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Modelling of hydrogen gas generation from overmature organic matter in the Cooper Basin, Australia

Christopher Boreham[1*], Dianne Edwards[1], Andrew Feitz[1], Andrew Murray[2], Nicolaj Mahlstedt[3], Brian Horsfield[3]

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Exploring for the Future (EFTF)
- Low Carbon and Geoscience Advice project

Mapping H_2 production and storage

- AusH2 – Current hydrogen projects in Australia (AusH2.ga.gov.au)
- HEFT – Hydrogen Economics Fairways Tool (ga.gov.au/heft)
- Searching for salt accumulations in Australia
- Geomechanics of underground hydrogen storage

H_2 from geologic sources (Natural H_2)

- Document natural H_2 in natural gases and fluid inclusions
- H_2 surface seepage studies
- Numerical modelling and resource potential of natural H_2

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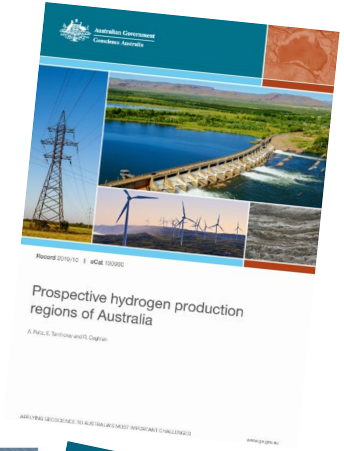


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Peer reviewed paper

Hydrogen in Australian natural gas: occurrences, sources and resources

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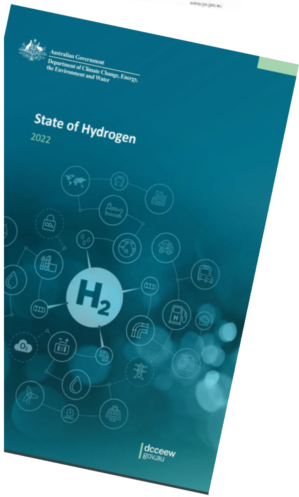

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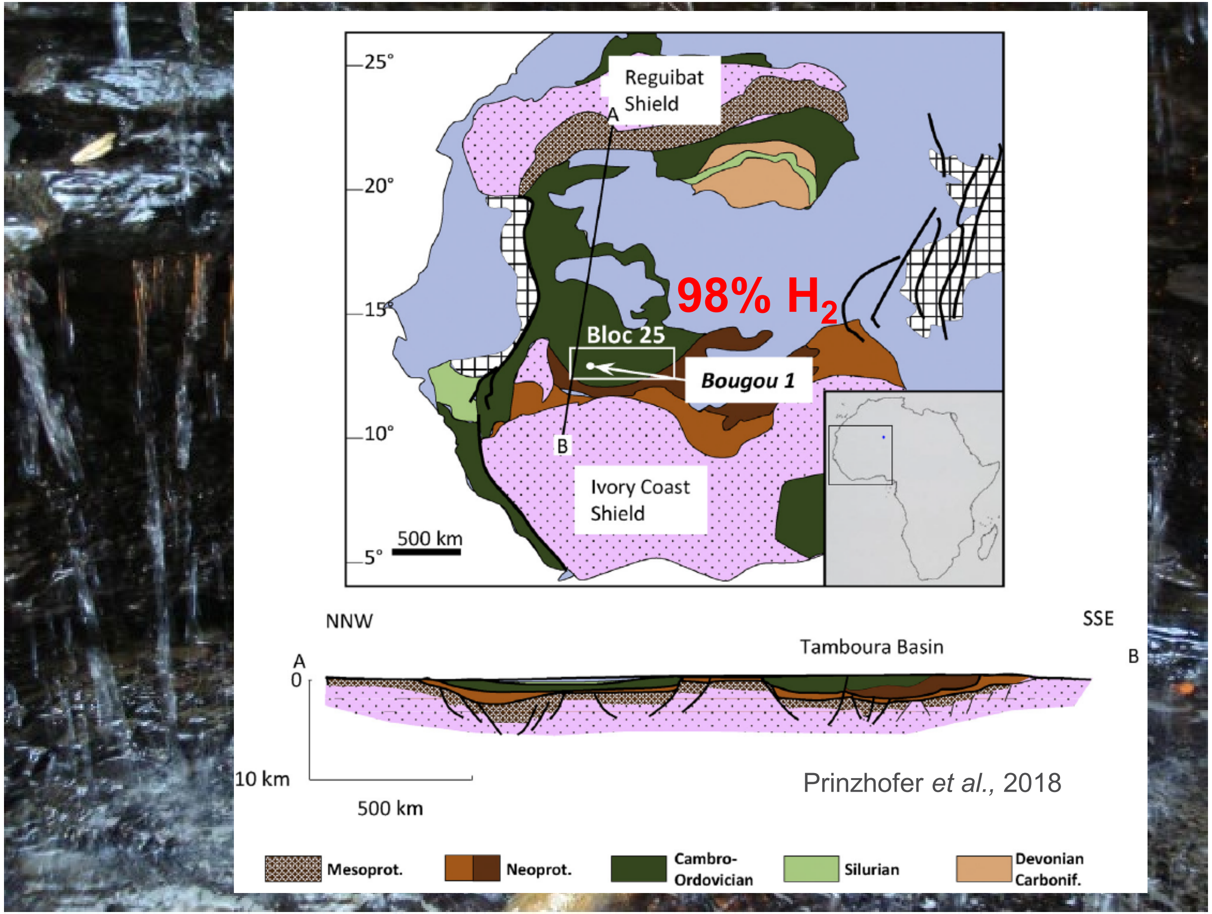
The Chimaera burning gas (CH_4 and H_2) Turkey.
Etiope & Schoell, 2014. DOI: 10.2113/gselements.10.4.291



