Subsurface Carbon Mineralization Resources in Hawai'i Basalt
FE0032245

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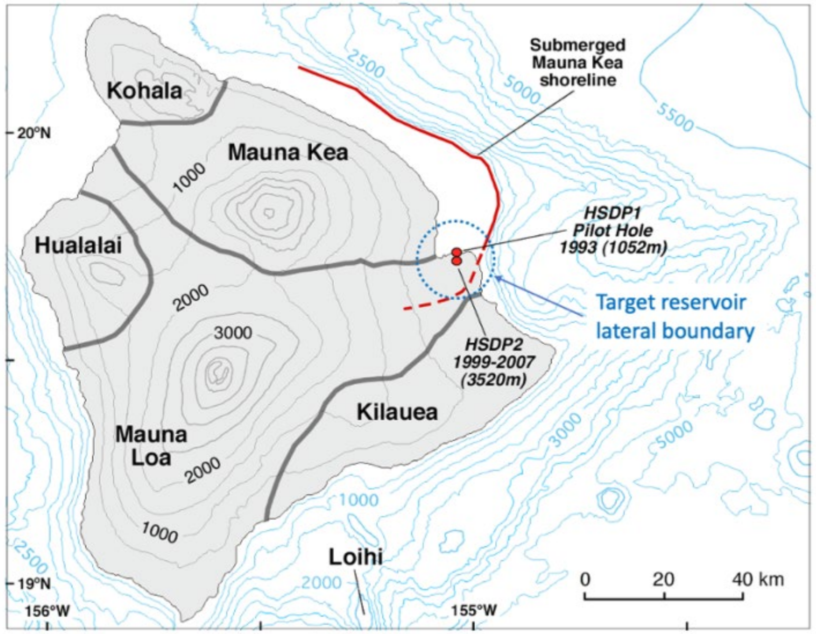

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Saeko Mito – RITE, Japan

Cost share and support:
Grantham Foundation (CS)
Par Pacific Holdings (CS)
Climeworks (S)
UC Berkeley (CS)

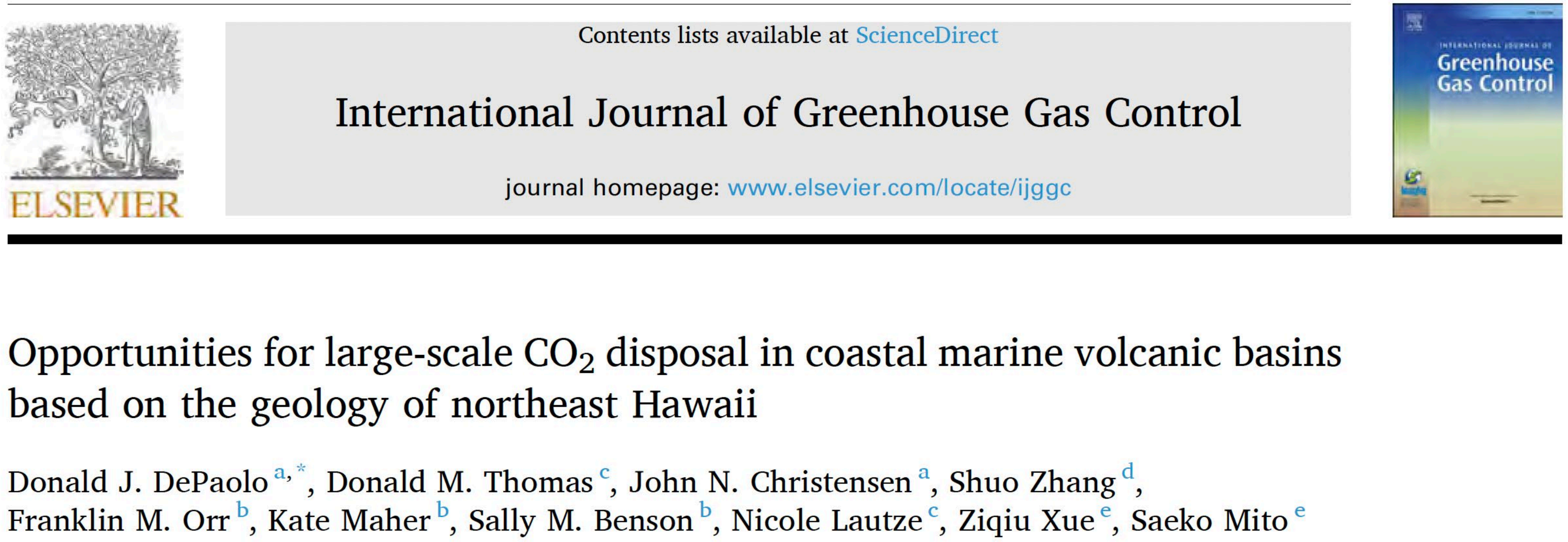
Talk outline

1. **Background**
   - Prior project components and preliminary results
   - Conceptual model for storage and mineralization in Hawaii basalt
   - Key characteristics of Hawaii basalt related to CO_2 disposal
   - Site geological model based on previous work
2. **Current project**
   - Task updates
     - Downhole Sampling, Logging, Pumping, and Flow Tests (UH)
     - Geophysical Characterization and Monitoring of Subsurface Reservoirs (UH, LBNL)
     - Reactive Transport Modeling of CO_2 Mineralization in Basalt (LBNL)
     - Laboratory Measurement of Basalt Reaction Kinetics (RITE, LBNL)
     - Reservoir Modeling of meteoric infiltration and thermohaline convection (LBNL)
3. **Broader significance and outlook**
   - Other targets in Hawaii
   - Vision for the future
   - General questions for storage and mineralization in basalt

Preliminary project (2019-2023)

Large-scale carbon storage potential of saline volcanic basins (LBNL lead)

1. Geochemical characterization of archived fluid samples and implications for mineralization
2. Hydrologic modeling of thermohaline circulation and subsurface temperatures
3. Basin scale flow and reactive transport modeling of CO_2 injection
4. Laboratory experiments to constrain kinetics of mineralization using basalt minerals
5. Development of TOUGH+ module for CO_2 hydrate trapping
6. Inversion of water level and tidal data for deep permeability



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Opportunities for large-scale CO_2 disposal in coastal marine volcanic basins based on the geology of northeast Hawaii

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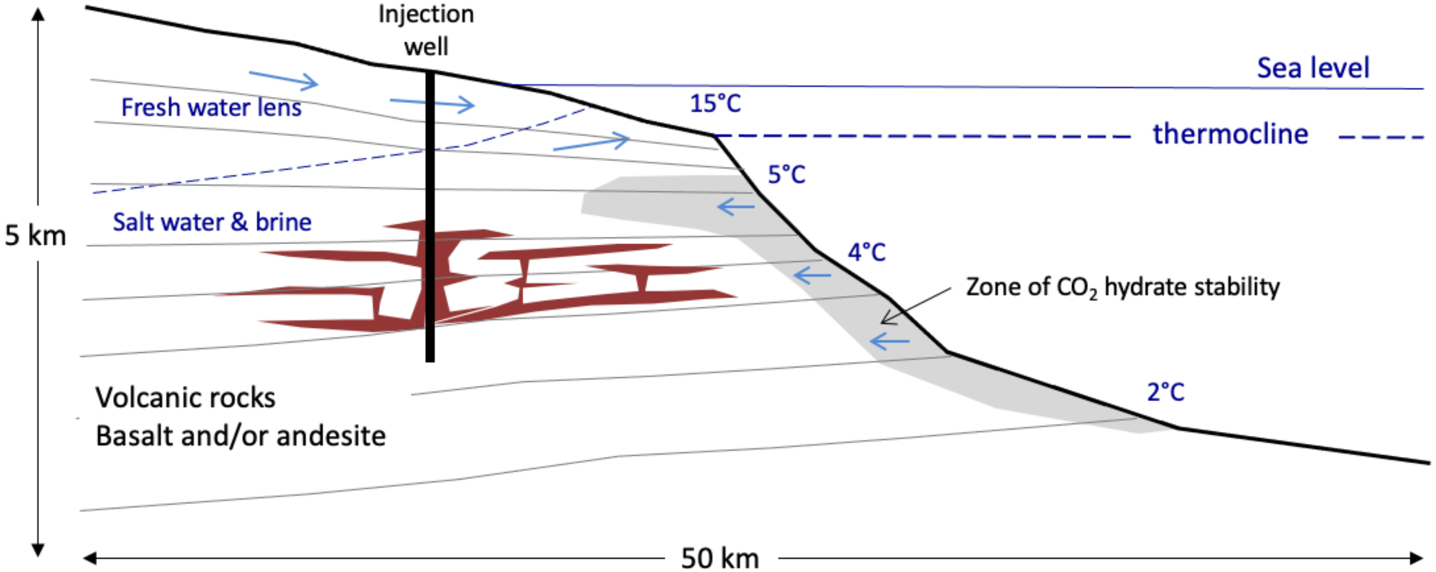
Concept for large scale CO_2 disposal

The concept is based on the subsurface geology and hydrology of the NE portion of the island of Hawaii, for which there is direct information available from previous drilling and coring



Schematic concept of near-shore geological and thermal structure of large oceanic volcanic edifices like those of Hawaii

Key characteristics:

