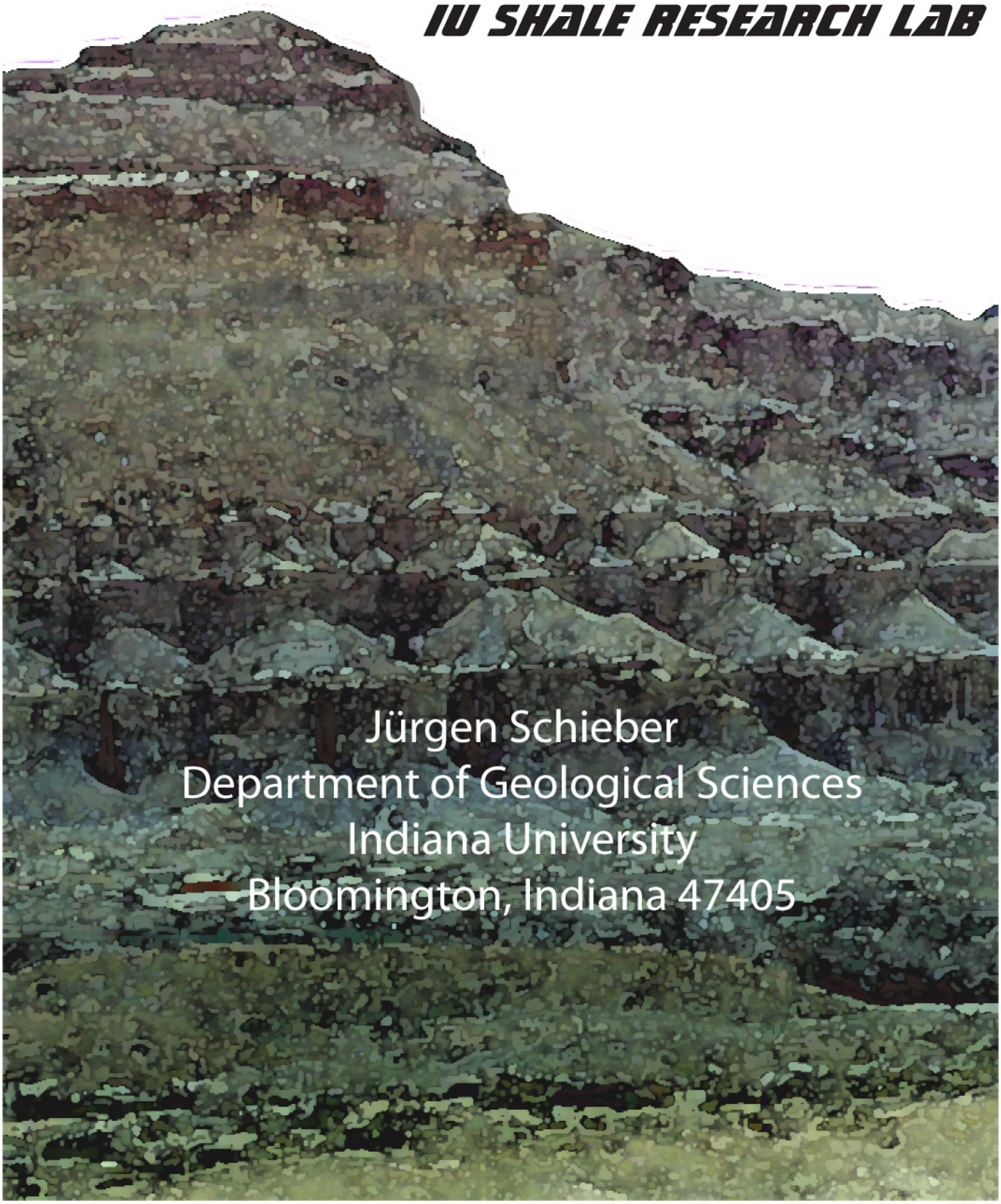
Research Prospectus



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Research Prospectus 2014

Indiana University Shale Research Consortium

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Introduction

The Indiana University Shale Research Lab conducts cutting edge research into fundamental processes that determine distribution and petrophysical properties of shales and mudstones. Our inventory of research methodologies includes sedimentological and stratigraphic field studies, experimental studies in race-track flumes, geochemical investigations (organic carbon, major and trace elements, stable isotopes), petrographic studies under optical/petrographic microscopes, and electron microscopy with a high performance analytical FEG SEM.

