Training Students to Analyze Spatial and Temporal Heterogeneities in Reservoir and Seal Petrology, Mineralogy, and Geochemistry: Implications for CO_2 Sequestration Prediction, Simulation, and Monitoring

Project Number DE-FE0001852

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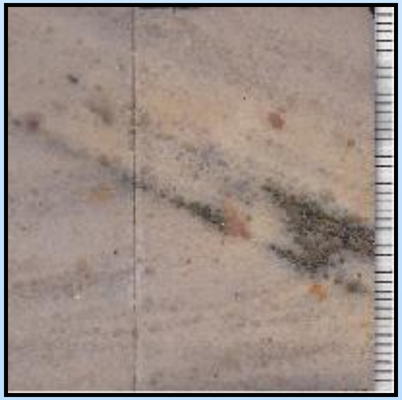
U.S. Department of Energy

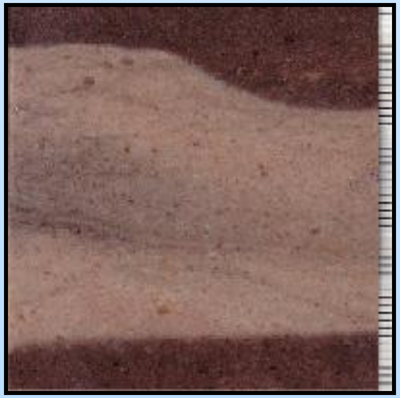
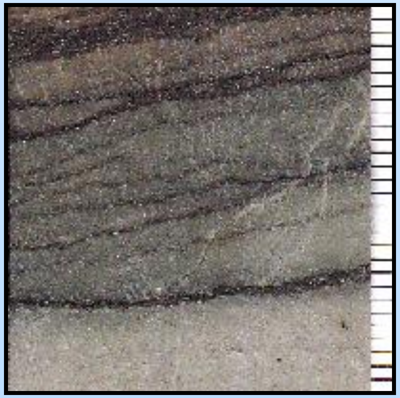
National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO_2 Storage

August 21-23, 2012

Presentation Outline

- Introduction to the project
- Tasks
- Student training
- Student research successes
- Lessons learned and future plans



Benefit to the Program

- Addresses Carbon Storage Program major goals:
  - Develop technologies that will support industries' ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
  - Conduct field tests through 2030 to support the development of BPMs for site selection, characterization, site operations, and closure practices.

- Benefits to CCS Program:
  - This project is providing multiple graduate students with geological training and research experience related to ongoing CCS projects. Benefits to the Sequestration Program include analyses of DOE Partnership related sample, improved understanding of reactivity, testing and refining reservoir and seal characterization techniques, and providing inputs for modeling. On a larger scale, we are developing the foundation for a CCS aware geoscience workforce and investigating curricular strengths and needs related to this field.

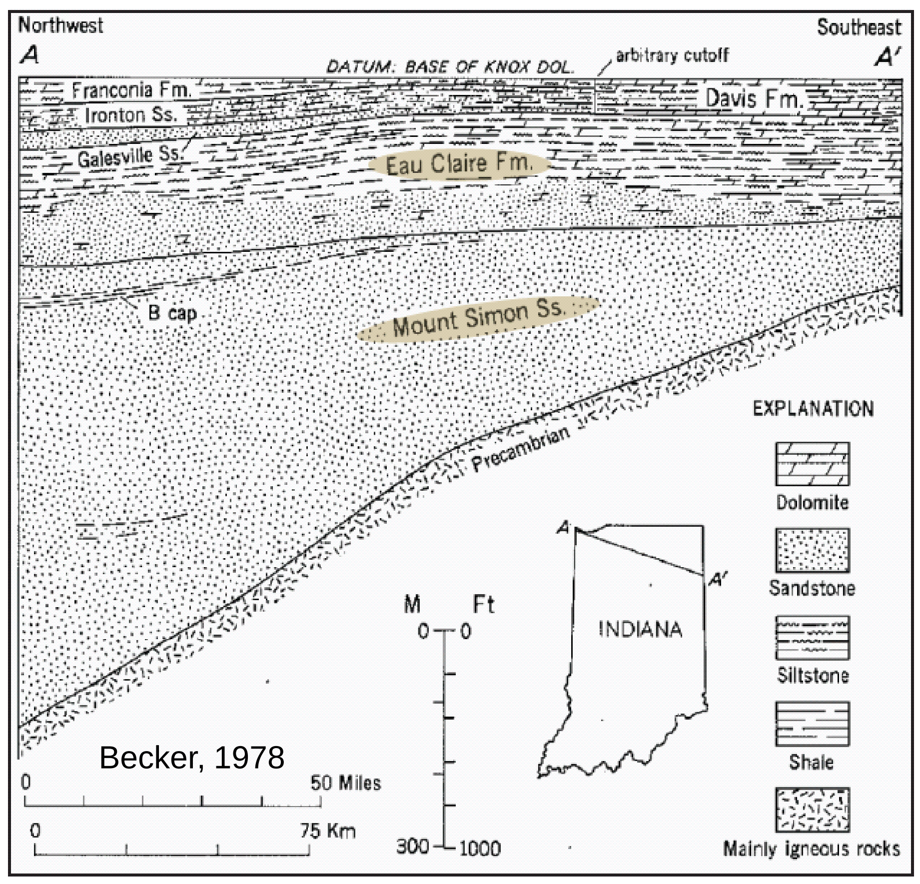
Project Overview: Goals and Objectives

- ***Expose and train multiple graduate students in geological tools that are essential to reservoir characterization and geologic sequestration***
  - Petrological, mineralogical, and geochemical methods
  - core analysis, and geophysical well-log interpretation
  - Identify appropriate geologically based curriculum

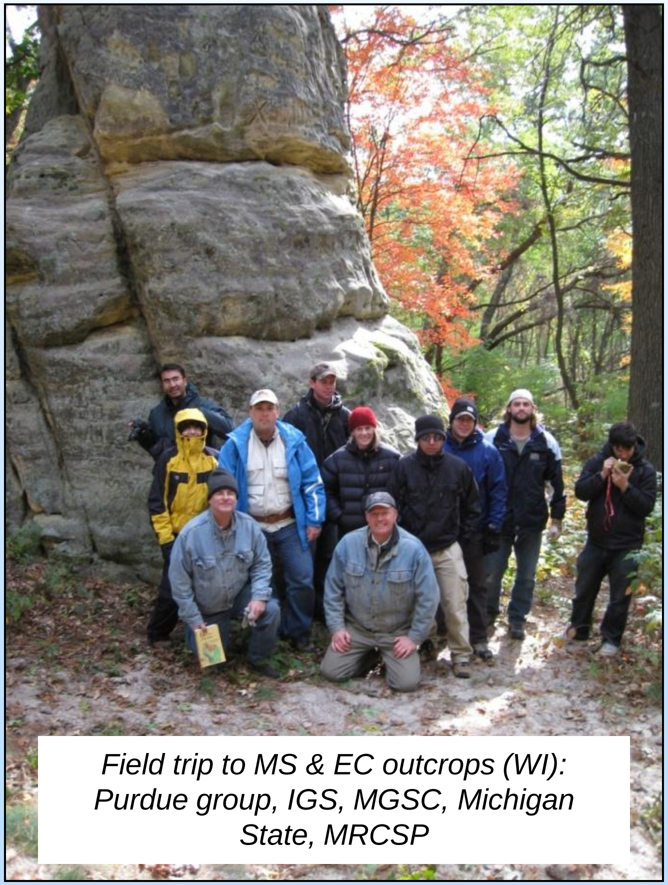
- ***Conduct original scientific research on lithological, textural, and compositional variability in formations that are being targeted as CO_2 sequestration reservoirs and seals***
  - Focus on the Mount Simon Sandstone (MS) and overlying Eau Claire Formation (EC) seal, but applicable to other targeted CCS reservoirs
  - Research goal: Understand how different depositional and diagenetic histories affect the reservoir quality; identifying important soluble mineral phases with emphasis on those that are in contact with pore space and would be reactive with CO_2-saturated brines.
  - *Tools: Reflected and transmitted light petrography, cathodoluminescence, x-ray diffraction, reflectance spectroscopy, scanning electron microscopy/ energy dispersive X-ray analysis, and stable isotope geochemistry…*

Context of Research

- Focus on MS and EC as a CCS system in Illinois Basin
- Train students working within a collaborative group of academic, government, and industry partners- the CCS community

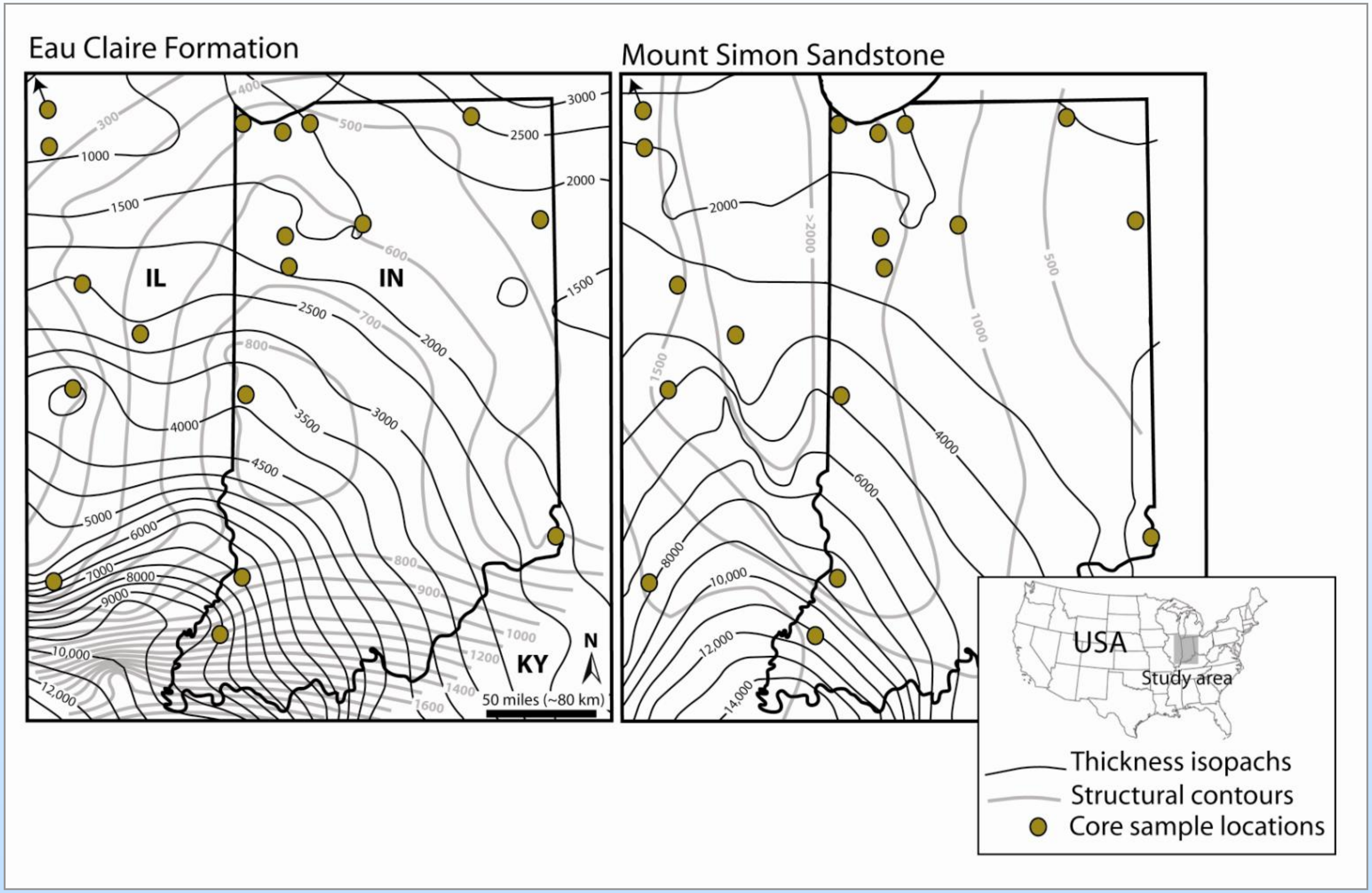


Becker, 1978



Field trip to MS & EC outcrops (WI): Purdue group, IGS, MGSC, Michigan State, MRCSP