(1) Lower temperatures make CO_2 less buoyant

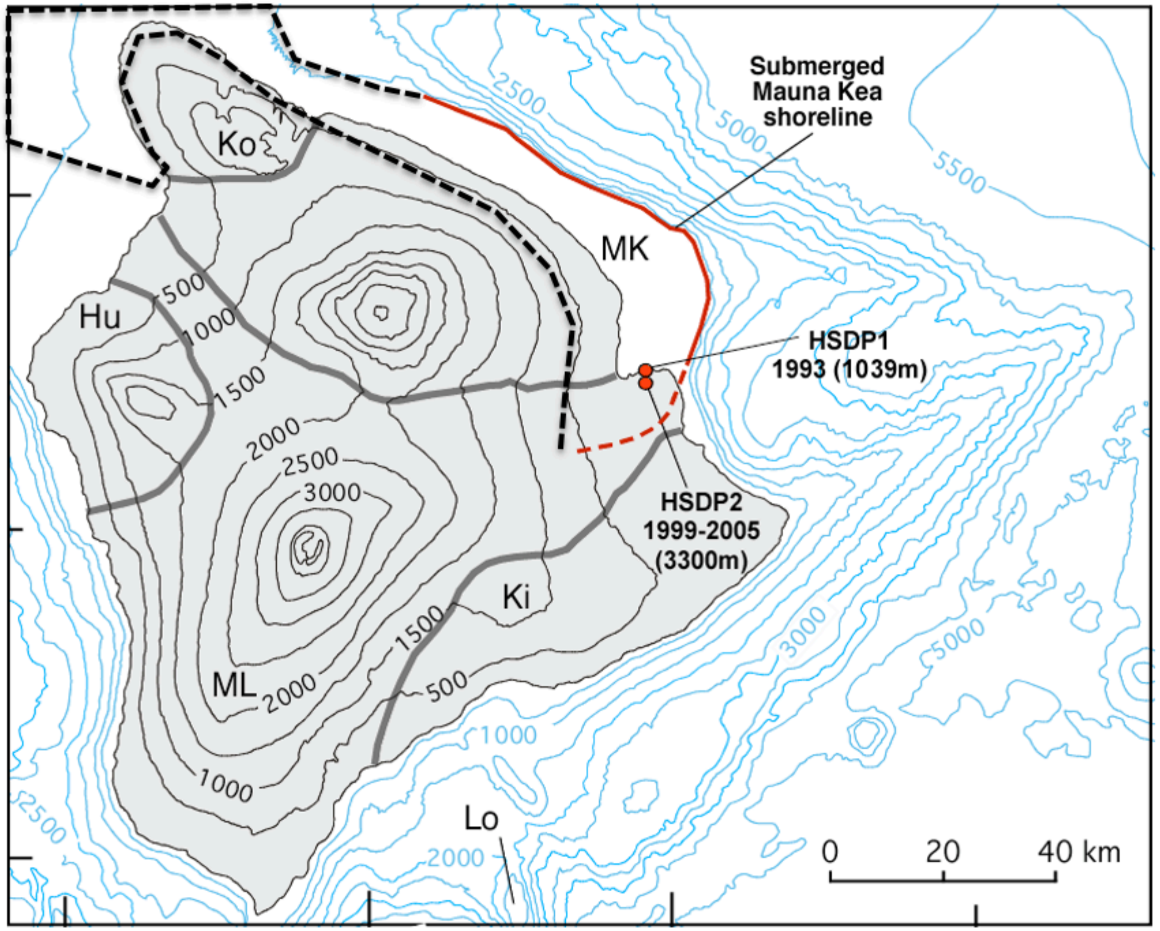
(2) Large formation thicknesses (>3 km) and heterogeneity provide structural trapping

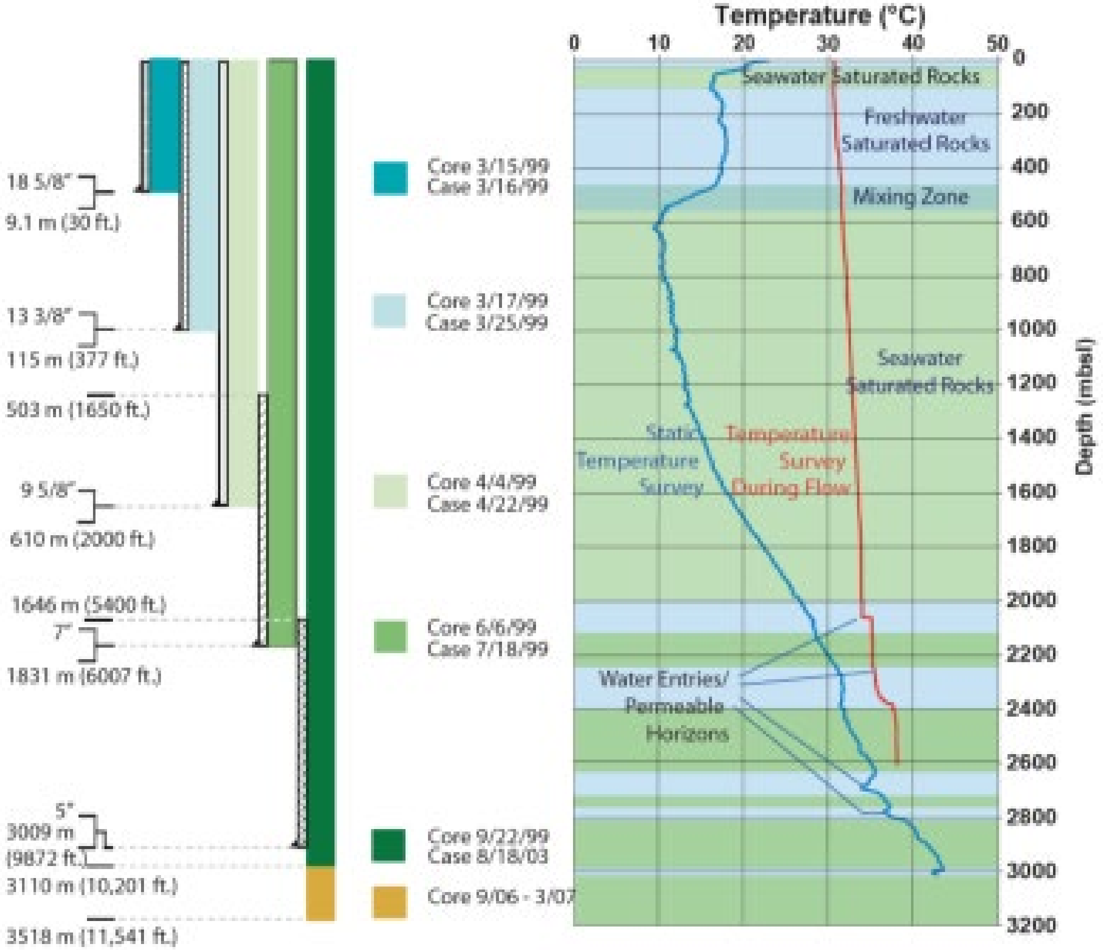
(3) Pure CO_2 could potentially be injected from onshore wells into submarine basalt

(4) Dissolution, capillary, and mineral trapping, as well as CO_2-hydrate formation, could contribute to immobilizing CO_2

Field test site – Northeast Hawaii

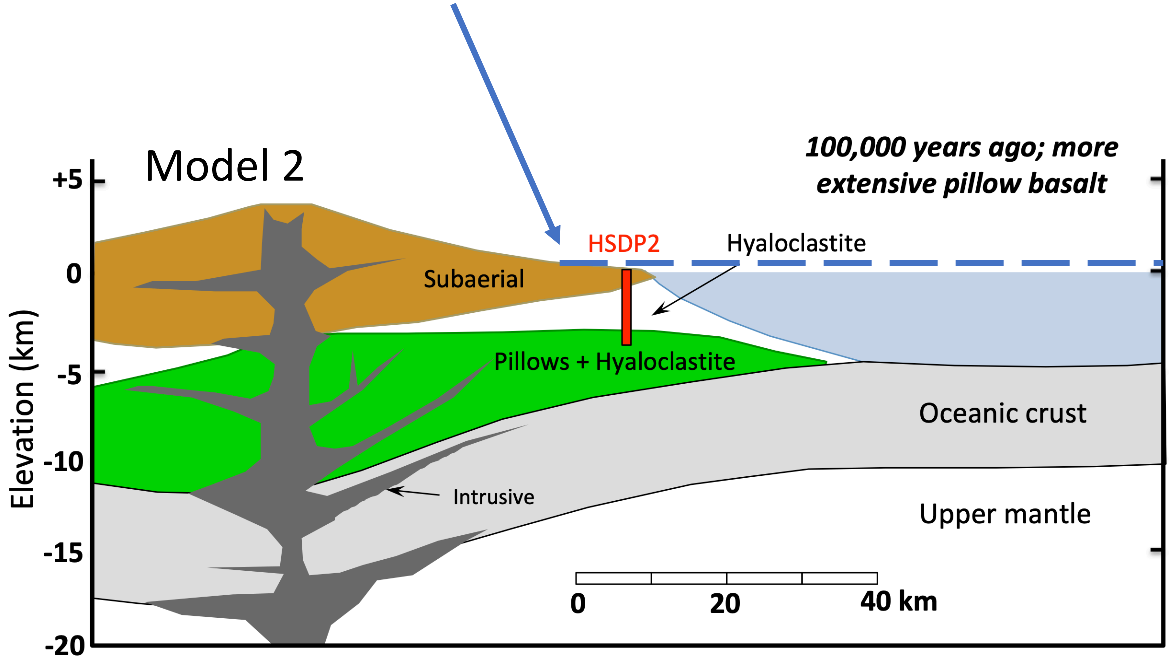
Existing 3540’ deep well drilled and cored as part of an NSF project in 1999 – 2006 (HSDP2)



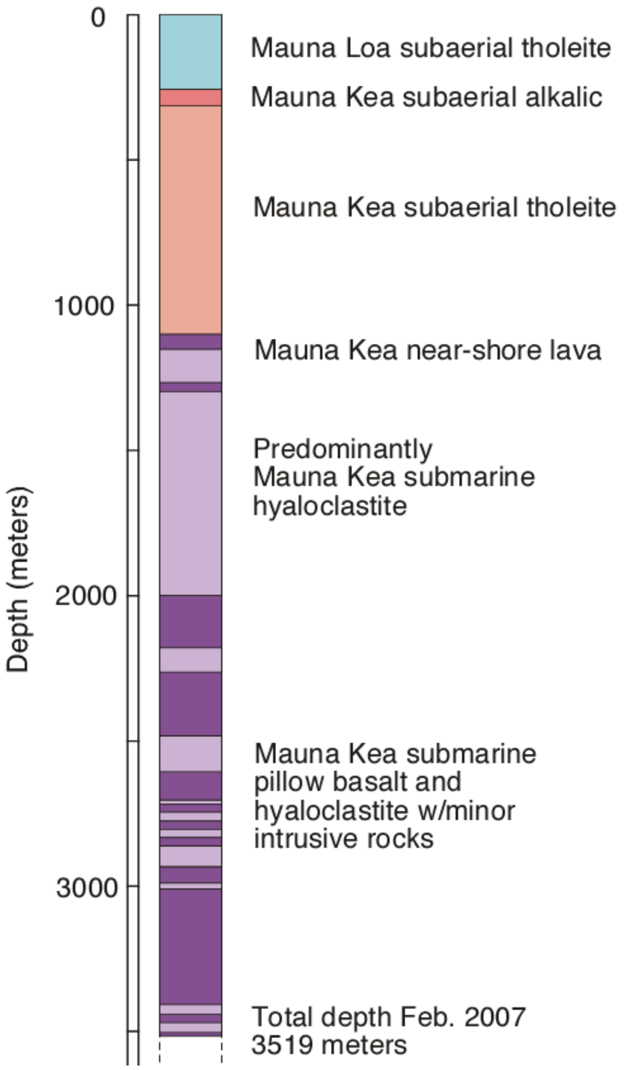


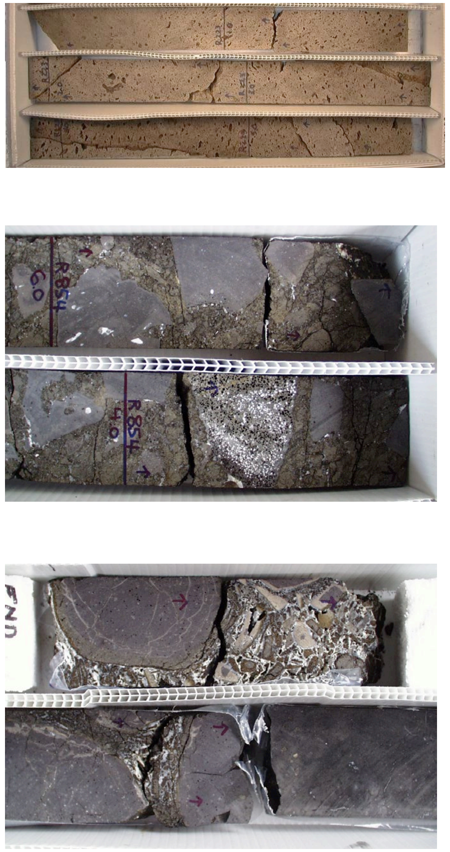
Growth of Hawaiian volcanoes is sufficiently systematic that facies models have been developed

