ES:AAPG LEXINGTON KY
BASINS TO BARRELS
2016

Eastern Section American Association of Petroleum Geologists 45th Annual Meeting Lexington, Kentucky September 24–28, 2016

Program with Abstracts

AAPG
Eastern Section

Hosted by:
The Geological Society of Kentucky
Kentucky Geological Survey
University of Kentucky

Geological Society of Kentucky 1940

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Eastern Section American Association of Petroleum Geologists

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Cover Photo:

Newly filled bourbon barrels waiting to be stacked and aged in the rickhouse at Woodford Reserve Distillery, Versailles, Kentucky.

Photo by Ashley Bandy, hydrogeologist, University of Kentucky.

Contents

Contents (continued)

Lexington-Fayette Urban County Government
OFFICE OF THE MAYOR

Jim Gray
Mayor

Welcome everyone,

Lexington is pleased to host the annual meeting of the Eastern Section of the American Association of Petroleum Geologists, coming up this September.

We hope you have time to enjoy some of the beautiful things the Bluegrass Region has to offer while you are here.

Take time to explore our lively downtown, rich cultural diversity and world class landscape. Try a variety of our wide range of excellent restaurants and unique shopping opportunities, or visit the Bourbon Trail.

Travel a short distance out of the city and feel like you have entered another country with the rolling green of the Bluegrass horse farms. In Lexington, there is truly something for everyone.

We are proud of our city and hope you have the opportunity to return to Lexington, whether for business or pleasure. Again, thank you for visiting this truly special place.

Sincerely,

Jim Gray
Mayor

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HORSE CAPITAL OF THE WORLD

Welcome

The Geological Society of Kentucky, the Kentucky Geological Survey, and the University of Kentucky welcome you to Lexington for the 45th Eastern Section AAPG annual meeting. Since our last meeting in Lexington in 2007, our industry has experienced an unprecedented oil and gas boom, and more recently, a profound drop in commodity prices that has affected many Eastern Section members. These cycles make running a business and planning a technical conference challenging. The organizing committee has worked hard to make this meeting relevant, cost-effective, and a financial success. We appreciate your attendance, whether as a presenter, exhibitor, sponsor, professional, student, or guest.

Our meeting theme, "Basins to Barrels: Kentucky 2016," links Kentucky's two producing basins with the growing interest in Kentucky bourbon. We have planned a number of bourbon-related events, including tastings, a field trip, distillery tour, and a guest program. Along with Eastern Section traditions such as Jammin' Geologists on Sunday evening, we have a unique selection of entertainment choices on Monday evening. Entertainment and dining options in downtown Lexington have increased significantly since 2007, and we hope the meeting will offer something for everyone. Thanks for being here, and we hope you have a great meeting!

2016 Organizing Committee

General Co-Chairs	Dave Harris, Rick Bowersox
Technical Program	John Hickman, Brandon Nuttall, Donnie Lumm
Finance	Patrick Gooding
Registration	Tom Sparks, Liz Adams
Exhibits	Dan Wells, Tommy Cate
Sponsorship	Mike Sanders, Gil Cumbee
Publicity	Liz Adams, Mike Lynch
Web and Social Media	Brandon Nuttall, Liz Adams, Rebecca Wang
Entertainment	Carrie Pulliam, Liz Adams
Workshops	Marty Parris, Charlie Mason
Field Trips	Steve Greb
Judging	Ralph Bandy, Steve Ferris, Patrick Cullen
Audio/Visual	Richard Smath
Final Progam	Meg Smath
Guest Programs	Jeanne Harris
Student Volunteers	Mike McGlue
Meeting Coordinator	Geaunita Caylor

Eastern Section AAPG Officers

Website	www.esaapg.org
President	Craig Eckert, EQT Production
Vice President	John Hickman, Kentucky Geological Survey, University of Kentucky
Treasurer	Andrew Waggener, Triana Energy
Secretary	Patrick Gooding, Kentucky Geological Survey, University of Kentucky

Geological Society of Kentucky Officers

Website	www.uky.edu/otherorgs/gsk
President	Frank Ettensohn, Department of Earth and Environmental Sciences, University of Kentucky
Secretary/Treasurer	Patrick J. Gooding, Kentucky Geological Survey, University of Kentucky
Councilor at Large	Ray Daniel, Kentucky Geological Survey, University of Kentucky
Councilor at Large	Julie Ross, Engineers Consultants Scientists International

Kentucky Geological Survey

Director and State Geologist	Bill Haneberg
Associate Director	Jerry Weisenfluh

General Information

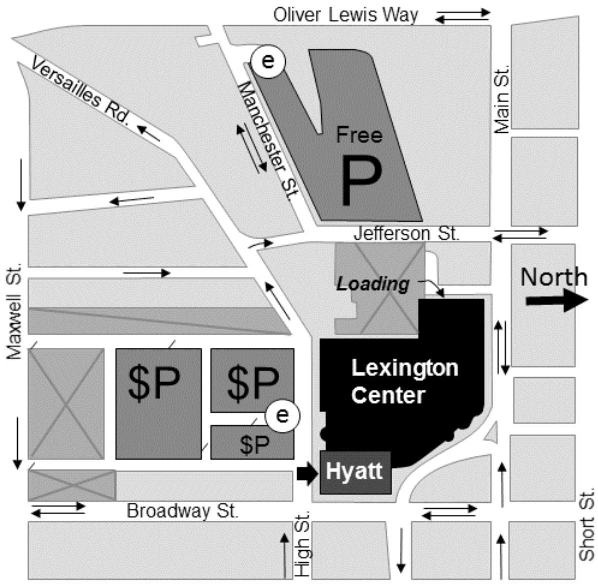
Registration Hours

Lexington Center Heritage Hall

Sunday, September 25	12 noon–8 p.m.
Monday, September 26	7:30 a.m.–5 p.m.
Tuesday, September 27	7:30 a.m.–5 p.m.

Parking

Complimentary self-parking for Hyatt Regency guests is available in the Civic Center lot directly across High Street from the Hyatt. This is a pay lot for those not staying at the Hyatt ($P on map below). Valet parking is also available for $20 overnight or $15 per day. Free parking (but a longer walk) is also available in the large surface lot west of Rupp Arena (Free P on map), accessed from Cox Street off of Manchester Street, below the Jefferson Street overpass. Parking entrances are indicated by "e."



Airport Transportation

The Hyatt Regency Hotel provides a complimentary hotel shuttle to and from Blue Grass Airport. For further information or inquiries, please contact the hotel directly at 859-253-1234.

Maps

Floor plans of the Hyatt Regency and Lexington Center are located on the last page of this program.

Exhibits

We are pleased to have 26 exhibitors at this year's meeting, and would like to thank these companies and agencies for their support. Exhibits are centrally located in Heritage Hall East, adjacent to the technical session rooms. Exhibit hours are as follows:

Sunday, September 25	6–8 p.m.
Monday, September 26	8 a.m.–5 p.m.
Tuesday, September 27	8 a.m.–3 p.m.

Presenters and Judges Room

Oral presenters should drop off a copy of their presentations as soon as possible in the Presenters and Judges Room (Elkhorn A/D) to allow transfer to the correct session and room. DO NOT plan on loading your presentation in the session room prior to your talk. A laptop computer will be available to edit or review slides in Elkhorn A/D.

Judges may volunteer or pick up judging paperwork in the same room, during the following hours:

Sunday, September 25	12 noon–8 p.m.
Monday, September 26	7:30 a.m.–5 p.m.
Tuesday, September 27	7:30 a.m.–3 p.m.

Wireless Internet Access

Free wireless internet access (WiFi) is available throughout the meeting space. You may connect using the following login:

Network: AAPG2016

Password: geologists

Professional Development Hours (PDH) Certificates

The meeting will provide certificates for professional development hours (PDH) credit. The number of hours will depend on the events attended (field trips, workshop, technical sessions). Please see Geaunita Caylor at Registration to obtain your certificate.

Meeting Program and Schedule on Your Phone

The schedule and abstracts for the Eastern Section AAPG meeting are available online at SearchandDiscovery.com and can be accessed using the Search and Discovery application for iOS and Android smart mobile devices. For more on the application, see www.searchanddiscovery.com/app_help.html.

1. Download and install the free application. For QR codes, depending on your scanner app, you might have to tap "Search" or "Go to URL."
2. When installed, tap the in-app "Store" link in the upper left corner of the screen.
3. Scroll down to "Sections and Regions" and tap "Download" for Eastern Section 2016 Lexington.
4. Once downloaded, the schedule and abstracts can be found in "My Library" and don't require WiFi or a data connection to access the information.

At the Google Play Store, play.google.com, search for "aapgmeetings" or scan the QR code.

At the iTunes Store, itunes.apple.com, search for "aapgmeetings" or scan the QR code.

Presenters, Judges, and Session Chairs Breakfast and Information

Hyatt Regency Ballroom 1 (lobby level)

All speakers, poster presenters, judges, and session chairs should attend the complimentary breakfast at 7 a.m. on the morning of their session to receive instructions for session timing, audio-visual equipment, and judging.

Speakers should bring their presentation file to Elkhorn A/D as soon as possible to allow time to organize the presentations for each session.

Poster presenters should attend the breakfast to receive information on poster board assignments and times for judging. Poster presenters should set up their posters between 7:30 and 8 a.m. Posters may be removed after 5 p.m. Poster authors should be present from 9:30–10:30 a.m. and 3–4 p.m.

Judges will receive forms and instructions from Ralph Bandy, Judging Chair. If you are unable to attend this breakfast, please pick up your judging forms in Elkhorn A/D. All forms should be returned to the Presenters and Judges Room as soon as possible after your session.

Business Meetings

AAPG House of Delegates Breakfast

Monday, September 26, 7–8 a.m.
Hyatt Regency Ballroom 3, lobby level (by invitation)
Hosted by Jim McGhay, Chairman, AAPG House of Delegates

Eastern Section AAPG Executive Council Luncheon

Monday, September 26, 12 noon–1:30 p.m.
Hyatt Regency Ballroom 1, lobby level (by invitation)

Eastern Section AAPG Committee on Section Meetings Breakfast

Tuesday, September 27, 7–8 a.m.
Hyatt Regency Ballroom 3 (by invitation)

Special Events

Opening Session

Sunday, September 25, 3–4 p.m.
Heritage Hall Ballroom 2

Our meeting officially begins with the opening session on Sunday afternoon. Please join us for comments and updates from our host organizations, Eastern Section President Craig Eckert, AAPG President Paul Britt, House of Delegates Chair Jim McGhay, and division presidents.

Honors and Awards Ceremony

Sunday, September 25, 4–5 p.m.
Heritage Hall Ballroom 2

A true highlight of the Eastern Section annual meeting is our Honors and Awards presentation. Honors and Awards Committee Chair Joan Crockett and Eastern Section AAPG President Craig Eckert will recognize Eastern Section professional service awardees and scientific presentation winners from last year's meeting in Indianapolis. Professional service awards are:

- John T. Galey Memorial Award
- Honorary Membership
- Distinguished Service Award
- George V. Cohee Public Service Award
- Outstanding Educator Award
- Gordon H. Wood Jr. Memorial Award
- Division of Environmental Geosciences Meritorious Contributions Award
- Presidential Award
- Certificates of Merit

Please join us to congratulate your deserving colleagues.

Icebreaker Reception

Sunday, September 25, 6–8 p.m.
Lexington Center Heritage Hall East

Don't miss the icebreaker reception in the main Exhibit Hall. We will have plenty of food and refreshments, and a bourbon tasting. Music will be provided by a local band, with our own Tommy Cate on harmonica. Take this opportunity to visit with exhibitors, meet old friends, and make new contacts. Included with registration.

Jammin' Geologists

Sunday, September 25, 9–11:30 p.m.
Hyatt Hyttops Room

A tradition at Eastern Section annual meetings, Jammin' Geologists is the premier venue for your musically gifted colleagues to show off their talents. We promise a lively event, with cash bar and snacks provided. All are welcome to participate, so please bring an instrument and join the fun. Or just sit and watch, and sing along. This event has become a highlight of Eastern Section meetings, so don't miss it! For more information, please contact Kevin Strunk, kstrunk@indy.net.

AAPG Young Professionals Happy Hour

Monday, September 26, 5 p.m.
Pies & Pints, 401 West Main Street, across from the Lexington Convention Center

AAPG's young professionals are invited to gather after the last technical session on Monday for happy hour at Pies & Pints, 401 West Main Street, about a block from the convention center. Drinks are on your own, and a full menu is available if you decide to stay for dinner. Contact Merril Stypula, Young Professionals Liason, at yp@esaapg.org, for more details.

Monday Evening Entertainment

We have planned a diverse program of entertainment on Monday evening. Conference attendees can choose one of the following options for their Monday night entertainment. The event of your choice will be included in your conference registration fee. Events are limited to the first 25 to sign up, but please add yourself to the wait list if your preferred event is full. Any event could and may be extended to include more people if there is enough interest!

Alltech Brewery and Distillery Tour
Monday, September 26
6–7 p.m.
Transportation provided from and to the Hyatt

SOLD OUT

Take a guided tour of the Alltech Town Branch Distillery and Kentucky Ale Brewery. The tour will last approximately an hour and comes with four tastings among the various offered beers and spirits. You'll receive a souvenir glass and, if interested, you can get your first stamp in both your Brewgrass Trail and Bourbon Trail passports!

Start time will be 6 p.m., giving you plenty of time for dinner afterward at any of Lexington's many downtown eateries. Transportation will be provided, although it's a quick and lovely five blocks to Alltech if you wish to walk.

Visit www.kentuckyale.com for more information on the Alltech Lexington Brewing and Distilling Company.

Wine + Market Bourbon Cocktail Class
Monday, September 26
6–7 p.m.
Transportation provided from and to the Hyatt

SOLD OUT

Take a one-hour class on crafting bourbon-based cocktails at Wine + Market, just a few short blocks from the convention center. You'll be able to sample bourbons and enjoy some nice palate-cleansing munchies as Seth Brewer, owner and proprietor, teaches about making the perfect bourbon cocktail.

Start time will be 6 p.m., giving you plenty of time for dinner afterward at any of Lexington's many downtown eateries. Transportation will be provided, although it's a quick and lovely three blocks to Wine + Market if you wish to walk.

Visit wineandmarket.com for more information on the Wine + Market café and grocery.

Enoteca Wine Tasting and Tapas
Monday, September 26
6 p.m.
Transportation provided from and to the Hyatt

SOLD OUT

Participate in a one-hour wine tasting just a few short blocks from the convention center. Along with a variety of wines to sample, light tapas will be served to cleanse the palate and enhance the wine. Owner and sommelier Renee Brewer will be your host in her Spanish-inspired wine and tapas bar, Enoteca.

Start time will be 6 p.m., giving you plenty of time for dinner afterward at any of Lexington's many downtown eateries. Transportation will be provided, although it's a quick and lovely three blocks to Enoteca if you wish to walk.

Visit enotecalex.com for more information on the Enoteca Tapas Bar and Restaurant.

A Taste of the Pepper District, After Dinner Beer and Ice Cream
Monday, September 26
8:30 p.m.
Transportation provided from and to the Hyatt

After dinner on your own, you'll be transported to Lexington's Pepper Distillery District, one of the most popular new social areas in the Bluegrass. You'll receive tickets for two 10-ounce beers from Ethereal Brewing and tickets for two ice cream scoops from Crank & Boom Ice Cream. You'll then have time to explore, eat, and drink more on your own time, as transportation will be provided periodically throughout the evening, so you can enjoy all the Pepper District has to offer.

Start time will be 8:30 p.m., giving you plenty of time for dinner beforehand. Transportation will be provided from 8:30 to 11:30 p.m. so you can visit the Pepper District at your leisure.

Visit www.etherealbrew.com for more information on Ethereal Brewing.

Visit www.crankandboom.com for more information on Crank & Boom Ice Cream Lounge.

Visit www.peppercampus.com for more information on the Pepper Distillery Entertainment District.

All-Division Luncheon

Tuesday, September 27
12 noon–1:30 p.m.
Hyatt Regency Regency Ballroom
Ticketed event: $28 ; open to all attendees

An annual favorite! Please join us for lunch on Tuesday, September 27, sponsored by three of AAPG's divisions: Division of Professional Affairs, Energy Minerals Division, and Division of Environmental Geology. Officers from all three divisions will be in attendance, and our speaker will be Paul Britt, AAPG President. A special locally sourced Kentucky menu is planned. Meeting and exhibitor door-prize winners will be announced after lunch.

Guest Activities and Hospitality

Registered guests are encouraged to visit the guest hospitality table outside the exhibit hall during the meeting. This will be a central location for organized or individual activity information, plus you can grab a cup of coffee or a snack, and chat with other guests. Some of the organized activities will also meet here.

There will be a number of opportunities for the guests of attendees to see the Bluegrass. Please note the fees for these events are NOT included in your registration fees. Tickets for the Monday morning horse farm tour need to be purchased prior to the tour as directed below. Seats are limited, so we suggest purchasing tickets at your earliest convenience. For other events, you will purchase tickets at the location. You can pick and choose the organized events you're interested in, and we'll have information available to help you explore Lexington on your own, if you prefer.

Monday, September 26

Morning: Bluegrass Horse Farm Tour

Discover the Best of the Bluegrass on a three-hour horse farm tour. Roll by miles of white fences, through Thoroughbred horse country, as you see spectacular horse barns and also enjoy a behind-the-scenes tour at historic Keeneland Race Course. The fee for this tour is $35 per person. To purchase tickets, visit bluegrasstours.com. Select "Tours"→"Horse Farm Tours in Lexington, KY"→"Reserve Horse Farm Tour," and purchase your ticket for the 9 a.m. tour on Monday, September 26. Make sure you specify the Hyatt as your pick-up location and note the pick-up time.

Lunch: Saul Good

Join the "guest group" for lunch at Saul Good (saulgoodpub.com) in downtown Lexington. This restaurant is a short walk from the Lexington Convention Center. We'll meet at the guest table in the exhibit area at 12:30 p.m. and walk over as a group.

Afternoon: Alltech Distillery Tour

Alltech Lexington Brewing and Distilling Company (www.kentuckyale.com/products) has the unique distinction of being both a brewery and a distillery. The Town Branch Distillery is a member of the Kentucky Bourbon Trail and the brewery is a premier barrel-aging brewery, thanks to its location in the heart of bourbon country. Come and experience a behind-the-scenes look at beer and spirits production and sample beer and bourbon. The cost of the tour is $10. Space is limited, so purchasing tickets ahead is recommended (www.peek.com/purchase/activity/55f9cce222116d2127021f23?action=widget_redirect) for the September 26 tour at 3 p.m. Meet at the guest table in the exhibit area at 2:30 p.m. and we can walk as a group to the distillery. It is a short (approximately five blocks) walk.

Tuesday, September 27

Morning: Mary Todd Lincoln Home Tour

Visit the first site restored to honor a first lady, the Mary Todd Lincoln House (www.mtlhouse.org). This was the Todd family residence where Mary Todd resided from the ages of 13 to 21 and where the Lincolns stayed during visits to Lexington. The cost of the tour is $10 and you will need to pay on site. We will meet at the guest table in the exhibit area at 9:30 a.m. and take a short walk to the Mary Todd Lincoln House.

Lunch: Lexington Diner

Join us for us for lunch at the Lexington Diner (www.lexingtondiner.com), a Lexington favorite. One of the chefs has appeared on Food Network shows including "Cutthroat Kitchen" and "Guy's Grocery Games." We'll meet at the guest table in the exhibit area at 11:30 a.m. and walk to Lexington Diner.

Afternoon: Walking Tour of Downtown Lexington

Downtown Lexington has a fascinating history! Following lunch we'll take a walking tour of Lexington. We'll leave from the Lexington Diner (124 North Upper Street) at approximately 1 p.m. and take a one-hour walking tour (subject to weather). Please wear comfortable walking shoes.

For More Information

For questions about any of the above activities, contact Jeanne_harris@outlook.com. We hope you take the opportunity to enjoy the unique opportunities the Bluegrass has to offer. The Lexington Visitor's Center (www.visitlex.com/about/visitors-center) has lots more information about things to do in Lexington and is conveniently located across the street from the Lexington Convention Center.

Calendar of Events

Saturday, September 24

8 a.m.–5 p.m.	Field Trip 1: Distillery Hydrogeology; departs from Hyatt lobby

Sunday, September 25

8 a.m.–5 p.m.	Field Trip 2: Upper Ordovician Reservoir Analogs in the Lexington Limestone/Point Pleasant Interval; departs from Hyatt lobby
10 a.m.–12 noon	Student Chapter Leadership Summit—Hyatt Regency Ballroom 3
12 noon–8 p.m.	Registration open—Heritage Hall
12 noon–5 p.m.	Exhibitor setup—Heritage Hall East
12 noon–2:30 p.m.	Student Expo—Hyatt Regency Ballroom 3
2–8 p.m.	Presenters and Judges Room open—Elkhorn A/B
3–4 p.m.	Opening session—Heritage Hall Ballroom 2
4–5 p.m.	Honors and Awards Presentation—Heritage Hall Ballroom 2
6–8 p.m.	Exhibit Hall open—Heritage Hall East
6–8 p.m.	Icebreaker Reception—Heritage Hall East
9–11:30 p.m.	Jammin' Geologists—Hyatt Hyttops bar

Monday, September 26

7–8 a.m.	Presenters and Judges Breakfast—Hyatt Regency Ballroom 1
7–8 a.m.	House of Delegates Breakfast—Hyatt Regency Ballroom 3
7:30 a.m.–5 p.m.	Registration open—Heritage Hall
8 a.m.–5 p.m.	Exhibit Hall open—Heritage Hall East
9 a.m.–4 p.m.	Guest Program—various locations
12 noon–1:30 p.m.	Eastern Section Executive Council Luncheon—Hyatt Regency Ballroom 1
8 a.m.–12 noon	Oral Session: Emerging Unconventional Shale Plays—Heritage Ballroom 2
8 a.m.–12 noon	Oral Session: Methods and New Techniques—Heritage Ballroom 3
8 a.m.–12 noon	Oral Session: Structure and Tectonic Effects on Reservoirs—Elkhorn C/D
8 a.m.–5 p.m.	Poster Session—Heritage Hall East
1–2:30 p.m.	Oral Session: Emerging Unconventional Shale Plays 2—Heritage Ballroom 2
1–5 p.m.	Oral Session: Methods and New Techniques 2—Heritage Ballroom 3
1–4:30 p.m.	Oral Session: Groundwater and Environmental Issues—Elkhorn C/D
5–7 p.m.	Young Professionals Happy Hour—Pies & Pints
6–7 p.m.	Offsite Entertainment (limited free tickets)—various locations; depart from Hyatt lobby
8:30–11:30 p.m.	A Taste of the Pepper District (after dinner beer and ice cream); departs Hyatt lobby every 20 minutes

Tuesday, September 27

7–8 a.m.	Presenters and Judges Breakfast—Hyatt Regency Ballroom 1
7–8 a.m.	Eastern Section Committee on Section Meetings Breakfast—Hyatt Regency Ballroom 3
7:30 a.m.–3 p.m.	Registration open—Heritage Hall
8 a.m.–5 p.m.	Exhibit Hall open—Heritage Hall East
9:30 a.m.–2:30 p.m.	Guest Program—various locations
8 a.m.–12 noon	Oral Session: Ordovician Shale Resources—Heritage Ballroom 2
8 a.m.–12 noon	Oral Session: Sedimentology: Source to Sink—Heritage Ballroom 3
8 a.m.–12 noon	Oral Session: CO_2 Use and Storage—Elkhorn C/D
8 a.m.–5 p.m.	Poster Session—Heritage Hall East
12 noon–1:30 p.m.	All-Division Luncheon (ticketed)—Regency Ballroom
1–4:30 p.m.	Oral Session: Marcellus Shale Energy and Environment Laboratory—Heritage Ballroom 2
1–4:30 p.m.	Oral Session: Sedimentology: Source to Sink 2—Heritage Ballroom 3
1–2:30 p.m.	Oral Session: CO_2 Use and Storage 2—Elkhorn C/D

Wednesday, September 28

8 a.m.–5 p.m.	Field Trip 3: Pennsylvanian Sequence Stratigraphy and Coal Geology; departs from Hyatt lobby
9 a.m.–4 p.m.	Workshop: Introductory Geochemistry for Shale-Gas, Condensate-Rich Shales, and Tight Oil Reservoirs—Kentucky Geological Survey, University of Kentucky (transportation provided from Hyatt lobby)

2016 Meeting Sponsors

We sincerely appreciate the strong support we have received from our 2016 meeting sponsors in this difficult business climate. Their sponsorship keeps registration costs down and ensures a financially successful meeting. Please thank these generous companies and individuals during the meeting.

Single Barrel ($2,500–$4,999)

University of Kentucky, Vice President for Research Conference Grant	
2018 Eastern Unconventional Oil and Gas Symposium	
Antero Resources	
Cabot Oil and Gas	*Technical Program Signs*
EQT	*Registration Bags*

Small Batch ($1,000–$2,499)

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Pioneer Natural Resources	
AAPG Division of Professional Affairs	*All-Division Lunch, Workshops*
Raptor Consulting	*Icebreaker Reception*
West Bay Exploration	
Visit LEX	

Straight Bourbon ($250–$999)

Eastern Section AAPG Young Professionals	*YP Travel Grants*
Pittsburgh Association of Petroleum Geologists	
Pittsburgh Geological Society	
RS Energy LLC	
AAPG Energy Minerals Division	*All-Division Lunch*
AAPG Division of Environmental Geosciences	*All-Division Lunch*
Battelle Memorial Institute	
TGS Geophysical	
Cumberland Valley Resources LLC	
Terra Nova Exploration	
Precision Geophysical Inc.	

Mash ($100–$249)

Scout Check Report Inc.

Jura Energy Corporation

Exhibitor List and Contacts

We would like to thank our 2016 exhibitors who helped make this a successful meeting. Please take time to visit their booths during the meeting. An exhibit hall floorplan with booth numbers can be found on the last page of this program..

Booth	Company	Contact	Email	Website
1 & 2	Evans Geophysical	Annette Evans	annette@evansgeo.com	www.evansgeo.com
1 & 2	Precision Geophysical	Steve McCrossin	steve@pgigeo.com	www.precisiongeophysical.com
3	Horizon Well Logging	Ryan Nostrud	ryan.nostrud@hzmud.com	www.hzmud.com
4	LMKR Geographix	Alexxis Holquin	aholquin@lmkr.com	www.lmkr.com
5	Illinois Geological Society	Stephanie Storckman	stephanie@podolskyoil.com	www.ilgeosociety.org
6	AAPG Bookstore	Karin Alyea	kalyea@aapg.org	store.aapg.org
7	AAPG Geocare	Melissa Hughes	melissasuehughes@gmail.com	www.aapg.org/about/aapg/overview/programs#5627705-benefits
8	Indiana Geological Survey	Polly Sturgeon	proot@iu.edu	www.igs.indiana.edu
9	Selman & Associates	Tom Selman	tselman@selmanlog.com	www.selmanlog.com
10	West Virginia Geological & Economic Survey	Jessica Moore	jmoore@geosrv.wvnet.edu	www.wvgs.wvnet.edu
11	ALS Oil & Gas	Misty Parker	misty.parker@alsglobal.com	www.alsglobal.com
12	PTTC	Doug Patchen	doug.patchen@mail.wvu.edu	www.pttc.org/regions/eastern
13	RPSEA	Jack Belcher	jbelcher@hbwresources.com	www.rpsea.org
14	TRICON Geophysics Inc.	Steve Guzowski	steven.guzowski@tricongeophysics.com	www.tricongeophysics.com
15	Emerson Geophysical LLC	Peter Kiewit	Pkiewit@aol.com	www.emersongeophysical.com
16	Nair Innovations Inc.	Akshay Nair	anair@nairinnovations.com	www.nairinnovations.com
17	Neuralog	Bryan Mills	bmills@neuralog.com	www.neuralog.com
18	Diversified Well Logging LLC	Bryan Whitby	bwhitby@dwl-usa.com	www.dwl-usa.net
19	Kentucky Geological Survey	Mike Lynch	mjlync2@uky.edu	www.uky.edu/KGS
20	Geostabilization International	Frank Amend	frank@gsi.us	www.geostabilization.com
21	Raptor Consulting	Robert McCue	robert.mccue@raptorconsult.com	www.raptorconsulting.com
22	Scout FDC	Paul Marino	paul.marino@scoutfdc.com	www.scoutfdc.com
23	Eastern Unconventional Oil & Gas Symposium	Alice Marksberry	alice.marksberry@uky.edu	www.euogs.org
24	ESAAPG 2017 Annual Meeting, Morgantown, W.Va.	Pete Sullivan	psullivan@eca.com	www.euogs.org
25	UK AAPG Student Chapter			
26	Eastern Section AAPG	Joan Crockett	jcrocket@illinois.edu	www.esaapg.org

Student Activities

Two events for geoscience students will be held on Sunday, September 25. Details on these events are listed below. These events are sponsored separately from the annual meeting. Eastern Section would like to thank the following sponsors for supporting this year's student chapter summit and student expo:

Cabot Oil and Gas

Northeast Natural Energy

EQT

Tug Hill Operating

This sponsorship also provides funds for cash prizes for the student expo.

Student Chapter Leadership Summit

Sunday, September 25

Hyatt Regency Ballroom 1

10 a.m.–12 noon

Free, but must preregister with liaison: daniel.chandonais@cabotog.com

The Eastern Section will hold a student chapter leadership summit on Sunday morning, prior to the Student Expo. Representatives from AAPG student chapters or those interested in starting a student chapter are welcome. The leadership summit will include a review of student chapter bylaws and grant/funding resources, and a guest speaker. Our speaker this year will be Bo McCue from Raptor Consulting, who will be discussing well-site geology and geosteering. The summit is meant to give students a chance to get their questions answered, and interact with other student chapter leaders. To sign up or for more information, please contact Dan Chandonais, Student Chapter Liaison: daniel.chandonais@cabotog.com.

Eastern Section Student Expo

Sunday, September 25

Hyatt Regency Ballroom 1

12 noon–3 p.m. (lunch provided)

Free, but must preregister with Student Expo Chair: student-jobs@esaapg.org

Due to the very tight job market, the annual Student Expo will be condensed this year, but will still be a great way to meet energy industry representatives. The expo will consist of lunch and student poster displays. There will be cash awards for best posters (as determined by industry judges), and students will have an opportunity to speak and interact with industry representatives. Although there will not be formal interview times, industry representatives can arrange interviews on Sunday or at other times throughout the meeting. Preregistration with Student Expo Chair Dr. Tim Carr is required. To register or for more information, please contact Dr. Carr at student-jobs@esaapg.org.

Companies that want to sponsor and be part of the expo should also contact Dr. Carr at the address above.

