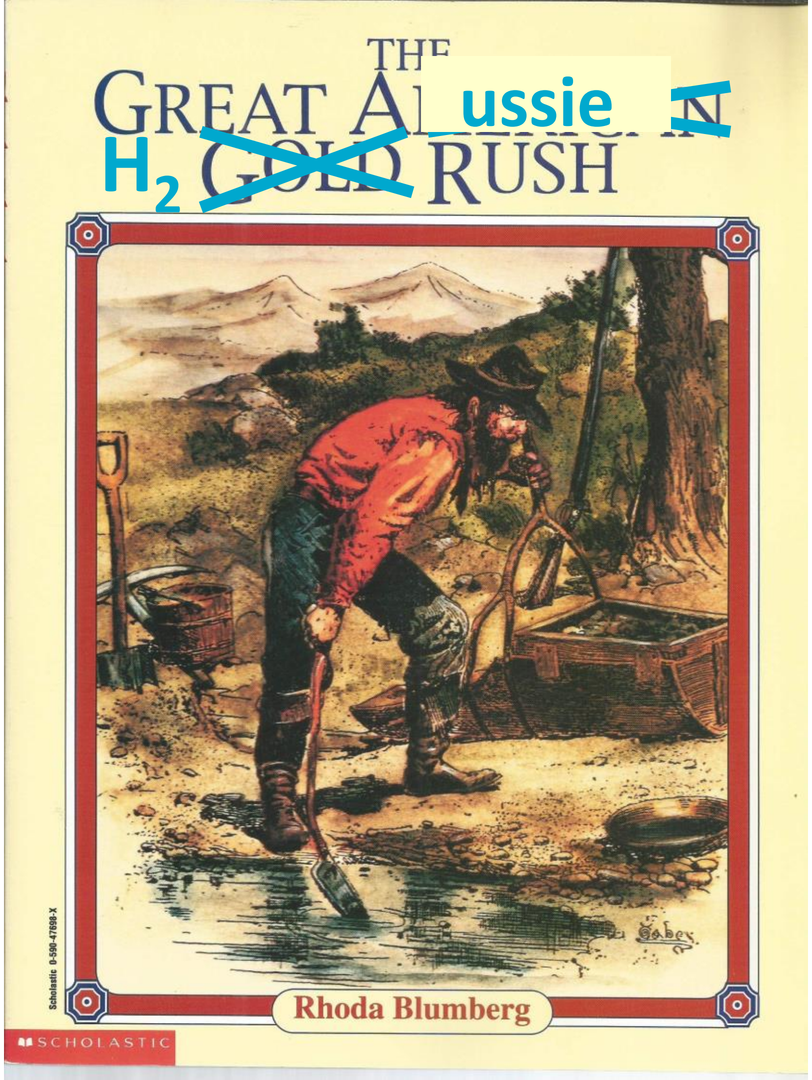
Gold (H_2) rush:

Risks and uncertainties in exploring for naturally occurring H_2

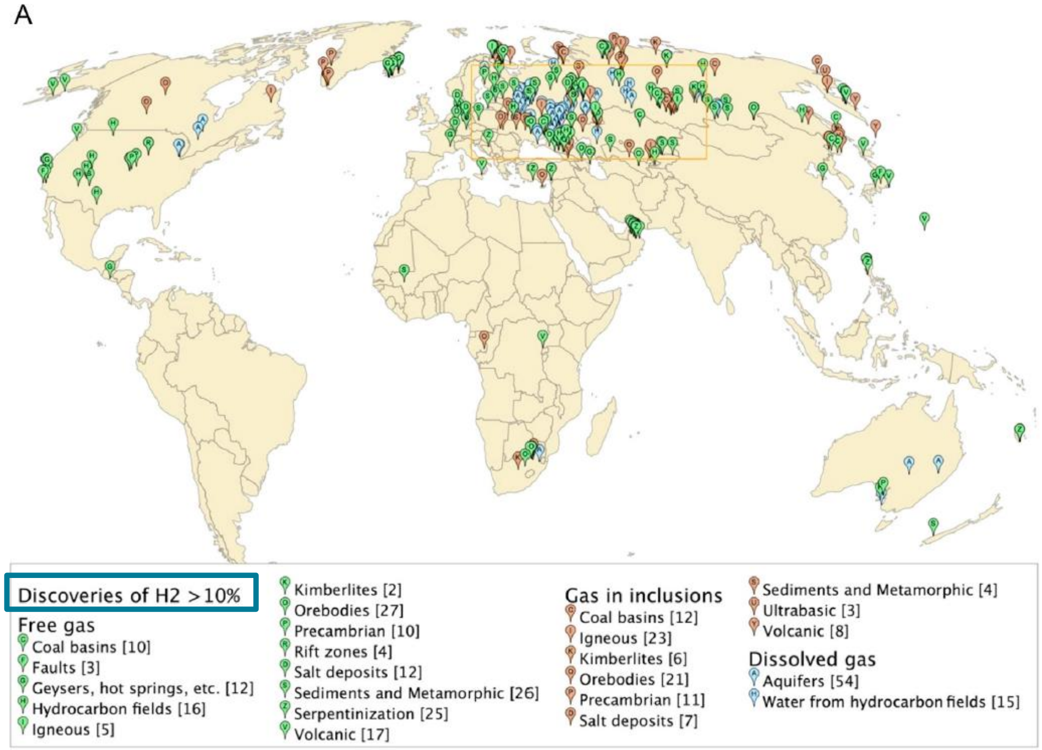
Linda Stalker| May 2022

& Talukder, Strand, Josh & Faiz

Australia’s National Science Agency



Global distribution



Ref. Zgonnik, 2020

Skewed datasets

- This study only looks at >10% H_2

Old datasets

- Usually means data is a bit more unconstrained

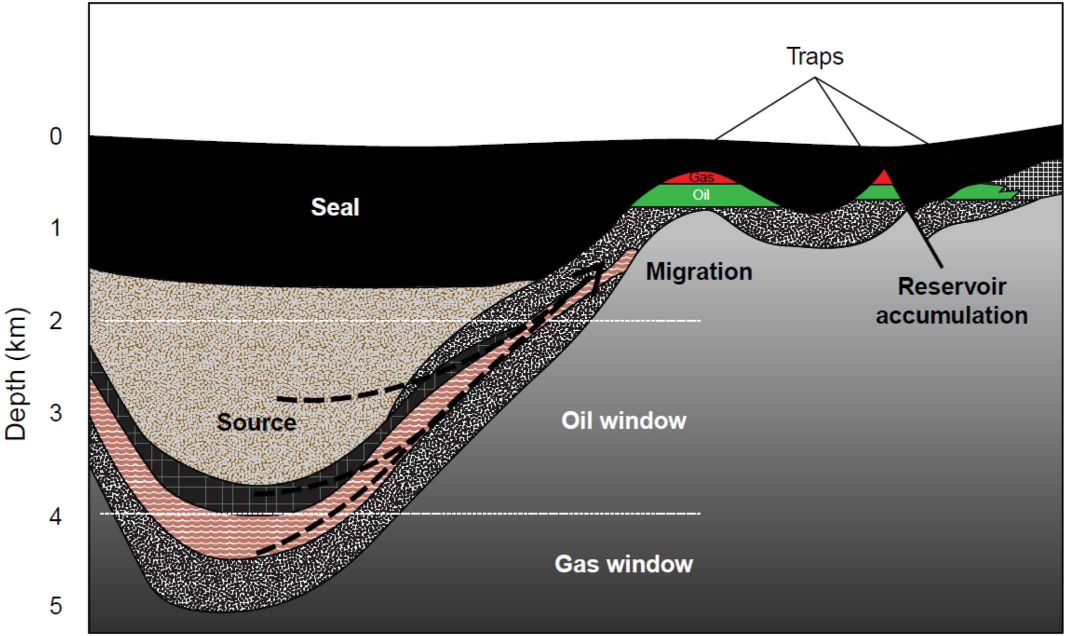
Not looking…

- We weren't looking for tight/shale gas
- Didn't check for H_2 or He in natural gas

Healthy scepticism

- Abiogenic gas becomes popular (again….!)

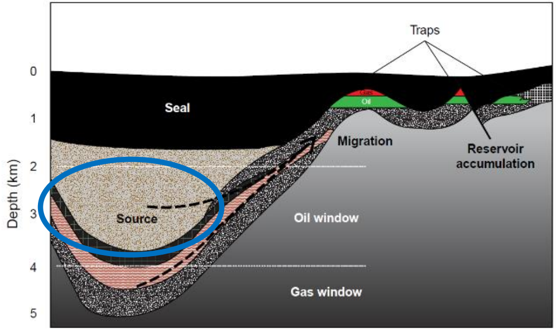
An Exploration Mindset



- Source
- Migration
- Trapping & Accumulation
- Leakage

Source

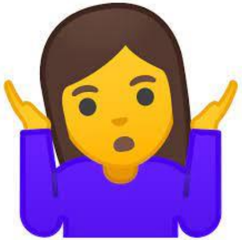
There's lots!



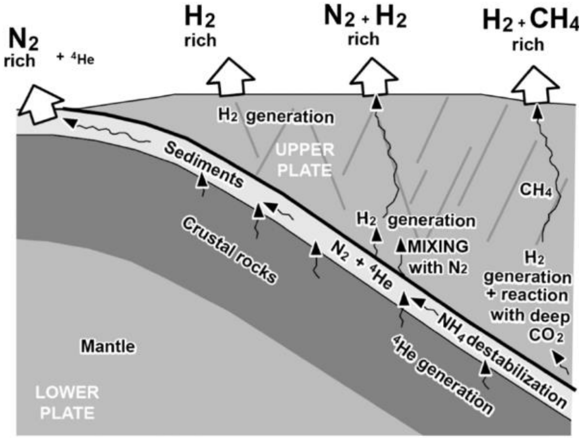
- Ancient rocks
- Ophiolites/serpentinisation
  - Ultramafics
  - Mid-ocean ridge basalt (MORB)
- Volcanics/arcs
- Role of iron-bearing rocks
- Magmatic/primordial
- Radiolysis
- Organics and biological
- Etc.

- Mechanisms of generation of hydrogen
  - Heat/temperature
  - Depositional age
  - Structural impacts/metamophism
  - Chemistry
  - Rates & timing
  - Co-produced materials & proxies

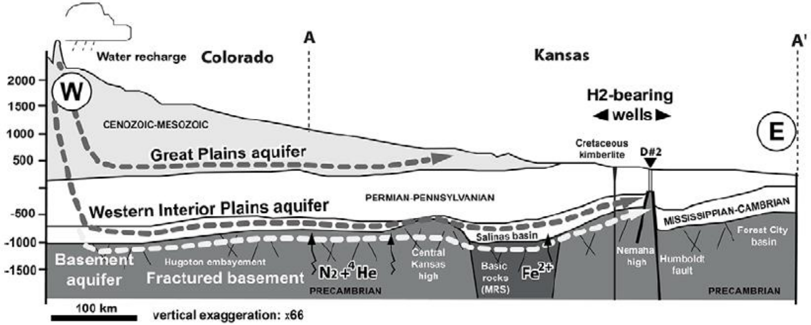
Migration



- **Hypotheses**
  - Buoyancy
  - Pressure changes
  - Dissolved in water
  - Importance of wettability
  - All manner of fault-based unknowns….
  - Seepage and leakage indicators
  - How much is lost in diagenesis/mineral reactions/microbiology