Chesnut Ridge Park, N.Y. https://www.livescience.com/29510-eternal-flames-natural-gas-source.html

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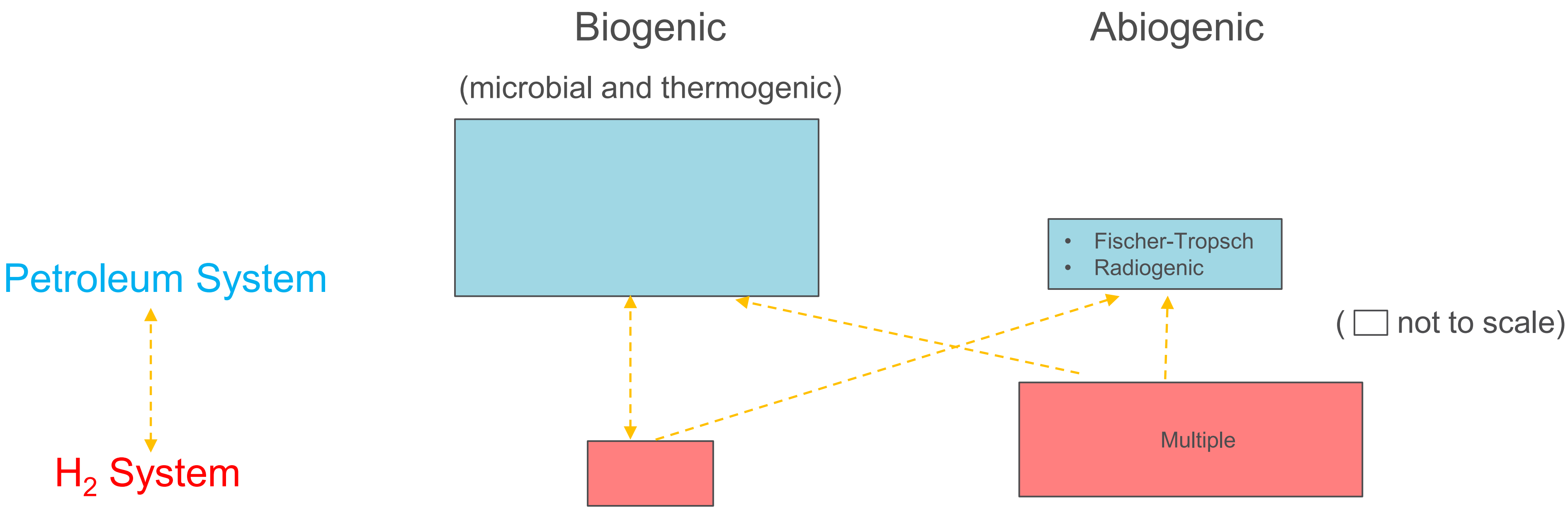
Sources of Natural Hydrogen



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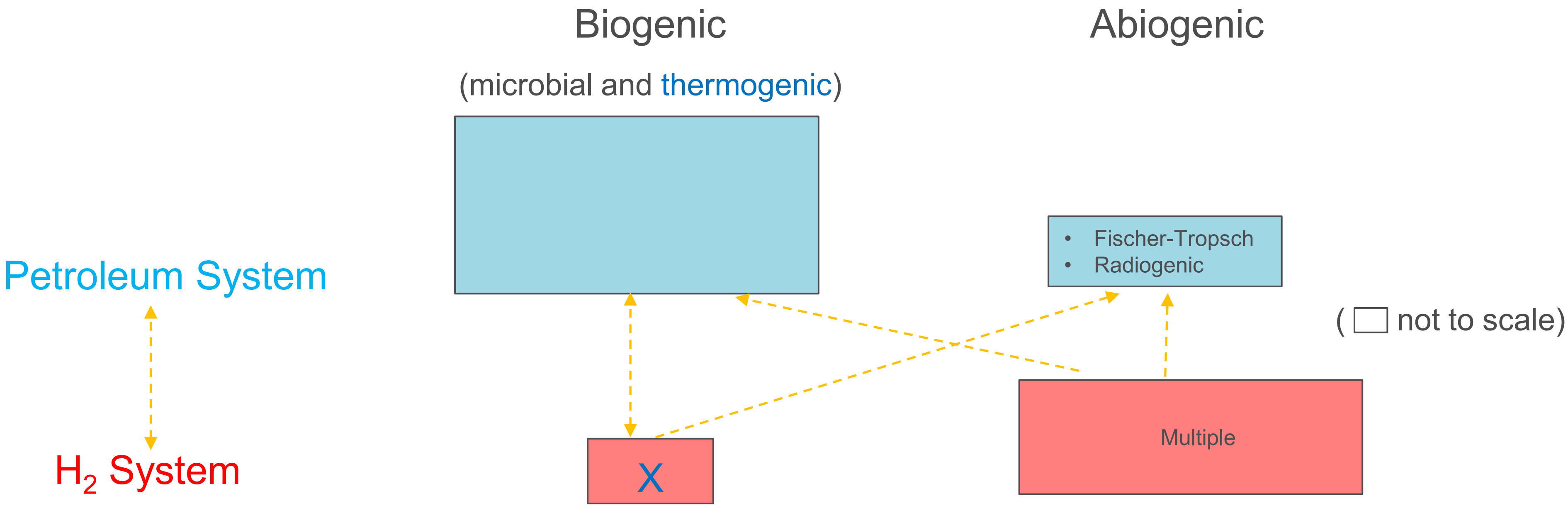
Sources of Natural Hydrogen



