Sixth Annual Conference on Carbon Capture & Sequestration

Evaluation of Geologic Formations (1)

CO_2 Flood tests on Basalt: An Examination of the Basalt and Basalt-Cement Interface

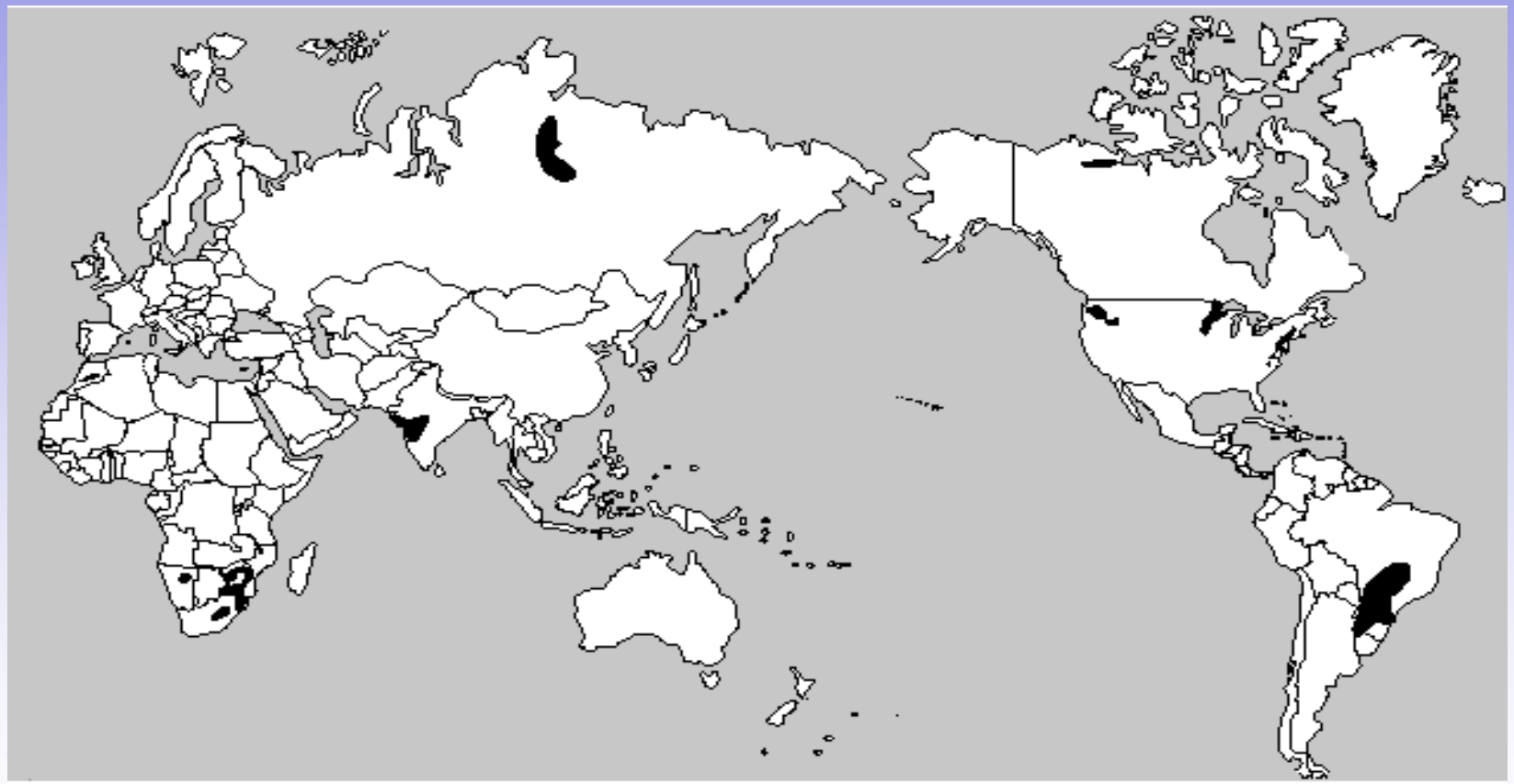
W.K. O'Connor and G.E. Rush

May 7-10, 2007 • Sheraton Station Square • Pittsburgh, Pennsylvania

Basalt for CO_2 Storage

- Potential for CO_2 storage in Pacific Northwest
- Saline formations at depth in the Pasco Basin
- Local point sources for CO_2
  - Coal-fired power plants
  - Lime kiln
- High porosity interflow zones
- Favorable mineralogy for mineral trapping