After eruption ceases the volcanoes continue to subside and the shoreline moves upslope toward the summit

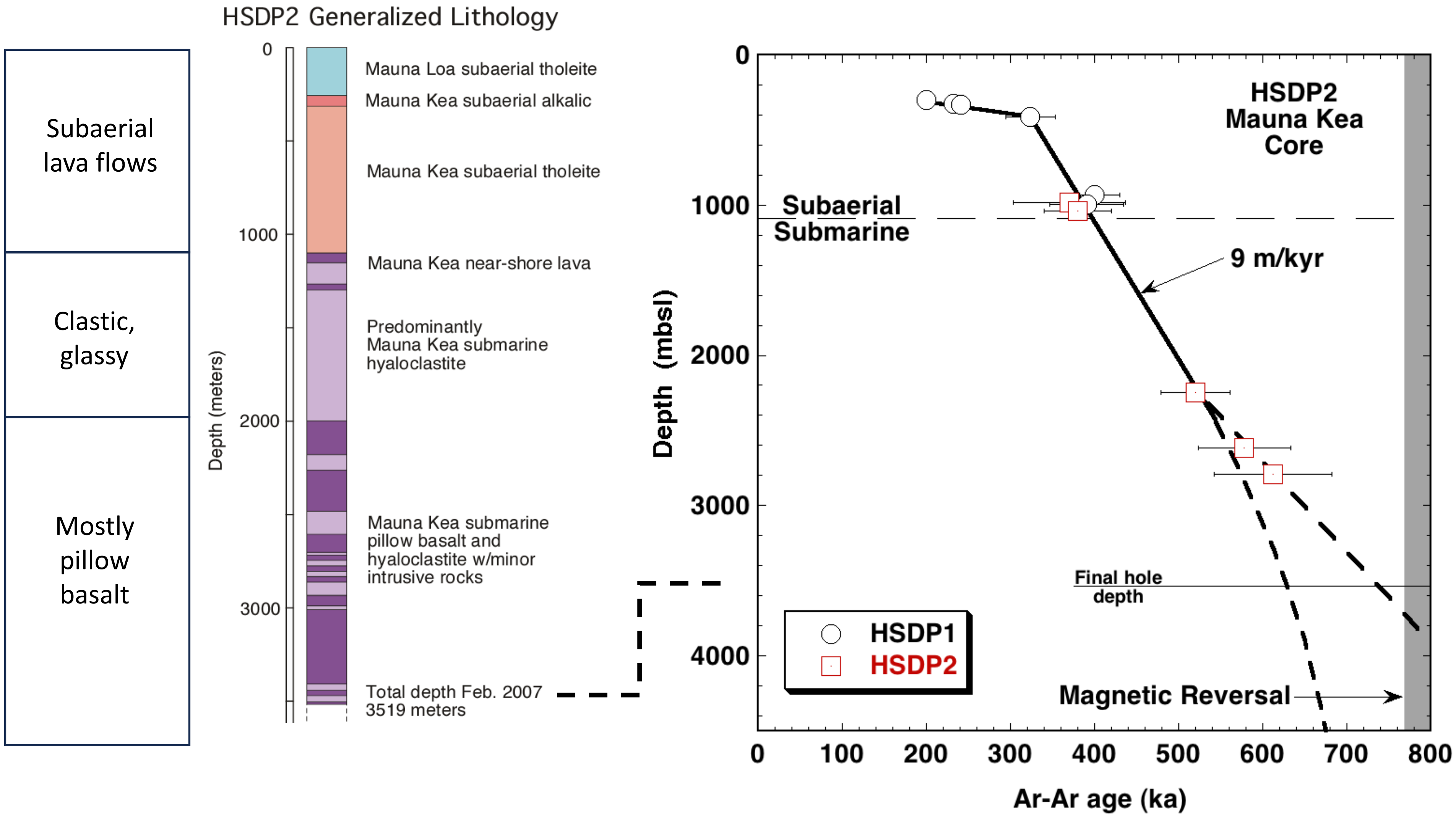


HSDP2 Generalized Lithology

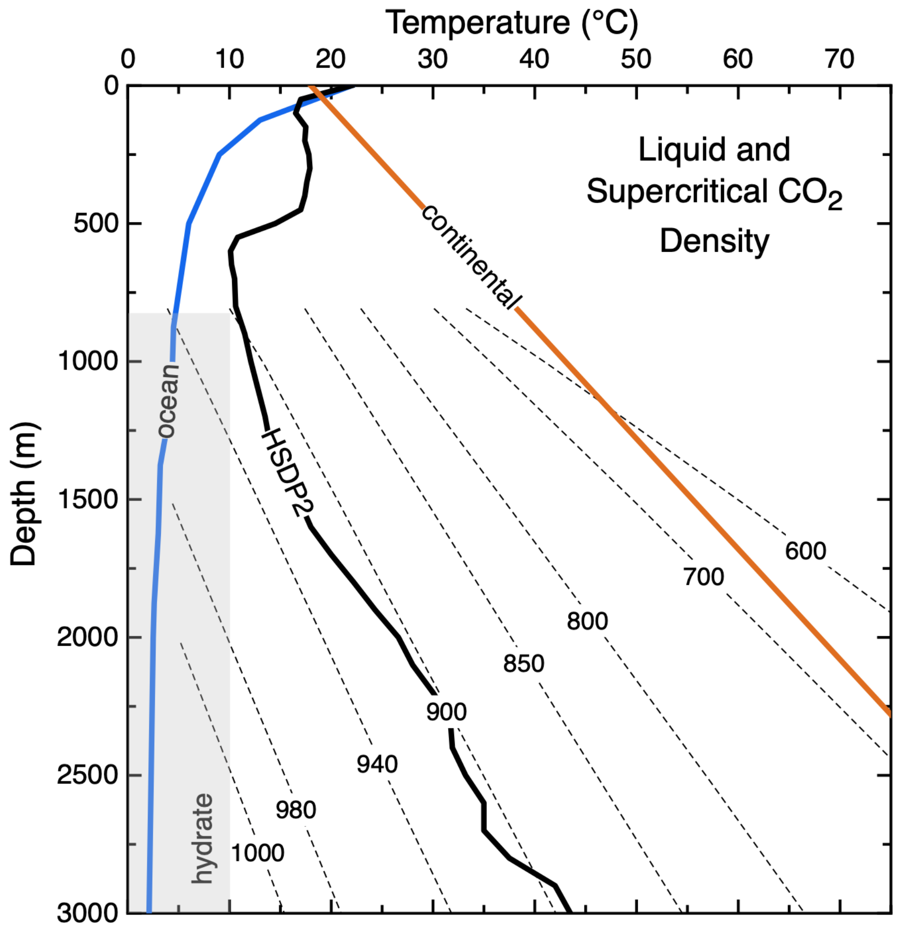


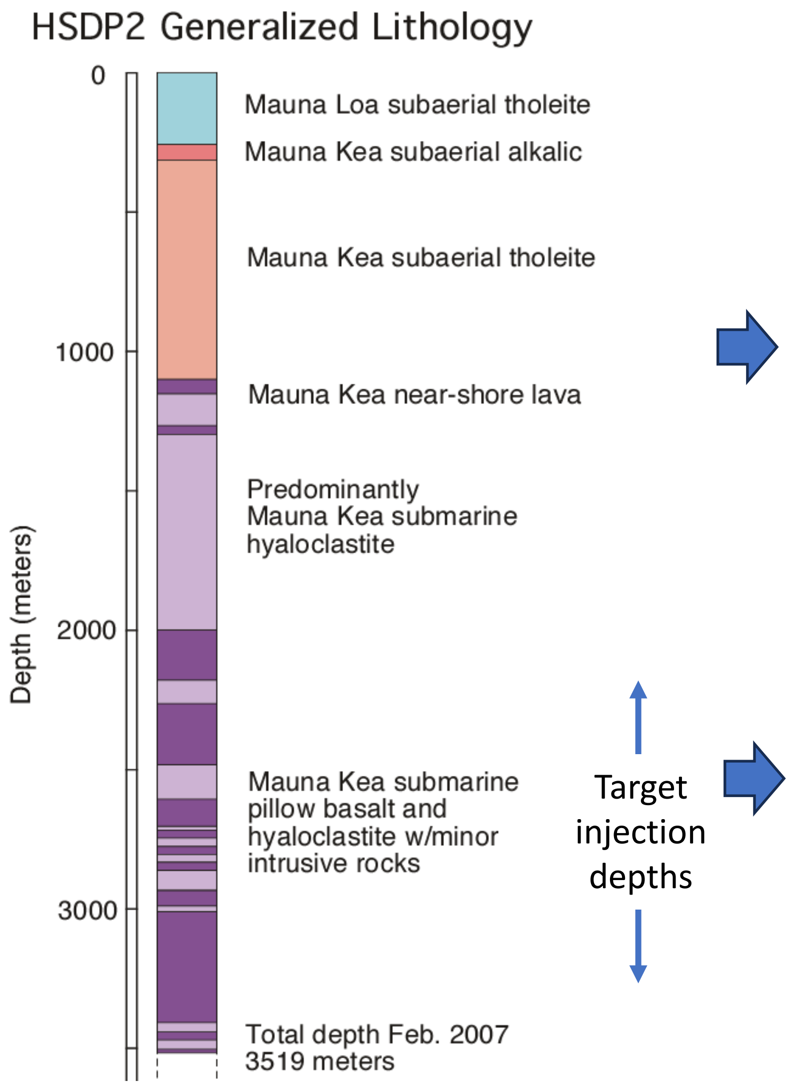


Basaltic rocks are geologically young (< 1 Ma) and reactive, enhancing mineralization potential



