SALT LAKE CITY
AAPG-RMS
2013

ENERGY ELEVATED
SEPTEMBER 22-24

Official Meeting Program

2013 AAPG Rocky Mountain Section Meeting

Hosted by the
Utah Geological Association

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AAPG-RMS SALT LAKE CITY 2013

ENERGY ELEVATED

SEPTEMBER 22-24

WE WELCOME YOU TO SALT LAKE CITY

On behalf of the Rocky Mountain Section of AAPG and the Utah Geological Association, we welcome you to Salt Lake City.

The 2013 organizing committee has worked hard to prepare an excellent conference with diverse field trips, comprehensive short courses, and a technical program that highlights the latest research on a wide variety of geoscience topics. Don't forget to check out the core posters, located in the exhibit hall, representing several major reservoir types in the Rockies.

There are still tickets available for the private party at the new Natural History Museum of Utah on Monday evening. Located on the east bench, with panoramic views of the Salt Lake Valley, this 163,000-square-foot facility is one of the finest Natural History Museums in the country. The entire museum will be yours to explore and enjoy, along with dinner, drinks, and live music by the local folk band Otter Creek.

The All-Convention Luncheon on Tuesday will step away from the traditional petroleum discussion and look to the heavens. Dr. Rebecca Williams, Mars research scientist with the Planetary Science Institute, will present the latest findings from the Mars Science Laboratory Curiosity. Many of Utah's geologic landscapes have served as analogs to the features seen on Mars.

One of the committee's goals was to greatly increase the number of student attendees (over 100 students are registered). As a professional, please take time to engage these students, inquire about their future goals, and share your hard-earned experiences. Help make this meeting the beginning of an exciting career.

Salt Lake City has changed significantly since it last hosted a RMS meeting. We encourage you take some time to explore all the new amenities the city has to offer and hopefully you will get a chance to make it up into the mountains and enjoy the wonderful fall weather.

Craig Morgan, RMS Conference General Chair and UGA President
Michael Vanden Berg, RMS President

RMS Officers

President – Michael Vanden Berg
President-Elect – Elmo Brown
Secretary-Treasurer – Sue Cluff
Secretary-Treasurer-Elect – Cat Campbell
Past President – Robert Suydam

UGA Officers

President – Craig Morgan
President-Elect – Grant Willis
Treasurer – Paul Inkenbrandt
Secretary – Sonja Heuscher
Program Chair – Danny Horns
Past President – Kimm Harty

CONFERENCE COMMITTEE CHAIRS

COMMITTEE	CHAIRPERSON
General Chair	Craig Morgan
RMS President	Michael Vanden Berg
Finance	Roger Bon
Technical Program	Tom Chidsey
Short Courses	Tom Anderson
Field Trips	Paul Anderson
Exhibit Hall	Robert Ressetar
Publicity and Awards	Steve Schamel
Registration	Stephanie Carney
Judging	Brad Hill
Guest Activities	Terri Morgan Mary Chidsey
Social Events	Paul Inkenbrandt
Volunteers	Lauren Birgenheier
Sponsorship	David Wavrek Randy White Marc Eckels
Convention Signs	Terry Massoth
Teacher Activities	Sandy Eldredge

Standing (left to right): Randy White, Steve Schamel, Dave Wavrek, Brad Hill, Mary Chidsey, Tom Chidsey, Robert Ressetar, Terri Morgan, Craig Morgan, Stephanie Carney

Sitting/kneeling (left to right): Michael Vanden Berg, Terry Massoth, Lauren Birgenheier, Roger Bon, Tom Anderson, Paul Inkenbrandt

Not pictured: Paul Anderson, Marc Eckels, Sandy Eldredge

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Cover photo credit, Adam Barker; others courtesy of Michael Vanden Berg

MEETING SCHEDULE OF EVENTS

All activities and events will be held at the Hilton Salt Lake City Center in downtown Salt Lake City unless otherwise noted.

FRIDAY, SEPT. 20

7:30 AM Departure **(returns 8:30 PM Sat.)**	Field Trip 1 – San Rafael Swell: Geological Centerpiece of Utah

SATURDAY, SEPT. 21

8:00 AM - 5:00 PM	Short Course 1 – Geology and Geomechanics of Shale Reservoirs (at TerraTek, A Schlumberger company)

SUNDAY, SEPT. 22

8:00 AM - 7:00 PM	Registration
8:00 AM - 4:30 PM	Field Trip 2 – The Greatest Story Ever Told by Nine Miles of Rock: Exploring the Geology of Little Cottonwood Canyon, Wasatch Mountains
8:00 AM - 4:00 PM	Short Course 2 – Petrophysical evaluation of Unconventional Resources (Seminar Theater)
8:00 AM - 4:00 PM	Short Course 3 – Effective Use of Seismic Attributes for the Interpreter (Energy & Geoscience Institute, University of Utah)
8:00 AM - 4:00 PM	Exhibitor Set-up (Grand Ballroom)
8:45 AM - 10:00 AM	Mormon Tabernacle Choir performance
9:00 AM - 4:00 PM	Field Trip 3 – Great Salt Lake and Pleistocene Lake Bonneville (Free field trip for students and young professionals)
10:00 AM - 4:00 PM	Speaker Ready Room (Canyons C)
12:00 Noon - 5:00 PM	Guest Hospitality Suite (Conrad Suite, Room 1807)
5:00 PM - 7:00 PM	Icebreaker (Grand Ballroom/Lobby)

MONDAY, SEPT. 23

6:30 AM - 7:45 AM	AAPG House of Delegates' Breakfast (Granite Conference Center, by invitation only)
7:00 AM - 7:45 AM	Speaker/Poster Presenter Breakfast (Salon II)
7:00 AM - 7:45 AM	Judges' Breakfast (Salon I)
7:00 AM - 5:00 PM	Registration
7:00 AM - 5:00 PM	Speaker Ready Room (Canyons C)
8:00 AM - 5:00 PM	Guest Hospitality Suite (Conrad Suite, Room 1807)
8:00 AM - 8:30 AM	Opening Session (Alpine)
8:40 AM - 5:00 PM	Exhibit Hall Open (Grand Ballroom)
8:40 AM - 12:00 Noon	Oral Sessions (Alpine/Canyons A&B)
8:40 AM - 12:00 Noon	Poster Sessions (Topaz/Lobby)
8:40 AM - 5:00 PM	Core Posters (Grand Ballroom)
9:00 AM - 4:00 PM	Guest/Spouse Field Trip – Sundance Resort
10:00 AM - 10:40 AM	Morning Break (Grand Ballroom/Lobby/Topaz)
12:15 PM - 1:20 PM	DPA Luncheon (Granite Conference Center, ticketed event)
1:20 PM - 5:00 PM	Oral Sessions (Alpine/Canyons A&B)
1:20 PM - 5:00 PM	Energy Policy Forum (Seminar Theater)
1:20 PM - 5:00 PM	Poster Sessions (Topaz/Lobby)