Our research philosophy is multi-scale data integration for accurate assessment of critical qualities of shale successions. We take a holistic approach to the geologic understanding of fine grained sediments and strive to study shales from a wide range of depositional settings in order to arrive at comprehensive depositional models. Our research program spans more than two decades and encompasses strata that range in age from Archean to Tertiary. The general goal is to derive fundamental insights into shale depositional systems from in depth studies of particular stratigraphic units. In recent years, we have been engaged in sequence stratigraphic and sedimentologic research of Devonian age shales, due to a combination of availability of outcrops, drill core, and favorable funding.

In this prospectus we also summarize the research objectives that we would like to pursue with consortium funds. Consortium members are encouraged to suggest additional research topics, in particular if such cooperation involves application of our research methodology to shale successions and depositional scenarios that have not previously been investigated, or which were not examined in detail.

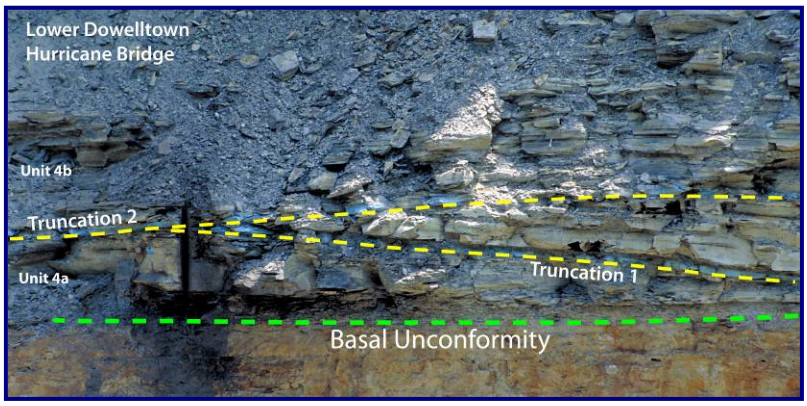
Sponsorship of our research program will help to advance the understanding of fine-grained sediments and of parameters that are critical for their economic development. In addition, consortium funds will benefit the training of a new generation of petroleum geoscientists that will have a solid grounding in the particulars of fine-grained sediments. Their integrated training, involving basin scale evaluation of entire formations, detailed petrographic

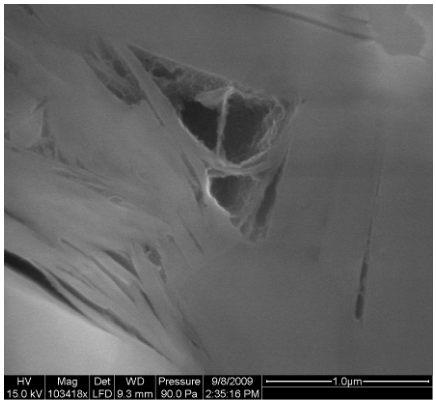
and pore studies, as well as flume experiment analogs, will be a powerful combination to address future challenges in the shale gas industry. Our research program is the only one available that provides comprehensive exposure to these multiple investigative methodologies, and builds on more than two decades of experience in shale research.

General Research Interests

The research areas our lab is engaged in include:

(1) Shale facies studies and assessment of depositional settings
(2) Flume studies of mud deposition and "reverse engineering" of specific sedimentary features and textures found in the rock record. The objective is to calibrate depositional models with actual physical data.
(3) Sequence stratigraphic studies of shale successions.
(4) Diagenetic processes and their relationship to depositional conditions and sequence stratigraphic stages.
(5) Pore development in shales and its relationship to depositional process, depositional fabric, and burial history.





Studies of the IU Shale Research Lab range from the basin-scale to the nano-scale. At left erosional truncations (sequence boundaries) in Devonian black shales, at right SEM image of an ion-milled sample that shows phyllosilicate framework pores in shale of same age.