Vacquand et al (2018)



Guelard et al. 2017

Wettability & Solubility

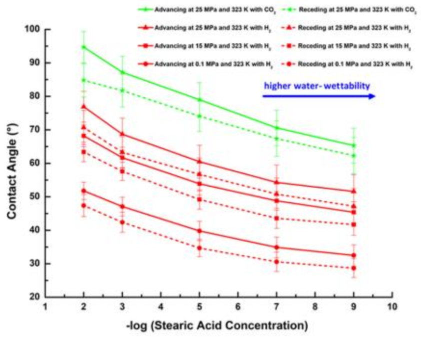


Figure 1. Brine contact angles on the quartz surface in H_2-atmosphere as a function of stearic acid concentration. The green lines show literature data for CO_2 taken from Ali et al. (2019). Water wettability increases to the right as indicated by the blue arrow. Note that stearic acid concentration is plotted as the negative decadic logarithm on the *x* axis, that is, stearic acid concentration decreases exponentially toward the right side.

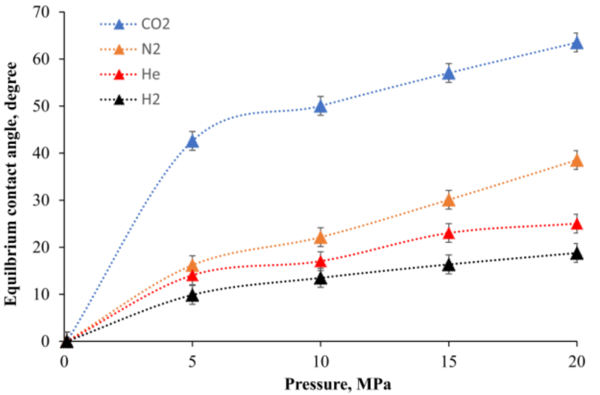


Fig. 1. Equilibrium brine contact angles for CO_2, N_2, He, and predicted equilibrium brine contact angles for H_2 on Basalt substrate as a function of pressure at constant temperature (323 K).

Iglauer et al. (2020)

Al-Yaseri & Jha (2021)

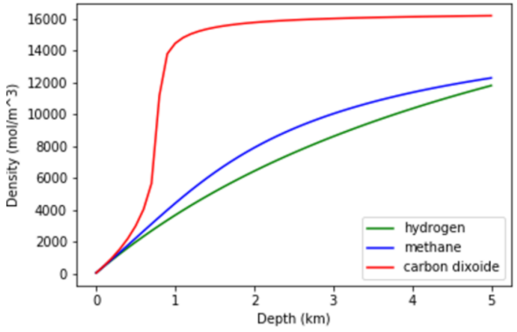


Figure 27: Comparison of molar density (in mol/m³) of hydrogen (green curve), methane (blue curve) and carbon dioxide (red curve) as a function of depth, for a hydrostatic gradient of 10 MPa/km, and a geothermal gradient of 25 C/km, with an average surface pressure of 0.101325 MPa and an average surface temperature of 15C.

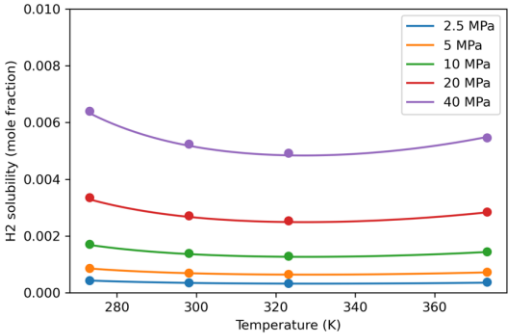
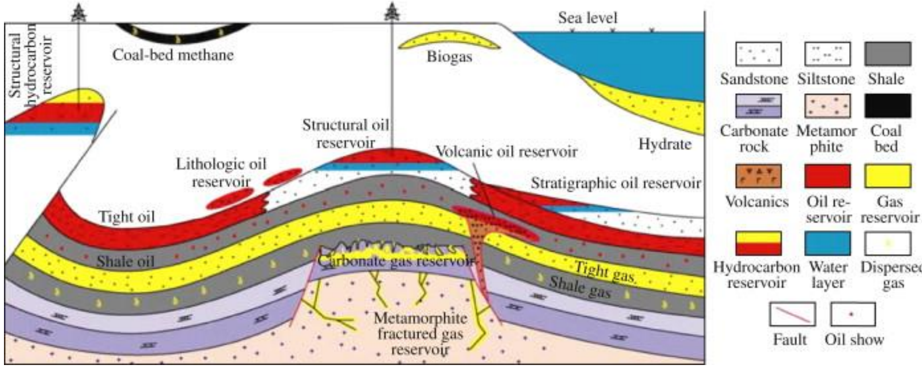


Figure 30: Solubility of hydrogen in water as a function of temperature, for various pressures. The solid lines are the representations of Li et al. (2018), and the dots are the experimental data of Wiebe and Gaddy (1934).