3:00 PM - 3:40 PM	Afternoon Break (Grand Ballroom/Lobby/Topaz)
5:00 PM - 6:00 PM	RMS Foundation Meeting (Granite Boardroom, by invitation only)
6:00 PM - 10:00 PM	Night at the New Natural History Museum of Utah (Ticketed event, transportation provided to and from the museum, 301 Wakara Way, Salt Lake City)

TUESDAY, SEPT. 24

6:00 AM - 7:45 AM	RMS Executive Committee Meeting (Granite Conference Center, by invitation only)
7:00 AM - 7:45 AM	Speaker/Poster Presenter Breakfast (Salon II)
7:00 AM - 12:00 Noon	Registration
7:00 AM - 4:00 PM	Speaker Ready Room (Canyons C)
8:00 AM - 5:00 PM	Guest Hospitality Suite (Conrad Suite, Room 1807)
8:00 AM - 11:00/11:20 AM	Oral Sessions (Alpine/Canyons A&B)
8:00 AM - 11:20 AM	Forum – Rocky Mountain Natural Gas: A Marketer's Perspective
8:00 AM - 11:20 AM	Poster Sessions (Topaz/Lobby)
8:30 AM - 5:00 PM	Core Posters (Grand Ballroom)
8:30 AM - 5:00 PM	Exhibit Hall Open (Grand Ballroom)
8:45 AM - 11:00 AM	Guest Activity – Family Search Genealogy Class
9:20 AM - 9:40 AM	Morning Break (Grand Ballroom/Lobby/Topaz)
11:40 AM - 1:40 PM	All-Convention Luncheon (Alpine, ticketed event)
2:20 PM - 4:00 PM	Oral Sessions (Alpine/Canyons A&B)
2:20 PM - 5:00 PM	Poster Sessions (Topaz/Lobby)
4:00 PM - 5:00 PM	Closing Reception (Grand Ballroom/Lobby/Topaz)
6:00 PM - 10:00 PM	President's Reception (Squatters Pub, by invitation only, 147 W. Broadway, SLC)

WEDNESDAY, SEPT. 25

6:30 AM - 7:30 PM	Field Trip 4 – Geology of Nine Mile Canyon, Wasatch and Green River Formations
8:00 AM - 4:30 PM	Short Course 4 – Microbial Carbonate Reservoirs from Utah - Core Workshop (Utah Core Research Center, transporation provided to and from UCRC, 240 North Redwood Road, Salt Lake City)

THURSDAY, SEPT. 26

8:00 AM Departure	Field Trip 5 – Modern and Ancient Microbial Carbonates in Utah: Examples from Great Salt Lake and the Uinta Basin's Tertiary (Eocene) Green River Formation

Thor's Hammer, Bryce Canyon National Park

GENERAL INFORMATION AT A GLANCE

Registration (Registration Office, Second Level)

Sunday 8:00 AM - 7:00 PM
Monday 7:00 AM - 5:00 PM
Tuesday 7:00 AM - 12:00 Noon

Separate queues will be set up for advance and onsite registration.

Speaker Ready Room (Canyons C)

All oral presenters will be required to check in at the Speaker Ready Room to load their presentations and receive any last-minute instructions. Morning speakers will need to check in the preceding day, while afternoon speakers need to check in before 9:00 AM the day of their talk. Practice tables and electrical hook-up for laptops will be available. Poster presenters will likewise find assistance, as well as “emergency” supplies such as tape and Velcro.

The Speaker Ready Room will be open:
Sunday 10:00 AM - 4:00 PM
Monday 7:00 AM - 5:00 PM
Tuesday 7:00 AM - 4:00 PM

The Speaker Ready Room will also serve as the place where judges may complete their ballots and deposit them in the box provided.

Exhibition (Grand Ballroom)

Sunday 5:00 PM - 7:00 PM (during the Icebreaker)
Monday 8:40 AM - 5:00 PM
Tuesday 8:30 AM - 5:00 PM (Closing Reception 4:00 - 5:00 PM)

Icebreaker Reception (Sunday, 5:00 - 7:00 PM, Grand Ballroom)

Sponsored by: Kodiak Oil and Gas Corp. and Integrated Water Management

Free with registration badge

Join us for this annual conference kick-off. Enjoy meeting up with old friends and making new ones, all while browsing the exhibit hall and partaking in some great food and drink.

Speaker/Poster Presenter Breakfast (Monday & Tuesday, 7:00 - 7:45 AM, Salon II)

All session chairmen, speakers, and poster presenters should plan to attend a complimentary breakfast on the morning of their scheduled session, beginning at 7:00 AM. Reminders will be given regarding session timing, audiovisual equipment, how speakers will be introduced, and when poster presenters should be present in their booths.

Judges’ Breakfast (Monday ONLY, 7:00 - 7:45 AM, Salon I)

All judges should plan to attend a complimentary breakfast on Monday to receive packets containing ballots and instructions, including where and when ballots need to be turned in.

AAPG House of Delegates' Breakfast (Monday, 6:30 - 7:45 AM, Granite Conference Center)

If you are an AAPG delegate, plan to attend a special breakfast on Monday morning. All delegates are welcome; you should have received an invitation prior to the meeting.

Session Refreshment Breaks (Monday Morning and Afternoon, Tuesday Morning, Grand Ballroom/Lobby/Topaz)

Free with registration badge

We've built breaks into the oral sessions to allow for exploration of posters and exhibitors' displays. Come to the exhibit hall for refreshments, conversation, and more cross-generational education, thanks to some great poster presentations and the presence of the young professionals and students in our midst.

Closing Reception (Tuesday, 4:00 - 5:00 PM, Grand Ballroom/Lobby/Topaz)

Sponsored by: Robert L. Bayless, Producer and TerraTek, A Schlumberger company

Free with registration badge

You're invited to one last toast – to the success of RMS-AAPG 2013! Exhibits and posters will stay open through the end of Tuesday, so please plan to stick around in support of our vendors, speakers, and poster presenters. It will be a fitting way to put a wrap on yet another great Rocky Mountain Section Meeting.

Deneen Pottery

The finest logo mugs!

We are the premier producer of handmade logo mugs with a custom stoneware clay body. We are also a family business that was started in 1972 by my parents, Peter and Mary Deneen, in the Lowertown of St. Paul, Minnesota. Today we occupy over 10,000 square feet and employ 35 skilled craftspeople.

This is an exciting time for our company and we're proud to be manufacturing handmade stoneware in the USA. We're equally proud to carry forward a long tradition of handthrown stoneware designs that meet your personal or business needs. While every piece shares the same level of quality, each one is also individually created by hand so that no two are exactly alike.

Our products celebrate our heritage, our sense of community, and most of all… our customers.

"Our life's work is (LITERALLY) in your hands."