Relatively speaking, shale research is still a young field of inquiry, but the results from above studies have the potential to have a significant impact on:

(1) Understanding the boundary conditions of source rock formation.
(2) Origin and development of petrophysical properties that impact mechanical modification/fracturing of shale gas reservoirs.
(3) Production characteristics of shale gas reservoirs.

Our integrated approach to the study of shale facies and mud deposition has value for predicting reservoir distribution as a consequence of underlying sedimentary processes and diagenetic

modification in shale dominated depositional systems. Thus, consortium studies will have direct applicability to shale gas reservoir characterization and efforts to model shale gas reservoir facies.

Currently Projects (multi-year)

1) Sequence stratigraphic study of Devonian black shales in the eastern US
2) Shale facies studies of selected Phanerozoic shale successions (Eau Claire, Maquoketa, New Albany, Ohio, Chattanooga, Green River, Mancos)
3) Early diagenetic silica precipitation in shales
4) Pore development in the New Albany Shale along a maturity gradient
5) Study of ion milling artifacts in gas shale reservoir rocks
6) Flume simulation of sedimentary features and fabrics in shales across a range of depositional conditions (unidirectional flow, combined flow, wave, tidal flow)

Additional information about our past work can be found at the following web site:
http://www.shale-mudstone-research-schieber.indiana.edu/
Information about ongoing projects will be accessible to consortium subscribers on a dedicated web site.

Facilities at the IU Shale Research Lab

1) *Three large flumes* designed specifically for mudstone research
2) A dedicated *sample processing lab*
3) An *optical petrography lab* with 3 Zeiss research microscopes
4) An *electron microscope lab* with a fully equipped FEI Quanta 400 FEG analytical electron microscope (EDS, ESEM, EBSD, Chroma-CL)
5) An *ion milling lab* with two GATAN 600 Duomills equipped with liquid nitrogen cooled sample stages, and GATAN Ilion with liquid nitrogen cooling.
6) All the *equipment needed for field studies* of shales (including portable gamma ray spectrometer)
7) *Focused Ion Beam System (FIB)* for 3D investigation of mineral relationships and pore characteristics. As Co-PI of a funded NSF equipment proposal we have access to a new FEI FIB that has been installed on the IU campus.

The IU flume lab is the only flume facility for mudstone research worldwide. Through contributions to lab funding, sponsors will benefit from access to new results and concepts coming out of our experimental work on mudstone sedimentology. We currently operate three flumes (see below); and by end-2013 we plan to have four flumes in service that will allow us to simulate all typical flow conditions (unidirectional flow, waves, tides) and a variety of sea water chemistries (oxic, suboxic, anoxic, etc.).

The flume facility of the IU Shale Research Lab. The above two flumes are large racetrack flumes for the study of mud deposition and erosion. We are in the process of building two additional flumes in a new lab facility. These will allow simulation of tidal and storm wave currents, as well as control of water column chemistry to study controls on carbon burial.

The newest addition to our flume lab (above), a flume that allows control of dissolved gases and temperature. This will allow us to more closely examine source rock formation in energetic settings with variable oxygen conditions.

Costs and Benefits

The consortium fee of $50,000 is structured to contribute to the support of graduate students, to provide summer salary for the PI, and to support infrastructure needs for the IU Shale Research Lab (~$80,000 per year w/o personnel costs). All consortium sponsors will receive a yearly report of research activities. In addition, preprints of research papers, presented posters, and oral presentations, will all be provided via a proprietary web-based format (mainly PDF files). These can be printed and used by subscribers at their own convenience and discretion. Proprietary web sites will be password protected for the sole use of consortium sponsors. We will run an annual short course that combines (1) a field trip to illustrate outcrop examples of concepts we are working on, typically in (2) conjunction with lab visits for flume demonstrations and petrographic exercises. Specifics of a given short courses can be adapted to collectively expressed interests of consortium sponsors.

