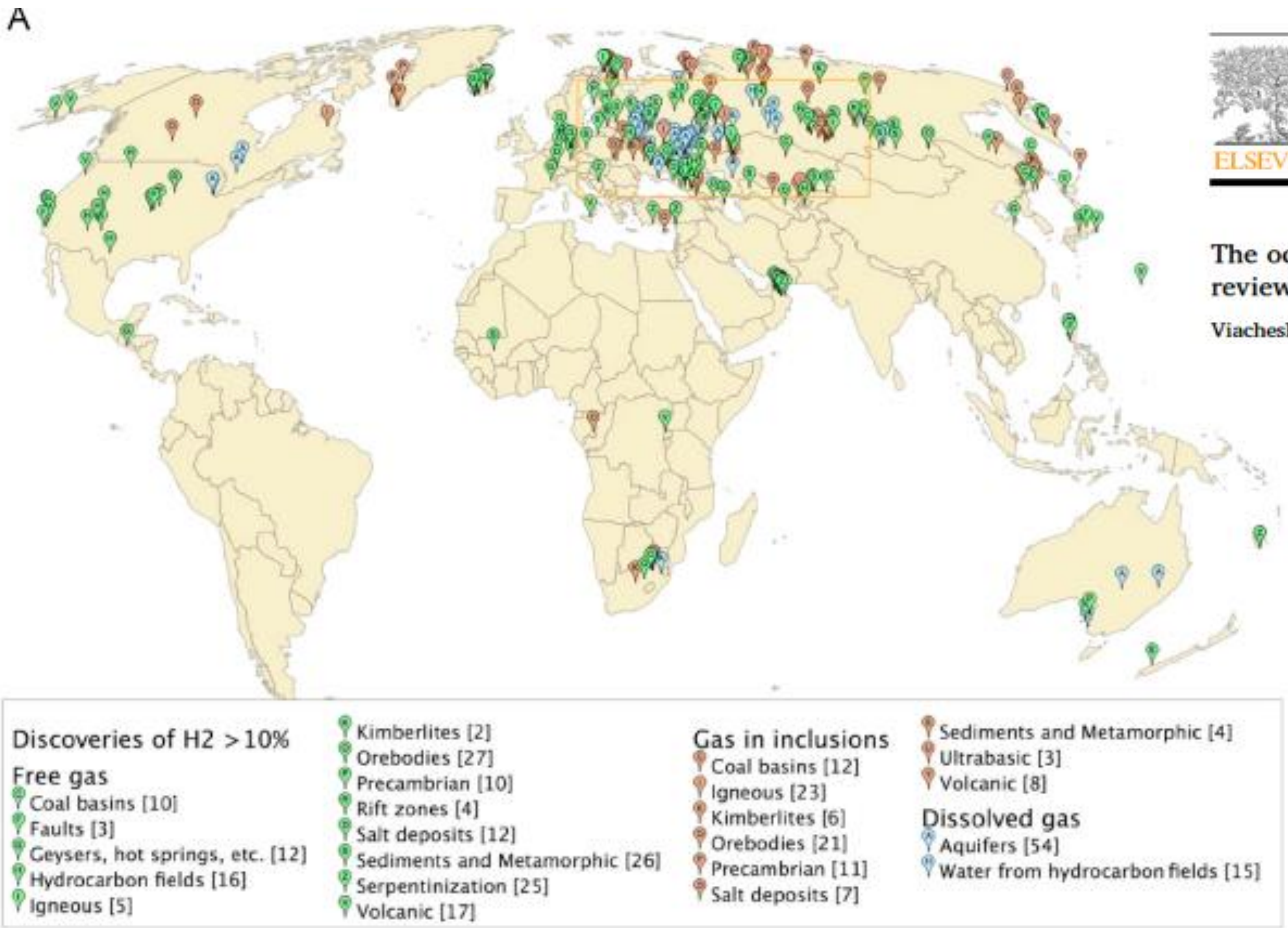
- Average age of continental crust is ~2 Billion years (2Ga).

the energy from 1 Billion years (1Ga) of hydrogen generation is…

➢ **Equivalent to 170,000yrs of present day oil production**

- Even a small proportion is valuable if trapped and accessible

Where is the (Gold) H_2? - global occurrence of seeps



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ELSEVIER

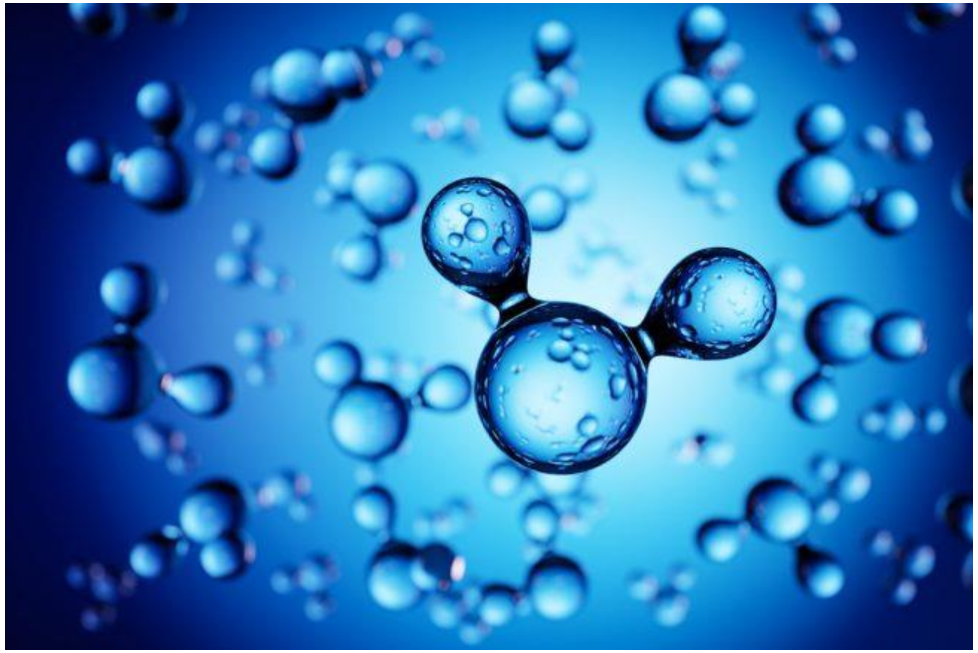
The occurrence and geoscience of natural hydrogen: A comprehensive review

Viacheslav Zgonnik

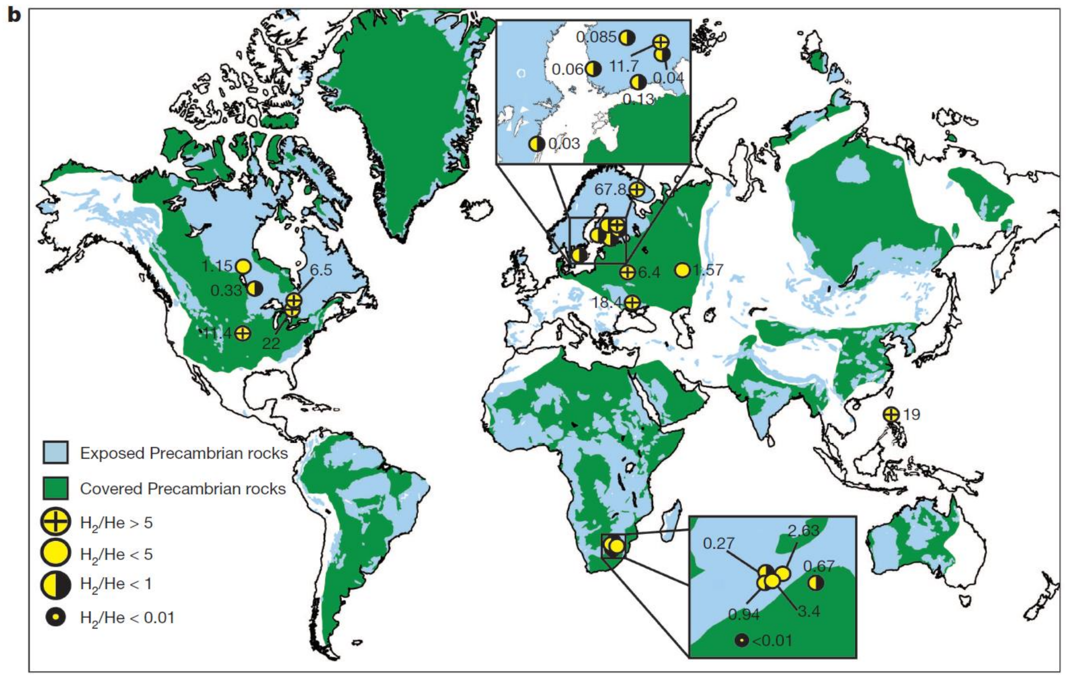
- **Seeps and gas shows:**
- **Gas phase H_2 >10% observed widely**

Where is the (gold) hydrogen ? – what we need to know

- **Preservation in the deep crust on geological timescales ?**
- **Mechanism/controls on release from the deep crust ?**
  - **Rate of release**
- **Gas phase formation ?**
- **Geological trapping structures ?**
- **Preservation in the trapping structure ?**



^{4}He and H_2: related genesis and migration



LETTER

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The contribution of the Precambrian continental lithosphere to global H_2 production

Barbara Sherwood Lollar[1], T. C. Onstott[2], G. Lacrampe-Couloume[1] & C. J. Ballentine[3]