Opening Session Agenda

Sunday, September 25

3 p.m., Heritage Hall Ballroom 2

Welcoming Remarks

3 p.m.	Dave Harris/Rick Bowersox, General Chairs
3:05 p.m.	Frank Ettensohn, President, Geological Society of Kentucky
3:10 p.m.	Bill Haneberg, Director and State Geologist, Kentucky Geological Survey
3:20 p.m.	Craig Eckert, President, Eastern Section, AAPG

Introduction of National AAPG Officers

3:40 p.m.	Paul Britt, President, AAPG
	Charles Sternbach, President-Elect, AAPG
	Dan Schwartz, Vice President, Sections
	Jim McGhay, Chair, AAPG House of Delegates
	Chandler Wilhelm, President, AAPG Division of Professional Affairs
	Tim Murin, President, AAPG Division of Environmental Geology
	Bob Trevail, Past-President, AAPG Energy Minerals Division

Honors and Awards Ceremony

Sunday, September 25

4 p.m., Heritage Hall Ballroom 2
Joan Crockett, Chair, Honors and Awards Committee, presiding
Ed Rothman and Murray Matson, committee members

Eastern Section AAPG 2016 Presentation Awards from 2015 Annual Meeting

Pittsburgh Geological Society Award for Best Presentation on Appalachian Geology: Christopher Laughrey and Thomas Darrah

Best Student Poster Award: Qian Zhang

Division of Environmental Sciences Best Poster Award (Eastern Section): Autumn Haagsma, Srikanta Mishra and Ola Babarinde

Division of Environmental Geosciences Best Paper Award (Eastern Section): Erica Howat, Amber Conner, Srikanta Mishra

Energy Minerals Division Best Poster Award (Eastern Section): William A. Rouse

Ralph L. Miller Memorial Best Energy Minerals Division Paper Award (Eastern Section): Christopher Laughrey and Thomas Darrah

Vincent E. Nelson Memorial Best Poster Award: Diar Ibrahim, Michael C. Pope, Brent V. Miller, Brian J. Witzke, and William C. McClelland

Margaret Hawn Mirabile Memorial Best Student Paper Award: Matthew Rine

A.I. Levorsen Memorial Award Best Paper Award: Thomas M. Parris, Jared Grider, Ethan Davis

2016 Eastern Section AAPG Service Awards

Certificates of Merit (2016 Annual Meeting Committee): David C. Harris, J. Richard Bowersox, Geaunita Caylor, Brandon C. Nuttall, John B. Hickman, Donald K. Lumm, Patrick J. Gooding, Dan Wells, Thomas W. Cate, Michael P. Sanders, Gil Cumbee, Stephen F. Greb, Thomas M Parris, Elizabeth L. Adams, Michael J. Lynch, Carrie Pulliam, Thomas N. Sparks, Rebecca Wang, Steven M. Ferris, Ralph Bandy, Patrick Cullen, Richard A. Smath, Meg Smath, Jeanne H. Harris, Michael M. McGlue

Presidential Award: Cabot Oil and Gas, Albert “Buddy” Wylie

Division of Environmental Geology Meritorious Contributions Award: Dr. Donald I. Siegel

Gordon H. Wood Jr. Memorial Award: Robert A. Trevail

Outstanding Educator Award: Dr. Elizabeth Gierlowski-Kordesch, Dr. Donald Neal

George V. Cohee Public Service Award: Edith C. Allison

Distinguished Service Award: Craig A. Eckert

Honorary Membership: Thomas H. Partin, Robert D. Jacobi

John T. Galey Memorial Award: Michael R. Canich

John T. Galey Memorial Address: Michael R. Canich

Technical Program Schedule

Speaker is first author unless designated by an asterisk (*)

Monday Morning, September 26

Emerging Unconventional Shale Plays
Sponsored by Eastern Unconventional Oil and Gas Symposium 2018
Heritage Ballroom 2
Session Co-chairs: Brandon Nuttall and Donna Caraway Willette

8 a.m.	Gas Shales: A Largely North American Phenomenon?—Frank R. Ettensohn
8:30 a.m.	Geochemical Characterization of Lower Wolfcamp Unconventional Reservoirs, Midland Basin (Texas)—Michael McGlue, Patrick Ryan, Patrick Baldwin, Zac Perlman, Joseph Lucas, Lowell Waite, and Olivia Woodruff
9 a.m.	Gas Generation from Natural Oils—The Details Matter in Resource Assessment—Donna Caraway Willette
9:30 a.m.	(Cancelled)
10 a.m.	Break
10:30 a.m.	Petroleum Geochemistry of Devonian Rocks and Produced Oil and Natural Gas in the Caseman–Gross Unit #1 Well, Bradford County, Pennsylvania—Christopher D. Laughrey and Fred J. Baldassare
11 a.m.	Unconventional Resource Potential of the Sunbury Shale, Berea Sandstone, and Antrim Shale in Central Michigan—Richard D. Fritz
11:30 a.m.	Summary of Publicly Available Production Data for the Devonian Berea Sandstone Play, Eastern Kentucky—Brandon C. Nuttall

Methods and New Techniques
Heritage Ballroom 3
Session Co-chairs: Merril Stypula and Seth Carpenter

8 a.m.	Cyclic Pressure Pulsing: A Promising Method to Improve Recovery from Hydraulically Fractured Stripper Wells of Appalachian Basin—Emre Artun, Ozgur Irgav, and Nurum Khairzhanov
8:30 a.m.	Improving Unconventional Hydrocarbon Recovery by Reducing Formation Damage—David P. Cercone, Andrew M. Kiss, Yijin Liu, Anna L. Harrison, Adam D. Jew, Megan K. Dustin, Gordon E. Brown Jr., and John R. Bargar
9 a.m.	Optimizing Lateral Placement and Production While Minimizing Completion Costs Using Downhole Geochemical Logging—Rick Schrynemeeckers
9:30 a.m.	(Cancelled)
10 a.m.	Break
10:30 a.m.	Elemental Data Collected in the Berea Sandstone of Eastern Kentucky: Applications to Wellbore Placement, Horizontal "Chemosteering" and Completion Strategy—Merril J. Stypula, David R. Blood, and Ashley S.B. Douds
11 a.m.	Monitoring Induced Microseismicity in the Rome Trough, Eastern Kentucky U.S.A.—Andrew S. Holcomb, N. Seth Carpenter, Edward W. Woolery, and Zhenming Wang
11:30 a.m.	Assessing Potential Seismic Hazards from Induced Earthquakes in the Central and Eastern United States—Zhenming Wang, N. Seth Carpenter, and Lifang Zhang

Structure and Tectonic Effects on Reservoirs
Elkhorn C/D
Session Co-chairs: John Hickman and John Rupp

8 a.m.	Structural Origin of Henderson Dome: Stratigraphic and Geophysical Study of an Upper Ordovician Impact Crater—Travis Duran and Andrew Smith
8:30 a.m.	Favorable Areas to Focus Future Trenton Exploration in Indiana—Alan W. Hinks
9 a.m.	New Insights and Perspectives on the Effects of Structural Reactivation on the Upper Devonian Antrim Shale, Michigan Basin—Cameron J. Manche, Kyle J. Patterson, and William B. Harrison III
9:30 a.m.	(Cancelled)
10 a.m.	Break
10:30 a.m.	Sinistral Transpression Along Previously Existing Faults, Appalachian Basin, Ohio—Michael P. Solis

11 a.m. State of Stress in the Illinois Basin and Constraints on Inducing Failure—John A. Rupp, Richard W. Lahann, and Cristian R. Medina

11:30 a.m. Kinematics of Past Tectonic Forces Inferred from Differential Sedimentation—John B. Hickman

Monday Afternoon, September 26

Emerging Unconventional Shale Plays 2
Sponsored by Eastern Unconventional Oil and Gas Symposium, 2018
Heritage Ballroom 2
Session Co-chairs: Mark Baranoski and Bill Harrison

1 p.m. Redefined Sauk Sequence Rocks in the Ohio Region Suggest Emerging Plays on the Ohio Platform and Adjacent Rome Trough—Mark T. Baranoski

1:30 p.m. Assessing Thermal Maturity in Cambrian Source Rocks, Rome Trough, Appalachian Basin: Organic Petrology Complexities—Tim E. Ruble, Wayne R. Knowles, Samuel D. Ely, and Albert S. Wylie Jr.

2 p.m. Maturation Patterns of the Cambrian Rogersville Shale in the Rome Trough of Eastern Kentucky and West Virginia—Christopher G. Willan, Craig A. Eckert, and Alex P. O’Hara

2:30 p.m. End session

Methods and New Techniques 2
Heritage Ballroom 3
Session Co-chairs: Pete MacKenzie and Donald Lumm

1 p.m. Long Period, Long Duration (LPLD) Seismic Events Observed During Monitoring of Hydraulic Fracturing in Pennsylvania and West Virginia—Abhash Kumar, Erich Zorn, Richard Hammack, and William Harbert

1:30 p.m. Geomechanical Lithology-Based Analysis of Microseismicity in Organic Shale Sequences: A Comparison from Multiple Hydraulic Fracturing Field Sites—Erich Zorn, Richard Hammack, William Harbert, and Abhash Kumar

2 p.m. Utilization of Factor of Safety in Geotechnical Solutions—Peter MacKenzie, Stephen Harrison, and Corey Mislinski

2:30 p.m. Break

3 p.m. Estimation of Saturation-Dependent Relative Permeability in Shales Based on Adsorption-Desorption Isotherm—Shiv P. Ojha, Siddharth Misra*, Ali O. Tinni, Carl H. Sondergeld, and Chandra S. Rai

3:30 p.m. Improved Oil-in-Place Estimates in Clay- and Pyrite-Bearing Shales Based on Inversion of Multi-frequency Electromagnetic Measurements—Siddharth Misra and Yifu Han

4 p.m. EIA Expanded Geographic Coverage of Oil and Natural Gas Production, with New Data for 10 States—Garry Long, Jeffrey Little, Barbara Mariner-Volpe, Elizabeth Panarelli, Neal Davis, Emily Geary, and Olga Popova*

4:30 p.m. Preventative Maintenance for Paraffin Management in Production Tubing Using Non-invasive Ultrasonic Technology—Kayte M. Denslow

Groundwater and Environmental Issues
Elkhorn C/D
Session Co-chairs: Amy Townsend-Small and Charles Taylor

1 p.m. NORM and TENORM—Are We Heading for a New Legal Normal?—Karen J. Greenwell

1:30 p.m. Evolving EPA Subpart W Greenhouse Gas Reporting Rules Challenge Oil and Gas Operators—Thomas S. Seguljic and John P. Martin

2 p.m. Class II Injection Wells in Kentucky—An Update of the Map Service of Wastewater, Brine-Disposal, and Enhanced-Recovery Wells in Kentucky—Thomas N. Sparks

2:30 p.m. Break

3 p.m. Assessing Methane in Shallow Groundwater for the Berea Sandstone and Rogersville Shale Play Area, Eastern Kentucky—Junfeng Zhu, Steven E. Webb, Bart Davidson, Richard Smath, Charles J. Taylor, Thomas M. Parris, Ann P. Smith, Stephen D. Richardson, and Jenna S. Kromann

3:30 p.m. A Protocol for Baseline Sampling of Water Sources in Areas of Shale Oil and Gas Development—Stephen D. Richardson, Jenna S. Kromann, Lisa J. Molofsky, Ann P. Smith, John Connor, and David P. Cercone

4 p.m. Stable Isotopic Constraints on Methane Migration into Groundwater and Emissions to the Atmosphere from Unconventional Natural Gas Extraction: Examples from OH, CO, TX—Amy Townsend-Small

Monday Posters, September 26

Heritage Hall East

8 a.m.–5 p.m.

New Insights into Precambrian Seismic Stratigraphy, South-Central Indiana—Andrew M. Parent, Ernest C. Hauser, and Doyle R. Watts

Analysis on Distribution and Controlling Factors of Paleogene Reservoir, Beibuwan Basin—Xiaoqiang Yuan and Guangqing Yao

Revising the Fresh-Saline Water Interface in Eastern Kentucky—Ethan S. Davis and Thomas M. Parris

A Devonian *Callixylon* Log of the *Archaeopteris* Tree Found in Marion County, Kentucky—Patrick Gooding, Richard Smath, Cortland F. Eble, and Frank R. Ettensohn

An Analysis of a Near-Surface Big Clifty (Jackson) Sandstone Reservoir in Logan County, Kentucky—Tyler S. Bodine and Michael T. May*

Depositional and Sequence Stratigraphic Framework of the Middle Pennsylvanian Allegheny Formation, South-Central West Virginia: Analyzing Autogenic and Allogenic Influence on Depositional Elements—Oluwasegun Abatan and Amy Weislogel

The Formation of Diagenetic Trap in the Squirrel Sandstone—Landis Bates, Ian McGougan, Jeremy Gerdau, and Eric Law

Thinning Marine Zones of the Breathitt Group Along Kentucky Highway 15, Breathitt County, Kentucky—Stephen F. Greb, Rhodri M. Jerrett, and Cortland F. Eble

Stratigraphy and Reservoir Characterization of the Grundy Formation (Pennsylvanian, Eastern Kentucky) in Relation with the Overlying Pikeville and Hyden Formations—A. Le Cotonnec, R. Lathion, D. Ventra, and A. Moscariello

Late Silurian–Early Devonian Paleogeography Part 4—Explaining Devonian Brachiopod Provinciality and Distributions—Bill Pfalzer

Most Effective Methods in Identifying, Etching, and Dissolving Limestones—Patrick Gooding and Malcom X. Gooding

Improving the Estimations of Shale Permeability with Process-Based Pore Network Modeling Approach—Shanshan Yao, Xiangzeng Wang, Ning Ju, and Fanhua Zeng

***Methanohalophilus* Is the Dominant Source of Biogenic Methane in Hydraulically Fractured Shales—**Mikayla A. Borton, Rebecca A. Daly, David M. Morgan, Anne E. Booker, David W. Hoyt, Paula J. Mouser, Shikha Sharma, Michael J. Wilkins, and Kelly C. Wrighton

Applications of Scientific Core Drilling in North Carolina: Cumberland-Marlboro Basin, and the Triassic Rift/Lacustrine Dan River Basin—Jeffrey C. Reid, Kenneth B. Taylor, Katherine J. Marciniak, Walter T. Haven, Ryan A. Channell, Ann T. Shields, and Chandler I. Warner

Thermal Maturity Assessment in the Lower Huron Using Raman Micro-spectroscopy—Travis B. Warner and Katie Heckman

Tuesday Morning, September 27

Ordovician Shale Resources
Heritage Ballroom 2
Session Co-chairs: Larry Wickstrom and Martin Schumway

8 a.m.	An Overview of Development of the Utica–Point Pleasant Play—Larry Wickstrom and Martin Shumway
8:30 a.m.	Analysis and Characterization of Utica–Point Pleasant Production—Timothy Knobloch and Martin Shumway*
9 a.m.	Late Ordovician (Katian) Upper Lexington-Kope Equivalents in the Point Pleasant Basin of Eastern Ohio: Correlation and Paleoenvironments of the Utica Point Pleasant System—Allison L. Young, Carlton E. Brett, Peter Holterhoff, Thomas Algeo, and Patrick I. McLaughlin
9:30 a.m.	Clay Mineralogy, Provenance, and Sequence Stratigraphy of Upper Ordovician Shales in Eastern Ohio—Devin R. Fitzgerald and Greg C. Nadon
10 a.m.	Break
10:30 a.m.	Redox Conditions During Deposition and Early Diagenesis of the U. Ord. Point Pleasant Ls of Southwestern PA and Northern WV: Insights from Pyrite Framboids and Trace Elements—David R. Blood
11 a.m.	Organic Matter Maturation Trends and Source Rock Quality in the Utica Shale, East-Central Ohio—Cortland F. Eble and John B. Hickman

11:30 a.m. Creating a 3D Hydrocarbon Profile to Increase Production and Reduce Poor Economic Wells: A Utica Case Study—Rick Schrynemeeckers

Sedimentology: Source to Sink
Heritage Ballroom 3
Session Co-chairs: J. Richard Bowersox and Stephen Greb

8:30 a.m. Reevaluation of the Heavy Oil and Bitumen Resources of the Western Kentucky Tar Sands: What Did We Learn About the Tar Sands that Is New?—J. Richard Bowersox

9 a.m. Changing Duration of Carboniferous Cyclothems; Implications for Coal and Lithofacies Distribution—Stephen F. Greb and Cortland F. Eble

9:30 a.m. Deep Cores Through the Pennsylvanian Section of Western Kentucky, Illinois Basin—Gerald A. Weisenfluh, Stephen F. Greb, Caleb Essex, J.P. Sparr, and David A. Williams

10 a.m. Break

10:30 a.m. Subsurface Analyses of the Bedford-Berea Petroleum System in Eastern Kentucky—Julie Floyd and Stephen F. Greb

11 a.m. Quantifying Microporosity in Clay Minerals of the Cypress Sandstone: Implications for Petrophysical Analysis and Diagenesis—Leo G. Giannetta, Shane K. Butler, and Nathan D. Webb

11:30 a.m. Cypress Sandstone Reservoir Characterization Across the Clay City Anticline, Richland and Clay Counties, Illinois—Zohreh Askari, Yaghoob Lasemi, and Nathan D. Webb

CO_2 Use and Storage
Elkhorn C/D
Session Co-chairs: Cristian Medina and Erica Howat

8 a.m. Petrophysical Characterization of the Kerbel Sandstone in Central Ohio for CO_2 Storage Potential—Autumn Haagsma, Erica Howat, and Neeraj Gupta

8:30 a.m. CO_2 Storage Resource Estimates for Cambrian-Ordovician Formations in Eastern Ohio—Isis Fukai, Autumn Haagsma, Mackenzie Scharenberg, Priya Ravi Ganesh, and Neeraj Gupta

9 a.m. Analysis and Integration of Advanced Logs and Core Data: Characterization of the Copper Ridge Dolomite in Morrow County, Ohio—Amber Conner, Erica Howat, Isis Fukai, and Srikanta Mishra

9:30 a.m. An Integrated Approach to Identifying Residual Oil Zones in the Cypress Sandstone in the Illinois Basin for Nonconventional CO_2-EOR and Storage—Nathan D. Webb, Nathan P. Grigsby, Joshua J. Arneson, Leo G. Giannetta, and Scott M. Frailey

10 a.m. Break

10:30 a.m. Progress Towards Safe and Effective Geologic Storage of Carbon Dioxide in Midwest and Mid-Atlantic States—Lydia Cumming, Neeraj Gupta, and Joel Sminchak

11 a.m. Integrated Sub-basin Scale Exploration for Carbon Storage Targets: Advanced Characterization of Geologic Reservoirs and Caprocks in the Upper Ohio River Valley—Erica Howat, Neeraj Gupta, Mark Kelley, Jared Hawkins, Autumn Haagsma, Isis Fukai, Amber Conner, Oladipupo Babarinde, Glenn E. Larsen, Joel Main, Caitlin McNeil, Jacqueline Gerst, and E. Charlotte Sullivan

11:30 a.m. Hierarchical Evaluation of Geologic Carbon Storage Resource Estimates: Cambrian-Ordovician Units Within the MRCSP Region—Cristian R. Medina, John A. Rupp, Kevin Ellett, David A. Barnes, Matthew J. Rine, Matthew S. Erenpreiss, and Stephen F. Greb

Tuesday Afternoon, September 27

Marcellus Shale Energy and Environment Laboratory
Heritage Ballroom 2
Session Co-chairs: Tim Carr and Paula Mouser

1 p.m. The Marcellus Shale Energy and Environment Laboratory (MSEEL)—Timothy R. Carr, Shikha Sharma, Thomas Wilson, Paul Ziemkiewicz, B.J. Carney, Jay Hewitt, Ian Costello, Emily Jordon, Zachary Arnold, Ryan Warner, Andy Travis, David R. Cole, Jeffery Daniels, Paula J. Mouser, Kelly C. Wrighton, Ray Boswell, Dustin Crandall, and Robert Vagnetti

1:30 p.m. Preliminary Analyses of Core from the Marcellus Shale Energy and Environment Laboratory—Dustin Crandall, Johnathan Moore, Thomas Paronish, Alexandra Hakala, Shikha Sharma, Christina Lopano, Thai Phan, and Mengling Stuckman

2 p.m. Marcellus Shale Energy and Environment Laboratory Approach to Water and Waste Studies—Paul Ziemkiewicz

2:30 p.m. Break

3 p.m. Understanding Biogeochemical Controls on Spatiotemporal Variations in Total Organic Carbon in Cores from Marcellus Shale Energy and Environment Laboratory—Shikha Sharma, V. Agrawal, Rawlings Akondi, and A. Warrier

3:30 p.m. Phospholipid Fatty Acid Evidence of Recent Microbial Life in Pristine Marcellus Shale Cores—Ryan V. Trexler, Rawlings Akondi, Susan M. Pfiffner, Rebecca A. Daly, Michael J. Wilkins, Shikha Sharma, Kelly C. Wrighton, and Paula J. Mouser

4 p.m. Mineral/Organic Matter Associations and Pore Microtextures in the Marcellus Formation, West Virginia—Julie Sheets, Alexander Swift, Tim Kneafsey, Susan A. Welch, and David R. Cole

Sedimentology: Source to Sink 2
Heritage Ballroom 3
Session Co-chairs: Julie Floyd and David Williams

1 p.m. Unification of Compositional Data and High-Resolution Facies Analysis in the Union Springs Formation of New York—John Mason, Michael McGlue, Teresa Jordan

1:30 p.m. A Sequence Stratigraphic Model for the Silurian A-1 Carbonate of the Michigan Basin—Matthew J. Rine, Jonathan D. Garrett, Stephen E. Kaczmarek, and William B. Harrison III

2 p.m. Late Silurian–Early Devonian Paleogeography Part 1—Basal Sands of the Sealevel Lowstand—Bill Pfalzer

2:30 p.m. Break

3 p.m. Silurian Reef Systems in the Illinois and Michigan Basins—What Can Be Learned from Modern Quarrying Operations in North-Central Indiana—Dennis R. Prezbindowski, Benjamin Dattilo, Jon Havens, and Rick Lucas

3:30 p.m. Manistique Group Reservoirs in the Michigan Basin: An Overlooked Resource—Peter J. Voice, Matthew J. Rine, Andrew Caruthers, Jeffrey Kuglitsch, and William B. Harrison III

4 p.m. Lithofacies and Sequence Framework of the Upper Cambrian Galesville and Ironton Sandstones in Illinois—Yaghoob Lasemi and Zohreh Askari

CO_2 Use and Storage, 2
Elkhorn C/D
Session Co-chairs: Kris Carter and Nathan Webb

1 p.m. Thermodynamically Driven Fluid Mixing Across Phases Induced by Viscous Flow Instabilities in Porous Media—Mohammad Amin Amooie, Joachim Moortgat, and Mohamad Reza Soltanian

1:30 p.m. Using Ultrasensitive Surface Detection to Evaluate Potential and Actual CO_2 Sequestration Sites—Alan Silliman and Rick Schrynemeeckers

2 p.m. Reservoir Simulation of Tracer Transport in Multicomponent Multiphase Compositional Flow with Applications to the Cranfield CO_2 Sequestration Site—Mohamad Reza Soltanian, Joachim Moortgat, David R. Cole, David Graham, Susan M. Pfiffner, Tommy Phelps, Seyyed Abolfazl Hosseini, and Susan Hovorka

Tuesday Posters, September 27

Heritage Hall East

8 a.m.–5 p.m. **Understanding Kerogen Composition and Structure in Pristine Shale Cores Collected from Marcellus Shale Energy and Environment Laboratory—**V. Agrawal, Shikha Sharma, and A. Warrier

Comparing Different Extraction Methods for Analyses of Ester-Linked Diglyceride Fatty Acids in Marcellus Shale—Rawlings Akondi, Ryan V. Trexler, Susan M. Pfiffner, Paula J. Mouser, and Shikha Sharma

Sulfide Generation by Dominant Colonizing *Halanaerobium* Microorganisms in Hydraulically Fractured Shales—Anne E. Booker, Mikayla A. Borton, Rebecca A. Daly, Susan A. Welch, Carrie D. Nicora, Shikha Sharma, Paula J. Mouser, David R. Cole, Mary S. Lipton, Kelly C. Wrighton, and Michael J. Wilkins

Microbes in the Marcellus Shale: Distinguishing Between Injected and Indigenous Microorganisms—Rebecca A. Daly, Mikayla A. Borton, Travis A. Wilson, Susan A. Welch, David R. Cole, Shikha Sharma, Michael J. Wilkins, Paula J. Mouser, and Kelly C. Wrighton

Temporal Changes in Fluid Biogeochemistry and Microbial Cell Abundance After Hydraulic Fracturing in Marcellus Shale—Mary Evert, Jenny Panescu, Rebecca A. Daly, Susan A. Welch, Jessica Hespen, Shikha

Sharma, David R. Cole, Thomas H. Darrah, Michael J. Wilkins, Kelly C. Wrighton, Morgan Volker*, and Paula J. Mouser

Analysis of Microbial Lipid Biomarkers as Evidence of Deep Shale Microbial Life—Andrea J. Hanson, Ryan V. Trexler, and Paula J. Mouser

Addressing Health Issues Associated with Air Emissions Around UNGD Sites—Michael McCawley, Travis Knuckles, Maya Nye, and Alexandria Dzomba

***Arcobacter* Isolated from the Produced Fluids of a Marcellus Shale Well May Play a Currently Unappreciated Role in Sulfur Cycling—**Jenny Panescu, Mary Evert, Jessica Hespen, Rebecca A. Daly, Kelly C. Wrighton, and Paula J. Mouser

Indigenous Life in Extreme Environments: Characterizing Pristine Shale Rock Hosted Biomass—Casey Saup, Rebecca A. Daly, Danielle Goudeau, Rex Malmstrom, Paula J. Mouser, Kelly C. Wrighton, and Michael J. Wilkins

Core Reflectance Spectroscopy and Well Logging of the Point Pleasant/Utica Sub-basin, Ohio—Julie M. Bloxson and Beverly Z. Saylor

Phosphate Minerals in Utica Shale: A Possible Source of Trace Metals in Flowback Water—Susan A. Welch, Julia M. Sheets, John Olesik, Anthony Lutton, Alexander Swift, Matt Edgin, Steve Chipera, and David R. Cole

Development of Quick-Look Maps for CO_2-EOR Opportunities in the Appalachian and Michigan Basins—Eric Lewis, Jessica P. Moore, Philip Dinterman, Michael E. Hohn, Ronald McDowell, and Susan Pool

Insights on Porosity and Pore Size Distribution Using Multiple Analytical Tools: Implications for Reservoir Characterization in Geologic Storage of CO_2—Cristian R. Medina, Maria Mastalerz, and John A. Rupp

Subsurface Geomechanics, Fracture Breakdown Pressures, and "Fracture-Tunnels" in the Midwest U.S.—Joel R. Sminchak, James E. Hicks, and Glenn E. Larsen

CO_2 Storage Capacity Estimation and CO_2-EOR Evaluation for Jacksonburg-Stringtown Oil Field, West Virginia, USA—Zhi Zhong and Timothy R. Carr

In Situ Stress Characterization of Appalachian Basin Cambrian-Ordovician Caprock and Reservoirs via Detailed Image Log Analysis—Zachary Cotter, Samin Raziperchikolaee, and Mark Kelley

Field Trips

Distillery Hydrogeology

Leaders: Ashley Bandy, a University of Kentucky Ph.D. candidate, and Charles Taylor, Kentucky Geological Survey Water Resources Section Head

Saturday, September 24

Cost: $80

Description: Kentucky is famous for its karst and bourbon whiskey, and this trip will offer both! Participants will explore the role of geology in the history of bourbon whiskey, which originated in the late 1700s in the Bluegrass Region of north-central Kentucky. Bourbon must be distilled from a grain mix of at least 51 percent corn, and aged for at least two years in new, charred, white oak barrels, all available in central Kentucky. Karst spring water was also historically favored for bourbon distillation because it filters out minerals that influence the taste of bourbon, and its pH promotes fermentation. This field trip will visit several springs that were sites of historic whiskey production, as well as tour two operating distilleries. Participants will learn about the distillation process, and bourbon tasting will be available after the tours. Up to five students may register at $50 per person.

Upper Ordovician Reservoir Analogs in the Lexington Limestone/Point Pleasant Interval

Leaders: Ben Dattilo, Associate Professor of Geology, Department of Geosciences, Indiana/Purdue University–Fort Wayne, and Kevin Strunk, Wabash Resources & Consulting

Sunday, September 25

Cost: $80

Description: The organic-rich Point Pleasant Formation in the Appalachian Basin has been an exploration target in Pennsylvania and eastern Ohio. Recent work has resulted in precise correlations from the Point Pleasant in the Appalachian Basin to remarkably similar facies in the lower part of the Lexington Limestone outcrop in north-central Kentucky, and to the subsurface southern flank of the Seebree Trough in southwestern Ohio. On this trip in the Lexington Dome area and near the ESAAPG convention location, we will look at the full thickness of the Trenton-equivalent Lexington Limestone and the lowest part of the overlying Kope Formation in central Kentucky, with discussions focusing on the correlation, genesis, and significance of the organic shale facies. Several large roadcut stops are planned along U.S. 127, with a return to the convention hotel in advance of the icebreaker.

Pennsylvanian Sequence Stratigraphy and Coal Geology

Leaders: Steve Greb and Cortland Eble, Kentucky Geological Survey Energy and Minerals Section

Wednesday, September 28

Cost: $80

Description: The Pennsylvanian coal fields of the Midcontinent and Appalachian Basin have been the birthplace and testing ground for many concepts related to the vertical and lateral arrangements of clastic rocks. The Eastern Kentucky Coal Field has offered scientists unlimited data and resources for understanding coal-bearing rocks. Modern concepts of sequence stratigraphy have also been applied to the strata in the coal field and are vividly illustrated in the roadcuts of eastern Kentucky. Data from coal exposures and mines have brought a wide array of results, often of significant import to understanding the depositional and burial history of the surrounding strata. This field trip will take advantage of relatively new roadcuts near Jackson, on the western edge of the Eastern Kentucky Coal Field, a little more than an hour east of the conference location in Lexington. They provide good examples of typical coastal-deltaic facies including coal-peat; underclay-paleosols; tidal-estuarine channels, fluvial channels, and paleoslumps. We will look at a variety of these facies, the vertical stacking of facies, and at important sequence boundaries on the basin margin, where sequences are thinner than toward the basin axis to the east. Up to five students may register at $50 per person.

Workshops

Dolomite and Dolomitization: Current Knowledge and Its Applications

Saturday, September 24, 8:30 a.m.–4:30 p.m.

Kentucky Geological Survey Well Sample and Core Library

Instructor: Dennis Prezbindowski, Ph.D., Petroleum Consulting Inc., 16 EMS D13 Lane, Syracuse, IN 46567; with assistance from Jay Gregg, Ph.D., Professor, V. Brown Monnett Chair of Petroleum Geology, Boone Pickens School of Geology, 105 Noble Research Center, Oklahoma State University, Stillwater, OK 74078-3031; Michael Grammer, Ph.D., Professor, Chesapeake Energy Chair of Petroleum Geology, Boone Pickens School of Geology, 105 Noble Research Center, Oklahoma State University, Stillwater, OK 74078-3031; Dave Harris, Core Workshop Coordinator, Kentucky Geological Survey, University of Kentucky, Lexington, KY 40506, dcharris@uky.edu 859-323-0[illegible]45

CANCELLED

Description: Dolomite makes up a significant percentage of the sedimentary rock record. It is an important petroleum reservoir type and repository for industrial wastes, including being a target for CO_2 sequestration. Moreover, dolomite is an excellent source for construction aggregate and mineral supplements. Despite this, a complete understanding of the origin of dolomite is elusive. This short course is designed to provide geologists with an overview of what we know about dolomite and its formation, and how to apply this knowledge to projects involving dolomite reservoirs. The short course will be divided into two sessions, with the morning session covering the following example topics in a lecture and discussion format:

- History of dolomite and dolomitization
- Development and discussion of dolomitization models
- Case studies of dolomite systems
- An open discussion of how to use this information to better characterize the dolomite systems and reservoirs

The afternoon session will be a core workshop focused on dolomite cores from various locations in the Eastern Section. Specific cores are still being selected, but will include the Cambrian-Ordovician Knox Group, Ordovician Trenton–Black River, and Silurian Lockport Dolomite. The Knox cores will be from several deep CO_2 storage test wells recently drilled in Kentucky and possibly West Virginia. If you know of an interesting dolomite core that could be used, please let us know.

Dennis is a carbonate geologist, stratigrapher, sedimentologist, and petrologist, with more than 33 years of professional experience. He is a certified professional geologist and certified petroleum geologist who has consulted for many energy companies on various geologic aspects of exploration and development of carbonate oil and gas reservoirs around the world. He also teaches a week-long professional seminar, "Integrated Carbonate Reservoir Characterization," for PetroSkills Inc.

Congress Needs You: Communicating with Your Washington Legislators

Sunday, September 25, 9 a.m.–12:30 p.m.

Hyatt Regency Hotel

Instructor: Edith Allison, Director, AAPG Geoscience and Energy Policy Office, Washington, D.C., 4220 King St., Alexandria, VA 22302; Ms. Allison directs AAPG's Washington office, assisting policymakers with science information and helping AAPG members communicate with policy leaders.

Cost: $50 (professional) and $25 (students, limit five); includes handout and break

CANCELLED

Description: Energy and science concepts and data are important to current and ongoing legislative and regulatory issues (for example, whether and how Congress should act against EPA's new emissions rules or annual funding levels for induced seismicity research at the U.S. Geological Survey). As a petroleum professional, you are a potential source of valued science and technical information, but you have to start the communication.

This seminar will provide the information you need to communicate with your senators and representatives and become a trusted resource. Take-aways include online information resources, contact information for legislators and staff involved in energy issues, and bill tracking and budget resources.

This short course is directed toward geoscience professionals and students, and energy lawyers interested in influencing government policy or seeking insights into how Congress works. After completion, course participants will:

- Be familiar with key policymakers shaping legislative and regulatory issues that affect petroleum geologists
- Know how to arrange a meeting with their senator or representative
- Have the resources to tailor the discussion to a particular legislator's interest

Agenda: "How the System Works" with Edith Allison (Director, AAPG Geoscience and Energy Policy Office, Washington, D.C.) will cover the major players, authorization and appropriation bills, federal agencies, sources of information about Congress, and key contacts.

“Communicating with Congress,” a panel discussion and Q&A, will include: J. Tyler White (District Director for Rep. Andy Barr, Ky. Sixth District), Brydon Ross (Consumer Energy Alliance), Eric King (University of Kentucky Director of Federal Relations), Pete Mackenzie (AAPG member and advocate), and Liz Edmondston (Director of Energy and Environment Policy, Council of State Governments).

“Logistics of Your Congressional Meeting,” by Edith Allison, will cover ways to deliver your message: meeting formats—Washington or local district office; inviting your legislator to an event; and developing your own 5-minute message.

Unconventional Reservoir Quality Analysis

CANCELLED

Sunday, September 25, 8 a.m.–4:30 p.m.

Kentucky Geological Survey, University of Kentucky

Instructor: Dan Krygowski, Senior Petrophysical Advisor, The Discovery Group, Denver, Colo.; Dan has more than 30 years of experience in petrophysics and the design and development of petrophysical software. He also teaches the AAPG “Basic Well Log Analysis” course and “Basic Openhole Log Interpretation.”

