Storing CO_2 in buried volcanoes

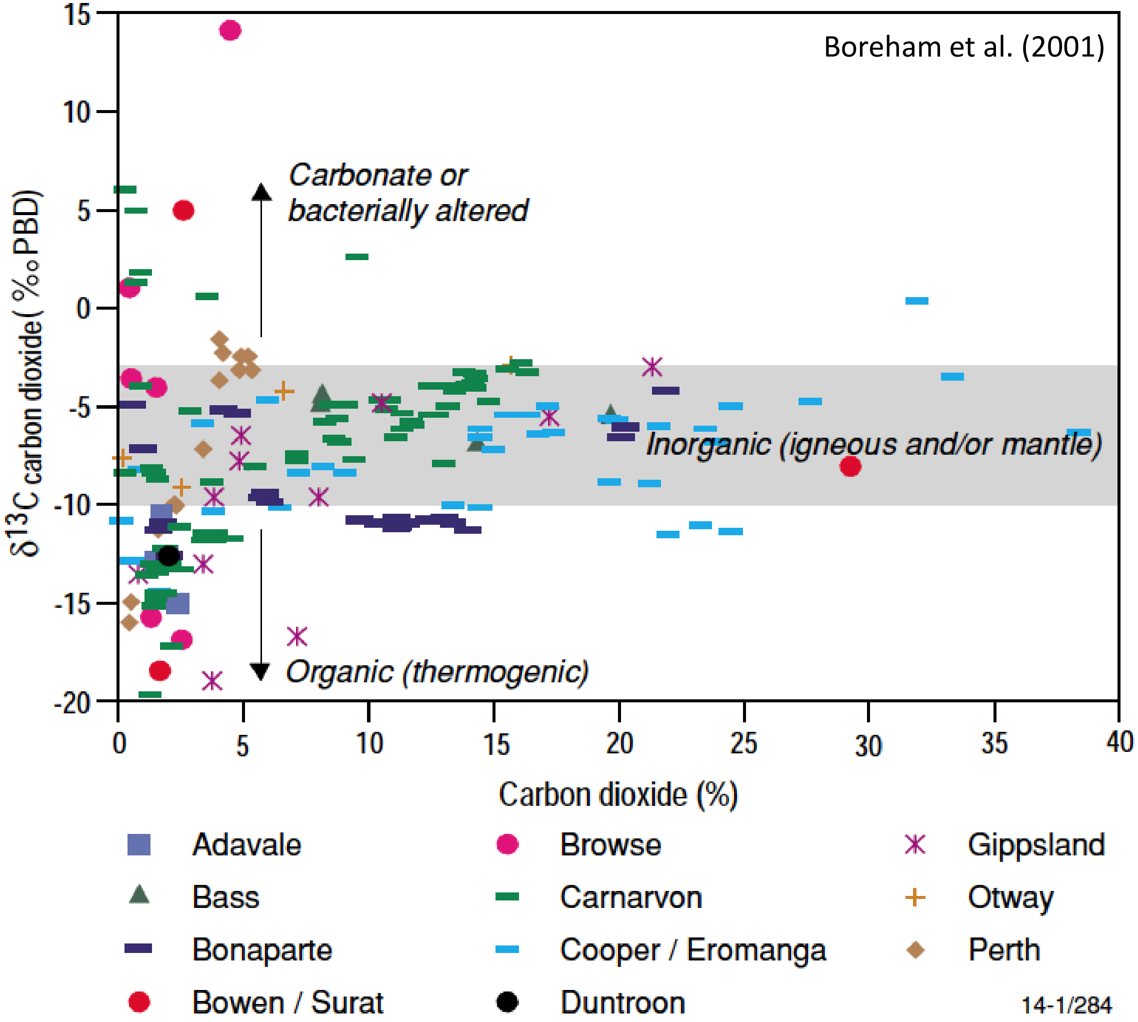
Simon Holford[1], *Nick Schofield*[2], *Mark Bunch*[1],
Alan Bischoff[3] & *Ernest Swierczek*[1]

[1]*Australian School of Petroleum and Energy Resources, University of Adelaide, Australia*

[2]*Department of Geology and Geophysics, University of Aberdeen, Scotland*

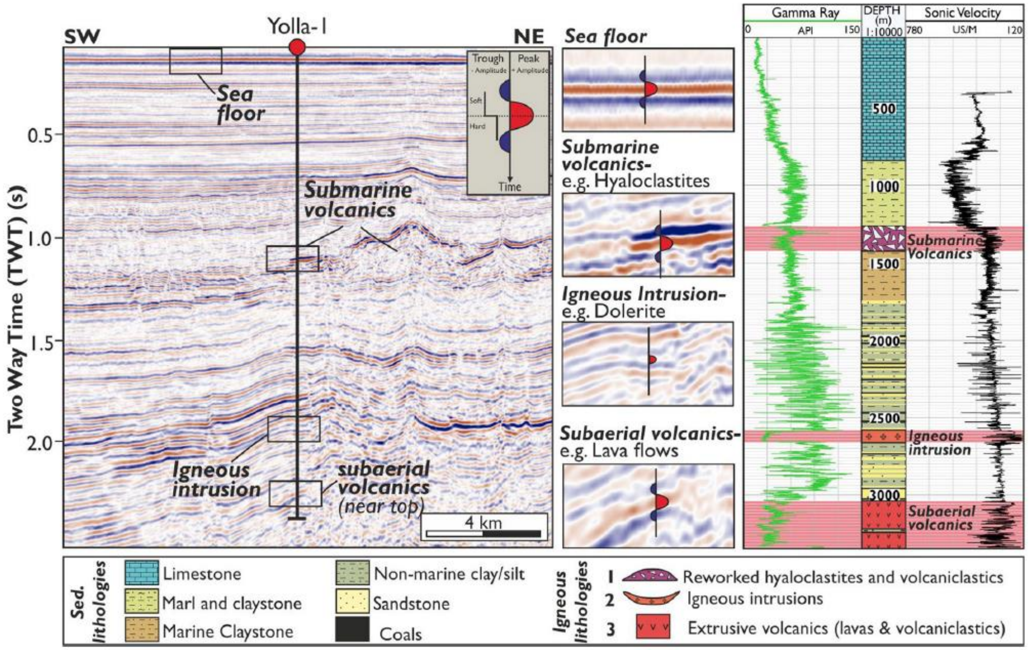
[3]*School of Earth and Environment, University of Canterbury, New Zealand*

Natural CO_2 in Australian basins


Boreham et al. (2001)

Yolla, Bass Basin; CO_2 = 17-20%

Ichthys, Browse Basin; CO_2 = 8% (Brewster), 17% (Plover)



Watson et al. (2019)