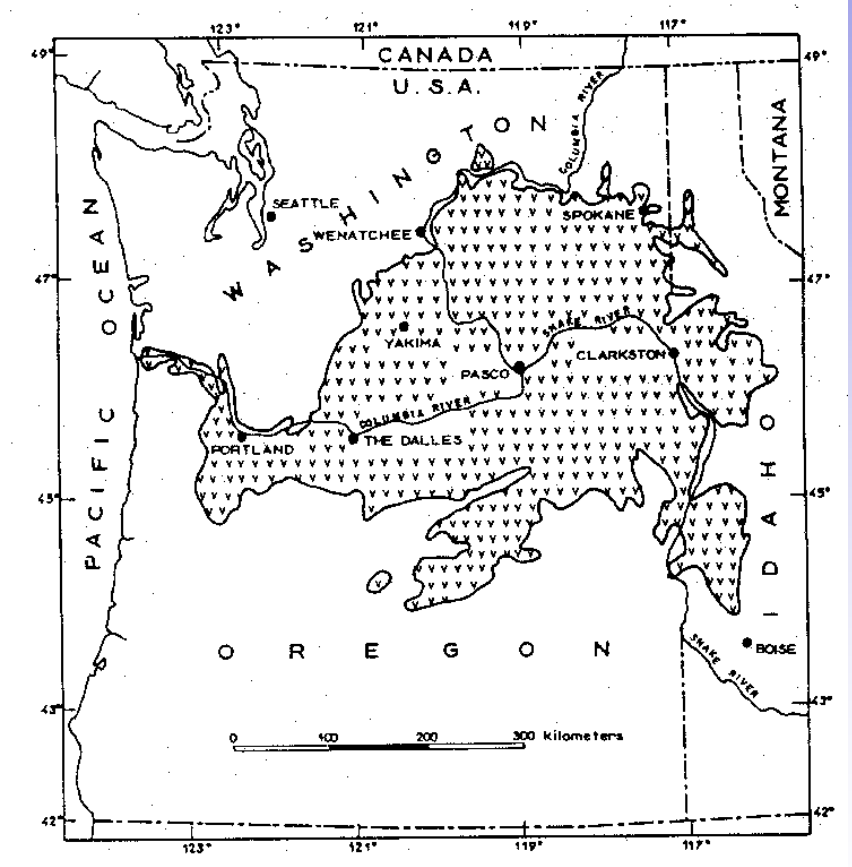
Continental Flood Basalts



Antarctica not shown here

Columbia River Basalt Group (CRBG)

- Flood basalt province
  - Area over 200,000 km^2
  - Average thickness of 1 km
- Multi-flow structure
  - Numerous aquifers
  - Isolated stratigraphically
- Aquifer horizons
  - 10-30 m thick
  - 10-30% porosity
  - Vast storage capacity
    - 100 Gt CO_2 (0.1% total volume)
- CRBG Core samples
  - Grand Ronde formation provided by Dr. Stephen Reidel, PNNL