Cost: $150 (professional) and $75 (students; limit five); includes handouts, lunch, and breaks

Description: The course takes a brief, but focused, look at the interpretation of shale gas reservoirs, in the category considered to be unconventional, or organic mudstones. It offers a hands-on approach to interpretive techniques, and considers traditional reservoir properties of porosity and fluid saturation in the context of those unconventional reservoirs, as well as the determination of total organic carbon (TOC). It considers techniques in the context of availability of both older data, and newer more extensive data.

The course assumes a basic understanding of common openhole logging measurements and interpretation, and uses that working knowledge to expand the measurement responses and interpretation of those responses into the environments for which the measurements were not originally designed.

Introductory Geochemistry for Shale Gas, Condensate-Rich Shales, and Tight Oil Reservoirs

Wednesday, September 28, 9 a.m.–4 p.m.

Kentucky Geological Survey, University of Kentucky (transportation provided)

Instructor: Christopher D. Laughrey, Senior Petroleum Systems Analyst, Weatherford Laboratories’ OilTracers Interpretive Services Group

Cost: $125 (professional) and $60 (students; limit five); includes handouts and morning and afternoon breaks

Description: The course is a practical and applied introduction to geochemical techniques routinely employed in shale-gas, shale-condensate, and tight-oil reservoir assessment. Emphasis is on explaining which tools and techniques best address specific questions, the caveats that accompany these tools, the strengths and limitations of petroleum geochemistry in resource play evaluation, and how to interpret conflicting data from different analyses. The focus will be on using practical exercises to review geochemical data, recognize problems with data, and interpret and integrate geochemical data with geologic data. Analytical techniques to be discussed include Leco TOC, bulk pyrolysis, Dean Stark and Soxhlet extraction, liquid and gas chromatography, gas chromatography–mass spectrometry, organic petrology using reflected light microscopy, fluorescence microscopy, and advanced scanning electron microscopy. Special emphasis is given to caveats associated with using vitrinite reflectance measurements in marine shales. Participants will complete exercises interpreting pyrograms, gas chromatograms, and elementary biomarker data. The class will employ various cross plots and simple mathematics to interpret gas isotope data and calculate original TOC, hydrogen index, and oil and cracked gas yields. The course will generally follow the outline:

- Overview of shale gas, condensate-rich shales, and tight-oil reservoirs
- Fundamentals of petroleum source-rock screening, including generation potential, kerogen type and petroleum products, thermal maturity and generation, hydrocarbon yields
- Advanced evaluation techniques including hydrous pyrolysis, source rock kinetics, diamondoids, gas chromatographic fingerprints, and C7 hydrocarbons
- Biomarkers, including their use for correlation, and assessing source-rock depositional environment, thermal maturity, and biodegradation
- Stable isotope geochemistry

Laughrey has 39 years of experience, specializing in areas that include isotope and petroleum geochemistry, basin analysis, and geophysical log analysis.

Abstracts

Speaker is first author unless designated by an asterisk.

Depositional and Sequence Stratigraphic Framework of the Middle Pennsylvanian Allegheny Formation, South-Central West Virginia: Analyzing Autogenic and Allogenic Influence on Depositional Elements

Oluwasegun Abatan and Amy Weislogel, Department of Geology & Geography, West Virginia University

The Middle Pennsylvanian Allegheny Formation (MPAF) represents a NW-prograding clastic wedge which originated from tectonically uplifted highlands along the east-central Appalachian Basin. MPAF sandstone units located above and below the Lower Kittanning Coal exhibit distinct variations in composition and depositional structures. This suggests a change in sediment source, higher energy flows, and/or climatic conditions during deposition. This study aims to test the hypothesis that the observed variation in depositional elements is due to changes in conditions of allogenic controls of the depositional system that drove the autogenic response of the depositional system.

The test of the hypothesis will integrate measurement and description of sedimentology and stratigraphy from outcrop, wireline logs of the MPAF from wells in the region of the outcrop drilled for coal assessment, and petrographic analysis to reconstruct the paleohydrologic and paleoenvironmental conditions during the deposition of the MPAF, with the goal of discriminating sedimentary response(s) and changes in fluvial architecture to allogenic versus autogenic processes. Comparison of the MPAF's paleoclimate and paleohydrologic conditions with ancient and modern analogues around the world will allow identification of the processes that influenced sedimentation, sediment distribution, and depositional structures during deposition of the MPAF. Knowledge from this study will improve understanding of internal and external processes influencing depositional elements.

Understanding Kerogen Composition and Structure in Pristine Shale Cores Collected from Marcellus Shale Energy and Environment Laboratory

V. Agrawal, Shikha Sharma, and A. Warrier, Department of Geology & Geography, West Virginia University

Organic-rich black shales have become a vital component of the U.S. energy portfolio. Kerogen is the high molecular weight organic matter (OM) that serves as starting material for the oil and gas in these shales. Despite its importance, kerogen still remains one of the least studied components because traditional methods used to study it have limited applicability, especially in mature shale reservoirs. It has been noted that shales with a similar amount and type of kerogen and similar reservoir parameters, such as maturation, have different biomarker distribution, carbon (organic) isotopic signature, and produce different amounts of hydrocarbons. These heterogeneities highlight the need to better understand the variability in composition and structure of kerogen to identify sweet spots for hydrocarbon production. This study utilizes sidewall cores collected from the experimental well at Marcellus Shale Energy and Environment Laboratory (MSEEL) in Morgantown, West Virginia. Samples were collected from different organic-rich zones in Marcellus Shale, and from its contact with the underlying Onondaga and overlying Mahantango formations. Samples were ground to a particle size less than 500 µm and homogenized. Kerogen was extracted from ground samples by removing soluble OM and mineral matrix using chemical and physical separation. Soluble OM, carbonate minerals, and silicate minerals were dissolved using dichloromethane (DCM), hydrochloric acid (HCl), and hydrofluoric acid (HF), respectively. Heavy minerals and pyrite were separated using zinc bromide ($ZnBr_2$) solution. Different functional groups such as C=O, CH_2, CH_3, C=C, C-O, OH, C-OH were identified using FTIR (Fourier Transformed Infrared) analysis and the molar percentage of different carbon bonds were quantified using XPS (X-ray Photoelectron Spectroscopic) analysis. The data on functional groups and carbon bonds will be used in conjunction with isotopic, geochemical, and mineralogical data to understand the effect depositional environment and redox conditions have on structure and composition of kerogen.

Comparing Different Extraction Methods for Analyses of Ester-Linked Diglyceride Fatty Acids in Marcellus Shale

Rawlings Akondi[1], Ryan V. Trexler[2], Susan M. Pfiffner[3], Paula J. Mouser[2], and Shikha Sharma[1]
[1]Department of Geology & Geography, West Virginia University, Morgantown, WV 26506
[2]Center for Environmental Biotechnology, University of Tennessee, Knoxville, TN 37932
[3]Civil, Environmental and Geodetic Engineering, Ohio State University, Columbus, OH 43210

This work contributes to the recent advances being made towards the comprehensive assessment of microbial biomass and diversity in the deep subsurface environments. Microbes have been known to inhabit the deep subsurface ecosystem, surviving severe conditions of starvation and extreme temperatures. While microbes have been known to survive in such environments, their existence in the shale ecosystem could be significantly compromised by the complex nature of the shale organic matter matrix and small pore sizes. Due to low biomass in these shales, it becomes very vital to develop methods that have the ability to yield higher and persistent recovery of microbial lipid biomarkers. In this study, three extraction methods, i.e., modified Bligh and Dyer (mBD), Folch (FOL), and Microwave-Assisted Extraction (MAE), were used to extract the ester-linked diglyceride fatty acids (DGFA) from homogenized shale samples. Phosphate (Phos) and citrate (Cit) buffers were used for the mBD extractions together with $MgCl_2$, *Escherichia coli (E. coli)* biomass, and phospholipid (POPC) spikes. To determine the variation in the different lipid profiles obtained from different methods, the extracted lipids were separated by column chromatography and the DGFA were eluted from the chloroform fraction and trans-esterified into fatty acid methyl esters (FAMEs) by methanolic potassium hydroxide. The FAMEs were then analyzed by gas chromatography mass spectrometry. The treatments had relatively comparable biomass yields and total lipid abundances except for the mBD-Cit and mBD+Phos+Mg_2+, which had less yield compared to the other treatments. Based on the NMDS and PCA analysis, the differences in diversity of FAMEs between the different treatments were attributed to the less common fatty acids. For example, polyunsaturated, cyclopropyl, terminally branched saturated, and epoxy FAMEs were detected consistently in mBD-Phos+Ecoli, mBD-Phos + POPC, and Folch treatments while the Keto FAMEs were only captured in the mB&D-Phos+Mg_2+ treatment. However, the mBD-Phos+POPC had the best reproducibility and yield among all the other methods, suggesting that the addition of a lipid spike helps with recovery of lipid biomarkers that would otherwise not be released from the shale matrix.

Thermodynamically Driven Fluid Mixing Across Phases Induced by Viscous Flow Instabilities in Porous Media

Mohammad Amin Amooie, Joachim Moortgat, and Mohamad Reza Soltanian, School of Earth Sciences, The Ohio State University, Columbus, OH 43210

Fluid mixing and its interplay with flow instabilities and/or channeling through heterogeneous media have been studied in some detail for mostly fully miscible conditions in which a single phase is generally represented by two components, e.g., a solvent and a solute. In such studies, fluid properties are assumed to be either constant or to follow simple mixing rules depending only on concentration. In particular, viscous fingering, a hydrodynamic instability due to the displacement of a more viscous fluid with a less viscous one, has been studied predominantly for immiscible or fully miscible fluids.

However, many problems of interest, such as gas injection in hydrocarbon reservoirs, involve multiple species and fluid properties, even in single-phase, and depend non-linearly on temperature, pressure, and composition through an equation of state (EOS). Moreover, depending on the minimum miscibility pressure, solubility factor, and in situ conditions, a two-phase region may develop, e.g., in a partially (multi-contact) miscible system. Fingering in this regime and its interplay with mixing have gained less attention in previous studies, and never been compared to those in single-phase.

This work aims at studying mixing of a finite volume of CO_2 with multi-component oil in various regimes of miscibility, with fluid properties determined by rigorous EOS-based (Peng-Robinson) phase-stability and phase-split computations. Fickian diffusion, driven by chemical potential gradients, is modeled to capture the diffusive fluxes across sharp phase boundaries, e.g., across a finger perimeter in absence of perfect miscibility. Flow and transport are modeled on very fine grids with our in-house, higher-order, finite element reservoir simulator.

In addition to compositional effects across different degrees of miscibility, we investigate the impact of correlated heterogeneities for a wide range of (geostatistically generated) correlation lengths and lognormal permeability distributions.

Our numerical framework is capable of resolving small-scale fingering patterns on one hand, and the potentially dispersed flow caused by heterogeneity. The results provide a broad perspective into mixing mechanisms coupled with complex fingering patterns in porous media while demonstrating critical differences in dynamics of fluid mixing in single- and two-phase flow through both homogenous and heterogeneous media.

Cyclic Pressure Pulsing: A Promising Method to Improve Recovery from Hydraulically Fractured Stripper Wells of Appalachian Basin

Emre Artun, Ozgur Irgav, and Nurum Khairzhanov, Middle East Technical University, Northern Cyprus Campus, Petroleum and Natural Gas Engineering Program, Kalkanli-Guzelyurt, TRNC, Mersin 10, Turkey 99738

Cyclic-pressure pulsing is a single-well EOR method that has been successfully applied in naturally fractured systems. The process is driven through diffusion of the injected gas from the fractures into the matrix. After diffusing, the gas displaces remaining oil towards the fractures, which eventually results in higher production rates. In this study, the process is studied for hydraulically fractured wells to understand its effectiveness. Injected gas composition is varied as pure nitrogen, pure carbon dioxide, and mixture of these gases. Appalachian Basin is considered as a case study, due to many hydraulically fractured stripper wells in the region. A numerical compositional simulation model is constructed and flow around the hydraulic fracture is represented using local grid refinement. A 36 API gravity crude oil taken from Appalachian Basin is defined, and reservoir characteristics represent the Appalachian Basin sandstones. The process is analyzed with a large number of simulation runs from the perspectives of operational, reservoir, and hydraulic-fracture characteristics. Key sensitivity parameters for the operational part are chosen as the injection rate, injection/soaking durations, and the economic rate limit to stop the production and restart the injection. For the reservoir/hydraulic fracturing part, reservoir permeability, hydraulic fracture's effective permeability, thickness, and half-length are chosen. After collecting key performance indicators, a proxy model was constructed to obtain a screening tool for future studies and to understand key sensitivities. The study showed that within the ranges studied, cyclic-pressure pulsing with both carbon-dioxide and nitrogen can be successfully applied for three to 12 cycles within a 20-year project period with discounted injection efficiencies representing net present values greater than zero for any realistic oil price scenario. To ensure maximum efficiency, injection and hydraulic fracture related design parameters must be considered. Injection volume and overall effectiveness of the hydraulic-fracture (width, half-length, permeability) affect the performance significantly. While benefits of soaking are clearly observed, the duration does not significantly affect the process. Economic limit must be optimized for balancing the remaining energy in the reservoir before starting the injection and maximizing barrels of oil recovered as early as possible.

Cypress Sandstone Reservoir Characterization Across the Clay City Anticline, Richland and Clay Counties, Illinois

Zohreh Askari, Yaghoob Lasemi, and Nathan D. Webb, Illinois State Geological Survey, University of Illinois at Urbana-Champaign, 615 E. Peabody Dr., Champaign, IL 61820

The Upper Mississippian Cypress Sandstone is the most prolific siliciclastic unit in the Illinois Basin and commonly produces from southwest trending lenticular reservoirs. The boundaries of Cypress with the overlying Beech Creek Limestone and the underlying Ridenhower Formation are conformable. However, in places thick Cypress Sandstone cut into Ridenhower that commonly consists of shale and discontinuous sandstone and limestone beds. A persistent paleosol horizon is present near the top of Cypress, recording a subaerial unconformity. Detailed well to well correlation and lithofacies analysis in the deeper part of the basin (Fairfield Basin) have indicated that the Cypress (over 60 m thick) commonly consists of lenticular sandstone bodies interbedded with shale. In places, shale and siltstone are the dominant lithology or the only lithology present.

In Richland and Clay Counties, along the Clay City Anticline, Cypress oil production is from the upper part of amalgamated thick sand bodies (mainly on anticlinal closures) and from porous lenticular and compartmentalized sandstones developed in the upper part of the formation. Sandstone bodies consist of fine to medium grained sublitharenite to quartzarenite attaining an average porosity of over 18 percent. The Cypress succession comprises: (1) a mainly deltaic unit in which prodelta mudstone passing upward into distal to proximal coarsening-upward distributary channel mouth-bar sandstones or blocky to fining-upward sandstone lenses interpreted as distributary channel fill deposit, (2) a shallow marine succession of mudstone to mature sandstone interpreted as offshore bar or shoreface deposit, and (3) major lenticular, multistory sand bodies at several horizons with shale partings or shale interbeds displaying blocky or bell shaped profile. These sand bodies cut down several meters into the succession and the lowermost horizon may reach the limestone or shale of the underlying Ridenhower Formation. They may correlate with the paleosol horizons reported within the Cypress and are interpreted as incised-valley fills that cut into the previous deposits during fourth-order sea level falls.

Redefined Sauk Sequence Rocks in the Ohio Region Suggest Emerging Plays on the Ohio Platform and Adjacent Rome Trough

Mark T. Baranoski, Retired, Ohio Department of Natural Resources, Division of Geological Survey, Columbus, OH 43229

The search for new hydrocarbon reserves in unconventional plays and targets for CO_2 sequestration has provided new data for updating the Sauk sequence (Knox and pre-Knox) stratigraphy of the west-central Appalachian Basin. Redefined sub-Knox units of the Ohio region illustrate that the Mt. Simon Sandstone is not the regional basal “blanket sandstone” deposited on a Precambrian peneplain. The Ohio term “Rome Formation” is not correlative to the Rome Formation of the Rome Trough. The term “Sandusky formation” replaces Ohio’s now obsolete term “Rome Formation.” The Sandusky formation has up to six mappable quartzarenite subunits separated by tongues of highstand marine dolostone. The quartzarenite subunits may have potential stratigraphic traps along pinchouts and disconformities on the Ohio Platform and along the Rome Trough High. The Sandusky may also have promise in stratigraphic and structural traps within the Rome Trough. Historical production and shows in the Knox and Sandusky of the southeastern Ohio River region point to the Cambrian Rogersville Shale as a more likely source rock than Ordovician Point Pleasant/Utica for these emerging plays. Recent deep drilling activity in the Rome Trough of northeastern Kentucky and northwestern West Virginia reaffirms the Rogersville source rock potential.

The Formation of Diagenetic Trap in the Squirrel Sandstone

Landis Bates, Ian McGougan, Jeremy Gerdau, and Eric Law, Geology Department, Muskingum University, 163 Stormont St., New Concord, OH 43762

Samples of Pennsylvanian Squirrel Sandstone from one producing well in Kansas are examined on their petrography in order to determine the diagenetic history of the sandstone and the nature of petroleum trap. The sandstone is made of fine size (< 1 mm in diameter), angular monocrystalline quartz, and euhedral feldspars. The degree of quartz overgrowth is minor and partial. The feldspars, including both K-feldspar and Na-plagioclase, show features of extensive dissolution. The clay matrix is dominated by kaolinite, in both detrital and authigenic morphology. There existed two layers of recrystallized coquinas, free of quartz and feldspars. Pore space in the reservoir quality sandstone is sporadically filled by authigenic kaolinite and siderite. In between the reservoir layers, pores of the sandstone are partially or totally filled up with kaolinite.

Based on the observations, the depositional and diagenetic history of the Squirrel Sandstone is suggested as the following: immature sediment was provided by the nearby cratonic rocks to the low energy basin. The reservoir quality sands were

deposited with little or no clay matrix. Detrital kaolinitic clay was episodically deposited in other sand layers to form much less impermeable layers. Feldspars' dissolution continued to take place in shallow burial, and provided material for the authigenic kaolinite precipitated, before the feldspars were totally dissolved, the emplacement of petroleum into layers that are still porous, and arrested all diagenetic reactions.

Redox Conditions During Deposition and Early Diagenesis of the U. Ord. Point Pleasant Ls of Southwestern PA and Northern WV: Insights from Pyrite Framboids and Trace Elements

David R. Blood, EQT Production, 625 Liberty Ave., Ste. 1700, Pittsburgh, PA

The mode and occurrence of sedimentary pyrite has often been used to assess the redox conditions of bottom and pore waters in ancient sediments. Framboids form rapidly in the zone of iron reduction immediately below the sulfide chemocline, while euhedral pyrite grains form at more protracted rates in hydrogen sulfide (H_2S)-bearing water. Sediments accumulating under dysoxic water are characterized by a low occurrence of pyrite which takes the form of euhedral grains with a subordinate occurrence of framboids. However, in anoxic pore waters, morphology shifts to framboidal pyrite of variable and often large (> 10 µm) size. Further, sediments accumulating under an anoxic water column illustrate a framboid population that is small in diameter (< 5–6 µm) and less variable in size. Pyrite in 16 samples retrieved from three horizontal Point Pleasant wells was analyzed by SEM. Results demonstrate a dearth of pyrite in the Point Pleasant (0.02–1.7 percent of area analyzed). While pyrite morphology is dominated by euhedral grains and masses (~80 percent of pyrite encountered), the framboids are uniformly small on average (4.7 µm), with just a few > 10 µm. The lack of pyrite and its occurrence as mostly euhedral grains and masses suggest accumulation under a dysoxic water column. Conversely, the size of the framboids suggests they formed in a water column containing free H_2S. Two models can explain this apparent paradox: (1) Anoxia developing within marine snow aggregates suspended in the water column could have produced a micro-environment conducive to the precipitation of framboids in an otherwise dysoxic water column or (2) the occurrence of small framboids may be explained by a lack of reactants necessary to sustain pyrite growth in anoxic pore waters. Indeed, the latter model is consistent with low production of H_2S inferred from low total organic carbon (TOC) content of the Point Pleasant. Further, total iron content below average shale values in the Point Pleasant indicates low delivery of reactive iron to the seafloor. Both models are consistent with the Point Pleasant accumulating under a dysoxic water column where TOC preservation was accomplished by its burial and removal from zones of oxidation and biologic degradation.

Core Reflectance Spectroscopy and Well Logging of the Point Pleasant/Utica Sub-basin, Ohio

Julie M. Bloxson and Beverly Z. Saylor, Case Western Reserve University, Department of Earth, Environmental and Planetary Sciences, 10900 Euclid Ave., Cleveland, OH 44106

The Ordovician Point Pleasant Formation and Utica Shale are calcareous shales interbedded with limestone that extend throughout Ohio, and lie on top of the Trenton and Lexington carbonate ramps. These shales have previously been linked to the Sebree Trough, a bathymetric low where carbonate production ceased and silicliclastics were deposited in a deep, anoxic sea. To analyze the change in environments, well logs were used to analyze the thickness, structure, and contact between the Point Pleasant and the carbonate ramps, and reflectance spectroscopy on rock core was used to observe high spatial resolution changes in mineralogy with depth in order to determine changes in the environment during deposition. Well logs and rock core indicate an abrupt change between the Point Pleasant and Trenton on the northwestern edge of the basin, while the contact with the Lexington on the southeastern edge of the sub-basin is a gradation (interbedded?) contact and consists of more frequent limestone beds within the shale. Mineralogy and core descriptions confirm these contacts between the formations, with a gradational change in mineralogy from more shale to more carbonate on the southeastern edge (Point Pleasant and Lexington), and an abrupt change from shale to carbonate within the basin (Point Pleasant and Trenton). This suggests two different mechanisms affecting the two contacts between the Point Pleasant and the underlying carbonate platform.

An Analysis of a Near-Surface Big Clifty (Jackson) Sandstone Reservoir in Logan County, Kentucky

Tyler S. Bodine and Michael T. May*, Department of Geography and Geology, Western Kentucky University, Bowling Green, KY 42101

The Big Clifty (Jackson) Sandstone Member of the Golconda Formation is the most important of the Mississippian (Chesterian) heavy-oil reservoirs in the southeastern Illinois Basin. Heavy-oil reservoirs, or asphalt rock deposits, have been studied extensively in south-central and western Kentucky, and ~2 billion barrels of original oil in place (OOIP) is proposed to occur in the Big Clifty. Heterogeneities related to depositional facies changes are poorly understood in Kentucky, where the Big Clifty has been mostly described as a 60- to 120-ft-thick sandstone unit. In some locations, in contrast, such as at the Stampede Mine in Logan County, the Big Clifty occurs as two distinct sandstone bodies with intercalated mud-rich units. Currently, no predictable depositional model exists to explain abrupt facies changes observed during open pit mining conducted over the last couple of years.

This study integrates sedimentological, stratigraphic, and geophysical datasets to characterize the lithological changes occurring in Big Clifty reservoirs and may be used as a model downdip into the basin where conventional-oil Jackson reservoirs are targeted. Datasets used in this study include over 30 cores retrieved from across Stampede Mine's acreage, surface-mine exposures, Electrical Resistivity Tomography (ERT) surveys, and bitumen concentration values.

The Big Clifty Sandstone formed in a tidally influenced deltaic system occurring on a low-angle dipping ramp. Shallow marine ichnofacies occur in rhythmically bedded deposits. A brecciated mudstone and red-green shale occur above the lower sandstone reservoir. This muddy facies represents an exposure surface that separates regressive and transgressive parasequences. Sedimentary features and bitumen concentration vary across the exposure surface, making bitumen concentration trends difficult to ascertain without close subsurface control. The extent of channelized sandstone bodies and bitumen-rich units, however, can be generally documented.

Sulfide Generation by Dominant Colonizing *Halanaerobium* Microorganisms in Hydraulically Fractured Shales

Anne E. Booker[1], Mikayla A. Borton[1], Rebecca A. Daly[1], Susan A. Welch[2], Carrie D. Nicora[3], Shikha Sharma[4], Paula J. Mouser[5], David R. Cole[2], Mary S. Lipton[3], Kelly C. Wrighton[1], and Michael J. Wilkins[1, 2]
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Black shale formations underlay much of the continental United States, and through the use of hydraulic fracturing represent a significant natural gas resource. Despite the use of biocides, *Halanaerobium* species become the dominant microbial community member in produced fluids from many of these fractured shales, regardless of their location. This accumulation of biomass in pipelines and reservoirs is viewed as detrimental by industry, due to potential for souring (production of H_2S), microbially induced corrosion, and pore clogging by cells and biogenic gases. Sulfide is a particular problem in both conventional and unconventional reservoirs; toxicity associated with this compound poses health risks to workers, while biogenic sulfide causes corrosion of steel infrastructure pipes by stimulating cathodic reactions that continuously leach protons from the metal. Here we investigate *Halanaerobium* biogenic sulfide production from a strain isolated from hydraulically fractured Marcellus Shale using coupled "omics" technologies, geochemical field observations, and laboratory growth experiments. *Halanaerobium* is a gram negative, obligate anaerobe that ferments glucose to acetate, ethanol, formate, lactate, and hydrogen. Genomic analysis identified the presence of three rhodanese-like thiosulfate:cyanide sulfur-transferases and an anaerobic sulfite reductase capable of converting thiosulfate to sulfide within this microorganism. Proteomics verified these proteins were up-regulated when thiosulfate was present in the growth media. While the growth rate of *Halanaerobium* is not enhanced by the presence of thiosulfate, an acid volatile sulfide assay could only track sulfide accumulation when thiosulfate was present. With these observations we hypothesize that *Halanaerobium* uses thiosulfate as a way to remove excess reductant during fermentation. During this process, rhodanese-like enzymes convert thiosulfate to sulfite, which is subsequently converted to sulfide via anaerobic sulfite reductase. These findings emphasize the detrimental effects thiosulfate-reducing microorganisms may play in hydraulically fractured shales, which would go undetected using current industry-wide corrosion diagnostics.

Methanohalophilus Is the Dominant Source of Biogenic Methane in Hydraulically Fractured Shales

Mikayla A. Borton[1], Rebecca A. Daly[1], David M. Morgan[1], Anne E. Booker[1], David W. Hoyt[2], Paula J. Mouser[3], Shikha Sharma[4], Michael J. Wilkins[1, 5], and Kelly C. Wrighton[1]
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Hydraulic fracturing provides access to shale oil and gas, while also creating a microbial ecosystem that produces biogenic methane. Recent single-gene investigations from our laboratory and others have revealed a single methanogen type *(Methanohalophilus)* is conserved in produced fluids from several shale formations, including Antrim, Burket/Geneseo, Marcellus, and Utica–Point Pleasant. Here we reconstructed multiple *Methanohalophilus* genomes collected from produced fluids after hydraulic fracturing of Marcellus and Utica shales. Each of the recovered methanogen genomes encoded metabolic pathways for utilizing methylamines and methanol, and unlike other subsurface methanogens could not generate methane using hydrogen or acetate. Metabolite analyses of injected fracturing fluids revealed high concentrations of methylamines and methanol that support the growth of methanogens in fractured shales. Furthermore, our work uncovered that these substrates, specifically trimethylamine, could also be synthesized in situ by a network of interconnected microbial metabolisms commonly found across shales. Batch experiments demonstrated that microbially produced substrates could be a source of biogenic methane in the laboratory, producing 6.5 times

more methane per day than unamended controls. From produced fluids sampled from multiple Utica and Marcellus wells, we cultivated several strains of this dominant shale methanogen. Laboratory cultivation techniques confirmed that shale-derived *Methanohalophilus* are halotolerant (growing at or above 80 g/L NaCl) and piezotolerant (> 3,000 psi), demonstrating that these organisms are well adapted to growing and persisting in fractured shales. Given the prevalence of *Methanohalophilus* across hydraulically fractured shale formations, it is plausible that the gas isotope signatures widely used to assess biogenic versus thermogenic methane fail to account for contributions of biogenic methane produced from methyl-C1 compounds in these shales. We are currently focusing on assessing isotopic signature of methane produced from *Methanohalophilus* grown in the laboratory under shale conditions to quantify the contribution of newly produced biogenic methane. Our results leave open the possibility that, analogous to coalbed methane, fractured shales could be managed to increase energy recovery and longevity through biostimulation.

Reevaluation of the Heavy Oil and Bitumen Resources of the Western Kentucky Tar Sands: What Did We Learn About the Tar Sands that Is New?

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Upper Mississippian Big Clifty and Hardinsburg Sandstones and overlying Lower Pennsylvanian Caseyville Formation host heavy oil and bitumen in a belt extending from Logan County north to Breckinridge County. After more than 100 years of study, however, the tar sands' source rock, heavy oil and bitumen origins, reservoir partitioning observed in outcrops and in the subsurface, and resources volume have remained controversial. This study addresses and answers these questions. Trace-metal geochemical evidence demonstrates that tar sand oils were sourced from the New Albany Shale, and are geochemically indistinguishable from other Mississippian oils in the southern Illinois Basin. Early Triassic primary migration from the New Albany was vertically along fault planes into Big Clifty and Hardinsburg reservoirs developed in downthrown fault blocks, with secondary migration into the Caseyville where erosion at its base breached underlying reservoirs. Reservoir compartmentalization observed in outcrops and cores was associated with oil migration, where the oil was a geochemically reducing fluid reacting with pore water and the surrounding matrix to precipitate a distinctive diagenetic mineral suite. Migrating oil was biodegraded to heavy oil and bitumen during oil emplacement by microbes sequestered in the reservoirs during burial. During biodegradation of the oil, immobile bitumen was deposited on the pore walls, causing the tar sand reservoirs to be oil-wet, leaving only about 40 percent of the total oil in place as mobile and potentially producible. One characteristic of the tar sands is that total fluids saturations in cores are much less than 100 percent. Reservoir porosity expansion during rapid pre-Middle Cretaceous tectonic uplift, reservoir fluids cooling, and lack of an active aquifer connection led to the tar sand reservoirs becoming undersaturated in water. Additional pore space filled with low-pressure methane evolved from the water, evidenced by methane bubbling from cores and isolated gas caps developed over heavy oil in the Big Clifty. Estimated oil in place in the tar sands is 3.36 MMMBO; however, the only commercial process for developing these resources was mining rock asphalt for road surfaces from 1889 to 1957. No EOR or bitumen extraction process has been developed since that time beyond technically successful, but uneconomic, projects.

The Marcellus Shale Energy and Environment Laboratory (MSEEL)

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The Marcellus Shale Energy and Environment Laboratory (MSEEL) consists of a multidisciplinary and multi-institutional team undertaking integrated geoscience, engineering, and social science research in cooperation with the operator, Northeast Natural Energy, numerous industrial partners, and the National Energy Technology Laboratory of the U.S. Department of Energy. MSEEL consists of two legacy horizontal production wells, two new instrumented horizontal production wells, a vertical pilot borehole, a microseismic observation well, and surface geophysical and environmental monitoring stations. Production from the new horizontal wells began in December 2015. The MSEEL approach is data driven with a platform to store, manage, publish, and share very large and diverse (multiple terabyte) datasets among researchers. MSEEL integrates drilling and fracture stimulation operations, geophysical observations, fiber-optic monitoring of high-resolution temporal and spatial flow of injected and produced fluids during completion and production, mechanical properties logs, microseismic and core data to better characterize subsurface rock properties, stimulated reservoir volumes, faults, and fracture systems. Surface monitoring of operating machinery emissions was undertaken at the exhaust pipe, pad, and regional scales. Produced fluids and gases are being monitored during completion and production. The MSEEL goal is to develop and validate new knowledge and technology and identify best practices for field implementation that can optimize hydraulic fracture stimulation, minimize environmental impacts of unconventional resource development.

We provide several examples that illustrate technologies and approaches that are being developed to store, query, display, and analyze large and diverse data sources and new data types derived from surface and subsurface to evaluate stimulation effectiveness, cluster-by-cluster, and design innovative stage spacing and cluster density practices that can be used to optimize recovery efficiency.

Improving Unconventional Hydrocarbon Recovery by Reducing Formation Damage

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The low commodity price for hydrocarbons has made increasing EURs while decreasing CAPEX for unconventional wells a critical factor to operator survival. While the DOE has been instrumental in advancing the science that formed the North American shale play, it will be necessary to have another technology renaissance to improve the hydrocarbon recovery factor from the 7 to 10 percent range that is currently being realized, to a step change to 15 percent or more. Although unconventional wells are typically fracked in even stages, production is not uniform. Why is that? Uneven production is likely due to differences in fracture-achieved surface area, pore connectivity, and permeability variability. Coupled geochemical-transport processes occurring at fluid-shale interfaces can profoundly alter these parameters and thus EUR. Our goal is to understand primary and secondary nanoscale reactions that are occurring in and likely damaging shale through the fracking process. Relatively little has been published on this subject.

The work, being conducted by SLAC and managed by NETL, is using world-class, synchrotron transmission X-ray microscopy (TXM) and reactor and modeling studies to advance the understanding of nanopore-scale reactions caused by fracking fluid-shale interactions. The TXM uses high-flux focused X-rays to image shales at a spatial resolution of 30 nm such that pore networks and reaction products can be directly observed. This research is yielding knowledge that supports a step change in hydrocarbon recovery by customizing stimulation fluids and techniques to the formation-specific chemistry. The work is also explaining the release of contaminants from kerogen and the rock matrix.