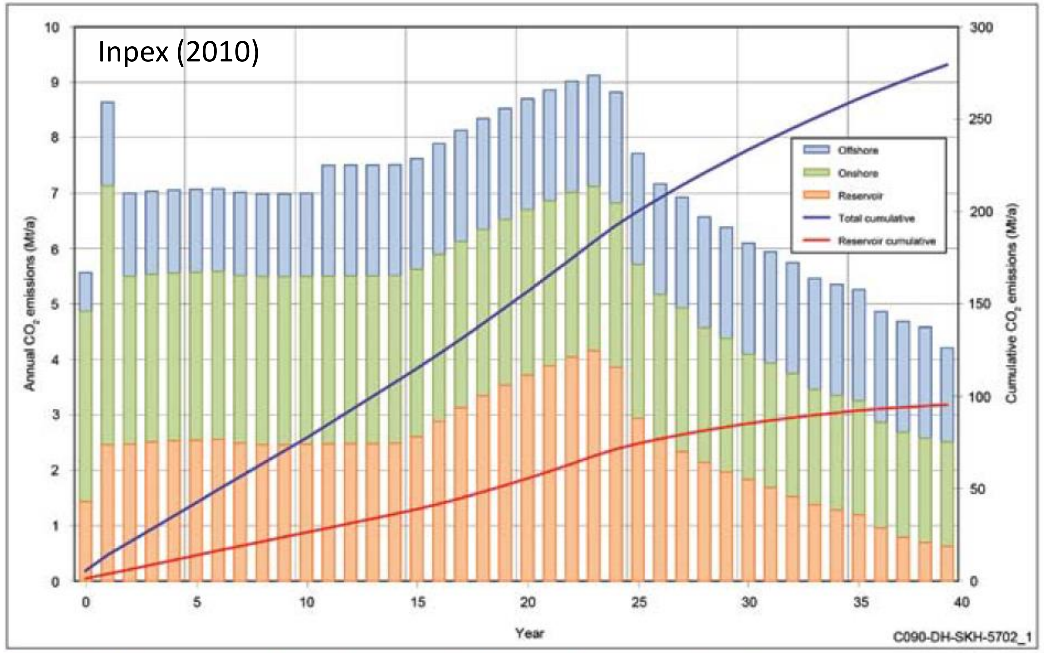
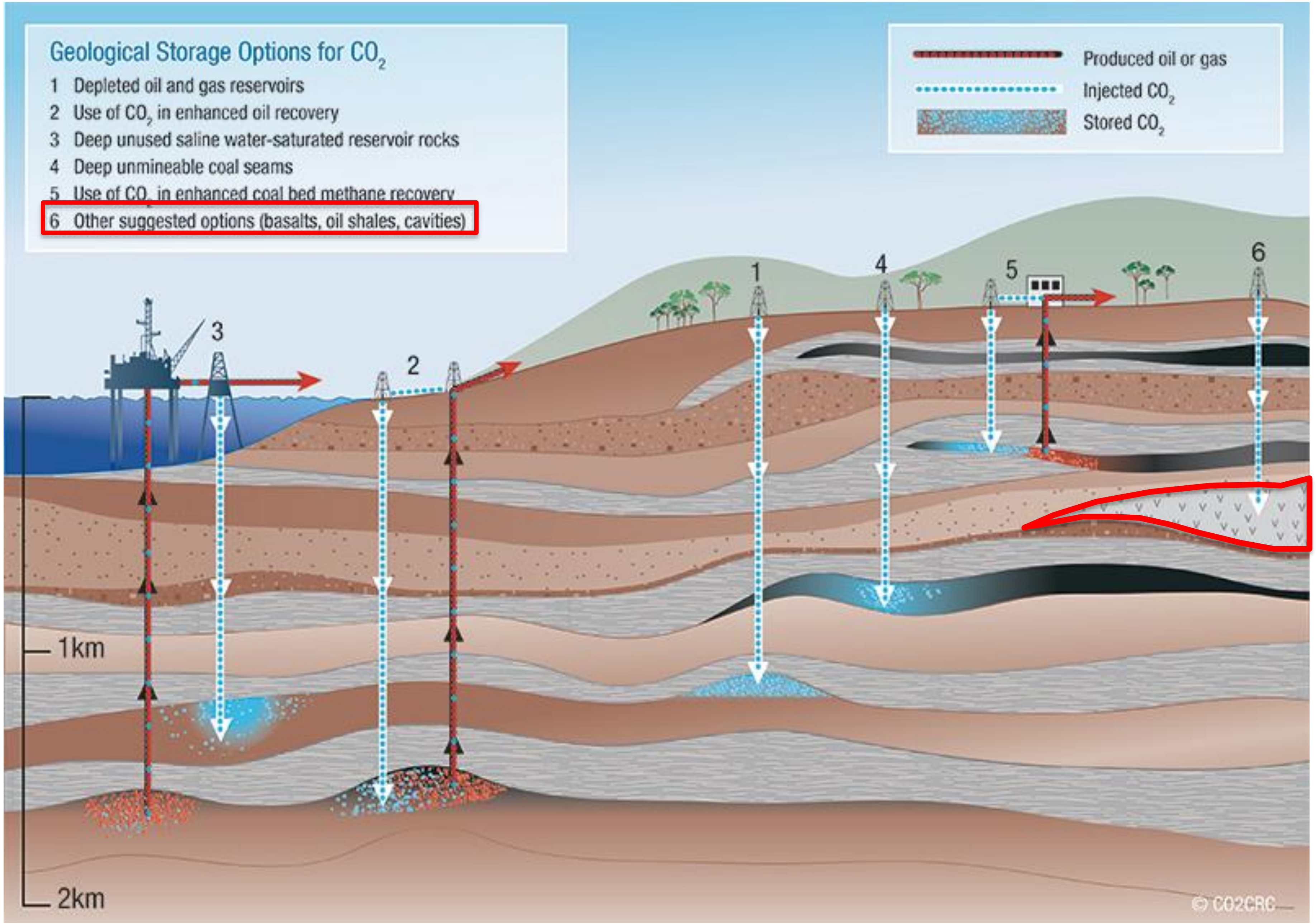

Inpex (2010)

Figure 9-3: Estimated annual CO_2 emissions over the Project's 40-year operational life



https://co2crc.com.au/about-ccus/what-is-ccus/

Underground storage capacity in 'conventional' saline aquifers and depleted hydrocarbon reservoirs

~5,000-25,000 Gt CO$_2$

Underground storage capacity in 'unconventional' mafic and ultramafic igneous rocks (including volcanic basalts)

<60,000,000 Gt CO$_2$

(Kelemen et al., 2019)

Basalt: dark-coloured, fine-grained extrusive igneous rock formed from cooling of mafic (Si-poor, Mg and Fe-rich) lava

In situ mineral carbon mineralization in basalt reservoirs

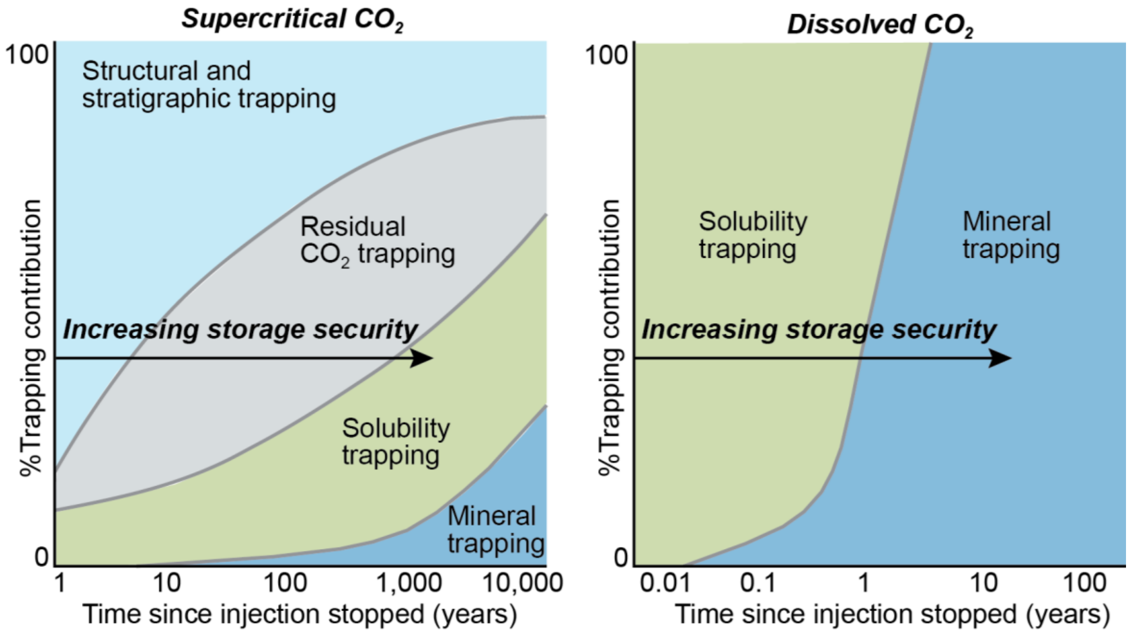
$$Mg_2SiO_4 + \boxed{2CO_2} = 2MgCO_3 + SiO_2$$