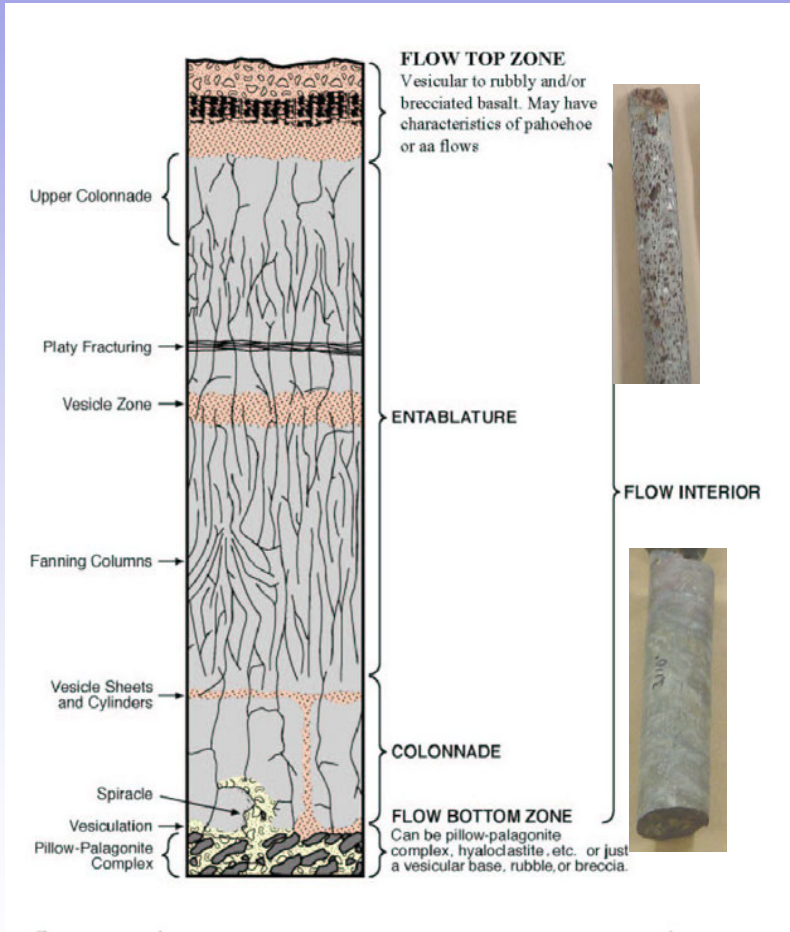


Multi-Layered Flows

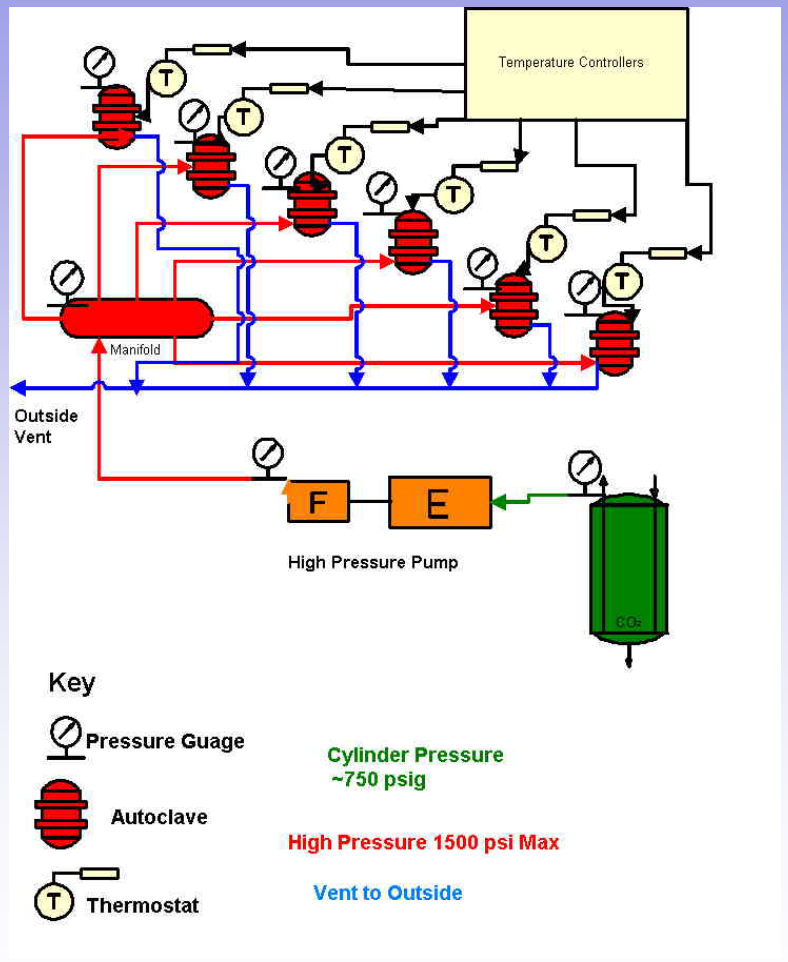
Joseph Canyon, NE Oregon

Idealized Cross-Section With Typical Core

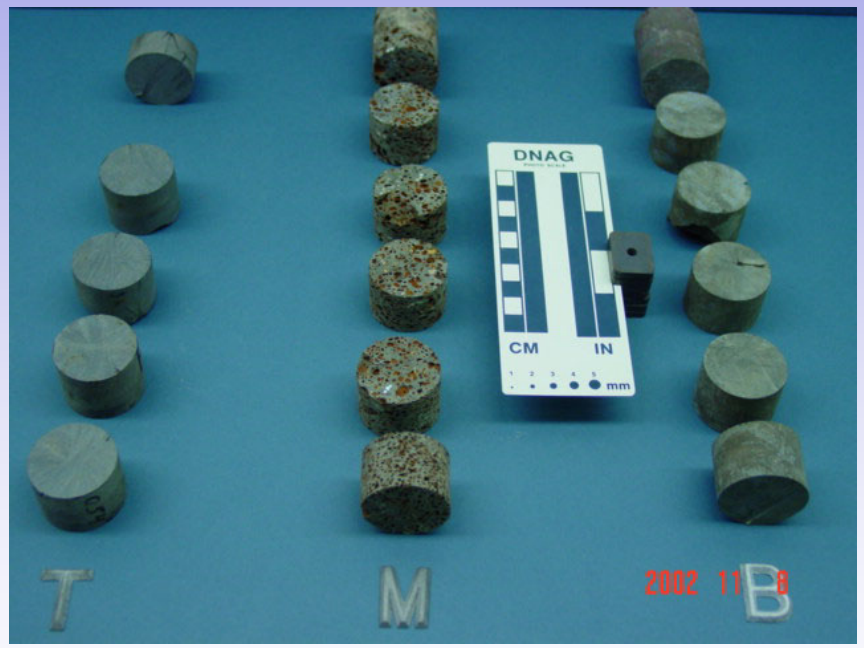
- Flow top
  - Volcanic gases escape during emplacement
  - Vesicular basalt with high porosity
- Flow bottom
  - Pillow complex, brecciated
  - Lies above prior flow top
    - Interflow zone
- Entabulature
  - Massive interior section
  - Seals interflow zone
    - Cap rock
    - Bottom aquitard