Helium and Hydrogen

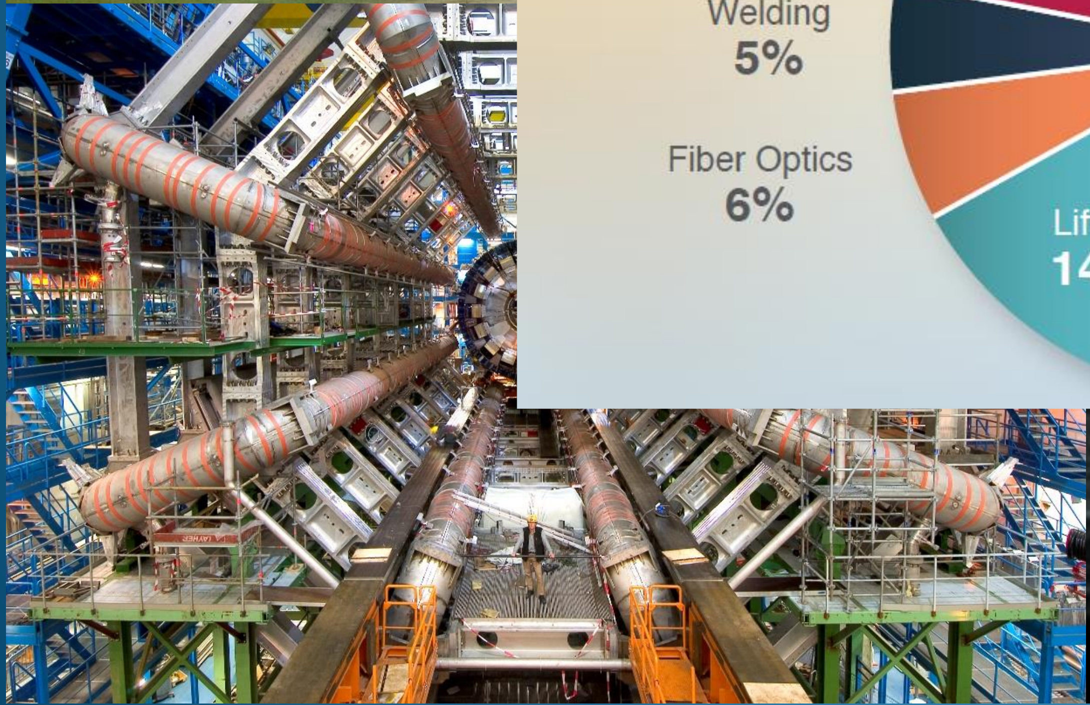
BOTH

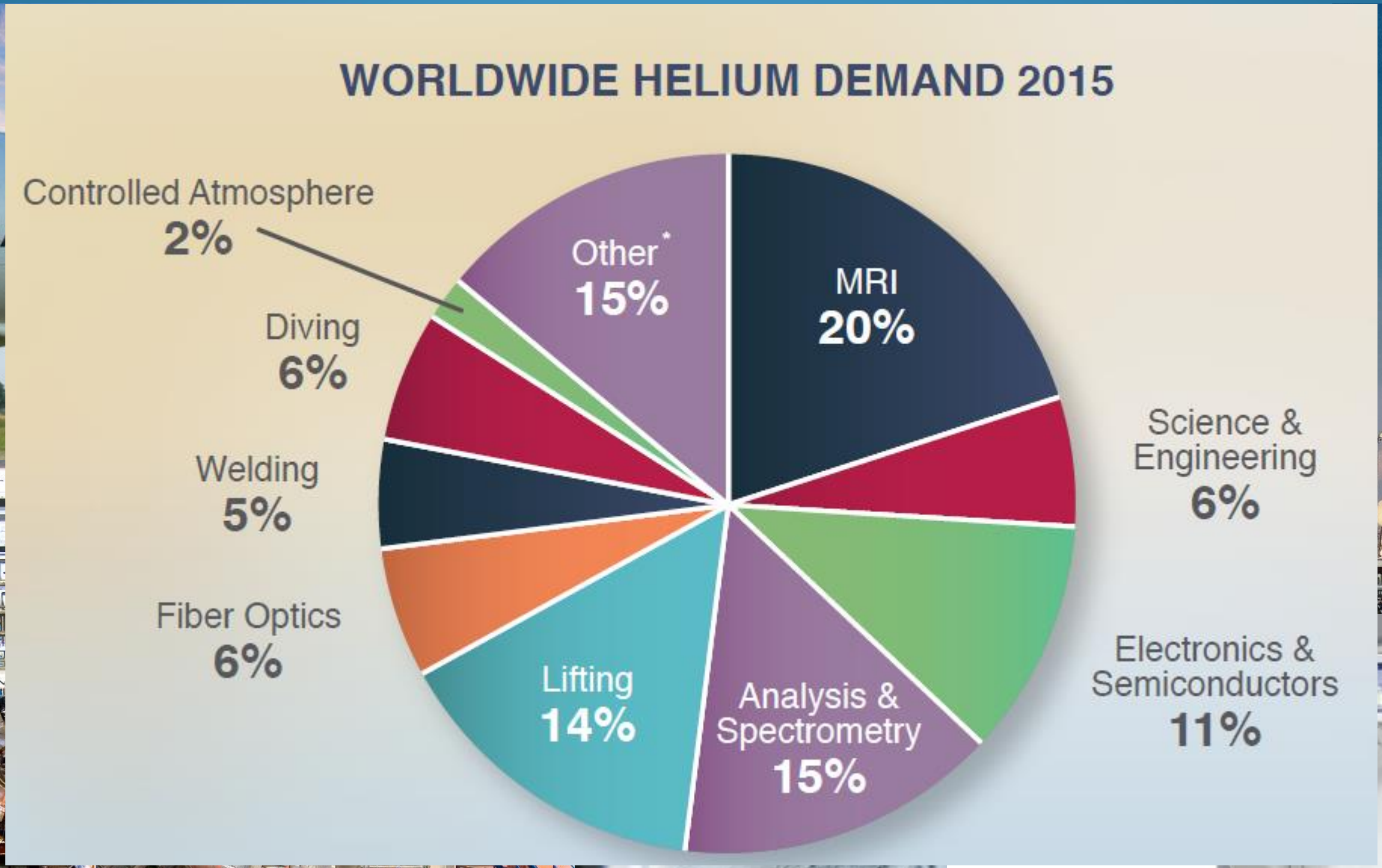
- **Produced** - by slow dispersed processes in the terrestrial crust
- **Released** - from site of production
- **Transported** - to the shallower crust
- **Focussed** - by shallow migration and gas phase formation
- **Trapped** - within accessible geological structures

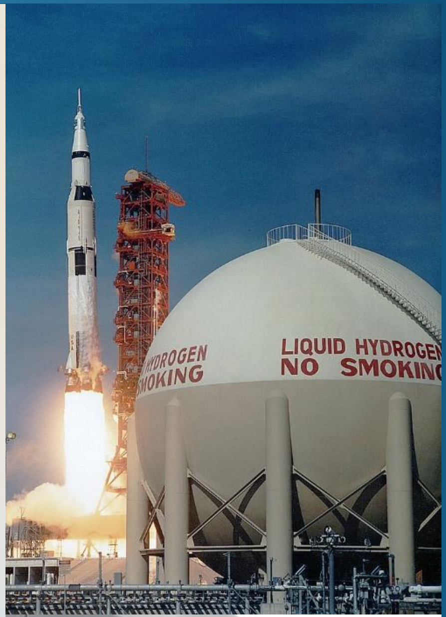
BUT

- H_2 is NOT conservative
- ***Controls on helium accumulation the starting point for a hydrogen exploration strategy.***

Helium – Enabler of Innovation and $Billion Industries





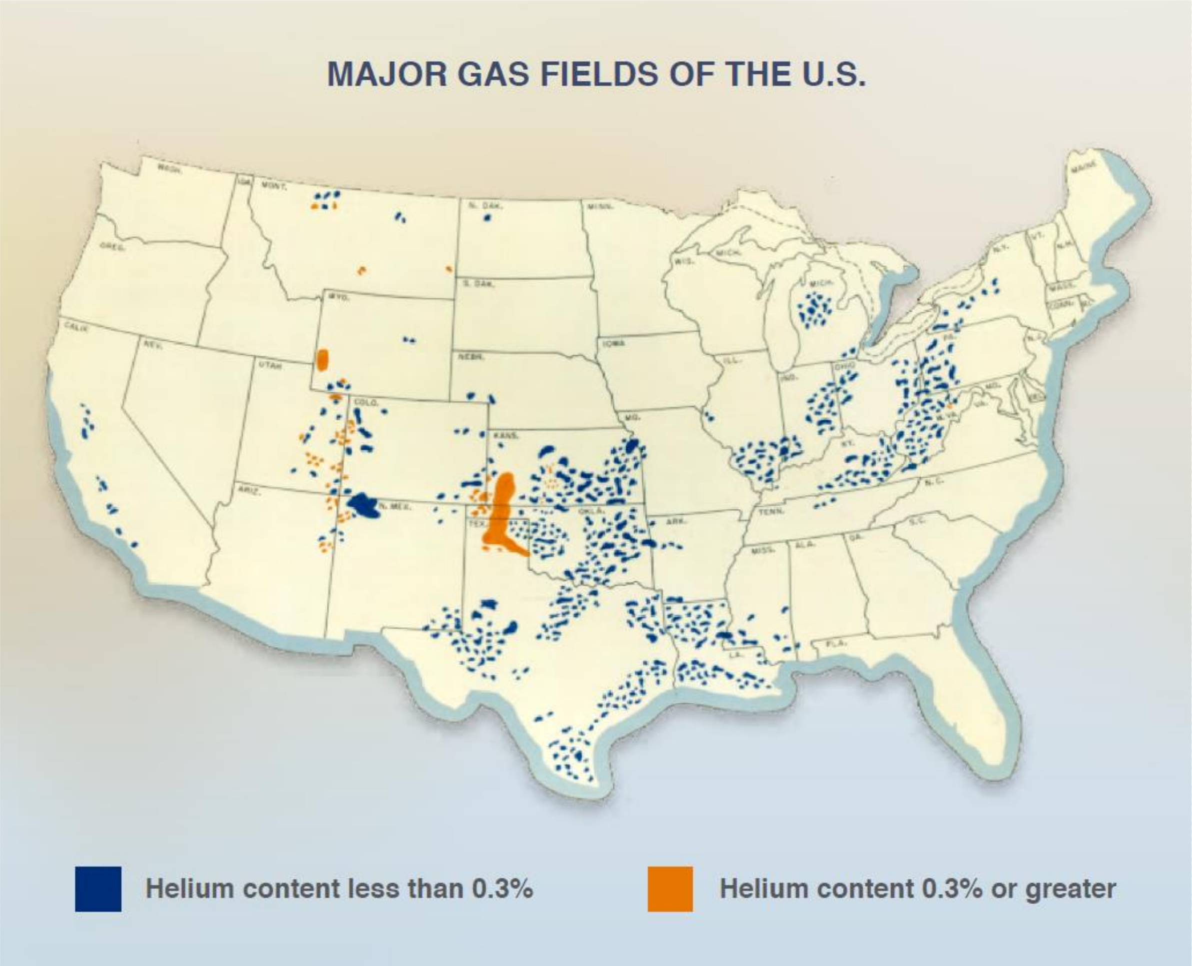


A (very) brief history of helium

- First discovery of commercial helium = Dexter, Kansas 1903.
- Since then:
  - Hugoton-Panhandle (KS, OK, TX),
  - LaBarge field (WY); and
  - Cliffside (Storage) (TX)

  Have been main suppliers of the world's helium.

- **Discoveries all incidental to hydrocarbon exploration**



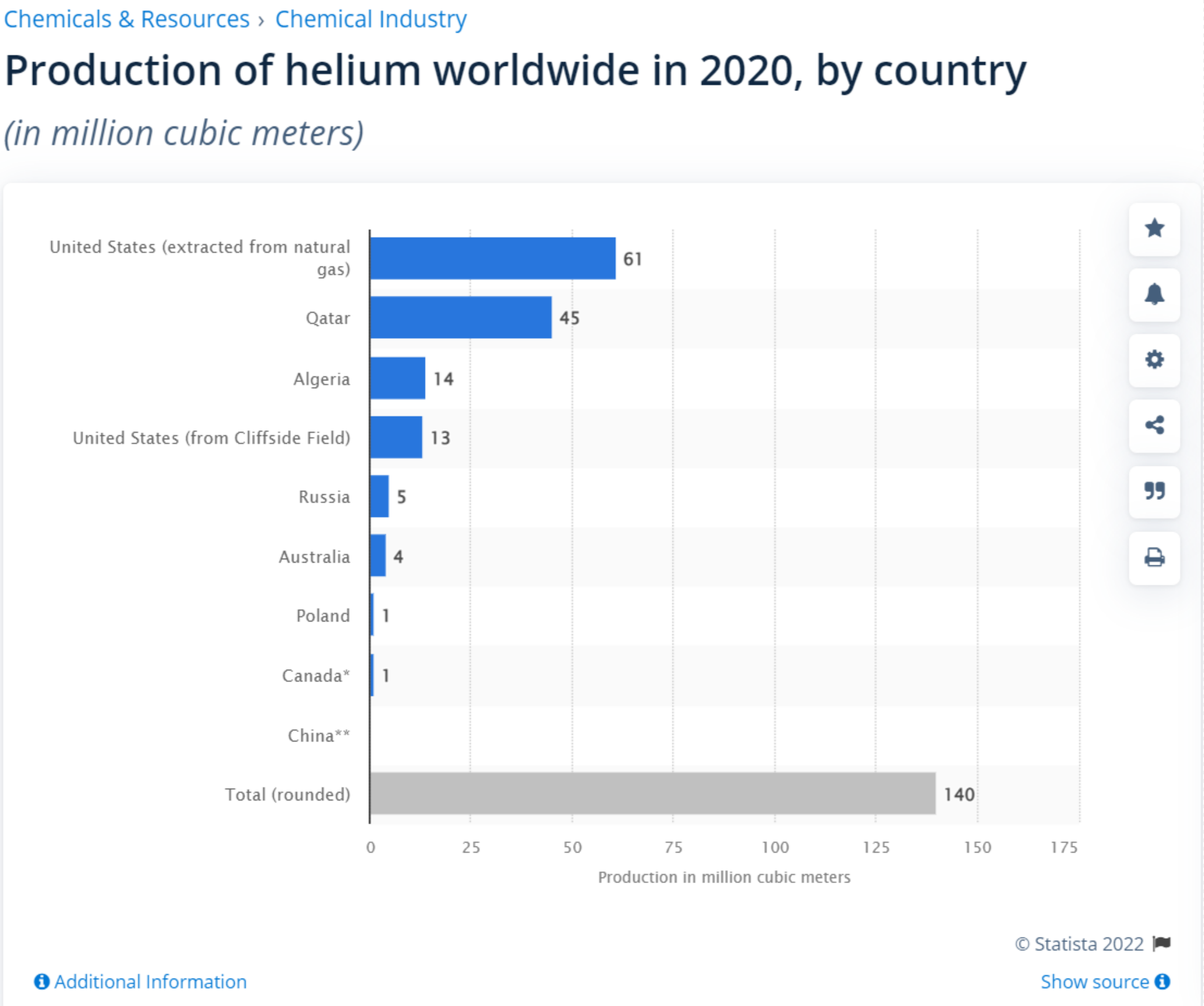
Helium content of major gas fields in the U.S. Only a small number of gas fields contain the minimum concentration (>0.3%) of helium necessary to make recovery commercially viable.