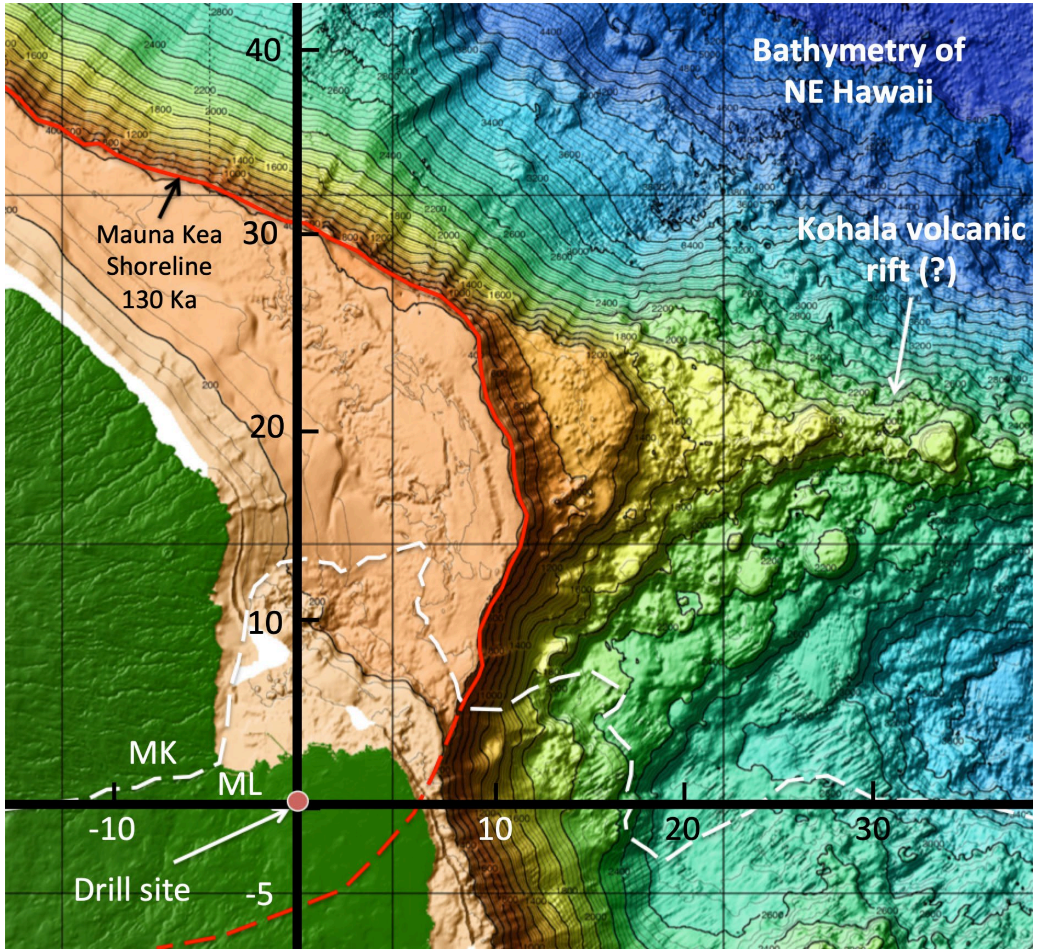
Temperature and preliminary hydrologic properties

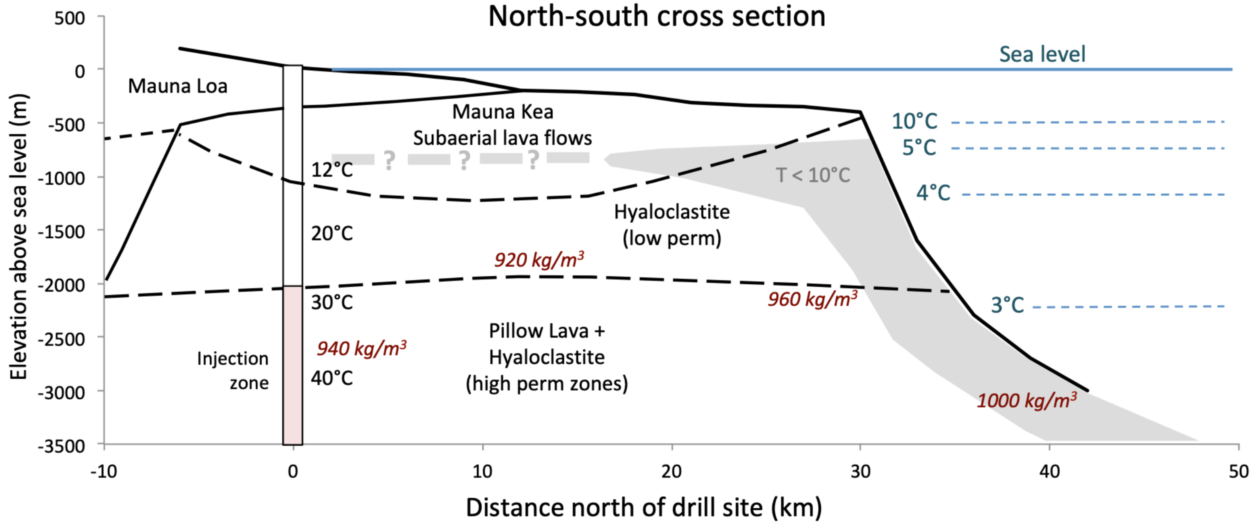


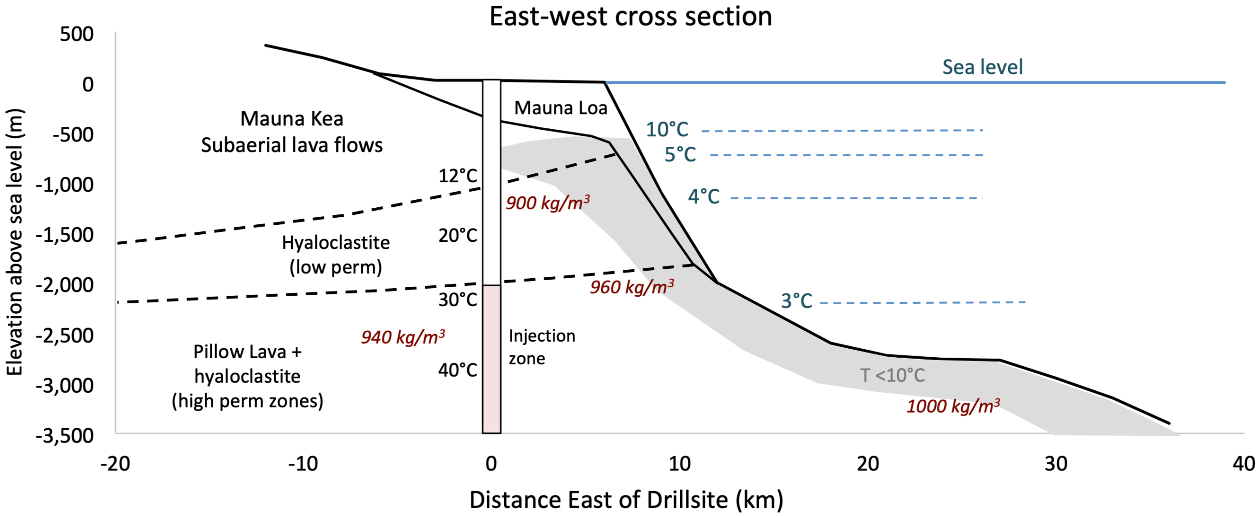


≥ 10 D	High-k Fresh water
≥ 1 D	High-k Seawater
< 1 mD	Very low-k Seawater
Zones > 100 mD (?)	Intercalated Low-k and high-k layers Brackish to hypersaline
Zones > 50 mD (?)	

Subsurface site model based on drill core, bathymetry, and volcano growth models



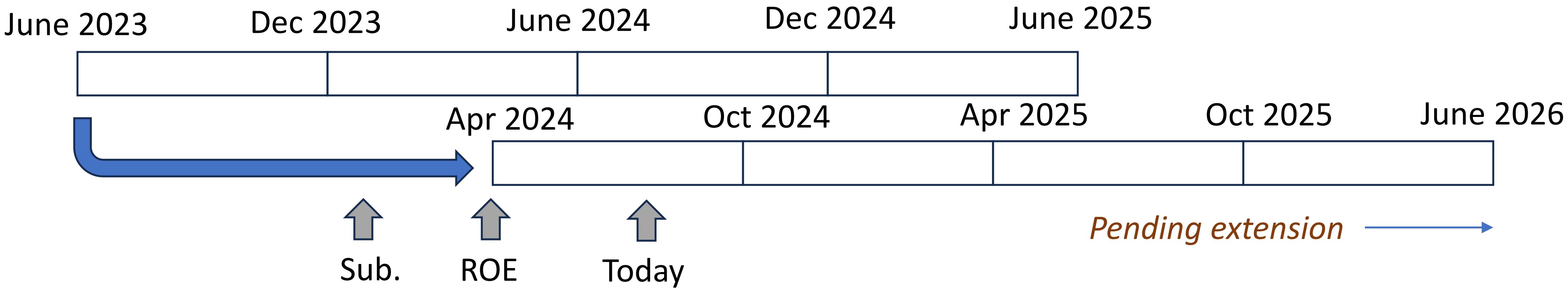




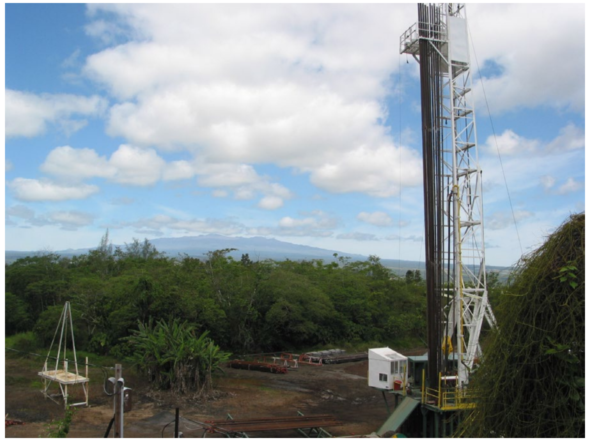
(Current) Project FE0032245: Tasks and Schedule

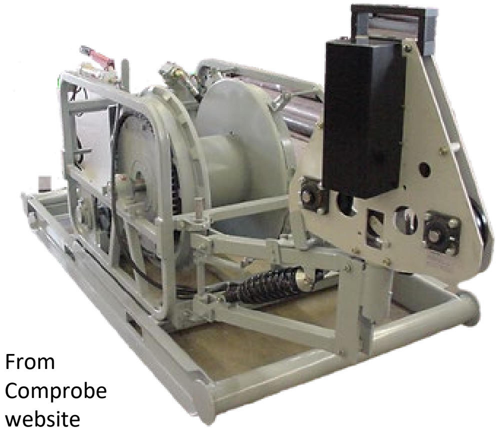
2. Downhole fluid sampling, logging, pumping, and flow tests (UH)
3. Geophysical Characterization and Monitoring of the Subsurface Reservoirs (UH, LBNL)
4. Reactive Transport Modeling of CO_2 Mineralization in Basalt (LBNL)
5. Laboratory Measurement of Basalt Reaction Kinetics (RITE, LBNL)
6. Reservoir Modeling of meteoric infiltration and thermohaline convection (LBNL)

Schedule modifications (all tasks now in progress)