Analysis and Integration of Advanced Logs and Core Data: Characterization of the Copper Ridge Dolomite in Morrow County, Ohio

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The Morrow Consolidated oilfield, a Knox Group oil play in Ohio, produces from the Copper Ridge Dolomite, also known as the Trempealeau Formation. This prolific formation underwent large-scale erosion during the Knox unconformity of the Ordovician Period, leaving behind carbonate remnants with relatively high porosities. As part of a regional characterization study of anthropogenic CO_2 storage potential in these depleted oil fields, Battelle has collaborated with an industry partner/local well operator to collect whole and rotary sidewall cores in addition to a suite of advanced wireline logs. Analysis and integration of core data and wireline data provide the opportunity to conduct a detailed characterization of reservoir injection/storage potential and caprock properties. Additionally, establishing correlations between core and logs is essential in calibrating wireline logs in complex carbonate systems, allowing for better geologic and petrophysical characterization of potential reservoirs.

Two sections of whole core were recovered from the Upper Copper Ridge and Copper Ridge “B” formations. Rotary sidewall cores were collected from the Gull River Formation, a potential caprock, and the Copper Ridge Dolomite (Upper, “B,” and Lower). Whole and rotary sidewall core analyses consisted of core photography, helical computed tomography (CT) scans, grain density, porosity, permeability, X-ray diffraction (XRD), scanning electron microscopy (SEM), and thin-section petrography. Results were used to constrain key potential reservoirs and to analyze caprocks in south-central Ohio.

Comparison of core and advanced wireline log data from the Copper Ridge Dolomite suggests wireline logs underestimate porosity in these carbonates remnants. Core photography shows abundant vugs, corroborating high porosity and permeability core data. Grain densities derived from elemental spectroscopy capture (ESC) log data and bulk density logs are in good agreement with measured sidewall core values. The correlation of core to log data provides a better understanding of calibration of logging tools in the Morrow Consolidated oilfield and assists with better geologic characterization of potential reservoirs.

In Situ Stress Characterization of Appalachian Basin Cambrian-Ordovician Caprock and Reservoirs via Detailed Image Log Analysis

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Characterization of in situ stress orientation and magnitude within potential caprock and reservoir units is essential for identifying candidate formations for long term geologic CO_2 storage at regional or site specific scales. A regional study of in situ stress orientations and magnitudes for various Cambrian-Ordovician formations in eastern Ohio, above and below the Knox unconformity, was conducted to characterize prospective CO_2 storage zones and caprock units in this region.

Wellbore breakouts and drilling induced fractures were identified on acoustic and resistivity based image logs for multiple wells in the study area. Analysis of these features provided estimates of the orientation (azimuth) of the maximum horizontal stress in multiple formations and multiple wells, which were plotted on a map to visualize the regional variability in this parameter. Results of this image-log analysis show that the orientation of maximum horizontal stress from wellbore breakouts and drilling induced fractures are in agreement with previously established regional values for both reservoir and caprock units. Another key observation from this multi-well analysis is that the prevalence of breakouts and drilling induced fractures vary considerably from well to well; further work is underway to elucidate stress-related information from this finding.

In addition to the multi-well image-log analysis, one well was selected for a more detailed analysis in which breakout widths were measured and used to constrain the magnitude of the maximum horizontal stress for both caprock and reservoir formations intersected by the borehole. Another aspect of the single-well analysis involved diagnosing the stress regime from characteristic shapes of the wellbore breakouts determined from image logs. Results of the single-well analysis showed that the calculated maximum horizontal stress magnitudes vary across the various formations that were evaluated and there are different breakout shapes in study area.

This study shows that image-log analysis can be used for detailed characterization of in situ stresses to provide additional insight into the potential for safe, long-term geologic storage of CO_2 within the Appalachian Basin region of Ohio. This project is funded by the Ohio Development Services Agency OCDO Grant OOE-CDO-D-13-22 and the U.S. DOE through the Midwest Regional Carbon Sequestration Partnership (MRCSP) award DE-FC26-05NT42589.

Preliminary Analyses of Core from the Marcellus Shale Energy and Environment Laboratory

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Natural gas production from the Marcellus Shale is influenced by factors at many scales. At each scale, detailed characterization can provide insights that improve our understanding of how to best utilize these resources. Here we present a preliminary multiscale examination of core obtained from the Marcellus Shale Energy and Environment Laboratory (MSEEL) in Morgantown, West Virginia, coupling well-log interpretations, millimeter to micron scale computed tomography (CT) scanning and physical laboratory measurements, geochemical sampling, and high-resolution isotope analysis.

Within 24 hours of extraction from the MSEEL 3H well, 112 feet of vertical core was CT scanned at the National Energy Technology Laboratory to examine the millimeter scale variations in structure. This data was coupled with P-wave velocity, X-ray fluorescence, magnetic susceptibility, and gamma density data obtained at 2-cm resolution along the length of the core using a Geotek Multi-Sensor core logger. Variation in natural constituents and locations of natural vertical fractures were examined to correlate with the field deployed well logs.

These high resolution measurements were used to organize sampling protocols of preserved side-walls for in situ isotope analysis and geochemical sampling. Measurement of metal isotope variability within the core will allow for improved understanding of the shale depositional environment and the range in variability expected for naturally occurring geochemical tracers. Metal isotope signatures for Sr, Li, B, and U are being evaluated in the homogenized samples through chemical extraction and analysis using multicollector ICP-MS techniques. Chemical variations in the shale due to variations in depositional environments may impact the pore scale reactions in the matrix. Geochemical analysis of the homogenized core samples, compared with results from analysis of drill cuttings, will provide additional insight into how drill cuttings may impact the environment. Preliminary results illustrate the heterogeneity of this formation, where small scale features influence the production processes and interactions during production. Work continues to link these laboratory observable properties to well-scale descriptions of the subsurface for upscaling and model development.

Progress Towards Safe and Effective Geologic Storage of Carbon Dioxide in Midwest and Mid-Atlantic States

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By signing the Paris Agreement under the United Nations Framework Convention on Climate Change, the United States entered into a global commitment to restrain global warming to below 2°C. Achieving this goal requires significant changes that policy makers and the public are only beginning to comprehend. Geologic storage of carbon dioxide (CO_2 GS) is one mitigation strategy for lowering global emissions of carbon dioxide (CO_2) while meeting the need for secure, affordable, and environmentally sound fossil energy supplies. It is the only technology capable of substantially reducing greenhouse gas emissions from coal-fired power plants and enabling the use of this plentiful fuel source, required for universal electricity access. Studies indicate that without commercial scale CO_2 GS, the cost of global climate change mitigation will increase by hundreds of billions of dollars.

The Midwest Regional Carbon Sequestration Partnership (MRCSP) was established to assess the public acceptance, technical and economic feasibility of CO_2 GS. Geologic and engineering knowhow, practical experience, and commercial scale-up are required to help CO_2 GS to reach its full potential. Field tests function to help address issues such as public acceptance and cost by demonstrating that CO_2 GS is a safe, environmentally friendly solution for CO_2 emissions from energy production and industry. To this end, MRCSP has performed field tests in six different geologic formations, tested monitoring technologies, distilled key modeling input parameters, and built a geologic knowledge base to support future CO_2 GS implementation. In addition to tests conducted under MRCSP, studies related to well integrity assessment, characterization of storage zones in offshore and onshore areas, and evaluation of regional geomechanical issues are strengthening the foundation of future CO_2 GS deployment. The role of CO_2 GS in a clean energy future, as well as issues affecting safe, effective deployment of CO_2 GS at commercial scale, will be presented.

Microbes in the Marcellus Shale: Distinguishing Between Injected and Indigenous Microorganisms

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Hydraulic fracturing is the industry standard for extracting hydrocarbons from shale formations. While several studies have demonstrated microbial activity in fluids from hydraulically fractured wells, it is not known if these microbes are indigenous to the deep subsurface before energy extraction. Here we compare the microbial communities in fluids used during drilling and hydraulic fracturing to those in pristine sidewall cores from the Marcellus Shale Energy and Environment Laboratory (MSEEL) in Morgantown, West Virginia. Fluid samples included drilling muds, source water in hydraulic fracturing fluids (Monongahela River water, recycled produced fluids), and fracturing fluids. Fluids were filtered to collect microbial biomass. Sidewall cores were collected from a 360-foot span within the MIP-3H well in the Genesseo, Tully, Mahantango, Marcellus, and Onondaga formations. After collection, cores were surface sterilized (verified by microscopy to confirm removal of 0.5 μm fluorescent microsphere tracers), ground, and homogenized before DNA extraction. Initial analyses of DNA extracted from drilling muds show that the microbial community contains the functional capacity for fermentation of hydraulic fracturing chemical additives, sulfide production, creation of biofilms, and the production of methane. These metabolisms could allow injected microorganisms to thrive in the subsurface, with both negative and positive effects on the energy extraction process. Ongoing analyses of microbial communities in the remaining fluid and shale samples will ultimately identify the indigenous and introduced microbes in these formations. This is the first study of its kind to distinguish between indigenous microorganisms and those injected in the deep subsurface by the process of hydraulic fracturing. Genomic reconstruction of injected and indigenous microbes will allow us to identify metabolic pathways and adaptations that define microbial roles in hydrocarbon reservoirs, before and during energy extraction.

Revising the Fresh-Saline Water Interface in Eastern Kentucky

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Shallow drilling depths in the Devonian Berea Sandstone oil and gas play and potential high-volume hydraulic fracturing in the budding Cambrian Rogersville Shale play have generated a renewed interest in protecting groundwater quality in eastern Kentucky. The depth to the base of potable water was mapped by H.T. Hopkins in 1966 in his “Fresh-Saline Water Interface Map of Kentucky.” The map remains an important guidance document for well operators and the Kentucky Division of Oil and Gas when evaluating surface casing depth. To create the map, Hopkins assumed that the total depth of domestic water wells equaled the base of fresh groundwater (total dissolved solids equal less than 1,000 ppm) or the fresh-saline water interface. However, it is likely that most water wells did not penetrate the base of the deepest fresh water. As a result, Hopkins’s map likely underestimates the depth of the fresh-saline water interface.

To increase the accuracy of the map, post-1966 domestic water-well data were added to the Hopkins data in a 14-county area covering the Berea and Rogersville plays in eastern Kentucky. The number of wells increased from 50 used by Hopkins to

4,824 in this study. The elevation range for the interface increased from 300 ft to 1,020 ft in the Hopkins map to 75 ft to 2,198 ft in our analysis.

Despite the increased robustness, the data from shallow wells continued to underestimate the fresh-saline water interface in regions of the map. Groundwater depth is influenced by topography and surface water, and to ameliorate underestimation, the added wells were examined in relation to their respective watershed elevations defined by hydrologic unit codes (HUC). Specifically, wells with total depths deeper than the minimum stream elevation in a HUC (pour point) were used to map the fresh-saline water interface. Excluding wells with total depth elevations above their HUC pour points resulted in reducing the maximum fresh-saline water interface elevation by 1,173 ft. Despite the improvement, the true depth of the interface in any given area remains uncertain, and we suggest the alternative term "deepest observed fresh water."

Preventative Maintenance for Paraffin Management in Production Tubing Using Non-invasive Ultrasonic Technology

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Preventative maintenance of paraffin deposition ("fouling") in production tubes can be accomplished by maintaining the temperature of paraffinic crude oil above the wax appearance temperature (a.k.a. cloud point). Downhole resistive heating (trace heating) systems are mature, commercially available options for preventative maintenance; however, the total cost of resistive heating systems and associated insulation make this solution financially inaccessible by most small oil producers. In addition, resistive heating systems expend significant energy heating the production tube and surrounding metal surfaces first and the oil within the production tube last. Pacific Northwest National Laboratory (PNNL) is developing and testing a non-invasive ultrasonic liquid processing technology that can be installed around the outside of a production tube. This technology takes advantage of the inherent ultrasound-absorptive properties of oil to preferentially heat the oil first, and the production tubing last. This heating mechanism is more rapid and efficient than heat transfer mechanisms that rely on resistive heating and conductive heat transfer. The PNNL ultrasonic liquid processing technology was designed for the non-invasive, volumetric treatment of liquid process streams in a pipe or tube. This has many applications for the oil industry, including treating liquid hydrocarbon streams to reduce oil viscosity, stimulate flow, aid coalescence, and mitigate fouling from paraffin waxes and other deposits in the production tubing. A status of the development project will be provided.

Structural Origin of Henderson Dome: Stratigraphic & Geophysical Study of an Upper Ordovician Impact Crater

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Henderson Dome is an anomalous 8 km wide, roughly circular structural oil and gas field in Mercer Co., PA. Earliest production goes back more than a century in the Upper Devonian sandstones which are now used for gas storage. Deeper production from the Upper Silurian Lockport Dolomite is more notable, as commercial accumulations are uncommon outside of this field. The crest of the dome structure does not migrate with depth, though there is evidence of erosional beveling inferred from the absence of regionally persistent formations in the Lower Silurian and Upper Ordovician. Previous interpretations suggested deformation in the Cambrian basement that was linked to several speculative origins for the field. Stratigraphic analysis of Silurian formations suggests intermittent vertical reactivation of faults within the dome that may be related to Appalachian Basin orogenic episodes.

With the help of modern 2D seismic data, the origin of this uplift can be linked to a Late Ordovician disturbance that mimics the outline of the dome. This presentation will discuss evidence that this disturbance resulted from an ancient meteorite impact during the Ordovician. This study details how this impact may have caused the uplifted section seen throughout the Silurian and Devonian that defines Henderson Dome.

Organic Matter Maturation Trends and Source Rock Quality in the Utica Shale, East-Central Ohio

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The Utica Shale in east-central Ohio was recently evaluated to assess its petroleum resource potential. To achieve this, drill core and cutting samples were analyzed for total organic carbon content (TOC) and bitumen reflectance (BRo random). Additional TOC and Rock-Eval pyrolysis data from existing datasets were also incorporated into the study. In the Northern Appalachian Basin, the Upper Ordovician Utica Shale includes, in stratigraphically descending order, the Kope, Utica, Point Pleasant, and Upper Trenton/Lexington Limestone formations, and Logana and Curdsville Limestone Members.

TOC results were found to be highly variable, both spatially and stratigraphically, with values from < 1 to > 5 percent being observed. Much of this variation appears to be the result of fine-scale organic-rich shale, and organic-poor limestone interlamination. In general, however, the Utica and Point Pleasant Formations and Logana Member tended to have the highest TOC. Previously collected results for Rock-Eval analyses of Upper Ordovician strata were also analyzed. Examination of these data revealed a high degree of variability in the pyrolysis results, both between adjacent wells, and even within the same unit of individual wells. This variability is similar to the TOC results.

Petrographically, most of the organic material in the Utica Shale play samples occurs as amorphous organic matter (AOM), with varying amounts of solid bitumen. Zooclasts, mainly in the form of graptolite fragments, occur frequently as well. The level of thermal maturity in the Utica play, based on bitumen reflectance values (BRo), shows a progression of increasing bitumen reflectance from west to east, with a very steep increase occurring in eastern Ohio. BRo random values from central Ohio ranged from 0.66 to 0.84 percent, where sample depths were between 100 and 4,800 ft. In eastern Ohio, sample depths were much deeper, ranging from 8,700 ft to more than 15,000 ft. In this area, corresponding BRo random values ranged from 0.94 to 1.43 percent. Thermal maturity analyses of bitumen reflectance broadly match expected petroleum products based upon the fluid content (oil, wet gas, dry gas, etc.) from initial production reports. The reflectance values are also in broad agreement with calculated R_o values from Rock-Eval T_{max} values.

Gas Shales: A Largely North American Phenomenon?

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Black shales are back in the "limelight" again, largely in response to the so-called "shale-gas revolution." This revolution has changed the nature of global diplomatic relations and encouraged other countries to seek their own shale-gas revolutions. In fact, the EIA developed estimates of possible shale-gas reserves for countries across the world, again spawning hopes for "revolutions," energy independence, and a surge in the use of cleaner fuels. A closer look at the situation, however, suggests that the U.S. shale-gas revolution was not really a revolution at all, and that abundant shale gas may largely be a North American phenomenon related to geology and developmental factors. Geologically, North America has more than 30 recognized shale-gas basins, and the development of so many basins probably reflects large size and stability of the continent through nearly 500 Ma. Continental deformation, when it did occur, only occupied continental margins, and in the process, generated many foreland, intracratonic, and yoked basins that served as repositories for the organic-rich sediments generated in the process of basin formation. Moreover, during Paleozoic and Mesozoic time, when most organic-rich sediments were accumulating, critical parts of North America were situated in the tropics or subtropics, where generation of organic matter was enhanced during both greenhouse and icehouse climates. After Triassic and Jurassic breakup of Pangea, even more repositories were generated in the form of rift and rift-margin basins along the eastern and southern continental margins. As important as geological factors were, developmental factors since 1975 were just as important. These factors include more than 40 years of research into the nature of eastern and central U.S. gas shales, economic factors that reflect private ownership, abundant water, and adaptable political and social institutions, as well as technological factors that reflect the work of many small independent operators, supporting contractors, and infrastructure. In truth, as some have noted, the situation in North America reflects more of an "evolution" than a "revolution." Whether or not the same alignment of factors that has occurred in North America can happen elsewhere, I am doubtful. Hence, similar "revolutions" in other parts of the world are unlikely.

Temporal Changes in Fluid Biogeochemistry and Microbial Cell Abundance after Hydraulic Fracturing in Marcellus Shale

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Hydraulic fracturing methods used to enhance gas production in shales result in biogeochemical changes that are poorly understood. Here, temporal trends in macronutrients and redox active elements important for supporting microbial life in shale wells are reported. In this paired study at the Marcellus Shale Energy and Environment Laboratory (MSEEL) well pad near Morgantown, WV, one well was fractured using a traditional geometric design (5H) while a second used a non-traditional engineered design (3H). Source water, fracturing fluids, and produced fluids were sampled over a period of more than six months and analyzed for biogeochemical parameters and the abundance of microbial cells. Dissolved organic carbon decreased through time from 69 to 42 mg/L in the traditional design (5H) and 312 to 68 mg/L in the engineered design (3H). Total dissolved nitrogen (TDN) concentrations decreased dramatically in initial flowback, and then show a rapid increase to approximately 90 mg/L in both wells. Trends in ammonia parallel TDN through time, with NH_3 consistently comprising 93 percent TDN by mass. Dissolved manganese (Mn) and ferrous iron (Fe(II)), both potential products of microbial respiration under anaerobic conditions, were below detection in the source water and fracturing fluids, but increased during flowback. Fe(II) levels in the geometric design (5H) were consistently higher than the engineered design (3H). Mn reached a maximum of 0.3 and 0.7 mg/L for 3H and 5H, respectively, then decreased below detection limits in both wells one month after the start of flowback. Concurrent with a decrease in sulfate concentrations to levels below detection, sulfide increased with time into flowback, leveling off at more than 20 mg/L in both wells. The number of microbial cells decreased dramatically after hydraulic fracturing in the engineered design well (3H), dropping from 1 x 106 cells/mL to

2 x 105 cells/mL after four months. In contrast, cells in the geometric design (5H) were initially level (0.7 x 10^5 to 5 x 10^5 cells/mL) over the first two months of flowback, then decreased an order of magnitude (0.6 x 10^4 cells/mL). These data provide initial insight into available nutrients and changes in redox-active elements potentially supporting microbial life in deep fractured shale.

Clay Mineralogy, Provenance, and Sequence Stratigraphy of Upper Ordovician Shales in Eastern Ohio

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A combination of X-ray diffraction analyses of core data and spectral gamma ray logs was used to interpret the largely shale succession of the Late Ordovician between the top of the Trenton Limestone and the Queenston Shale in the subsurface of east-central Ohio. The four county study area is within the back-bulge region of the foreland basin associated with the Taconic Orogeny. The XRD data from the basal portion of the section reveal an increase upward in chlorite and quartz along with a decrease in carbonate, which is consistent with an increase in detrital rather than authigenic clays. Detrital chlorite is a common clay mineral in sediments shed from mountain belts and the appearance of the clay allows constraints to be placed on the transition from under- to overfilled foreland basin. Isopach maps of six 4th-order sequences from 300 wells show that subsidence across the area was consistent and augmented by some combination of compaction over pre-existing structural and depositional features.

Subsurface Analyses of the Bedford-Berea Petroleum System in Eastern Kentucky

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The Berea Sandstone is a Late Devonian tight oil and gas reservoir that has gained new interest with the advent of horizontal drilling. The sandstone is actually a siltstone over much of its extent, which complexly interfingers with Bedford shales. This study utilized subsurface well data and core and previous outcrop descriptions to map the interval's distribution, evaluate potential structural influences, and attempt to differentiate the Berea Sandstone from the Bedford Shale.

To evaluate the Bedford-Berea interval, 555 geophysical well logs from the Kentucky Geological Survey's oil and gas database were used to generate structure maps, isopach maps, and cross sections of the Bedford-Berea interval and its possible hydrocarbon source rocks: the Sunbury Shale above and the Ohio Shale below. To differentiate the Berea Sandstone from the Bedford Shale, five core descriptions were correlated to gamma-ray logs to establish an API cutoff for Berea coarse siltstones and sandstones on subsurface gamma-ray logs. A Berea isolith map was then generated utilizing the API-cutoff parameter.

The Bedford-Berea has an elongate, north–south-oriented thickness trend that cuts across basement structures subparallel to the interpreted paleoshoreline of the Berea to the east in West Virginia. This trend is different than both the underlying and overlying source rocks. Within the elongate trend, areas of thicker Berea occur on a (1) structural high north of the Kentucky River Fault System and east of the Waverly Arch, (2) along the Irvine–Paint Creek Fault System including the Wallbridge Fault, (3) along the Rockcastle River and Warfield Faults (and uplifts) on the southern end of the Rome Trough, and on the Pike County Uplift, especially along the flanks of the D'Invilliers Structure.

The association of thicker Berea facies with structural highs in eastern Kentucky suggests structural influences on deposition, and either (1) reverse movement on some basement structures or (2) differential compaction of Bedford shales and truncation by Sunbury transgression.

Unconventional Resource Potential of the Sunbury Shale, Berea Sandstone, and Antrim Shale in Central Michigan

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The Early Mississippian to Late Devonian Sunbury Shale, Berea Sandstone, and Antrim Shale are part of a total petroleum system found throughout the Appalachian and Michigan Basins which is responsible for significant petroleum generation, migration, and production. The Antrim Shale is known for its high TOCs, although it has various degrees of maturity across the area. The Berea Sandstone is a shallow oil and gas reservoir in the Appalachian Basin and has limited production in the Michigan Basin. Some of the oldest production in Michigan is from the Berea Sandstone, where it has produced from several fields in and around Midland County. The latest significant Berea production was developed in the Williams field starting in 1980. The Berea Sandstone in the Williams field is a deltaic to marine deposit with offshore bar development. The Williams field is a combination strat-structural trap and to date nearly 2 million barrels of oil has been produced in the field from the Berea Sandstone. Although the Berea is primarily a conventional target, in the last few years operators started using horizontal wells to explore for these sands, especially in eastern Kentucky. The production in Kentucky is from shallow (< 2,000 ft), half-mile laterals which can produce as much as 40 MBO per well. Operators are considering horizontal drilling in the Sunbury-Berea-Antrim interval in central Michigan; however, poor data on Berea reservoir character combined with low commodity prices have stalled new development. An interesting characteristic of the upper Antrim Shale under and around Williams field is the resistivity changes from an average of 100 ohm-m outside of Midland County to an average of more than 1,000 ohm-m underneath the field area. Maps of the high resistivity area show an

apparent relationship between shallow oil production in central Michigan. The initial thought was this area of high-resistivity represented areas of mature hydrocarbon (oil-prone) generation; however, maturity studies showed the Antrim to be barely mature in the area. Additional migration studies are needed to understand the hydrocarbon potential of the Sunbury-Berea-Antrim sequence.

CO_2 Storage Resource Estimates for Cambrian-Ordovician Formations in Eastern Ohio

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Screening-level carbon dioxide (CO_2) storage resource estimates are essential for providing initial constraints on the feasibility of geologic CO_2 storage at regional and site-specific scales. The volumetric methodology developed by the U.S. Department of Energy's National Energy Technology Laboratory (DOE-NETL) was applied to nine Cambrian-Ordovician saline formations in eastern Ohio to characterize the prospective CO_2 storage resource of this region. "CO_2 storage resource" is defined by DOE-NETL as the volume of porous and permeable rock available for storage of CO_2. Geologic and petrophysical properties characterized as part of this project were used as input into the DOE-NETL CO_2-SCREEN tool to calculate CO_2 storage resource at the P10, P50, and P90 percentiles. Area, depth, thickness, pressure, temperature, and porosity were mapped for each formation and incorporated into single-layer static earth models (SEMs) for the heterogeneous scenarios. Multiple scenarios compare probabilistic heterogeneous and homogenous averaged values to evaluate resource estimation at various levels of input data resolution. Sensitivity analyses were conducted to determine the minimum representative number of grid cells, appropriate efficiency factors, and how to best represent mixed-lithology formations. The resulting static storage resource estimates were finally mapped for each formation to help create a roadmap to CO_2 storage in eastern Ohio.

Results suggest that the basal/Mt. Simon Sandstone, Maryville Dolomite, and Lower Copper Ridge Dolomite have the greatest CO_2 storage potential of the formations examined. The highest values were generally observed in central and south-central Ohio within the extent of Delaware, Fairfield, and Scioto Counties. Storage resource results are similar across the carbonate formations (Maryville, Conasauga, Copper Ridge, and Beekmantown), with spatial trends correlating to the presence of vugs, faults, and facies changes. This feasibility study provides insight into the storage potential of deep saline formations in eastern Ohio and highlights potential storage sites with the highest CO_2 storage resource. This project is funded by the Ohio Development Services Agency OCDO Grant OOE-CDO-D-13-22 and the U.S. DOE through the Midwest Regional Carbon Sequestration Partnership (MRCSP) award DE-FC26-05NT42589. The DOE-NETL CO_2-SCREEN tool (beta V1) was downloaded from the U.S. DOE's Energy Data Exchange (EDX) online platform.

Quantifying Microporosity in Clay Minerals of the Cypress Sandstone: Implications for Petrophysical Analysis and Diagenesis

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A petrographic study was conducted to characterize clay mineralogy and quantify clay microporosity in the incised valley fill facies of the Upper Mississippian Cypress Sandstone in the Illinois Basin. Clay micropores contain immobile water that causes increased formation conductivity. Microporosity also impacts estimates of clay mineral volume and water saturation; thus, microporosity should be included in calculated estimates. Additionally, observed clay mineral morphology and occurrence provides useful information pertaining to the formative diagenetic processes. This study utilizes electron beam methods to investigate whether water-saturated clay mineral micropores are causing anomalous well log analyses results, and to characterize micro-scale clay mineralogy.

Thirty-five petrographic thin sections of Cypress core exhibiting clay textures were analyzed using scanning electron microscopy, which was supplemented by back-scatter imaging (BSE) and energy dispersive X-ray spectroscopy. Observed clay mineral occurrences and morphologies include pore-filling kaolinite booklets, vermicules, chlorite clusters, illite mats, filamentous illite-smecite, grain-coating chlorite rosettes, and pore-bridging hairy illite. Percent-volumes of microporosity particular to clay mineral species were determined using BSE image analysis. Average values of microporosity in kaolinite, chlorite, illite, and illite smectite were 40 percent, 55 percent, 65 percent, and 65 percent, respectively. Effective clay mineral volumes including micoroporosity showed a > 2-fold increase over X-ray diffraction determined-estimates. To evaluate the accuracy of petrophysical techniques, samples with effective clay mineral volume were compared against volume of shale calculations based on neutron density-porosity and gamma ray logs. Petrographic analysis also revealed textural relationships indicative of diagenetic replacement between clay minerals. Mats of illite, for example, surround kaolinite booklets in pore-space, indicating an illitization process of a kaolinite precursor. Multiple morphologies of kaolinite, chlorite, and illite imply formation by multiple diagenetic processes, such as replacement of framework grains, or by direct precipitation from ion-rich pore-water.

As part of a multidisciplinary study to identify residual oil zones in the Illinois Basin, detailed petrographic study has resulted in quantification of clay mineral microporosity and additional details about diagenetic processes that affect reservoir quality. Together, these findings will enhance petrophysical estimates of water saturation, improve understanding of the diagenetic

history of the Cypress Sandstone, and highlight the importance of studying micro-scale mineralogical properties during reservoir characterization.

Most Effective Methods in Identifying, Etching, and Dissolving Limestones

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Limestones of different composition occur in Kentucky's subsurface, in addition to being exposed on over 50 percent of the surface. Limestones are of great importance in the geologic record worldwide. This sedimentary rock is composed largely of calcium carbonate ($CaCO_3$) composed of algae, fecal matter, and skeletal fragments of thousands of different types of marine organisms of various sizes. These remains were compacted and cemented together over millions of years. Seventy samples from four locations were slabbed into cubes of fairly similar size and weight, then tested with various concentrations of different acids.

Geologists' preferred method for testing for limestones is applying a 10 percent concentration of hydrochloric acid. Because limited published information was available, an experiment to test different concentrations of multiple acids was warranted to determine the most efficient methods for identifying, etching, and dissolving limestones. Hydrochloric, muriatic, acetic, sulfuric, and nitric acids in concentrations of 40, 20, 10, 5, and 3 percent were selected. Rocks were placed into glass beakers, and 100 ml of each acid was poured slowly onto the various rocks. Reaction was observed and noted during the next four hours and over the course of seven days.

Hydrochloric acids were very efficient in reacting with the limestones. They ranked first, third, seventh, and 11th. The 38.5 percent hydrochloric acid ranked first of all acids tested and 20 percent, third. They had a long and very violent reaction when added to the limestones. Nitric acids ranked second, fifth, ninth, and 12th. The 40 percent concentration reduced the limestone weight by 47.21 percent while exhibiting a moderately violent reaction. Muriatic acids ranked fourth, sixth, 10th, and 13th. The 31.5 percent acid concentration produced a forceful reaction, dissolving 43.22 percent of the limestone in a week. Sulfuric acids with concentrations of 40, 10, and 5 percent did not perform well; they ranked 15th, 16th, and 17th of all 17 acids tested. Sulfuric acid with a concentration of 20 percent ranked eighth. Acetic acid with a concentration of 3 percent was the only acetic acid used in the experiment. It was also the weakest of all acids used, but ranked 14th in efficiency.

A Devonian *Callixylon* Log of the *Archaeopteris* Tree Found in Marion County, Kentucky

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A rare fossil discovered in Kentucky gave geologists and paleontologists an opportunity to learn more about the natural history and origin of the rocks and fossils in the state. While excavating on his property in Marion County, a landowner encountered what appeared to be a tree imbedded in the black shale. He contacted the Kentucky Geological Survey at the University of Kentucky and asked them to investigate the find.

The petrified log was horizontal in the Devonian shale. It measured 20 inches in diameter, and about 13 ft of it had been excavated from the bed; however, more of it remained in place. Initial identification indicated that it was *Archaeopteris (Callixylon)*, a Middle to Late Devonian progymnosperm with fern-like leaves and gymnosperous wood *(Callixylon* is the formal genus name given to the petrified wood of *Archaeopteris).* A paleobotanist at KGS further confirmed the initial identification. Parts of the tree were cut into slabs and polished for closer examination, which revealed internal cell structures of wood, growth rings, quartz crystals, and fragments of woody material. The cell structures are similar to those of modern conifers. The organic black color and minerals, mainly quartz, were absorbed into the cell structure from the sediments as the log underwent petrification. Analysis of the petrified wood and surrounding material confirmed that the three most prominent constituents, in descending order, were silicon dioxide, aluminum oxide, and iron oxide.

The *Archaeopteris* tree is Middle to Late Devonian, about 370 to 390 million years old. One possible explanation is that it was transported by ocean currents from a forest located to the northeast, coming to rest in shallow water on the Cincinnati Arch. The trees eventually became waterlogged, sank, and were embedded in accumulating organic-rich black sediments. Or it may have grown in close proximity to where it was found, but no root casts have been found to date.

Changing Duration of Carboniferous Cyclothems; Implications for Coal and Lithofacies Distribution

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The concept of cyclothems and cyclic stratigraphy began in the U.S. Midcontinent and Appalachian Basins. Vertically repetitive alterations of lithofacies in Upper Mississippian through Upper Pennsylvanian strata in several basins have long been inferred, first relative to cyclothems, then transgressive-regressive cycles, and more recently sequence stratigraphy. The underlying causes of cyclicity, lithofacies distribution, and lithofacies continuity within parts of cycles have been attributed to glacio-eustacy, tectonics, sediment flux, and climate, with different researchers stressing the importance of one over the other. A parameter that generally has been kept constant relative to sedimentation in previous research is time.