Ennis-King et al. (2021)

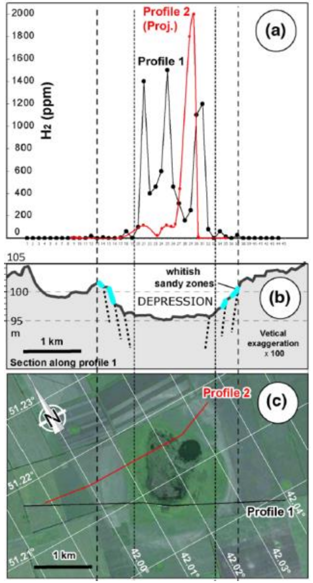
Trapping and accumulation

- **Barriers, traps and baffles….which work?**
  - Is it all vertical migration based
  - Geometry and focal points? Concentration of fluids?
  - Optimum depths for accumulation
    - Proximity to source
    - Proximity to trap
  - Charge versus recharge - important or essential?
  - Phase – free gas, dissolved, phase envelopes etc
  - Role of minerals and clays on adsorption/alteration
- Does it only work for the tightest barriers (Mali dolerite sills example)
- Salt!
- Mass balance - multiple source feed AND dynamic accumulation??

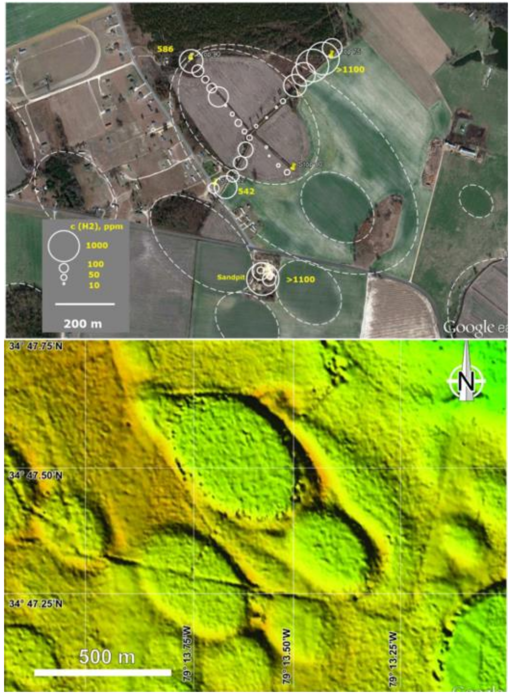


Caineng Zou, 2013

Seeps and leaks: enigmatic surface features



European Craton in Russia, Larin et al. 2015



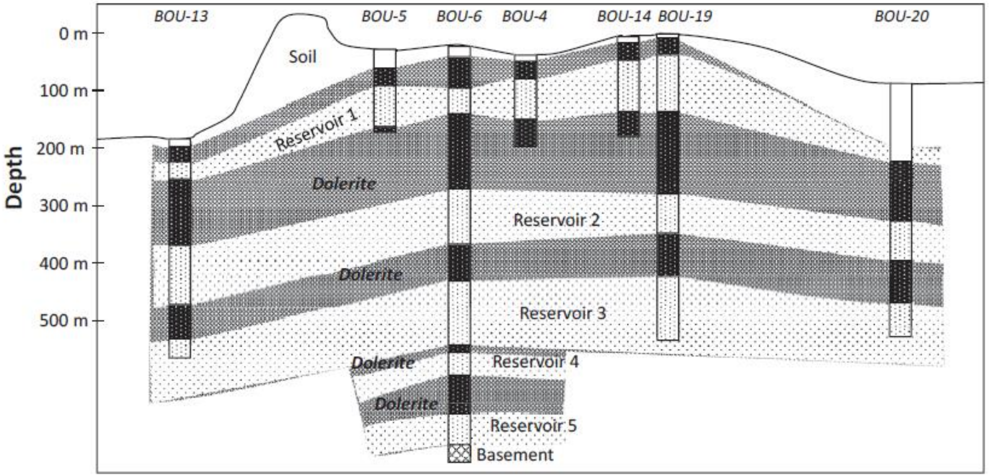
Carolina Bay, Zgonnik et al (2015)

1. AKA fairy circles, H_2 seepage occurs mainly through the peripheral sand rim.
   Features only occur where the weathered bedrock below the soil consists of unconsolidated granular sediments (Larin et al. 2015; Zgonik et al., 2015)
2. These features can be everywhere…
3. See Frery et al 2021 for more info

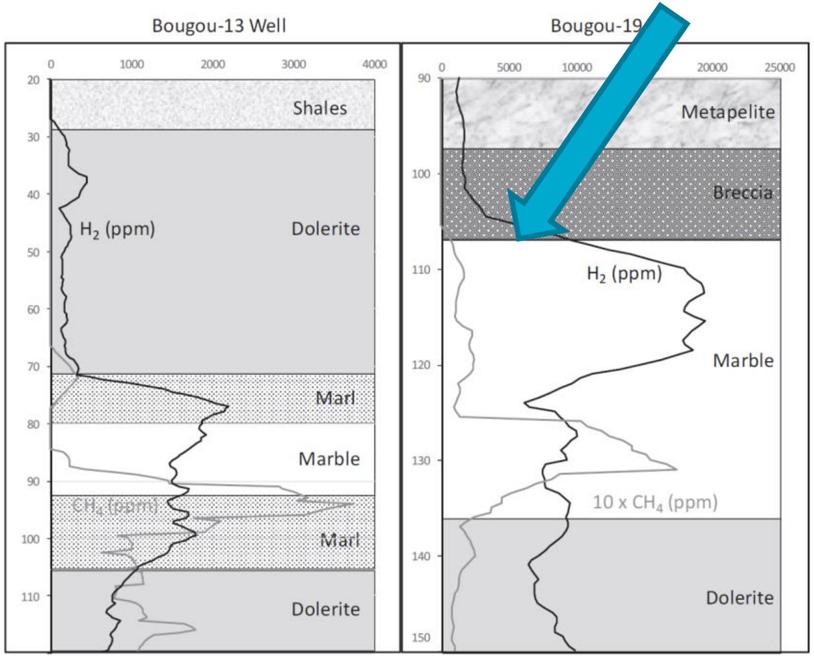
Pingrup, WA
And many other examples

Hydrogen trapping

Mali Case Study (Prinzhofer et al, 2018)