The Need for Primary Helium Exploration

Risks to Helium Supply

- Limited number of operating fields
  (single point of failure)
- Algeria/Qatar: a waste product of LNG
  (hydrocarbon footprint/ market reliance)
- Russia – Amur – 35% global production planned
  (political risk)

Qatar Liquified Natural Gas (LNG) plant



The Helium Exploration Checklist

Di Danabalan et al., 2022

Stage	Petroleum System	Helium System
Source	Organic matter	U and Th decay
Maturation	Burial and heating	Time to accumulate
Primary migration	Pressure driven (phase change)	Heat and pressure (tectonism) –Nitrogen?
Secondary migration	Buoyancy driven	Buoyancy or dissolved in Groundwater
Entrapment	Structural traps	Exsolution (Swept or contact with existing phase in traps) + Structural traps
Trap integrity & longevity	Capillary failure, fracture failure, tectonic destruction of trap	Capillary failure, fracture failure, tectonic destruction of trap, filled to spill.

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Precambrian Crystalline Basement

= Helium Source Rocks

LETTER

doi:10.1038/nature12127

Deep fracture fluids isolated in the crust since the Precambrian era

G. Holland[1,2], B. Sherwood Lollar[3], L. Li[3]†, G. Lacrampe-Couloume[3], G. F. Slater[4] & C. J. Ballentine[1]

- Some of the most ancient isolated fluids on Earth

LETTER

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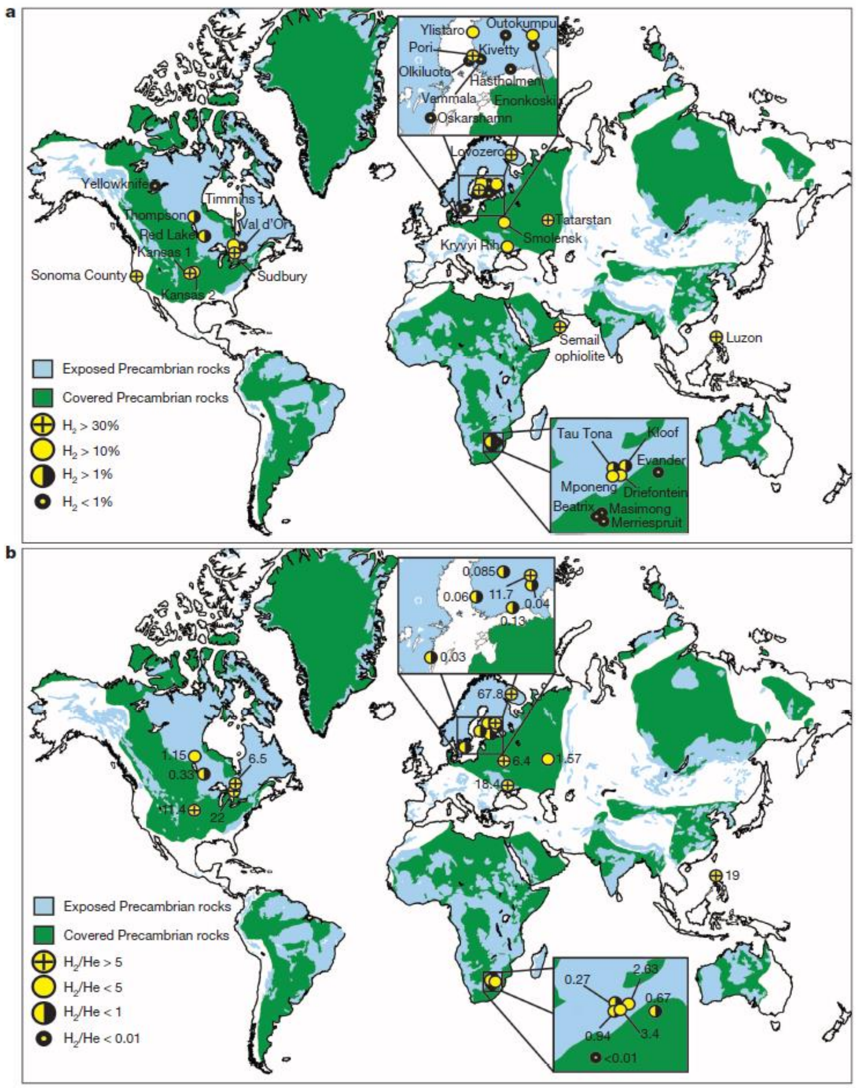
The contribution of the Precambrian continental lithosphere to global H_2 production

Barbara Sherwood Lollar[1], T. C. Onstott[2], G. Lacrampe-Couloume[1] & C. J. Ballentine[3]

- Helium and nitrogen rich (up to 30% helium)



2390m underground, Timmins, VMS deposit, Canada

- **Noble gas accumulation ages from deep mine fracture fluids…..**

- **…. show that some portions of the crust can retain their fluids on Ga timescales.**

- Saline fracture fluids from freely discharging boreholes (to ~10,000ft)
- Rich in H_2, CH_4, ^4He, N_2


LETTER

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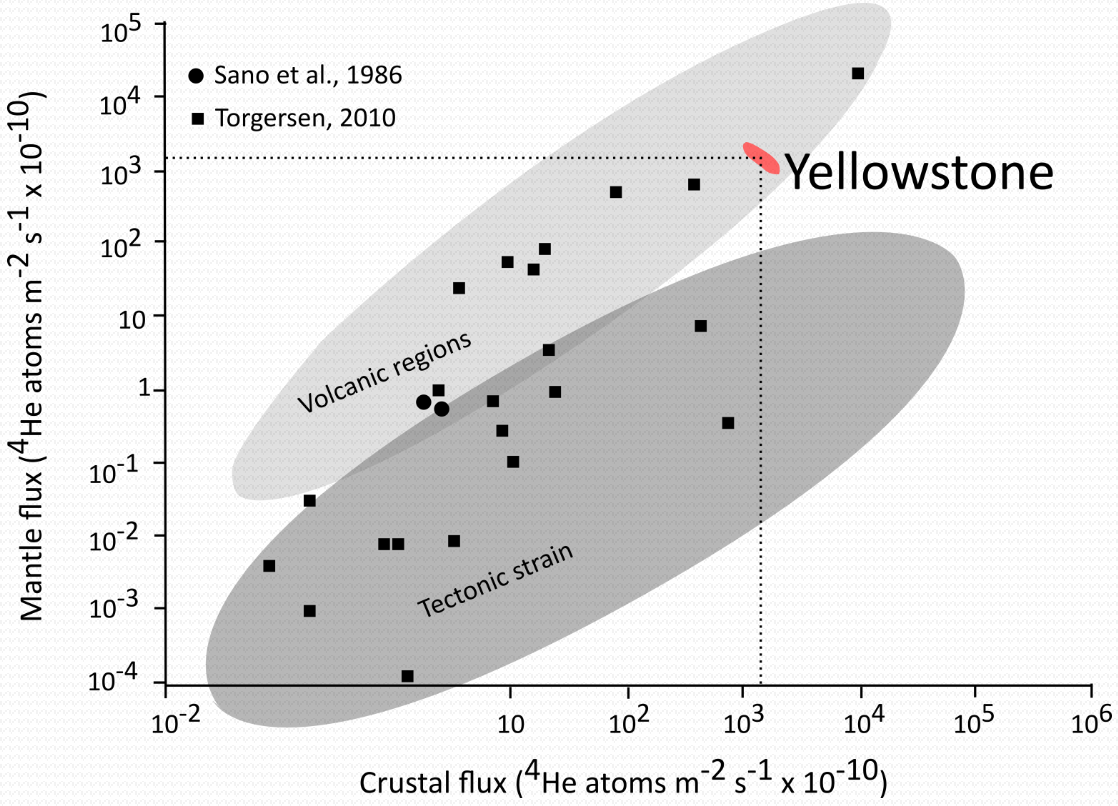
Release of Helium – Rifting and Volcanism

LETTER

doi:10.1038/nature12992

Prodigious degassing of a billion years of accumulated radiogenic helium at Yellowstone