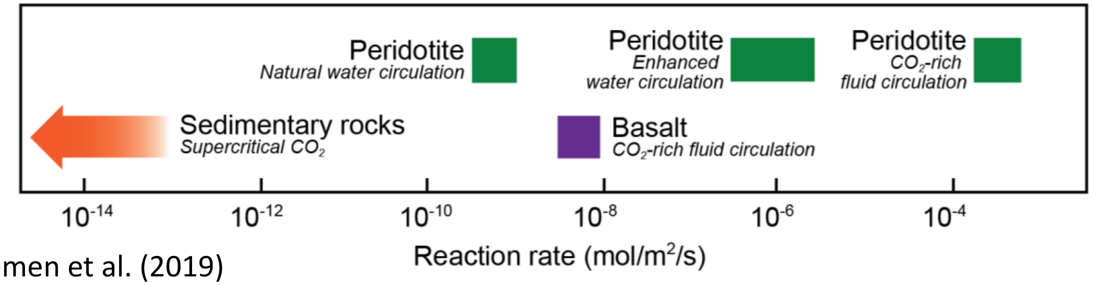
FORSTERITE MAGNESITE QUARTZ

and

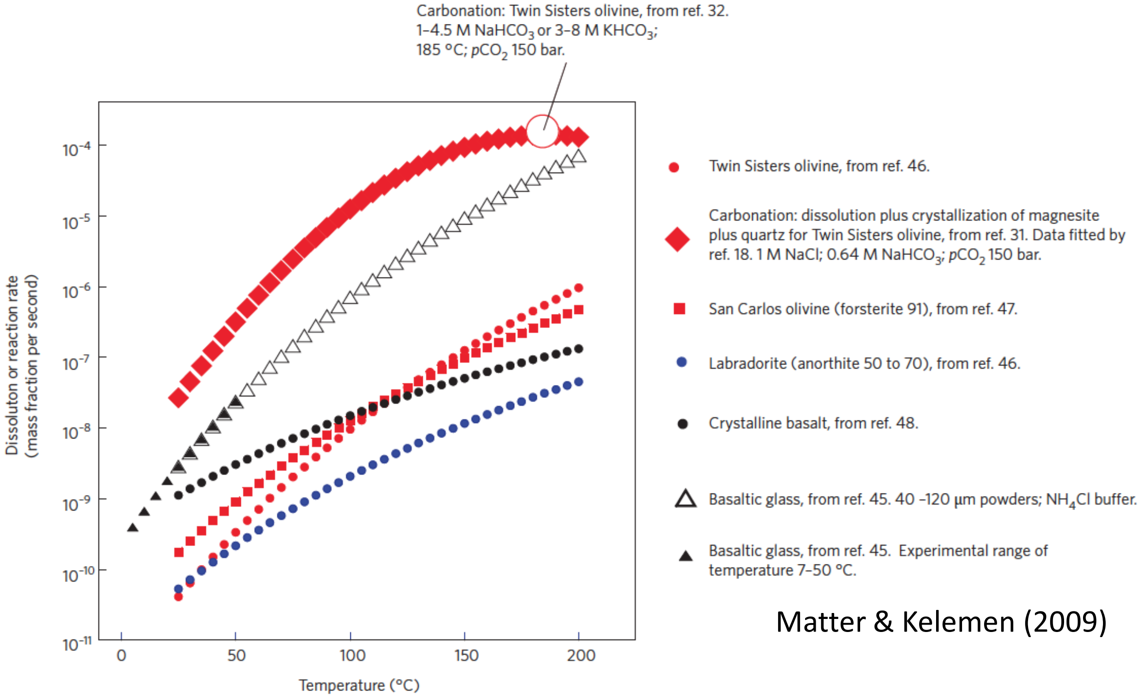
$$CaAl_2Si_2O_8 + \boxed{CO_2} + 2H_2O = CaCO_3 + Al_2Si_2O_5(OH)_4.$$

ANORTHITE CALCITE KAOLINITE

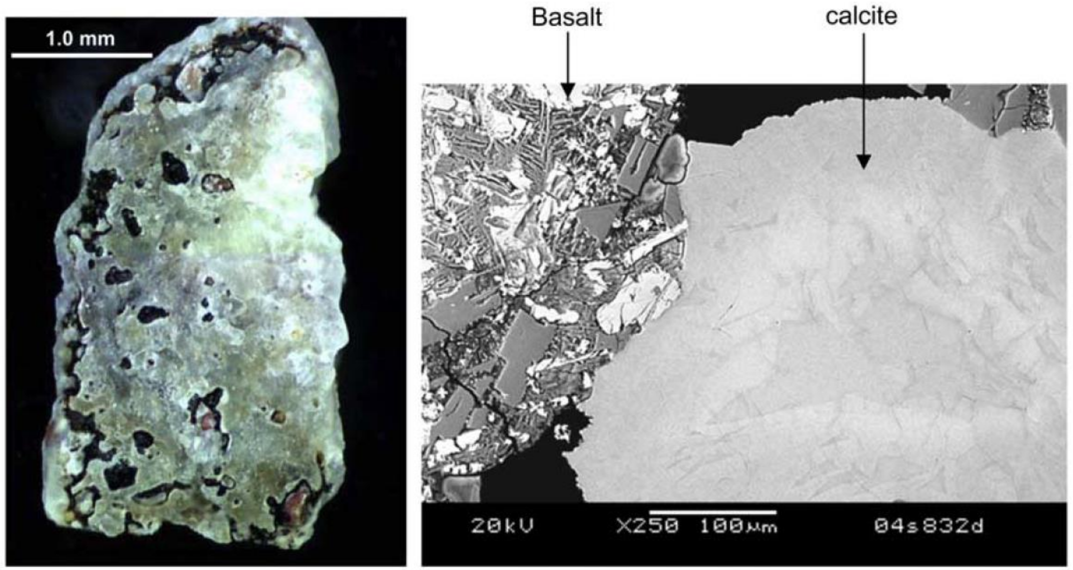




Kelemen et al. (2019)

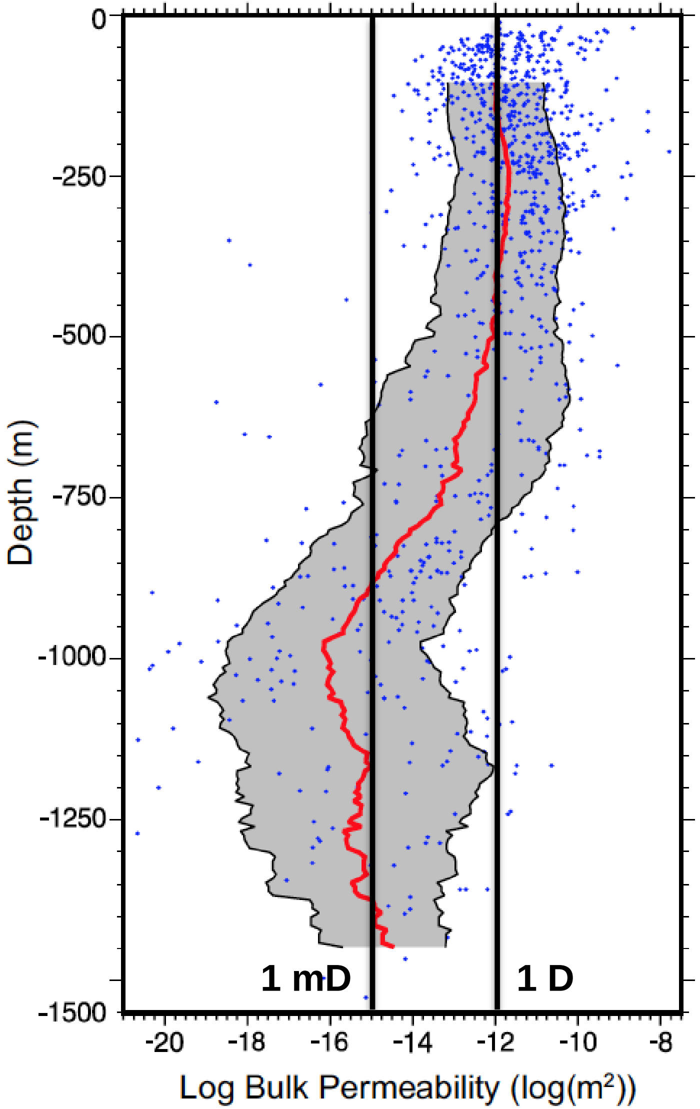


Matter & Kelemen (2009)



