DOE-ARRA Geologic Sequestration Training and Research
2011 Yearly Review Meeting

Project: DE-FE0002416

Geoscience Perspectives in Carbon Sequestration – Educational Training and Research Through Classroom, Field, and Laboratory Investigations

Missouri University of Science & Technology

Presenter: David Wronkiewicz,

Department of Geological Sciences and Engineering

February 23rd, 2011

Project Participants

David J. Wronkiewicz, PI

<u>Graduate Students</u>

1) **Alsedik M. Abousif; Ph.D. Student - Midcontinent Rift System.**
2) **David Davison; MS Student - Lamotte Formation Sandstone (supported under DOE Grant DE-NT 0006642)**
3) **Varun Paul; Ph.D. Student - Biomineralization processes in carbonate systems.**
4) **Kyle Rybacki; MS Student – Maramec Springs**

<u>Undergraduate Students Involved in Research Projects</u>

1) **Hanani Tajul Nahar**
2) **Robert Swain**
3) **Rebecca Nuckolls**
4) **Airin Price**

<u>Undergraduate Students Enrolled in Courses with Carbon Sequestration Content</u>

1) **GEOL 275 Introductory Geochemistry**
   - **103 students for past two years (43 in 2010, 60 in 2011)**
2) **GEOL 372 Spring Field Studies Bahamian Platform**
   - **Eight students in 2011**

Introduction

Background on the project:

- Underground CCS may produce;
  i. Supercritical phase (or gas at lower pressures)
  ii. Dissolved aqueous carbonate species
  iii. Solid carbonate minerals
- ***Carbonate mineralization*** is generally a slow process, but represents most stable disposal product for CO_2 over geologic time scales.

Anticipated benefits

- Determined rates and mechanisms for carbonate mineralization in potential repository scenarios.
- Provide graduates into CCS workforce with skills in carbon sequestration.

Project Objectives

- <u>Objective 1 – Undergraduate Curricula</u>
  - Enhance undergraduate curricula by focusing into CO_2 reactions, providing analytical equipment to students, and field trips investigating carbonate in natural systems.
  - Produce highly trained workforce of scientists and engineers who are knowledgeable in CO_2 + H_2O + rock reactions.
- <u>Objective 2 – Student Research</u>
  - Disposal potential in unique repository horizons
  - Long-term carbon trapping by mineral formation
  - Dissolution processes occurring at sites of CO_2 injection
  - Self-sealing microfractures by carbonate mineralization

Project Funding

- Total Project Cost: $360,796
- DOE Share: $299,590
- Non-DOE Cost Share: $61,206
- Cost Share Provider: Missouri University of Science & Technology

Highlights of Project to Date

- To date, 111 students from three departments have enrolled in courses that have been impacted by DOE Education & Training Program.
- One MS student graduated, K. Rybacki - Maramec Springs study.
- D.J. Wronkiewicz co-chaired session on CCS at Geological Society America Sectional Meeting, Branson, MO; 4/12/2010.
- Publications:
  - Journal paper Fang et al., *Petroleum Science* (2010)7:83-92.
  - Journal paper Rybacki & Wronkiewicz, *Chemical Geology* (in prep).
  - Two abstracts, Geological Society of America (2010)

Project Schedule

MILESTONE STATUS REPORT

Task/ Subtask #	Project Milestone Description*	Project Duration - Start: End												Planned Start Date:	Planned End Date:	Actual Start Date:	Actual End Date:
		Project Year (PY) 1				PY 2				PY 3							
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12				
Enhancement Undergrad. Curriculum																	
1a	Intro. Geochemistry	√	√			√								January	May	1/1/2010	
1b	Field Studies-Bahamas					√								1/1/2011	6/1/2011	1/10/2011	
1c	Aqueous Geochemistry													8/1/2011	12/20/2011		
Training Through Student Research																	
2-1a	Midcontinent Rift West Arm	√	√	√	√	√								8/1/2010	12/31/2011	1/1/2010	
2-1b	Midcontinent Rift East Arm													8/1/2011	12/31/2012		
2-1c	Lamotte Formation	√	√	√	√	√								1/1/2010	12/31/2011	1/1/2010	
2-2a	Long-term Mineral Trapping			√	√	√								6/1/2010	12/31/2012	6/1/2010	
2-2b	Dissolution Processes	√	√	√	√	√								1/1/2010	12/31/2011	1/1/2010	
2-2c	Self-Sealing Fractures				√	√								8/1/2011	12/31/2012	10/15/2010	