Hand, 2023 “If thermogenic H_2 survives, geologists thought, it should not accumulate”

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Sources of Natural Hydrogen

Serpentinisation of ultramafics ($Fe^{2+} \rightarrow Fe^{3+}$)
Volcanic activity and hydrothermal vents
Cooling of CO_2-CH_4-C fluid systems
Basic magmatic crystallisation
Degassing primordial H_2
Metasomatisation with metal hydrides
Hydration of biotite
Hydration of siderite
Magnetite to hematite crystallation
Pyritisation
Water hydrolysis
Water radiolysis
Radiolysis of organic matter
Radiolytic dehydrogenation of oil
Radiation inducted polymerisation of methane
Cataclastic of silicates

Phosphine hydrolysis
H_2 release from fluid inclusions
Decomposition of methane to graphite
Oxidative coupling of methane
Mixing of water with different ionisation potentials
High temp reaction of ammonium ion with sulfate ion
Dehydrogenation of clay minerals
H_2 from H_2O at high metamorphic temperatures
Biological activity
Thermogenic OM cracking during aromatisation/condensation
High temperature decomposition of alkanes & carboxylic acids
Thermochemical sulphate reduction
Drill bit metamorphism
Oxidation of steel pipes
Corrosion of steel well casing by H_2S
Acidic corrosion reactions…

Boreham *et al.*, 2021; Milkov, 2022

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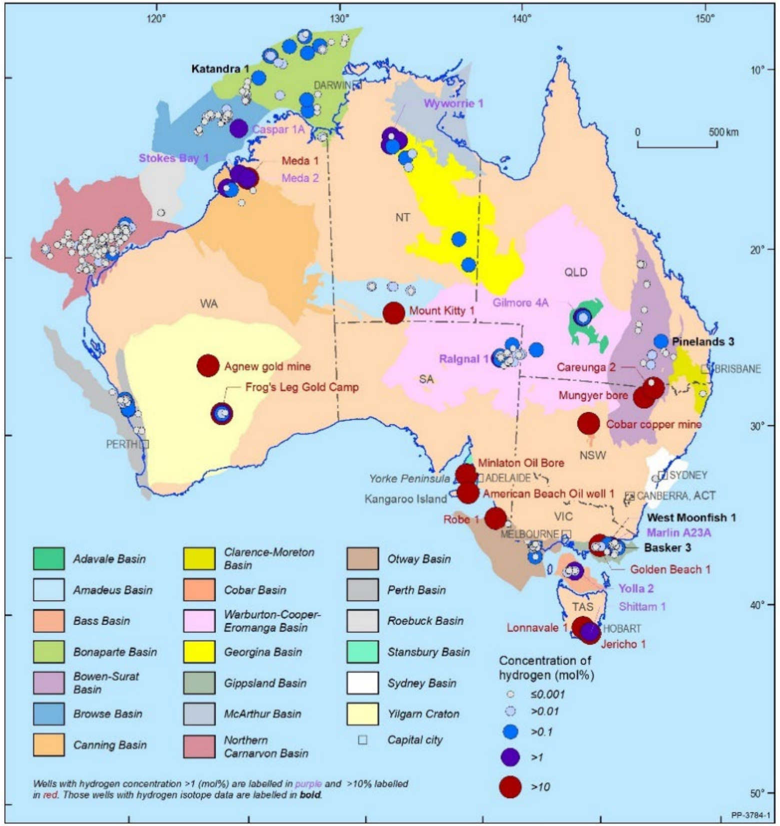
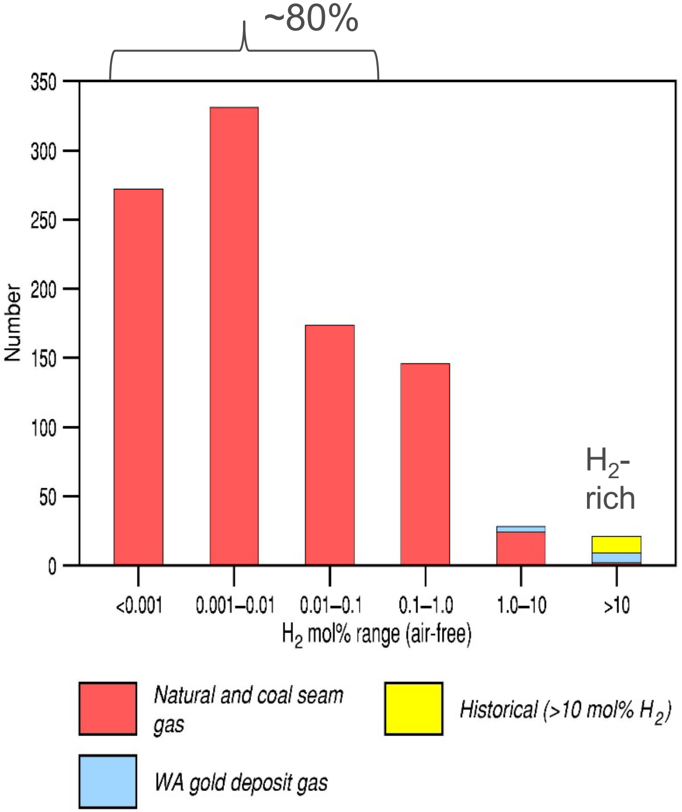
How much and where is hydrogen found in Australia natural gases?