McGrail et al. (2006)

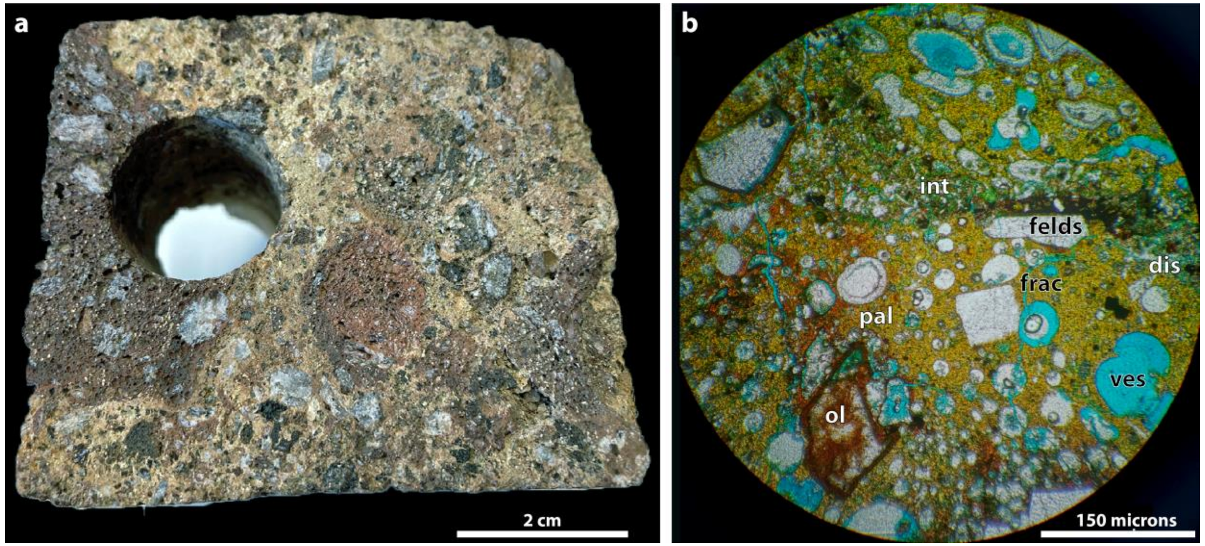
Porosity and permeability of volcanic rocks



Columbia River Basalt Group

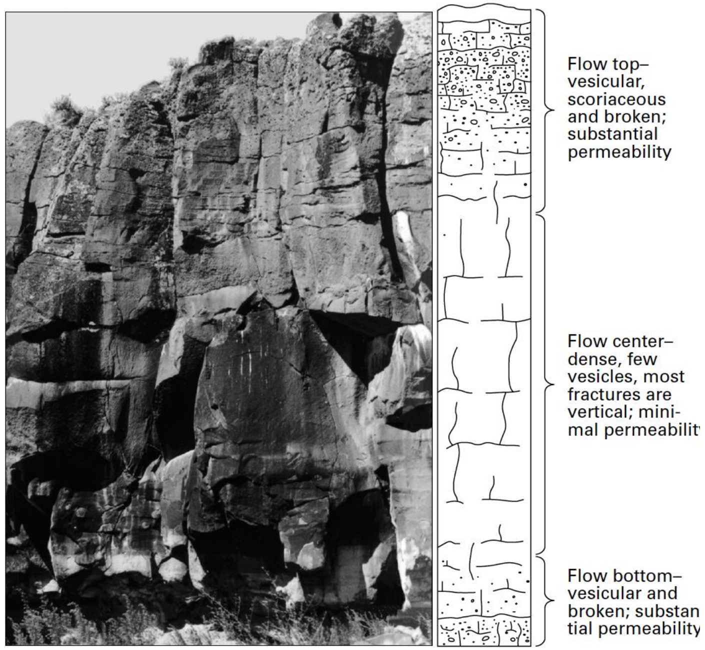
Jayne & Pollyea (2018)

Trachybasalt crystal-rich lapilli tuff, Banks Peninsula

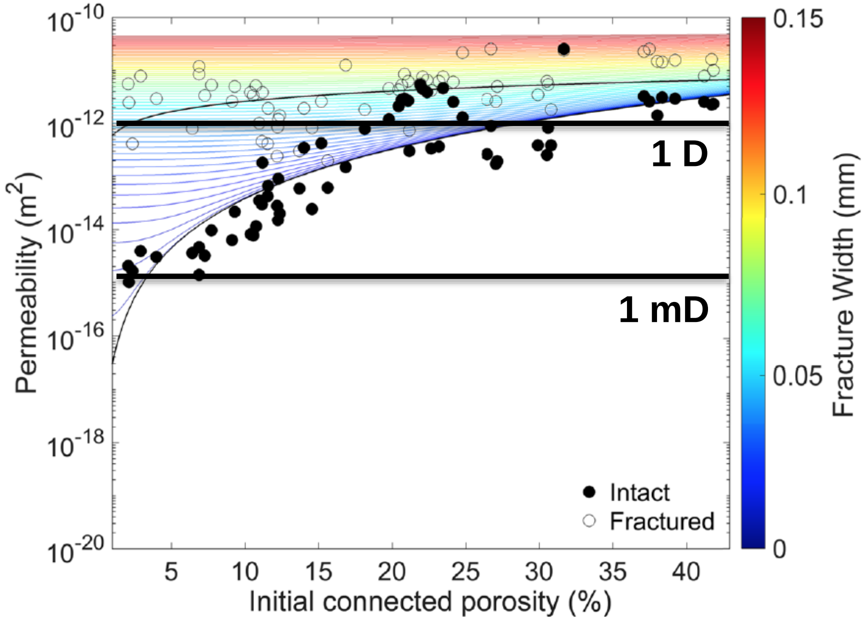


Porosity = 48%

Permeability = 800 mD



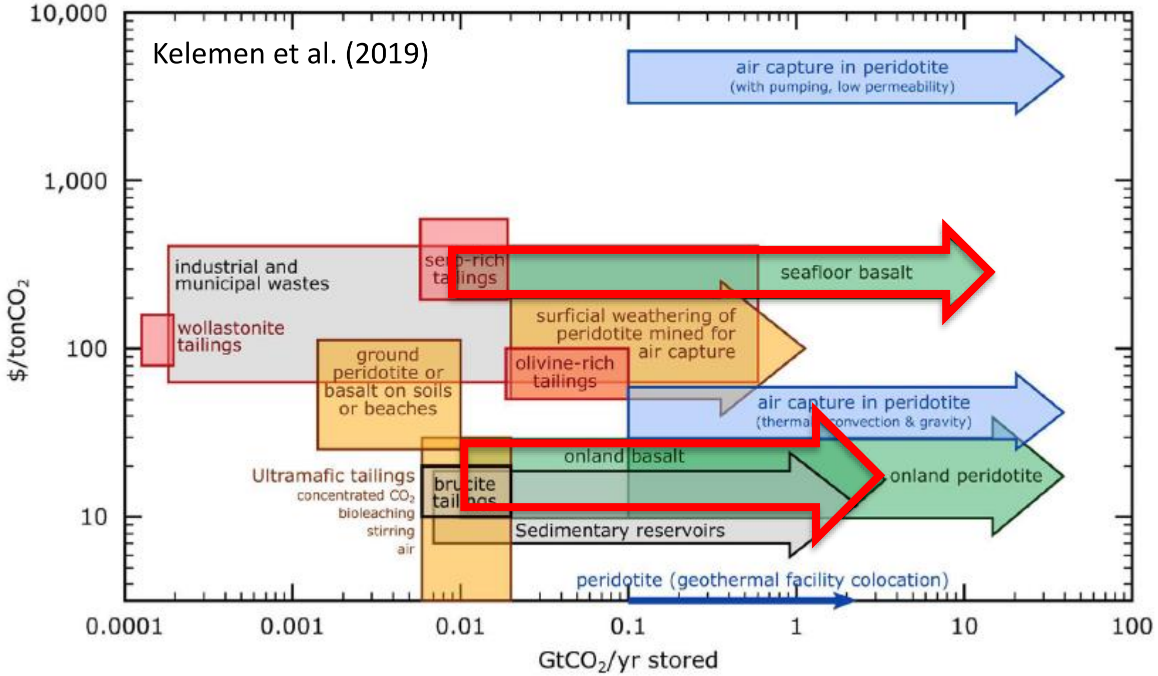
Whitehead (1992)