Discussion – Task 1

- **Enhancing Undergraduate Curriculum**
- Key Subtasks

a) Introductory Geochemistry (GEOL 275)

   i. Spring Semester 2010 (43 students) **Completed √**

   ii. Spring Semester 2011 (60 students) **Current**

   iii. Spring Semester 2012

b) Spring Field Studies (GEOL 372) – **Current**

   i. Weekly meeting - discussion groups started January 12th

c) Aqueous Geochemistry (GEOL 376) – Course will be taught Fall 2011.

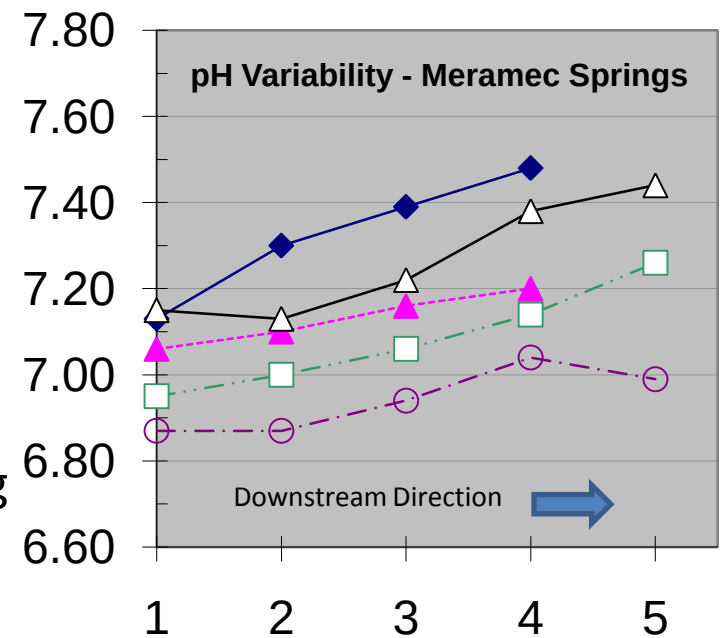
Discussion – Task 1. Curriculum Enhancement Introductory Geochemistry

- Responsible party: David J. Wronkiewicz
- Task Status (45 % complete)

➢ Major accomplishment(s)

  - Enrollment 103 students (2010 & 2011)
  - Students from Geology, Geological Engineering, & Environmental Engineering
  - Class lecture and demonstrations of carbonate reactions, bicarbonate buffering, isotopes, & climate change.
  - Field trip to Maramec Springs Study Area
    - Spring 2010 completed April 16th & 17th.
    - Spring 2011 scheduled April 15th & 16th

- Major issues/problems
  - Large class size with limited equipment (e.g., two pH meters) presents challenge in keeping all students involved.



Discussion – Task 1. Enhancement of Undergraduate Curriculum

- Major accomplishment(s)
  - GEOL 372 – weekly reading discussion topics
    - Sediment sources and carbonate genesis
    - Stratigraphy of San Salvador Island, Bahamas
    - Coral mineralization, life cycles, climate change
    - Oolitic and carbonate mud – biomineralization?
    - Beach and coastal landforms
    - Lagoon facies
    - Eolian features – dunes
    - Carbonate diagenesis and cementation
    - Stromatolites
  - Field Excursion:
    - Trip is scheduled March 26th to April 3rd, 2011