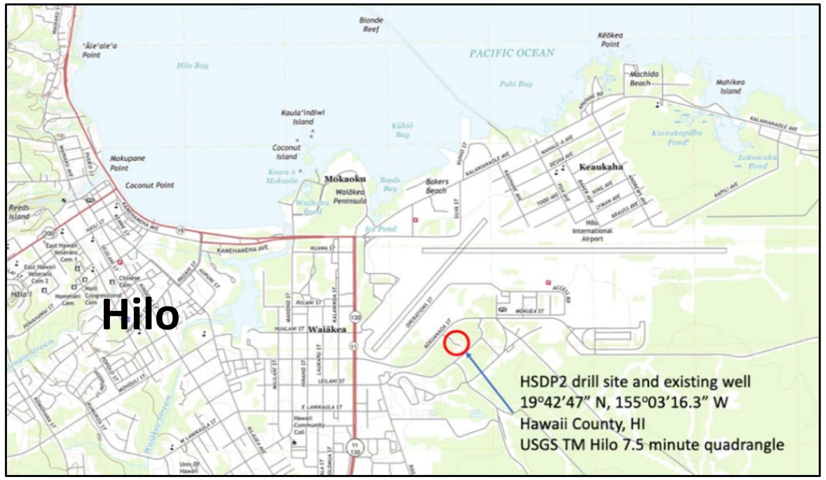


2. Downhole Sampling, Logging, Pumping, and Flow Tests





From Comprobe website

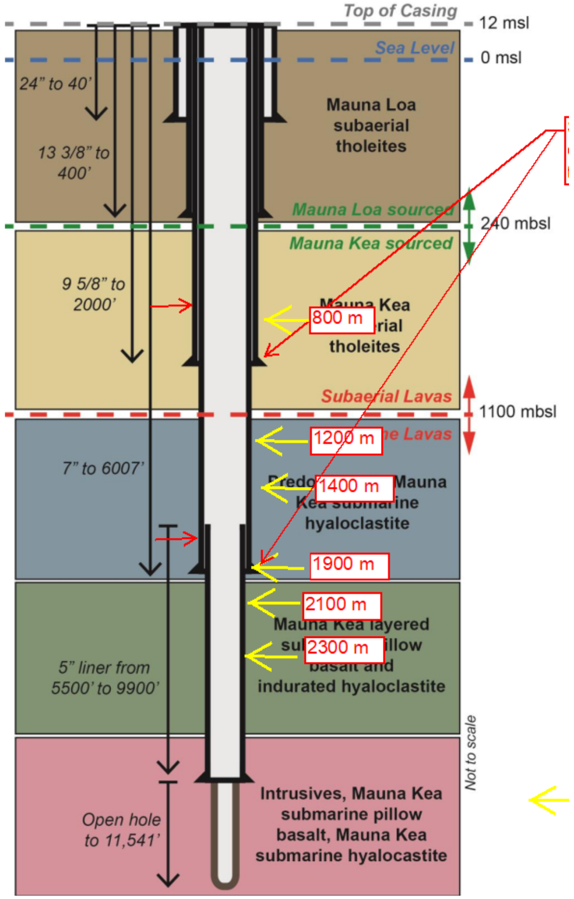


HSDP2 drill site and existing well
19º42'47" N, 155º03'16.3" W
Hawaii County, HI
USGS TM Hilo 7.5 minute quadrangle

A custom winch equipped with 6000 meters of 3/16" 4 conductor cable is being delivered to the site.

Flowmeter, fluid sampler, and a pressure-temperature tool will be run individually or in a string, while flowing the well, pumping, or stagnant.

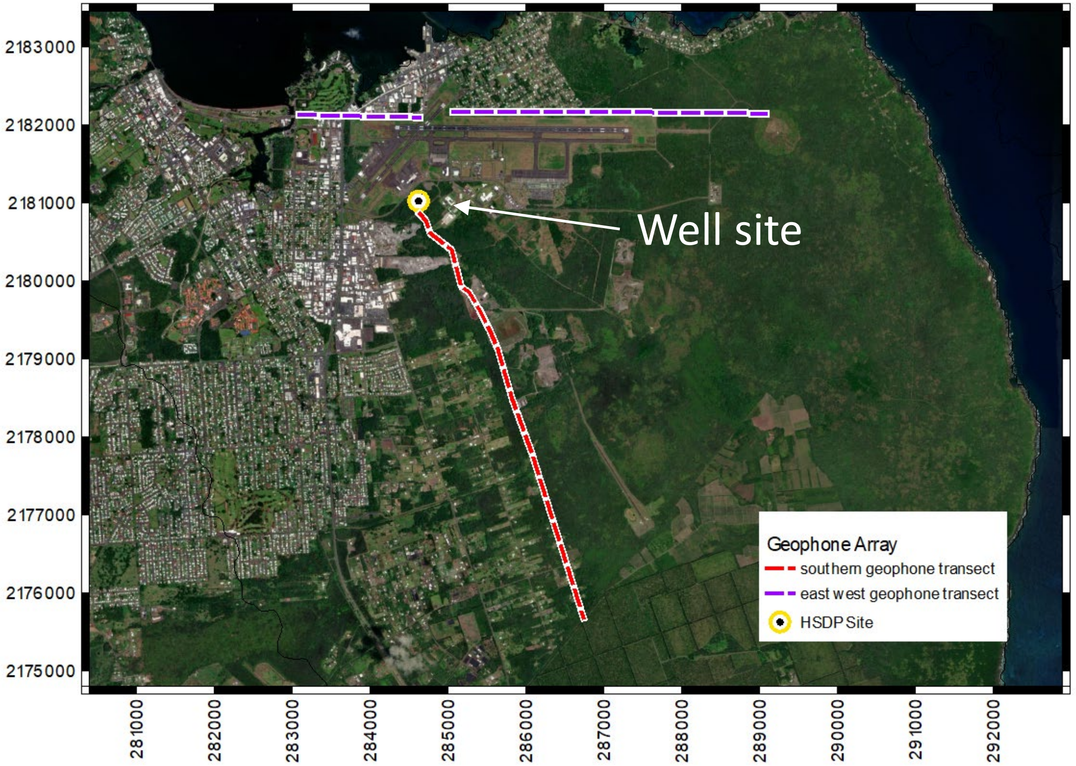
Winch will be skid-mounted

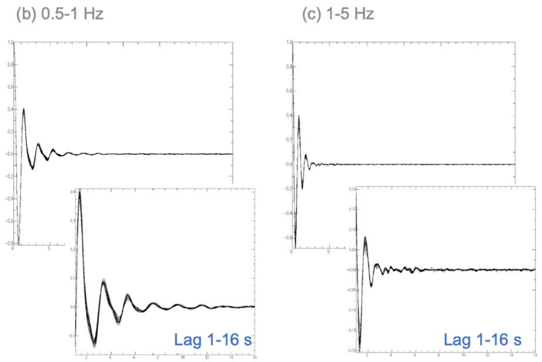


3350 m to total depth

3. Geophysical Characterization and Monitoring of Subsurface Reservoirs

- **Passive seismic** imaging will take advantage of local and teleseismic events to image the inferred volcanic stratigraphy.
- Seismic survey is composed of two almost-perpendicular geophone lines, each 5 km in length; average spacing is 50m, requiring **200-250 geophones**.
- Magseis Fairfield ZL and 3-axis geophones with a 5Hz corner frequency deployed simultaneously for **3-4 months, starting winter 2024 or spring 2025**, depending on instrument availability from Earthscope PASSCAL.
- A **magnetotelluric** station will also be deployed at the well site to determine if MT could be used as a monitoring tool for CO_2 injection.
- The closest station to the well site from the Hawaiian Volcano Observatory Network is being used to analyze teleseismic events (13/year) for single-station receiver-function analysis. Ambient noise wavefields can yield information on near-surface structure and will also be used in conjunction with the seismic array that will be deployed later this year.





Auto-correlation functions at HV.NAGD with ambient-noise data in 2022. At 1-5 Hz (c), reflections are observed around 2.5-6 s, which are related to the structure at 3-8 km depth.

4. Reactive Transport Modeling of CO_2 Mineralization in Basalt (LBNL)

Bhavna Arora and Dipankar Dwivedi

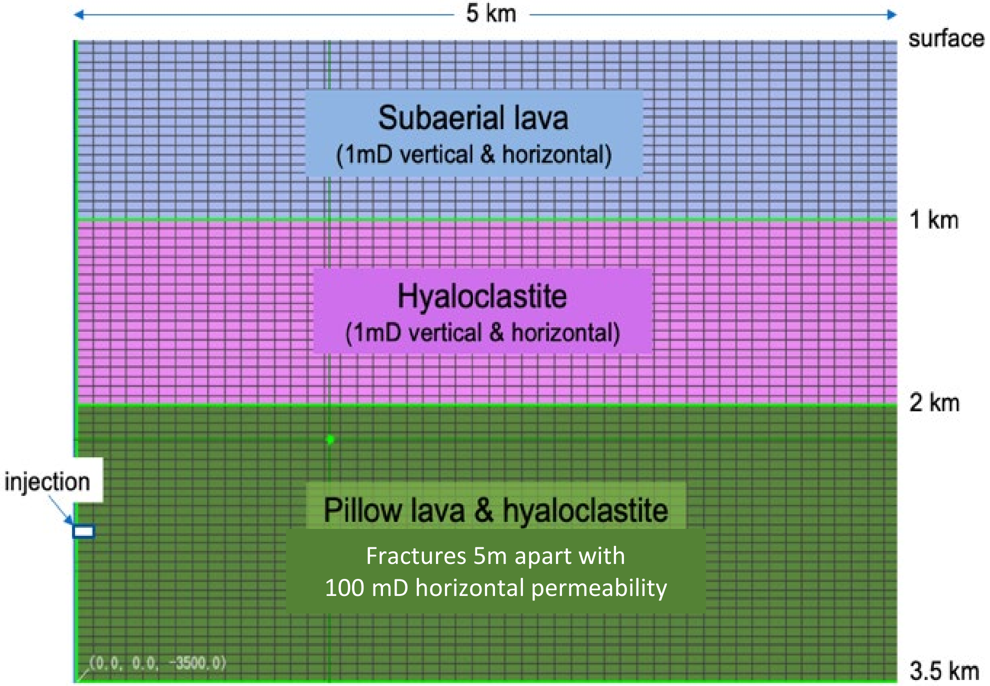
Work to date…

1. Adapting previous models to new thermodynamic database and mineralogy
2. Preliminary parameter sensitivity analysis

Code: TOUGHREACT 4.173 eco2n

Thermo database: Soltherm (Palandri, 2015)

Kinetics - still under review:
Palandri and Kharaka (2004)
Hermanska et al (2022)



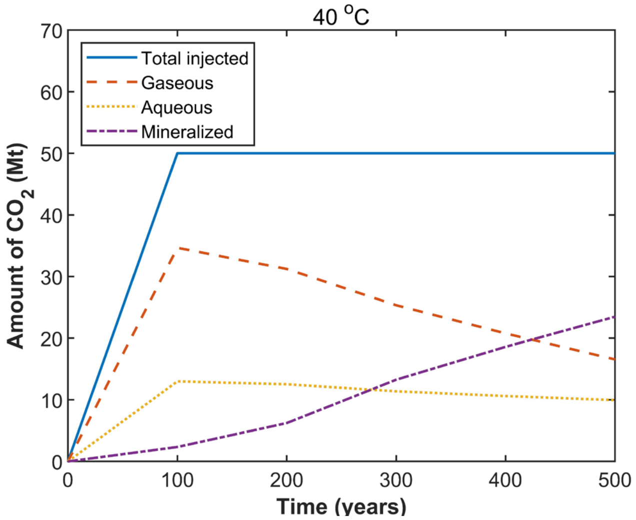
Preliminary computational grid for initial parameter testing; radial symmetry