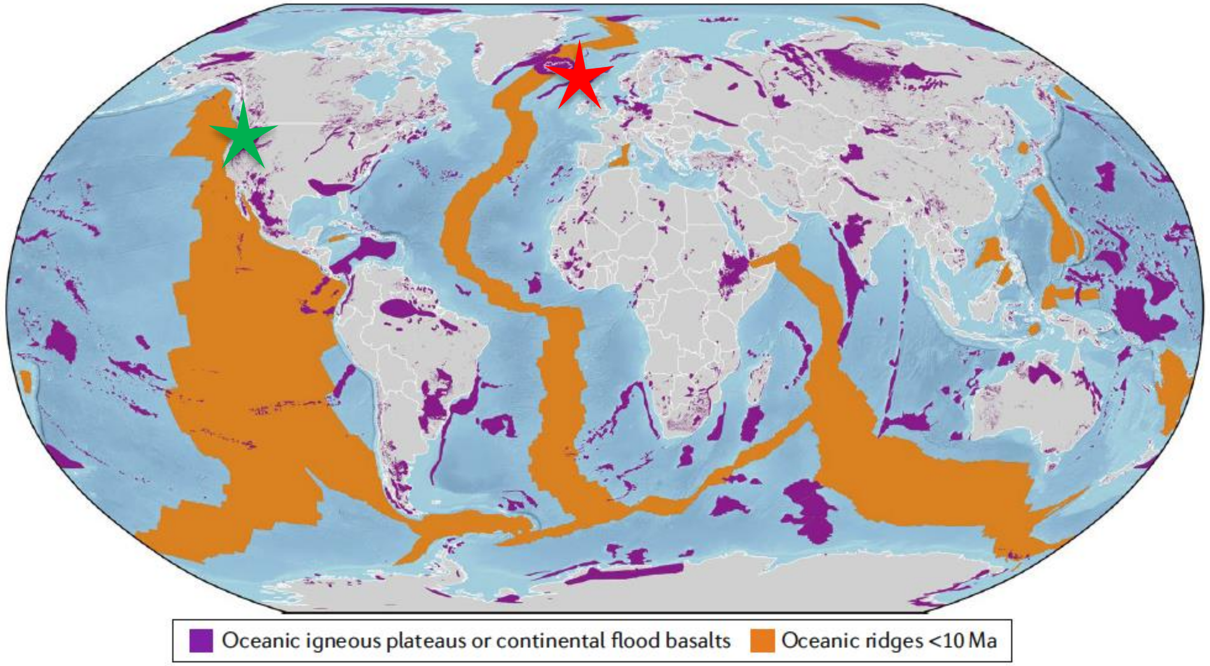
Lamur et al. (2017)

Feasibility of CO_2 storage in basalts

- Most of the ocean's floor (~70% of Earth's surface) and >5% of the continents are covered by basalts
- Cost of onshore storage of CO_2 in basalts estimated at US$20-30/t$CO_2$ (National Academies of Sciences, 2019)
- In the past decade two pilot projects have demonstrated the potential for CO_2 storage; CarbFix in Iceland and Wallula in Washington, USA

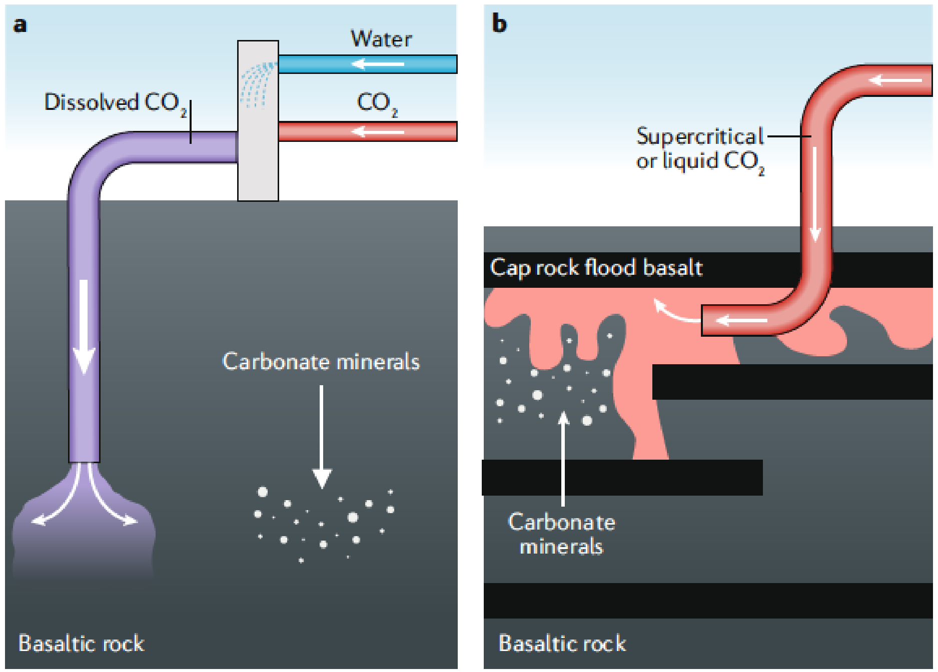


Kelemen et al. (2019)