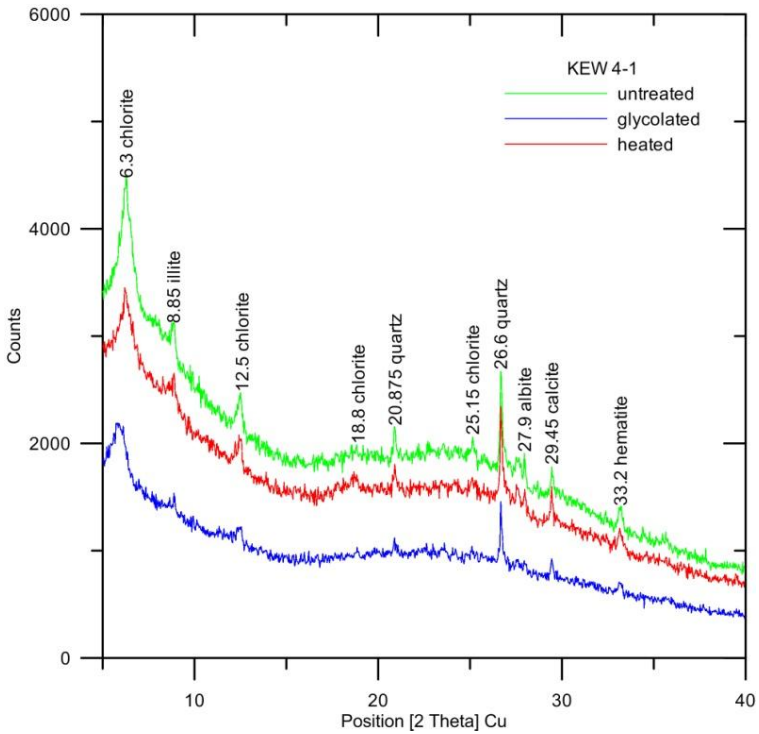
Discussion – Task 2

Student Research Training Projects

2a) <u>Investigation Unique Repository Horizons – Midcontinent Rift</u>

- Personnel: (Alsedik M. Abousif & D.J. Wronkiewicz)
- Task Status (20% complete)
  - Collection 24 surface samples Lake Superior Region
  - Thin section and X-ray Diffraction analysis
- Major issues/problems
  - Favorable rock strata with high Ca Mg Fe contents (in silicate or oxides), unfortunately also display low porosity-permeability.

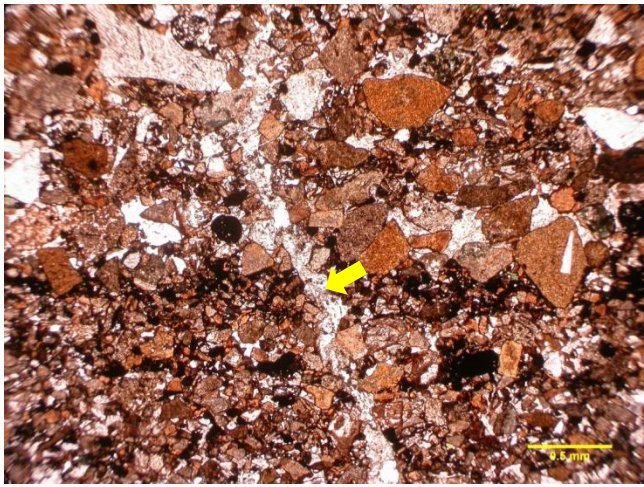
2a) Investigation Unique Repository Horizons – Midcontinent Rift

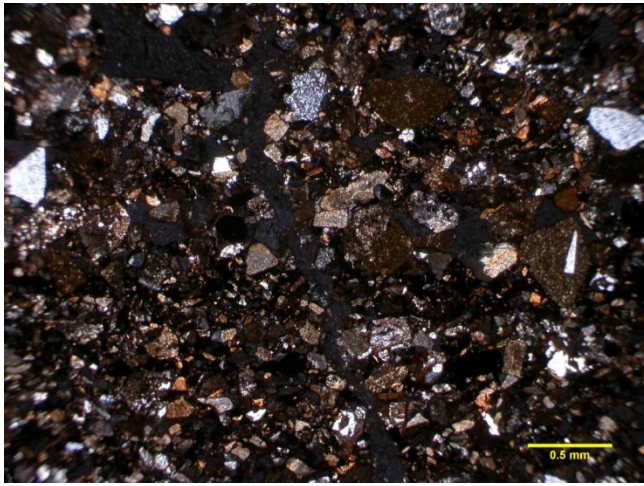


X-Ray Diffraction - Copper Harbor Conglomerate clay-sized fraction: untreated, heated, and glycolated sample scans.