Boreham *et al.*, 2021. APPEA J. https://www.publish.csiro.au/aj/pdf/AJ20044

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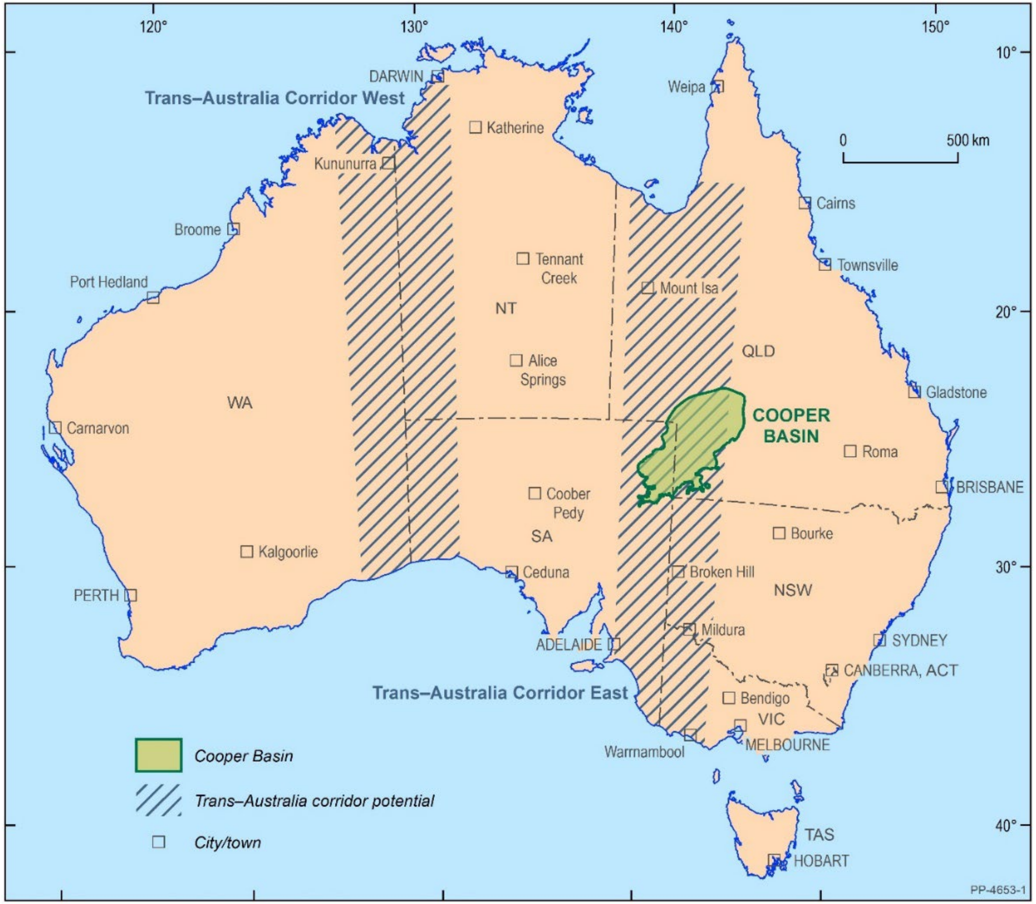

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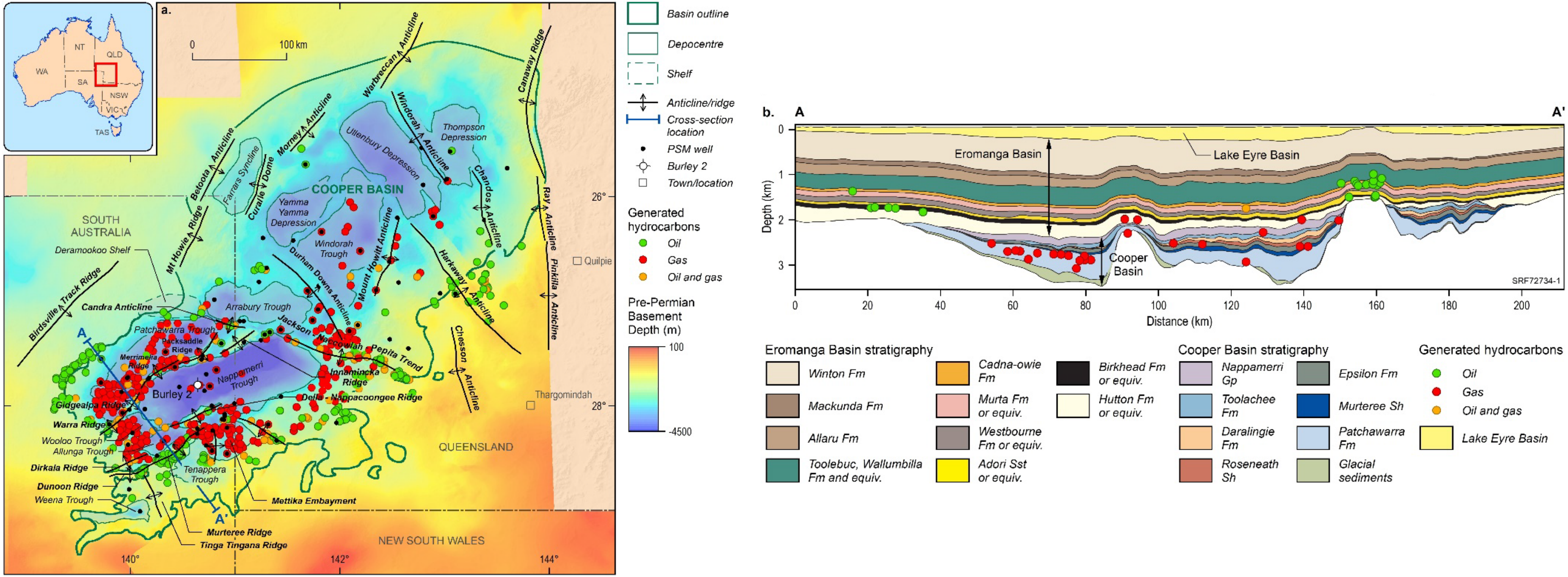