Niles Deneen, CEO

deneenpottery.com

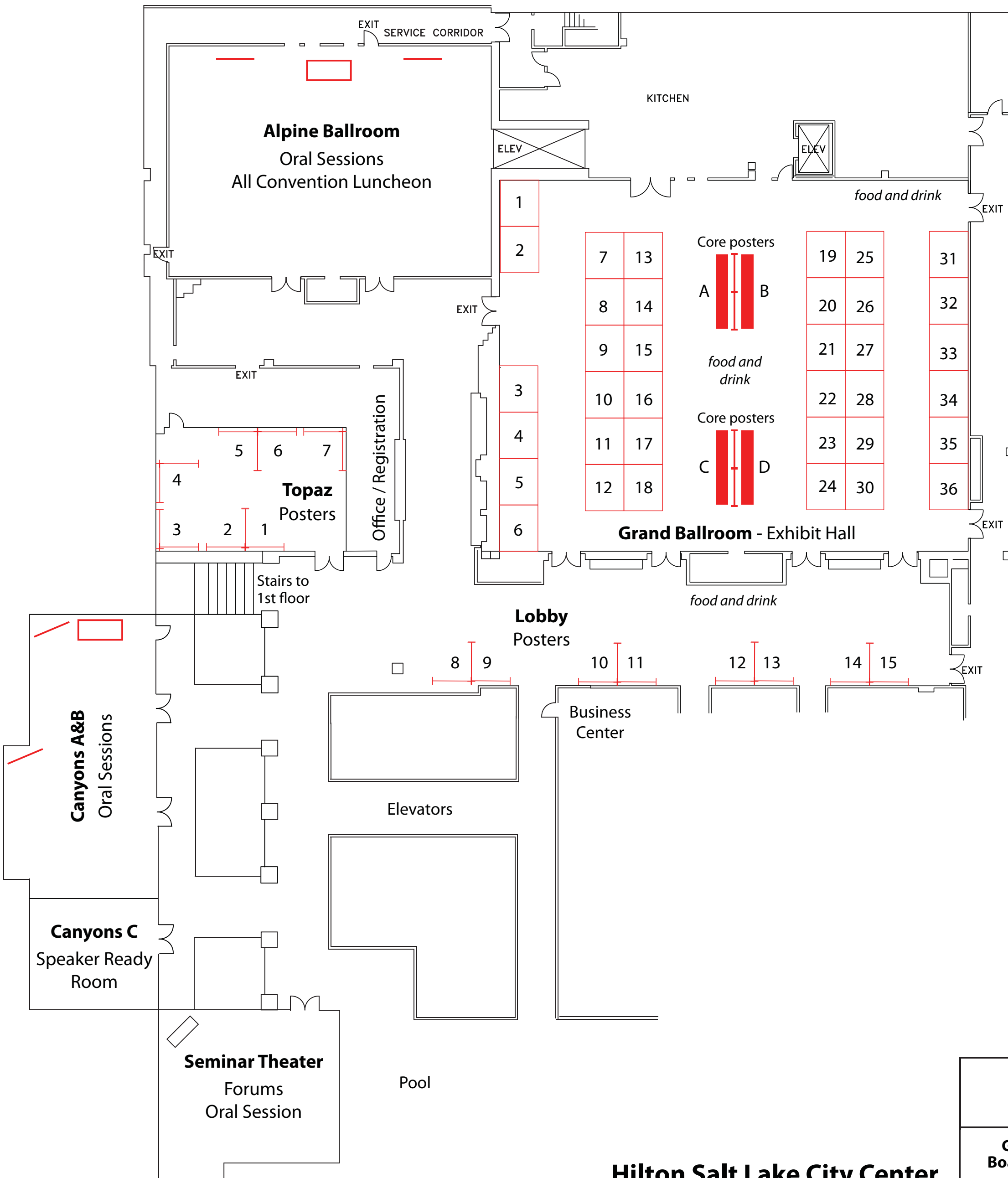
DENEEN POTTERY

Our life's work is in your hands.™

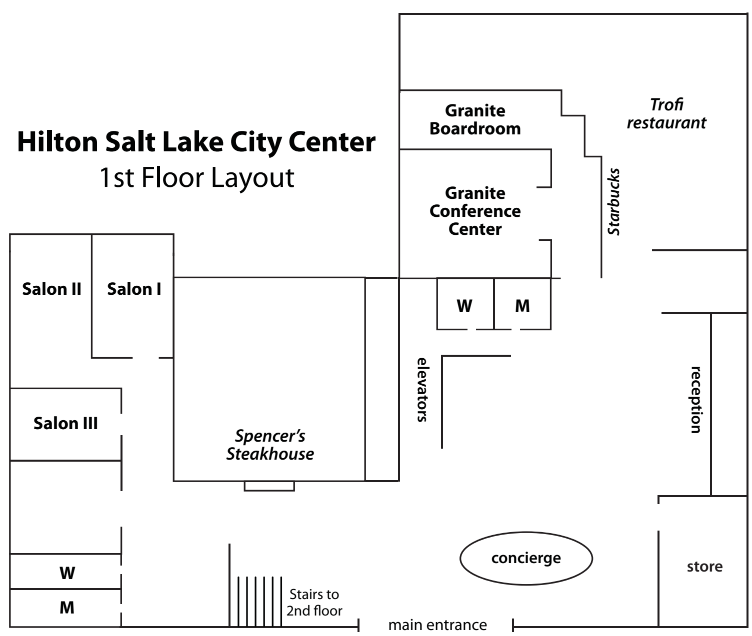
Mugs will be presented to all speakers and judges in appreciation for their contribution to the meeting

HILTON LAYOUT

Hilton Salt Lake City Center
2nd Floor Layout



Hilton Salt Lake City Center
1st Floor Layout



SPECIAL EVENTS

Opening Session

Monday, 8:00 - 8:30 AM, Alpine

Please plan to attend the Opening Session, which will feature welcome comments by Utah's Lieutenant Governor Greg Bell. In addition, there will be brief comments from Craig Morgan, conference general chair and UGA president, and Michael Vanden Berg, RMS president.

Energy Policy Forum: Environmental, Economic, and Cultural Impacts of Unconventional Oil and Gas Development

Monday, 1:20 - 5:00 PM, Seminar Theater

Sponsored by: AAPG GEO-DC and the Division of Professional Affairs (DPA)

Moderator: Edith Allison, Director AAPG GEO-DC

The Energy Policy Forum will highlight policy issues that may be peripheral to petroleum geologists' usual work, but that significantly impact oil and natural gas exploration and production. This forum will help illuminate an inescapable fact: As unconventional oil and gas production expands into new regions, or exploration and production activity swells in historic producing areas, non-technical concerns increase.