Summary of clay sized fraction – XRD Analysis.

Sample	Clay Minerals (% of total clay content)				Other Minerals Peaks	Formation
	Illite	Smectite	Chlorite	Kaolinite		
BAY 2b	0	0	0	99	Quartz	Chequamegon
CFSP 2	6	64	30	0	Quartz, Laumontite?	Nonesuch
FON 2	24	4	72	0	Quartz, Albite	Fond du Lac
KEW 1-1	19	5	76	0	Quartz, Calcite, Hematite	Copper Harbor
KEW 4-1	**23**	**7**	**70**	**0**	**Quartz, Calcite, Hematite**	**Copper Harbor**
POT 8-1	2	42	43	13	Quartz, Calcite	Copper Harbor
JAC 1	9	1	1	89	Quartz	Jacobsville
L'ANSE 1	5	1	7	87	Quartz, Albite?	Jacobsville





KEW 1-1. Thin section Copper Harbor sample showing poor sorting, low porosity, and calcite filled vein (arrow). Plane polarized light image (above) and cross-polarized image (below). Scale bar = 0.5 mm.

Discussion – Task 2

Student Research Training Projects

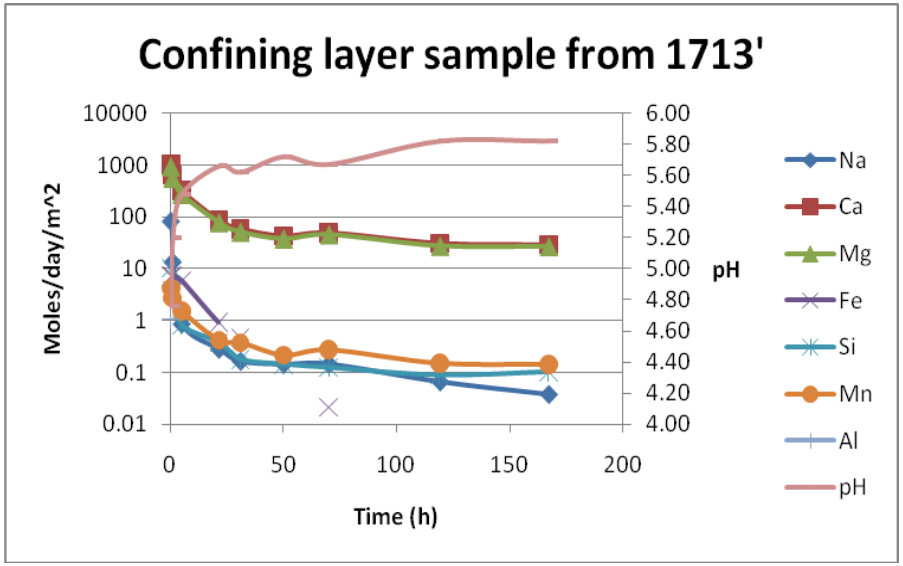
2b) Investigation of Unique Repository Horizons – Lamotte Fm. Sandstone