Context of Research



- *Opportunities for student training on relevant samples*

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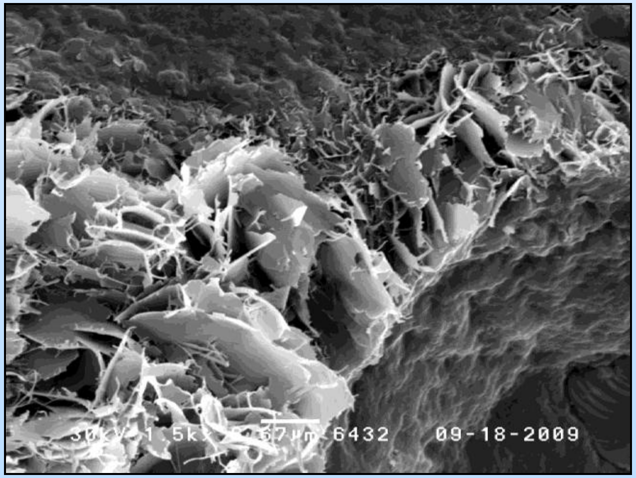
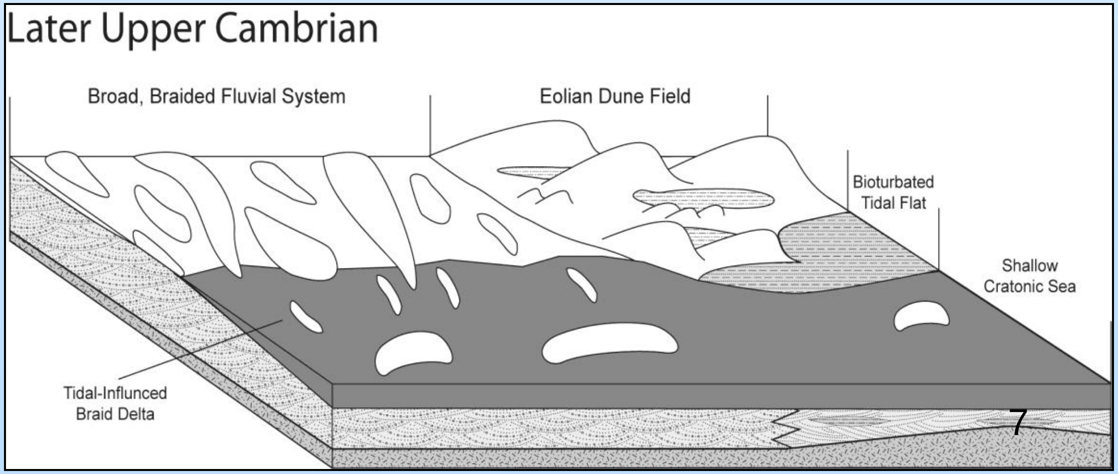
Technical Status

- Multiple graduate and undergraduate students supported to do CCS related research
- Collaborative work with NETL, MGSC, MRCSP, Indiana Geological Survey, New Mexico Tech and synergies with other DOE-funded projects
- Major accomplishments:
  - Quantitative understanding of variations in reservoir and seal composition on micro (sub-mm) to macro (basin-wide) scales





Tasks – Overview

Task #	Task Description	Task Duration
1	Project Management and Planning	12/01/2009 – 09/30/2013
2	Establish Initial Research Team	12/01/2009-08/01/2010
3	Define Courses for Geologic CO_2 Sequestration Graduate Curriculum	12/01/2009-11/01/2010
4	Literature, Data, and Sample Review	12/01/2009-05/01/2011
5	Quantifying spatial heterogeneity in reservoir characterization	04/01/2010-06/01/2012
6	Experimental evaluation of temporal changes in reservoir character	01/01/2011-09/30/2013
7	Documentation of Results and Final Report to DOE	12/01/2009 09/30/2013

Accomplishments to Date

- Partial to full support of 5 graduate and 3 undergrad students
- Student research:
  - Ochoa MS thesis, completed Dec. 2010
    - **"Porosity Characterization and Diagenetic Facies Anaysis of the Cambrian Mount Simon Sandstone: Implications for a Regional CO_2 Sequestration Reservoir"**
  - Neufelder MS thesis, completed May 2011
    - **"Petrographic, mineralogical, and geochemical evidence of diagenesis in the Eau Claire Formation: Implications for sealing capability in a CO_2 sequestration system"**
  - Thomas Lovell PhD research, in progress
    - **"Investigating changes in composition and texture in the Mount Simon Sandstone and Eau Claire Formation within the Illinois Basin"**

Accomplishments to Date

- Student research, continued:
  - Gonzalez MS research, in progress
    - **“Geochemical and mineralogical evaluation of CO2-brine-rock experiments: Characterizing porosity and permeability variations in the Cambrian Mount Simon Sandstone”**
  - Undergraduate research examples:
    - Chentnick: **“Characterizing fractures and deformation bands: Implications for long-term CO_2 storage within the Cambrian Mount Simon Sandstone”**
    - Shufflebarger: **“Petrographic and stable isotope analysis of carbonates in the Eau Claire Formation”**

- Development of new “Geologic CO_2 Sequestration” graduate course

Literature-based "textbook" for geologic CO_2 sequestration course

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Topics in CO_2 Sequestration

Course Reading List

What are natural fluxes in the global carbon cycle and how does geologic sequestration impact them?

- Berner, R.A., 1992, Weathering, plants, and the long-term carbon cycle: Geochimica et Cosmochimica Acta, v. 56, p. 3225-3231.
- Falkowski, P. et al., 2000, The global carbon cycle: A test of our knowledge of Earth as a system: Science, v. 290, 291-296.
- Dessert, C., et al., 2003, Basalt weathering laws and the impact of basalt weathering on the global carbon cycle: Chemical Geology, v. 202, p. 257-273.

What changes in mineralogy, porosity, and chemistry could occur in a reservoir with CO2 injection?

- Kharaka, Y.K., et al., 2006, Gas-water-rock interactions in Frio Formation following CO2 injection: Implications for the storage of greenhouse gases in sedimentary basins: Geology, v. 34, p. 577-580.
- Palandri, J.L and Kharaka, Y.K., 2005, Ferric iron-bearing sediments as a mineral trap for CO2 sequestration: Iron reduction using sulfur-bearing waste gas: Chemical Geology, v. 217, p. 351-364.
- White, S.P., et al., 2005, Simulation of reactive transport of injected CO2 on the Colorado Plateau, Utah, USA: Chemical Geology, v. 217, p. 387-405.
- Parry, W.T., et al., 2007, Geochemistry of CO2 sequestration in the Jurassic Navajo Sandstone, Colorado Plateau, Utah, AAPG Bulletin, v. 14, p. 91-109.
- Wigand, M., et al., 2008, Geochemical effects of CO2 sequestration in sandstones under simulated in situ conditions of deep saline aquifers: Applied Geochemistry, v. 23, p. 2735-2745.

What monitoring methods are used to track migration of CO2 post-injection?

- Arts, R. et al., 2004, Monitoring of CO2 injected at Sleipner using time-lapse seismic data: Energy, v. 29, p. 1383-1392.
- Benson, S.M. and Myer, L., year?, Monitoring to ensure safe and effective geologic sequestration of carbon dioxide: IPCC workshop on carbon dioxide capture and storage.
- Emberly, S., et al., 2005, Monitoring of fluid-rock interactions and CO2 storage through produced fluid sampling at the Weyburn CO2-injection enhanced oil recovery site, Saskatchewan, Canada: Applied Geochemistry, v. 20, p. 1131-1157.
- Wells, A.W., 2007, The use of tracers to asses leakage from the sequestration of a CO2 in a depleted oil reservoir, New Mexico, USA: Applied Geochemistry, v. 22, p. 996-1016.
- Hovorka, S.D., et al., 2006, Measuring permanence of CO2 storage in saline formations: the Frio experiment: Environmental Geosciences, v. 13, p. 105-121.

What processes "trap" CO2 with geologic sequestration?

- Gunter, W.D., et al., 2004, The role of hydrogeological and geochemical trapping in sedimentary basins for secure geologi storage of carbon dioxide: Geological Society, London, Special Publications, v. 233, p. 129-145.
- Hesse, M.A., et al., 2008, Gravity currents with residual trapping: Jounral of Fluid Mechanics, v. 611, p. 35-60.
- Spycher, N., et al., 2003, CO2-H2O mixtures in the geologic sequestration of CO2. I. Assessment and calculation of mutual solubilities from 12 to 100 C and up to 600 bar: Geochimica et Cosmochimica Acta, v. 67, p. 3015-3031.
- Xu, T., et al., 2004, Numerical simulation of CO2 disposal by mineral trapping in deep aquifers: Applied Geochemistry, v. 19, p. 917-936.

What are the health, safety, and environmental risks of CO2 leakage?

- Bachu, S., 2008, CO2 storage in geologic media: Role, means, status and barriers to deployment: Progress in Energy and Combustion Science, v. 34, p. 254-273.
- Damen, K., et al., 2006, Health, safety and environmental risks of underground CO2 storage- Overview of mechanisms and current knowledge: Climatic Change, v. 74, p. 289-318.
- Halbawachs, M., et al., 2004, Degassing the "Killer Lakes" Nyos and Monoun, Cameroon: EOS, v. 85, p. 281-288.
- Palmgren, C.R., et al., 2004, Initial public perceptions of deep geological and oceanic disposal of carbon dioxide: Environmental Science and Technology, v. 38, p. 6441-6450.
- West, J.M., et al., 2005, Issue profile: Environmental issues and the geologic storage of CO2: European Environment, v. 15, p. 250-259.
- Wilson, E.J., et al., 2007, Research for Deployment: Incorporating risk, regulation, and liability for carbon capture and sequestration: Environmental Science and Technology, v. 41, p. 5945-5952.