★ *CarbFix, Iceland*

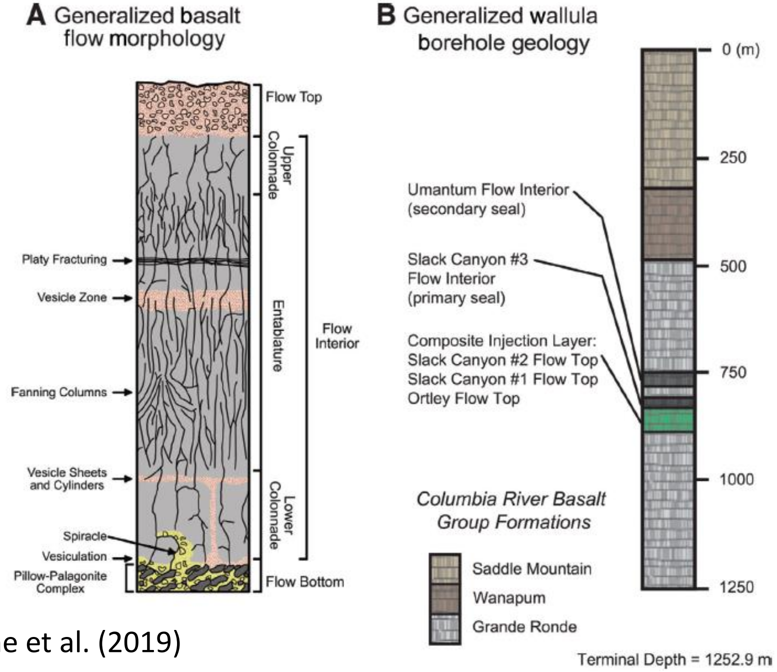
★ *Wallula, USA*



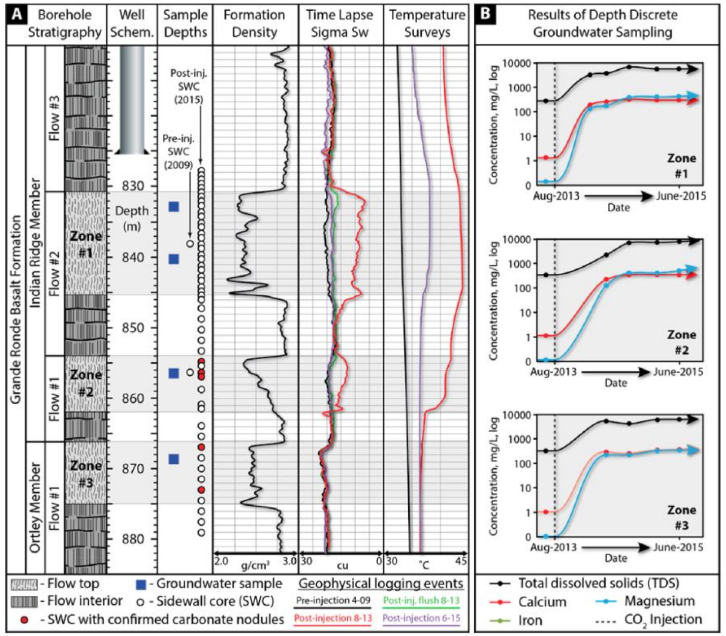
Snæbjörnsdóttir et al. (2020)

Wallula Pilot Borehole

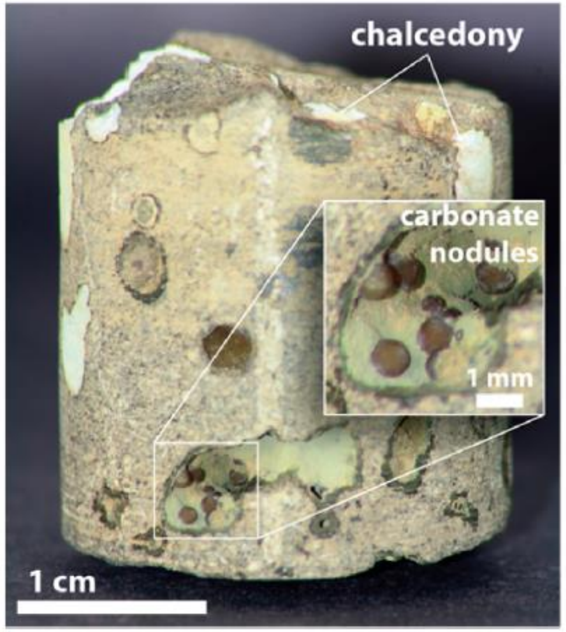
- 1000 tons of supercritical CO_2 injected into Miocene basalts over three weeks in 2013
- Injection zone targeted three brecciated flow tops (k=70-150 mD) separated by low-permeability (<0.1 mD) seals
- Sidewall cores acquired in 2015 revealed ankerite nodules with the same isotopic signature as the injected CO_2
- Post-injection flow tests indicate that 60% of CO_2 had mineralized within 2 years, occupying 4% of available pore space (White et al. 2020)



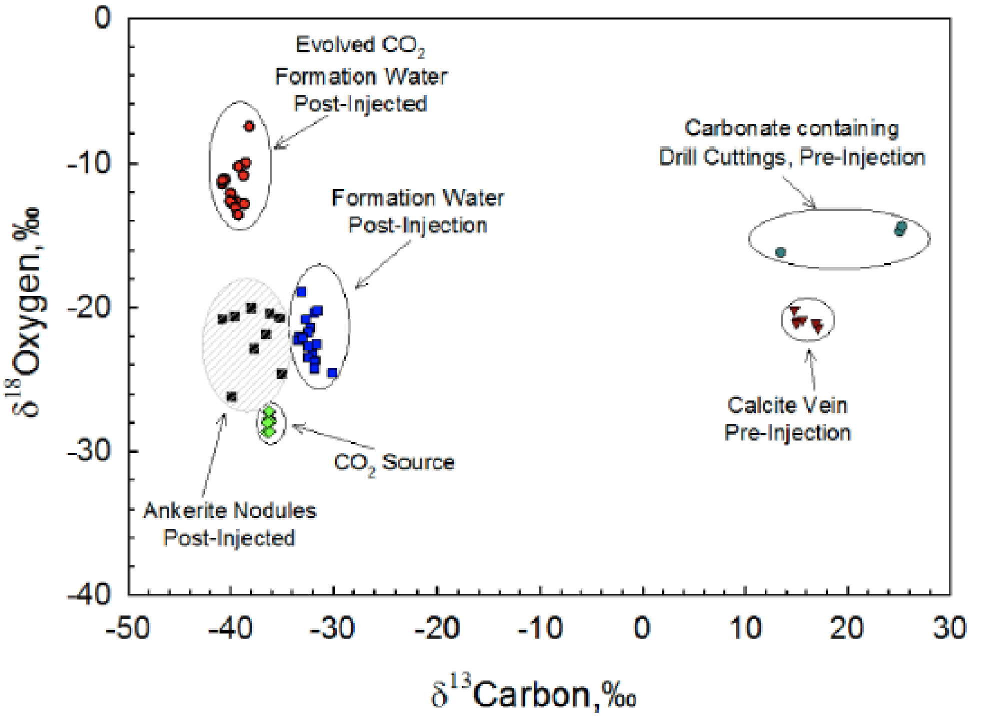
Jayne et al. (2019)



McGrail et al. (2017)



Sidewall core from injection zone 24 months after CO_2 injection

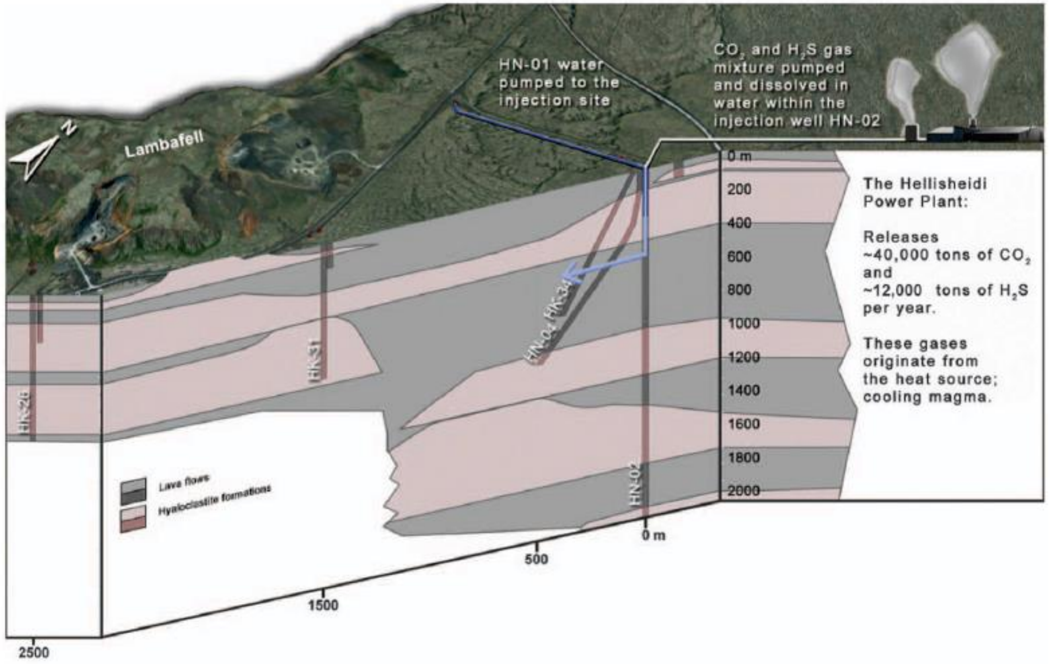


McGrail et al. (2017)