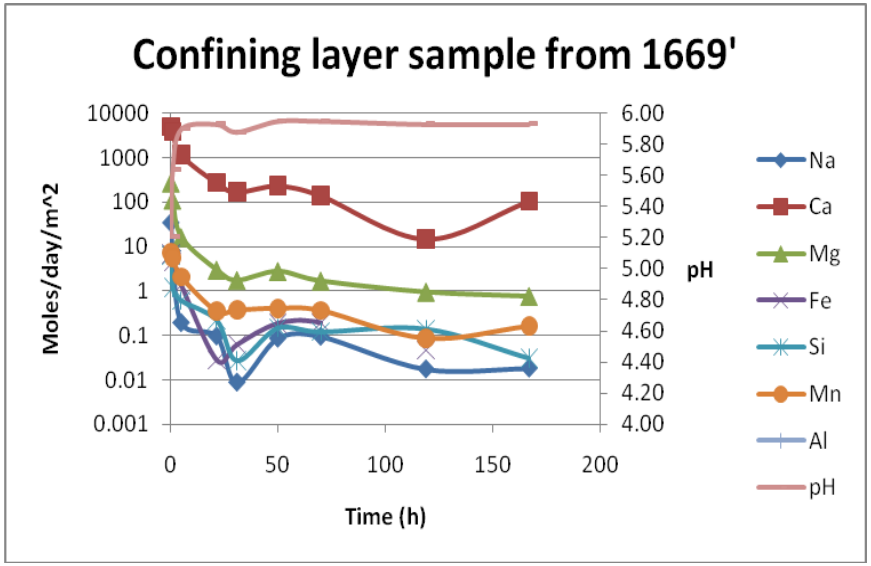
- Personnel: (David Davison & D.J. Wronkiewicz)
- Task Status (75% complete)
- Major accomplishment(s) Drilling completed to basement rocks ~2200', samples collected, and corrosion testing in progress.
- Major issues/problems: Lamotte Sandstone (Mt. Simon in Illinois) lacks sufficient Ca, Mg, Fe in silicates-oxides to form carbonate solids.

2b) Investigation of Unique Repository Horizons – Lamotte Fm. Sandstone

Summary results from XRD analysis from segregated clay-sized fraction.

Core Depth (ft)	Clay Mineral Types Found	Other Minerals	Formation
1578	Illite, possibly trace Ca-smectite?	Dolomite	Davis / Derby- Doerun
1601	Small Illite peak	Calcite, Dolomite	Davis/Derby-Doerun
1669	Illite	Quartz, Calcite, Dolomite	Davis
1713	Illite	Dolomite, Quartz	Bonneterre
1988-2147	Not yet analyzed		Lamotte





Corrosion test with1713' Bonneterre Formation (reservoir layer) sample, DIW, and bubbling CO_2. High Ca and Mg release combined with pH increase reflect dissolution of dolomite ($CaMg(CO_3)_2$).

Corrosion test with1669' Davis Formation sample (confining layer), DIW, and bubbling CO_2. Dissolution of dolomite ($CaMg(CO_3)_2$) and calcite ($CaCO_3$) is reflected in data.

Discussion – Task 2

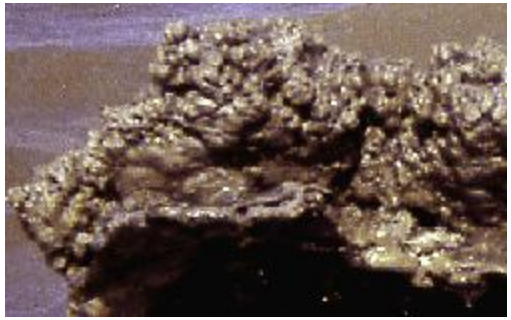
Student Research Training Projects

2c) <u>Carbon Trapping - Carbonate Biomineralization</u>

- Personnel: (Varun Paul & D.J. Wronkiewicz)
- Task Status (15% complete)
- Major accomplishment(s)
  1) Collected two microbial communities OK and NM
  2) Initiated batch reactor tests for carbonate precipitation
  3) Microbial enhancements of sulfate reducers
  4) Constructed dynamic reaction chambers.

2c) Carbon Trapping - Biomineralization of Carbonate Minerals

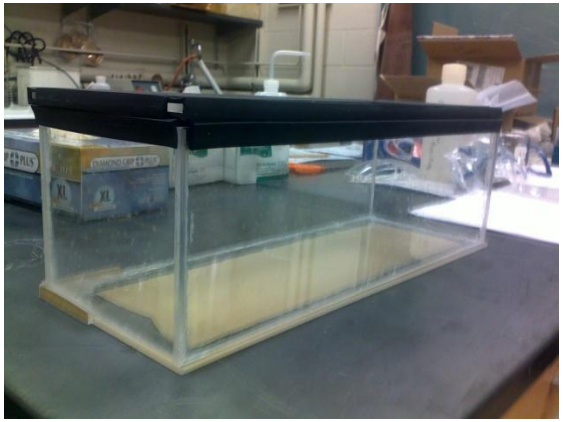
Sediment profile from Great Salt Lake, Oklahoma showing several organic rich (black) horizons where microbes were collected in 2010.