Hydrogen is reservoir in sedimentary layers
Primary seal is a series of dolerite sills
At shallower levels low water solubility can potentially act to trap H_2 e.g. shallow water-filled breccia



H_2 systems framework

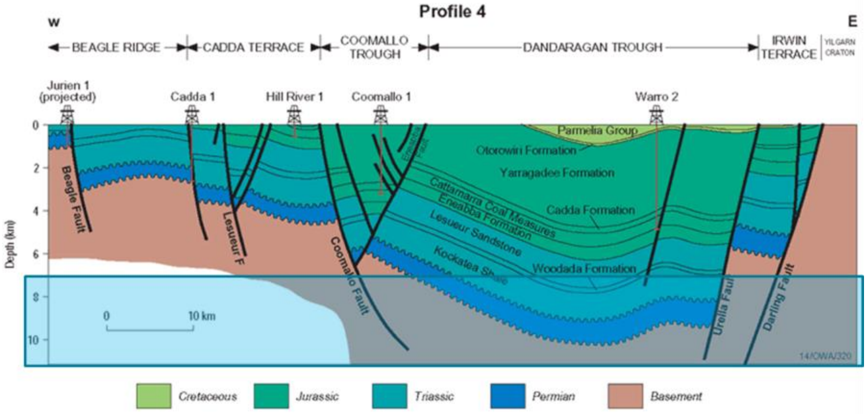
Target	Definition	Basin scale/ craton scale	Prospect	Tools & sensors
Leakage indicators	Fairy circles, faults reaching surface, evidence of hydrogen generation	Potentially many, may not be related to hydrogen, may be hydrology	Zero –many: may not be related to hydrogen, may be hydrology	Google Earth!
# sampling targets	i.e. leakage indicators and observed accounts combined	Could be hundreds – could be none – the cover will be critically important.	From zero to many – could be difficult to rank without other information	GA and State Geological Survey information, GIS evaluations. Industry work released, journals and reports
H_2 observed	Documented evidence of H_2, or He (proxy) in well completion reports, or other sample reporting	Data mining of well completion reports and other databases show indicators – poorly curated	Well samples with data reported, depths and formations – integration with surface indicators	Historical WCRs, State, Fed, industry databases. Laboratory records. New lab practises, field sampling
Source	Geological information that fits with any (or several) of the possible sources of H_2 e.g. Basement/mantle, greenstones/ultramafics, radiolysis/radioactive, other Fe-rich materials, (micro)biological…..	Many possible sources. May be mixed sources, co-contributions from more than one source	Absent to multiple sources depending on location	Inferred from new sample analyses, older geological data, hypotheses and models based on other examples. May require lab experimentation, modelling and analogues in the absence of modern analyses.
Potential traps/seals	Mechanism that retards or reduces migration & escape of H_2. From thick mudstones, salt, igneous intrusions, or structural/stratigraphic geology	May be localised. Hard to define when mechanisms of migration/ accumulation/ trapping are poorly understood and unpredictable. General geological information	Geological evidence of a barrier from existing geological/seismic data & any well data	State, Fed, industry databases, seismic data packages other information. Well logs, GIS to define presence/absence of key geological features
Accumulation potential	A place in which hydrogen can migrate to and stay (relatively) in place. Where H_2 comes in faster than it leaks out (low flux to surface) – i.e. what might a reservoir look like?	May be localised, and at small scale relative to the area. Will provide some rationale as to potential areas to target for greater data acquisition. Depth of accumulation would be important to understand relative to source, migration and secondary effects	Geological evidence of a body of porous rock that can hold a volume of gas, defined by existing geological/seismic data & any well data. Gives enough information to define potential volumes of gas in place	State, Fed, industry databases, seismic data packages other information. Well logs, GIS to define presence/absence of key geological features
Accessibility	(a) For testing/evaluation (b) For accessing/integrating with relevant infrastructure (c) Tenements/permits/resource conflicts	(a) Australian scale issues and access (b) Ability to bring gas to market (c) Provides focus areas within wide regions, can align access already granted	Same issues as for the basin/craton scale.	Google Earth! And understanding of infrastructure, pipelines, points of utilisation, temporary or permanent storage of H_2 prior to use or export