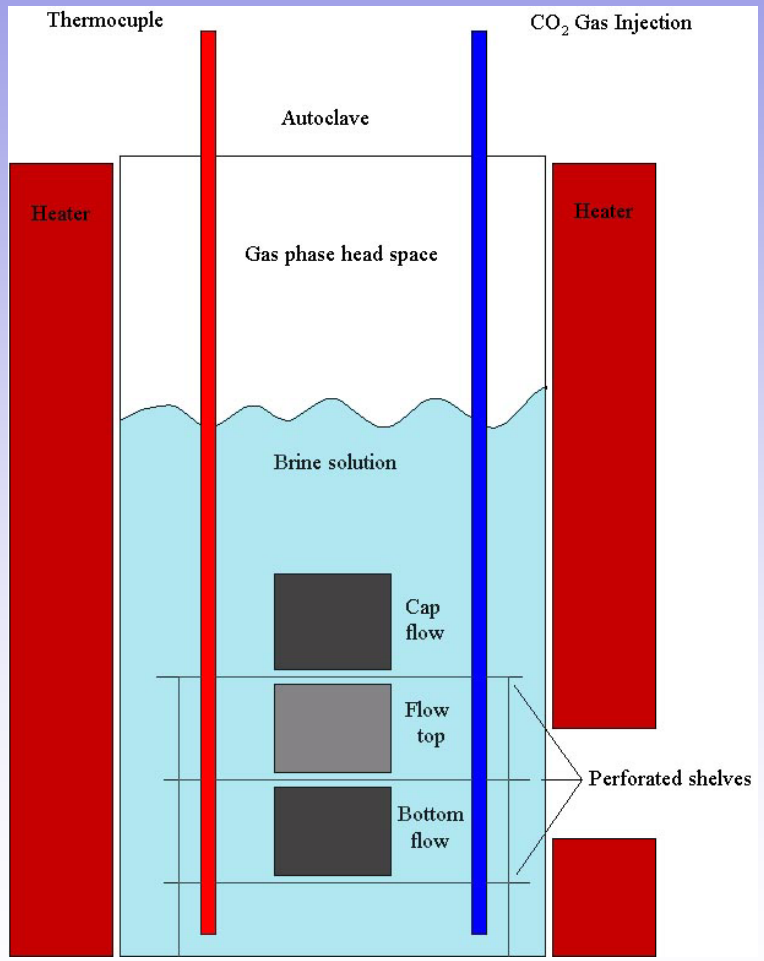


Experimental Apparatus



Sectioned Cores & Autoclave Placement

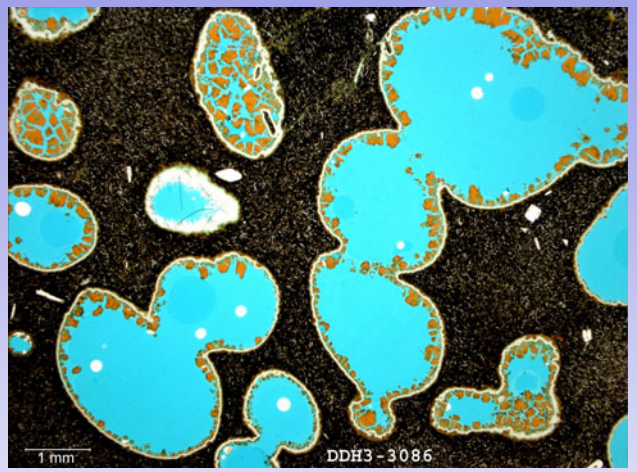




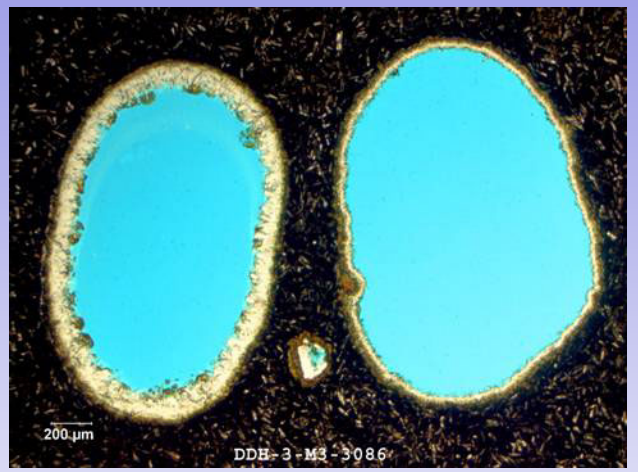
Experimental Conditions

- Brackish solution (pH ~9.24)
  - Cl: 240 mg/l; F: 40 mg/l
  - Na: 260 mg/l; HCO_3: 120 mg/l
  - 35°C temperature
  - P_{CO2}= 1,500 psig (100 atm)
- FT core porosity: ~15-30% @ ~3000 ft depth interval
- Time series
  - 100, 500, 1,000, 1,500, & 2,000 h conducted