These short courses are excellent training opportunities for employees of consortium sponsors and also provide a hands on view of the latest research that is conducted in the IU Shale Research Lab. In the past, these field trips have included exposures of classical shale successions, such as the Mancos Shale of the Book Cliffs, the Green River Shale, and the Devonian of the eastern US.

We are also always interested to discuss opportunities for student participation in specific projects of consortium sponsors, as part of a student's MS or Ph.D. project. Such interactions provide our students valuable experience in an industry setting and are encouraged.

The IU Shale Research Lab regularly solicits funding from other agencies (NSF, DOE, NASA, PRF/ACS) to support ongoing research. Thus, funds of consortium sponsors may be leveraged against significant sums from these agencies and further enhance the total research output that sponsors have access to.

Sponsors will have access to new ideas, new concepts, and research breakthroughs as they happen, versus the larger community that only has access to the final published papers. The latter routinely appear several years after work has been completed. They also have access to myself, students, and post-docs via in house visits and the annual short course.

Selected Publications:

1. Schieber J (2013) SEM Observations on Ion-Milled Samples of Devonian Black Shales from Indiana and New York: The Petrographic Context of Multiple Pore Types. AAPG Memoir 102, *Electron Microscopy of Shale Hydrocarbon Reservoirs.*
2. Schieber, J., Southard, J.B., and Schimmelmann, A., 2010, Lenticular Shale Fabrics Resulting from Intermittent Erosion of Muddy Sediments – Comparing Observations from Flume Experiments to the Rock Record. *Journal of Sedimentary Research*, v. 80, p. 119-128.
3. Schieber, J., and Southard, J.B., 2009, Bedload Transport of Mud by Floccule Ripples – Direct Observation of Ripple Migration Processes and their Implications. *Geology*, v. 37, p. 483-486.
4. Schieber, J., and Yawar, Z., 2009, A New Twist on Mud Deposition - Mud Ripples in Experiment and Rock Record. *The Sedimentary Record*, v. 7/2, p. 4-8.

5. Schieber, J., 2009, Discovery of Agglutinated Benthic Foraminifera in Devonian Black Shales and Their Relevance for the Redox State of Ancient Seas. *Paleogeograpy, Paleoclimatology, Paleoecology*, v. 271, p. 292-300.
6. Schieber, J., Southard, J.B., and Thaisen, K.G., 2007, Accretion of mudstone beds from migrating floccule ripples. *Science*, v. 318, December 14, 2007, p. 1760-1763.
7. Schieber, J., and Lazar, R.O., 2004, (eds.) Devonian Black Shales of the Eastern U.S.: New Insights into Sedimentology and Stratigraphy from the Subsurface and Outcrops in the Illinois and Appalachian Basins. Field Guide for the 2004 Great Lakes Section SEPM Annual Field Conference. Indiana Geological Survey Open File Study 04-05, 90pp.
8. Schieber, J., and Riciputi, L., 2004, Pyrite ooids in Devonian Black Shales record intermittent Sea level drop and shallow water conditions. *Geology*, v. 32, p. 305-308.
9. Schieber, J., 2003, Simple gifts and hidden treasures – Implications of finding bioturbation and erosion surfaces in black shales. *The Sedimentary Record*, v. 1, p. 4-8.
10. Schieber, J., Krinsley, D., and Riciputi, L., 2000, Diagenetic origin of quartz silt in mudstones and implications for silica cycling. *Nature*, v. 406, p. 981-985.
11. Schieber, J., 1999, Distribution and deposition of mudstone facies in the Upper Devonian Sonyea Group of New York. *Journal of Sedimentary Research*, v. 69, p. 909-925.
12. Lobza, V., and Schieber, J., 1999, Biogenic sedimentary structures produced by worms in soupy, soft muds: Observations from the Chattanooga Shale (Upper Devonian) and experiments. *Journal of Sedimentary Research*, v. 69, p. 1041-1049.

Appendix

Clarifications and Planned Research Projects for 2014

Research Activities Planned for 2014

Flume studies of laminated shale fabrics. These experiments aim to reproduce classical parallel laminated fabrics from a range of clays and clay/silt mixtures that are deposited from continuous flows. The guiding principle is that we want to recreate textures observed in the rock record.