A template for identifying possible locations

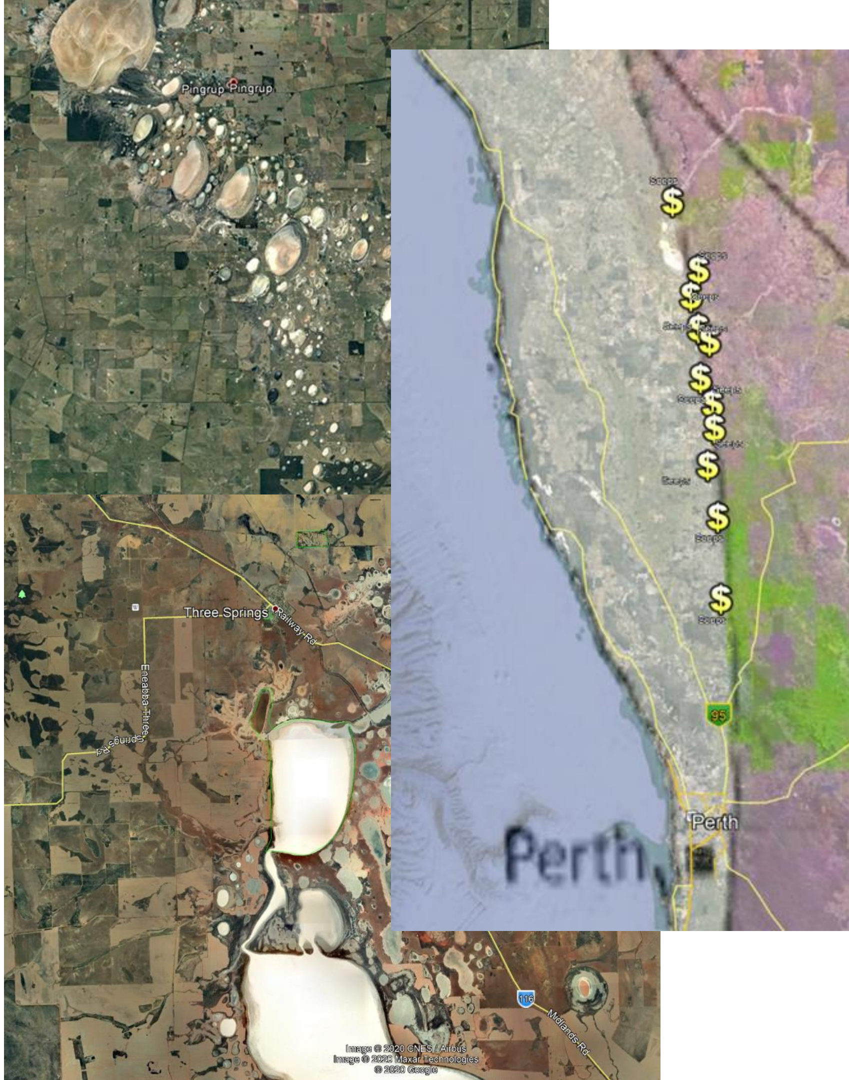
Target	North Perth Basin	Yilgarn Craton	Kangaroo Is/ Yorke Peninsula	Lake Dora, South Canning	Amadeus Basin wells	Meda-1, North Canning
Leakage indicators	Many	Even more	Many	Several	Undetermined	Few, not close by
# sampling targets	Hundreds	Erm… thousands	Many tens	A couple of dozen	Many including Mt Kitty 1 and Magee 1. Both showing helium, Mt Kitty showing hydrogen	Abandoned well site; possible surface features nearby
H_2 observed	Yes, Aramall-1 WCR 50-75% (not to mention Varma, Underschultz & al.)	Yes, recent Frogs Leg gold mine paper (Boreham et al, 2021) 19.9-68.7 mol% (and hydrocarbons)	Yes, Ward (1933) paper, WCR equivalents, 60-85% range	No, although I doubt anyone has looked	Yes, H_2 present in some reservoirs Helium also observed	Significant H_2 locally in Meda-1. Numerous well tests, 2 with ~90% H_2
Source	Yilgarn Craton Basement Potential greenstones/ultramafics	Yilgarn Craton Basement Potential greenstones/ultramafics	Gawler Craton? Whatever is underneath the Adelaide Superbasin? Donington Granite was a potential radio-active source here?? Belpiro et al 1995 and Gehling et al 2011.	Pilbara Craton Basement, uranium, and probably others…	? whatever basement is under the Amadeus Basin?	Kimberly Craton
Potential traps	Proven hydrocarbon traps	Evidence of intrusives and sediments/reservoirs (c.f. Prinzhofer et al, 2016 Mali case study)	Potential hydrocarbon-style traps	Potential hydrocarbon-style traps or salt-related traps	Proven hydrocarbon traps. Gillen salt formation also a proven hydrogen/helium trap from the Peter Haines publications, and other papers	Proven hydrocarbon traps nearby
Accessibility to **(a) population/infrastructure**	(a) Good (e.g.….) (b) No..?	(a) Variable (e.g. Frog's leg close to Kalgoorlie infrastructure	(a) Good (b) doubtful	(a) Not so much… an unsealed road goes quite near	(a) guessing not too handy	1. Quite remote, not too far from Derby