This half-day energy policy session will focus on several issues specific to the Rocky Mountain region such as:

- Wildlife Protection, Sage Grouse – Bob Budd, Wyoming Wildlife and Natural Resource Trust
- Produced Water Disposal Issues – John Rogers, Associate Director, Utah Division of Oil, Gas, and Mining
- Air Quality Issues – Ursula Rick, Regulatory Affairs Analyst, Western Energy Alliance
- Economic Impacts of Unconventional Resource Plays – Headwaters Economics
- Public Environmental Concerns about Gas Development in the Western Rockies – Simona Perry, C.A.S.E. Consulting Services
- Managing Social Risk: Best Practices for Shale Gas Companies – Susan Reider and Robert Wasserstrom, Senior Partners, Terra Group

Forum – Rocky Mountain Natural Gas: A Marketer's Perspective

Tuesday, 8:00 - 11:20 AM, Seminar Theater

Presenters: Curtis Chisholm and David Lillywhite, Summit Energy, LLC

Please join us for this timely discussion applicable to better understanding the future of natural gas in our country; topics will include:

- Rocky Mountain Gas Marketing
- Transportation of Natural Gas
- Managing Price Risk
- Hope for the Future

AAPG Division of Professional Affairs Luncheon

Monday, 12:15 - 1:20 PM, Granite Conference Center

Cost: $40 (check with the registration desk to see if tickets are still available)

Speaker: Rick Allis – Director of the Utah Geological Survey and State Geologist

Title: Our Transforming Energy Sector – A Utah Perspective on Trends and Changes

The changes occurring in Utah's energy industries mimic many of the recent national trends in energy substitution. Oil production has doubled during the last 10 years and at present rates will reach Utah's historic peak oil production in about 10 more years. Natural gas production is at record levels, but coal production has declined to levels last seen 25 years ago as new electricity generation is gas-fired. Declining petroleum consumption since 2005 and substitution of coal for gas in electricity generation has caused state CO_2 emissions to decline to levels last reached during the late 1990s. Renewable electricity generation has increased to 6% of Utah's total generation due mainly to new wind and geothermal plants. This talk will speculate on future trends and will address the issues and possibilities of nuclear power, oil shale development, carbon sequestration, geothermal power from hot basins, and development constraints due to limited water availability.

Speaker Bio: Rick Allis has been Director of the Utah Geological Survey for 13 years. He was Research Professor at the Energy and Geoscience Institute, University of Utah, between 1997 and 2000, and prior to that worked for GNS Science and its predecessor organizations in New Zealand. He has broad interests in energy resources and has specialized in geothermal energy.

A Night at the Natural History Museum of Utah

Monday, 6:00 - 10:00 PM

Cost: $50 (check with the registration desk to see if tickets are still available)

Sponsored by: Sinclair Oil Corp. and WPX Energy

Transportation provided to and from the museum. Buses will leave from the Hilton's main entrance at 5:30, 5:45, 6:00, and 6:15 PM. Buses will return to the Hilton at 9:00, 9:15, 9:30, 9:45, and 10:00 PM.

Join us for a private party at this new, extraordinary museum. The night will include food and beverages, music by the local folk band Otter Creek, and private access to all museum galleries, including the paleotology prep room.

The extraordinary new 163,000-square-foot Natural History Museum of Utah, clad in 42,000 square feet of copper, occupies a prominent place at the edge of Salt Lake City and the University of Utah. The facility blends seamlessly into the foothills of the Rocky Mountains, the angles of the roof rising and falling with the slope of the foothills in the background. The design reflects the Museum's mission to illuminate the natural world through scientific inquiry, educational outreach, mutual cultural experience and human engagement of the past, present, and future of the region and the world.

With the artful integration of sound principles of sustainability, the design of the Natural History Museum of Utah will play a seminal role in enhancing the public's understanding of the earth's resources and systems and be a model for responsible and environmentally sensitive development. By incorporating the use of recycled materials, local resources, photo voltaic energy, radiant cooling, and the implementation of an extensive storm water catchment and management system, the Natural History Museum of Utah is seeking LEED Gold certification, which would make it one of only 18 buildings in Salt Lake City with that distinction.

The Museum's collections form the basis for all of the Museum's educational functions, from public exhibits and programming to scholarly research and publication. Its systematic collections in the fields of earth sciences, biology, and anthropology rank among the largest and most comprehensive in the western United States. While emphasizing the Great Basin and Colorado Plateau, they also include material from throughout the world.

All-Convention Luncheon – Including Presentation of RMS Awards

Tuesday, 11:40 AM - 1:40 PM, Alpine

Cost: $40 (check with the registration desk to see if tickets are still available)

Sponsored by: Enerplus

Speaker: Dr. Rebecca Williams, Planetary Science Institute

Title: Roving the Red Planet: A Field Geologist Explores Gale Crater

On August 5, 2012, the Mars Science Laboratory Curiosity landed in northwest Gale Crater. The landing site is on plains next to the ~5 km high Mount Sharp and near an alluvial fan. With the most sophisticated suite of scientific instruments ever employed to investigate the Martian surface, Curiosity has been assessing the character of ancient environments based on the development of facies models derived from sedimentary rocks almost 4 billion years old. As a co-investigator on this mission, Williams uses her experience as a field geologist with interest in fluvial processes to aid the science team in reconstructing the aqueous history preserved at Gale Crater. Terrestrial analogs have been particularly useful in deciphering the initial photographic and geochemical results in Gale Crater. Work by Williams and colleagues on ancient fluvial systems near Green River, UT, the Atacama Desert in Chile, and central Australia, may be helpful in assessing the wealth of data from Curiosity. In this presentation, Williams will discuss the rationale for selecting this landing site, will provide insight into how the science team participates in daily operations from their home institutions, and will provide an update on rover activities and science results after one year of surface operations.

Speaker Bio: Rebecca M. E. Williams received her BA in 1995 from Franklin & Marshall College. She earned her Ph.D. in planetary science from Washington University in St. Louis in 2000. She is a senior scientist at the Planetary Science Institute. The overarching objective in her research is to understand the role of water in shaping the surface of Mars through qualitative and quantitative characterization of landforms using image and topographic datasets. Her research builds upon field observations of terrestrial fluvial landforms to enhance the interpretation of remotely sensed data from Mars. One of her research topics has been on investigating inverted channels in Utah, California, Australia, and Chile. She has served in the role of principal investigator in seven NASA-funded projects and as a team member with the MOC, CTX, and THEMIS VIS cameras. In 2006, she was awarded the NASA Carl Sagan Fellowship for Early Career Researchers. She is a participating scientist on the Mars Science Laboratory (MSL) rover Curiosity, which landed in the northwest corner of Gale crater on August 5, 2012. She lives in Waunakee, WI, with her husband, Scott, and their two daughters.

The conference bag this year is a little different. Instead of the typical briefcase style, we went with a more simple bag (great for groceries) associated with a great cause. The 575 bags purchased for this meeting will provide 5,750 meals for hungry children.

CREATING GOOD PRODUCTS THAT HELP FEED THE WORLD.