- fracture spacing: 5 m
- volume fraction of fractures: 0.05

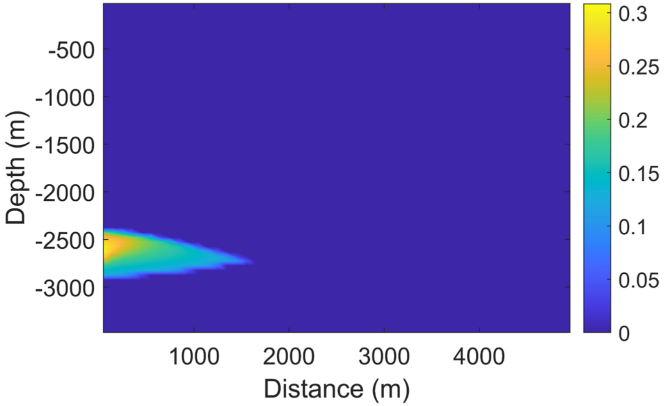
Permeabilities and porosity
- subaerial lava: fracture 1mD, matrix 1mD
- hyaloclastite: fracture 1mD, matrix 1mD
- pillow lava: fracture x-100mD, y, z 1mD, matrix 0.1mD
- Porosity of fracture: 0.1, porosity of matrix: 0.1

4. Reactive Transport Modeling of CO_2 Mineralization in Basalt (LBNL)

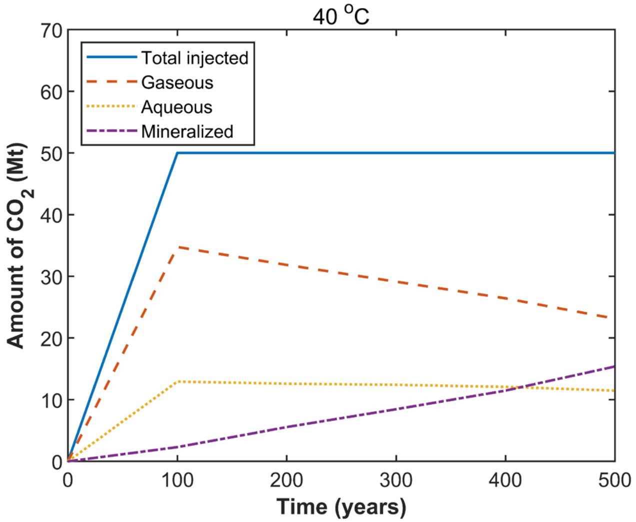
No olivine, seawater



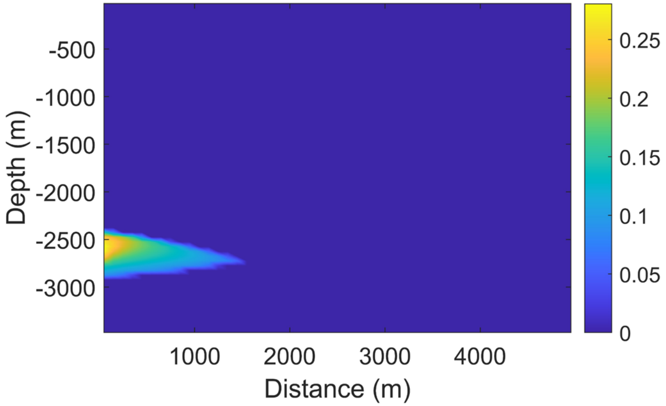
Gas saturation in matrix at 500 years
k_x(fracture)=100 mD, 40 °C



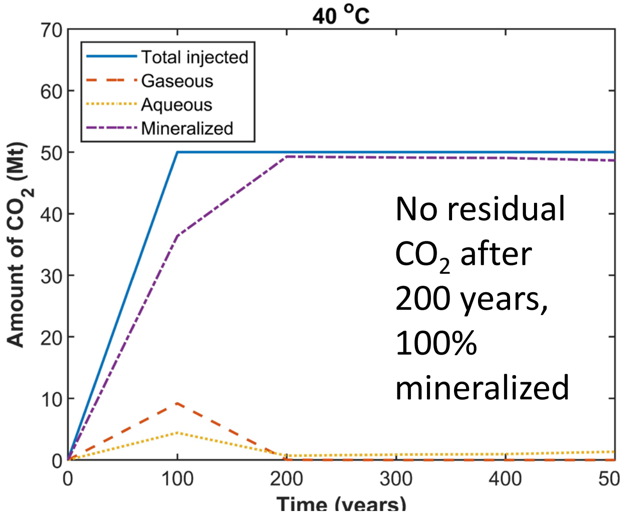
No olivine, High-Ca, low Na, Mg porewater*



Gas saturation in matrix at 500 years
k_x(fracture)=100 mD, 40 °C

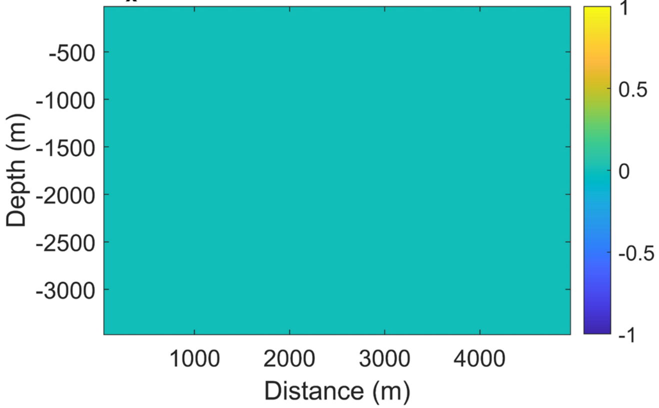


7% olivine, seawater



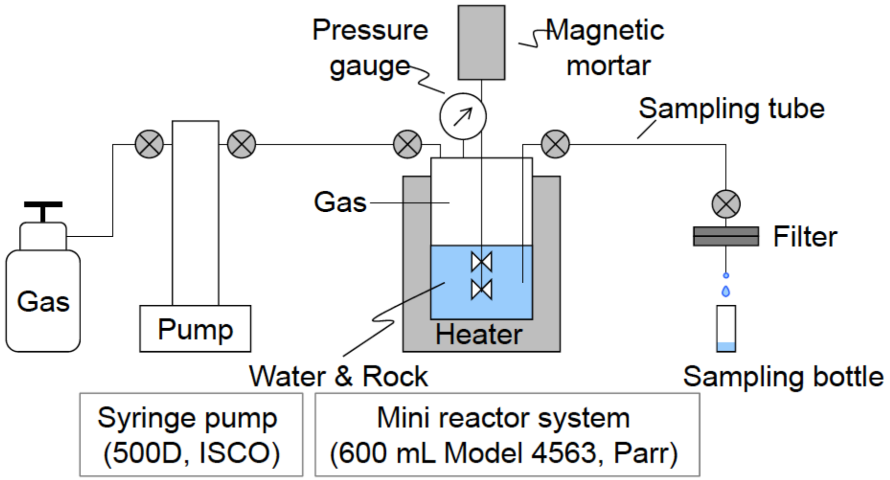
No residual CO_2 after 200 years, 100% mineralized

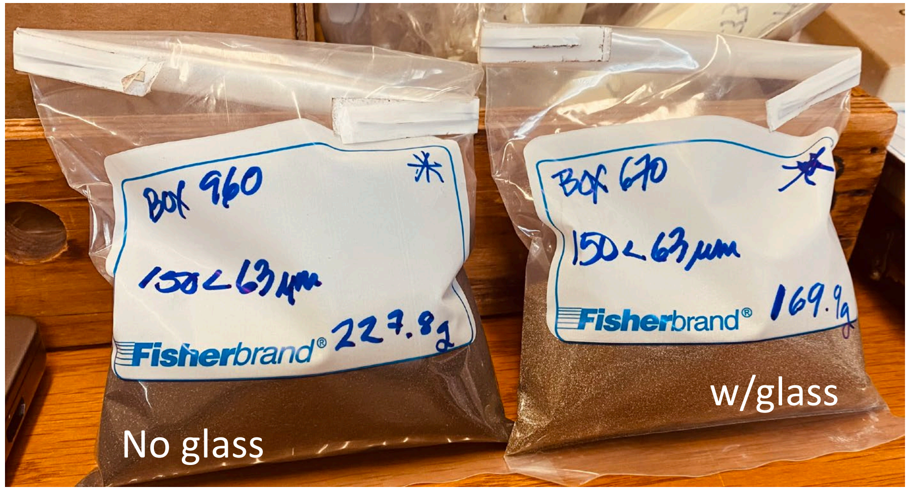
Gas saturation in matrix at 500 years
k_x(fracture)=100 mD, 40 °C



These results from Shuo Zhang, Tsinghua U.

5. Laboratory Measurement of Basalt Reaction Kinetics



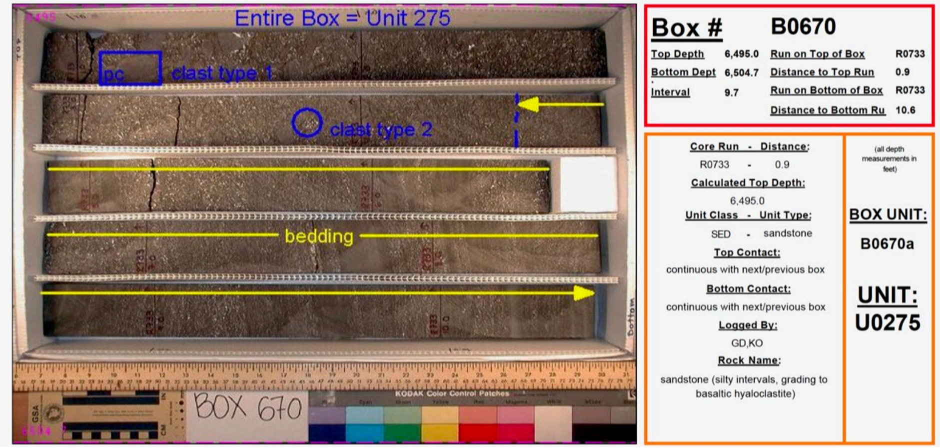


Closed-system experiments performed at RITE

1. 15g solid with 300g fluid
2. Fluid has seawater Na, Cl, Mg (no Ca, Fe, Si …)
3. Fluid sampled at varying intervals, 10 samples per experiment up to maximum of 275 days
4. *Time correction* made to account for decreasing fluid volume from sampling
5. Fluids measured for Ca, Mg, Fe, Si, Al, and trace elements Mn, Sr, Ba
6. **2 experiments at 80°C and 100 bar CO_2**
   Hyaloclastite (63 – 150 µm)
   Pillow basalt (63 – 150 µm)
7. Measured Mg/Ca to estimate contribution of olivine (OL: Mg/Si ≈ 1.7; rock: Mg/Si ≈ 0.25)
8. Geometric surface area is about 1 m^2/kg
9. TOUGHREACT simulations to evaluate effects of secondary mineral formation