J. B. Lowenstern[1], W. C. Evans[1], D. Bergfeld[1] & A. G. Hunt[2]



Helium released from Yellowstone totals **13 Bcf/Ma**

The Helium Exploration Checklist

Danabalan et al., 2022

Stage	Petroleum System	Helium System
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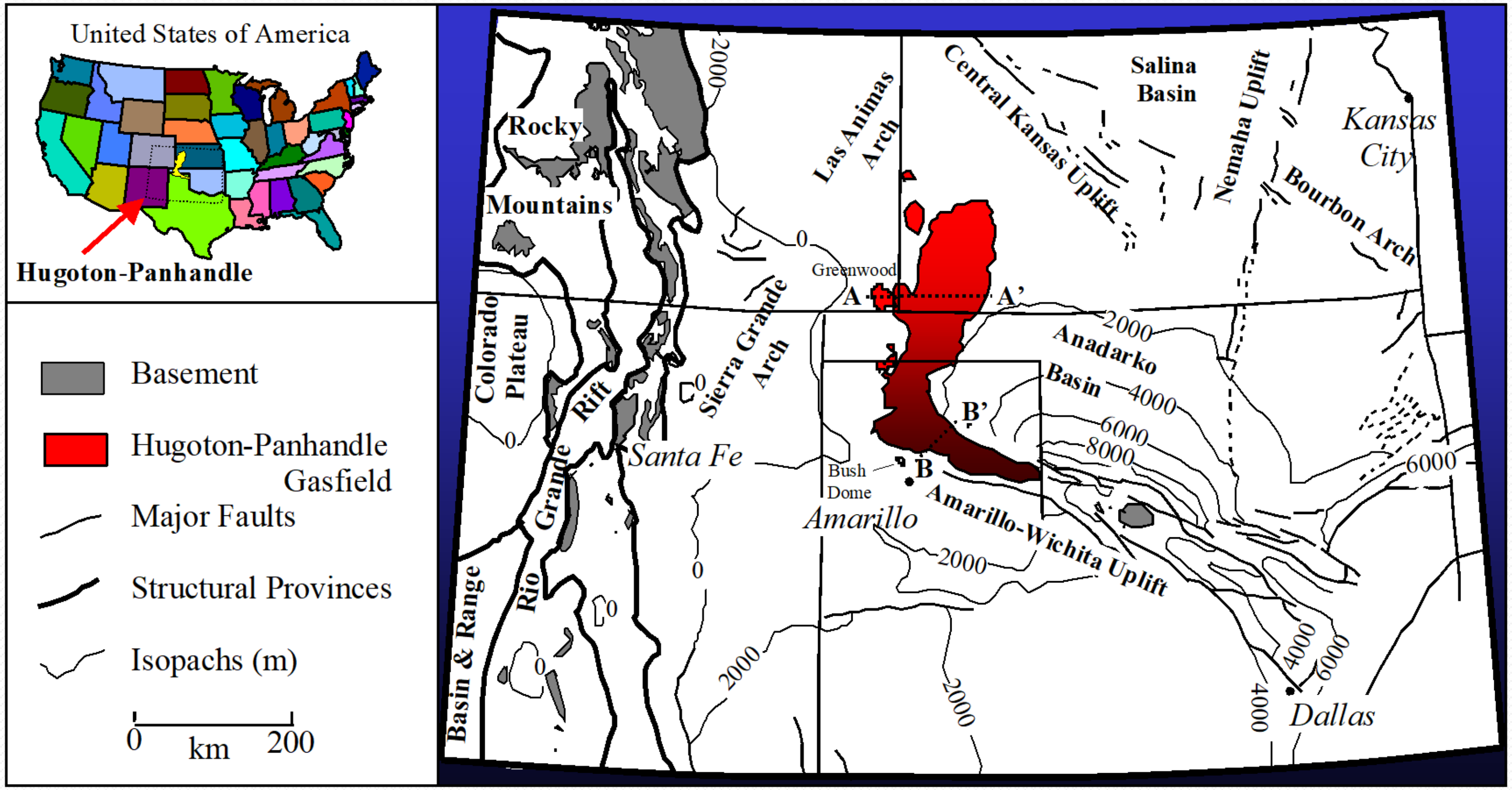
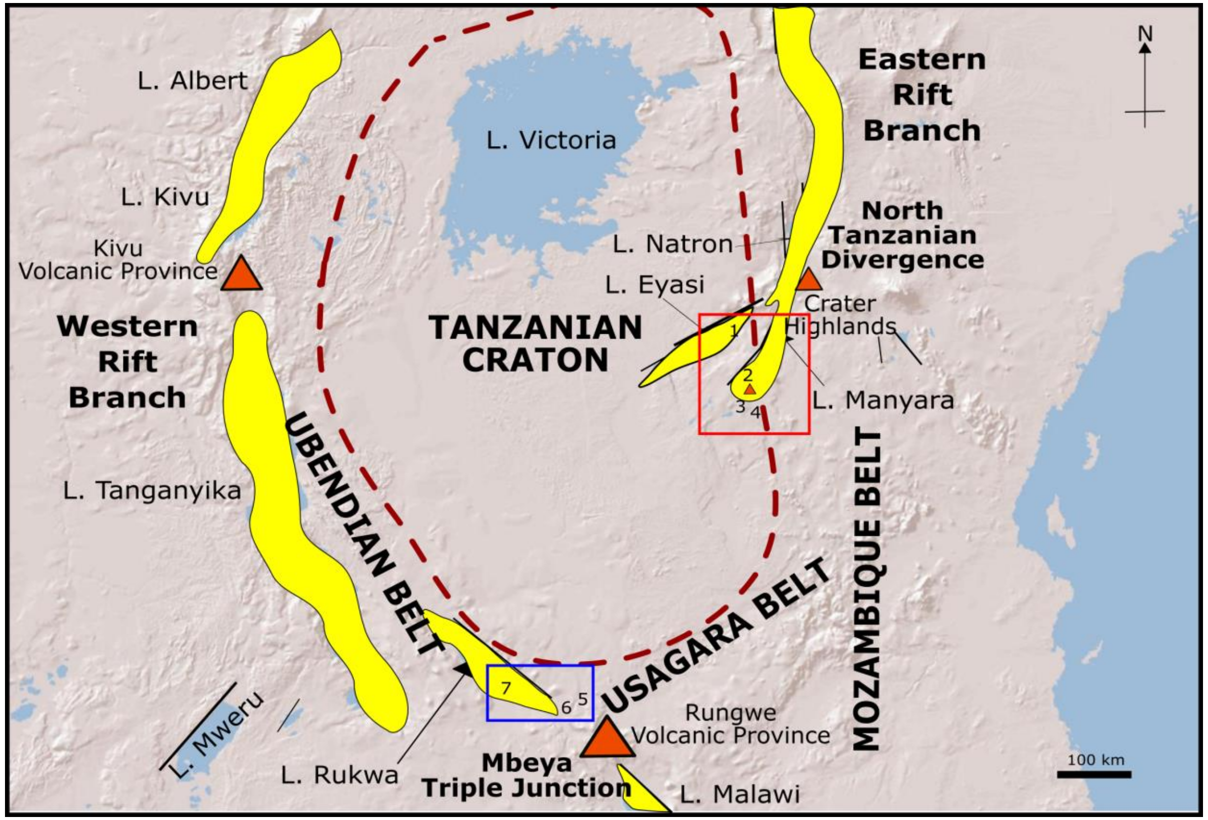
Hugoton – Panhandle Giant Natural Gas Field



- CH_4 dominated, ^4He>0.3%
- Groundwater key component of focussing and/or transport
- ^4He concentration in groundwater 'in solution' at reservoir P, T and salinity
- CH_4 essential for gas phase formation

Hugoton-Panhandle giant gas field (Ballentine & Sherwood Lollar, 2002)

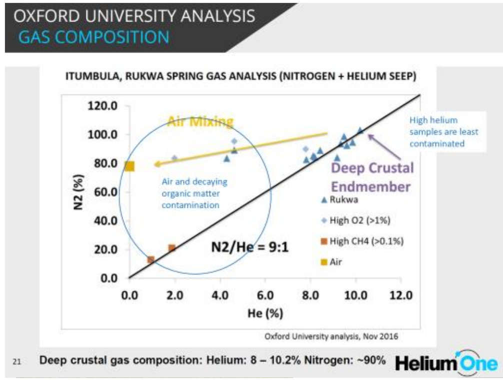
Tanzania – A helium 'Play Fairway'



Rukwa Basin, Tanzania

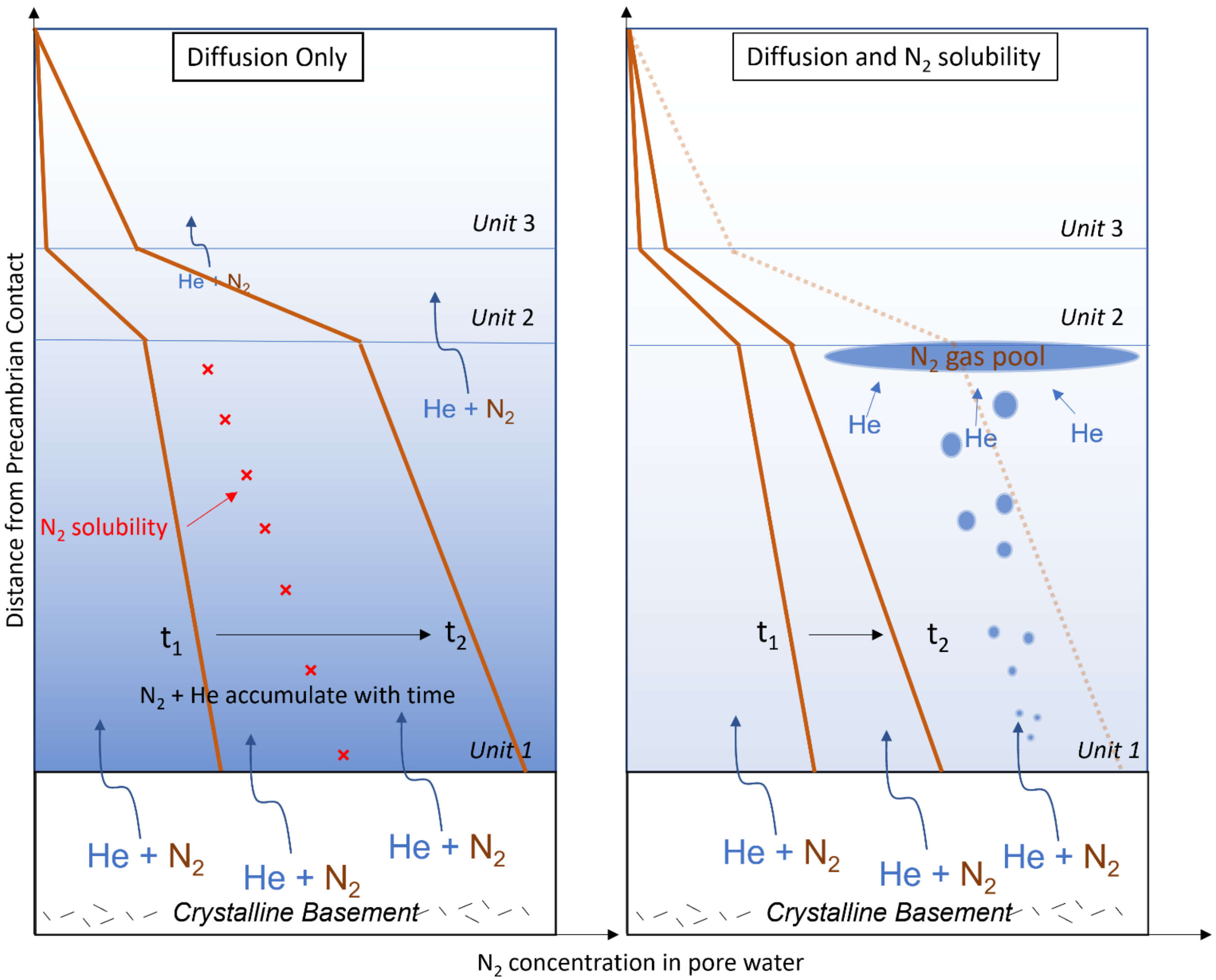
- Source Rock +
- Primary Migration +
- Geological Traps =
- Exploration Target

Danabalan PhD Thesis 2017
Danabalan et al., 2022



- **P_{50} Rukwa = 138 BCF ^{4}He**
- **Alone, would supply world consumption for 14 yrs**