ABOUT FEED:

After witnessing the effects of hunger firsthand when traveling as a World Food Programme Honorary Spokesperson, Lauren Bush Lauren founded FEED Projects in 2007 with the mission of creating good products that help FEED the world. Every product sold has a measurable donation attached to it and, to date, the social business has been able to donate over $6 million and provide nearly 60 million school meals globally through the United Nations World Food Programme. FEED has also supported nutrition programs around the world, providing vitamin supplements to over 3.5 million children through UNICEF.

Over the past six years, FEED has forged successful partnerships with companies such as Target, Disney, Pottery Barn, Clarins, Whole Foods, Gap, DKNY, Links of London, Godiva and TOMS.

FEED products are available online and at retail locations around the world. For more information, please visit www.FEEDprojects.com or follow FEED on Facebook (FEED Projects) and Twitter (@FEEDProjects).

ABOUT the FEED FOUNDATION:

Co-founded by Lauren Bush Lauren, the FEED Foundation is dedicated to ending world hunger – one child at a time. As of 2012, the FEED Foundation and its partner FEED Projects have provided nearly 60 million free, nutritious school meals to kids around the globe. In collaboration with UNICEF and the United Nations World Food Programme, the organization's mission is to relieve hunger and help meet the basic nutritional needs of children, both stateside and abroad.

The foundation has since expanded its focus on school meals, funding hunger relief efforts during natural disasters and humanitarian crises and launching its first United States venture – FEED USA – which funds nutrition-related programs in classrooms across America.

The FEED Foundation now offers targeted ways to give through "FEED Funds." These funds include FEED Love, a fund which provides both meals and ARV drugs in communities ravished by HIV/AIDS, and FEED Nutrients, which provides Vitamin A and micronutrients to children in countries like Guatemala, which has the highest rate of malnutrition in Latin America.
For more information, please visit www.theFEEDfoundation.org.





www.feedprojects.com

SPOUSE AND GUEST ACTIVITIES

We welcome you to one of America's prettiest cities during one of our prettiest times of year. We have selected a variety of events that we hope you will take part in and know you will enjoy. And when you're not with us on a trip or relaxing in the hospitality suite, be sure to avail yourself of all there is to do, see, and eat in close proximity to the Hilton.

You'll note that we have Tuesday afternoon for some leisure time, just so you can explore downtown. Don't miss City Creek Center, a spectacular brand-new facility just two blocks from the hotel. The center covers 2.5 city blocks with unique design features such as a 250-foot by 60-foot retractable roof and a pedestrian skybridge. The actual City Creek cascades over a waterfall into the outdoor courtyard and flows through the central walkway of the center.

We hope you have a great time visiting and exploring Salt Lake!

Terri Morgan and Mary Chidsey, Guest Activities Chairs

Guest Hospitality Suite – Conrad Suite, Room 1807

Sunday 12:00 Noon - 5:00 PM
Monday 8:00 AM - 5:00 PM
Tuesday 8:00 AM - 5:00 PM

As a special treat, we have reserved the Hilton's Presidential Suite (Conrad Suite, Room 1807) as the Guest Hospitality Suite. Come and enjoy continental breakfast, a simple lunch, or just come up to the 18th floor to relax and enjoy the views.

Mormon Tabernacle Choir Live Broadcast

Sunday, 8:45 - 10:00 AM

Hear the world-famous Mormon Tabernacle Choir as they perform their weekly live broadcast of "Music and the Spoken Word," a wonderful half hour of inspirational music. The marvelous acoustics of the historic Tabernacle on Temple Square and the singing of the Choir make this an experience not to be forgotten. We will meet in the lobby of the Hilton where we will walk (about 10-15 minutes) to the performance. We need to be seated by 9:15 for the complimentary 9:30 to 10:00 AM program.

Sundance Resort Tour

Monday, 9:00 AM - 4:00 PM

Cost: $75 (check with the registration desk to see if space is still available)

The tour will leave from the Hilton and go up Provo Canyon with a brief stop at Bridal Veil Falls. Sundance Resort is at the base of the 12,000-foot Mount Timpanogos. The resort is owned by Robert Redford who in 1969 purchased a small ski (one chair lift) resort called Timphaven and most of the surrounding land. He felt the area was the "ideal locale for environmental conservation and artistic experimentation." You can enjoy the stunning natural scenery as you take a chair lift ride up to Ray's Summit, returning to the resort for lunch at Sundance's Foundry Grill.

Genealogy at the Family History Library

Tuesday, 8:45 - 11:00 AM

The Family History Library has vast genealogical resources available to the general public at no cost for individual family research. Remember to bring any information you already have on your family, including names, places, and birth, marriage, and death dates. Tracing your family tree can be very exciting as you discover your roots! The Family History Library has knowledgeable volunteers to help you get started, and is open Monday through Friday 9:00 AM to 9:00 PM and Saturday 9:00 AM to 5:00 PM. We will meet in the lobby of the Hilton on Tuesday at 8:45 AM where we will walk (about 10 minutes) to the Family History Library. We will return to the Hilton in plenty of time to attend the All-Convention Luncheon, a facinating presentation on the Curiosity rover currently exploring the surface of Mars.

Delicate Arch, Arches National Park

Redmond Real Salt

When most people think of salt in Utah, they tend to think of the Great Salt Lake. While it is true, a lot of commercial salt is processed and refined in factories from the shores of the salty lake, Real Salt comes from a completely different source. The Redmond Salt Mine is located more than 150 miles south of the Great Salt Lake in the town of Redmond, Utah. After the salt is mined, it is shipped to the Redmond corporate headquaters in Heber City, Utah, for packaging.

The salt beds occur in the Arapien Formation of middle Jurassic age and were deposited as part of the Sundance Sea, an arm of what is now the Artic Ocean that extended south into the central western United States. A cap of bentonite clay has preserved the salt and kept it free from modern day contaminants.

The Redmond Company has generously donated 2 oz. salt shakers for all registrants, so everyone can take home a little sample of Jurassic Utah.