How is CO2 injection used in enhanced oil recovery, and how is it similar / different to Mt.Simon-type sequestration?

- Klusman, R.W., 2003, A geochemical perspective and assessment of leakage potential for a mature carbon dioxide– enhanced oil recovery project and as a prototype for carbon dioxide sequestration; Rangely field, Colorado: AAPG Bulletin, v. 87, p. 1485-1507.
- Storing CO2 with enhanced oil recovery, DOE/NETL report, February 2008.
- Thomas, S., 2007, Enhanced oil recovery- An overview: Oil and Gas Science and Technology, v. 63, p. 9-19.
- Kovscek, A.R., et al., 2004, Geologic storage of carbon dioxide and enhanced oil recovery. II. Cooptimization of storage and recovery: Energy Conversion and Management, v. 46, p. 1941-1956.

What do we know about natural subsurface CO2-rich reservoirs?

- Lewicki, J.L., et al., 2007, Natural and industrial analogues for leakage of CO2 from storage reservoirs: identification of features, events, and processes and lessons learned: Environmental Geology, v. 52, p. 457-467.
- Haszeldine, R.S. et al., 2005, Natural geochemical analogues for carbon dioxide storage in deep geologic porous reservoirs, a United Kingdom perspective: Oil and Gas Science and Technology, v. 60, p. 33-49.
- Moore, J., et al., 2005, Mineralogical and geochemical consequences of the long-term presence of CO2 in natural reservoirs: An example from the Springerville–St. Johns Field, Arizona, and New Mexico, U.S.A.: Chemical Geology, v. 217, p. 365-385.
- Shipton, Z.K., et al., 2004, Analysis of CO2 leakage through 'low-permeability' faults from natural reservoirs in the Colorado Plateau, east-central Utah: from From: Baines, S.J. and Worden, R.H. (eds), Geological Storage of Carbon Dioxide. Geological Society, London,Special Publications, v. 233, p. 43-58. The Geological Society of London.

How is geologic sequestration in basalts different from sequestration in conventional reservoirs?

- Goldbergy, D.S. et al., 2008, Carbon dioxide sequestration in deep-sea basalts: Proceedings of the National Academy of Science, v. 105, n. 29.
- Matter, J.M., et al., 2007, Experimental evaluation of in situ CO2-water-rock reactions during CO2 injection in basaltic rocks: Implications for geologic CO2 sequestration: Geochemistry Geophysics Geosystems, v. 8.
- McGrail, B.P., et al., 2006, Potential for carbon dioxide sequestration in flood basalts: Journal of Geophysical Research, v. 111, B12201.

What is the current status regarding the policy and economics of CO2 sequestration?

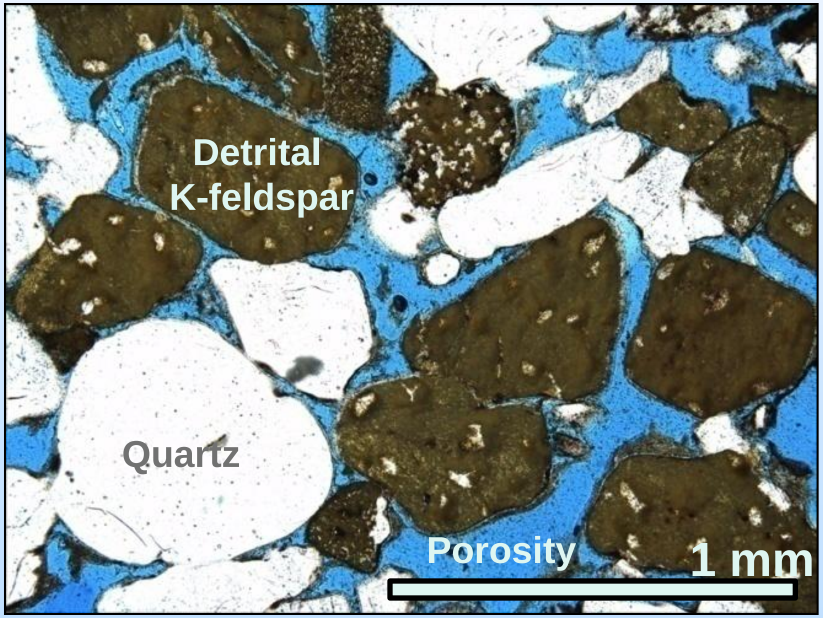
- Duncan, I.J., et al., 2009, Pore space ownership issues for CO2 sequestration in the U.S.: Energy Procedia, v. 1, p. 4427-4431.

Student Research Successes

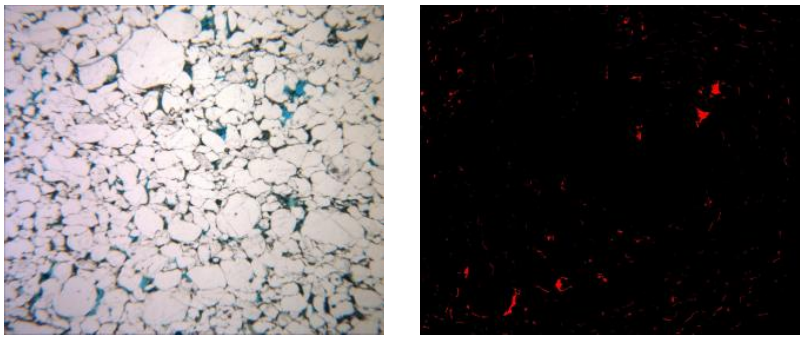
- Ochoa MS thesis, completed Dec. 2010

  "Porosity Characterization and Diagenetic Facies Anaysis of the Cambrian Mount Simon Sandstone: Implications for a Regional CO_2 Sequestration Reservoir"

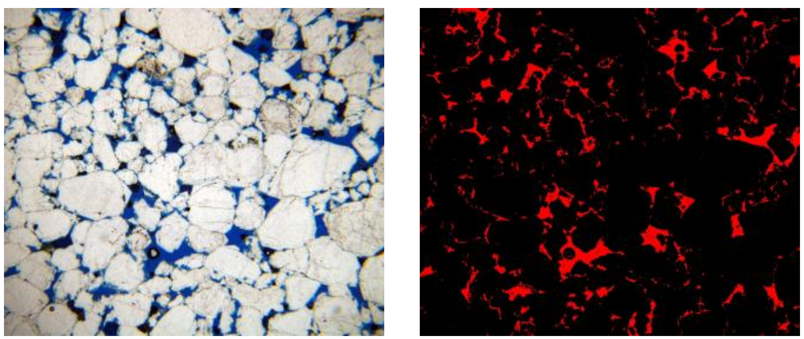
  - **Objective:** to understand what processes cause porosity and spatial variations in porosity in the MS.
  - **Approach:** petrographic image analysis of 150 thin sections to quantify porosity and identify porosity type and formation process
  - **Major conclusions:** 4 dominant types of porosity; dissolution porosity significant at injection-relevant depths; link to detrital composition



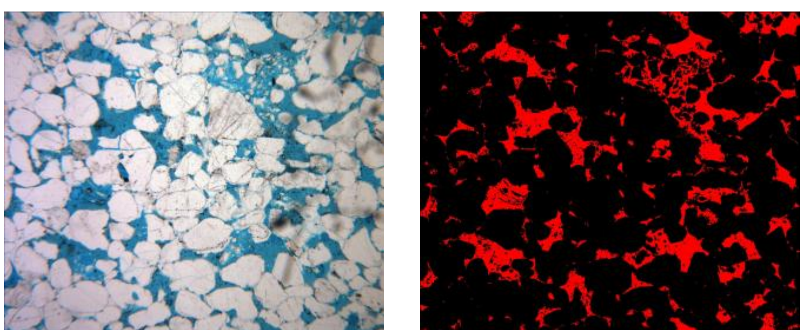
Petrographic Image Analyses (PIA)