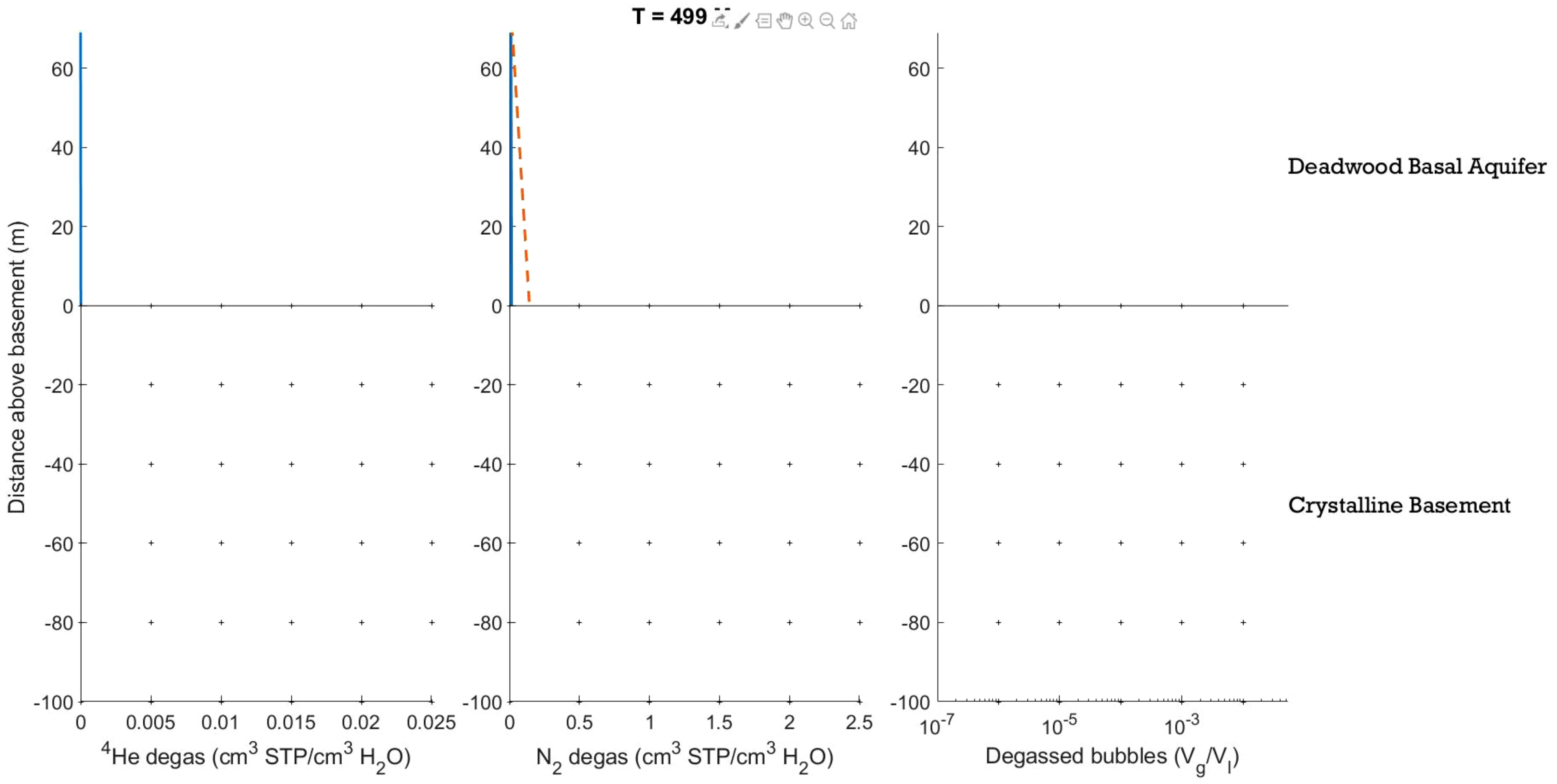
^4He and H_2: The role of N_2 in forming a gas phase



- Consider N_2 accumulating in the groundwater with ^4He.
- With typical N_2 /^4He basement flux ratios of 20-50, the nitrogen solubility limit can be exceeded.
- The N_2 gas phase is a sink for the ^4He (and H_2) and buffers any further change in the ^4He water concentration.
- **… a mechanism to account for observed primary ^4He + N_2 gas fields.**

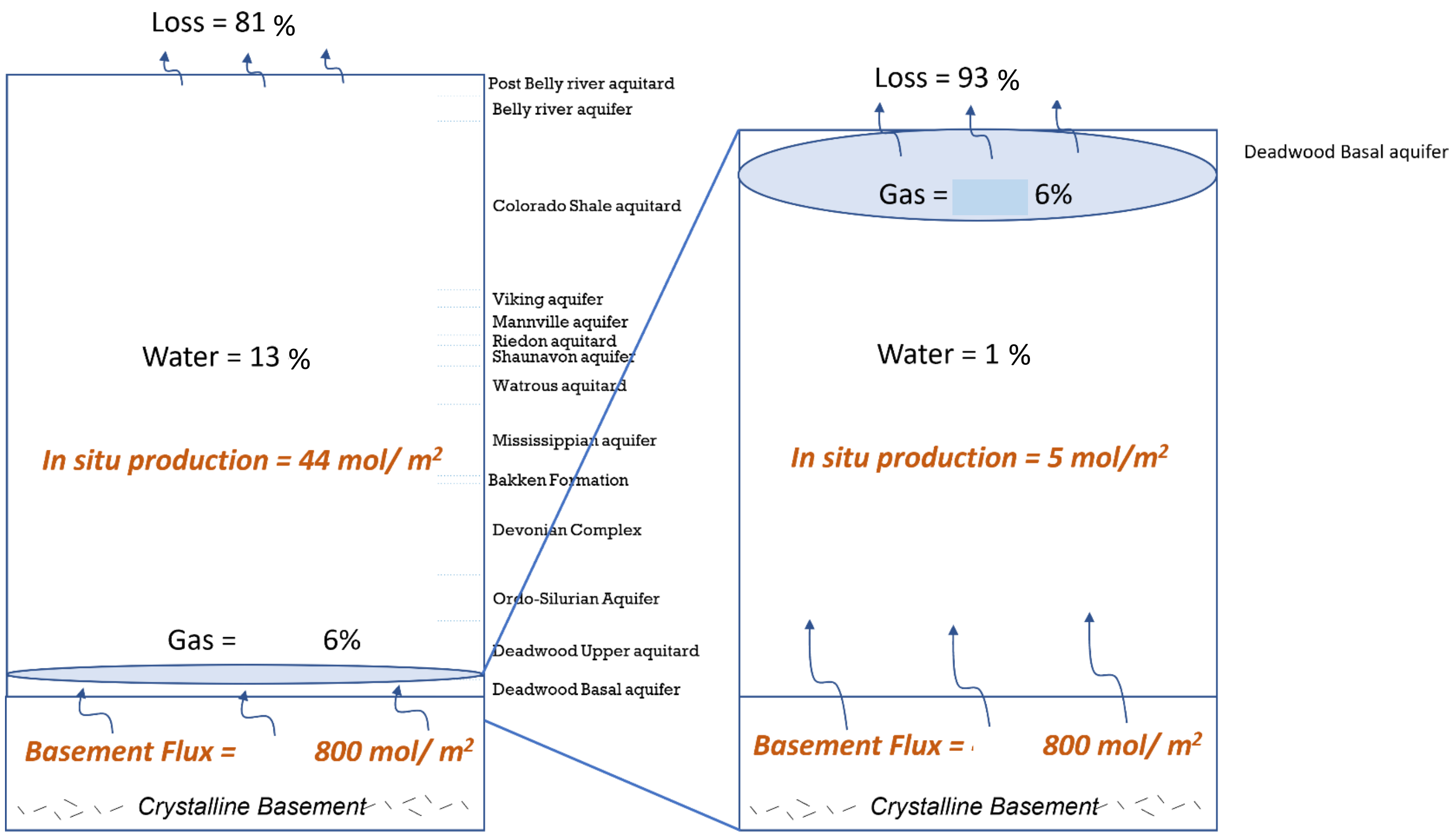
Cheng et al., 2020 PhD thesis
Cheng et al., Nature, in Review

^4He and H_2: The role of N_2 in forming a gas phase



Cheng et al., 2020 PhD thesis
Cheng et al., Nature, in Review

^4He – How Much is Still in the Basin ?

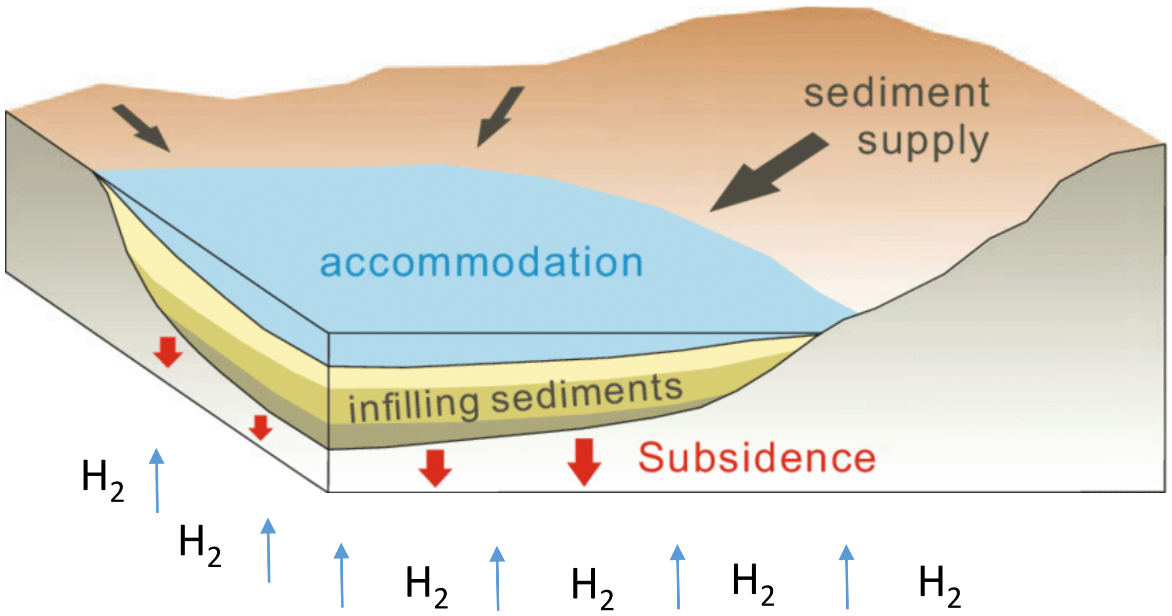


- 81% He lost through diffusion
- 13% He dissolved in the water column

- **6% of all He fluxed from basement is a gas phase in the Deadwood**

Cheng et al., Nature, in Review

H_2 potential - The Williston Basin, USA/Canada



Surface area 150,000km^2
= 0.1% of Archean crust by area

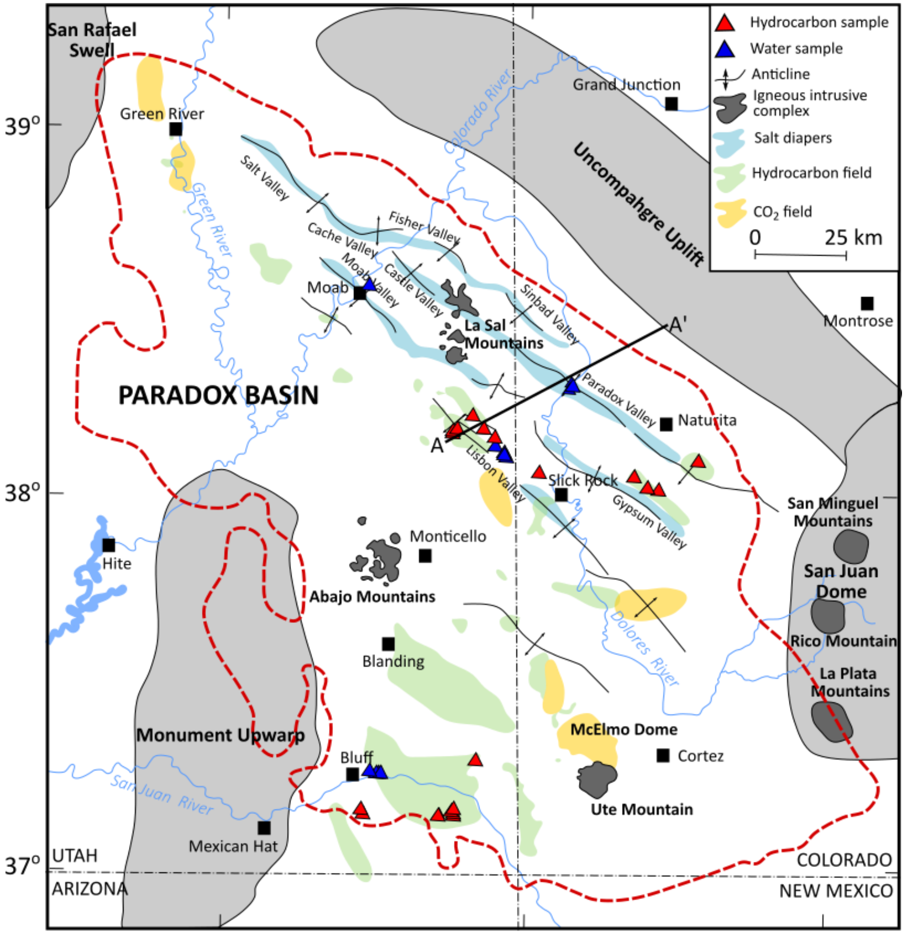
Has received, at steady-state:
0.1%*170,000PDOP/Ga = **170 PDOP**