5. Laboratory Measurement of Basalt Reaction Kinetics

Hyalo-
clastite



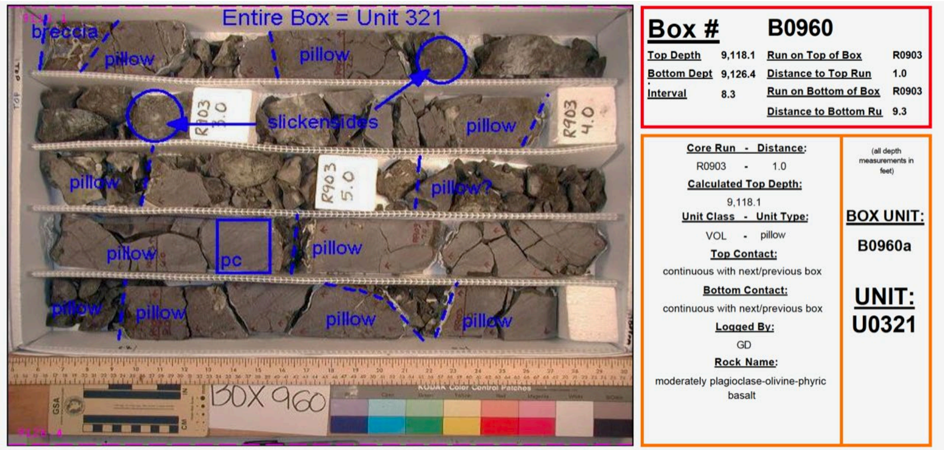
Box #	**B0670**		
Top Depth	6,495.0	**Run on Top of Box**	R0733
Bottom Dept	6,504.7	**Distance to Top Run**	0.9
Interval	9.7	**Run on Bottom of Box**	R0733
		Distance to Bottom Ru	10.6

Core Run - Distance:
R0733 - 0.9
Calculated Top Depth:
6,495.0
Unit Class - Unit Type:
SED - sandstone
Top Contact:
continuous with next/previous box
Bottom Contact:
continuous with next/previous box
Logged By:
GD,KO
Rock Name:
sandstone (silty intervals, grading to basaltic hyaloclastite)

(all depth measurements in feet)

BOX UNIT:
B0670a

UNIT:
U0275



Box #	**B0960**		
Top Depth	9,118.1	**Run on Top of Box**	R0903
Bottom Dept	9,126.4	**Distance to Top Run**	1.0
Interval	8.3	**Run on Bottom of Box**	R0903
		Distance to Bottom Ru	9.3

Core Run - Distance:
R0903 - 1.0
Calculated Top Depth:
9,118.1
Unit Class - Unit Type:
VOL - pillow
Top Contact:
continuous with next/previous box
Bottom Contact:
continuous with next/previous box
Logged By:
GD
Rock Name:
moderately plagioclase-olivine-phyric basalt

(all depth measurements in feet)

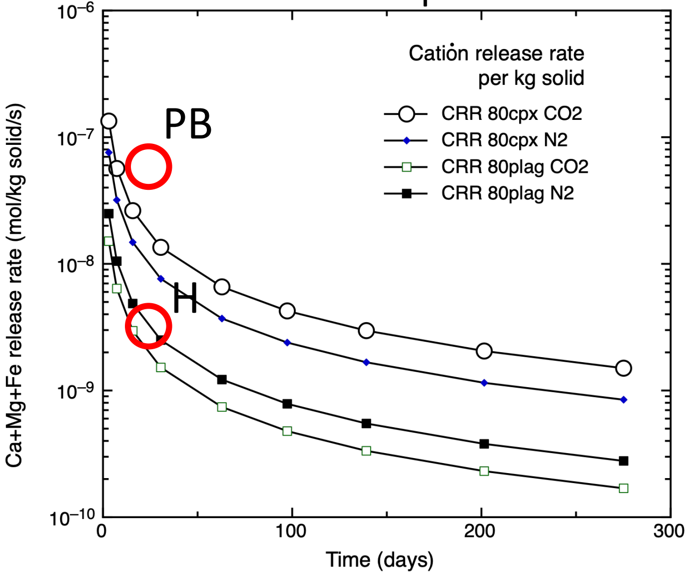
BOX UNIT:
B0960a

UNIT:
U0321

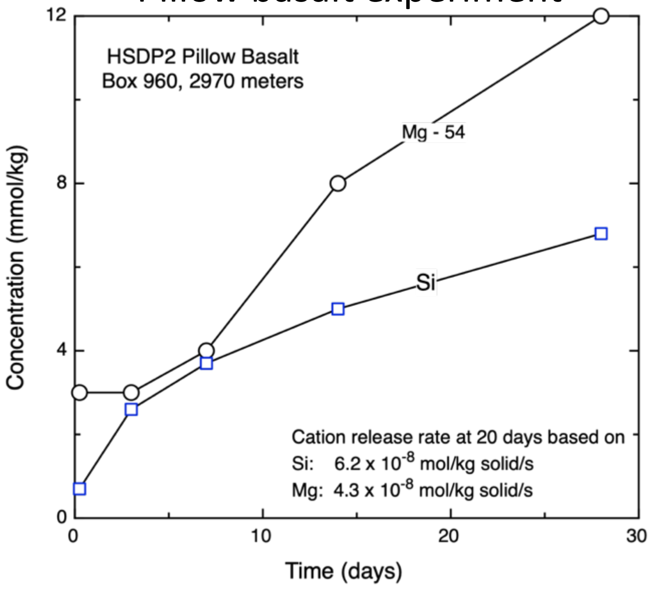
Pillow
basalt

Olivine is dissolving rapidly in pillow basalt, but not (so far) in the hyaloclastite

2-mineral experiments



Pillow basalt experiment



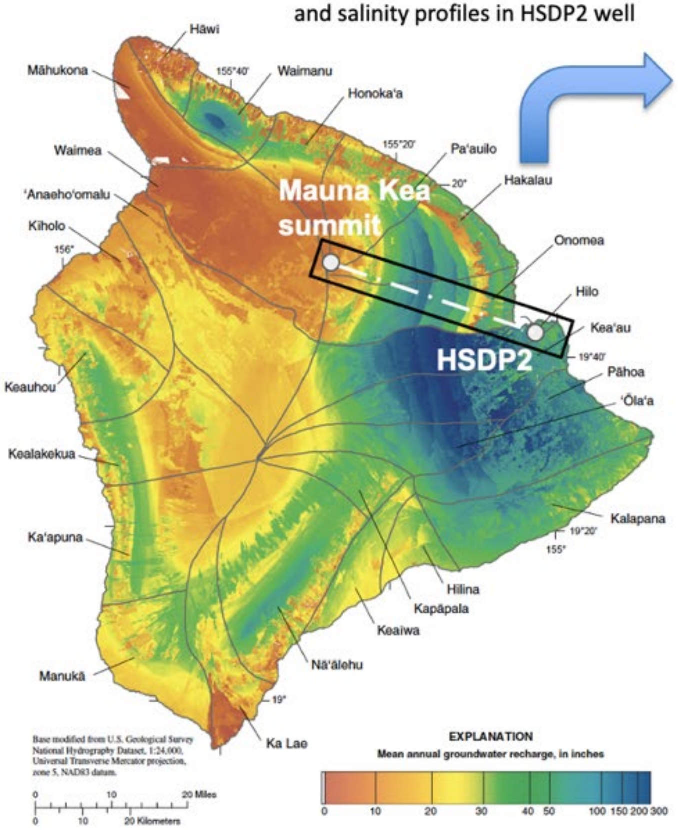
Cation release rate at 20 days based on
Si: 6.2 x 10^{-8} mol/kg solid/s
Mg: 4.3 x 10^{-8} mol/kg solid/s

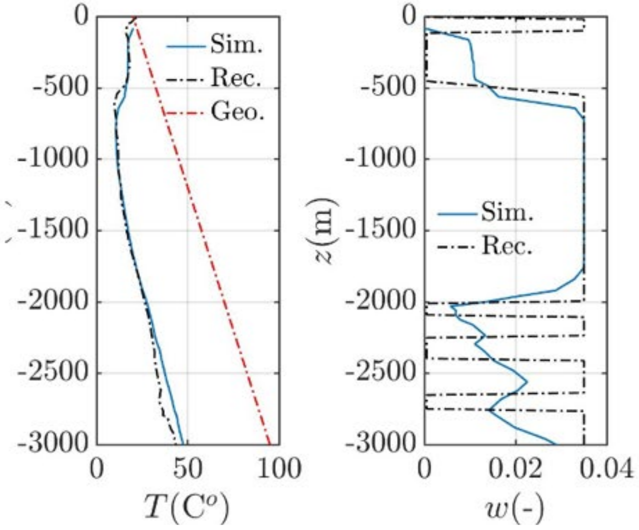
Pillow basalt preliminary estimate at 20 – 25 days 5 x 10^{-8} mol/kg solid/s

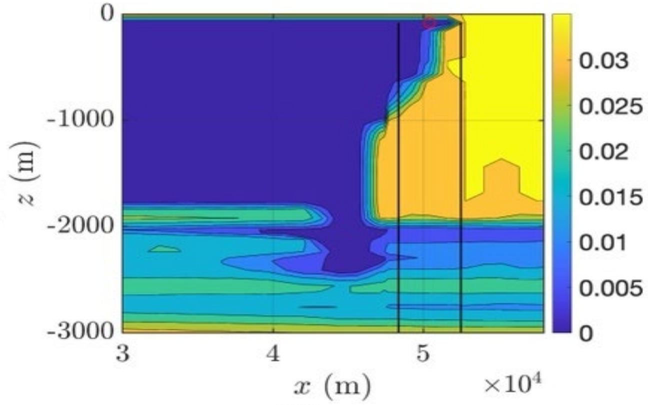
Hyaloclastite estimate is 3 x 10^{-9} mol/kg solid/s 10x slower than pillow basalt