Stephenson
1339 ft
<1 %

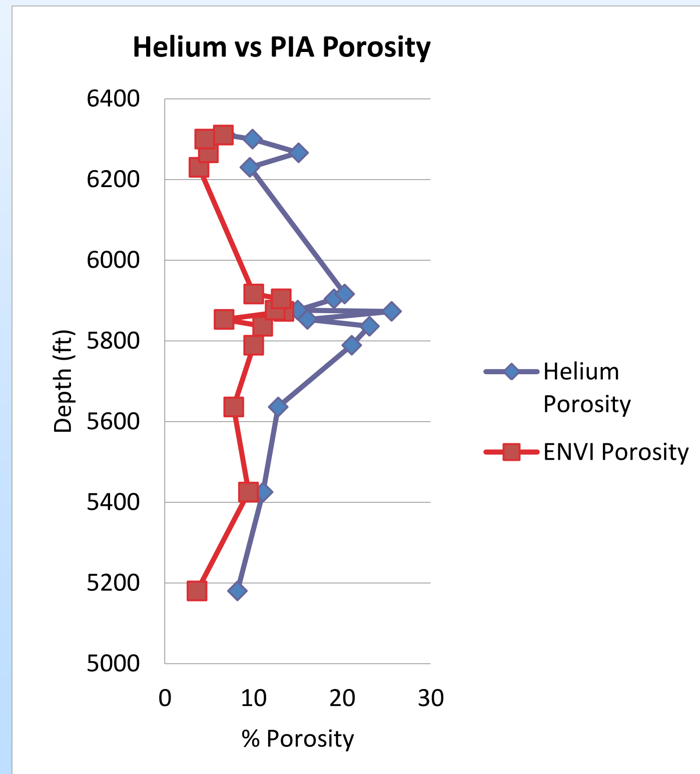


Jasper
3350 ft
~10 %

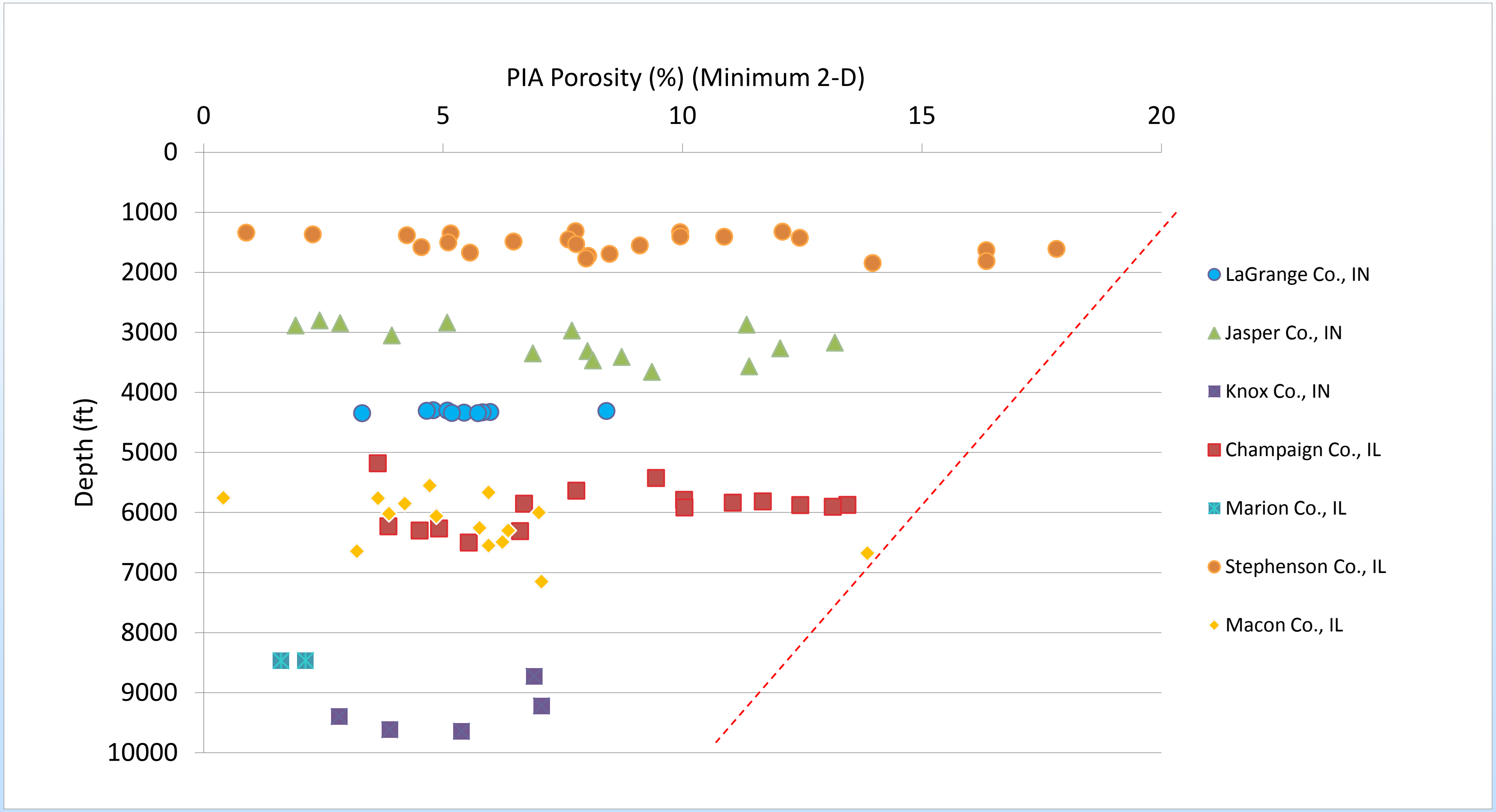


Stephenson
1810 ft
~15 %

PIA studied by others and correlate with well data. Interpreted as “effective porosity” and not total porosity.

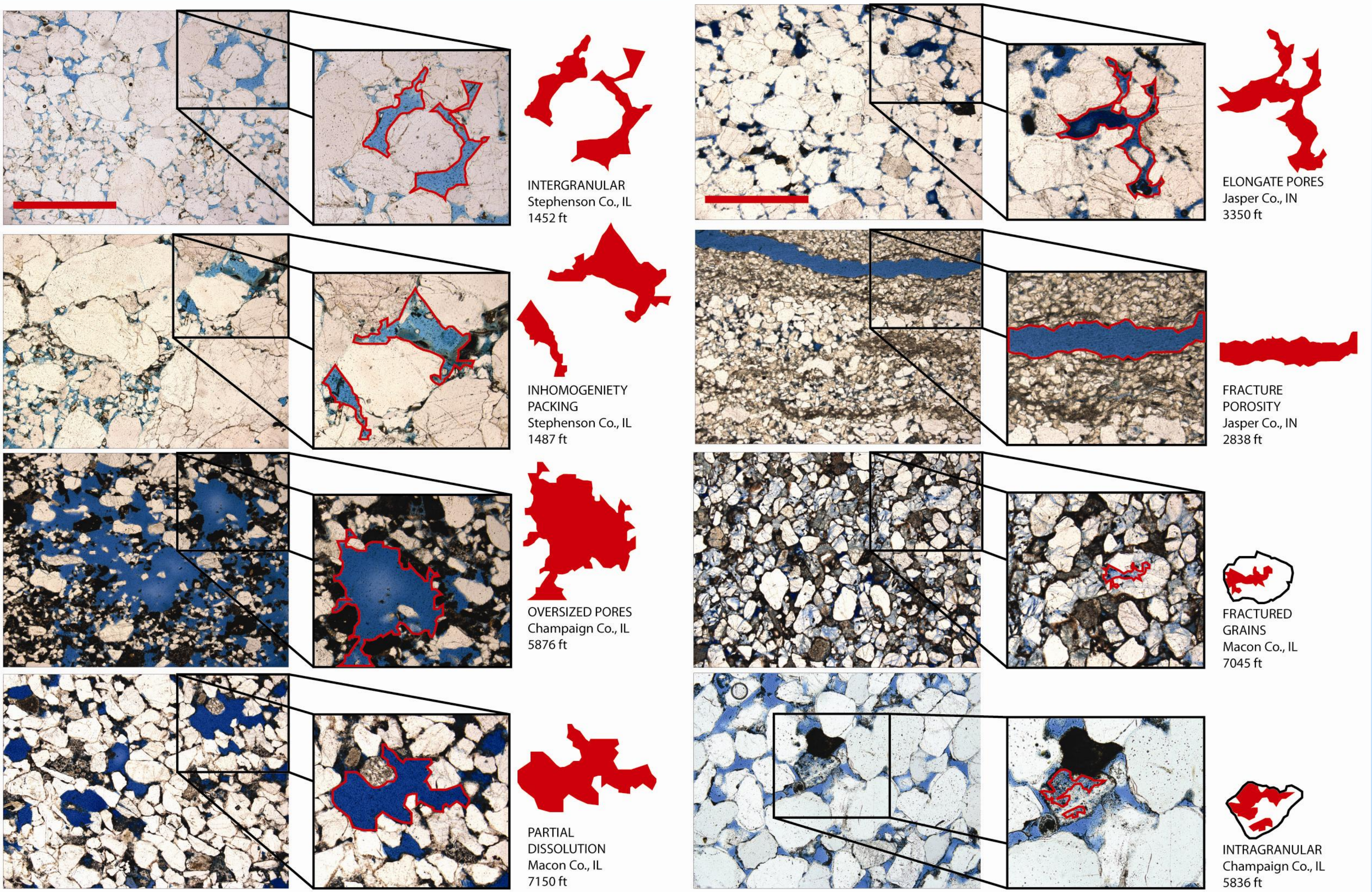


Mount Simon Sandstone PIA Porosity Analyses



- Large range in porosity at given depth- why?
- Reduction in the maximum porosity with depth

Mount Simon Sandstone porosity types



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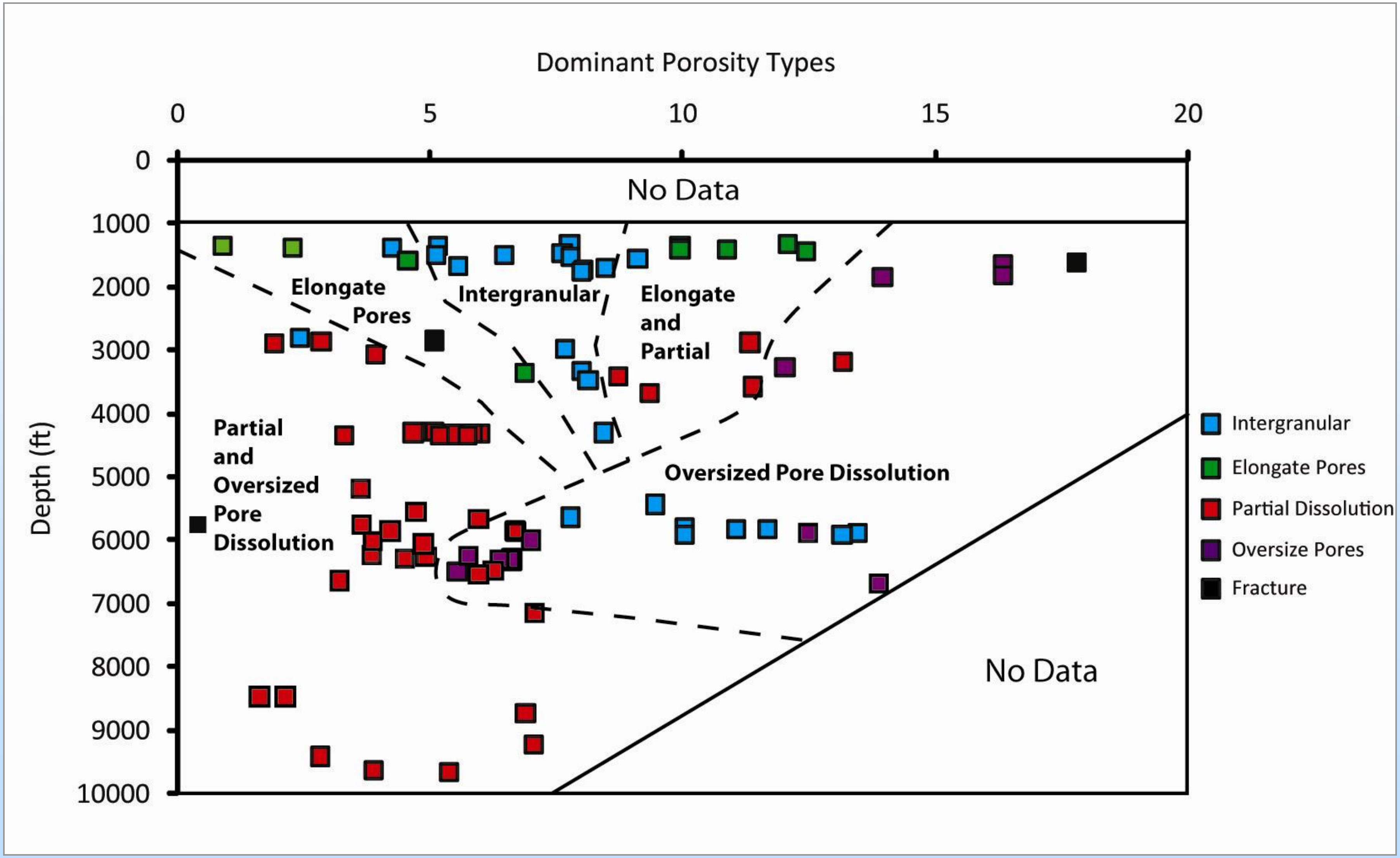
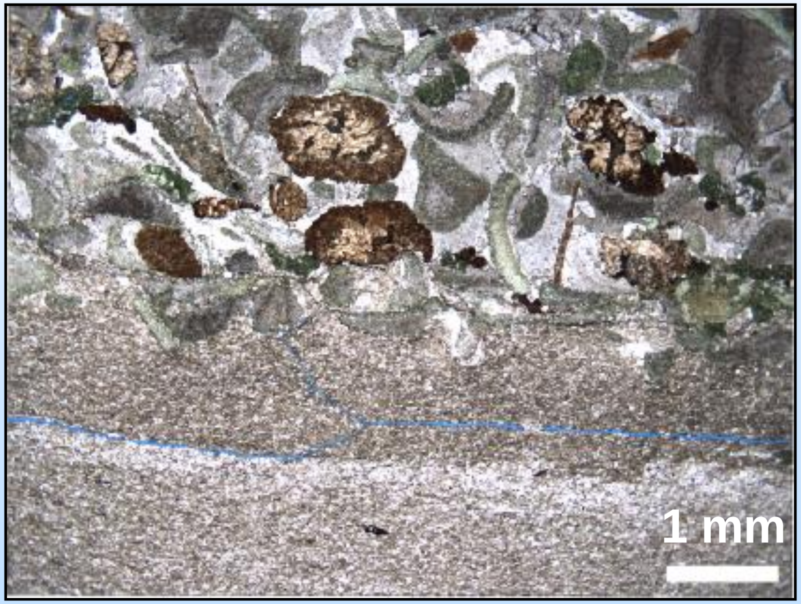
Mount Simon Sandstone dominant pore types