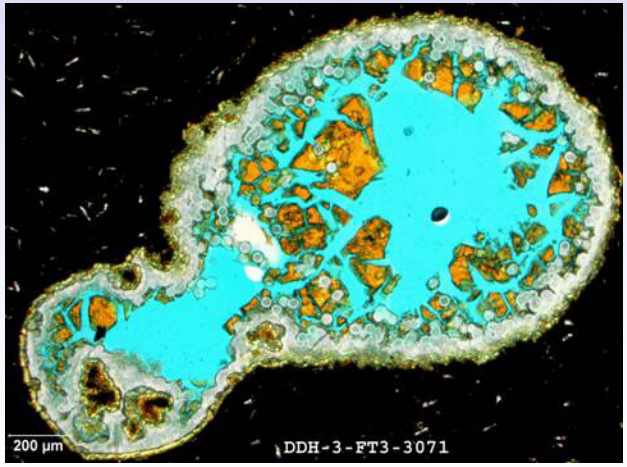
Basalt Core Alteration Over Time



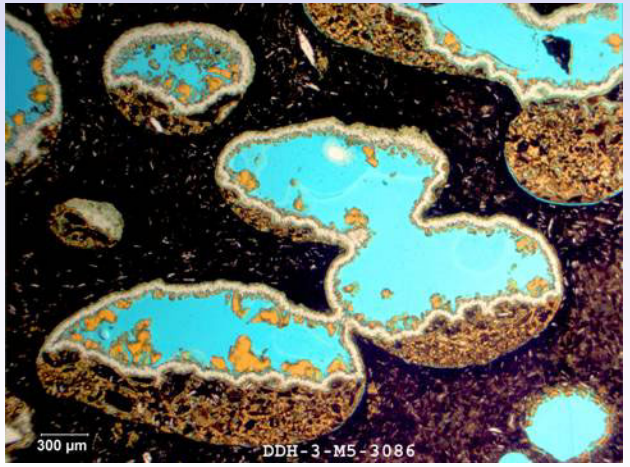
Pretest



500 h



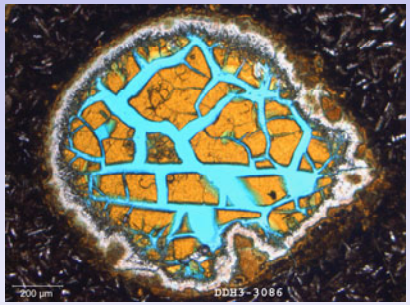
1000 h



2000 h

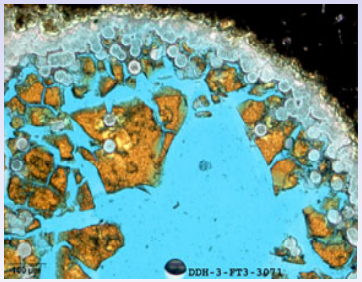
Pre- & Post CO_2 Flood Mineralogy

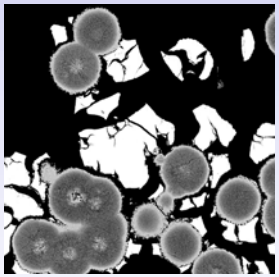
- Pre- CO_2 Flood
- Anorthite, augite primary phases
- Magnetite trace phase
- Pre-existing secondary minerals
  - Zeolite
  - Hydrated
  - Fe oxide (limonite)



- No carbonate minerals identified
  - Siderite mentioned in literature, but not found here
- Solids: <0.01 wt pct CO_2

- Post- CO_2 Flood
- Pre-existing secondary minerals
  - Zeolites absent from 500 h test solids
  - Carbonate minerals - trace
- Microscopic analysis
  - Amorphous silica precipitate





- Solids: Up to 0.26 wt pct CO_2

Wellbore Cement Studies

- LaFarge Class H wellbore cement (Portland)
- Examined impact of the CO_2 flood on cement
  - Pre-cured cement
  - Supercritical CO_2 (SCC)-cured cement
- Impact of several novel additives on cement alteration under SCC
- Conducted several series of CO_2 flood tests
  - Brine solution, 35˚C, P_{CO2}=1,500 psig, 2,000 hours