Flume studies of co-burial of marine organic matter and clays in continuous flows. These experiments look at differences in carbon burial between flow deposited and still water settled muds. Issues: Global carbon cycling. Do we get better source rocks with current deposition? Can we deposit source rocks a large distance from the site of original production?

Sedimentology of Middle Devonian black shales along the Cincinnati Arch. Includes Blocher/Trousdale/Portwood.

Sedimentology of Geneseo Shale in New York. Data will als help to contrast proximal (near sediment input) and distal (Cincinnati Arch) sequence development.

Shale porosity in relation to maturity. In this study we work a set of samples through the Illinois Basin, from R_o 0.5 to 1.2 , by using geochemical maturity measures, R_o values, and SEM of ion milled surfaces.

Geochemical and physical constraints on genesis, storage and producibility of shale gas. We are covering the petrographic aspects of a multidisciplinary study that combines instrumental measurements of porosity, SEM observations, and geochemical changes during artificial maturation of immature shales (heating under confining pressure).

Annual Report of Research Activities:

That report will contain a summary of the various projects underway or completed, with major findings emphasized. The format will most likely be PowerPoint of PDF, and the web links to the more detailed materials will be part of the report.

Access: *Preprints, Posters, Presentations*

I have a web developer at hand that will set up a password protected site where the results from our projects, such as meeting presentations, papers, and theses/dissertations will be accessible. The material will typically be in PDF format, and the files will be downloadable from the site. The site will be searchable with a web browser, and if that is impractical we can always set up a searchable project data base.

Annual Short Course (conducted at IU):

The plan is to conduct a course that combines outcrop observations (Kentucky), petrography (IU-lab), and flume observations (IU-lab). Objective is to give participants an up to date appreciation of the process spectrum that produces shales from semi-liquid muds. We change/rotate the emphasis of this course on a regular basis.

Another alternative for an Indiana-based short course would be a core workshop that we can conduct in Houston, either at Core Labs or at a sponsor owned core facility.

Research Plans for the Coming Years

Upcoming research at the Lab, on no particular order. The rock studies (except for Romania) are student thesis projects that we try to tie in with flume research projects. The time scale on all this is multi-year.

1) Work through sample collection from Romanian source rocks
- Assess depositional environment
- Microfacies and petrography
- Whatever we can glean from outcrop samples about pore systems
- Large scale depositional bedforms/mudwaves

2) Fundamental research on the deposition of muds with high organic contents (10-20% TOC). Because the organic matter originally was highly hydrated (marine snow etc.), it probably dominated the sediment by volume and that is likely to drastically alter the way this stuff is transported and how it behaves after being deposited. There is a whole complex of issues that simply have never been addressed for sediment like that, and the only way to make progress is via experiments.

3) Experimental work on the formation conditions and boundary conditions for pyritic lags. The latter are common in source rock successions, and we want to sort out what is the main control, oxygenation levels, or just energy at the seafloor. We have a cooler full of pyritic mud from the Santa Barbara basin that we will use here, as well as some synthetic sediments.

4) Microfacies and deposition of the basal Huron Shale in Ohio. That sort of ties in with the experimental work for These 3 and 4. We may also do some experiments to understand the load carrying capacity of such muds, trying to explain how large concretions (up to a meter) were able to grow in a watery sediment (~80% initial water content).

5) Constraints on seal breach and mineralized vein formation in the New Albany Shale (fluid inclusions, stable isotopes, and SEM-CL). These veins contain hydrocarbons, and they were comparatively early.

6) Facies and stratigraphic study of Devonian Shales (focus Geneseo) in New York, with some added work on pore systems.

7) Subsurface study of the Huron Shale interval in Kentucky and Ohio, going eastwards from the outcrop belt. Develop a better mental picture of sequence development in more proximal areas of the Appalachian basin.

8) Finish construction (currently under way) of flume that can simulate tidal regimes and storm waves. Once in place we will explore the microfabrics that develop under those conditions in muds, and look for fossil analogs.

9) Explore feasibility of simulating larger scale muddy bedforms in the lab. We have seen them in outcrop, not its time to get some hard data.