6. Reservoir Modeling of meteoric infiltration and thermohaline convection

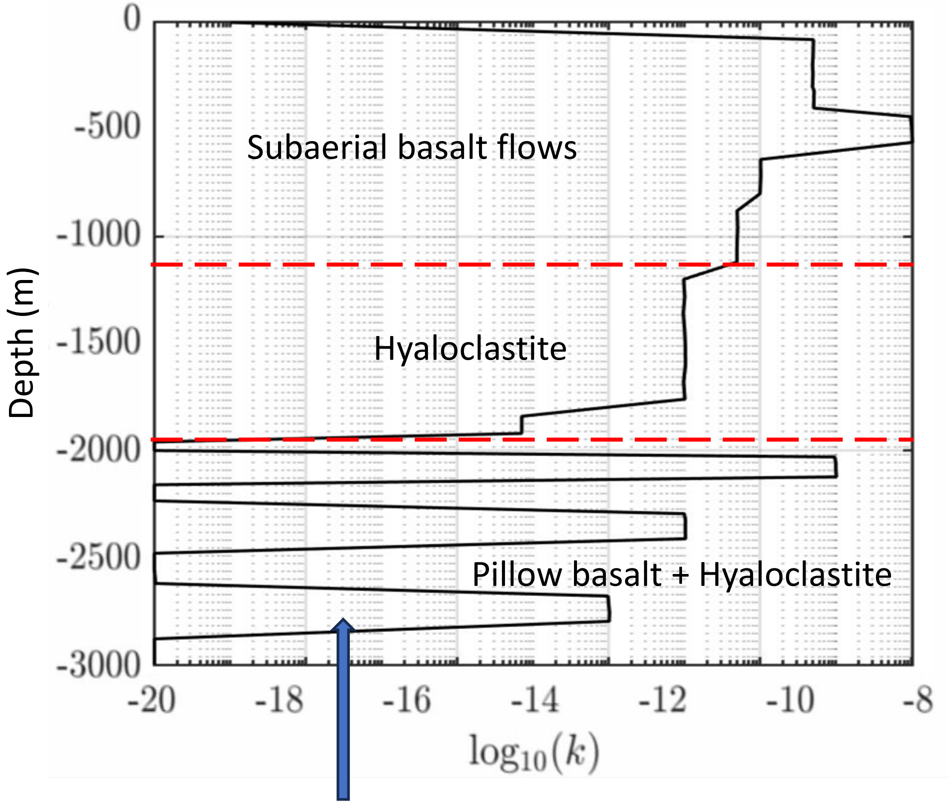
Infiltration – convection – permeability model can match observed temperature and salinity profiles in HSDP2 well







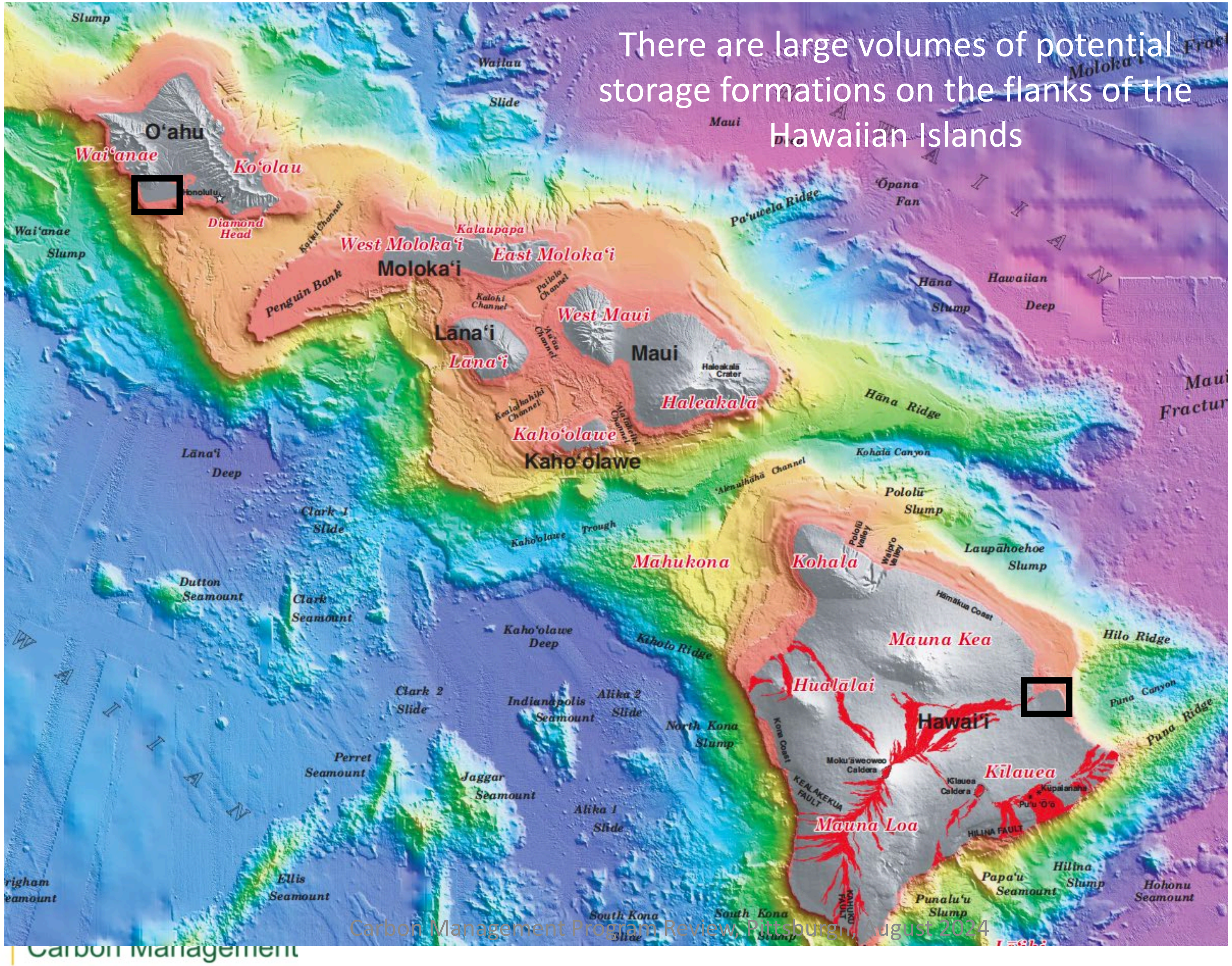
Model permeability structure at HSDP2 well site



Origin of artesian aquifers at >2000 m depth?

Broader impacts in carbon storage program

2/3 of Hawaii emissions are from Oahu (5 Mton/y)



There are large volumes of potential storage formations on the flanks of the Hawaiian Islands

Broader impacts in carbon storage program

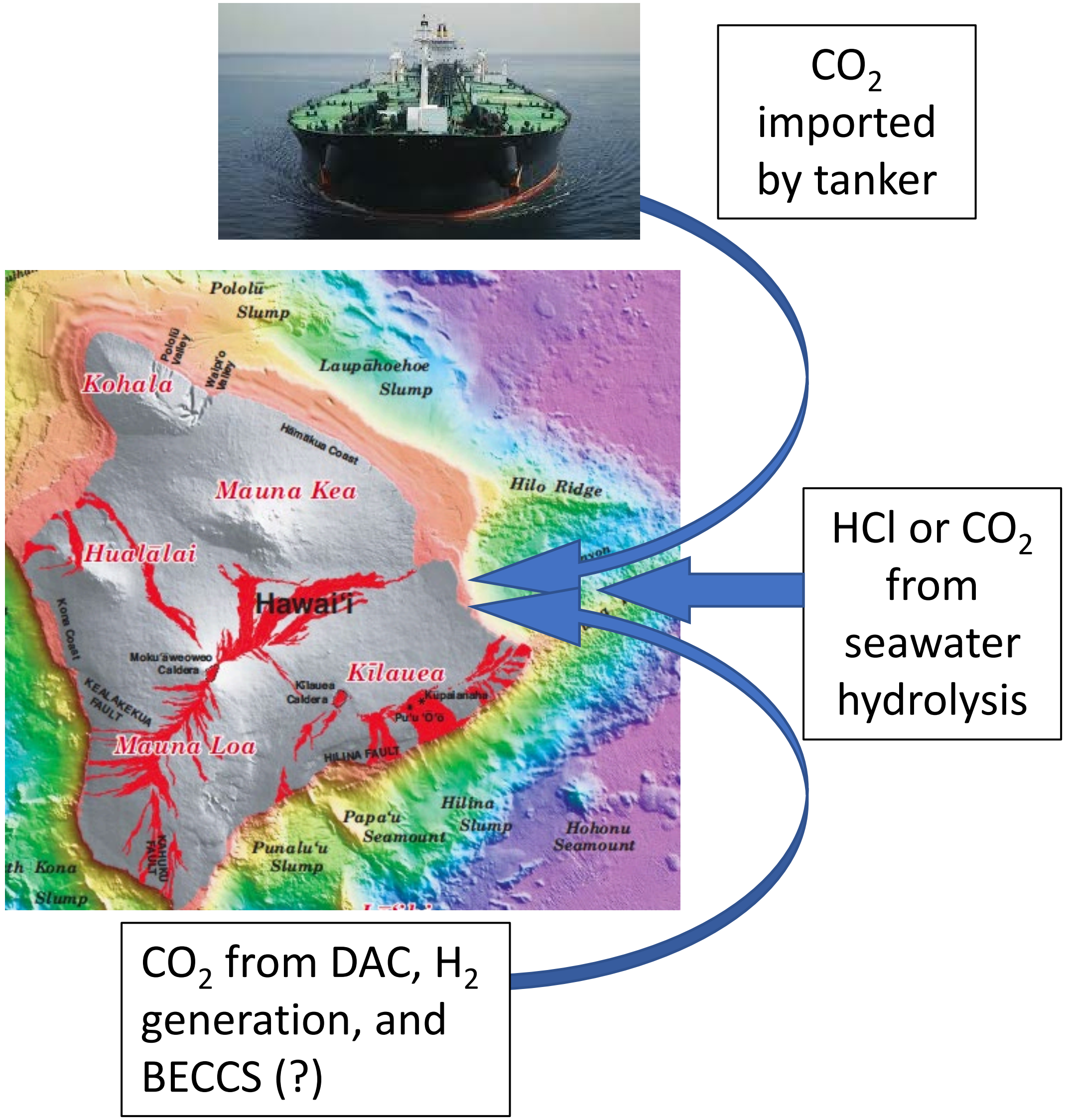
Near - shore storage injection sites in the Hawaiian Islands, if proven to have gigaton+ storage capacity could become destination storage facilities for countries around the Pacific with poor storage geology.

CDR approaches that extract either HCl or CO_2 from seawater can benefit from near-shore storage facilities. HCl could be disposed of in basalt and could be combined with CO_2 disposal.

DAC can be done anywhere and requires storage. Wind and solar energy are potentially available.

Existing H_2 generation plants in Hawaii produce pure CO_2 streams but need storage.

BECCS could also make sense in Hawaii but would need storage.



CO_2 imported by tanker

HCl or CO_2 from seawater hydrolysis

CO_2 from DAC, H_2 generation, and BECCS (?)

Key questions for proof of concept

1. What is the likely range of **vertical permeability** in submarine volcanic sections?
2. What is a likely range of horizontal permeability, how much **interconnected pore space** is typical, and on what length scales?
3. How efficient is **capillary trapping** in basalt?
4. Can **mineralization rates** be adequately estimated? What is the tradeoff between CO_2 density (low-T; high-P) and mineralization rates?
5. Can storage capacity be estimated? Are glass-rich horizons effective **seals**? Are they self-sealing?
6. How effective is **hydrate formation** as a CO_2 trapping mechanism?
7. Does the combination of characteristics and multiple trapping mechanisms ensure **permanent storage**?