Most previous researchers have attributed Late Mississippian and Late Pennsylvanian cyclicity to fourth-order (400K), long-eccentricity, glacio-eustatic cycles. Intervening Early and Middle Pennsylvanian coal-bearing cycles were thought to have the same duration. However, recent radiometric age dates for coals in the central Appalachian Basin suggest that at least part of the Early and Middle Pennsylvanian sedimentary record was dominated by fifth-order (100K) short-eccentricity cycles. If the record is at all incomplete, or thick marine zones represent more than one cycle, then parts of the section may even represent sixth-order (41K) cycles, stacking into larger fifth-order cycles.

Longer lowstands in fourth-order cycles would lead to more weathering and erosion, which could lead to more extensive and thicker paleosols as are seen in the Late Mississippian and Late Pennsylvanian. Longer weathering might also result in more tabular depositional surfaces and lithofacies distribution, as are typical in the Late Mississippian and Late Pennsylvanian. The average thickness and extent of coal beds, which is thicker in the Late Pennsylvanian than Early Pennsylvanian, might also be attributed to mires of longer duration in the Late Pennsylvanian.

Thinning Marine Zones of the Breathitt Group Along Kentucky Highway 15, Breathitt County, Kentucky

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The coal-bearing Breathitt Group is divided into formations by major, laterally correlative marine zones such as the Betsie Shale, Kendrick Shale, and Magoffin Members. In much of the basin, these members are easily recognized by their thickness (tens of meters), basal, variably fossiliferous black or very dark shales, and vertical profiles comprising one or more coarsening-upward successions. The shales represent major marine transgression followed by highstand progradation of delta front mouth bars into relatively deep water. Large (meter-scale) carbonate concretions are common. Major marine zones contrast with “minor” and more marginal marine zones, which are typically a few meters thick, lack black shale, rarely show well-developed coarsening-upward profiles, and rarely contain marine fossils. Minor marine zones represent delta-top lake or bay-fill successions.

On Ky. 15, which is located on the western cratonic margin of the basin, major marine and minor marine units are difficult to distinguish because gray shales in the major marine zones are thin (0–5 m), and the distinctive coarsening-upward part of the highstand tract is truncated by overlying sharp-based, fluvio-estuarine lowstand-transgressive sandstones. In addition, major marine zones on the basin margin may lack carbonate concretions, and only the base of the Magoffin Member contains abundant marine fossils. Stratigraphic correlations aid in narrowing down the interval in which the major marine zones occur. The Kendrick Shale is thick near Jackson, but mostly truncated northward. In the Betsie Shale, thin intervals of graded beds representative of deeper-water mouth bar or bayhead delta facies help to differentiate it from shallower-water gray shale facies. Also, the Betsie Shale along Ky. 15 contains several large slumps in which part of the original coarsening-upward strata have rotated below the incision level of the overlying sandstone. The slump fill provides evidence of at least some of the eroded section toward the basin margin.

NORM and TENORM—Are We Heading for a New Legal Normal?

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A byproduct of oil production is naturally occurring radioactive material (“NORM”), and its disposal in connection with primary recovery has historically not been unduly problematic for the oil industry. With secondary recovery projects such as waterfloods, the recirculation of water can enhance the level of radioactive material, creating technologically enhanced radioactive material (“TENORM”). The same effect can be created with hydraulic fracturing and recycling of wastewater. The widespread use of hydraulic fracturing, and the resultant public concern about it, has brought NORM and TENORM to the forefront of the public consciousness.

That new awareness of the existence and necessary disposal of NORM and TENORM has spawned a host of regulatory and legal actions related to its proper handling and disposal. This presentation would discuss generally the regulatory frameworks currently in place in the states comprising the Eastern Section. It would also review the trends of proposed changes in regulations and the state and federal litigation that may be driving some of those proposals. Finally, it will discuss the impact some of the proposed changes may have on oil and gas operations and waste disposal activities.

Petrophysical Characterization of the Kerbel Sandstone in Central Ohio for CO_2 Storage Potential

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Deep saline formations are of interest in eastern Ohio for CO_2 storage. Little is known of these formations due to the lack of oil and gas development, wireline data, and core data. Battelle conducted a regional geologic characterization of Ohio to assess the CO_2 storage feasibility for Cambrian-Ordovician age formations, including the Kerbel Sandstone. Limited existing data showed high porosity and permeabilities in the Kerbel Sandstone, making it a prime candidate for CO_2 storage in Ohio.

The Kerbel Sandstone was first proposed as a new formation by Janssens in 1973 as a replacement or lateral equivalent to the Cambrian-aged Maynardville and Franconia-Dresbach formations due to the different lithologies. It was originally interpreted as a delta deposit and later considered a barrier island (Banjade, 2011). The Kerbel Sandstone occurs in central Ohio and pinches out under the Knox Dolomite/Copper Ridge Dolomite in eastern and western Ohio (Janssens, 1973). The full extent has been interpreted to end in southern Ohio (Janssens, 1973) and central Ohio (Baranoski, 2012).

Detailed petrophysical analysis was conducted on 155 wells which penetrated the Kerbel Sandstone in central Ohio. Gamma ray, neutron porosity, and bulk density wireline logs were the most dominant data available with fewer than 40 wells having more advanced logs such as photoelectric index, resistivity, and acoustic logs. Core data were available for six wells and used to calibrate and interpret logs. The greatest CO_2 storage resource was interpreted to be in north-central Ohio where the porosities were highest and the net thickness was greatest. The lithology became more dolomitic and mudstone in southern Ohio, which correlates with a decrease in porosity and net thickness.

This work was supported by Ohio Coal Development Office Grant/Agreement OOE-CDO-D-13-22, and the Midwest Regional Carbon Sequestration Partnership (DOE-NETL Cooperative Agreement DE-FC26-05NT42589).

Analysis of Microbial Lipid Biomarkers as Evidence of Deep Shale Microbial Life

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The presence of native, viable microbial life from deep shale formations has ramifications on the extraction and production of oil and natural gas resources in the U.S. Wells at the Marcellus Shale Energy and Environment Laboratory (MSEEL) near Morgantown, West Virginia, have provided unprecedented access to pristine shale cores to probe microbial life at borehole depths reaching 7,500 feet below the surface. Lipid biomarker-based analyses applied to shale can provide insights to microbial life history, viability, community structure, and physiological strategies employed to cycle carbon and survive extreme environmental conditions. Preliminary analysis of phospholipids from cores in the upper Marcellus indicated recent life exists at some depths in the formation with biomarker signatures differing from those in drilling muds. However, the shale chemical matrix and low microbial biomass present multiple challenges; therefore, developing optimal methods for extracting and analyzing these biomarkers is of paramount importance. This research details our continued methods optimization process for characterizing microbial lipid biomarkers from pristine sidewall core samples obtained from MSEEL. We present strategies to maximize the recovery and preservation of bacterial and archaeal lipid signatures, as well as purification and chromatographic separation techniques used to isolate intact polar lipids, which are indicators of viable microbes. Direct analysis of intact polar bacterial and archaeal lipids through the use of ultra-performance liquid chromatography coupled with tandem mass spectrometry systems is also discussed. Lastly, the identification of non-polar lipid constituents using gas chromatography–mass spectrometry is described with emphasis placed on differentiating modern and ancient biomolecules. These methods, optimization procedures, and lipid biomarker analyses will improve our fundamental understanding of microbial life in deep shales, and enhance our knowledge of in situ biogeochemical processes, with practical relevance to energy production after shale development.

Kinematics of Past Tectonic Forces Inferred from Differential Sedimentation

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By analyzing changes in thickness of stratigraphic intervals across major fault systems, syndepositional fault movement during the respective depositional periods can be inferred. Major thickness differentials across faults are interpreted as evidence of tectonic-related syndepositional fault movement. Additional sedimentation occurs within the increased accommodation space created by vertical displacements along faults. These areas of increased thickness are greatest along normal faults that are perpendicular to the extension direction, and decrease to zero along faults that are parallel to the extension direction. Regional extension directions and relative magnitudes through time can be interpreted by analyzing differential sedimentation patterns across populations of normal faults with varying strike directions.

Detailed subsurface mapping of six stratigraphic units was used to produce a map-view summary of interpreted fault movements from the Early–Middle Cambrian (Reelfoot Arkose) to the Early Mississippian (New Albany Shale) in the Rough Creek Graben and Northern Reelfoot Rift in the southern Illinois Basin. Given the set of faults that were active during the deposition of the Early–Middle Cambrian Reelfoot Arkose, the interpreted extension ($\sigma 3$) direction is northwest-southeast. During this time, the Laurentian tectonic plate was separating from the Amazonian Plate, and the active spreading center that ultimately produced the Iapetus Ocean was shifting from the Blue Ridge rift to the Ouachita rift. The northwest-southeast directed strain vector interpreted from syndepositional fault movement corresponds well with this tectonic environment.

Extension continues throughout the deposition of the Middle–Late Cambrian Eau Claire Formation; however, the vector of extension appears to rotate to a north-northeast to south-southeast direction by the end of that period. This extension direction appears to then diminish to zero during the deposition of the Late Cambrian–Early Ordovician Knox Group. Relatively minor fault offsets occurred throughout the Middle Ordovician–Early Devonian Period. During the Late Devonian, an intriguing pattern of fault offsets occurred on the northeastern and southern edges of the Rough Creek Graben. This deposition is contemporaneous with the Acadian Orogeny to the east, and is interpreted as a far-field tectonic effect of the west–southwest-directed tectonism.

Favorable Areas to Focus Future Trenton Exploration in Indiana

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Public domain geological and geophysical data has been used to define basement structural features and to determine their influence on Trenton Formation structures and hydrocarbon production in Indiana. The study has identified several favorable areas to focus future exploration efforts.

The crust in Indiana probably formed from the accretion of island arcs to a NE/SW trending continental margin approximately 1.5 bya followed by rifting approximately 1.3 bya. Basement zones of weakness associated with the accretion and subsequent rifting caused much of the structural grain in the region. The crustal extension associated with rifting allowed the emplacement of intrusives, which caused partial melting of the crust and overprinting of the previous structural grain.

Numerous tectonic events along the eastern and southern margins of the craton subsequently reactivated basement structures in Indiana. The most significant events affecting the Paleozoic section were the Taconic and Alleghenian Orogenies.

The relationship between Trenton structure and basement structure is often profound on both regional and local levels. Of particular importance in northern and east-central Indiana are basement calderas. In southern and west-central Indiana, the interaction between linear faults is important.

Definition of favorable exploration trends can be refined as areas of interest are identified. Detailed potential field data can be used to define leads, minimizing the need for seismic data. In some areas the public domain magnetic data is adequate for this task. Detailed gravity data has been shown to be particularly useful for identifying Trenton structures.

Monitoring Induced Microseismicity in the Rome Trough, Eastern Kentucky, U.S.A.

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The Cambrian Rogersville Shale is a part of a recently discovered petroleum system in the fault-bounded Rome Trough of eastern Kentucky and West Virginia. In Kentucky, the Rogersville Shale ranges in depth from approximately 5,000 ft to 10,000 ft below surface. Oil and gas from this system can be produced only with high-volume hydraulic fracturing (fracking). Subsurface injection of the large volumes of wastewater produced from similar operations and, less frequently, fracking has led to cases of induced seismicity in other locations. Although fracking operations and wastewater injection are ongoing in eastern Kentucky, no related seismicity has been detected in the area. The Kentucky Geological Survey (KGS), with Cimarex Energy, the University of Kentucky Department of Earth and Environmental Sciences, and Nanometrics Inc., has begun a multi-year, collaborative monitoring project to establish baseline microseismic data in the Rome Trough, focusing on areas of completed and planned oil and gas test wells in the Rogersville and clustered wastewater injection wells.

Currently, 12 broadband seismic stations have been deployed. Two more stations are planned for installation this year to yield an average station spacing of 25 km (~15 mi) in the project area. Existing University of Kentucky and USGS-adopted EarthScope seismic stations are contributing to the network. Data are wirelessly telemetered and acquired in real time at KGS, and real-time event locations have been established. Four local (< 20 mi) earthquakes have been detected and located using this network since June 2015. None of these events was proximal to any operational disposal or oil and gas wells in the project area, nor did any occur in the Rome Trough of eastern Kentucky.

Integrated Sub-basin Scale Exploration for Carbon Storage Targets: Advanced Characterization of Geologic Reservoirs and Caprocks in the Upper Ohio River Valley

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The goal of this study was to collect and analyze geologic data for assessment of CO_2 storage feasibility in the parts of the Appalachian Basin covering eastern Ohio and the adjacent Midwestern area. The deep geology is relatively unknown as the formations are not prospective for oil and gas development. As such, very few deep wells have been drilled, logged, and tested.

The research characterized potential caprocks and reservoirs. This required integration of numerous data sources including publicly available wireline logs, core data and production records, new log and core data through synergistic partnerships with local operators, the purchase of available seismic volumes and data from 10 new brine disposal wells in Ohio. Data collection included advanced wireline logs and core that helped characterize geomechanical, lithological, mineralogical, and geochemical properties of reservoirs and caprocks.

Basin scale mapping was performed to characterize structure, extent, and depths for selected geologic zones from Ordovician, Cambrian, and Precambrian formations. Petrophysical parameters including net to gross thickness, porosity, porosity feet, and porosity-permeability relationships were evaluated for each formation. Petrophysical results indicated a formation's suitability as a storage resource or sealing formation. Conclusions suggest that both sands and carbonates in the Appalachian Basin are potential storage resources. The discontinuous nature of individual formations means that a series of stacked reservoirs and seals are needed to form the basis of the basin scale geologic carbon sequestration system. Ongoing static and dynamic modeling will demonstrate the ability of the stacked reservoir system to function for long-term CO_2 storage.

Analysis and Characterization of Utica–Point Pleasant Production

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The presentation will begin with an overview of Utica development in Ohio, Pennsylvania, and West Virginia over time including a summary of the wells drilled by state, county, and operator and summaries showing production by state, county, and operator.

A regional look will then review Utica–Pt. Pleasant Estimated Ultimate Recovery (EUR) and EUR per 1,000 ft of lateral length, and progression of the EUR per 1,000 ft over time. A detailed review of one to two counties per state will then be reviewed showing mapping of the EUR per 1,000 ft and example individual well production decline curves as well as EUR summaries by operator.

Finally, an even more detailed analysis will be presented on one to two counties comparing production results and EUR to frac stages, frac volumes, lateral lengths, IPs, geophysical logs, lateral landing depths, and operator.

Long Period, Long Duration (LPLD) Seismic Events Observed During Monitoring of Hydraulic Fracturing in Pennsylvania and West Virginia

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Hydraulic fracturing is a well-established completion technique to efficiently extract significant volumes of natural gas from unconventional formations such as shale, which would otherwise behave as impermeable formations. Diffusion of water outward from the newly created hydraulic fractures into the reservoir helps reactivate the preexisting faults and fractures and initiates shear failure on complex networks of preexisting planes of weaknesses. We carried out surface seismic monitoring of hydraulic fracturing in Greene County, Pennsylvania, and in Monongalia County, West Virginia. We used a single broadband seismometer within the footprint of six lateral wells for surface monitoring in Greene County. In Monongalia County, we monitored the hydraulic fracturing operation at an active well pad with five seismometers. Common field observations related to microseismic fracture-mapping indicates preferential growth along the maximum horizontal stress. Recent findings on long period, long duration tremors suggest that "slow slip emission" along weaknesses that are unfavorably oriented in the ambient stress field is likely the dominant mechanism of deformation and plays a vital role in reservoir stimulation. We identified 117 high-amplitude, impulsive events and 473 long period, long duration (LPLD) events from the combined dataset of hydraulic fracturing in Marcellus Shale in Greene County and Monongalia County. The timing and location of the majority of the impulsive events does not favor any causal relationship with the hydraulic fracturing in the study area. We used a mine blast database and three component surface seismic recordings of blasts to accurately characterize these events, which could be misinterpreted for LPLD events. The LPLD events identified in this study show a low-frequency, low-amplitude precursor followed by a relatively high-frequency, high-amplitude primary S wave signal and similar to other long duration events identified in previous studies. Spectral analysis of LPLD events revealed an anomalous concentration of energy at low frequencies (1–30 Hz). During various stages of hydraulic fracturing, LPLD events were found to occur most frequently when the pumping pressure and rate were at maximum values. These observations suggest that long period, long duration events are generated in response to highly elevated fluid pressure and may play a significant role in the reservoir stimulation.

Lithofacies and Sequence Framework of the Upper Cambrian Galesville and Ironton Sandstones in Illinois

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The Upper Cambrian (Furongian) Galesville Sandstone and the overlying Ironton Sandstone cover the northern half of Illinois and are an important aquifer in the northern part of the state. They are a part of the Knox Group and constitute the upper part of the Sauk II subsequence. The Galesville and Ironton are over 200 feet thick in northern Illinois but their thickness decreases toward the south where they grade into a dominantly carbonate lithofacies. This study focuses on lithofacies analysis, depositional setting, stratigraphy, and lateral distribution of the succession using available subsurface data.

In northern Illinois, the Galesville (up to 100 feet thick) conformably overlies the Eau Clair Formation and underlies, with a gradational contact, the dolomitic Ironton Sandstone. It is a white, very porous, and fine-grained mature quartzose sandstone. The Ironton Sandstone (up to 100 feet thick) is fine- to coarse-grained, white, and porous quartzose sandstone that is interbedded with dense dolomitic sandstone or sandy dolomite containing relicts of ooids and bioclasts. Its contact with the overlying glauconitic sandstone of the Franconia Formation appears to be unconformable. Numerous erosive based dolomitic sandstone storm beds composed of quartz sand, shale clasts, and carbonate grains are present in the Ironton Sandstone. Exceptional maturity and coarsening-upward cycles of these units indicate deposition in a shoreface setting under fair to storm weather conditions. The upper part of the Eau Claire, the Galesville, and Ironton constitute a depositional sequence in which the gray glauconitic shale and sandstones in the upper parts of the Eau Claire represent the transgressive package and the succeeding coarsening-upward shoreface deposits of the Galesville-Ironton represent the highstand package. The Ironton and Galesville Sandstones thin southwestward and grade into dolomite and sandy dolomite of the upper part of the Bonneterre Formation. Deposition of Bonneterre carbonates in the southern part of the Illinois Basin occurred when sea level rose during early Late Cambrian, resulting in the development of a vast carbonate platform and confined terrigenous sedimentation to the northern part of the basin.

Petroleum Geochemistry of Devonian Rocks and Produced Oil and Natural Gas in the Caseman-Gross Unit #1 Well, Bradford County, Pennsylvania

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Predicting the thermal limits of crude oil stability in the earth's crust is a critical component of unconventional resource plays. Recent literature indicates that oil is stable in the subsurface up to temperatures of approximately 200°C. This observation has several implications for assessing the relative contributions of kerogen, bitumen, oil, and light hydrocarbon cracking to natural gases retained in shale-gas reservoirs. The thermal maturity of organic matter in source rocks influences the API gravity and the GOR/COR of hydrocarbon liquids produced from unconventional mudrock and tight-sandstone reservoirs. If the temperature history of an oil accumulation falls within the necessary range, secondary cracking of the oil will proceed.

The cracking of autochthonous post mature kerogen and residual oil was the source of thermogenic gas produced from the Marcellus Formation in Bradford County, Pennsylvania. The Marcellus was also the source of supermature light oil (API = 45.82; heptane ratio = 38.70) produced from shallow Upper Devonian tight sandstone in the Caseman-Gross Unit #1 well in Springfield Township, Bradford County. Various geochemical screening parameters show the produced liquids were generated in the late oil window at burial temperatures of approximately 130 to 150°C (VRe ~1.3–1.4 percent) long before the Marcellus Formation reached a maximum burial temperature of ±200°C and its presently observed level of maturity (VRe = 2.7, TAI = 3.7). Light oil produced from the Lock Haven Formation migrated upwards from the Marcellus Formation and escaped complete thermal destruction.

Stable gas isotope data show that associated gases produced with oil from the Lock Haven Formation in the Caseman-Gross #1 well are a mixture of primary and secondary hydrocarbons. The gases are cumulative, and exhibit a partial isotopic reversal with respect to carbon number. Methane mostly consists of late-mature primary gas co-generated with oil through kerogen cracking at VRe ~1.36 to 1.4 percent. Some methane, however, was generated by early oil cracking at a generation temperature of ~175°C. Ethane and propane are secondary gases generated by oil cracking at higher maturity (VRe ~1.8 percent).

Our data provide important constraints for modeling petroleum generation, migration, and preservation in the Marcellus-Catskill/Lock Haven Formations petroleum system in northeastern Pennsylvania.

Stratigraphy and Reservoir Characterization of the Grundy Formation (Pennsylvanian, Eastern Kentucky) in Relation with the Overlying Pikeville and Hyden Formations

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Pennsylvanian successions of eastern Kentucky are well known as excellent outcrop analogues for Carboniferous fluvio-deltaic reservoirs in coal-bearing strata. Well-established, high-resolution correlations and previous work on regional geology enable detailed studies of sedimentology and sequence-stratigraphic development. In addition, extensive roadcuts permit a direct, 3D analysis of architectural geometries and heterogeneities.

The Breathitt Group is a coarsening- and shallowing-upward succession of Lower to Middle Pennsylvanian shallow-marine and fluvial deposits, representing the infill of an elongated foreland basin developed during the Alleghenian Orogeny. It has been divided into eight formations, each bounded at base by a basin-wide marine unit. Stratigraphic cyclicity in the Breathitt Group is commonly attributed to high-magnitude glacioeustatic fluctuations driven by Gondwanan glaciations. The uppermost formations in the group (Pikeville, Hyden, Four Corners, and Princess) have been extensively studied since the early 80s. However, lower formations are poorly or not exposed, and therefore accessible only through subsurface data. Since 2014, new outcrops of the Grundy Formation have been exposed by roadworks for U.S. 460 in the area of Elkhorn City. Here we compare sedimentology, architecture, and stacking patterns of the Grundy Formation with the overlying Pikeville and Hyden Formations, outcropping along U.S. 460, near Pikeville.

In this study we focus primarily on an extensive outcrop, approximately 1 mile wide and 500 feet thick, exposing most of the Grundy Formation and the basal part of the Pikeville Formation. Twelve sedimentary logs have been measured, and 50 rock samples extracted for quantitative porosity, permeability, and QEMSCAN analyses aimed at an evaluation of reservoir properties for the main sandstone bodies. Previous authors established that the Pikeville and Hyden Formations are generally formed by vertically stacked, erosively based transgressive depositional sequences of (1) river-dominated deposits and incised-valley fills, (2) transitional coastal to marginal-marine sediments, including coal beds, and (3) regionally extensive, distal marine deposits. We aim at explaining the differences in the stacking patterns between the Grundy and overlying formations, especially the decreasing proportion of continental deposits and the lesser volume of incised-valley fills, as well as their different sedimentological expressions. In addition, this study aims to combine outcrop and subsurface data from the area into a geo-cellular, 3D facies and architectural model for fluvio-deltaic successions, thereby trying to link reservoir-rock properties to sequence-stratigraphic phase.

Development of Quick-Look Maps for CO_2-EOR Opportunities in the Appalachian and Michigan Basins

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The Midwest Regional Carbon Sequestration Partnership (MRCSP) is currently in the final phases of comprehensive characterization of carbon capture utilization and storage (CCUS) opportunities throughout the 10-state region. Spanning from the offshore Atlantic Coastal Plain through the Appalachian and Michigan Basins, this region hosts a diverse assemblage of reservoir types and provides multiple CCUS targets. A key component of this research is the evaluation of opportunities for enhanced oil recovery (EOR) in legacy oil fields via carbon dioxide (CO_2) floods. In support of this task, the West Virginia Geological and Economic Survey has developed a set of “quick-look” maps that illustrate state-specific opportunities for CO_2-EOR. These maps contain a variety of field-specific data, including CO_2 storage capacity, residual oil in place, and oil gravity.

Several data types, most notably reservoir permeability and oil gravity, are significantly under-represented in the dataset. Oil gravity is particularly useful as it is used to calculate minimum miscibility pressure. In this case, methods were developed to help predict values for oil fields in the Appalachian Basin where applicable.

For each of seven MRCSP partner states (NY, PA, WV, KY, OH, IN, MI), a map was developed illustrating the location and reservoir characteristics of key legacy fields, as well as their proximity to major CO_2 point sources. This work is designed to be used by any researcher or stakeholder interested in investigating viable CCUS opportunities within the MRCSP region.

EIA Expanded Geographic Coverage of Oil and Natural Gas Production, with New Data for 10 States

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In 2015 EIA has expanded its reporting of monthly oil (including lease condensate) and natural gas production by 10 additional states. The addition of these states—Arkansas, California, Colorado, Kansas, Montana, North Dakota, Ohio, Pennsylvania, Utah, and West Virginia—significantly enhances EIA’s monthly coverage, which was previously limited to Louisiana, New Mexico, Oklahoma, Texas, Wyoming, and the Federal Gulf of Mexico.

Accompanying EIA's expanded coverage has been a new webpage, Monthly Crude Oil and Natural Gas Production, which replaces the Monthly Natural Gas Gross Production Report. EIA uses it to report survey-based estimates for monthly crude oil and natural gas production from the states covered by the new EIA-914 survey, including production data categorized by API gravity, an important measure of crude oil quality.

Monthly oil and natural gas production estimates for 15 states, the Federal Gulf of Mexico, and the rest of the country (aggregated and reported as "Other States") are provided through February 2016. These estimates are based on data collected from a sample of U.S. operators on the expanded Form EIA-914 survey, with the exception of Alaska, which directly reports its volumes. Monthly production estimates for the expansion states, as with the original individually surveyed states and areas, are available with only a two-month lag; for example, the May release includes production estimates for February 2016. Previously, estimates for these 10 states were delayed by as much as two years.

The expanded geographic scope of the EIA-914 survey is in response to significant increases in U.S. oil and natural gas production over the past several years, as well as important changes in production sources over this period. For example, the original EIA-914 survey, which was initiated in 2005, did not offer individual coverage for states such as Pennsylvania that have undergone transformative natural gas production growth, or for other states.

Oil and natural gas production data collected on the EIA-914 survey are used as inputs to several EIA products, including the Natural Gas Monthly and EIA forecasts such as the Short-Term Energy Outlook and the Annual Energy Outlook.

Utilization of Factor of Safety in Geotechnical Solutions

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The factor of safety concept is indispensable to engineering practitioners. Factor of safety is simply the ratio of capacity to load. A factor of safety of 1.0 means the approximation of load is equal to the approximation of capacity. Increasing factor of safety to 2.0 means the expected capacity is twice the expected load.

The concept is frequently misunderstood, misapplied, and misrepresented. This latent confusion leads to excessive confidence in a design as well as excessive cost due to overdesign and unwarranted criticism of appropriate designs. Those who make decisions based on factor of safety need to understand what it means and what it does not mean.

Using engineering analysis, this paper demonstrates that a wide range of safety factors can be calculated for a given design problem, all of which could be considered reasonable. This paper will further review the costs associated with demanding an excessive factor of safety.

Two examples will be used to illustrate the associated costs of increasing the factor of safety. Engineering analysis will illustrate the design parameter changes that will need to be employed to increase each solution's factor of safety and the associated non-linear cost increase for each design. This paper will illustrate that (1) factor of safety alone is not sufficient to select an appropriate design, (2) site conditions and risk assessments must also be considered to effect an appropriate solution for the specific application, (3) factor of safety mandates can increase costs but may not increase safety.

New Insights & Perspectives on the Effects of Structural Reactivation on the Upper Devonian Antrim Shale, Michigan Basin

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The Upper Devonian Antrim Shale of the Michigan Basin has proven significant economic viability with a total cumulative gas production of > 3.43 TCF. Over 11,000 Antrim wells have been completed, with 9,181 of those wells being online as of January 2016. Spatially, production volumes and the chemical composition of both natural gas and formation waters vary throughout the Antrim Shale. Previous studies have attributed variable natural gas compositions to mixing, bacterial alteration, and migration, whereas formation waters indicated the mixing of brines from deeper formations with freshwater recharge. Recent studies of noble gas signatures suggest that the source of natural gas in the Antrim Shale has migrated vertically from deeper formations. Variability in the natural gas and formation waters composition were attributed to microbial methanogenesis of thermogenic gas due to the influx of meltwater proximal to the Antrim subcrop following the Wisconsin glaciation. Currently, there is limited knowledge on the mechanism that has induced migration and the controls on the distribution of thermogenically derived hydrocarbons. Evaluation of the spatial distribution of the specific gravity and chloride of formations waters and gas composition suggest the occurrence of localized thermogenic hydrocarbon (e.g., C^{2+}-ethane) anomalies. The preservation of thermogenic components is attributed to isolation from meltwater invasion or recent migration of hydrocarbons due to neotectonic influences. Localized thermogenic hydrocarbon anomalies were observed spatially proximal to the subcrop suggesting the occurrence of structural conduits that have enabled the migration of dense saline brines as well as thermogenically derived hydrocarbons. Evaluation of structural contour and derivative models suggest that these younger structural lineaments extend vertically through the Traverse Limestone as well as the

Sunbury Shale, the lower and upper stratigraphic boundaries of the Antrim Shale, respectively. It is proposed that these structural lineaments overlie deep seated basement faults enclosed within a regional transtensional pull-apart subbasin. Subsequent reactivation within the Michigan Basin is proposed to have induced movement along the deeper pull-apart system extending vertically through the Sunbury Shale. Overall, this study provides new insights and a conceptual model for the potential structural mechanism that controls the occurrence and distribution of thermogenically derived hydrocarbons.

Unification of Compositional Data and High-Resolution Facies Analysis in the Union Springs Formation of New York

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Compositional data and facies analysis are commonly employed to evaluate organic-rich mudstones within both the academic and industrial realms. Compositional analysis of these rocks, commonly performed using handheld X-ray fluorescence on drillcore or well cuttings, supplies workers with relative abundances of volumetrically major and trace elements within a rock. Often supported through the incorporation of total organic carbon data, these data are utilized to draw conclusions regarding paleodepositional environment, resource potential, and mechanical behavior. Facies analysis classifies rocks based upon a suite of visually identifiable characteristics including mineral content, bedding character, fossil abundance, and other properties related to their paleodepositional setting. This research examines the geochemical variability within and between facies categories, leading to a more comprehensive depositional assessment and a test of the predictive power of compositional data at the microfacies scale.

For the Union Springs Formation of central New York, microscopy and hand sample analysis reveal that 15 microfacies comprise three broad lithofacies groups in three complete sections at locations spanning a 38.6 km distance. Rocks of each microfacies were compositionally analyzed using handheld X-ray fluorescence in order to obtain major and trace elemental composition, and LECO carbon analysis in order to measure total organic carbon content. Inter-facies and intra-facies variability was statistically assessed to determine the relationships between the physically defined facies categories and major element, trace element, and total organic carbon abundances.

This study establishes the geochemical significance of physically defined facies categories. As expected, compositional analysis quickly provided valuable paleodepositional insight, and most microfacies display a compositional signal matching the mineralogic signals identified in thin section. However, major and trace element variability is not constant across microfacies, and some facies possess a narrow compositional range while others are variable. Geochemical variability between microfacies is strongly correlated with depositional features such as bedding character, and diagenetic features such as cementation. The incorporation of petrographic analysis, which supplies information about heterogeneity generated by cementation, bioturbation, and organic matter morphology, strengthens interpretations that are commonly based on composition alone. Assessments of paleoenvironments, resource potential, and mechanical behavior all improve through the combination of compositional and microfacies information.

Addressing Health Issues Associated with Air Emissions Around UNGD Sites

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Direct-reading aerosol sampling at one minute intervals was done at five locations around an Unconventional Natural Gas Development (UNGD) site located in a river valley in Morgantown, WV, as part of the Marcellus Shale Engineering and Environmental Laboratory (MSEEL) project. Sampling was done throughout all stages of well development other than pad preparation. Sampling locations included: on the drill pad itself, as well as 1 and 3 km distant. Background samples were also taken as reference. The first was 5 km upwind of the site and out of the valley. The second was located within the valley 8 km downwind but beyond the bend of a natural bowl in the valley, diminishing the effect of air emissions from the UNGD site.

EPA-regulated PM2.5 (particles less than 2.5 micrometers in diameter, capable of reaching the lung airspaces in a human) emissions were not detectable from background at 1 km downwind during highest emissions periods on the well pad. However, truck routes used for supplying the well were situated away from all the sampling sites and thus not monitored. Modeling data using sampling of similar truck routes in the area showed that levels expected to accompany well development could be above the background levels that were not from traffic sources and could therefore produce measurable health effects. Also, terrain and meteorological conditions are expected to influence the results at other locations and during other times.

Toxicological analysis of particulate matter sampled around active drill sites has shown the potential to produce cardiovascular damage upon exposure in laboratory animals. Future efforts are needed to delineate the effects of truck traffic from well pad activities to determine if either source, alone or in concert, may be responsible for the observed laboratory effects and to address a growing body of epidemiological evidence associating exposure from UNGD activities with disease symptoms, especially adverse birth outcomes, in populations residing in proximity to UNGD.