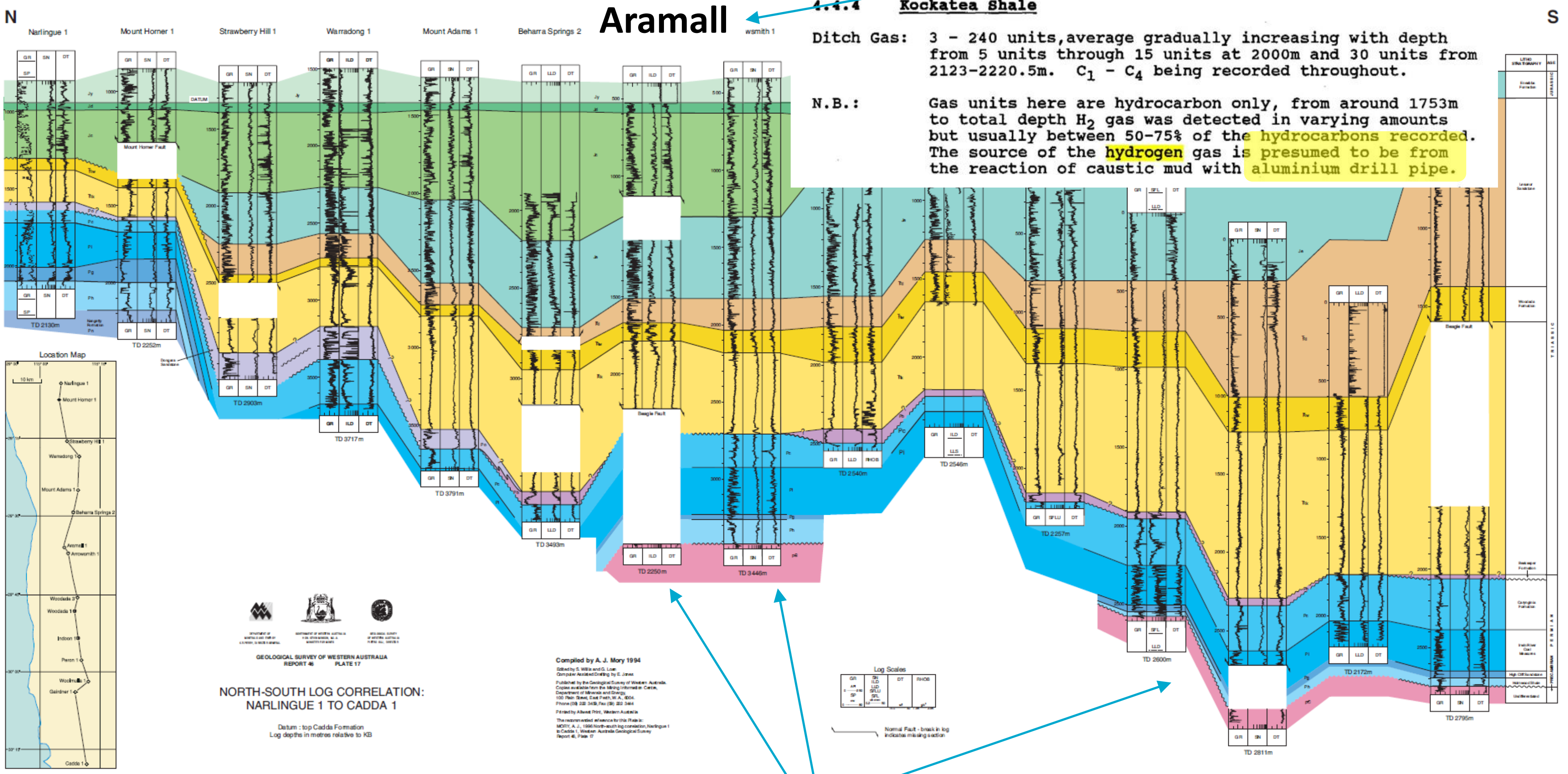
North Perth Basin

- Abundant leakage indicators
- H_2 find at Aramall-1 (50-75%) (north of Woodada)
- Source(s) of H_2
  - Serpentinization sweetspot at 7-12 km
  - Yilgarn basement adjacent/under?
  - Granite – radiolysis potential
- Accumulation
  - Potential sandstones from Perth Basin development
- Trapping
  - Thick shales



East-west structural section across Dandaragan Trough and adjacent terraces. (Modified from Crostella, 1995; Song & Cawood, 2000)



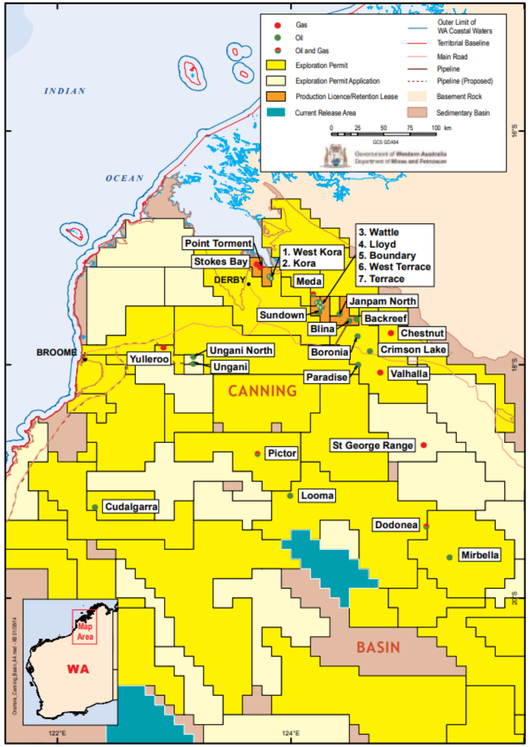


4.4.4 Kockatea Shale

Ditch Gas: 3 - 240 units, average gradually increasing with depth from 5 units through 15 units at 2000m and 30 units from 2123-2220.5m. C_1 - C_4 being recorded throughout.

N.B.: Gas units here are hydrocarbon only, from around 1753m to total depth H_2 gas was detected in varying amounts but usually between 50-75% of the hydrocarbons recorded. The source of the hydrogen gas is presumed to be from the reaction of caustic mud with aluminium drill pipe.