Microbialite-Stromatolite from Storr's Lake, Bahamas (samples to be collected during March 2011)

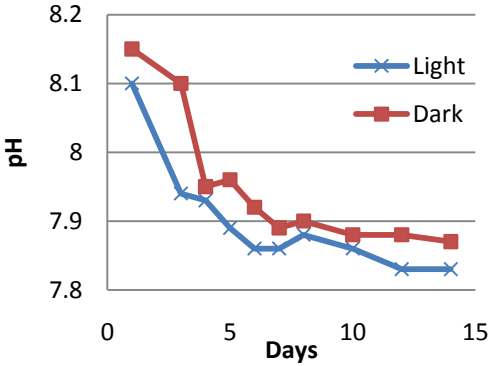
Batch reactor

Dynamic reactor



Operational batch test with Nalgene bottle (top) and constructed Plexiglas dynamic reactor. Both test formats are used to monitor carbonate precipitation under controlled CO_2, substrate, light, and microbial conditions.

Microbial enrichments to enhance growth of sulfate reducing bacteria (SRB). Reduced sulfides can be seen as black precipitates



Lake Estancia (NM) sediments in batch reactor with seawater shows initial pH decrease followed by stabilization. Collected sediments contain carbonate minerals.

Discussion – Task 2

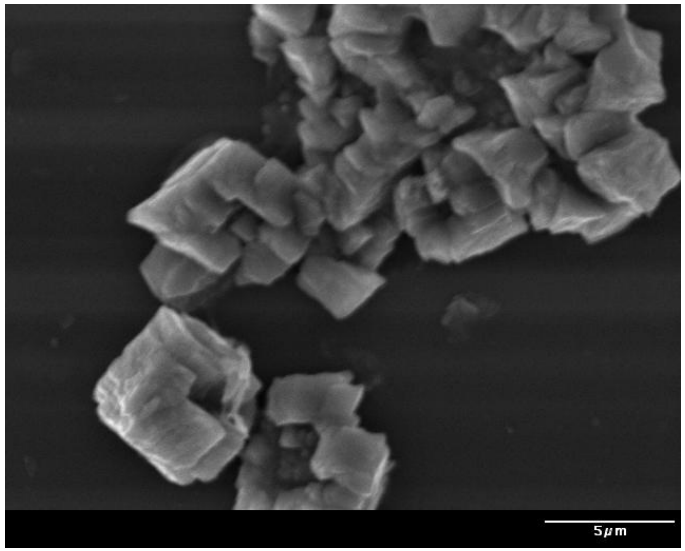
Student Research Training Projects

2d) <u>Carbonate Mineralization Processes Occurring at Maramec Springs</u>

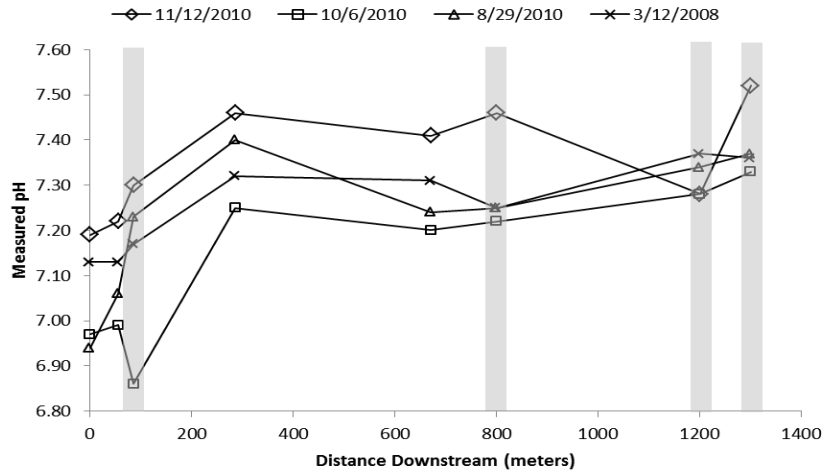
- Personnel: (Kyle Rybacki & D. Wronkiewicz)
- Task Status (95% complete)
- Major accomplishment(s):
  - Captured colloidal-sized carbonate minerals on site
  - MS Thesis completed – Kyle Rybacki
  - Draft publication in preparation for submission to *Chemical Geology*