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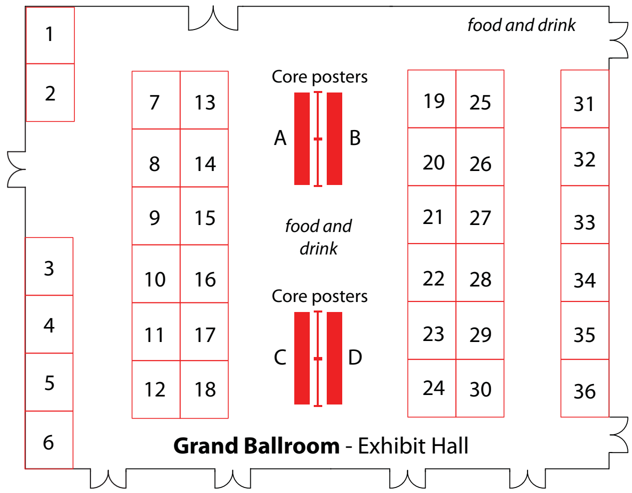
EXHIBITS



Exhibitor	Booth #	Products/Services
Alpine Minerals alpineminerals@gmail.com	26	
AAPG www.aapg.org	6	AAPG provides publications, conferences, and educational opportunities to geoscientists and disseminates the most current geological information available.
Columbine Logging, Inc. www.columbinelogging.com 303-915-6873	36	We are driven to be the best geological well-site service company in the country. Our professional well-site geologists utilize a massive team of resources and tools to provide the best in class and integrated formation evaluation services in the industry.
Corpro www.corpro-group.com Rob Potter rpotter@reservoir-group.com 281-782-5778	11	The number one provider of reservoir coring services for the global oil & gas industry. We deliver advanced, wireline and conventional services, quality core processing techniques, and robust data acquisition applications. We possess the ability, and the commitment, to address the most acute coring challenges in pursuit of your objectives: ever more efficient drilling operations and reduced costs.
Decollement Consulting Inc. www.decollementconsulting.com Roger Charbonneau rdc@decollementconsulting.com 303-249-4072	32	Mud-logging, consulting wellsite geology, and geo-steering services.
Digital Formation www.digitalformation.com 303-770-4235	7	Digital Formation provides quality consulting and technical services for geological and petrophysical activities of the E&P industry, as well as analysis and presentation software (for Microsoft® Windows™).
Dolan Integration Group www.digforenergy.com 301-531-2950	8	DIG delivers geology and geochemistry support in the rapidly changing world of unconventional petroleum systems. We have made it our business to understand the exploration, development and production of unconventional resources around the globe.
Empirica www.empirica-logging.com Rob Potter rpotter@reservoir-group.com 281-782-5778	12	Empirica brings all the niche areas of surface logging expertise into one customer-focused entity that reconfigures the boundaries of our industry. Our major in house R&D program, our training and development center, cutting edge equipment, and an unmatched service offering firmly places us as the experts in our industry.
Energy & Geoscience Institute www.egi.utah.edu 801-581-5126	17-18	The Energy & Geoscience Institute (EGI) at the University of Utah is the world's largest university-based industry cost shared upstream research program. With over 70 energy corporations across the globe as Corporate Associate Members, EGI has delivered a value of over $550 million of research across all seven continents for over 40 years.

Exhibitor	Booth #	Products/Services
Field Geo Services www.fieldgeoservices.com 970-270-4940	24	Field Geo Services is your solution to well site mudlogging within the United States. Based out of Grand Junction, CO, FGS covers geothermal, geo-steering, well site, mass spectrometer services and analysis, and x-ray diffraction.
Fluid Inclusion Technologies www.fittulsa.com 918-461-8984	30	FIT specializes in 1) laboratory analysis of geological samples for trapped organic and inorganic paleo-fluids, and 2) geochemical profiling of borehole fluids at well site with direct quadrupole mass spectrometry.
GeoCare Benefits Insurance www.geocarebenefits.com 800-337-3140	34	Announcing-Private Medical Insurance Exchange now available to choose from a variety of plans and rates to meet your needs. Open enrollment for coverage on a guaranteed-issue basis begins 10/1/13 for coverage effective on 1/1/14. Other GeoCare Plans include Life, Dental, Disability, Long Term Care, Medicare Supplement. The Program also sponsors Auto and Homeowner coverage. Please stop by our booth for more information.
Getech, Inc. www.getech.com 713-979-9900	20	Getech is the foremost provider of US gravity and magnetic data. We offer custom integrated interpretation services and non-exclusive knowledge-based studies.
Horizon Well Logging, LLC www.hzmud.com 918-284-7963	31	Horizon Well Logging is the premier mud logging and geosteering firm supporting natural gas and oil exploration companies from the Mid-Continent, S. Texas, Rockies, Appalachia regions and beyond since 1988 utilizing cutting edge technology.
Horizontal Solutions International www.horizontalsi.com George Gunn, ggunn@horizontalsi.com 972-416-1626 ext.104	33	Methods developed by HSI can maximize the return on investment by delivering performance improvements through wellbore efficiency, reliability and safety. HSI has over 17-years of experience and expertise drilling 8,000+ successful horizontal wells.
IHS www.ihs.com 713-485-9143	21	IHS is a global information company with world-class experts in the pivotal areas shaping today's business landscape: energy, economics, geopolitical risk, sustainability and supply chain management.
Lithologic & Stratigraphic Solutions richard.inden@comcast.net 303-623-6156	25-27	
LMKR GeoGraphix products@lmkr.com 1-281-495-5657	29	Designed by geoscientists for geoscientists, LMKR GeoGraphix is a powerful, fully integrated geological and geophysical interpretation system. Discover its potential by visiting the LMKR team at booth 29 or visit us at lmkr.com.
Neuralog www.neuralog.com Bryan Mills bmills@neuralog.com 281-240-2525	16	Neuralog provides solutions for: log data capture including mud log lithology, volumetric and reserves calculations, cross section modeling, well log printing and scanning, and managing working and historical data.
Old Dead Things, LLC www.olddeadthings.com 307-232-8894	3	Old Dead Things, LLC is a fossil company based in Casper, Wyoming. We collect, prep and sell fossils. The majority of our business involves Green River fossil fish and Cretaceous ammonites. We also sell minerals, jewelry, and rockhound supplies.
Pason Systems www.pason.com 720-880-2000	19	Pason provides drill rig instrumentation and data management, including data acquisition, well-site reporting, remote communications, and web-based information management. Pason equipment streamlines collaboration between rig and the office.
Pearson Technologies, Inc. pearsontech@comcast.net 303-989-2014	25	Rockies Basins regional basement structure, faulting and lead consulting using integrated geology and High-Resolution Aeromagnetic surveying. Shale exploration sweet spots within Niobrara, Bakken, Mississippian plays lie along imaged faults.
PTTC – Rocky Mountain Region www.pttc.org 303-273-3107	35	Not-for-profit organization located at Colorado School of Mines putting on high quality, low-cost Continuing Education and Technical workshops and short courses.