<u>**If**</u> 6% in gas phase then:
6% * 170 PDOP = **10 PDOP**

Maximum…

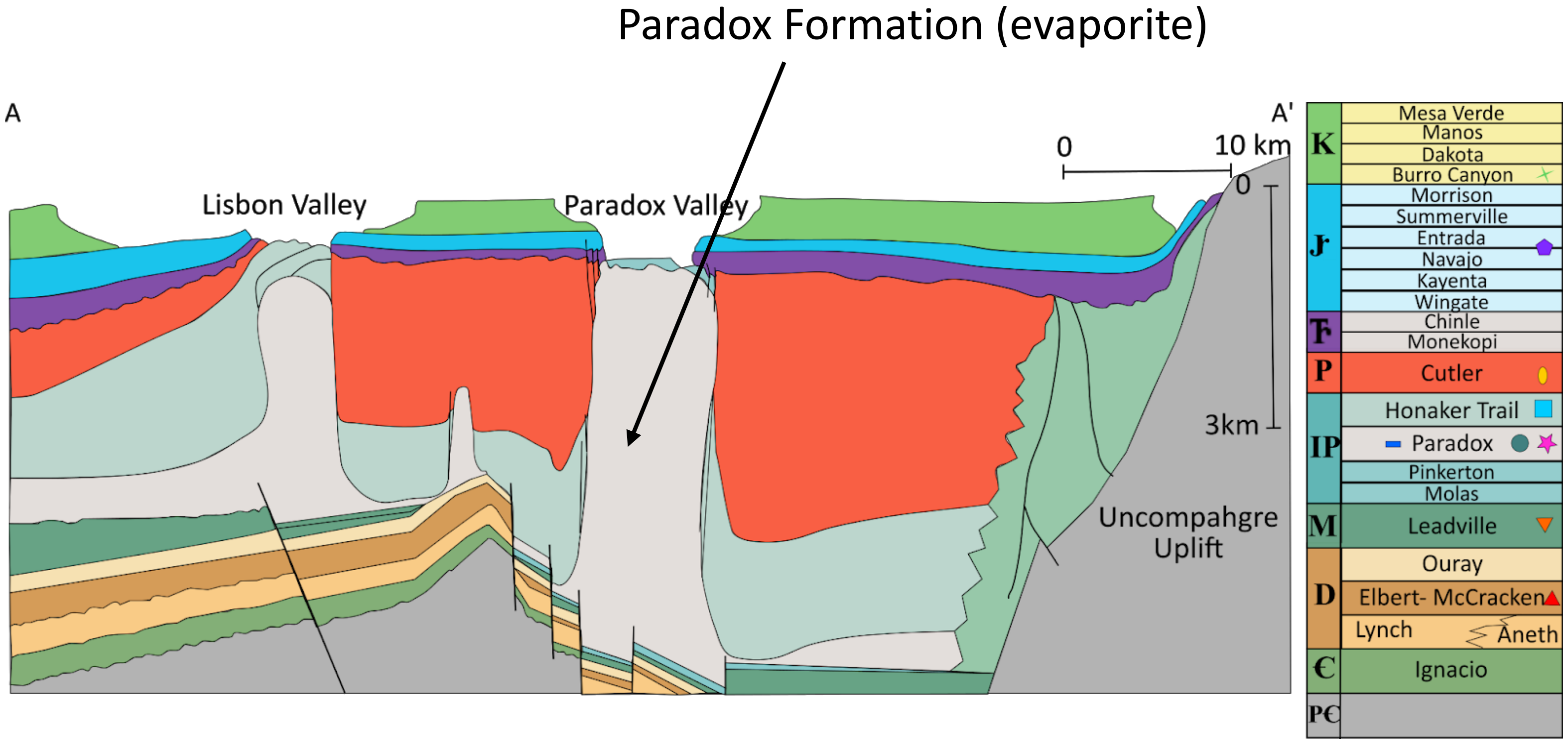
- Reference: Archean crust has generated H_2 equivalent to 170,000yrs of present day oil production (PDOP) in 1Ga (1xPDOP ~ $2 trillion)

Trapping structure efficiency: The Paradox Basin, USA I



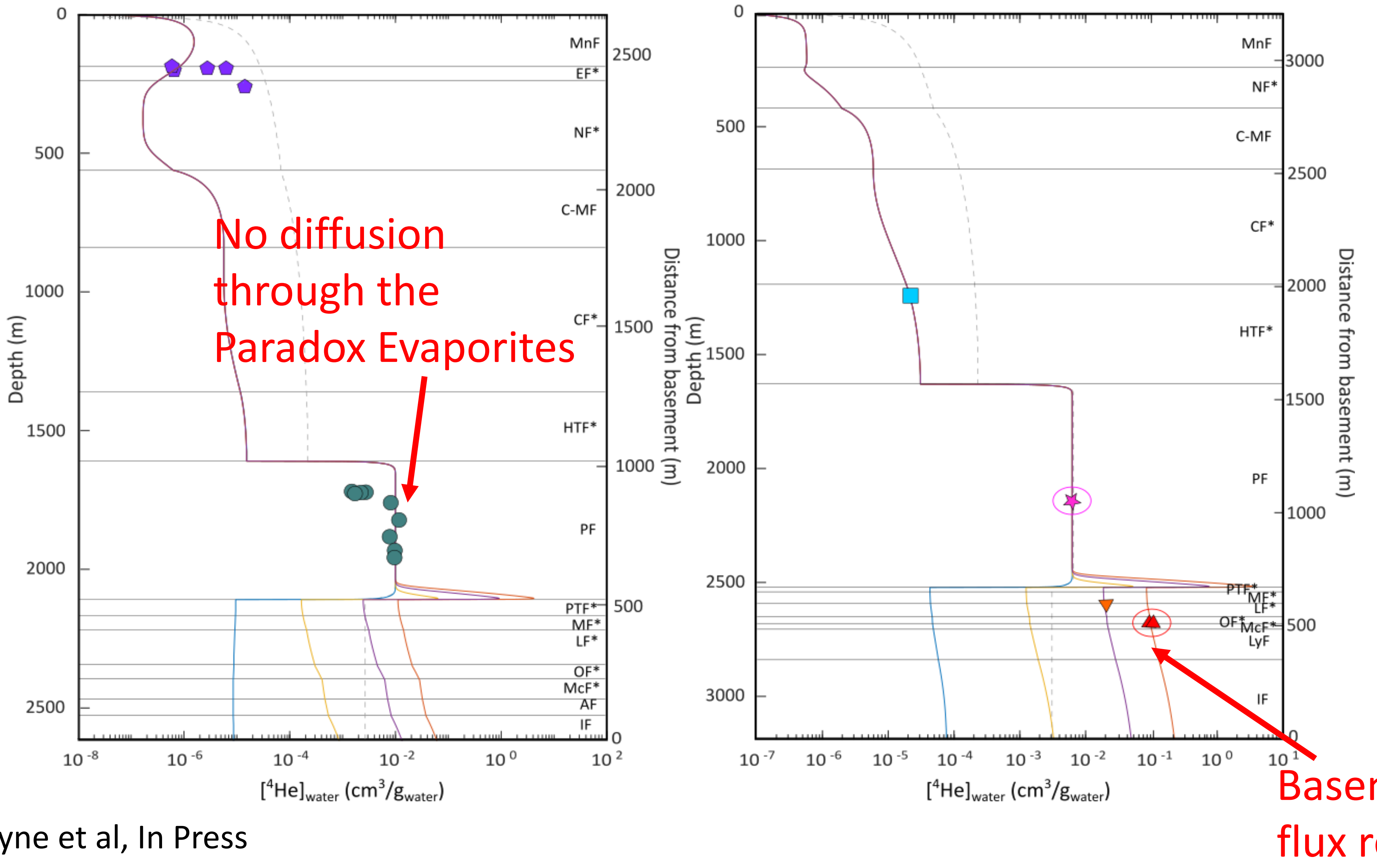
Tyne et al, In Press

- Basin defined by thick evaporite unit (Paradox Formation)
- Abundant Hydrocarbon and CO_2 deposits
- 7 different stratigraphic units
- Sampled multiple locations across the basin



After Kim et al., 2021

Trapping structure efficiency: The Paradox Basin, USA II



Basement Fluxes

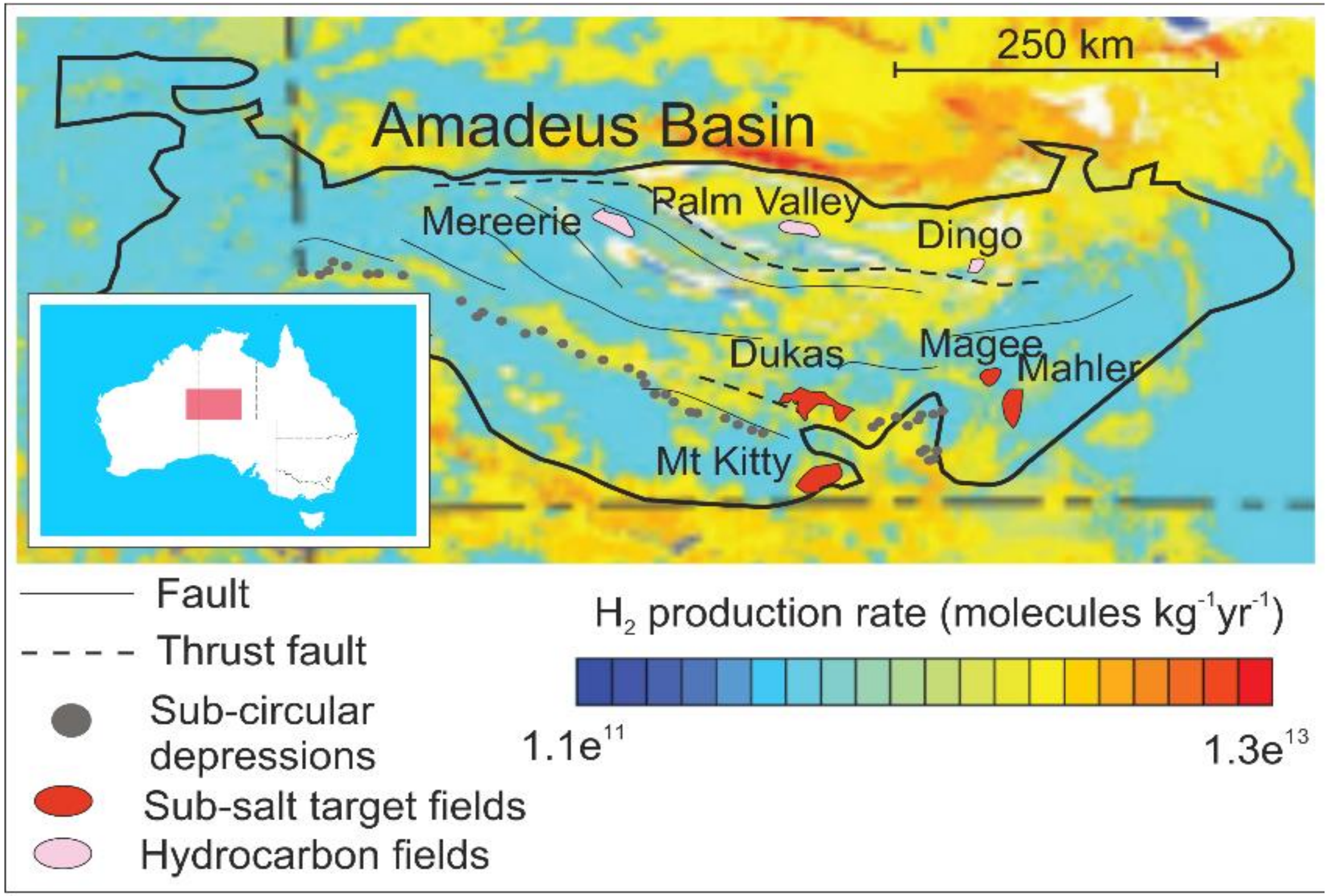
mmol $^4He/m^2/yr$

- 0
- 1.47
- 14.7
- 70

Vertical diffusion model: in-situ production and diffusion between formation

Tyne et al, In Press

Gold hydrogen – preservation in reservoir?