North Canning: Meda-1



Basin: FITZROY Field or Structure: MEDA State:

Company :	West Australian Petroleum Pty Ltd.			
Well Name :	Meda No. 1			
Well Location:	17° 24' 00" S 124° 11' 30" E			
Interval Tested (Feet) :	7594-7669	6594-6695	5110-5113	
Formation - Age & Name :	Dev. Fairfield (Reef Complex)	ditto	L. Carb.-Laurel	
Type of Test :	DST 6C	DST 7C	DST 9	
Flow Rate - Gas (MMCF/D) - Liquid (BBLS/D)			GCW	
Date of Sampling		29-10-59	14-11-58	
Date of Analysis :		19- 2-59	19-11-58	
Analysis by, and Method:	BMR GC	BMR GC	W.A.G.L. GC	
COMPONENT (MOLE %)				
Methane	75.2	56.7	0.5	0.4
Ethane	0.9	1.2		
Propane	0.14	0.37		
Isobutane	0.02	0.12		
N-Butane	0.02	0.09		
Isopentane				
N-Pentane				
2-Methyl Butane				
2-Methyl Pentane				
3-Methyl Pentane				
Hexane				
Heptanes+				
Nitrogen	19.4	21.2		
Oxygen	3.1	11.2	0.5	0.5
Argon				
Hydrogen		2.9	95.3	91.2
Helium				
Carbon Monoxide				
Carbon Dioxide	1.5	6.5	3.7	3.6
Hydrogen Sulphide				

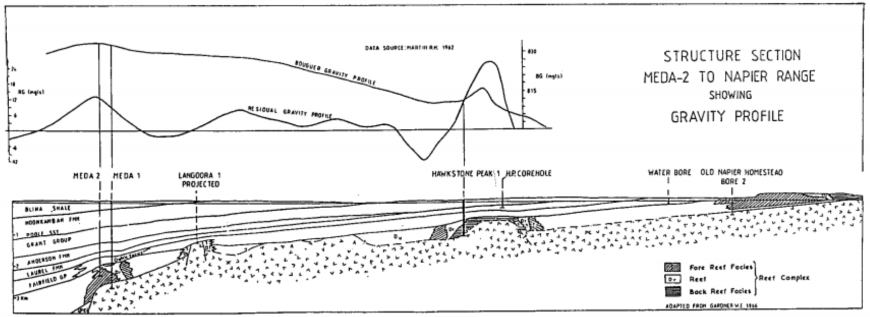


FIGURE 5
Geoseismic Structure Section Meda 2 to Napier Range
The location of this section is shown in Fig. 4. It crosses buried palaeo-Langoora Island and fringing reefs, palaeo-Napier Straits, and mainland fringing reef in outcrop. Residual gravity positives mark the position of basement ridges and/or carbonate build-ups.

Taylor, 1992

Conclusions

Gaps identified	Closing that gap
1. Lack of confirmatory data	i. Analogues and documented finds revisited
2. Lack of current practises for routinely analysing for hydrogen in well test fluids or production fluids	ii. How were early well tests characterised? What do we need to do differently to now (back to old methods)? Define the sampling and analytical protocol.
3. Need to confirm seep locations against existing observations to prove up potential for a **hydrogen system**	iii. Seeps are confirmation of source generation mechanisms – find seeps to reduce risk. Then look at the underlying geology
4. Further define the key components of a **hydrogen system**	iv. What components are missing – is CH_4 or other gases a good proxy to model a hydrogen system?

Check those assumptions!

Thank you

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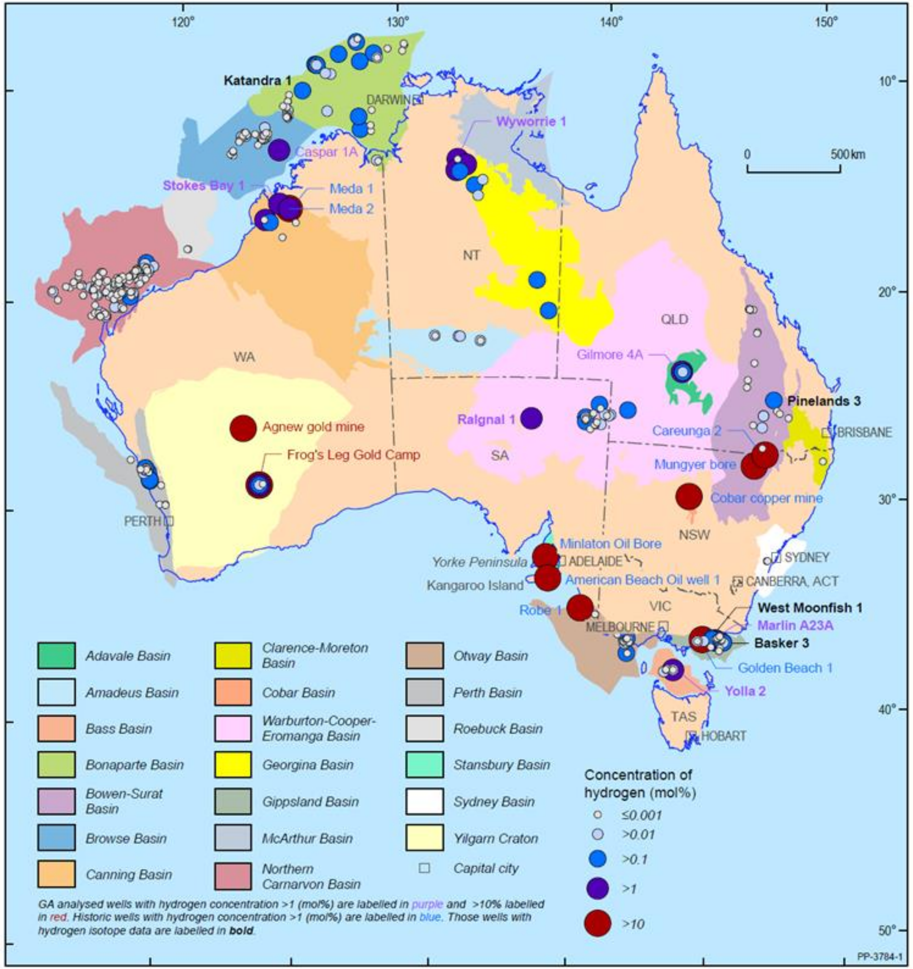

Boreham et al, 2021
APPEA 2021