Modified from Hall et al., 2019. AAPG Bulletin 103, 31–63. https://doi.org/10.1306/05111817249

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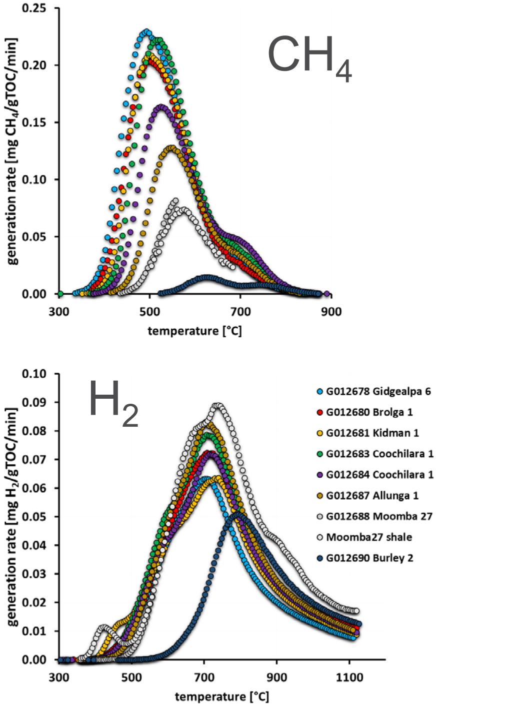
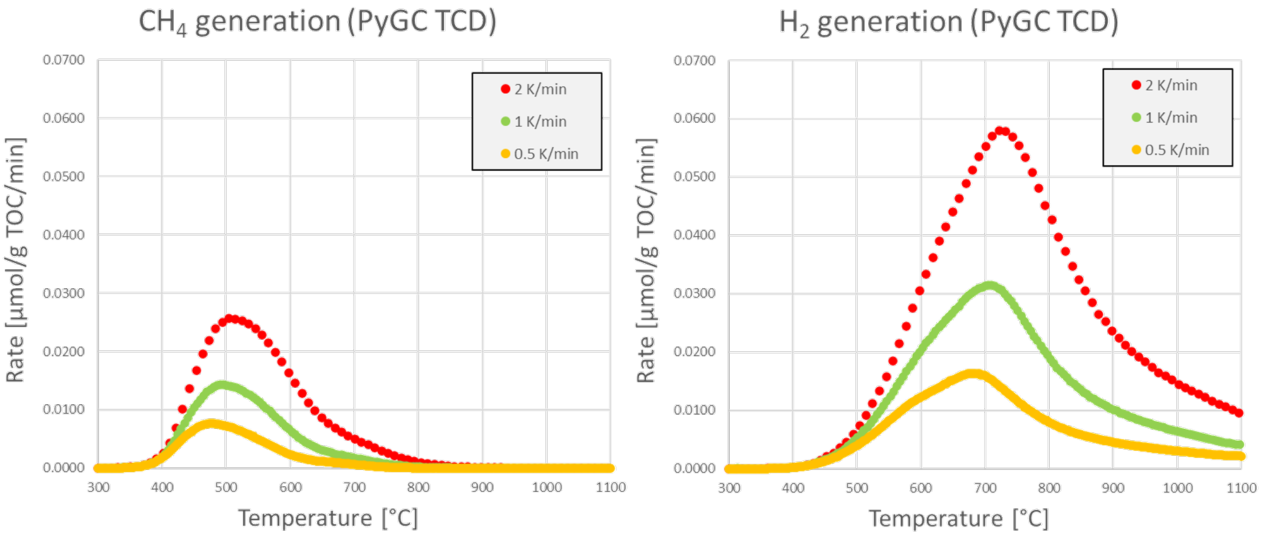
Artificial maturation of organic matter (kerogen)



Open system pyrograms displaying CH_4 and H_2 evolution (mg/gTOC/min) at 1 ^oC/min for a Patchawarra Fm. maturity sequence



CH_4 and H_2 generation rate curves for marginally mature Gidgealpa-6, Patchawarra Fm. at three different heating rates (0.5, 1.0, 2.0 ^oC/min).

Mahlstedt et. al., 2022. J. Nat. Gas Sci. Eng., 105, 104704

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Chemical kinetics: organic matter (OM) $\xrightarrow{\text{heat/time}}$ $H_2 + CH_4 + \ldots$