Wellbore Cements Cured Under SCC

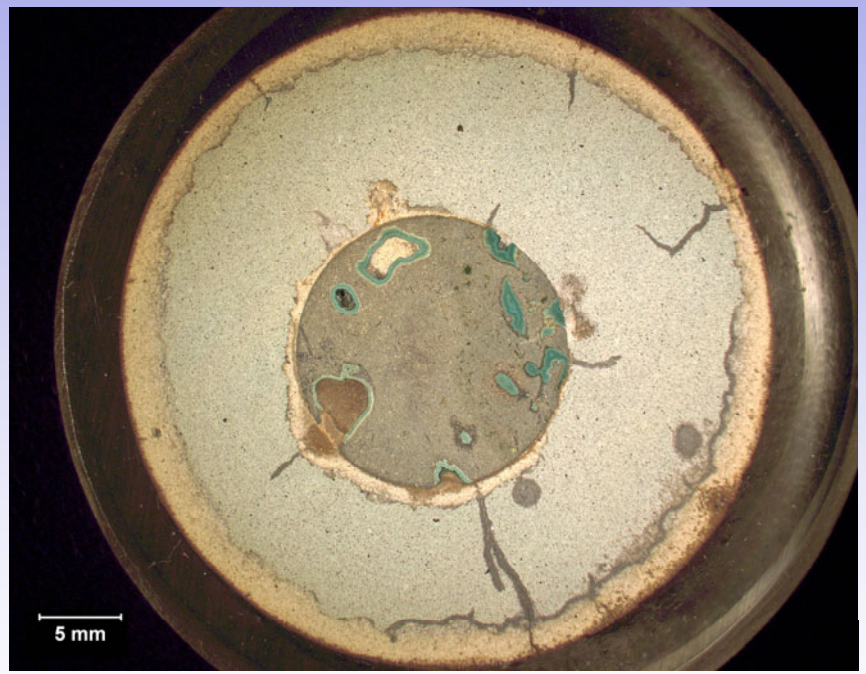
Combined Core & Cement Study

- Basalt/cement core study
  - Flow top core from ~3,000 ft depth
  - Brackish solution chemistry (Pasco Basin)
  - 35˚C, P_{CO2}=1,500 psig, 28, 56, & 84 days
- Sandstone/cement core study
  - Mt. Simon ss from Illinois Basin
  - Illinois Basin brine solution chemistry
  - 35˚C, P_{CO2}=1,500 psig, 28, 56, & 84 days
- 2 sets of tests
  - 100% LaFarge Class H cement
  - 80% LaFarge cement, 20% additive #2

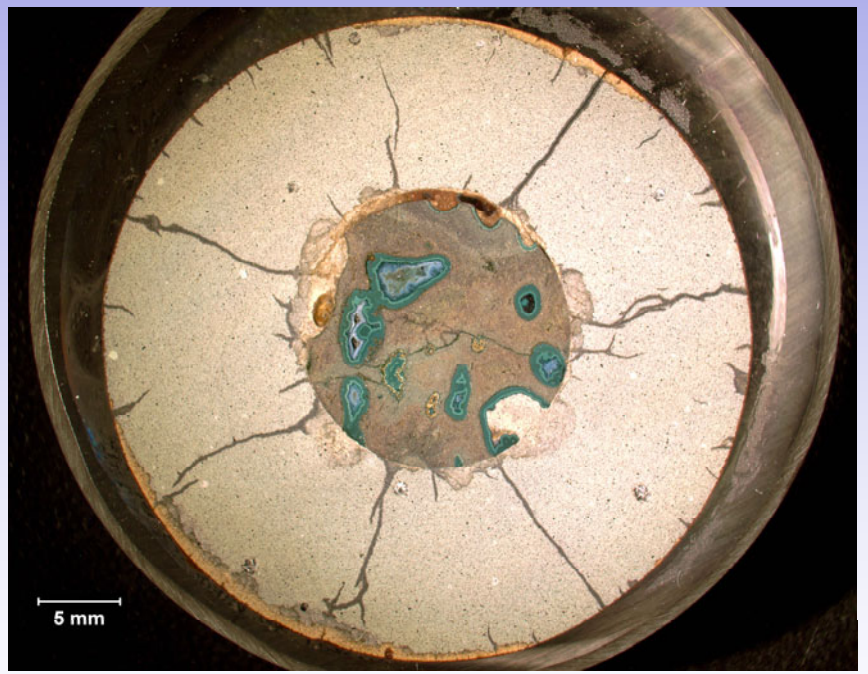
Experimental Procedure

- Cores drilled with 3/8-inch diamond core drill
- 3/8-inch core cast inside 1.5-inch cement core
  - Casting placed in autoclave, taken to T&P
  - Forms removed after 24 hours, autoclave returned to final T&P
- Cement cast within 3/8-inch cavity in core
  - Same procedure as above