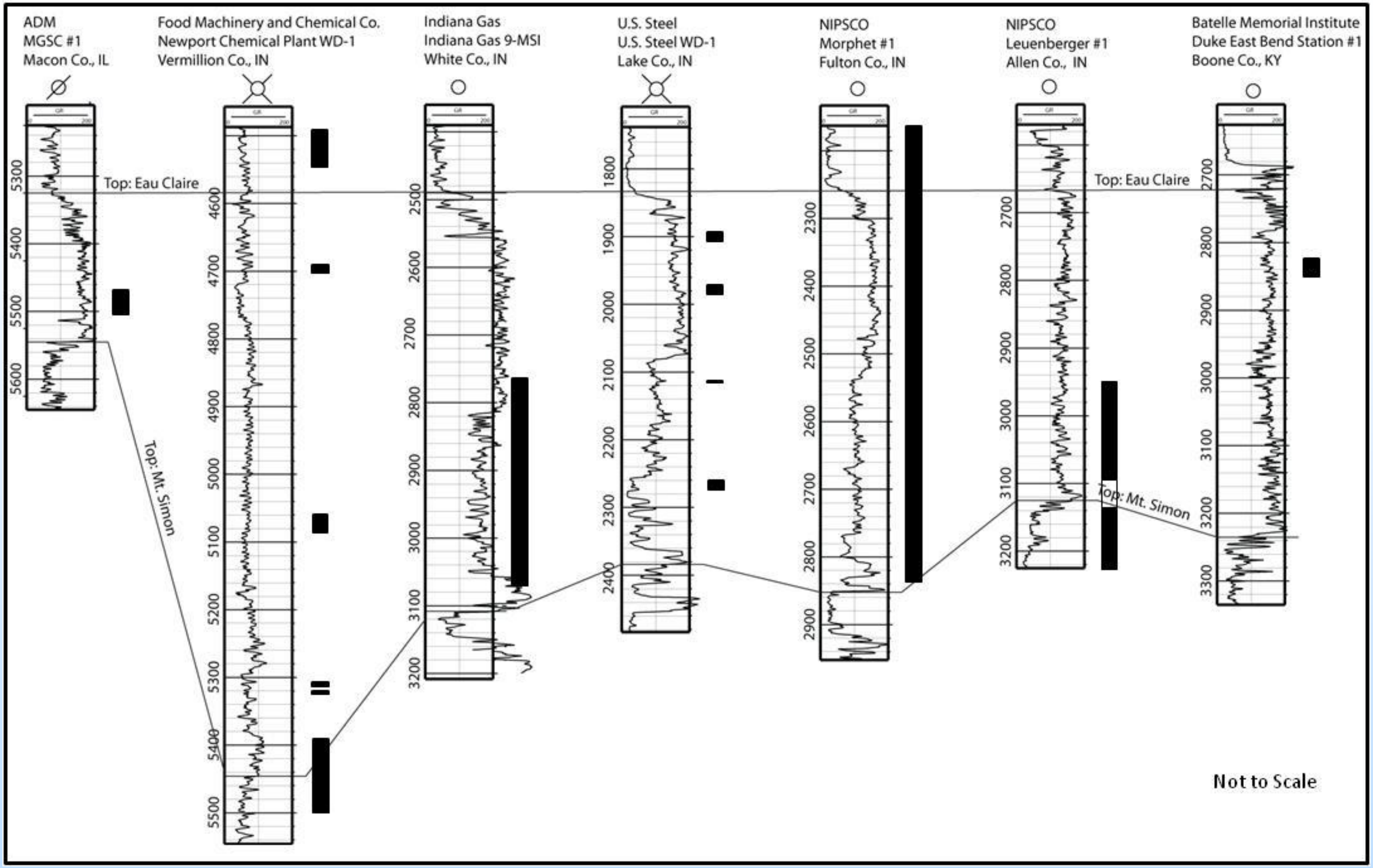


Student Research Successes

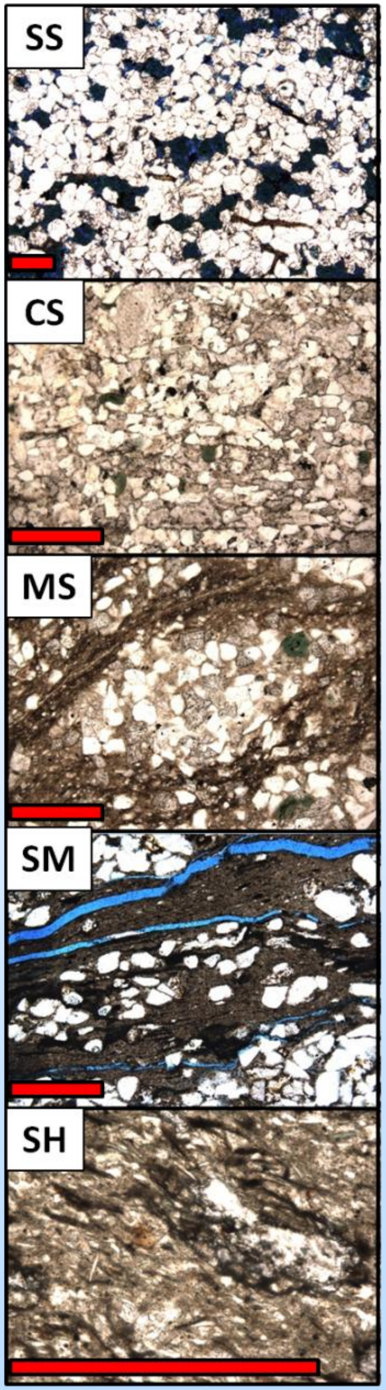
- Neufelder MS thesis, completed May 2011
  - **“Petrographic, mineralogical, and geochemical evidence of diagenesis in the Eau Claire Formation: Implications for sealing capability in a CO_2 sequestration system”**
  - **Objective:** to quantify compositional and textural variability within the EC
  - **Approach:** examine texture, mineralogy, and geochemistry of ~60 EC samples from wells across the Illinois Basin
  - **Major conclusions:** sealing capabilities quite variable depending on depositional fabric and diagenetic history; substantial dissolution porosity in some areas; need for intraformational mapping of lithofacies (ongoing with IGS) to focus on just shale as seal



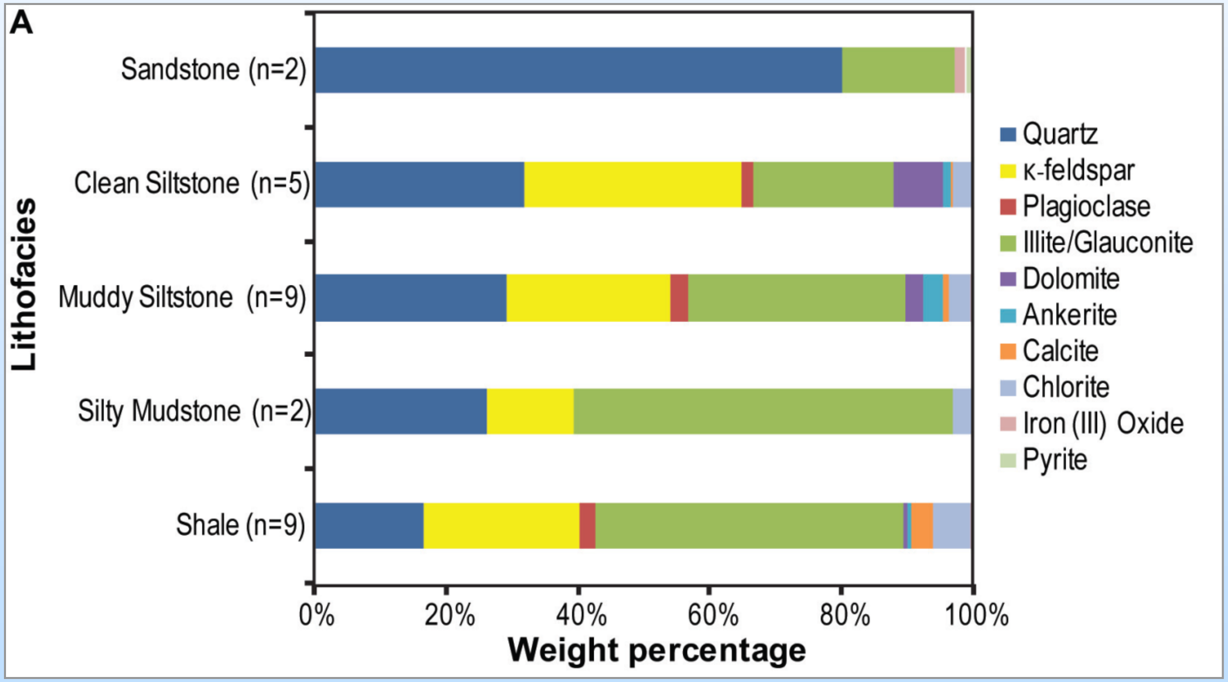
Eau Claire Formation sample context



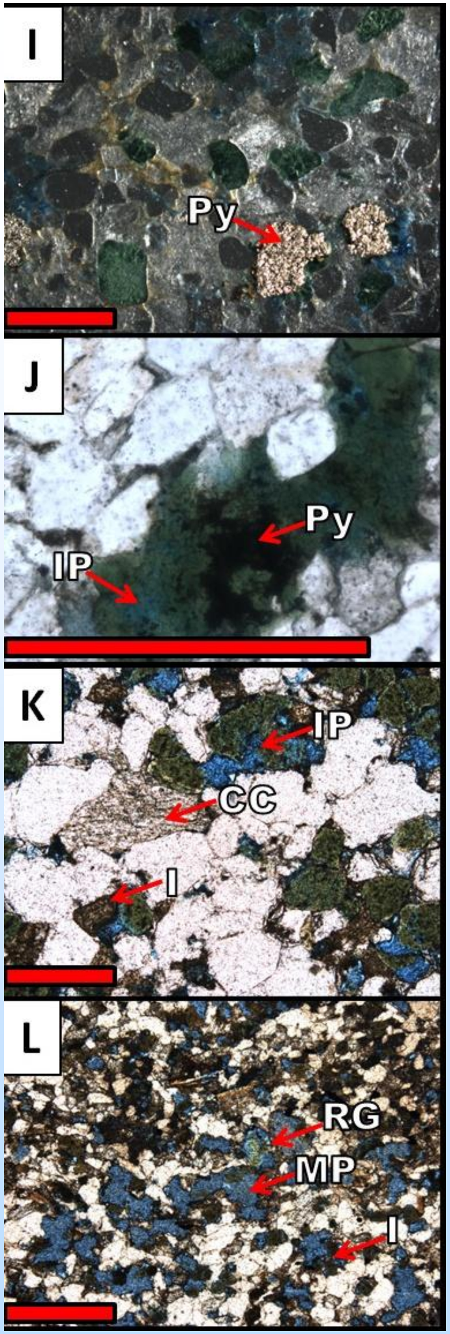
- *Inherent availability limitations for sample-based analysis*



- Textural and compositional variability between intraformational lithofacies
  - Sandstone, clean siltstone, muddy siltstone, sitly mudstone, and shale lithofacies
  - Extreme compositional and textural differences between lithofacies



Mineralogical variations from XRD analysis



Fluid history in a seal?