1º order reaction rate of X: $d[X]/dt = -k[X]$

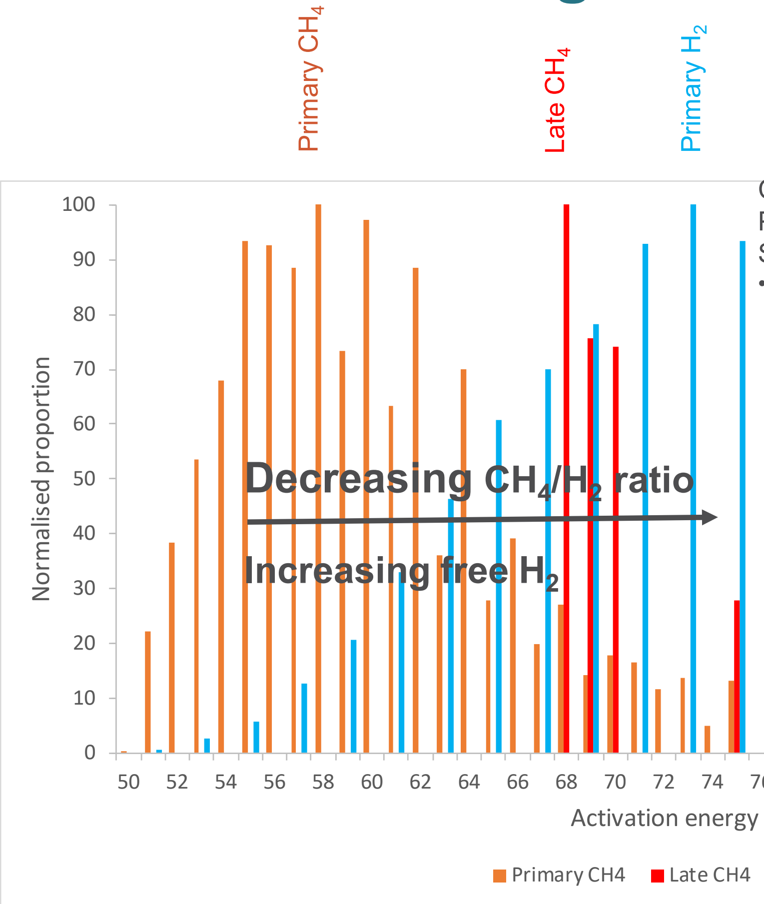
$k_{1..n} = A_{1..n}e^{-Ea_{1..n}/RT}$ (Arrhenius approximation)

Cooper Basin coal

Parallel 1º order reactions (incremental increase in Ea)

Set Arrhenius constant (A) = 1E+13 s^{-1}

- Mahlstedt et al.* where A is optimised
  - total H_2 generation potential = 20 mg H_2/g TOC



$$OM \xrightarrow{\text{heat/time}} \text{'}R^{\cdot} + R^{+} + RC{=}C\text{'} \xrightarrow{H_2} RH$$

'reactive intermediates'

*Mahlstedt *et al.*, 2022. J. Nat. Gas Sci. Eng., 105, 104704

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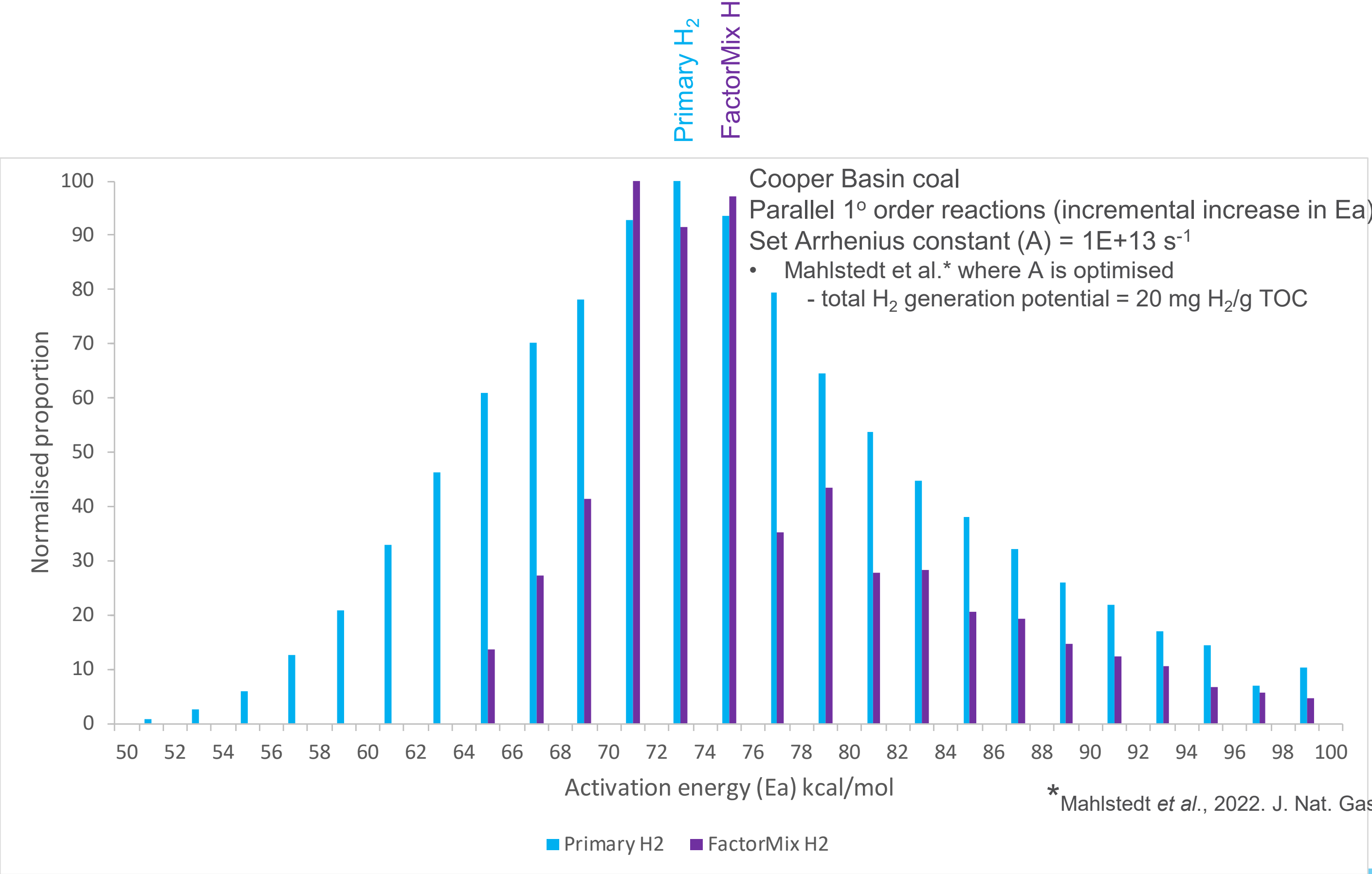