Geochemical Characterization of Lower Wolfcamp Unconventional Reservoirs, Midland Basin (Texas)

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The Lower Wolfcamp play (Wolfcamp D and C2) in the Midland Basin represents an important shale oil prospect in the portfolios of many operators holding acreage in western Texas. A defining characteristic of the Lower Wolfcamp is high frequency vertical facies variability, comprised of a diverse suite of marine mudrocks and carbonates. Cyclic facies stacking in the Lower Wolfcamp most likely reflects dynamic climatic, tectonic, provenance, and oceanographic processes that affected the Midland Basin deepwater and platform environments during the Late Pennsylvanian. Geochemical characterization of Wolfcamp D and C2 continuous drill cores using different analytical tools (X-ray fluorescence [XRF], LECO total organic carbon [TOC], Rock-Eval pyrolysis), supplemented by well-logs and thin section petrography, was performed to better understand unconventional reservoir characteristics along the strike of the basin. Major and trace elements derived from XRF scans revealed two distinct black mudrock facies, defined primarily by differences in silica and aluminum content. Although both black mudrocks are relatively rich in organic carbon (> 2.0 wt. percent), the siliceous variant exhibited higher average concentrations of TOC, pyrite, and redox-sensitive trace metals, suggesting that preservation of Type II organic matter was enhanced by low seafloor oxygen availability and stagnant recharge. In many instances, thin section data appear to show that the origin of excess silica in these mudrocks is biogenic, an interpretation that is supported by the presence of geochemical indicators with strong linkages to high surface water paleo-productivity. The thickness and distribution of silica-rich black mudrocks in Wolfcamp D is challenging to discern using well-log datasets or hand samples alone, thus validating the application of high-resolution chemostratigraphy for reservoir characterization in this petroliferous interval.

Insights on Porosity and Pore Size Distribution Using Multiple Analytical Tools: Implications for Reservoir Characterization in Geologic Storage of CO_2

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The geologic description and quantification of the physical properties that define a viable reservoir are fundamental for assessing the feasibility of a reservoir to receive and store injected CO_2 in the deep subsurface. Two petrophysical properties, porosity and permeability, constrain the reservoir in terms of its storage potential and injectivity. The analytical tools that are useful for measuring these properties vary and are optimally employed at various scales.

We analyzed 52 rock samples from the Cambrian-Ordovician Knox Supergroup spanning a significant area of the Midwestern United States. These samples represent a wide range in both the scale and magnitude of the porosity present in this prospective storage reservoir. The samples were analyzed for total porosity and pore size distribution, using petrographic image analysis, helium porosimetry, gas adsorption, mercury porosimetry, and (ultra) small-angle neutron scattering. These analytical techniques were collectively used to understand the relationship between porosity, permeability, and pore size distribution; they offer a unique opportunity to study a wide range of pore sizes and to understand the validity of employing these techniques collaboratively.

Results from nitrogen and carbon dioxide adsorption and from mercury injection capillary pressure are important in that they provide insights on small pore size that otherwise cannot be resolved by standard low-pressure helium porosimetry or by image analysis software. Additionally, results from analyses of these carbonate reservoir rocks suggest that microporosity does not have a considerable impact on permeability, but larger pores control this key petrophysical parameter for constraining fluid flow through the pore system.

Hierarchical Evaluation of Geologic Carbon Storage Resource Estimates: Cambrian-Ordovician Units Within the MRCSP Region

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The Midwest Regional Carbon Sequestration Partnership (MRCSP) aims to study the regional distribution and geologic storage suitability of units within the Cambrian-Ordovician sequences, including the Knox Supergroup, St. Peter Sandstone, Trenton and Lexington Limestones, and equivalent units across the MRCSP region.

To date, we have compiled a comprehensive dataset of wireline logs and petrophysical information that include core analysis for porosity and permeability and mercury injection capillary pressure (MICP) analyses. Using these data, carbon storage resource estimates (SRE) are evaluated using a hierarchical approach that addresses uncertainty in the estimates by incorporating different models of formation porosity based on a series of increasingly complex portrayals of the pore system. The simplest analysis follows the USDOE methodology whereby an SRE is calculated using a single value for porosity in the assessed formation. Additional estimates follow the same general methodology but employ increasingly precise spatially variable porosity models based on formation diagenesis (depth-dependent function), reservoir suitability (effective porosity), distinct petrofacies (advanced reservoir characterization), and multiple realizations of porosity using data-driven geostatistical methods.

Results from this hierarchical approach help illuminate the magnitude of uncertainty that should be expected in SREs as a function of data availability and the level of reservoir characterization that is achievable for a given formation. A semi-probabilistic SRE calculation methodology using Monte Carlo simulations to create models for porosity generally tends to underestimate the range of uncertainty in storage resource. Conceivably, the higher the order model, the lower the uncertainty in the SRE. Ongoing research is investigating whether improved precision implicit in higher orders of the hierarchy are generating more accurate estimates of storage volumes.

Improved Oil-in-Place Estimates in Clay- and Pyrite-Bearing Shales Based on Inversion of Multi-frequency Electromagnetic Measurements

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Subsurface electromagnetic (EM) measurements, namely galvanic resistivity, EM induction, EM propagation, and dielectric dispersion, exhibit frequency dependence due to the interfacial polarization (IP) of clay minerals, clay-sized particles, and conductive minerals. Existing oil-in-place estimation methods based on subsurface EM measurements do not account for dielectric permittivity, dielectric dispersion, and dielectric permittivity anisotropy arising from the IP effects. The conventional interpretation methods generate inaccurate oil-in-place estimates in clay- and pyrite-bearing shales because they separately interpret the multi-frequency effective conductivity and permittivity using empirical models.

We introduce a new inversion-based method for accurate oil-in-place estimation in clay- and pyrite-bearing shales. The inversion algorithm is coupled with an electrochemical model that accounts for the frequency dispersion in effective conductivity and permittivity due to the above-mentioned IP effects. The proposed method jointly processes the multi-frequency effective conductivity and permittivity values computed from the subsurface EM measurements. The proposed method assumes negligible invasion, negligible borehole rugosity, and lateral and vertical homogeneity effects.

The successful application of the new interpretation method is documented with synthetic cases and field data. Water saturation estimates in shale formations obtained with the new interpretation method are compared to those obtained with conventional methods and laboratory measurements. Conventional interpretation of multi-frequency effective conductivity and permittivity well logs in a clay- and pyrite-rich shale formation generated water saturation estimates that varied up to 0.5 saturation units, as a function of the operating frequency of the EM measurement, at each depth along the formation interval. A joint interpretation of multifrequency conductivity and permittivity is necessary to compute the oil-in-place estimates in such formations. Estimated values of water saturation, average grain size, and surface conductance of clays in that formation are in the range of 0.4 to 0.7, 0.5 micrometer to 5 micrometers, and 5 × 10 ^-7 S to 9 × 10^-7 S, respectively. The proposed method is a novel technique to integrate effective conductivity and permittivity at various frequencies. In doing so, the method generates frequency-independent oil-in-place estimates, prevents underestimation of hydrocarbon saturation, and identifies by-passed zones in shales.

Strange Sample-Thickness Dependence of Multi-frequency Complex Dielectric Permittivity of Shales and Sandstones

Siddharth Misra and Pratiksha Tathed, University of Oklahoma

Multifrequency complex dielectric permittivity measurements are widely used for material characterization. We used Keysight impedance analyzer E4990A and Keysight dielectric fixture 16451B to perform two-electrode complex dielectric permittivity measurements on 24 percent-porosity Berea sandstone and shale samples from various shale plays in the frequency range of 100 Hz to 30 MHz at ambient temperature and pressure conditions. The samples were studied in their dry state and also when fully saturated with deionized (DI) water and brine. All samples exhibit large frequency dispersion of complex permittivity and complex conductivity, which is attributed to the Maxwell-Wagner polarization mechanism. The dielectric constant of dry, DI-water-filled, and brine-filled samples vary smoothly from 3.5 to 15, 3.5 to 2,000, and 20 to 105, respectively, for variation in frequency from 30 MHz to 1 kHz. The DI-water-filled samples and brine-filled samples exhibit peak dielectric loss factor within 1 kHz to 10 kHz and 10 kHz to 100 kHz, respectively. Conductivity estimates for the samples obtained between 100 Hz and 1 kHz are 50 percent lower than those obtained between 10 kHz and 1 MHz, which are 100 percent lower than those obtained above 10 MHz. The high-frequency permittivity measurements were compared against CRIM predictions based on AP-608 confined porosity measurements and fluid saturation estimates. In comparison to non-contact method, the contact method generates higher quality measurements. No significant change in permittivity estimates was observed upon cleaning the Berea and shale samples with a mixture of toluene and methanol. The permittivity measurements decreased when the two transverse sample surfaces in contact with electrodes were polished to reduce the surface roughness. Permittivity measurements exhibit substantial low-frequency alteration below 20 kHz when the saturated samples were wrapped with parafilm to prevent water loss from the samples. Complex permittivity is a geometry independent property; nonetheless, the measured complex permittivities decrease with the decrease in sample thickness, such that the complex permittivity variation with thickness increases at lower frequencies. For DI-water-filled and brine-filled samples, multifrequency complex conductivity obtained from the complex permittivity measurements exhibit large deviation from those obtained from a resistivity cell.

Summary of Publicly Available Production Data for the Devonian Berea Sandstone Play, Eastern Kentucky

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The Devonian Berea "sandstone" was discovered in Lawrence County in the late 1870s. Major Berea development occurred in the 1920s and in the late 1950s with the advent of waterflooding. In the 1980s, Section 29 tight formation tax credits temporarily made the Berea interesting again. Recently, horizontal drilling and slickwater fracture stimulations have led to a Berea renaissance, with Lawrence County now the leading oil-producing county in the state. Berea wells completed since 1997 were selected that had enough periods of publicly available production data for analysis to characterize the initial performance of the wells.

The maximum reported monthly production rate, first year cumulative production volume, and production decline were modeled. For each well with sufficient data, the better fit of an exponential or hyperbolic decline curve was used to characterize production trends. A gas production index was defined as the ratio of gas production to the sum of oil and gas production on a barrels of oil equivalent basis and used to map regional trends in oil- and gas-prone production. Well performance was divided into three classes based on the first year cumulative production at the 25th and 75th percentiles. Typical oil and gas decline curves for each of these groups exhibit significant differences relative to predicted future performance.

Based on limited historic production data, Berea oil producers outperform typical Kentucky wells. The Berea in Greenup and Lawrence Counties is oil-prone while Pike County exhibits a significant wet gas-prone area with some wells reporting varying amounts of oil production.

Estimation of Saturation-Dependent Relative Permeability in Shales Based on Adsorption-Desorption Isotherm

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Relative permeability in shales is an important petrophysical parameter for purposes of accurate estimation of production rate and recovery factor, efficient secondary recovery, and effective water management. We present a method to estimate saturation-dependent relative permeability in shales based on the interpretation of the low-pressure nitrogen adsorption-desorption isotherm measurements. Relative permeability was determined for 30 samples from the gas- and oil-window of Eagleford and Wolfcamp Shale formations. These samples have low-pressure helium porosity (LPHP) in the range of 0.04 to 0.09 and total organic content (TOC) in the range of 0.02 to 0.06. The samples were ashed to study the effects of removal of organic matter on the pore size distribution, pore connectivity, and relative permeability. The estimated irreducible water saturation and residual hydrocarbon saturation are directly proportional to the TOC and LPHP, and exhibit 15 percent variation over the entire range. Pore connectivity, in terms of average coordination number, decreases by 33 percent with the increase in TOC from 0.02 to 0.06. The estimated fractal dimension is close to 2.7 for all the samples. The estimated relative permeability of aqueous phase and that of hydrocarbon phase at a given saturation is inversely proportional to the TOC. Relative permeability curves of the hydrocarbon phase for geological samples from various depths in a 100-ft interval indicate that the hydrocarbon production rate will vary drastically over the entire interval and these variations will increase as the hydrocarbon saturations reduce in the formation. In contrast, relative permeability curves of the aqueous phase suggest limited variation in water production rate over the entire interval. Further, based on the relative permeability curves, the hydrocarbon production is predicted to be negligible for hydrocarbon saturations below 50 percent and the water production is expected to be negligible for water saturations below 80 percent. Efforts are ongoing to use the laboratory-based estimates to predict field-scale production and recovery rates.

Arcobacter Isolated from the Produced Fluids of a Marcellus Shale Well May Play a Currently Unappreciated Role in Sulfur Cycling

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Microorganisms play a pivotal role in the corrosion of steel infrastructure and the biodegradation of chemical additives used for hydraulic fracturing in hydrocarbon-rich shales. Although numerous studies have reported the presence of novel microbial community members in produced waters recovered from shale gas wells within the U.S., cultivation of these microbes and characterization of their metabolisms relating to energy production has lagged. Here we report methods for isolation and cultivation of a novel bacterial species with a 16S rRNA gene sequence closely related to DNA sequences observed in produced fluids from

several Marcellus and Utica–Pt. Pleasant Shale wells. Phylogenetic analysis of the 16S rRNA gene revealed our isolate is closely (~99 percent 16S identity) related to *Arcobacter marinus* CS-L1, a halotolerant marine bacterium of the class Epsilonproteobacteria. The *Arcobacter* strain is one of several genera isolated from produced fluids collected from wells and separator tanks at the Marcellus Shale Energy and Environment Laboratory (MSEEL) field site near Morgantown, West Virginia. We are currently characterizing the salinities this *Arcobacter* strain can tolerate, the carbon substrates that it can utilize, and its preferred mode of respiration through cultivation studies and genome sequencing. Multiple species in previously characterized *Arcobacter* genus are known to be involved in sulfur oxidation (including hydrogen sulfide [H_2S], elemental sulfur, and thiosulfate) using oxygen and nitrate electron acceptors. This new isolate may therefore prove important for reducing concentrations of corrosive products (e.g., H_2S) under certain redox conditions in shale energy systems.

New Insights into Precambrian Seismic Stratigraphy, South-Central Indiana

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Analyzing Precambrian geology in intracratonic basins is restricted, almost exclusively, to geophysical investigations. We present and interpret three 2D seismic reflection profiles in south-central Indiana and interpret two distinct pre-Mt. Simon seismic reflection sequences in the context of regional geology. These seismic profiles were donated by CountryMark Inc. and were previously discussed by Walker and Hinks (2015). The two distinct seismic units are observed below the typical succession of well-stratified Paleozoic rocks and are comprised of an acoustically transparent zone of sporadic and discontinuous internal reflections overlying a highly reflective and well-layered interval that persists to at least 2.0 s TWTT. Marked westward thinning of this transparent unit occurs in east-west profiles accompanied by a thickening of the basal layered sequence.

Fitting our seismic data to a geologic model, we interpret the regional existence of a Precambrian clastic sedimentary unit overlying rocks of the Eastern Granite-Rhyolite Province (EGRP). Shrake (1990) and Drahovzal et al. (1997) discuss the occurrence of the Middle Run Formation in southwest Ohio as poorly reflective and underlain by a reflective, layered sequence. Recently, Freiburg (2015) described the existence of the pre-Mt. Simon Argenta Formation from core in central Illinois. A deep well in Lawrence County, Indiana, recovered basaltic rocks from below the Mt. Simon, which is consistent with the occurrence of mafic flows or sills within the Middle Run of northern Kentucky (Drahovzal et al., 1997). The deeper well layered unit observed in these profiles resembles that described on COCORP data across Illinois where it was termed the Centralia Sequence and part of the EGRP (Pratt et al., 1989). The pattern of poorly reflective clastic rocks overlying strongly layered sequence of the EGRP may be a consistent pattern seen in seismic data across the region.

Late Silurian–Early Devonian Paleogeography Part 1—Basal Sands of the Sealevel Lowstand

Bill Pfalzer, Independent Researcher (geologist and retired geotechnical engineer)

During Pridoli and Early Devonian, an exceptionally large magnitude, long lasting sealevel lowstand exposed huge areas of the North American craton that had formerly been sites of marine deposition. For millions of years, weathering and erosion became dominant geological processes. Karst was well developed within widespread carbonates, and a major unconformity developed. Sands were produced by erosion of highlands. With removal of fines (sedimentary bypassing) and carbonates, additional sands accumulated by concentration. During Early Devonian, most of the craton was exposed, and sands continued to accumulate in structurally higher settings through Middle and into Late Devonian. Middle and Late Devonian sealevel fluctuations were dominated by a progressive sealevel rise. As sealevel rose, unconsolidated sands that had accumulated primarily during Early Devonian were incorporated as basal beds of many different deposits. Traditionally, we have dated these sand intervals to match the ages of overlying deposits, but we should not allow that to blind us to the fact that they originated primarily during Early Devonian. In moderately low/deep portions of basins, exposed as dry land during the Early Devonian sealevel lowstand but subsequently flooded by Middle Devonian sealevel rise, sands are incorporated at and near the base of Middle Devonian carbonates. Sands continued to accumulate in terrestrial environments in areas not yet inundated by rising Middle Devonian seas. These were later incorporated at the base of Upper Devonian/Lower Mississippian black shales. We regard these sands as "younger" because areas in which they occur were not inundated until this much later period. However, the "younger" sands beneath the black shales accumulated throughout the same exposure period as the "older" sands at the base of Middle Devonian carbonates. All of these sands are time transgressive in terms of when various portions of the sand bodies were inundated and incorporated into sediments later lithified. Within individual stratigraphic sections, it is possible, even likely, to have sands occur at multiple levels. In areas previously inundated, with the principal sand at the base of the oldest post-Early Devonian rock unit, blankets of windblown or waterborne sands might subsequently be transported from higher areas not yet inundated.

Late Silurian–Early Devonian Paleogeography Part 4—Explaining Devonian Brachiopod Provinciality and Distributions

Bill Pfalzer, Independent Researcher (geologist and retired geotechnical engineer)

Based largely upon the work of Boucot, Johnson, and Talent (1967), it has been recognized that during most of Silurian time, “cosmopolitan” brachiopod genera were much the same everywhere. Beginning in latest Silurian, however, isolation of eastern America began to allow brachiopod evolution there to diverge from evolutionary developments elsewhere. Upon the North American craton west of the structural high referred to as the Continental Backbone, and in most other areas, brachiopod cosmopolitanism continued. However, in eastern North America, isolation continued through Early Devonian, and the distinct character of the “Appalachian Provincial Fauna” intensified. Johnson (1970), in “Taghanic Onlap and the End of North American Devonian Provinciality” (GSA Bulletin 81, p. 2077–2106) attributed resumption of a worldwide cosmopolitan brachiopod fauna in Late Devonian to rising sealevels. This implies, of course, that the cause of Appalachian Provincialism had been the falling sealevels of latest Silurian and Early Devonian. Brachiopods, as benthic marine organisms, are restricted to relatively shallow waters; their dispersal patterns necessarily follow shorelines, and their spread into new areas would be blocked both by deep water and emergent land areas. With severely falling sealevels, newly emerging structural highs constituted increasingly formidable barriers to brachiopod dispersal. Eventually, a complete isolation of eastern America was attained. Johnson reluctantly suggested that water temperature boundaries may have also played a role. Referencing studies of faunas along the western coast of the Americas, he noted that equatorial faunas could be dispersed only so far north or south before encountering waters too cold to allow their survival. Another very important aspect of these authors’ work is that the Appalachian Provincial Fauna has also been recognized in northeastern Mexico, Columbia, and Venezuela. Presented herein is a paleoreconstruction of the positions of continental landmasses that meets paleolatitude requirements of experts working in this field, but has the advantage of also explaining the isolation and extent of the Eastern America Realm. Because the proposed configuration presents a “Mediterranean” type sea in eastern America, it also eliminates the need for water temperature boundaries because the area of isolation is surrounded by landmasses.

Silurian Reef Systems in the Illinois and Michigan Basins—What Can Be Learned from Modern Quarrying Operations in North-Central Indiana

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The quarrying of dolomite and limestone material from the Silurian of north-central Indiana has been ongoing for over 100 years. These quarrying operations are located near the crest of the northwest to southeast trending Cincinnati Arch generally along river valleys where the amount of glacial overburden that needs to be removed prior to quarrying is minimal. These quarrying operations have created vertical outcrops that can be hundreds of feet in height and over 1,000 feet length of Silurian carbonates. A significant number of these quarrying operations have cross-cut and exposed Silurian reef complexes. These reef complexes range from tens of feet to over thousands of feet in width and up to 100 feet in height.

Silurian reef complexes are very important oil and gas reservoirs in the Michigan and Illinois Basins. In the Michigan Basin, over a thousand reef complex oil and gas fields have been discovered since the 1950s, producing approximately 500 MMBO to date. While in the Illinois Basin, production from Silurian reef complexes was initiated in 1946, with over 130 MMBO having been produced to date from nearly 100 reef complex reservoirs. Unfortunately, many of the Silurian reef reservoirs discovered in the 1950s through the 1980s are poorly documented by seismic, incomplete well penetrations of the reservoir interval, limited well logs and core material. Future enhanced oil and gas recovery and exploration programs targeting Silurian reef reservoirs will depend on a better understanding of these complex carbonate reservoir systems to be successful. Where can we get additional geological information on these complex carbonate systems? The exposed Silurian reef complexes and associated flank carbonate facies exposed in currently operating quarries in north-central Indiana can provide information on potential carbonate facies development, reservoir heterogeneity, geometry, and potential fluid flow characteristics of Silurian reef complexes not available from existing Silurian reservoirs in the Illinois and Michigan Basins or natural outcrops. Let’s take a virtual field trip of these man-made outcrops.

Applications of Scientific Core Drilling in North Carolina: Cumberland-Marlboro Basin, and the Triassic Rift/Lacustrine Dan River Basin

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State-funded continuous coring in the Cumberland-Marlboro “Basin” (CMB) and Dan River Basin (DRB) was undertaken to further evaluate the hydrocarbon potential of the state’s onshore Triassic rift/lacustrine basins.

The CMB, a large negative aeromagnetic anomaly buried beneath a thin (200–400 feet thick) Coastal Plain cover, is strike parallel and seaward of the Deep River Triassic rift basin assessed by the USGS for hydrocarbon potential. Geologic literature postulated the presence of a Triassic rift/lacustrine basin. The state groundwater well database (GW-1) provided equivocal data as to the presence of Triassic strata. Two basement studies presented equivocal data that could be interpreted either as paleoweathering of metavolcanic rocks or Triassic strata.

Three Rotasonic drillholes advanced into the basement recovered 4-inch-diameter cores along the CMB anomaly's strike extent and encountered metavolcanic rocks. Thin section study confirmed metavolcanic basement rock. Thus, a large Triassic rift/lacustrine basin is not present; however, the presence of a very small rift/lacustrine basin like that of Bertie County, NC, cannot be precluded in NC and SC.

The DRB 1,477-foot continuous wireline corehole (SO-C-1-15) penetrated, in descending stratigraphic order, Dry Fork Fm., Walnut Cove Fm., and the Pine Hall Fm., and terminated in metavolcanic basement rocks below surface at a depth of 1,451 feet. The core penetrated the 325-foot-thick Walnut Cove Fm. (the lacustrine source rock) from a drilled depth of about 98 feet to 424 feet containing previously unreported gassy coals, coaly intervals, and coarse silt intervals. Beginning at a depth of 253.1 feet, the side track corehole (SO-C-1A-15) recovered a 3-foot coal and coaly section followed by organic mudstone interspersed with siltstone, that when wetted with soapy water, showed apparent hydrocarbon outgassing, and confirmed a total petroleum system.

The DRB corehole confirms the Walnut Cove Fm.'s downdip continuity and thickness, and may become the future type section for the Pine Hall Fm. Organic geochemistry (TOC, percent Ro), thermal maturity, mineralogy, rock mechanics, MICP porosity and permeability, and pore studies are underway. Rock mechanics and mineralogy data will provide velocities for potential future industry seismic surveys.

A Protocol for Baseline Sampling of Water Sources in Areas of Shale Oil and Gas Development

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In many areas of shale oil and gas development, sampling of proximate water sources (e.g., residential water wells, springs, seeps, and surface waters) prior to installation or stimulation of production wells (i.e., "pre-drill") is standard practice for many oil and gas operators. These programs provide a "baseline" snapshot of water quality for comparison to conditions after oil and gas production commences (i.e., "post-drill"). This information is critical for evaluating whether reported changes in local water quality (e.g., methane, salts, taste, odor) are naturally occurring or the result of nearby drilling activities. Many state agencies require pre-drill and/or post-drill sampling of various water sources (primarily residential water wells); however, little guidance is currently available to operators, regulators, and contractors to support development of these sampling programs.

This talk presents the findings of a Department of Energy–funded research project, which evaluated key sources of variability in pre-drill sampling results from a series of residential water wells in northeastern Pennsylvania and eastern Kentucky. Results from these field studies culminated in the development of the practical protocol for sampling of residential water wells. The protocol includes: (i) current state regulations for pre-drill and post-drill sampling, (ii) sampling practices and lab analysis methods, (iii) data management and analysis procedures, and (iv) tools to discern natural variability in water quality from potential anthropogenic impacts. This talk provides an overview of the components of the protocol, critical findings from the field studies, and implications for development of future pre-drill and post-drill sampling programs in areas of shale oil and gas development.

A Sequence Stratigraphic Model for the Silurian A-1 Carbonate of the Michigan Basin

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The Lower Salina A-1 Carbonate is the primary source rock for hydrocarbons in the Silurian (Niagaran) Reef Complex reservoirs, which are some of the most prolific reservoirs in the Michigan Basin. To date, State records from the Michigan Office of Oil, Gas and Minerals report that A-1 Carbonate hydrocarbon production occurs in 31 fields as sole producing unit in that field or in combination with Niagaran or other Salina units. Nearly 3.3 million barrels of oil and 37.5 BCF of natural gas has been produced from the A-1 Carbonate throughout the MI Basin. Previous studies interpret the A-1 Carbonate as a shallow subtidal to supratidal deposit that sits on top of the reefs. Despite their close proximity and strong association in the hydrocarbon system, the sequence stratigraphic relationship between source and reservoir rock are poorly constrained.

To establish the timing and environments across the basin, fundamental sedimentological observations from cores are coupled with geochemical data collected with a handheld X-ray fluorescence spectrometer. One of the principal observations comes from an anhydrite unit called the "Rabbit-Ear Anhydrite (REA)," which has been previously interpreted as a localized supratidal deposit that formed only around the periphery of paleotopographic highs of the older Niagaran reefs. New observations from cores and wireline logs from deeper in the basin show that the REA is instead a basinwide depositional unit which ranges from sabkha to deep-water settings and separates the A-1 Carbonate into an upper and lower unit. This suggests that REA is a time-correlative unit across the basin and can be used to separate the A-1 Carbonate into upper and lower units.

Sequence stratigraphic correlations are further aided by lithofacies relationships and elemental trends (Mg, Ca, S, Fe, etc.), which point to four regionally-extensive, fourth-order shallowing upward cycles. Each shallowing upward cycle exhibits intervals of dolomite corresponding to the most regressive depositional facies. These dolomitic prone intervals are correlated across the basin and should allow for more informed exploitation of resources with the A-1 Carbonate. In contrast, elements such as S, Fe, Si, Sr, and K are more prominent within maximum flooding zones.

Assessing Thermal Maturity in Cambrian Source Rocks, Rome Trough, Appalachian Basin: Organic Petrology Complexities

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Interpretations of thermal maturation provide critical data needed for both conventional and unconventional resource assessments. The absence of true vitrinite in pre-Devonian sediments eliminates one of the most commonly measured geothermometers used for thermal maturity determination. Programmed pyrolysis parameters like T_{max} can be of limited utility given the maturity regime. However, other organic macerals are potentially available to constrain thermal maturity. The current organic petrology study has been undertaken to provide a very detailed comparison of reflectance measurements on pyrobitumens, "vitrinite-like" material and graptolites.

In the Appalachian Basin of North America, Cambrian-aged source rocks were deposited in shallow water mixed carbonate-siliciclastic depositional environments. Solid pyrobitumen material is found to occur in both lenticular lens/layer morphology as well as distinct pore-filling angular varieties. Published formulas to calculate Equivalent Reflectance (Eq. Ro) from solid bitumens have been applied to these discrete morphological populations. In addition, a newly developed formula to calculate Eq. Ro from angular pyrobitumen (VRc = 0.866 * BRo ang + 0.0274) is introduced based upon statistical evaluation of reflectance readings from a global dataset. "Vitrinite-like" organic macerals were found in rare abundance within these potential source rocks, but their occurrence enables an independent comparison to pyrobitumen Eq. Ro values. Graptolites are another organic maceral that can be evaluated via organic petrology, but caution should be utilized since these tend to show a high degree of anisotropy. The results of this investigation provide additional geochemical guidance to assist geologists in more accurately interpreting thermal maturity in the Rome Trough region of the Appalachian Basin.

State of Stress in the Illinois Basin and Constraints on Inducing Failure

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The stress regime in the Illinois Basin was investigated to assess how the rock column might respond to the injection of fluids, including co-produced formation brines and supercritical CO_2. This response is a concern as injection practices could increase pore pressure and potentially induce seismicity.

Data were collected to determine the magnitude and orientation of a three-component stress field: vertical (Sv), minimum (Sh), and maximum (SH) horizontal stresses. Sv was evaluated with a six-layer lithostratigraphic column. A two-layer pressure-depth Sv model for the central portion of the basin and a single pressure gradient model for the surrounding region were generated. In the central portion of the basin, the Sv gradient is 1.11 psi/ft to a depth of 7,000 ft, followed by a gradient of 1.20 psi/ft below 7,000 ft. In the area surrounding the deep basin, the Sv gradient was calculated as 1.13 psi/ft. Sh was evaluated from multiple data sources, primarily fracture closure values from either hydraulic fracture records or extended leak-off tests. Sh gradient calculations ranged from 1.07–1.21 psi/ft. The Sh values for the basal clastic units that directly overlie the crystalline basement complex are lower than those for units in the overlying horizons. SH was based on a critically stressed model yielding values between 1.77 to 2.65 psi/ft, which is significantly greater than the gradient values for Sv or Sh.

Stress orientation data for the Illinois Basin were collected from multiple sources. The orientation of the principal stress, SH, across the study area relatively uniform in strike at approximately N°60E, but has marked deviations. These deviations result from localized structural discontinuities in the crust.

Indigenous Life in Extreme Environments: Characterizing Pristine Shale Rock Hosted Biomass

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The terrestrial subsurface is estimated to be the largest global reservoir of bacterial and archaeal biomass, but few studies have been performed in this environment due to technical challenges and costs associated with sample recovery. This study seeks to characterize the diversity and distribution of microbial life in the Marcellus Shale formation and their associated interfaces within the Appalachian Basin, and to investigate the potential impact of these organisms on hydrocarbon reservoirs and extraction techniques. Pristine sidewall cores from the Marcellus Shale and associated formations were collected as part of the Marcellus Shale Energy and Environment Laboratory (MSEEL) research effort. We decontaminated the outer surfaces of the cores and used the resulting ground material to inoculate a variety of cultivation experiments. These assays, operated under atmospheric and high-pressure conditions, were designed to enrich for metabolisms potentially occurring in deep subsurface shale. Due to the low biomass within these formations, single-cell genomics are being utilized to characterize the cultivated microorganisms from pristine shale. Through previous preliminary experimentation with a *Halanaerobium* isolate obtained from hydraulic fracturing produced fluids, we have optimized methods for desorbing biomass from shale surfaces. Microbial populations enriched in the presence of sulfate and methylamines in pristine shales have been submitted for single cell genomic analyses. Future tasks include quantification and sorting of the shale derived cells using flow cytometry, followed by genomic DNA sequencing from individual cells. Data from these investigations will reveal adaptations and new metabolisms of these indigenous organisms persisting in this extreme shale environment. This study is the first of its kind to investigate the role of indigenous microbial life in the Appalachian Basin, and will provide insight into the role of deep subsurface organisms and how they may influence hydrocarbon extraction techniques.

Optimizing Lateral Placement and Production While Minimizing Completion Costs Using Downhole Geochemical Logging

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One of the most difficult battles that occurs with respect to well completions is efficiency versus effectiveness. A presentation by Chris Fredd at the 2014 Second EAGE/SPE/AAPG Shale Gas Workshop in Dubai reported that approximately 40 percent of all shale oil wells were not profitable because many of the frac stages were not effective. While there are many reasons for the lack of effectiveness, one of the most common reasons is the focus on efficiency over effectiveness. Once production drilling begins it is easy to understand the push to standardize drilling operation to preset well spacing, lateral lengths, the number of frac stages, and spacing to optimize operation and minimize costs.

However, effectiveness also plays an important part in optimizing profitability. For example, setting frac stages in zones that contain little or no hydrocarbons and low porosity increases completion costs without increasing production.

This case study will discuss how Downhole Geochemical Logging (DGL) indicated similar production could have been obtained by using five frac stages instead of eight, thus saving the company $600,000 in completion costs. Additionally, DGL data indicated that lateral placement had not been optimal, indicating greater liquid hydrocarbon intensity and better porosity upsection in the well.