- Diagentic fluids have left a strong fingerprint in some of the EC
  - Dissolution, secondary phases, oxidation, etc.

Fabric	Glauconite	Carbonate	Both	Neither	Total
Sandstone	1	1	0	0	2
Clean Siltstone	0	5	10	1	16
Muddy Siltstone	1	13	9	1	24
Silty Mudstone	2	2	2	0	6
Shale	2	10	1	5	18
Total	6	31	22	7	66

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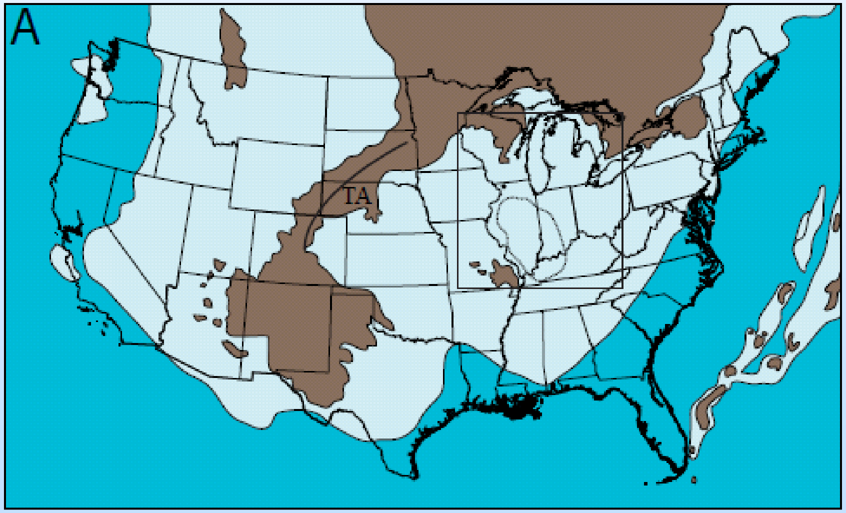
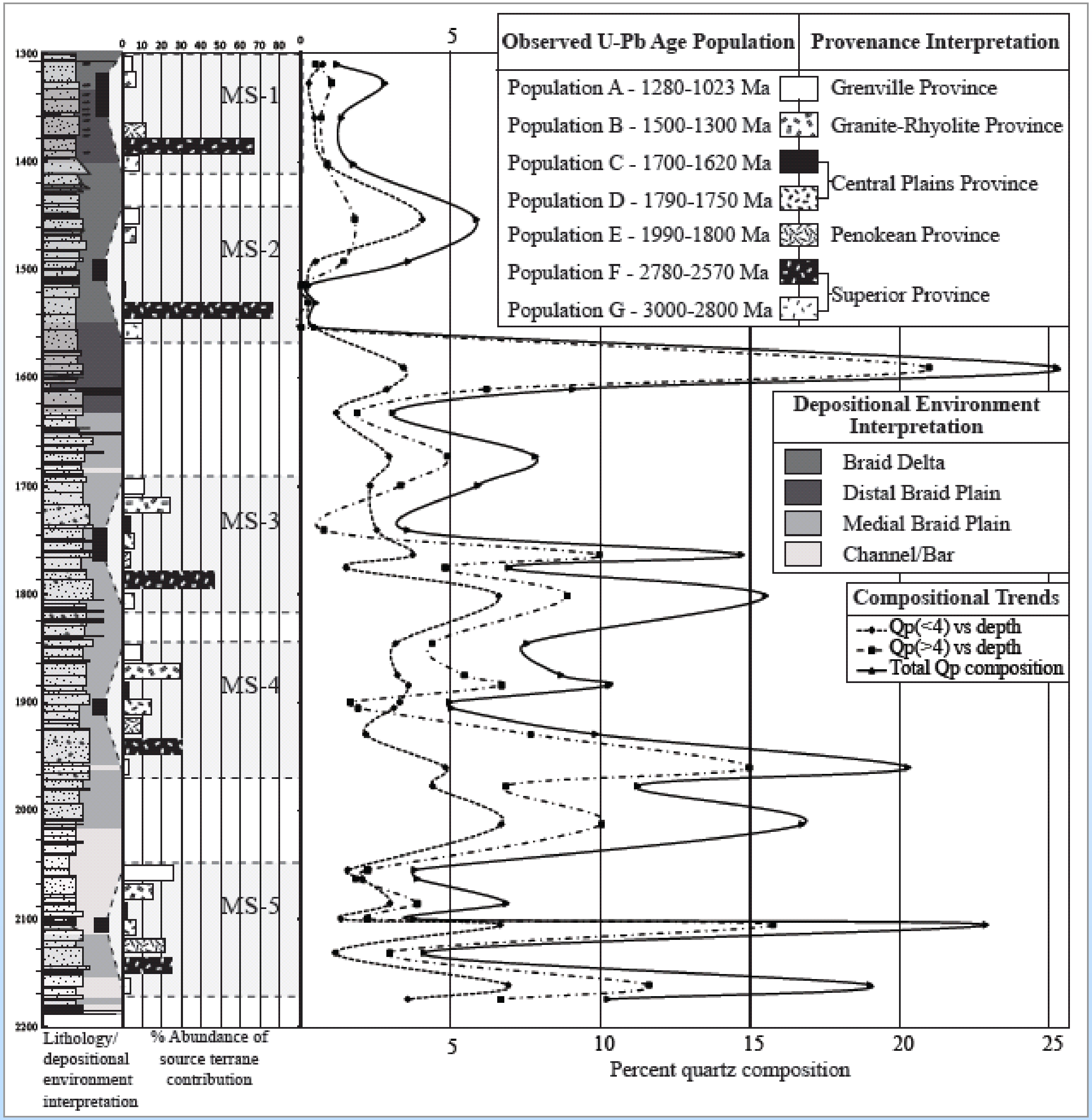
Student Research Successes

- Lovell PhD research, started August 2010

  “Investigating changes in composition and texture in the Mount Simon Sandstone and Eau Claire Formation within the Illinois Basin”

  - **Objective:** to characterize and explain regional compositional and textural trends in MS and EC
  - **Approach:** integrated well-log, core, thin section, geochemistry analyses to identify sedimentary provenance analyses (e.g., compositional variations, detrital zircon analyses, depositional and tectonic models)
  - **Major conclusions:** fluctuations in source terranes and facies architecture influence detrital composition





- Core analysis
- Composition via petrographic point counting
- Paleo-environmental interpretations
- Source terrane age ranges
- Basin-scale depositional model for better prediction of reservoir / seal qualities

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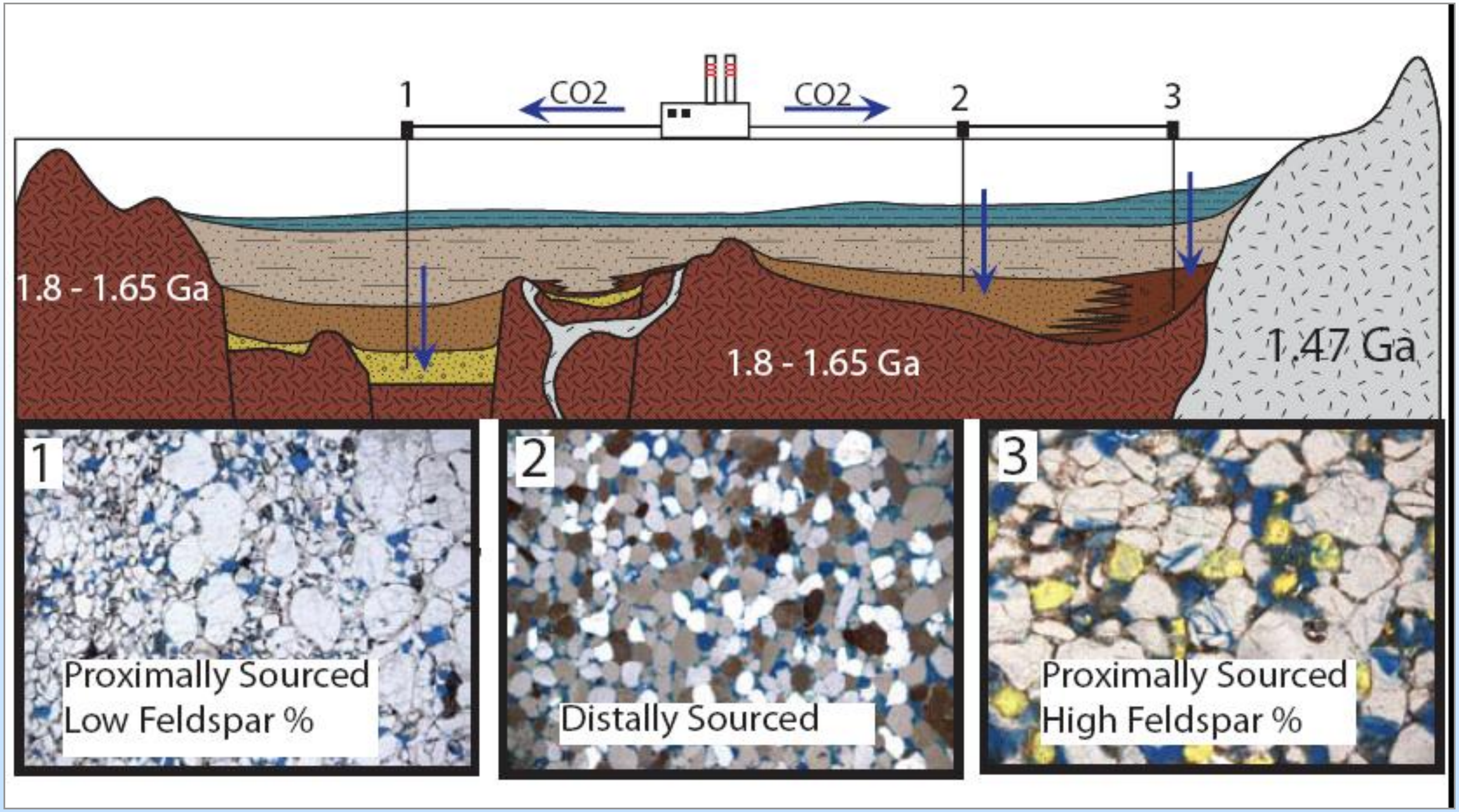
How sedimentary provenance affects reservoir quality



- Schematic diagram illustrating how detrital composition and reservoir quality can be affected by differences in sedimentary provenance. 1. Strata sourced proximally from the 1.8-1.65 Ga terrane yield low feldspar percentages. 2. distally sourced strata contains a moderate amount of feldspar. 3. Strata sourced from the 1.47 Ga terrane yield high feldpsar content. Feldspar dissolution creates porosity…

Student Research Successes

- Gonzalez MS thesis, in progress
  - **"Geochemical and mineralogical evaluation of CO_2-brine-rock experiments: Characterizing porosity and permeability variations in the Cambrian Mount Simon Sandstone"**

- **Objective:** to examine any compositional and textural changes in samples exposed to experimental CCS conditions for 6 months
- **Approach:** collaboration with NETL and IGS; microscopy and geochemistry
- **Major conclusions:** changes in brine composition before and after suggests dissolution of some soluble Fe-bearing phases; small change in porosity and permeability measured; microscopy observations illustrate changes in texture

Soong, Hedges, Rupp et al.