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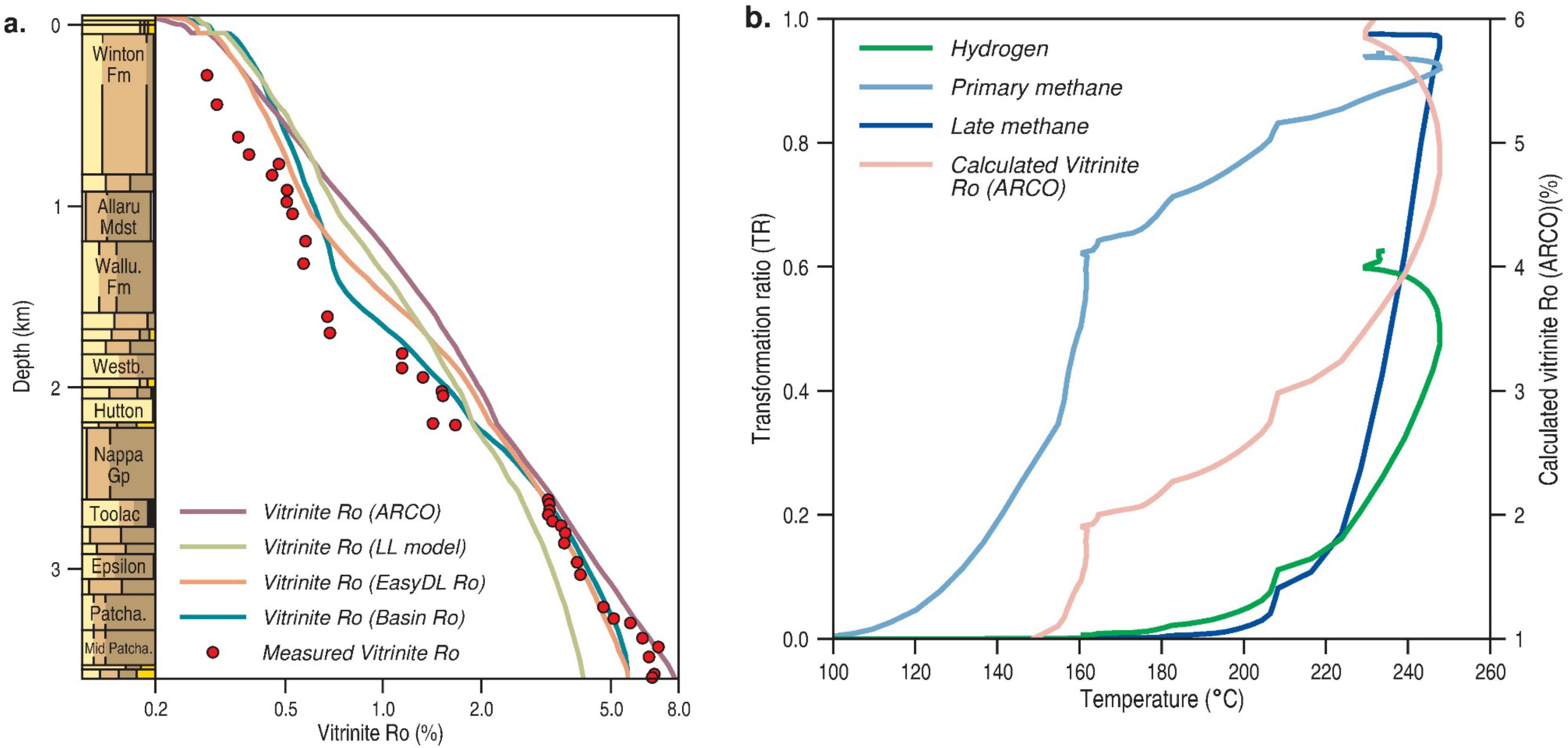
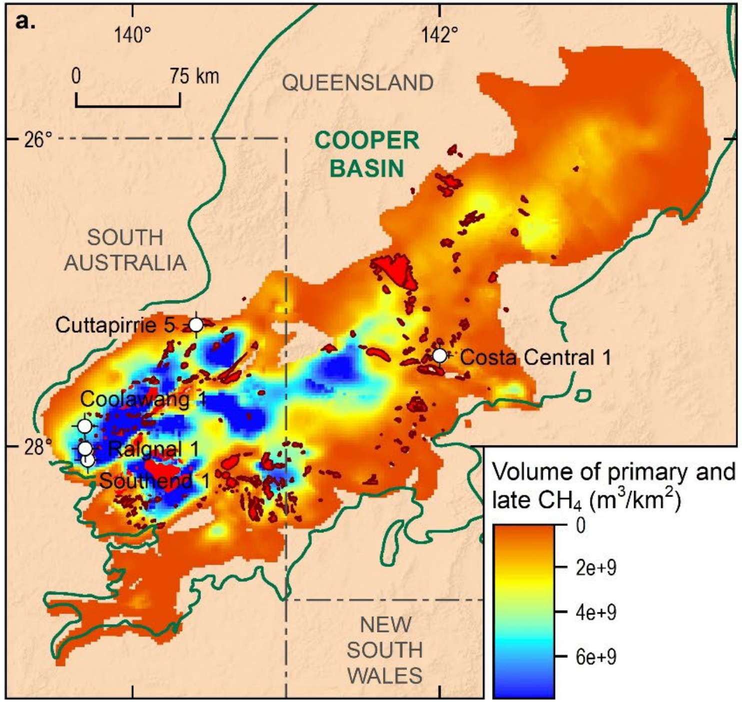
Mid-Patchawarra source rock: thermal & maturation history at Burley-2