In the lateral portion of the well the Downhole Geochemical Logging data was able to show:

- How to improve production by focusing the lateral in more hydrocarbon rich and better porosity zones
- How to reduce completion costs by optimizing the number of fracing stages
- Porpoising of the lateral drilling effort
- Identify when drilling efforts were in or out of the target formation

In the vertical portion of the well the Downhole Geochemical Logging data was able to:

- Infer multiple seals not detected in the well logs
- Clearly distinguish various hydrocarbon phases (i.e., gas, condensate, or oil)
- Identify bypassed pay
- Identify a water saturated zone in a deltaic sandy shale section

- Serve as a proxy for porosity which was of particular value in a wash-out section where the density log was misleading
- Identify one section as a conventional tight sand instead of a shale section.

Creating a 3D Hydrocarbon Profile to Increase Production and Reduce Poor Economic Wells: A Utica Case Study

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Shale plays represent a difficult arena in which to explore since each shale play is unique in terms of organic content and rock property. While general lessons can be translated from one play to another there are important differences which control exploration and development decisions. Due to the heterogeneity of resource plays they can even differ within a single field. This means that effectual development of shale plays requires extensive evaluation and coordination of various data sources such as geology, geophysics, geomechanics, petrophysics, and engineering. However, while these conventional disciplines bring a wealth of important data to the discussion, one important data set is often lacking—hydrocarbon data.

Given the heterogeneity of shale plays, it is important to identify the variability of hydrocarbon richness, pore pressure, and porosity in a three-dimentional sense across a field. This variability is often one of the primary reasons for production differences across a field. Traditionally these parameters are assessed by analyzing core or cuttings samples as wells are drilled and then this single-point data is extrapolated field wide. However, extrapolating this data across the field is suspect and numerous wells must be drilled to develop a remotely accurate model. Thus, the data could be deemed more postmortem rather than predictive.

This case history will demonstrate how ultrasensitive surface hydrocarbon mapping was used, with little well control, to:

- Identify areas of higher hydrocarbon richness and better porosity
- Differentiate and map areas with economic and noneconomic gas charge
- Differentiate and map gas and liquid hydrocarbon signatures throughout the area
- Map natural fractures charged with gas hydrocarbons

Additionally, the case history will demonstrate how ultrasensitive downhole geochemical logging was used to demonstrate:

- Where there was compartmentalization and seals in the upper section of the well
- There were three different liquid sources and two different gas sources in the well
- The noneconomic gas production was sourced from the Utica formation
- The economic gas was sourced from the Trenton formation
- The surface survey liquid anomalies were being sourced from the upper and lower Queenston formations.

Evolving EPA Subpart W Greenhouse Gas Reporting Rules Challenge Oil and Gas Operators

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Recent greenhouse gas (GHG) regulatory actions targeting oil and gas operations have led to complicated data collection and confusing emission calculation requirements. This presents a compliance challenge for operators, particularly in light of increased public and regulatory scrutiny of the industry. However, operators of petroleum and natural gas systems can avoid reporting pitfalls by implementing a management system to ensure compliance.

For the petroleum and natural gas industry, the key factor that makes Subpart W applicability so unique and expansive is its definition of "facility." The regulation does not apply a traditional definition of a facility, as in the physical boundaries of contiguous or adjacent property, but instead applies to the defined segment. For example, under the Natural Gas Distribution segment, "facility" is a local distribution company as regulated by a state public utility commission, whereas the Onshore Production segment defines a facility as all emission sources on well pads, or associated with well pads, that are under common ownership or control and is located in a single hydrocarbon basin as defined by the AAPG. What is traditionally termed the Appalachian Basin is actually defined as two AAPG basins (160 and 160A).

Given that companies potentially have hundreds or thousands of wells, gathering lines and associated equipment, thousands of datasets need to be collected to report GHG emissions. The sheer volume of information collected not only represents emissions data, but also the potential for non-compliance. Successful entities look at this process as an opportunity to not only track GHG emissions but to also establish a management system to ensure compliance with the myriad of operating requirements. A well-thought-out program that embraces the operator's organizational structure, operations, and field personnel, coupled with a robust tracking system, will lead to compliant operations. Keep in mind, a system itself will not be successful without management buy-in. Experience demonstrates that it is imperative for management to promote and emphasize inter-departmental collaboration to ensure that information is provided to compliance staff in a timely and complete fashion.

Understanding Biogeochemical Controls on Spatiotemporal Variations in Total Organic Carbon in Cores from Marcellus Shale Energy and Environment Laboratory

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Shale reservoirs are a critical and rapidly growing area of energy where research lags behind exploration and production activity. Since shale is not only a hydrocarbon source but also a reservoir, one of the key geological factors controlling its hydrocarbon potential is the concentration of organic matter (OM), its maturity, and its type. In the course of the last 15 years, hydrocarbon exploration of shale reservoirs has revealed significant temporal and spatial variations in the quality and quantity of total organic carbon (TOC). This variability is directly attributed to geological and biotic conditions at the time of deposition; however, the major controls on, and thus predictability of, organic-rich black shale deposition are still debated. The availability of pristine sidewall cores and an entire full hole core from Marcellus Shale Energy and Environment Laboratory (MSEEL) provides us the unique opportunity to significantly increase the resolution of subsurface stratigraphic characterization integrated with molecular/isotopic/elemental geochemistry to better understand the controls on lithofacies, including dilution by terrigenous detritus, OM productivity, preservation, and decomposition in organic-rich black shales. Some of the traditional techniques like source rock analysis used to understand sources and types of OM have limited application in mature to highly mature shales due to their low hydrogen and oxygen indices. Biological markers or biomarkers are excellent indicators of OM sources, redox, and maturity. Biomarkers are chemically stable during sedimentation and early burial but their preservation potential also decreases with maturity. The availability of samples at MSEEL enables us to optimize extraction and analytical methods to characterize the abundance and type of biomarkers present in the highly mature dry gas window of Marcellus Shale. The biomarker data will be used in conjunction with C/N/S isotopes and elemental geochemistry to develop elemental and molecular fingerprints of source/type of OM, microbial cycling of OM, and paleoenvironment during deposition of MSEEL core.

Mineral/Organic Matter Associations and Pore Microtextures in the Marcellus Formation, West Virginia

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Understanding detailed reservoir-rock mineralogy and pore structure is important for elucidating water-rock interactions that occur during hydraulic fracturing of Marcellus shale. Core samples from a depth of 7,451.5 feet from an active production well (MIP 3H) in Morgantown, West Virginia, have been interrogated by light and electron microscopy. We examined fresh cleavage fragments as well as rock surfaces that were gallium ion beam polished. Fragment orientations, based on rock cleavage planes, are observed both parallel and perpendicular to bedding. The goal is to assess the natural pathways for fluid migration and to link the resulting produced water chemistry to mineral and organic materials that contribute to that chemistry.

At least three texturally distinct types of organic matter (OM) are identified in Marcellus Shale samples. These include relatively large pods visible with the digital light microscope, and two finely disseminated occurrences associated with illitic clay or clustered (some framboidal) pyrite that are only resolved with scanning electron microscopy (SEM). Backscattered electron (BSE) images and energy dispersive X-ray spectroscopy (EDXS) reveal dendritic and needle-like Fe-Mg rich clay (consistent with chlorite) intimately intermingled with the pods, which are roughly circular and approximately 200 microns in diameter, as measured parallel to bedding. The matrix clay surrounding the pods is mostly illitic in composition. In addition, the pods also contain euhedral quartz and calcite crystals, which are interpreted to be diagenetic and possibly represent biologically mitigated crystallization.

Dual-beam focused ion beam (FIB)/SEM slices acquired with secondary electron detectors reveal different pore textures within these organics. The first, large, pod type OM does not show obvious pores. The second and third types (illitic clay- and pyrite-associated OM) have obvious pores and occur in much smaller clusters. The porous OM types range from approximately hundreds of nanometers to a few microns in size, and contain pores ranging in size from single to tens of nanometers. Nitrogen gas sorption measurements are planned to help assess the pore size distribution of the connected pore network.

Using Ultrasensitive Surface Detection to Evaluate Potential and Actual CO_2 Sequestration Sites

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A primary mode of Carbon Capture and Sequestration (CCS) is geologic sequestration in which carbon dioxide (CO_2) is injected into underground geologic sinks. Critical to the success of geologic sequestration is the need to ensure that underground storage sinks have adequate seal and do not leak to pose a potential threat to human health and the environment.

However, the ability to determine if these subsurface structures have adequate seal prior to CO_2 injection and that those seals remain leak-proof is difficult since there are not many CO_2 monitoring technologies available to provide adequate sensitivity and coverage for underground sequestration. However, ultrasensitive passive geochemical sorbers at the surface can provide the ability to monitor co-injected chemical tracers at nanogram mass levels (10–9 grams), thereby assessing the effectiveness of containment.

This case study took place in 2012 in the Yibal field located within the Fahud Salt Basin in northwestern Oman. The purpose of the survey was to ground-truth the ability of high sensitivity surface geochemical imaging to map elevated hydrocarbon compound response along faults, as a proxy for CO_2 tracers, and thus to identify segments of potential fault leakage from the Natih A reservoir.

Ultrasensitive samples were deployed at the surface over structural closures at depth (i.e., depleted petroleum reservoirs) to monitor indications of natural leakage pathways. After deployment, collection, and analysis, hydrocarbon signatures were detected and differentiated along fault trends. Enhanced light hydrocarbon signatures were mapped along coherent segments of fault projections inferring reservoir leakage along specific fault traces. The surface geochemical survey was able to detect subsurface leakage at low response levels.

In other projects involving this survey technique, fluorinated hydrocarbon tracers have been mixed with CO_2 and injected into structural closures, with geochemical data used to establish baseline leakage profiles for long term monitoring efforts. This work has taken place on three continents, as recently as 2015, and has shown that ultrasensitive passive geochemical sorbers can be used in CCS monitoring programs.

Subsurface Geomechanics, Fracture Breakdown Pressures, and "Fracture-Tunnels" in the Midwest U.S.

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A great deal of new geotechnical information is available from shale gas wells, carbon dioxide storage research, and brine disposal wells. Together, these data provide a better understanding of subsurface geomechanical conditions, which is an important factor for subsurface resource management. To characterize geomechanical conditions in the Midwest Region, a combination of geophysical image logs, fracture breakdown pressures, and horizontal shale gas well paths were compiled for analysis. Fourteen geophysical image logs were analyzed for breakouts, induced tensile fractures, and natural fractures. These data were processed to determine stress orientation and fracture density. Maximum horizontal stress axis was in an east-northeast to west-southwest orientation, consistent with regional stress records. The western part of the studied area appears to be more fractured than the eastern part, and fractures tend to strike subparallel to the axis of SHmax. Over 20,000 records from well treatment fracture breakdown pressures were compiled for evaluation. Maximum fracture breakdown pressures and instantaneous shut-in pressures were evaluated for different formations to constrain stress magnitudes. While data showed a large amount of variation, instantaneous shut-in pressures averaged 0.85 psi/ft gradient. Data from shale gas wells had higher fracture shut-in pressure gradients due to hoop stress effects and other factors. Finally, well paths for 12,793 horizontal Devonian Marcellus Shale and Ordovician Utica–Point Pleasant Formation wells were plotted based on top- and bottom-hole locations. The horizontal wells provide an empirical indication of the regional stress directions, because the wells are drilled along the minimum stress orientation. Geospatially visualizing of stimulated reservoir volumes suggests that horizontal wells with many fracture stages have resulted in swathes of "fracture tunnels" along the horizontal well paths in certain areas. These zones should be noted for other subsurface applications where the fractured zones may be considered caprocks. Data were integrated to provide representation of geomechanical conditions in the Midwest U.S. Together, this information may be used to support carbon dioxide storage projects, brine disposal, and hydrocarbon production in the region.

Sinistral Transpression Along Previously Existing Faults, Appalachian Basin, Ohio

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Recent mapping of Silurian and Devonian strata in Ohio shows a large-scale, regional structure pattern roughly parallel to the Cambridge cross-strike structural discontinuity (CCSD) south of the Akron-Suffield-Smith Township Fault System and east of the CCSD. This pattern is counterintuitive to the apparent strike of the Appalachian Basin slope, suggesting movement of previously existing faults.

Interpretation of two speculative seismic surveys in Ohio shows two prominent features in Belmont and Harrison Counties. These structural features illustrate a history of Cambrian extension followed by compression, similar to Killbuck Dome in Holmes County. The area in Belmont County shows down-to-the-east extension faulting followed by compression shortly after deposition of the Ordovician Trenton Limestone. Trenton fold reflector patterns do not continue high into the overlying Cincinnati Group while reflector patterns in the overlying Silurian horizons appear as a sag. In Harrison County, the Cadiz Anticline is clearly illustrated as a feature that initiated as a graben during Cambrian extension and then reactivated as a compressional feature during the Appalachian Orogeny. The Cadiz Anticline uplift is evident on the Pennsylvanian Lower Freeport coal structure map.

The faults identified from seismic lines and the structural trends from the recent Paleozoic mapping suggest sinistral transpression along previously existing faults which are subparallel to the CCSD. Antithetic, roughly east-west faults were reactivated as well. Most of these reactivated faults do not propagate high into the Paleozoic section, but they produced folds and highly fractured zones within the Paleozoic section.

Reservoir Simulation of Tracer Transport in Multicomponent Multiphase Compositional Flow with Applications to the Cranfield CO_2 Sequestration Site

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Reservoir simulators are widely used to constrain uncertainty in the petrophysical properties of subsurface formations by matching the history of injection and production data. However, such measurements may be insufficient to uniquely characterize a reservoir's properties. Monitoring of natural (isotopic) and introduced tracers is a developing technology to further interrogate the subsurface for applications such as enhanced oil recovery and CO_2 sequestration. Oak Ridge National Laboratory has been piloting this technology during and following three CO_2 injection campaigns at the Cranfield, Mississippi, CO_2 sequestration test site. Multiple perfluorocarbon tracers and isotopes were injected together with CO_2 and monitored at two wells at 68 m and 112 m from the injection site. Surprisingly, tracer breakthrough at both monitoring wells occurred at nearly the same time, and was not significantly affected when the CO_2 injection rate was nearly doubled. Multiple tracer peaks were also observed after breakthrough. These observations suggest that the CO_2 plume did not expand radially, but that multiple flow paths developed towards the monitoring wells. This is indicative of either channeling through high permeability pathways or of fingering. The results demonstrate that tracers provide an important complement to transient pressure data.

To aid the development of this new technology, we enhanced a fully compositional multiphase reservoir simulator to interpret inert tracer transport. Our research simulator uses higher-order finite element methods that can capture the small-scale onset of fingering on the coarse grids required for field-scale modeling, and allows for unstructured grids and anisotropic heterogeneous permeability fields. Mass transfer between fluid phases and phase behavior are modeled with rigorous equation-of-state based phase-split calculations. We present our tracer simulator and preliminary results related to the Cranfield tracer experiments.

Class II Injection Wells in Kentucky—An Update of the Map Service of Wastewater, Brine-Disposal, and Enhanced-Recovery Wells in Kentucky

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Following creation of a map service providing information on Kentucky's Class II injection wells, new data have been made available and integrated into the online map through permits issued by the Kentucky Division of Oil and Gas for proposed injection well locations, and by the release of new information from the U.S. Environmental Protection Agency (USEPA) through Freedom of Information Act (FOIA) requests. Administrative data identified an additional 18 injection wells now cataloged into the Class II database, 17 permitted or recompleted as brine disposal wells, and one permitted for enhanced recovery.

Monthly operations data (casing pressures and injection volumes) for selected active Class II wastewater wells covering a five-year period (2008–2012) were compiled from yearly records and examined during the course of a multistate research investigation of brine disposal in the northern Appalachian Basin. Subsequent to that study, injection volumes reported on a yearly basis were later released for 25- and 30-year periods for brine disposal and enhanced recovery wells, respectively. Analysis of this longer term injection history has identified increases in both disposal and recovery operations over the past 15 years.

Active injection zones include shallow Pennsylvanian sandstones to deeper Ordovician Knox Group porous dolomites and sandstones. Recently permitted injection wells are also targeting Cambrian Copper Ridge Dolomite (Lower Knox Group) and Conasauga Group intervals.

Kentucky has requested and received tentative approval for oversight (primacy) over Class II injection wells. Approval should result in more timely access to data for map service updates and in monitoring ongoing injection activity.

Elemental Data Collected in the Berea Sandstone of Eastern Kentucky: Applications to Wellbore Placement, Horizontal "Chemosteering," and Completion Strategy

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The use of elemental data derived from energy-dispersive X-ray fluorescence collected from drill cuttings is starting to gain popularity in the oil and gas industry, with applications spanning from spud through completion of the well. Whether analyzing the data prior to, during, or after drilling a horizontal well, there are many practical applications of utilizing this data. In this study, elemental data was used to build a chemostratigraphy within the Berea Sandstone and bounding units in three wells drilled in eastern Kentucky. Samples were collected on one Berea core at 1 foot intervals, on cuttings collected from three Berea vertical pilot holes at 5 foot intervals and along the corresponding horizontal wellbores at 10 foot intervals. This data was utilized to help select the target zone, determine the stratigraphic position of the wellbore, and to make completion recommendations. Subsequently, this dataset also proved the validity of elemental data collection as a useful component to geosteering. The elemental data collected from the pilot hole cuttings is compared to the elemental data collected from the horizontal cuttings in order to determine from which chemostratigraphic section the horizontal cuttings originated. Once the relationship between horizontal elemental data and pilot hole chemostratigraphic zonation is determined, a "look back chemosteer" of the wellbore path is developed. This study shows the usefulness of using elemental data in conjunction with gamma ray data to verify the stratigraphic position of the wellbore path. Further, results suggest that access to real-time elemental data can be a major benefit when drilling in areas where weak gamma ray character and limited structural control can make geosteering a horizontal wellbore difficult. Understanding chemostratigraphic packages within the Berea Sandstone can help guide target selection and wellbore placement prior to kicking off a horizontal wellbore as well as the ability to "chemosteer" the well real time. Finally, having accurate knowledge of where the wellbore was drilled based on interpretation of elemental data and determination of chemostratigraphic packages can help guide the completion of Berea wells, allowing engineers to avoid completing less desirable reservoir facies.

Stable Isotopic Constraints on Methane Migration into Groundwater and Emissions to the Atmosphere from Unconventional Natural Gas Extraction: Examples from OH, CO, TX

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An increase in natural gas drilling and use has led to concerns about migration of flammable methane gas into local groundwater resources, as well as worries that increased emissions of methane, a powerful greenhouse gas, will overwhelm the carbon dioxide savings associated with using natural gas versus oil or coal. In this talk I will present an overview of studies investigating these issues and tracking sources of methane using the stable isotopes of carbon and hydrogen, which can distinguish between methane produced by thermogenic versus biogenic processes. The first part of the talk will describe an investigation of methane concentrations and isotopic composition along a time series of hydraulic fracturing activity in the Utica Shale drilling region of Ohio. The second part of the talk will explore several examples of how stable isotopes can help to constrain atmospheric methane emissions from natural gas production and use.

Phospholipid Fatty Acid Evidence of Recent Microbial Life in Pristine Marcellus Shale Cores

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Organic-rich black shales are currently being targeted for natural gas development in formations across the U.S. Several studies have shown microbial communities exist in wells after hydraulic fracturing, but it is not known whether these microorganisms derive from the pristine shale before energy development. Previous research has characterized phospholipid fatty acids (PLFAs) in Cenozoic and Mesozoic aged shales; yet, no measurements have been reported for Paleozoic-aged black shales such as the Marcellus. Here, we report the first measurements of PLFAs in pristine cores originating from a scientific well at the Marcellus Shale Energy and Environment Laboratory (MSEEL) near Morgantown, West Virginia. We focused on sidewall core samples span-

ning the interface between the Marcellus and Mahantango formations. Sidewall cores were collected and cleaned using successive brine washes, microscopy verified removal of fluorescent tracers, surface sterilized cores were ground to a particle size less than 500 µm, and cores were homogenized. Lipids were extracted and methylated from six samples (three sidewall cores, the washing brine, and two drilling muds) and the resulting PLFA methyl esters (PL-FAMEs) were analyzed using GC-MS. Drilling muds had 37-fold higher biomass compared to the core samples and shared only common normal saturated PL-FAMEs, indicating minimal contamination from surface-derived microorganisms after cleaning. In pristine core samples, the Marcellus and Mahantango had similar biomass and similar numbers of PL-FAMEs. However, the Marcellus Shale had a 14-fold increase in hydroxy-PL-FAMEs compared to the Mahantango as well as a minor amount of polyunsaturated PL-FAMEs. Notably, the presence of keto- and hydroxyl-PL-FAMEs in all three cores suggests potential acclimatization of the microbial community to environmental stress. Our data indicate the Marcellus and Mahantango formations may harbor recent microbial life that is acclimated to deep biosphere conditions prior to shale gas development.

Manistique Group Reservoirs in the Michigan Basin: An Overlooked Resource

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In order to fill in the gap between the extensive studies of the overlying Niagara Group and underlying Burnt Bluff Group, initial work has been done to constrain the timing and nature of deposition of the Manistique Group. Manistique Group carbonates in the Michigan Basin include the nodular dolomites of the Schoolcraft Formation and cherty carbonates of the Cordell Formation. Several completions in the Manistique Group have been attempted, but currently there is no production. Reservoir characteristics include: (1) small pods of dolomite within the regional limestone, (2) association with structures and related fracture porosity, (3) enhancement of porosity through generation of intercrystalline and vuggy porosity by dolomitizing fluids, and (4) presence of porous, tripolitic cherts.

Carbon isotope chemostratigraphy shows that the Gray Niagaran hosts the Ireviken excursion (Sheinwoodian) above the contact with the Cordell Formation. Conodonts sampled from the Gray Niagara in the interval that records the Ireviken excursion are Sheinwoodian in age and include *Kockelella walliseri, K. ranuliformis,* and *Ozarkodina sagitta rhenana.* Above the contact of the Gray Niagara with the Cordell Formation, elements of *Pterospathodus amorphognathoides* were found, which constrains the earliest Niagara Group to uppermost Telychian in age. Previous work (Kuglitsch, 2000) found that the uppermost Burnt Bluff Group was early Telychian in age. These new data points constrain the age of the Manistique Group to the Telychian.

The Manistique Group carbonates exhibit elevated gamma ray signatures compared to the underlying Burnt Bluff Group and overlying lower Niagara Group. Handheld XRF data from the Miller Brothers Weinert #2-6 provided compositional data that shows that the Manistique Group is composed of a mix of argillaceous carbonates and cherts. The presence of chert, extensive bioturbation, and a low diversity fauna suggest that these carbonates were deposited in deeper water, likely above storm wave base.

Integration of biostratigraphic and geochemical data has enhanced our understanding of the deposition of the Manistique Group carbonates and has provided constraints on the nature of diagenetic overprints and reservoir development in these fields.

Assessing Potential Seismic Hazards from Induced Earthquakes in the Central and Eastern United States

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Induced seismicity related to unconventional oil and gas production has drawn much attention in recent years in the central and eastern United States, Arkansas, Kansas, Ohio, Oklahoma, and Texas in particular. For example, the 2011 M 5.7 Prague, Okla., earthquake resulted in more than $10 million in insured losses. However, assessing the seismic hazard from induced seismicity is not an easy task because of large inherent uncertainties in location, magnitude, and recurrence interval of earthquakes, as well as ground-motion attenuation. Thus, how to quantify and communicate the inherent uncertainty are critical for assessing seismic hazard from induced seismicity.

Seismic hazards include primary ones that are directly generated by an earthquake (fault rupture): surface rupture and ground motion (shaking); and secondary ones that could be caused by strong ground motion under certain site conditions: amplification, liquefaction, and landslides. Surface rupture occurs in the vicinity of the fault rupture, whereas ground motion can propagate far away from the fault, affecting a much larger area. Secondary hazards are concentrated at locations with certain site conditions under the influence of strong ground motion. No surface rupture has been found to be associated with induced earthquakes in the central and eastern United States. Also, amplification, liquefaction, and landslides are not major concerns because the magnitudes of induced earthquakes are less than M 6.0. Thus, ground-motion hazard is the main concern from induced earthquakes.

Probabilistic seismic hazard analysis has been used to assess ground-motion hazard from induced earthquakes. However, PSHA is scientifically invalid because it contains a mathematical error: equating the annual probability of exceedance (i.e., the probability of exceedance in one year and a dimensionless quantity) with a frequency or rate of exceedance (i.e., the annual frequency of exceedance and a dimensional quantity with the unit of 1/year). Thus, PSHA should not be used for ground-motion hazard assessment from induced earthquakes. We propose using a scenario-based seismic hazard analysis to assess ground-motion hazard from induced earthquakes.

Thermal Maturity Assessment in the Lower Huron Using Raman Micro-spectroscopy

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Raman micro-spectroscopy was utilized to confirm thermal maturity assessments in the “LHRN 7” lithologic unit in three cores which were part of a larger study on production mechanisms in the Lower Huron Shale. Traditional methods of determining thermal maturity provided conflicting results. These methods included optical vitrinite reflectance, programmed pyrolysis parameters TMAX and Hydrogen Index (HI), and organic porosity development (i.e., apparent transformation ratio (ATR), derived from scanning electron image analysis).

Raman micro-spectroscopy provides a spectrum of Raman shifts that are indicative of various bond types and their relative concentrations in a sample (e.g., carbon-hydrogen single bonds; carbon-oxygen double bonds, etc.). The peak at 1,500–1,650 cm-1 is indicative of the vibration mode of carbon-carbon double bonds. Baselined, intensity-normalized G-band full-width half-maximum (ΓG) narrows as concentration of carbon-carbon double bonds increases.

ΓG results from LHRN7 samples consistently agreed with associated HI and ATR measurements, as well as with thermal maturity derived from regional maps. These results suggest that this study’s optical vitrinite reflectance and programmed pyrolysis TMAX data are inaccurate.

The benefits of Raman micro-spectroscopy are that it is relatively low cost, rapid, non-destructive, in situ, spatially high-resolution, repeatable, does not require sample preparation, and the results are quantitative and objective. Raman micro-spectroscopy is therefore ideal for situations where traditional bulk analysis or destructive analysis is not feasible, not practical, is undesirable, has provided suspect or unusable results, or is subjective.

Limitations to Raman micro-spectroscopy are that the resulting spectra and the parameters associated, like ΓG, are excitation wavelength specific, possibly instrument configuration specific (e.g., grating size), and are subject to noise from fluorescence common with low maturity samples. Additionally, the power of the excitation laser must be kept low to prevent thermal degradation of the sample. Finally, various techniques of spectral deconvolution are often used in the literature (e.g., Lorentzian and Gaussian curve fitting) to obtain parameters similar to ΓG. For these reasons, comparison of data between different Raman studies can be challenging.

An Integrated Approach to Identifying Residual Oil Zones in the Cypress Sandstone in the Illinois Basin for Nonconventional CO_2-EOR and Storage

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The central portion of the Illinois Basin has a fairway of incised valley fill Cypress Sandstone deposits that exceeds 150 feet in thickness. Where local structural features are present, the Cypress may contain a relatively thin oil reservoir above a significant aquifer. Because of the thickness of the aquifer, nonconventional carbon dioxide (CO_2) enhanced oil recovery (EOR) is expected to require more CO_2 compared to a conventional CO_2 EOR for each barrel of incremental oil produced due to CO_2 migrating into the underlying aquifer. For this study, the entire incised valley part of the Cypress is being investigated for the presence of residual oil zones (ROZs), regardless of the presence of an overlying oil reservoir.

In a case study of Noble Field, western Richland County, Illinois, identification of ROZs in the Cypress Sandstone has required an integrated, multidisciplinary approach of detailed geologic characterization, petrography, and petrophysics. Geologic characterization suggested that the Cypress Sandstone occurs as multistory fluvial sandstones that become estuarine upward and were deposited in an accommodation limited setting. A tilted producing oil water contact (OWC), an indicator of an ROZ, was identified and mapped. A zone of dense diagenetic calcite cement occurs along the OWC, with a second similar zone 20 ft below, is an indication of a relict OWC.

Water saturation determined with Archie’s equation was found to be anomalously high for several wells, suggesting the presence of excessive conductivity, e.g., from water-saturated clay micropores. Clay mineral morphologies were identified, volume of clay was determined, and the percent-volume of clay micropores were quantified to correct water saturation estimates. The depths of the oil saturated, brine saturated, and ROZ within several wells was used to identify areas of the field that had the greatest potential to have an ROZ.

Integrating water-oil saturation into a detailed, representative geocellular model of the reservoir architecture will reduce CO_2 EOR and storage uncertainty in the results of reservoir simulations. A summary of how each discipline was used to better understand the ROZ and preliminary findings of this integrated study will be presented.

Deep Cores Through the Pennsylvanian Section of Western Kentucky, Illinois Basin

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Two deep, continuous coalbed-methane exploration cores, which were drilled south of the Rough Creek Fault System in the deepest part of the Western Kentucky Coal Field for coalbed methane exploration, have been donated to the Kentucky Geological Survey. Although thick coal beds and some roof shales were removed for analysis prior to donation, these cores are the most continuous cores through Pennsylvanian strata in western Kentucky, and for that matter, the Illinois Basin.

The Suncor SCC-H1 Louise Shelton core was drilled in the Bordley quadrangle, Union County. The core is 2,121 ft long, and extends from the Lower Pennsylvanian Caseyville Sandstone (within 10 ft of the Mississippian-Pennsylvanian unconformity) upward to approximately 160 ft above the base of the Upper Pennsylvanian Mattoon Formation. The well has an accompanying high-resolution gamma-density log.

The Suncor DCC-H2 Willoughby and Carver core was drilled in the Slaughters quadrangle, Webster County. The core is 2,162 ft long and extends from the Upper Mississippian Kinkaid Limestone beneath the Mississippian-Pennsylvanian unconformity upward to approximately 150 ft above the base of the Upper Pennsylvanian Mattoon Formation. The well has an accompanying gamma-compensated density log.

Both cores have been described and correlated. These cores provide insight into several stratigraphic intervals that are rarely cored in the deeper part of the coal field, including (1) thin rooting zones, coals, and fossiliferous shales in the Tradewater and Caseyville Formations and (2) thin rooting zones, coals, and carbonates in the McLeansboro Group. These two cores also provide a rare opportunity to observe the highly variable lithofacies represented by the seldom-cored Tradewater Formation. By comparing these cores to nearby well logs, we can better calibrate geophysical signatures to key beds and sequence surfaces and improve correlations within the basin.

Phosphate Minerals in Utica Shale: A Possible Source of Trace Metals in Flowback Water

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Understanding physical, chemical, and mineralogical properties of the Utica–Point Pleasant formations is important for predicting how the subsurface environment will respond during hydraulic fracturing. This study focuses on characterizing phosphate mineral assemblages and measuring trace element concentrations in Ca-phosphates as compared to other mineral assemblages in the fabric of the mudrock. Although phosphate phases constitute only a few percent of the total rock, they are of general interest geochemically and for hydraulic fracturing in particular because (1) they are commonly porous and thus potentially accessible to input fluids, (2) they are relatively soluble and reactive and may represent areas of increased porosity from water-rock interaction, (3) they contain elevated concentrations of trace metals (Sr, Ba, REE, U, Th) that can be released to flowback fluids, and (4) they represent a nutrient source for subsurface microbes.

A deep core sample (approximately 10,930 feet) of the Utica–Point Pleasant from Washington County, Pennsylvania, has been analyzed by SEM (backscattered electron [BSE]) imaging, energy dispersive X-ray spectrometry (EDXS), and laser ablation ICP-MS to determine concentrations of trace elements in phosphate phases compared to the surrounding carbonate-clay matrix. Laser ablation results show that the phosphate phases are enriched in La, Ce, U, and Th by one to three orders of magnitude compared to the surrounding carbonate-clay matrix and that the concentrations of these elements co-vary. Sr was also enriched in the phosphates, with a maximum measured concentration of ~10,000 ppm Sr; however, median Sr concentration in the phosphates was only two to three fold higher than the surrounding matrix (~500 to 2,000 ppm). Ba concentrations were substantially lower in the phosphates compared to the surrounding matrix, only a few ppm to a few tens compared to 50 to 150 in the clays and carbonates.

An Overview of Development of the Utica–Point Pleasant Play

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The combination of the Ordovician Utica and Devonian Marcellus Shale plays has made eastern Ohio, northern West Virginia, and western Pennsylvania one of the hottest areas in the developing U.S. resource play scene. Range Resources drilled the first Marcellus Shale well (the Renz #1) in 2004. Once the Marcellus play took off in earnest, geologists familiar with the local data began focusing on the potential of the Utica Shale and Point Pleasant Formation interval, another proven source rock interval.

Range Resources also drilled the first horizontal Utica well (the Lloyd #1 in Beaver County, Pennsylvania) in March 2010. Late in 2010 Marquette Exploration drilled three vertical tests in the Point Pleasant Formation in southeast Ohio. Chesapeake Energy (then operating under the name Ohio Buckeye Energy) completed the Buell #8H in March 2011 and placed it into production June 14, 2011, becoming the first horizontal completion in the Point Pleasant in Ohio. In late September 2011, Chesapeake issued a press release proclaiming the production from the Buell #8H (9.5 MMCF and 1,425 bbl liquids) and three other "Utica" discoveries, thus igniting huge interest in the play across the oil and gas industry.