Photomicrographs of Cured Cement/Cores

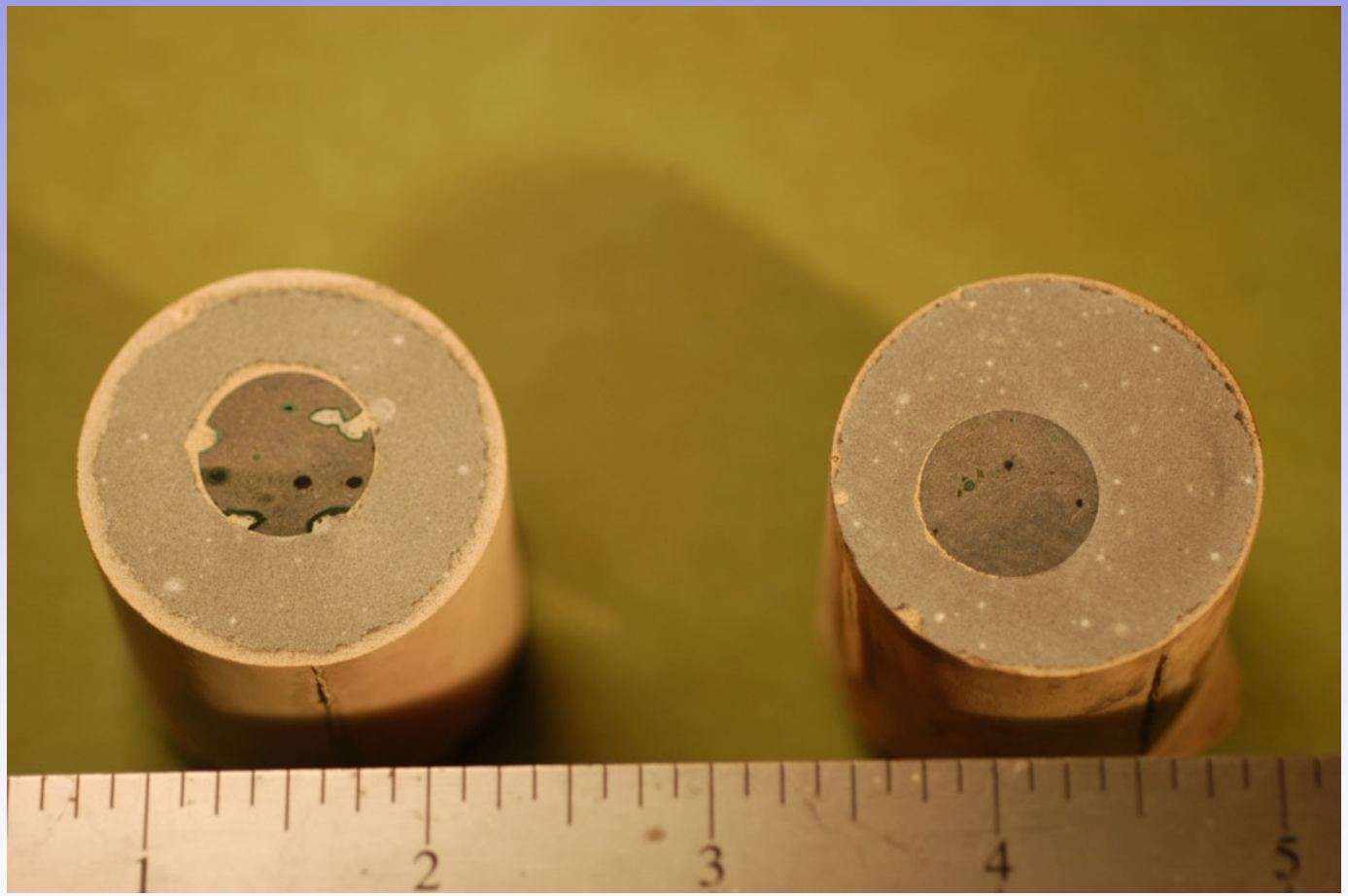


SCC-cured; 28 days; 20% add.