Brine Chemistry

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Symbol	pH	Na	Fe	Cl	Al	Mg	Ca	K	S	NO3 (as N)	Ti	Ba	Mn	Ni	Pb	Ba
Unit Symbol		mg/L	mg/L	mg/L	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Detection Limit		0.1	0.01	0.03	2	0.1	0.1	0.1	1	0.01	0.1	0.1	0.1	0.3	0.01	0.1
Analysis Method		ICP-OES	ICP-OES	IC	ICP-MS	ICP-OES	ICP-OES	ICP-OES	ICP-OES	IC	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS
Synthetic Control Brine	3.3	47400	75.8	130000	< 200	2500	19800	1440	168	23.9	21.4	10700	< 10	815	15.4	10700
Synthetic Control Acidified	1.4	42500	82	122000	NA	NA	Na	Na	Na	134	< 200	1940	0.02	392	20	1940
Vermillion 6 month	1.7	50800	123	133000	1090	2690	21300	1570	171	131	27.1	6000	127	1300	119	6000
Knox Co 6 Month	1.9	53100	126	144000	903	2820	22400	1650	175	122	37.2	9650	255	1710	206	9650

- All major ions and trace elements increase in concentration after the experiment suggesting dissolution of Na, Fe, Al, Mg, Ca, K, and several trace elements.

- No evidence of precipitation of phases from fluid chemistry.

- Knox and Vermillion samples displayed different rates of dissolution based on cation and trace element concentrations.

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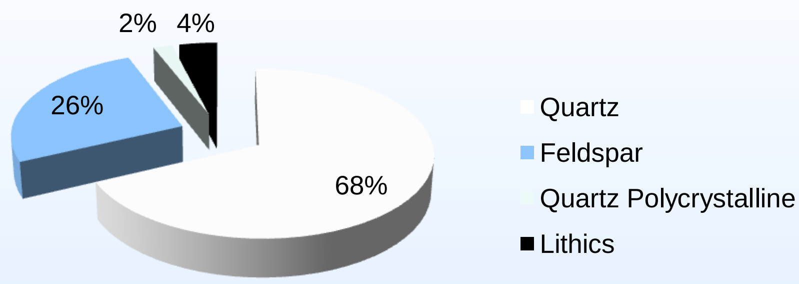
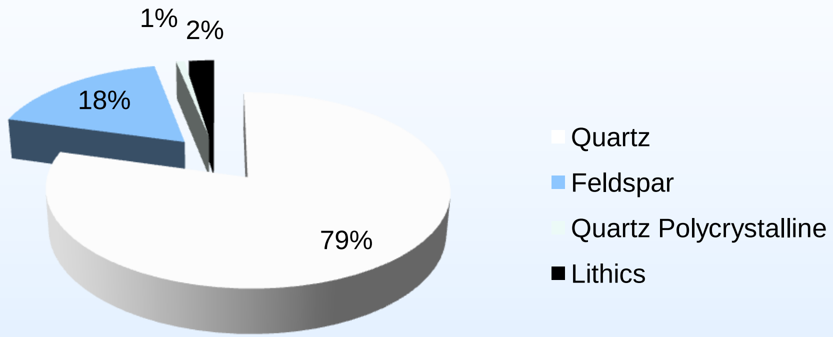
Point Count compositional results
(500 grain measurements per sample)

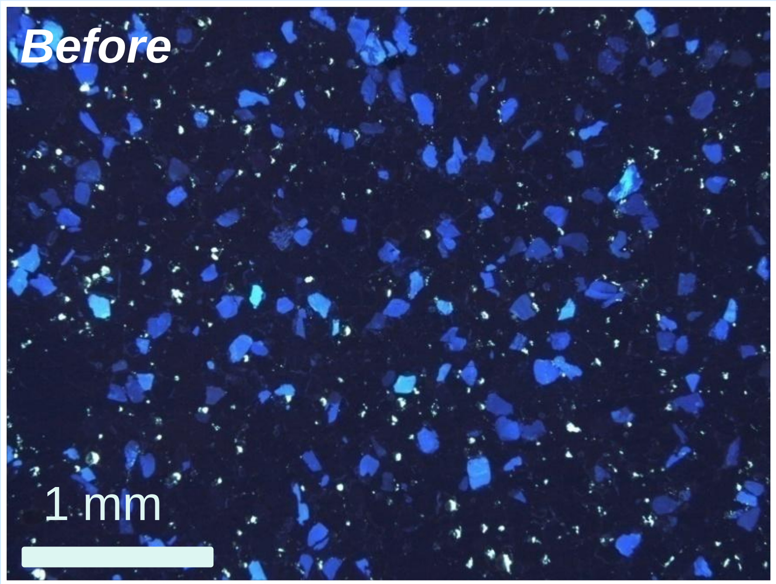
Mineral Composition for Knox 8542 2EE-

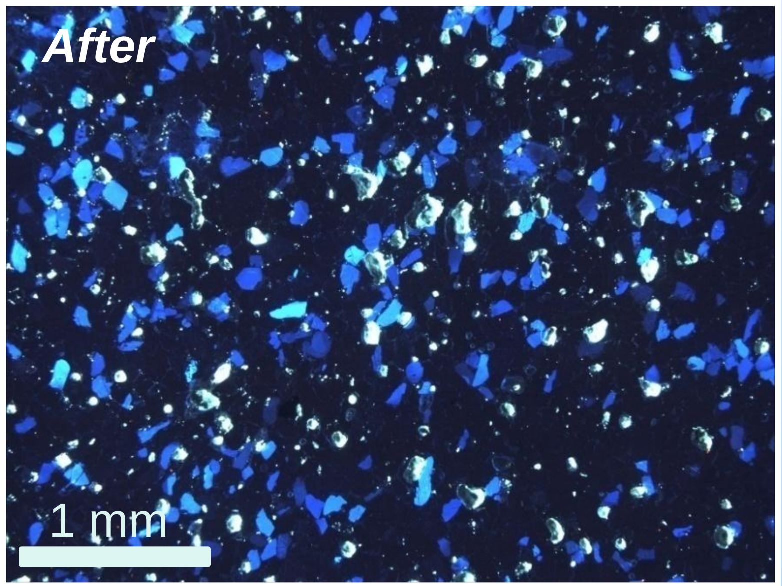


Mineral Composition for Vermillion 5805C 2EE-013



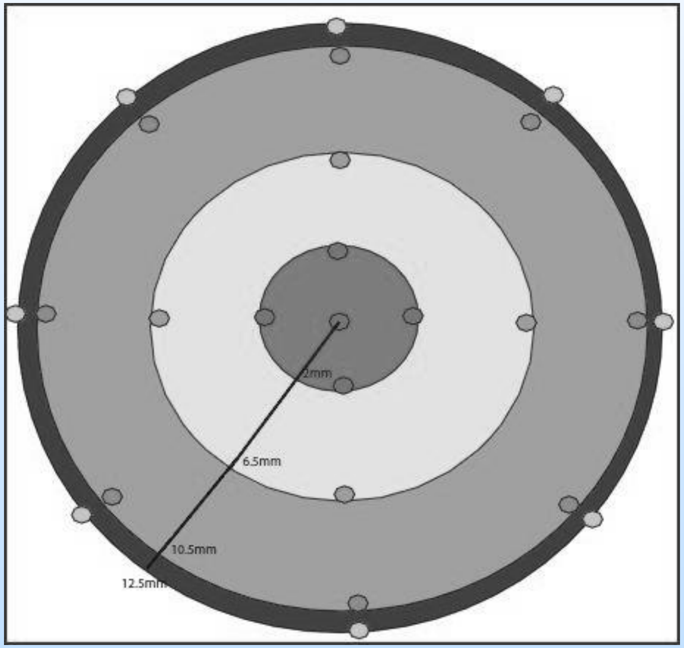
Cathodoluminescence microscopy



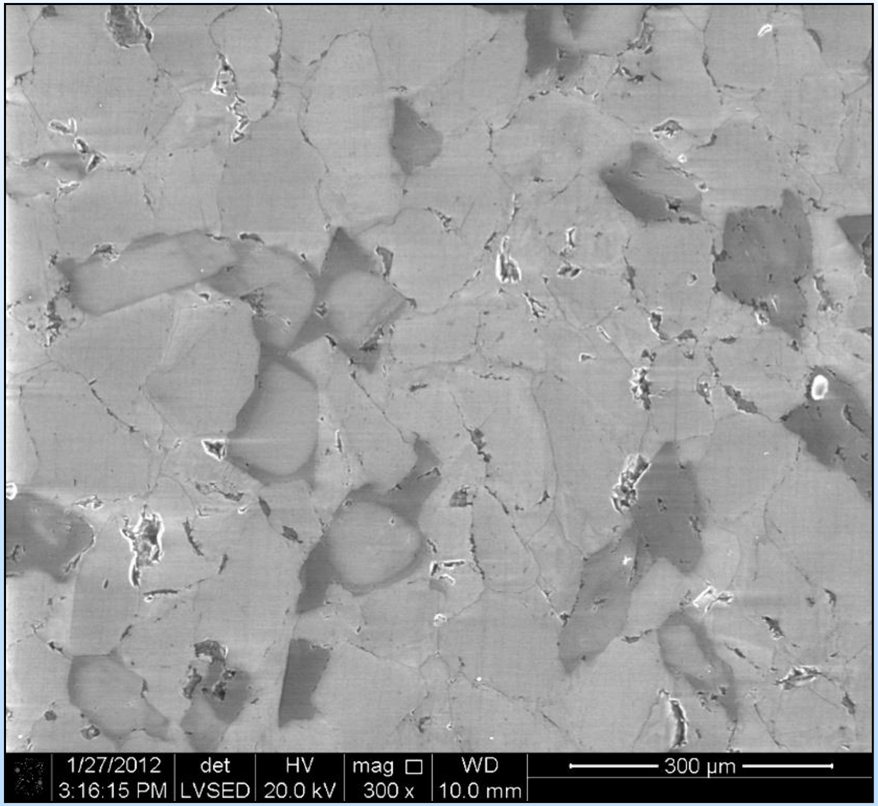


SEM-EDX analyses

- Systematically quantify pore and mineral textures and geochemistry on nm to micron scale across samples