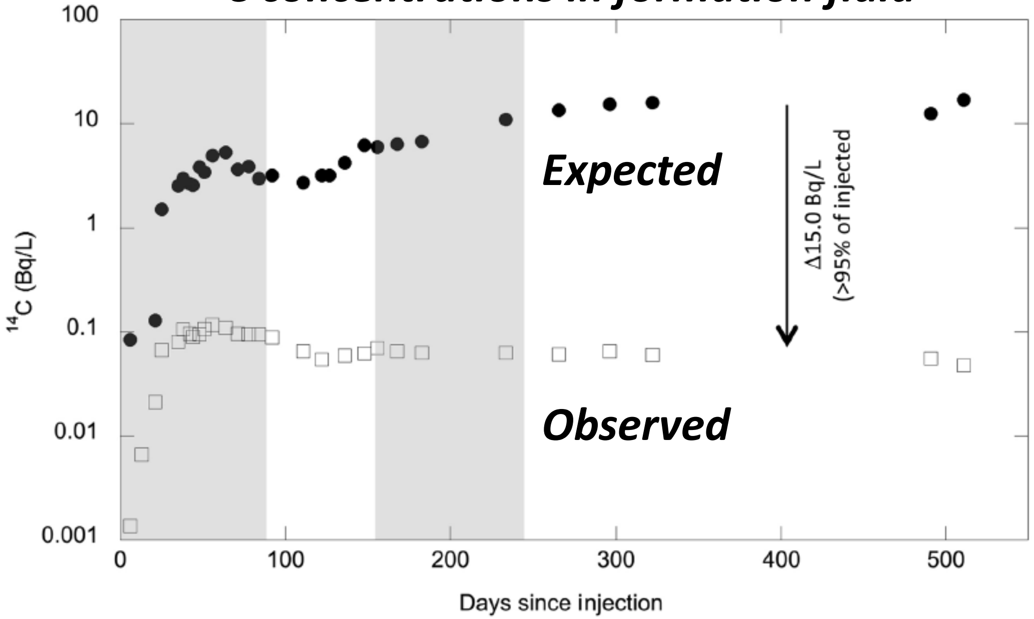
CarbFix Phases I and II

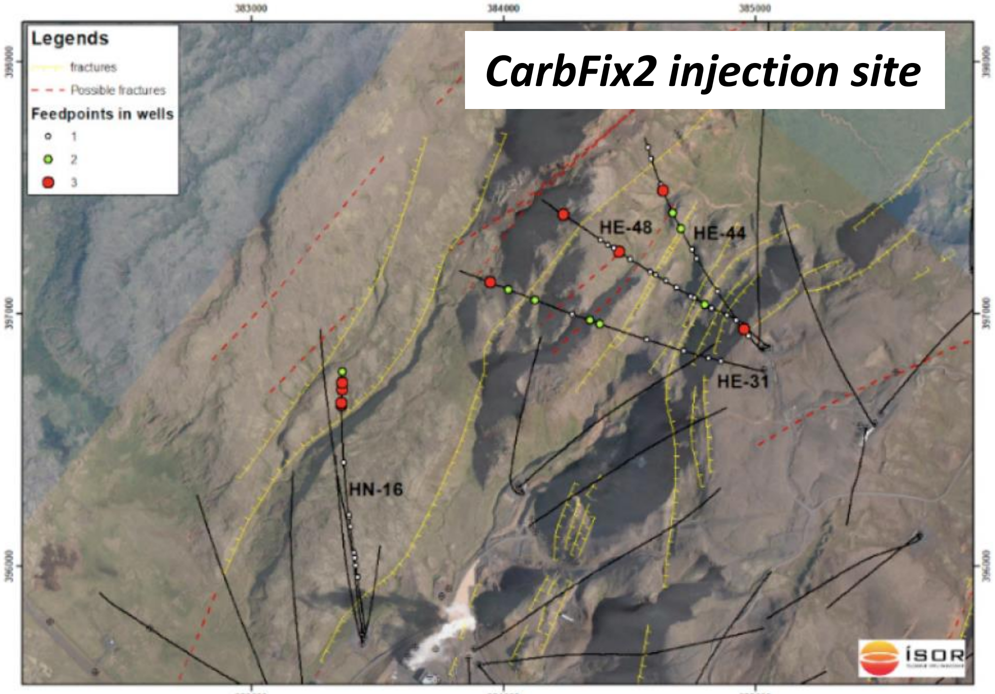
- Phase I injected geothermally-derived ~200 tCO_2 (plus H_2S) dissolved in water into basaltic lavas at 400-800 m depth
- Mass balance calculations indicate that >95% of CO_2 was mineralized within 2 years
- Phase II is injecting 10-20 $ktCO_2$/year (and comparable H_2S) at 1500 m depth (temperature ~250°C) across a 2000 m long flow path with fracture-controlled permeability
- Volume of precipitated calcite and pyrite estimated to comprise <0.01% of the reservoir (estimated porosity 8-10%)

Matter et al. (2016)



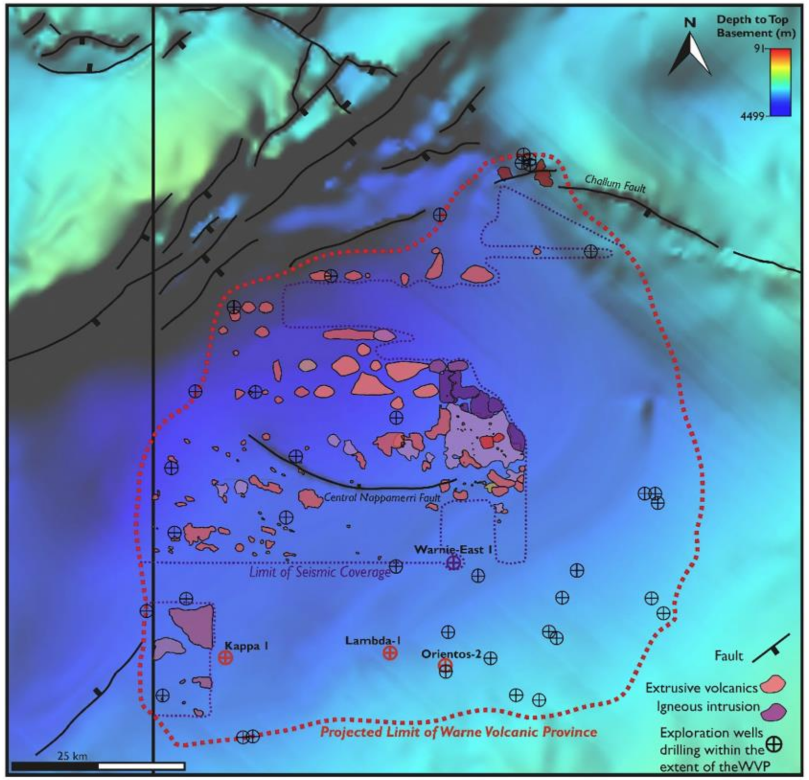
^{14}C concentrations in formation fluid