Over the next four years the geographic focus of the Utica–Point Pleasant play shifted a few times as operators tested the limits of the geology in different areas. Southeast Ohio (Belmont, Monroe, and Noble Counties) wells kept finding larger and larger initial production, then wells in southwest Pennsylvania and the panhandle of West Virginia came roaring in with even larger numbers. In July 2015 EQT announced initial production of 72.9 MMCF from their Scotts Run well in Greene County, Pennsylvania! Meanwhile, in the summer of 2014 Shell Appalachia announced very good results (11.2 and 26.5 MMCF) from initial Utica wells in Tioga County, Pennsylvania, potentially extending the play much farther to the northeast.

This paper will provide a brief look at this developmental history, some of the challenges which have faced the operators, and some differences in the geology across the producing region.

Maturation Patterns of the Cambrian Rogersville Shale in the Rome Trough of Eastern Kentucky and West Virginia

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The Rome Trough of eastern Kentucky and West Virginia records the failed rift of a larger Cambrian extension event along the modern day eastern and southern margins of North America. Rifting began in the Early to Middle Cambrian during the deposition of the Rome Formation and continued into the deposition of the Conasauga Group. The Upper Rome and Conasauga together reflect a series of transgressive shale and highstand carbonate sequences. These formations have been tested for conventional hydrocarbon traps numerous times over the last 40 years. While shows occur in multiple zones, these wells have yielded little in the way of economic discoveries, with few notable exceptions. Recently, there has been a shift to focus on the source beds as potential horizontal well targets.

The Middle Cambrian section of the Rome Trough contains multiple source beds within the Conasauga Group. These occur in the transgressive shales of the Pumpkin Valley, Rogersville, and Nolichucky Formations. The Rogersville has become the primary focus of recent efforts as previous studies have shown this formation to contain the highest amounts of total organic carbon (1–5 percent TOC), and studies on produced oils have been typed back to bitumen within the formation. Burial history models for many of the existing Rome penetrations have given insight into the tectonic and thermal development of the Rome Trough and show a large amount of variability in the maturation and expected hydrocarbon phase. These models rely on present day stratigraphy, lithology, temperature, and maturity of individual wells combined with regional conditions such as uplift, erosion, and heat flow. These 1D models have been applied within a sequence stratigraphic framework and then tied to an existing 2D seismic framework. After making calculations allowing for the decompaction of the section, a 3D burial history model results, showing where source rocks cross thermal maturation windows both spatially and temporally. The resulting maps allow the interpreter to determine the timing of generation, migration, and fault movement. Further, they provide meaningful interpolation into areas where well control and production are limited and allow for predictions of the amount and type of hydrocarbons generated and producible.

Gas Generation from Natural Oils—The Details Matter in Resource Assessment

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It is generally accepted that the kinetics of cracking reactions within the kerogen-bitumen-petroleum transformation control the thermal evolution of hydrocarbons in the subsurface. Pyrolysis experiments analyzing gas generation from natural oils and model compounds have been conducted to ascertain the kinetic parameters and estimate gas yield under varying conditions (Tsuzuki et al., 1999; Fusetti, Behar et al., 2010). Results from these kinetic studies are utilized in petroleum systems modeling to generate estimates of gas yields.

Unfortunately, depending upon the experimental method, composition of oil used, and whether ramped or isothermal heating is used to crack the oil to gas, the kinetic parameters vary dramatically. As an example, a comparison between seven different gas generation pyrolysis experiments produced Ea (activation energy) parameters that vary between 48–88 kcal/mol and A (frequency factor) values that range from 4.5×10^{10} to 3.2×10^{22} s^{-1} (Willette et al., in prep). Application of these various kinetic parameters in modeling gas yields will produce estimates that differ significantly.

It may be more useful to look directly at experimental gas yields and use those results for "ground truth" in the application of kinetic parameters in petroleum systems modeling.

Pyrolysis experiments were conducted on a natural oil under varying conditions: anhydrous, hydrothermal (with water in reactor), quartz sand in reactor, illitic shale in reactor, dolomite in reactor, and limestone in reactor. The gas generated from cracking the oil at 380°C ranged between 216 mg/gOo to 166 mg/gOo.

This difference may appear small, but if the difference in yields from just the anhydrous and hydrothermal experiments are converted to gas yield from a barrel of oil, an additional 2.1–2.4 Mcf is produced from a barrel of oil using the hydrothermal experimental yield. Using experimental yield data to constrain kinetic parameters will result in more realistic assessment of gas saturations in unconventional reservoirs, of original oil/gas in place, and provide insight into the common problem of initially underestimating the amount of gas produced during field development.

Improving the Estimations of Shale Permeability with Process-Based Pore Network Modeling Approach

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In shale, kerogen and clay make the pore network intricate. For example, in kerogen subspherical pores are connected by cylindrical throats while in clay both pores and throats are triangular or sheetlike. To our knowledge, few studies considered the influence of kerogen and clay in reconstructing pore networks. This study uses a process-based modeling approach to reconstruct pore networks of shale. Our process-based approach considers the influence of kerogen and clay on pore morphology and distribution. The estimations of shale permeability based on generated pore networks are improved.

First of all, analysis of FE-SEM images gives grain size distributions of shale. With the grain size distributions and the process-based method (Øren and Bakke, 1997), this study develops a network A that connects interparticle pores, organic matter (OM) particles, and clay agglomerates. With random sphere packing algorithm, this study extracts a network B which connects nanopores in OM particles and a network C which connects pores in clay agglomerates. The pore morphology is set to be different in networks B and C. Then networks B and C are inserted into the selected OM particles and clay agglomerates in network A for the final network D. The pore network D connects interparticle pores, subspherical nanopores, and triangular/sheetlike pores in clay. Finally, this study applies no-slip permeability equations in the network D and predicts no-slip permeability of shale. The permeability equations are modified according to pore morphology.

This study analyzed FE-SEM images of shales from Sichuan Basin in China and Appalachian Basin and then built pore networks. The pore size distributions (PSD) of our pore networks matched well with the PSD defined by the mercury intrusion data. And the resulted permeability estimations are in good agreement with the reported lab measurements. Based on our pore networks, this study further investigated the effect of shale diagenesis on shale permeability.

It comes to our knowledge that no process-based approach and networks are exclusively developed for shale. Our process-based modeling considers the influence of kerogen and clay distribution on ultimate pore structure in shale.

Late Ordovician (Katian) Upper Lexington–Kope Equivalents in the Point Pleasant Basin of Eastern Ohio: Correlation and Paleoenvironments of the Utica Point Pleasant System

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The "Point Pleasant" (mixed calcareous shale and thin limestones) and "Utica" (black shales) form a major target for unconventional oil and gas development, and the largest producing unit, in the state of Ohio. Despite major production, the paleoenvironmental interpretations, stratigraphic nomenclature, and the litho-, chemo-, bio-, and sequence-stratigraphic framework of these units in the Ohio subsurface remains poorly understood. Here we present detailed analyses of a core from Cadiz, OH, using an integrative stratigraphic approach to tie the sequences of this Point Pleasant Basin section to those of the shallow water facies of the Lexington Platform of Kentucky and suggest a paleoenvironmental interpretation of this distal section. High-resolution data on X-ray florescence (XRF), total organic carbon (TOC percent), and carbonate carbon isotopes were obtained throughout the entire profile of the core. These results, set within a framework of biostratigraphy and faunal epiboles, suggest that distal expressions of several divisions of the Lexington Formation are recognizable despite the absence of well-differentiated sequences. The "Point Pleasant" Formation of the subsurface is lithologically unlike that of the type area, and correlates with a middle portion of the Lexington Formation below the true Point Pleasant. "Utica Formation" of eastern Ohio is a distal expression of the Bromley and upper ("River Quarry") members of the Point Pleasant and Kope Formation of the Lexington Platform. Fluctuations in organic matter concentrations and redox conditions are interpreted using geochemical proxies developed from modern and ancient marine systems. The highest TOC percent zone occurs below the "Utica Formation" in the so-called "Point Pleasant Formation," the shalier regional expression of the middle/upper Lexington Formation approximately equivalent to the Brannon Member. Strong deviations of C/P values from modified Redfield ratios, in these dark shales, indicate fluctuating suboxic to anoxic benthic conditions in this interval but, surprisingly, not in the overlying Utica.

Analysis on Distribution and Controlling Factors of Paleogene Reservoir, Beibuwan Basin

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The present papers have studied characteristics of the tectonic-sedimentary evolution history in the Beibuwan Basin and discussed control factors of the synsedimentary fault and sendimentation on reservoirs. The study showed that six areas could be divided under the leading of source to sink system theory. Affected by Zhuqiong motion, the Beibuwan Basin started rifting phase in the Palaeocene Epoch, a lot of basement faults were developed and controlled the shape of red-fluvial depositional systems of Changliu Formation. In the late Eocene, the Liushagang Formation developed land-lacustrine sedimentary system with active tectonics and strong basin rift. In the Oligocene, affected by Nanhai motion, regional uplifts and denudation occurred in the Beibuwan Basin, controlled the upgrowth of semi-arid plain and shallow lacustrine sedimentary systems. The Beibuwan Basin has gone through many stages of evolution; the reservoir types and distribution are very complex. Most of the reservoirs distribute in the Liushagang Formation and Weizhou Formation. The four factors that sources, ancient landform, structure, the lake level fluctuation, and the interactions among them have played a significant controlling role in the differentiation in Beibuwan Basin reservoirs, of which the sources and ancient landform play a key role in the control of sand-body distribution. Besides, the methodology used in this study could have some effect on reservoir division and diagenesis analysis.

CO_2 Storage Capacity Estimation and CO_2-EOR Evaluation for Jacksonburg-Stringtown Oil Field, West Virginia, USA

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As concerns around global warming increase, effective actions and measures may be required to limit carbon dioxide emission into atmosphere. Carbon dioxide–enhanced oil recovery (CO_2-EOR) is an effective way, because it not only increases recovery from existing oil reserves, but bridges the gap between regional-scale CO_2 capture and geologic sequestration. Jacksonburg-Stringtown is an ideal candidate for CO_2 sequestration coupled with EOR because of supercritical depth (> 2,500 ft), minimum miscible pressure (941 psi), API gravity (46.5°), and good waterflood response, which indicates a high probability of successful CO_2-EOR operations. Several important issues including storage capacity, long-term containment, and oil recovery factor must be evaluated in such integrated system. To facilitate technical evaluation, a reasonable 3D geological model aids in calculating theoretical storage capacity, while a comprehensive numerical fluid model is used to evaluate long-term containment and oil recovery. Modeling scenarios include maximum allowable pressure, various maintenance pressure scenarios, and different injection rates. Depending on the proposed 3D geological model, the best regions for coupled CCUS-EOR are located in southern portions of the field, and the estimated CO_2 storage capacity for Jacksonburg-Stringtown oil field varies from 24 to 383 million metric tons.

Assessing Methane in Shallow Groundwater for the Berea Sandstone and Rogersville Shale Play Area, Eastern Kentucky

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[2]GSI Environmental Inc., 9600 Great Hills Trail, Ste. 350E, Austin, TX 78759

Rapid implementation of horizontal drilling and hydraulic fracturing technology in producing oil and gas from tight rock formations across the country has increased public concerns about possible impacts on the environment, especially on shallow drinking-water aquifers. In eastern Kentucky, horizontal drilling and fracturing activities in the Upper Devonian Berea Sandstone have increased in recent years. While production activities in the Berea Sandstone are at a relatively small scale, public attention has been drawn to the Rogersville Shale, a deeper, thicker, and more areally extensive organic-rich shale projected to become a major shale play in eastern Kentucky. Information about existing groundwater quality, especially dissolved methane, in aquifers overlying the Berea and Rogersville play areas is critical to help address the public's environmental concerns and protect groundwater resources.

The Kentucky Geological Survey, in collaboration with GSI Environmental, collected and analyzed groundwater samples from existing domestic and public water-supply wells located in Greenup, Carter, Boyd, Lawrence, Johnson, and Elliott Counties. The objectives of this project are to obtain an understanding of baseline groundwater chemistry throughout the study area and to use isotope data to evaluate possible sources of methane detected in the groundwater. A total of 51 water wells were sampled and analyzed for major cations and ions, metals, and dissolved gases including methane. Wells with elevated methane concentrations were also analyzed for carbon and hydrogen isotopes. Results from this study provide the first assessment of methane concentrations, possible sources of methane, and the relation of methane to water chemistry in the area.

Marcellus Shale Energy and Environment Laboratory Approach to Water and Waste Studies

Paul Ziemkiewicz, West Virginia Water Research Institute, West Virginia University, Morgantown, WV

The Marcellus Shale Energy and Environment Laboratory (MSEEL) is the first comprehensive field study coupling same site environmental baseline, completion, and production monitoring with environmental outcomes. One year into the program, the water and solid waste component of MSEEL has systematically sampled flowback and produced water volumes, hydraulic fracturing fluid, flowback, produced water, drilling muds, drill cuttings and characterized their inorganic, organic, and radio chemistries. In addition, surface water in the nearby Monongahela River is being monitored upstream and downstream of the MSEEL drill pad. Toxicity testing per EPA method 1311 (TCLP) was conducted on drill cuttings in both the vertical and horizontal (Marcellus) sections.

The MSEEL wells used green completion strategy including a water based drilling fluid. All drill cutting samples fell below TCLP thresholds indicating that they are non-hazardous per the Resource Conservation and Recovery Act. Maximum isotopic activity was recorded for 40K which was 28.32 pCi/g. Gross alpha accounted the highest reading at 60 pCi/g. Neither of these levels is considered hazardous.

The composition of the HF fluids in both wells is similar to the makeup water which was drawn from the Monongahela River. Its chemistry is typical of Monongahela River water. This is true of inorganics, organics, and radiologicals. Organic surrogate recoveries were in the range of 90 to 104 percent, indicating good quality control at the analytical laboratory. There was no evidence that Monongahela River quality was influenced by the MSEEL activities.

Concentrations of all parameters increased through the flowback/produced water cycle. 226 Ra and gross alpha reached 5,200 and 7,000 pCi/L by flowback day 83, indicating an important trend that will be carefully assessed in ongoing monitoring.

Geomechanical Lithology-Based Analysis of Microseismicity in Organic Shale Sequences: A Comparison from Multiple Hydraulic Fracturing Field Sites

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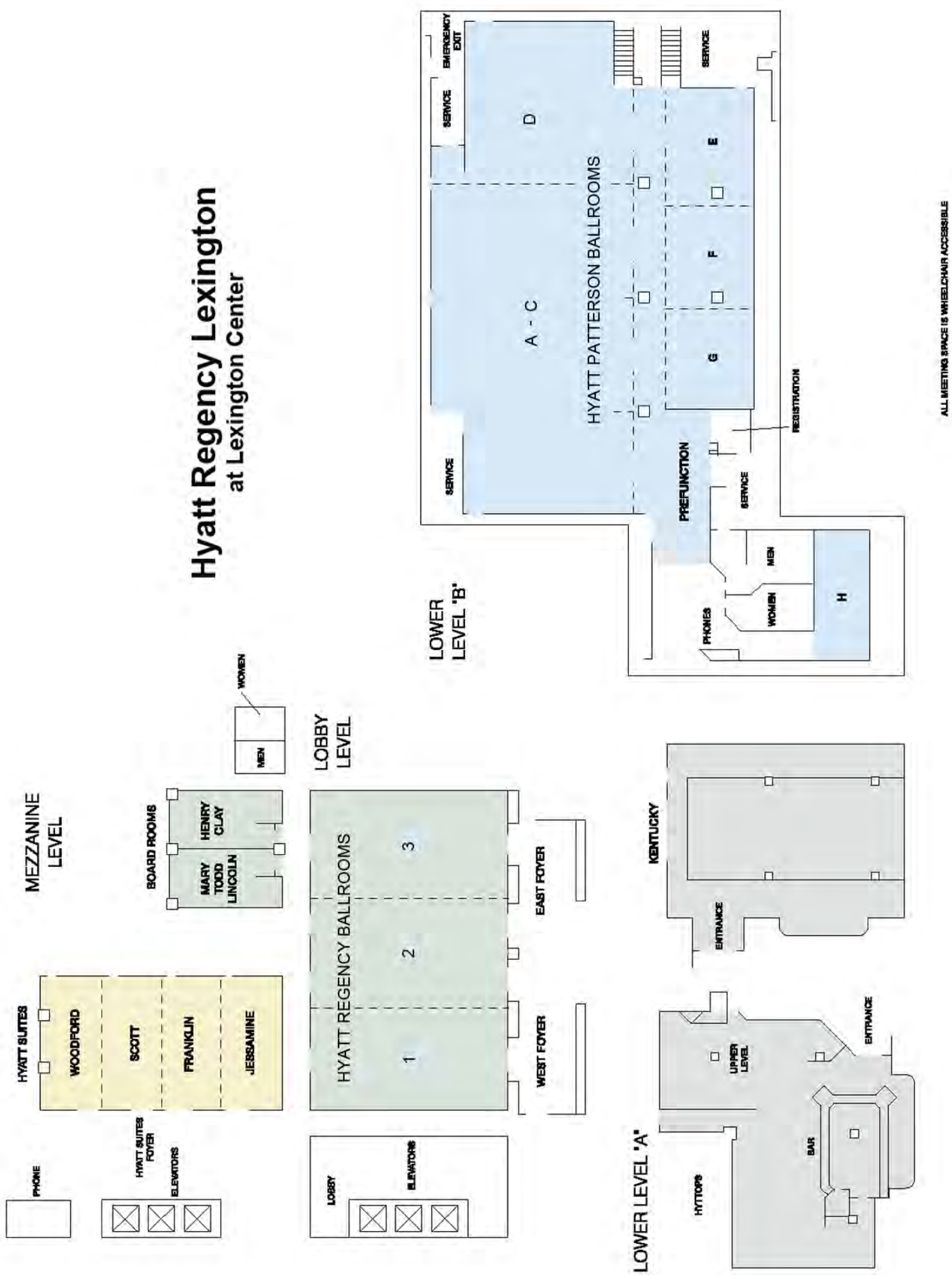
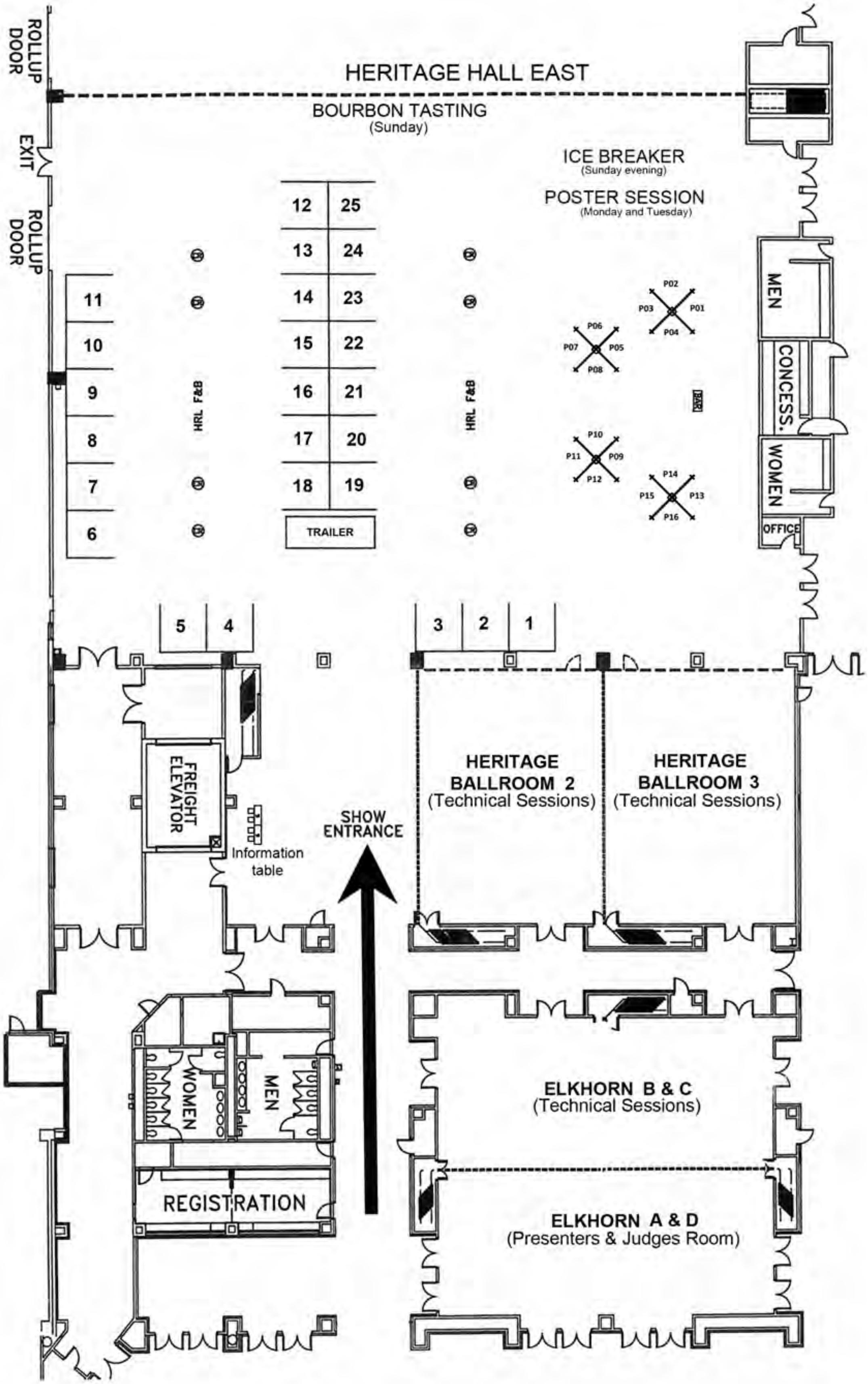
[1]U.S. Department of Energy–National Energy Technology Laboratory, Pittsburgh, PA
[2]University of Pittsburgh, Pittsburgh, PA

With the increased application of microseismic monitoring during hydraulic fracturing, it has become increasingly important to accurately categorize “fracability” in unconventional reservoir rocks. Typically this understanding of shale fracability is based upon Poisson’s ratio (PR) and Young’s modulus (YM) calculated from well logs. The manifestation of fracability is assumed to be simply represented by the number and density of microseismic events generated during hydraulic fracturing stimulation. To investigate hydraulic fracturing behavior in greater detail we have analyzed five high-quality microseismic datasets along with associated high-quality well logs. We investigated four field sites from the Marcellus Shale sequence and one field site from the Wolfcamp sequence in Texas. From the well log data we calculated all relevant geomechanical moduli and petrophysical parameters for a direct comparison to the vertical extent within which a high density of microseismic events was observed at each field site. A comparison of well log based (dynamic) elastic moduli to the vertical distribution of microseismic parameters, such as moment magnitude and event count, reveals both a positive and negative correlation between elasticity-based brittleness estimates and moment magnitude within shale rocks from the different field sites.

The seismological b-value has been shown to relate to the state of in situ stress at the time of failure in microseismic datasets, enabling differentiation between fault interaction and more diffuse tensile fracturing. Preliminary analysis of b-values suggests a relationship between stress/failure style and how geomechanical properties influence the expression of microseismicity. In accordance with seismological principles regarding the statistical analysis of seismic catalogs, we have taken great care to eliminate bias in the sampling. By excluding all microseismic events with moment magnitudes smaller than the magnitude of catalog completeness, and also focusing our analysis on only the shale rocks containing the highest number of microseismic events, we are confident that the observed relationships can provide insight into the geomechanical control over how microseismicity is expressed during hydraulic fracturing in unconventional shale.



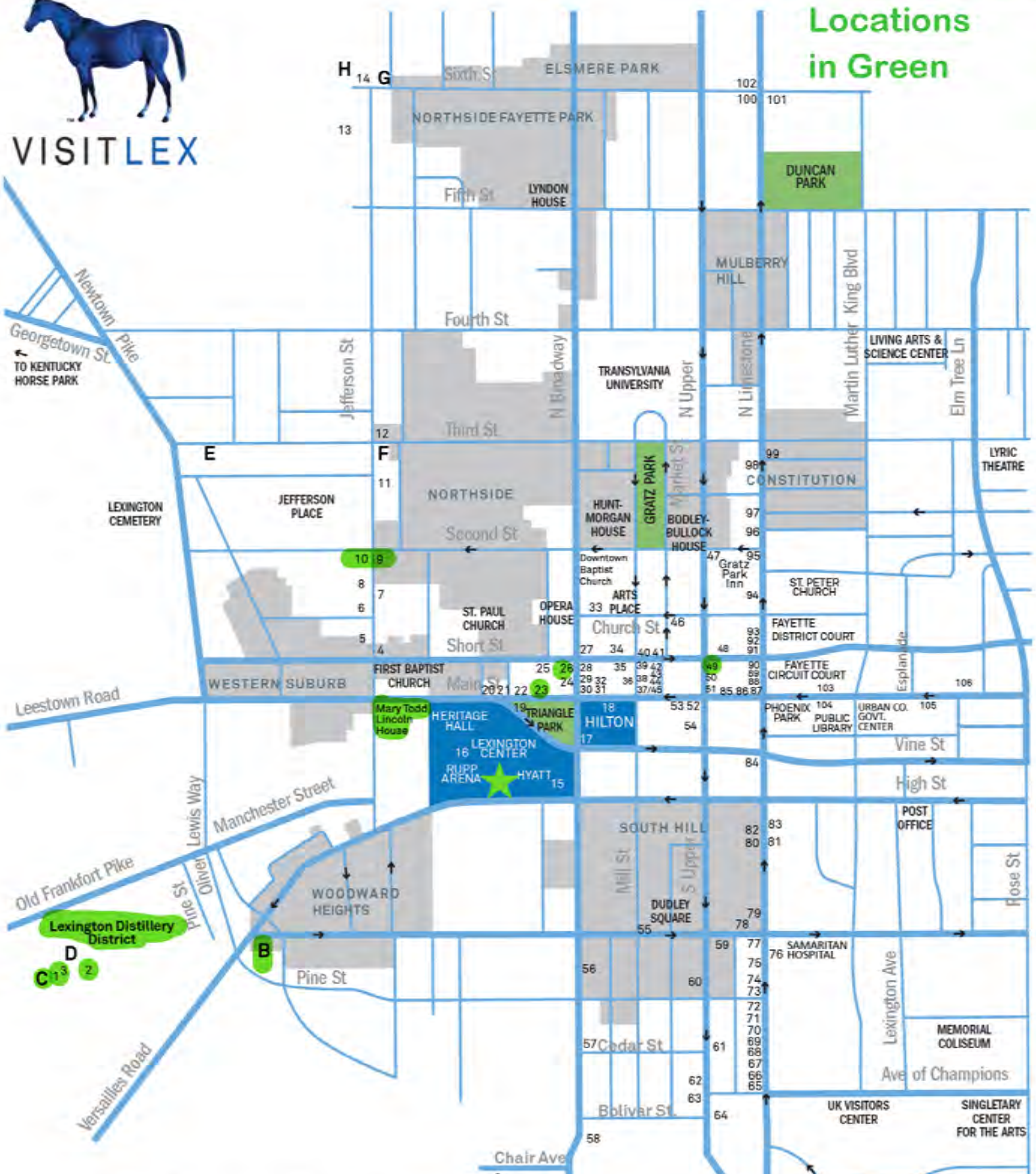
Hyatt Regency Lexington
at Lexington Center
MEZZANINE LEVEL
PHONE
HYATT SUITES FOYER
ELEVATORS
HYATT SUITES
WOODFORD
SCOTT
FRANKLIN
JESSAMINE
BOARD ROOMS
MARY TODD LINCOLN
HENRY CLAY
MEN
WOMEN
LOBBY LEVEL
LOBBY
ELEVATORS
HYATT REGENCY BALLROOMS
1
2
3
WEST FOYER
EAST FOYER
LOWER LEVEL 'B'
SERVICE
EMERGENCY EXIT
SERVICE
D
A - C
HYATT PATTERSON BALLROOMS
E
F
G
SERVICE
PREFUNCTION
SERVICE
REGISTRATION
MEN
WOMEN
PHONES
H
ALL MEETING SPACE IS WHEELCHAIR ACCESSIBLE
LOWER LEVEL 'A'
KENTUCKY
ENTRANCE
UPPER LEVEL
ENTRANCE
BAR
HYTTOPS



HERITAGE HALL EAST
BOURBON TASTING
(Sunday)
ICE BREAKER
(Sunday evening)
POSTER SESSION
(Monday and Tuesday)
ROLLUP DOOR
EXIT
ROLLUP DOOR
12 25
13 24
14 23
15 22
16 21
17 20
18 19
TRAILER
11
10
9
8
7
6
HRL F&B
HRL F&B
P01 P02 P03 P04
P05 P06 P07 P08
P09 P10 P11 P12
P13 P14 P15 P16
MEN
CONCESS.
WOMEN
OFFICE
5 4
3 2 1
FREIGHT ELEVATOR
Information table
SHOW ENTRANCE
HERITAGE BALLROOM 2
(Technical Sessions)
HERITAGE BALLROOM 3
(Technical Sessions)
WOMEN
MEN
REGISTRATION
ELKHORN B & C
(Technical Sessions)
ELKHORN A & D
(Presenters & Judges Room)

VISITLEX

Meeting Event Locations in Green



Craft Breweries & Distilleries

A. Country Boy Brewing
B. Alltech Lexington Brewing & Distilling
C. Ethereal Brewing
D. Barrel House Distilling
E. Blue Stallion Brewing
F. Chase Brewing
G. West Sixth Brewing
H. Bluegrass Distillers

Downtown Lexington Bars and Restaurants

1. Middle Fork Kitchen Bar
2. Break Room at Pepper
3. Crank & Boom Ice Cream Lounge
4. Wagon Bones Grill
5. Stella's Kentucky Deli
6. Nick Ryan's Saloon
7. The Grey Goose
8. Blue Heron Steakhouse
9. Wine + Market
10. Enoteca
11. Apiary Fine Catering & Events
12. The Green Lantern Bar
13. County Club
14. Smithtown Seafood
15. BlueFire Bar & Grille
16. Lexington Center Food Court
17. Bigg Blue Martini/Triangle Grill
18. Main Street Deli
19. Double H BBQ (inside Triangle Park)
20. Daily Offerings Roastery
21. Paulie's Toasted Barrel
22. Tony's Steaks & Seafood
23. Pies & Pints
24. Vinaigrette Salad Kitchen
25. HopCat
26. Saul Good Restaurant & Pub
27. Shakespeare & Co.
28. Clawdaddy's
29. The Sweet Spot
30. Starbucks
31. Sawyer's
32. West Coast Gourmet Pizza (interior)
33. The Courtyard Deli
34. The Village Idiot
35. Table Three TEN
36. Buddha Lounge
37. SkyBar
38. Goodfellas Pizzeria
39. Cheapside Bar & Grill
40. Dudley's on Short
41. Parlay Social
42. Bluegrass Tavern
43. Wild Cat Saloon
44. Centro
45. Stagger Inn
46. Belle's Cocktail House
47. Distilled Restaurant & Bourbon Bar
48. Shorty's Market & Tap Room
49. Lexington Diner
50. Henry Clay's Public House
51. Lockbox
52. Harvey's Bar
53. Hugo's Ultralounge
54. McCarthy's Irish Bar
55. Sabio
56. Ellos on Broadway
57. The JDI Grille & Tavern
58. Tolly-Ho
59. Joe Bologna's
60. Mellow Mushroom
61. Raising Cane's Chicken Fingers
62. Firehouse Subs
63. Smashburger
64. Fazoli's
65. Street Craves
66. Noodles & Company
67. Pazzo's Pizza Pub
68. Jimmy John's
69. Han Woo Ri
70. McDonald's
71. Chipotle
72. Blaze Pizza
73. Two Keys Tavern
74. Paddock Bar & Patio
75. Local Taco
76. Sav's Grill & West African Cuisine
77. Tin Roof
78. Red Bang Bang
79. Sav's Chill
80. House of Soul
81. Hanna's on Lime
82. Ole Hookers Bait & Tackle Bar
83. Sound Bar
84. El Habanero Loko
85. TrusT Lounge
86. Sunrise Bakery (breakfast only)
87. Taste of Thai
88. Sam's Hot Dog Stand
89. Molly Brooke's Irish Bar
90. Crossings Lexington
91. The Upstart Crow
92. Limestone Blue
93. Sidebar Grill
94. George's Deli
95. Le Deauville French Bistro
96. Columbia Steak House
97. Lexington Beerworks
98. Third Street Stuff & Coffee
99. Doodles (breakfast & lunch)
100. North Lime Coffee & Donuts
101. Arcadium
102. Al's Bar
103. Alfalfa
104. Panera To You
105. Dad's Favorites
106. Portofino

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EASTERN SECTION AAPG MORGANTOWN 2017

BEASTS OF THE EAST

UNCONVENTIONAL SHALES

Save the Date

2017 Eastern Section AAPG Annual Meeting

September 24–27, 2017

Morgantown, West Virginia

KOGA

KENTUCKY OIL & GAS ASSOCIATION

Representing the Oil and Gas Industry in Kentucky.