Exhibitor	Booth #	Products/Services
Selman & Associates, Ltd. www.selmanlog.com PO Box 2993 Rock Springs, WY 82902 307-382-5692	13-14	Selman & Associates, Ltd. has been setting new standards in quality and service for over 30 years! At Selman & Associates, Ltd., we understand our clients' needs, and we have developed and continue to develop the tools and services that will enable you to make important business decisions in a timely manner.
TerraTek, A Schlumberger company www.slb.com 801-584-2497	4-5	TerraTek rock mechanics and core analysis services provide vital answers needed to understand reservoir rock behavior and the mechanical changes associated with completion and production operations. From characterizing the reservoir and finding the most profitable zones to ensuring completion quality for long-lasting, predictable results, TerraTek rock mechanics and core analysis services offer a comprehensive suite of services that can be used throughout the life of your reservoir.
TGS Geological Products www.tgs.com info@tgs.com 713-860-2100	15	TGS provides multi-client geoscience data to oil and gas E&P companies worldwide. In addition to extensive global geophysical and geological data libraries that include multi-client seismic data and digital well logs, TGS also offers advanced processing and imaging services, interpretation products, permanent reservoir monitoring and data integration solutions.
Thompson Solutions www.thompsonsolutions.com 303-887-5398	9	Independent geophysical consulting firm based in Denver, Colorado. Exploration support with gravity and magnetic data, processing and integrated interpretation.
Utah Geological Association www.utahgeology.org	23	The purpose of the UGA is to increase and disperse geological information to the scientific community, and promote public awareness of the usefulness of geology in general. Stop by booth # 23 for information about monthly meetings, field trips, publications, and golf tournaments.
Utah Geological Survey www.geology.utah.gov 80-537-3300	22	The Utah Geological Survey provides timely scientific information about Utah's geologic environment, resources and hazards.
Utah Trust Lands www.trustlands.utah.gov 801-538-5100	28	The School and Institutional Trust Lands Administration--an independent agency of state government--is established to manage lands that Congress granted to the state of Utah for the support of common schools and other beneficiary institutions, under the Utah Enabling Act.
Vista Geoscience www.vistageoscience.com 303-249-2814	10	Geochemical tools: reduce your risk in O&G exploration and protect energy assets. Geochemical exploration surveys for land acquisition, seismic and drilling. Baseline environmental surveys: prevent/manage potential litigation.
Weatherford www.weatherford.com 832-249-2607	1-2	Weatherford is a Swiss-based, multinational oilfield service and technology company. We are one of the largest global providers of inventive solutions, technology and services for the oil and gas industry. With a product and service portfolio that spans the life cycle of a well — formation evaluation, well construction, completion and production — and a robust research and development effort, we are well positioned to meet the ever-evolving needs of the oil and gas industry.

Spiral Jetty, North Arm, Great Salt Lake

AWARDS

The Awards Ceremony will occur at the opening of the All-Convention Luncheon on Tuesday, September 24. This year there are two new awards being given by the Rocky Mountain Section.

Robert J. Weimer Lifetime Contribution Award

Given to **Dr. Robert J. Weimer**, Professor Emeritus, Colorado School of Mines, recognizing lifetime contributions to the practice of the geosciences and/or petroleum geology in the region of the Rocky Mountains.

Citation by John Robinson, Rocky Mountain Section Representative on the AAPG Advisory Council:

Robert J. Weimer has been active in the geosciences, either as a consultant, educator, or businessman for over 50 years. Bob's accomplishments are many and he continues to work on geologic problems with the same gusto as a graduate student. Let's review the background of one of the foremost geologists of our time.

Bob was born in Glendo, in east-central Wyoming, on the Hartville Uplift and within walking distance of some economically important Pennsylvanian strata. After service in the U.S. Navy, he received a BA and MA in Geology from the University of Wyoming in 1948 and 1949 and then headed west to Stanford and completed a Ph.D. in 1953. During this time he met and married Ruth Adams who has been a lifelong supporter and partner in Bob's career. In 1949 he began to work for Union Oil Co. and five years later decided to venture out on his own as a consulting geologist. As a consultant, he was instrumental in the discovery of the Arch Unit, which is essentially the north half of Patrick Draw oil field in Wyoming. The discovery was an outgrowth of detailed field work and stratigraphic intuition. The discovery established a new area of production and advanced the use of stratigraphic principles as a predictive tool in petroleum exploration.

With work experience and a dose of exploration success under his belt, he joined the Department of Geology and Geological Engineering at Colorado School of Mines in Golden in 1957. It was during his time at CSM where he made many of his lasting contributions to geology. He was head of the department from 1964-1969 and "retired" in 1983 as Getty Professor of Geological Engineering. Hundreds of undergraduate and graduate students at CSM and industry professionals have benefited from the courses he taught in stratigraphy, sedimentology and petroleum geology.

Bob has served in many capacities for professional and technical organizations. He was President of AAPG (1991-1992) and has received their highest honor, the Sidney Powers Medal (1984). He was President of SEPM (1972-1973) and has received their highest honor, the Twenhofel Medal (1995). At Colorado School of Mines he was awarded the Mines Medal in 1984 and the Brown Medal in 1990. He was given the Parker Medal from AIPG in 1992. He is past president of the Rocky Mountain Association of Geologists and the Colorado Scientific Society. In 1992 he was elected to the National Academy of Engineering for his application of stratigraphic principles to exploration and for promoting continuing professional education.

Bob has been an active member of GSA as a guidebook editor, chairman of the Rocky Mountain Section, and member of numerous committees. His most notable effort for GSA was serving as General Chairman of the 1988 Centennial Year Meeting in Denver.

Bob has given lectures at numerous universities around the world. He has been a distinguished lecturer for AAPG (3 times) and SEG, was a Fulbright lecturer at the University of Adelaide and a visiting professor in Indonesia and Canada. He has published nine books and was senior author on over 100 papers and numerous abstracts.

As many of us in the Rockies know, Bob was using sequence stratigraphic concepts long before the use of such terminology became vogue. His geological papers have been diverse with topics ranging from modern coastal sedimentation, deltaic sedimentation, paleotectonics, petroleum systems, sequence stratigraphy, sea-level change and professional ethics.

Figures from his 1960 *AAPG Bulletin* paper on Upper Cretaceous stratigraphy in the Rocky Mountains are still a standard reference point for many researchers. In the early 1970's his research focused on deltaic systems and their facies associations. By the late 1970's and early 1980's he was investigating the interaction of paleotectonics and valley-fill deposits. In the mid 1980's he was senior author on a paper that discussed the relationship of unconformities, tectonics and sea-level change on Cretaceous strata in the Western Interior. In the 1990's his papers dealt with sequence stratigraphy, fractured reservoirs and the history of oil and gas development in the Rocky Mountain region. These were all important papers and advanced our understanding of the nature of the stratigraphic systems in the western U.S.

Science is advanced through research and education, and geology is no exception. On the outcrop and in the core lab, Bob is quick to point out that the rocks do not change, but how we interpret them, does.

Based on his lifelong contributions as a scientist and mentor, it is an honor to recognize Bob Weimer as the first recipient of the Robert J. Weimer Lifetime Contribution Award.

Rocky Mountain Landmark Publication Award

Given to recognize the authors or editors of a book, guidebook, or other publication that over the past decade has had exceptional influence on developing new hydrocarbon plays or deeper understanding of fundamental geology within the Rocky Mountain region.

The 2013 award is given to **Susan M. Landon, Mark W. Longman, and Barbara A. Luneau**, co-authors of:

Longman, M.W., B.A. Luneau, and S.M. Landon, 1998, Nature and distribution of Niobrara lithologies in the Cretaceous Western Interior Seaway of the Rocky Mountain region: The Mountain Geologist, v. 35, p. 137-170.