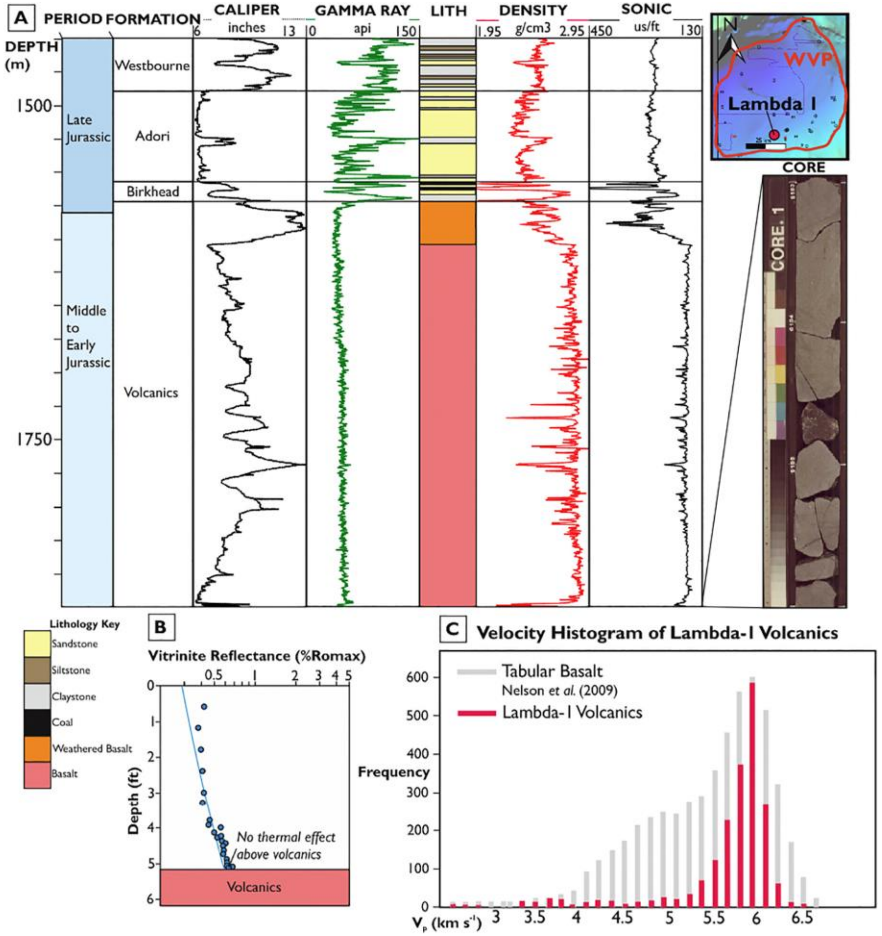




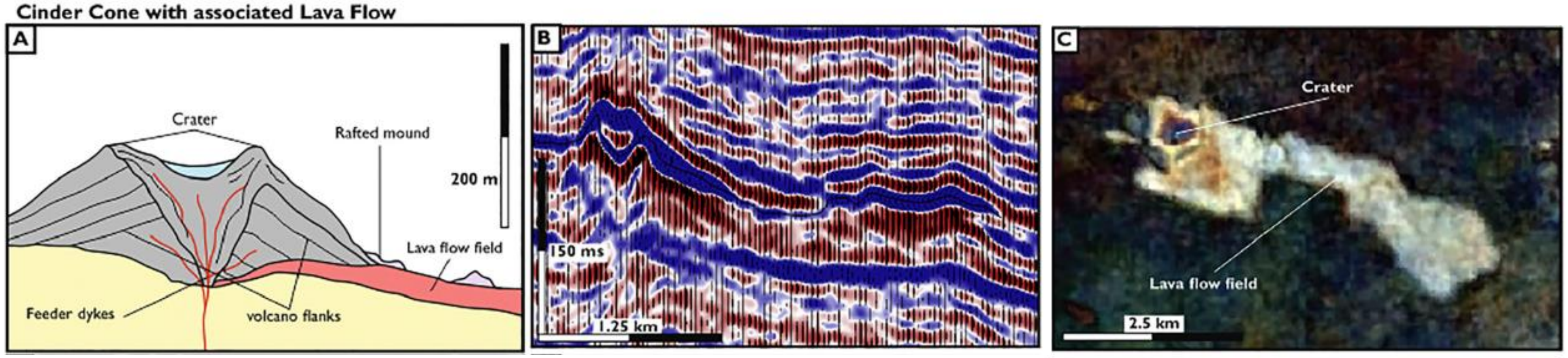
Snæbjörnsdóttir et al. (2018)

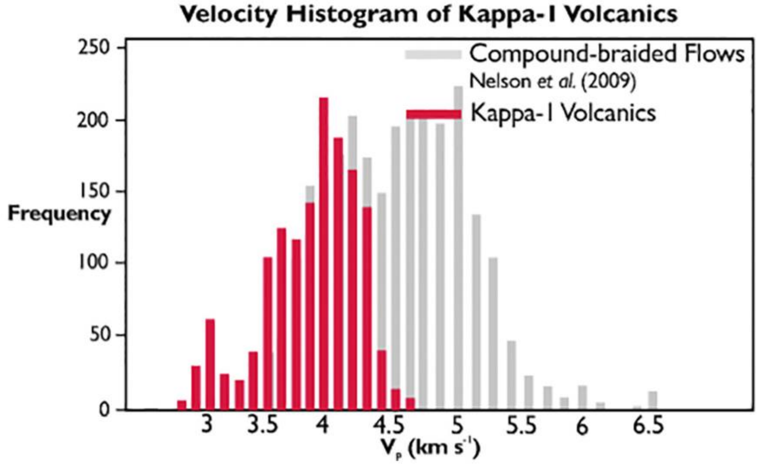
Cooper-Eromanga Basin





- CO_2 contents of >10-20% observed in many fields
- Highest concentrations in the Nappamerri Trough, which also hosts a >7,500 km^2 province of Jurassic basaltic volcanoes (Hardman et al., 2019)
- In some cases (e.g. Kappa-1) basalts are extensively alerted
- Lambda-1 drilled 283 m of volcanics, including 250 m of fresh, crystalline, fractured basalts

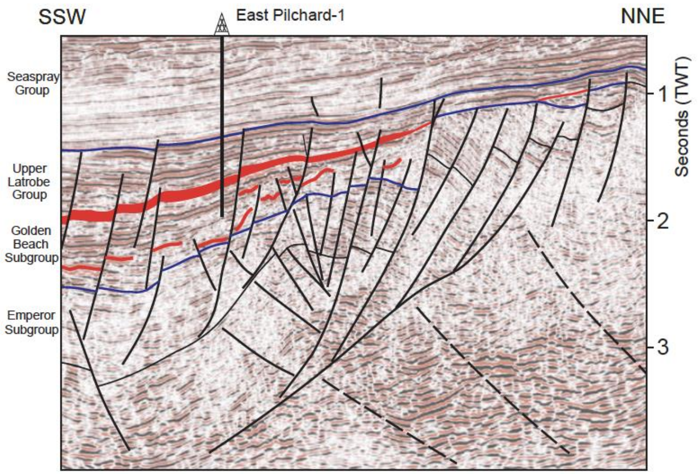


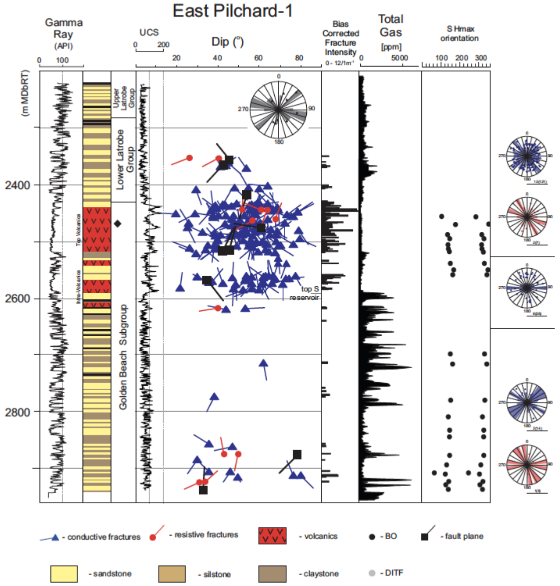


Hardman et al. (2019)

Volcanics & CO_2: Cause & solution?

- Many producing and undeveloped gas fields in Australia contain high CO_2 content
- In many cases CO_2 is related to volcanic activity; buried basaltic sequences are in close proximity to CO_2-rich fields in the **Bass, Browse, Gippsland and Cooper-Eromanga basins**





East Pilchard-1 CO_2 ~17% (10-52%)

Geo-engineering challenges

- Basalt-CO_2-fluid interactions e.g. passivation of mineral surfaces, clogging of pore spaces; site-specific data needed
- Defining precise mineral assemblages, including alteration phases, beyond the wellbore
- Defining first-order stratigraphic and permeability architecture of buried basalts
- Basaltic reservoirs are highly heterogenous, and at depth, porosity and permeability is likely to be highly fracture dependent
- Multiphase fluid flow in fractured basalts is poorly understood