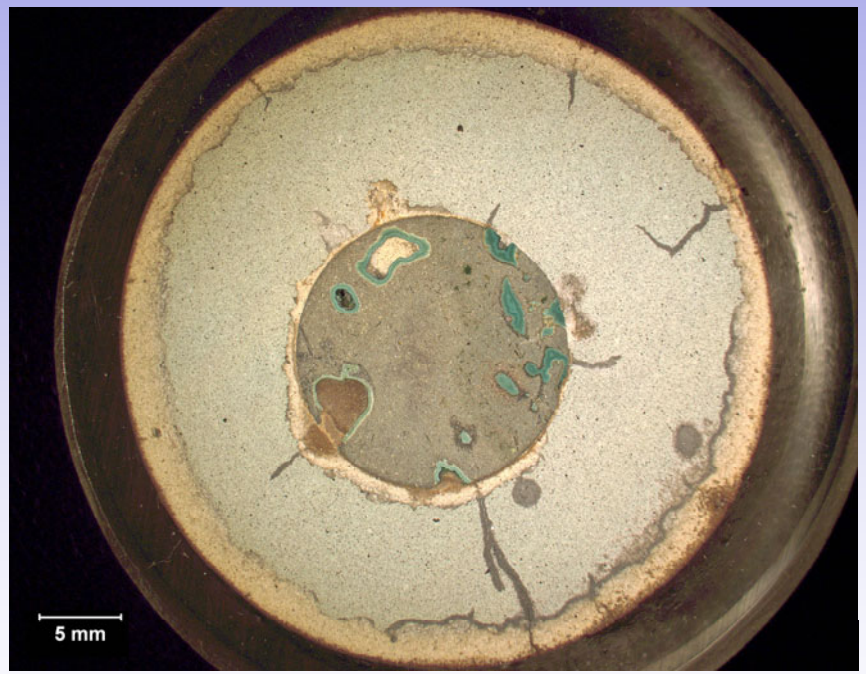
SCC-cured; 28 days; 100% cement

Cured Cement/Cores Prior to Drying

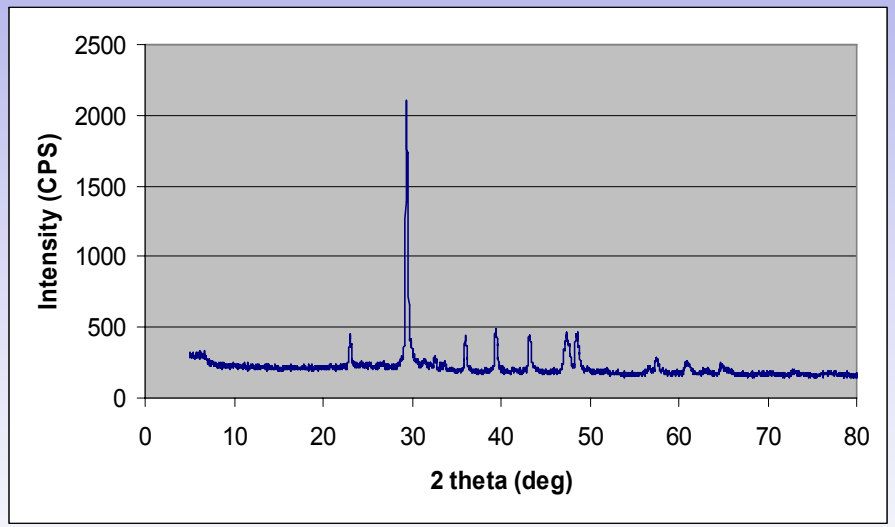


No radial cracking in wet basalt/cement cores

XRD of Alteration Rim



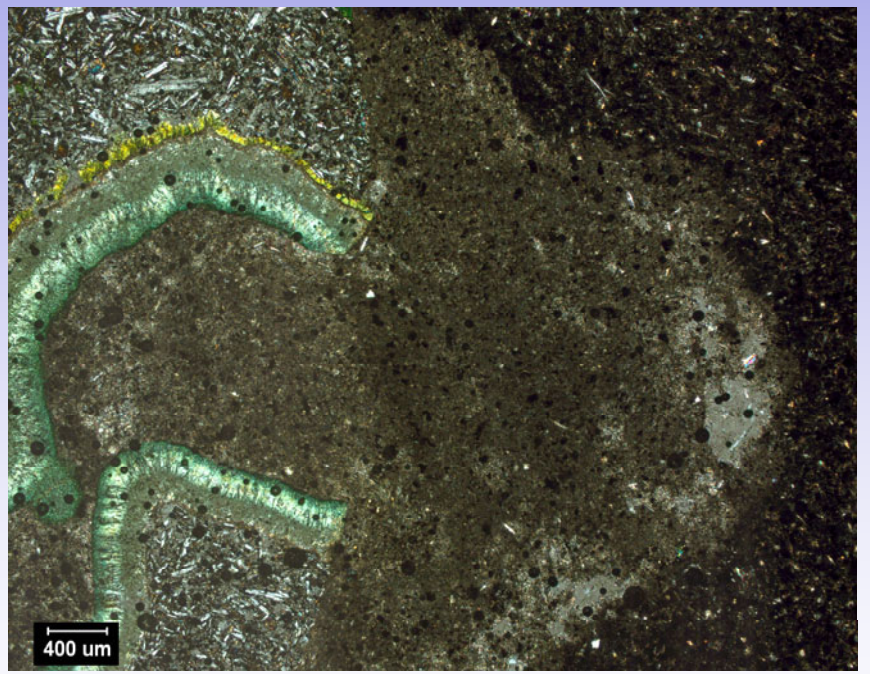
SCC-cured, 28 days, 20% add.



Calcite XRD pattern

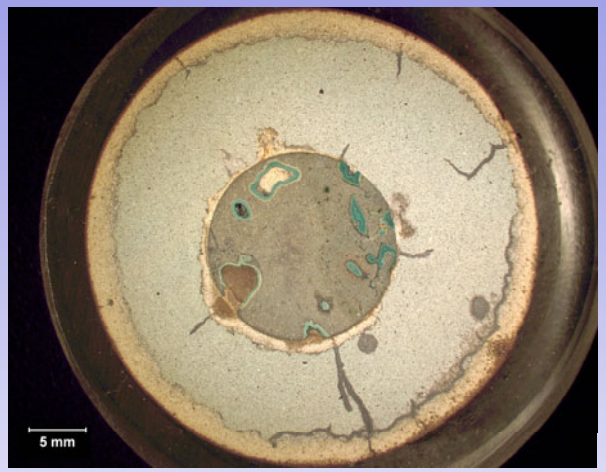
Basalt Pore/Cement Interface

- Thin section of basalt/cement interface
- Pore in basalt intersects surface
- Pore filled with cement
  - Cement within pore altered to carbonate
  - Alteration extends out into bulk cement
- Basalt porosity provides access for CO_2 to react with cement



Basalt Protecting Cement?

- Both photos
  - 80% cement, 20% add.
  - 28 days, brine, SCC
- Upper photo
  - Basalt surrounded by cement
- Lower photo
  - Cement within basalt
  - Little or no alteration
  - Cement filling pores



Summary

- CRBG Grand Ronde basalt cores are reactive under SCC conditions
- Partial filling of pores with reaction products
  - Silica
  - Carbonate
- Basalt/SCC-cured cement cores show cement alteration
  - Where cement is exposed to SCC during curing
  - Access to cement through basalt porosity
  - Carbonate alteration fills interface when present?

Continuing Studies

- Time series on SCC-cured cements
- Time series on basalt/SCC-cured cements
- Times series on Mt. Simon ss/SCC-cured cements
- Determine impact of additives on cement reactivity, extent of alteration
- Determine rate of alteration for SCC-cured cements
- Examine rock/cement interface