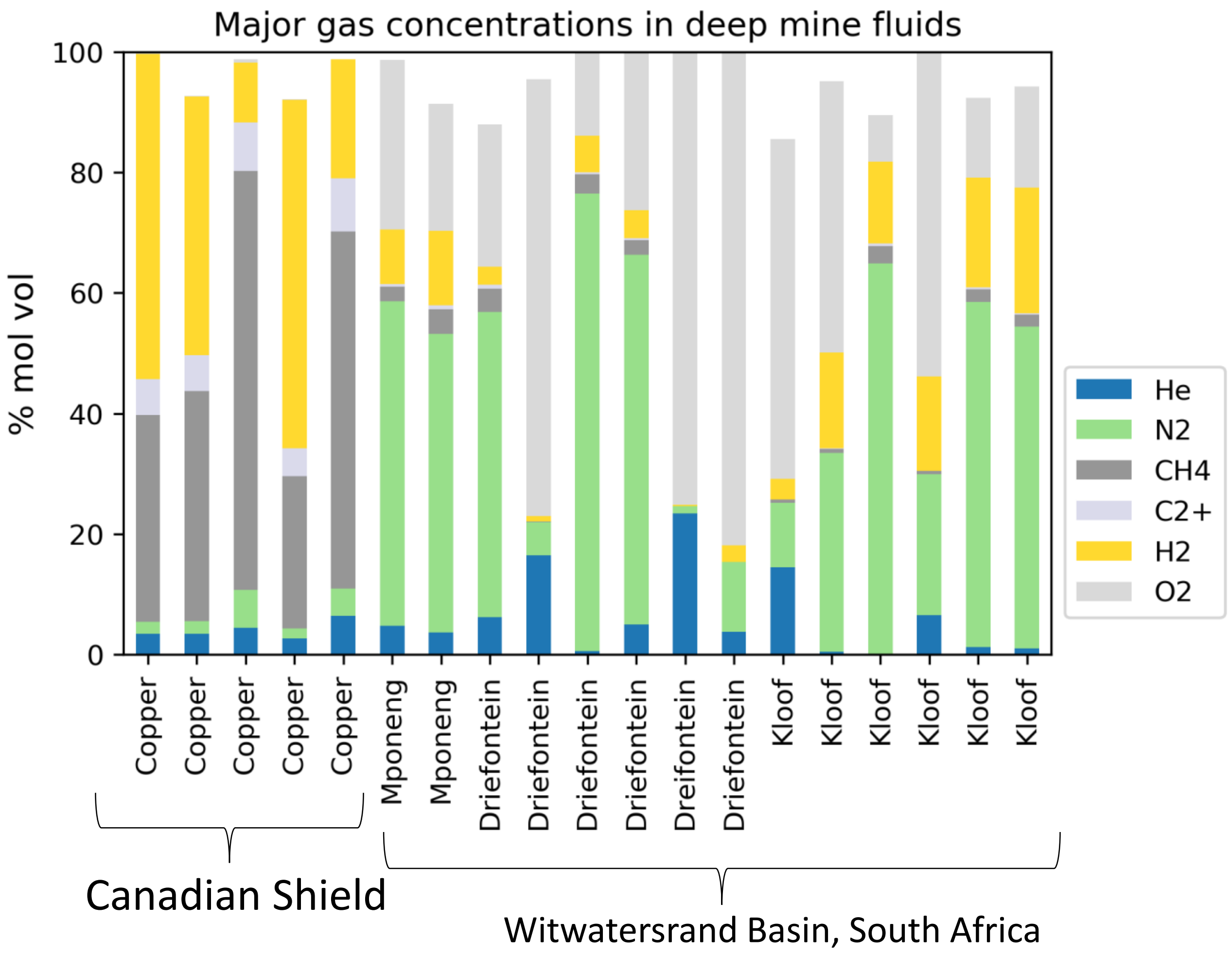
Where has the Hydrogen gone in Magee-1 ?

Magee 1 (2,696 m)
Pacific Oil & Gas 1992
63.1 Mscfd from 4.5 m sst
Shale 0.5-0.8% TOC
Nitrogen 43.61%
Methane 30.58%
Ethane 5.96% — 49.09%
Propane 1.94%
Butane+ 1.66%
Carbon dioxide 0.58%
Hydrogen 0.03%
Argon 0.46%
Helium 6.23%

Mt Kitty 1 (2,295 m)
Santos 2014 (Central Petroleum tenement)
420 Mscfd from weathered/fractured granite
Nitrogen 61%
Methane 13% — 18%
Ethane 4%
Hydrogen 11%
Helium 9%

Gold hydrogen – biological sinks

H_2 preserved in deep mine fluids in South Africa and Canada



Compiled from Sherwood Lollar et al., 2006

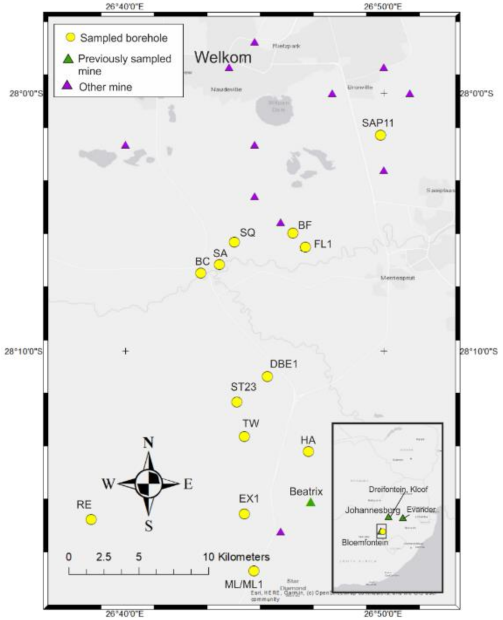
H_2 is preserved, but cell counts low:

- Sulfate reducers (Alkane oxidising, autotrophic)
- Methanogens, primarily CO_2 reducers (Methanobacterium curvum, bryantii, aarhusense; Methanosarcina bryantii)

- Cell counts below detection limit at ionic strength >1.9 M

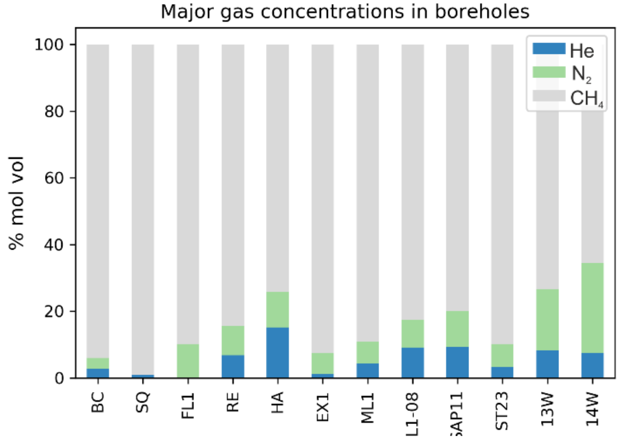
Lollar et al., 2019; Telling et al., 2018; Wilpiszeski et al., 2020

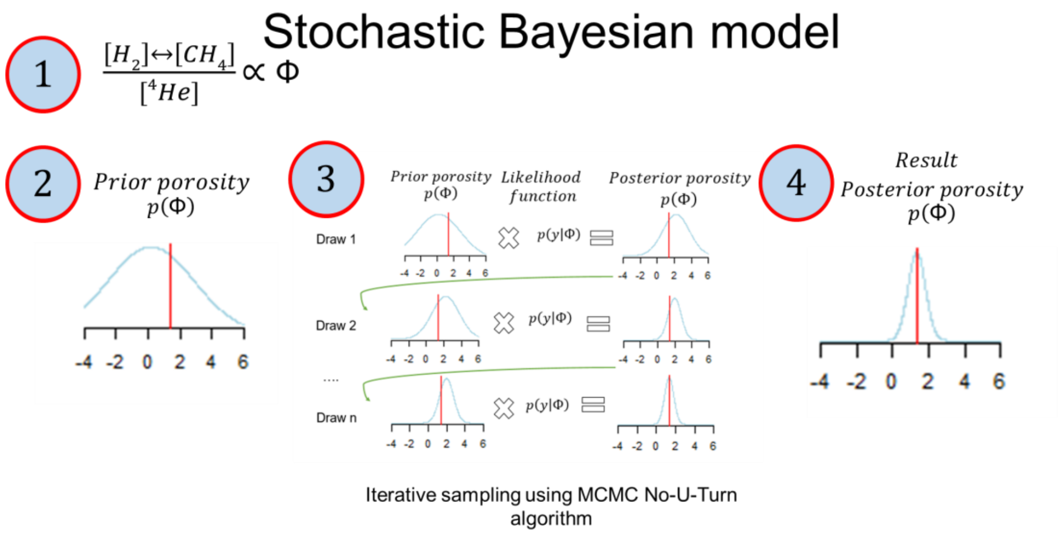
Shallow H_2 Preservation? S Africa

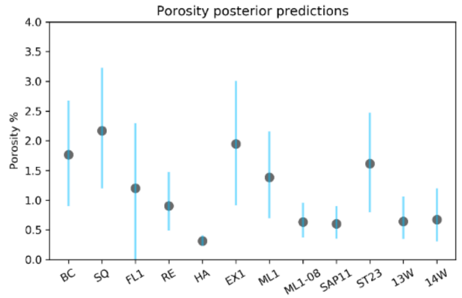


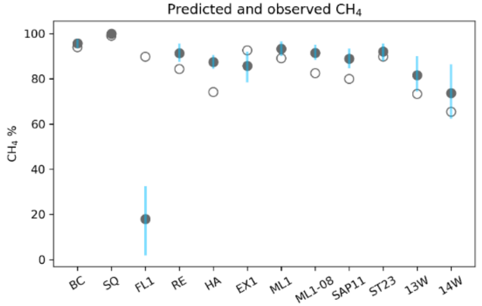
Locations of sampled ^4He-N_2 rich boreholes in the vicinity of Welkom, Free State, South Africa.