Mid-Patchawarra coal and carbonaceous shale

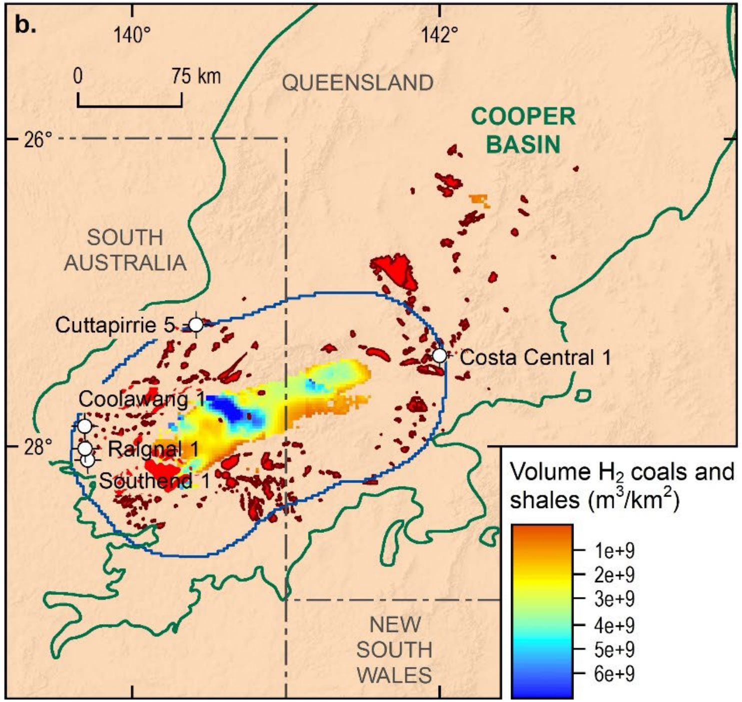
Primary Methane + Late Methane



Primary methane = max. 50 mg CH_4/g TOC

Late methane = max. 40 mg CH_4/g TOC

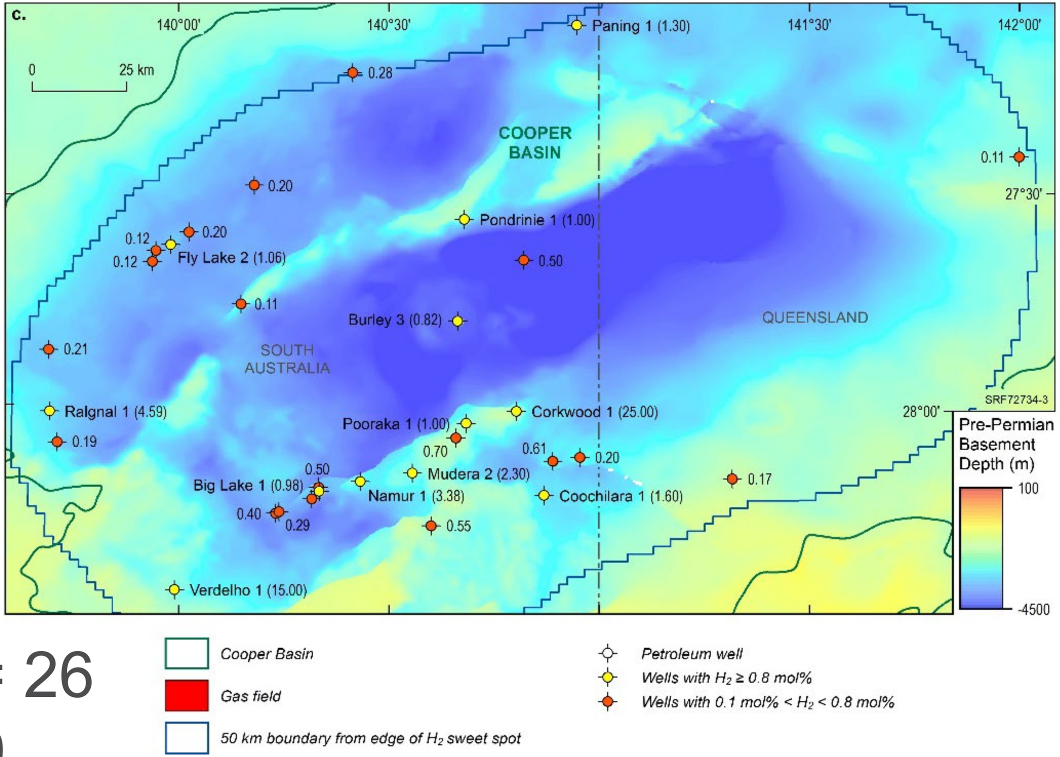
Thermogenic H_2



Thermogenic H_2 = max. 20 mg H_2/g TOC

Available H_2 mol% data

WCRs = 3346 wells
Wells with gas data = 557
Wells with H_2 mol% = 35
(108 analyses)



Wells with H_2 > 0.1 mol% = 26
Wells with H_2 > 1 mol% = 9

Conclusions

Natural H_2 has multiple sources (including thermogenic) from a wide range of geological settings and rock types → enormous potential resource (large # niche plays).

Cooper Basin is under-explored for (thermogenic) H_2 resource potential.

Natural H_2 has good Green credentials:

- Renewable;
- Blended gas transmission pipelines where >10 mol% H_2 (CH_4, low in CO_2);
- Where N_2 is high → concentrate H_2 (LNG He spin-off?);
- Use directly (98 mol% H_2) (e.g., Mali, W. Africa).

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