O	Al	Si	S	Cl	Ca
55.67	1.62	39.67	0.36	1.38	0.49



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Overall Summary

- Student-led research on CCS relevant samples producing significant new information about spatial and temporal heterogeneities in reservoir and seal formations
  - Training through hands-on research
  - Formal training: Challenges but importance of interdisciplinary coursework
- Lessons Learned
  - Challenges related to differences in perspective from gov't and industry needs versus academic training and research
  - Overlap in tools with oil and gas industry (all students now employed in energy industry)
- Future Plans
  - Completion of student work, publication of results

Appendix

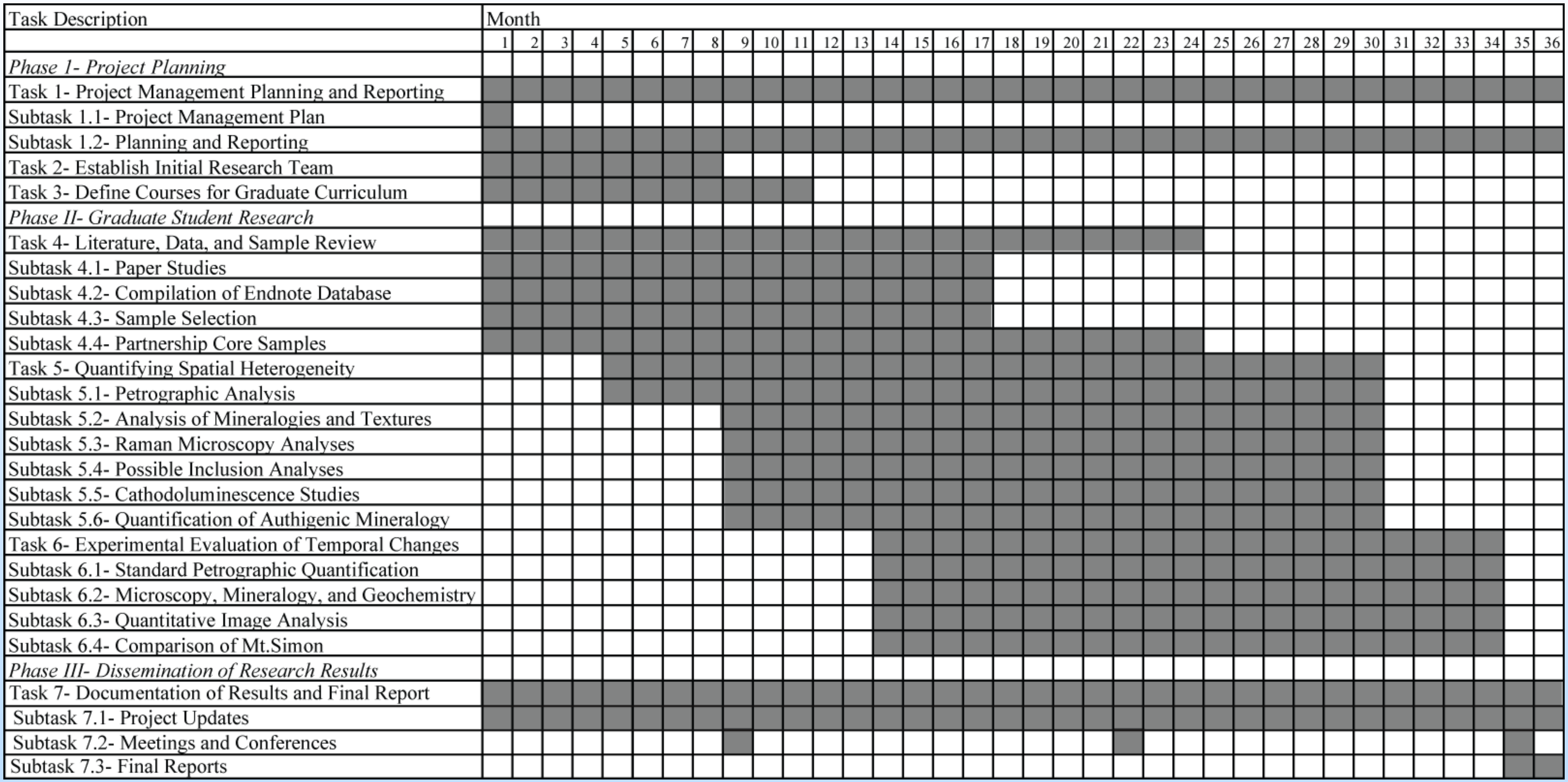
– Organizational chart: project team
– Gantt Chart: project timeline
– Project Milestones
– Budget
– Bibliography

• Thank you!

Organization Chart

- Project team: Purdue University
  - Dr. Brenda B. Bowen: PI, student advisor
    - Raul Ochoa: MS student
    - Ryan Neufelder: MS student
    - Alex Gonzalez: MS student
    - Stacy Story: PhD student
    - Thomas Lovell: PhD student
    - Nicholas Black: undergraduate student
    - John Shufflebargar: undergraduate student
    - Brenton Chentnik: undergraduate student

Gantt Chart


Task Description
Month
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36
Phase 1- Project Planning
Task 1- Project Management Planning and Reporting
Subtask 1.1- Project Management Plan
Subtask 1.2- Planning and Reporting
Task 2- Establish Initial Research Team
Task 3- Define Courses for Graduate Curriculum
Phase II- Graduate Student Research
Task 4- Literature, Data, and Sample Review
Subtask 4.1- Paper Studies
Subtask 4.2- Compilation of Endnote Database
Subtask 4.3- Sample Selection
Subtask 4.4- Partnership Core Samples
Task 5- Quantifying Spatial Heterogeneity
Subtask 5.1- Petrographic Analysis
Subtask 5.2- Analysis of Mineralogies and Textures
Subtask 5.3- Raman Microscopy Analyses
Subtask 5.4- Possible Inclusion Analyses
Subtask 5.5- Cathodoluminescence Studies
Subtask 5.6- Quantification of Authigenic Mineralogy
Task 6- Experimental Evaluation of Temporal Changes
Subtask 6.1- Standard Petrographic Quantification
Subtask 6.2- Microscopy, Mineralogy, and Geochemistry
Subtask 6.3- Quantitative Image Analysis
Subtask 6.4- Comparison of Mt.Simon
Phase III- Dissemination of Research Results
Task 7- Documentation of Results and Final Report
Subtask 7.1- Project Updates
Subtask 7.2- Meetings and Conferences
Subtask 7.3- Final Reports

Project Milestones

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Milestone	Completion Date	Validation
HQ Milestone: Project Kick-off Meeting	02/18/10	Documentation of completion can be found in the FY10Q1 quarterly report
HQ Milestone: Educational Program Instituted	06/30/10	Documentation of completion can be found in the FY10Q3 quarterly report
HQ Milestone: Semi-Annual Progress Report (i.e. Quarterly report ending June 30, 2010)	07/30/10	Quarterly report submitted for Q3
HQ Milestone: Yearly Review Meeting	02/24/11	Gave webinar presentation on research project to date
HQ Milestone: Provide at least 50 students with 20,000 research hours	Met ahead of schedule (06/03/11)	Note: This milestone was met collectively by all projects. No one project was held accountable to the milestone.
HQ Milestone: Semi-Annual Progress Report (i.e. Quarterly report ending June 30, 2011)	07/29/11	Quarterly report submitted
HQ Milestone: Provide at least 50 students with 20,000 of research hours.	03/31/12	Note: This milestone was met collectively by all projects. No one project was held accountable to the milestone.
HQ Milestone: Semi-annual progress reports (i.e. Quarterly Report ending March 31, 2012).	04/15/12	Quarterly report submitted
HQ Milestone: Yearly Review Meeting of all recipients; opportunities for information exchange and collaboration.	09/23/12	Present project at meeting

Budget to date

	Year 1: Start: 12/01/2009 End: 09/30/2010				Year 2: Start: 10/01/2010 End: 09/30/2011				Year 3: Start: 10/01/2011 End: 09/30/2012				Year 4: Start: 10/01/2012 End: 11/30/2012			
	Q1 (Dec 2009)	Q2 (Jan 2010)	Q3 (Apr 2010)	Q4 (Jul 2010)	Q1 (Oct 2010)	Q2 (Jan 2011)	Q3 (Apr 2011)	Q4 (Jul 2011)	Q1 (Oct 2011)	Q2 (Jan 2012)	Q3 (Apr 2012)	Q4 (Jul 2012)	Q1 (Oct 2012)	Q2 (Jan 2012)	Q3 (Apr 2012)	Q4 (Jul 2012)
Baseline Cost Plan (from Sf-424)																
Federal Share	7,912	23,736	23,736	23,736	24,238	25,242	25,242	25,242	25,496	26,004	26,004	26,004	17,328			
Non-federal Share				3,442												
Total Planned (federal and Non-federal	7,912	23,736	23,736	27,178	24,238	25,242	25,242	25,242	25,496	26,004	26,004	26,004	17,328			
Cumulative Baseline cost	7,912	31,648	55,384	82,562	106,800	132,042	157,284	182,526	208,022	234,026	260,030	286,034	303,362			
Actual Incurred Cost																
Federal Share	-	23,146	17,704	23,802	41,704	26,785	29,290	16,514	29,031	22,057	43,824					
Non-federal Share	-	662	1,246	-	1,156			-	-	852	(473)					
Total Planned (federal and Non-federal	-	23,808	18,950	23,802	42,859	26,785	29,290	16,514	29,031	22,908	43,351	-	-			
Cumulative Baseline cost	-	23,808	42,758	66,560	109,419	136,204	165,494	182,008	211,038	233,947	277,298	277,298	277,298			
Variance																
Federal Share	7,912	590	6,032	(66)	(17,466)	(1,543)	(4,048)	8,728	(3,535)	3,947	(17,820)	26,004	17,328			
Non-federal Share	-	(662)	(1,246)	3,442	(1,156)	-	-	-	-	(852)	473	-	-			
Total Planned (federal and Non-federal	7,912	(72)	4,786	3,376	(18,621)	(1,543)	(4,048)	8,728	(3,535)	3,096	(17,347)	26,004	17,328			
Cumulative Baseline cost	7,912	7,840	12,626	16,002	(2,619)	(4,162)	(8,210)	518	(3,016)	79	(17,268)	8,736	26,064			

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- *Note: student authors supported by project underlined*