Surface springs only exhibit helium, nitrogen and methane









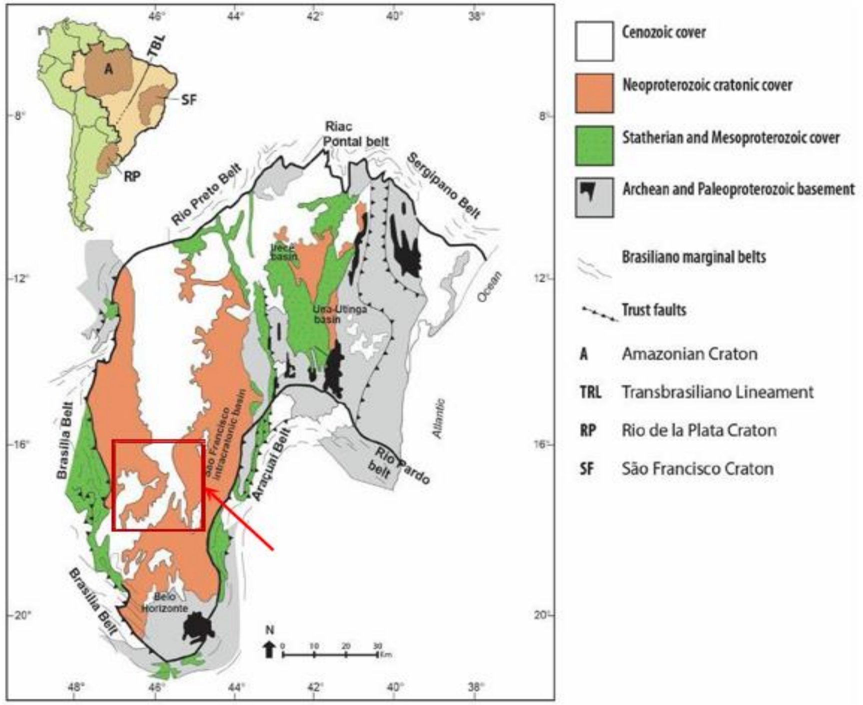
- **Modelling shows:**

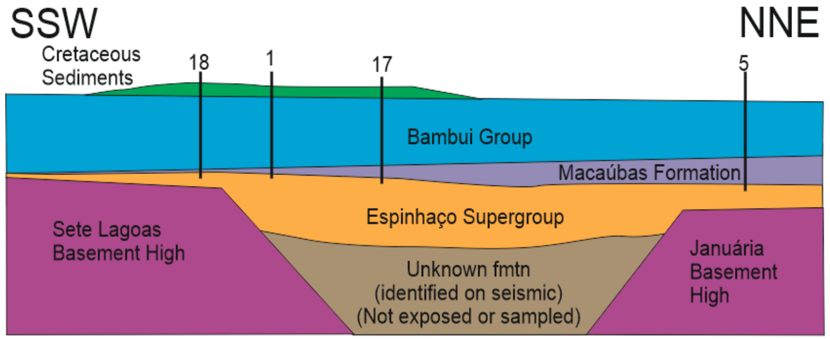
i) Confirmation of radiolytic hydrogen production efficiency;

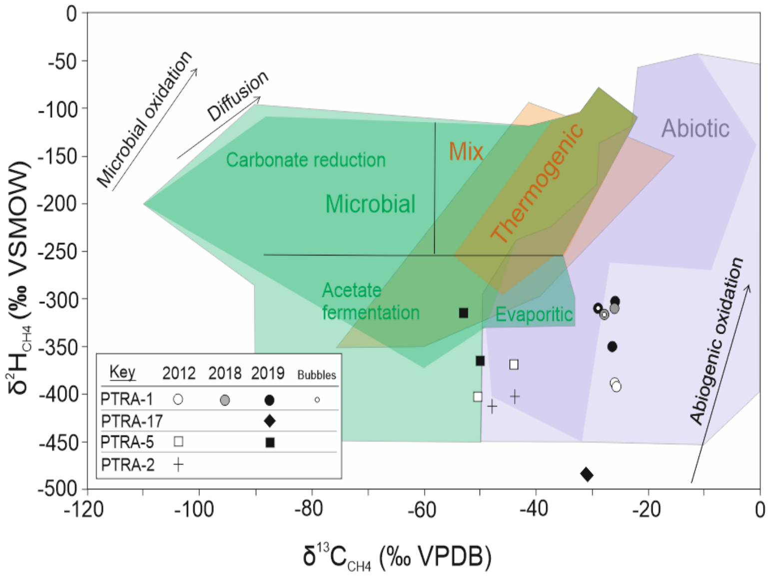
ii) Consistent with ALL methane derived from deep hydrogen converted to methane

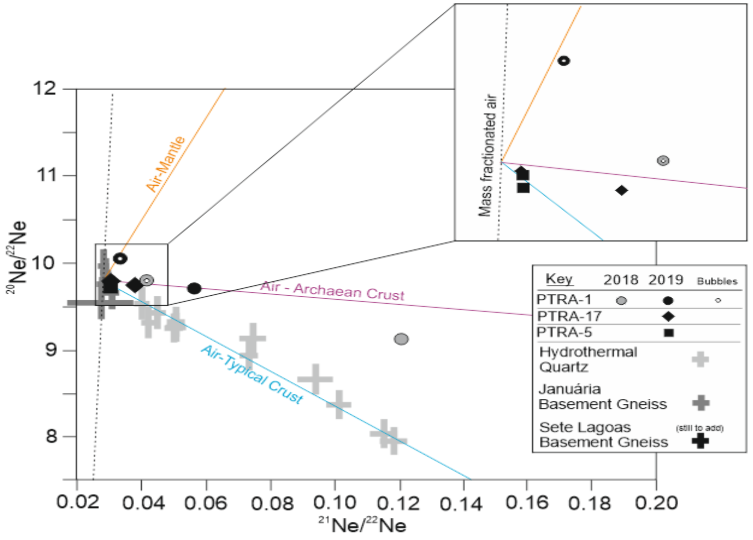
Karolyte et al., 2021

Shallow H_2 Preservation: São Francisco Basin, Brazil









Hydrocarbon exploration wells in the Neoproterozoic São Francisco Basin, Minas Gerais, Brazil, sample tight gas reservoirs rich in methane, native hydrogen (H_2), nitrogen (N_2) and helium.

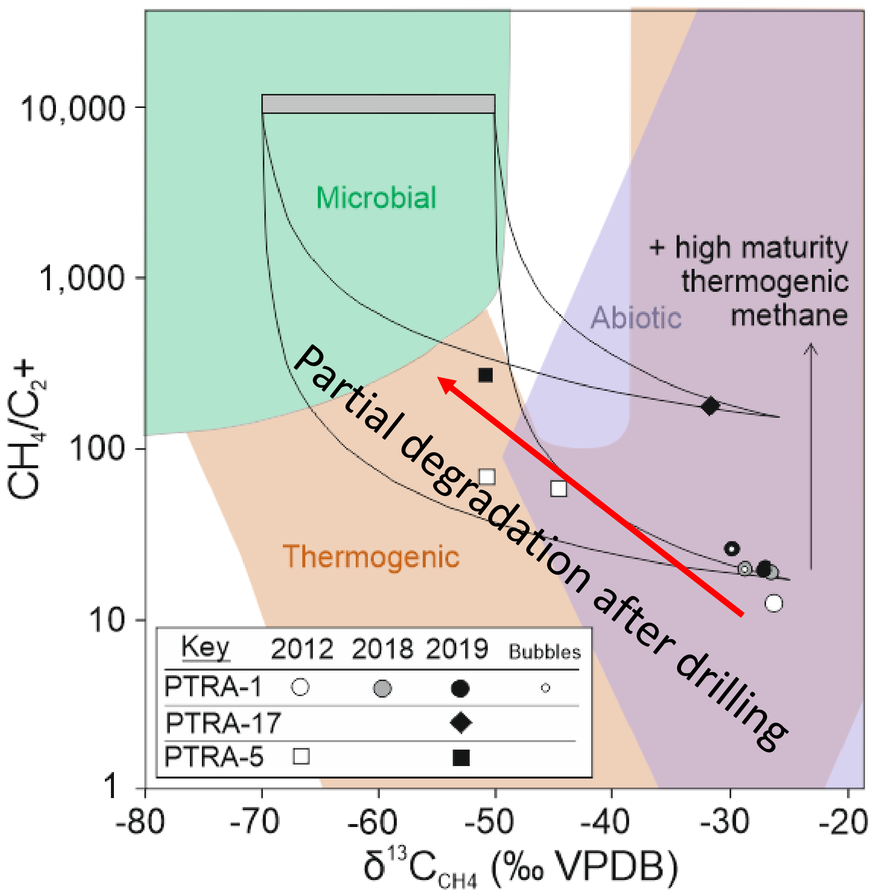
Multiple lines of evidence are consistent with a basement source for the hydrogen.

Data suggests that a significant amount of the basement hydrogen has been consumed by microbial methanogenesis.

Flude et al. Submitted

Gold hydrogen – rate of biological sinks

H_2 partially degraded in sedimentary basin above Precambrian basement

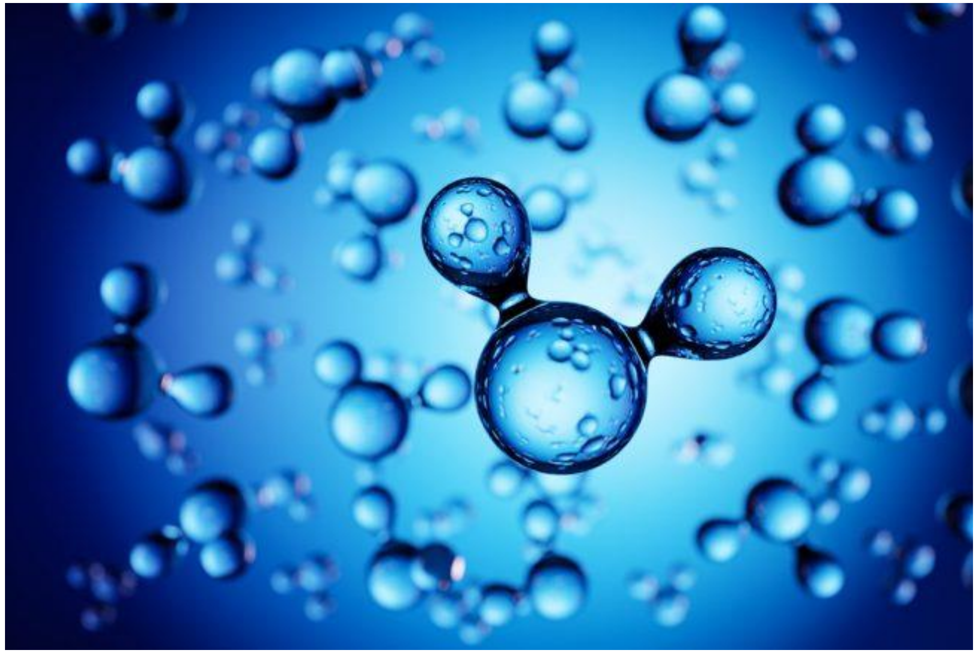


Flude et al., in prep

- H_2-rich gases in sedimentary basin above Neoproterozoic basement, Brazil
- H_2 concentrations drop by 50% in 7 years after drilling, microbial methane increases

Gold hydrogen ? – what we (still) need to know

- **Preservation in the deep crust on geological timescales**
- **Mechanism/controls on release from the deep crust ?**
    - **Rate of release**
- **Gas phase formation**
- **Geological trapping structures**
- <u>**Preservation in the trapping structure ?**</u>



THANK YOU VERY MUCH ! ANY QUESTIONS ?