2d) Carbonate Mineralization Processes Occurring at Maramec Springs

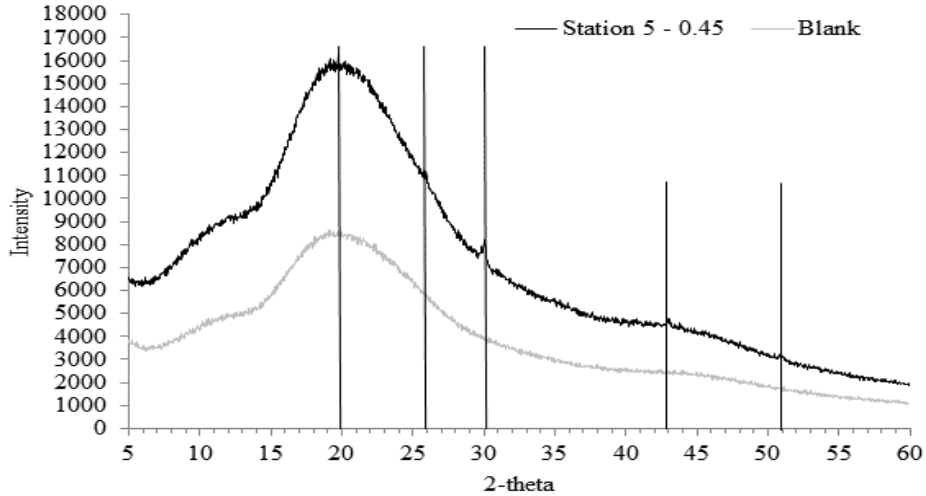
Maramec Spring displaying slightly turbid water due to generation of colloidal carbonate following upwelling.



Rhombohedral-shaped calcite crystals collected from centrifuged water. Similar precipitation may seal microfractures in leaking repository.



Stream pH showing increase downstream (left to right) Shaded portions indicate small rapids.



X-ray diffraction spectra for particulate material collected on a 0.45 μm filter. Grey scan displays background from unused filter. Largest peak at 2θ angle of ~30.0 corresponds to high-Mg calcite.

Project Milestones

(Include HQ and project milestones)

Milestone	Planned Completion Date	Actual Completion Date
HQ Milestone: Project Kick-off Meeting	03/31/10	03/18/10
HQ Milestone: Educational Program Instituted	06/30/10	04/16/10
HQ Milestone: Semi-Annual Progress Report	09/30/10	09/30/10
HQ Milestone: Yearly Review Meeting	03/31/11	02/23/11
HQ Milestone: Yearly Review Meeting	03/30/12	

Anticipated Efforts for the Coming Year

- Activity 1: **Enhancement of Undergraduate Curriculum**
  - ***GEOL 372 – 8 students to Bahamas - March 26th to April 3rd***
  - ***GEOL 275 – 60 students to Maramec Springs April 16th and 17th***
  - ***GEOL 376 – Aqueous Chemistry in Fall Semester 2011***
- Activity 2***a) Unique Repository Horizons – Midcontinent Rift***
  - ***Characterize remaining surface samples, secure drill core, and initiate corrosion tests.***
- Activity 2***b) Unique Repository Horizons – Lamotte Formation***
  - ***Complete host rock characterization & corrosion testing.***
  - ***Complete MS Thesis - David Davison.***
- Activity 2***c) Carbon Trapping by Biomineralization***
  - ***Induce carbonate precipitation using microbes, characterize chemical conditions, optimize biogeochemical reactions.***
- Activity 2***d) Carbonate Mineralization at Maramec Springs***
  - ***Submission of draft for publication in Chemical Geology.***

PI Contact Information

- If you have any questions or would be interested in collaboration please contact
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  - 573-341-4679