Landon, S.M., M.W. Longman, and B.A. Luneau, 2001, Hydrocarbon source rock potential of the Upper Cretaceous Niobrara Formation, Western Interior Seaway of the Rocky Mountain region: The Mountain Geologist, v. 38, p. 1-18.

Excerpt from nomination letter:

"These two papers established the stratigraphic and organic geochemical framework of the Niobrara Formation at a regional scale. That framework drew attention to the potential of the Niobrara Formation as a potential shale oil resource play across many Rocky Mountain basins. It just took a half-decade or so for the technology of drilling and well completion to catch up with the resource play so well outlined in these papers."

A.I. Levorsen Award

Given by the Rocky Mountain Section for the best paper, with particular emphasis on creative thinking toward new ideas in exploration, at the 2012 annual convention in Grand Junction, Colorado.

Awarded to **Timothy Nesheim** (speaker) and Stephen Nordeng, North Dakota Geological Survey, for the presentation "Examination of Source Rocks within the Tyler Formation (Pennsylvanian), North Dakota".

Steve Champlin Memorial Award

The Wyoming Geological Association sponsors this award, which is presented to the author of the best poster presentation. The award was created in 1986 to encourage poster authors to strive for excellence in their presentations and to foster the one-on-one discussions of geology for which Steve Champlin was well known. It is hoped that this award will carry on Steve's spirit of friendly cooperation for the exploration of our natural resources.

Awarded to **Edmund 'Gus' Gustason**, Enerplus Resources, and Matthew Prather, University of Colorado, Boulder, for the poster presentation "Integrated characterization and modeling of reservoir lithofacies and reserves of the Sussex Sandstone, House Creek North area, Power River Basin, Wyoming".

Runge Award

The award recognizes professional and scientific excellence in student papers presented at the annual AAPG-RMS meeting, with particular emphasis on creative thinking toward new ideas in exploration. The award was established in 1975 and is provided by John S. Runge, petroleum geologist in Casper, Wyoming.

Awarded to **Alyssa Franklin**, Colorado School of Mines, for the presentation co-authored by her advisor, Stephen Sonnenberg, "Bakken and Three Forks petroleum development, production and potential, western Williston Basin, northeastern Montana".

2012 Rocky Mountain Section Teacher of the Year Award

Awarded December 2012

Denece Lord, Earth Science teacher at West High School in Billings, Montana

"In the stories of Geology, the minerals are our ABCs. Just like in learning to read, the ABCs are put together to form words that become sentences and paragraphs of a story, we put minerals together to form rocks. These rocks then become the words that make the sentences and paragraphs of our geologic stories." – Denece Lord

Excerpt from nomination letter written by Kimberly Verschoot, West High Assistant Principal:

"Denece has worked in the Billings [school] system for 27 years and at West High School for the past 6 years. It has been a privilege to watch her work with students and staff to create a positive learning environment where the needs of all children are addressed. Denece is always looking for new and innovative ways to reach students at all levels. In fact, Denece has taught everything from Honors Earth Science to an Earth Science collaborative class where students, with lower reading skills, receive information in a more supported format. In addition, her honors classes are known for their rigor. In short, Denece has such a passion for her content that she is able to share that energy with students regardless of what background knowledge they bring to the classroom."

SHORT COURSES

Note the different locations for these short courses. Transportation will be provided to and from the Hilton for short course 1, 3, and 4.

Short Course #1 – Geology and Geomechanics of Shale Reservoirs

Date: Saturday, September 21, 8:00 AM – 5:00 PM

Instructors: John McLennan – University of Utah, Energy & Geoscience Institute; Lauren Birgenheier – University of Utah, Department of Geology and Geophysics

Location: TerraTek, A Schlumberger company

Sponsor: TerraTek, A Schlumberger company

Description: Effective hydraulic stimulation of shale relies on accurately predicting rock response and induced fracture characteristics (e.g. direction, frequency, length, aperture, etc.), which is in part controlled by a host of geologic characteristics. Geologic and geomechanical investigations of shale gas and shale oil plays are often undertaken separately, or perhaps, at best, occur in parallel. This is despite the fact that geomechanical properties directly impact economics and success of stimulation and the overall success of the play.

This 1 day short course will leverage the world class geomechanics testing facilities at TerraTek, A Schlumberger company, to introduce and demonstrate key parameters in geomechanics and their relevance to shale gas and liquids exploration and production. Importantly, the impact of geologic heterogeneity of shales on geomechanical properties will be addressed. The course will feature examples from the Mancos Shale and include a laboratory tour of TerraTek.

Short Course #2 – Petrophysical Evaluation of Unconventional Resources

Date: Sunday, September 22, 8:00 AM – 4:00 PM

Instructors: Robert Cluff – The Discovery Group, Inc.; Michael Holms – Digital Formation, Inc.

Location: Seminar Theater, Hilton

Sponsor: PTTC

Description: The course will cover the petrophysical approaches to the evaluation of Coal Bed Methane, Tight Gas Sands, and Shale Gas Techniques using both open and cased hole logs. Attendees will learn basic interpretation procedures to determine volumes of in-place hydrocarbons, recoverable hydrocarbons, identification of intervals to complete, assessment of mechanical properties (impact on stimulation), and the influence of natural fractures on reservoir performance. Worked examples from a number of Rocky Mountain reservoirs will be part of a comprehensive workshop manual to be provided to all attendees.

Short Course #3 – Effective Use of Seismic Attributes for the Interpreter

Date: Sunday, September 22, 8:00 AM – 4:00 PM (transportation to EGI departs from the Hilton at 7:45 AM)

Instructor: Bill Keach – Brigham Young University / Energy & Geoscience Institute

Location: Energy & Geoscience Institute, University of Utah

Sponsor: Energy & Geoscience Institute

Description: This course is an overview of the wide variety of seismic attributes available to the interpreter. Its focus is on post-stack/migration 3D seismic volumes. It is designed to focus the interpreter to understand how to use, select, and analyze attributes that are relevant to their needs. There is a strong emphasis on understanding principles and workflows. We will incorporate the use of interactive workstation to better illustrate workflows and selection of options. You will see examples from a variety of stratigraphic and structural environments including: carbonates, shales, and sandstones in the Rocky Mountain region, plus others from the US and other countries, onshore and offshore.

The goals for the course are for you to:

- Relate specific attributes to specific geologic interpretations
- Use and analyze seismic volume based attributes
- Use and analyze horizon based attributes (and what the difference is between the two)
- Determine which attributes to use for different depositional and structural environments
- Effectively sub-set attribute data for proper usage and analysis
- Understand the effective use of color

Short Course #4 – Microbial Carbonate Reservoirs from Utah – Core Workshop

Date: Weds., September 25, 8:00 AM – 4:30 PM (transportation to the UCRC departs from the Hilton at 7:45 AM)

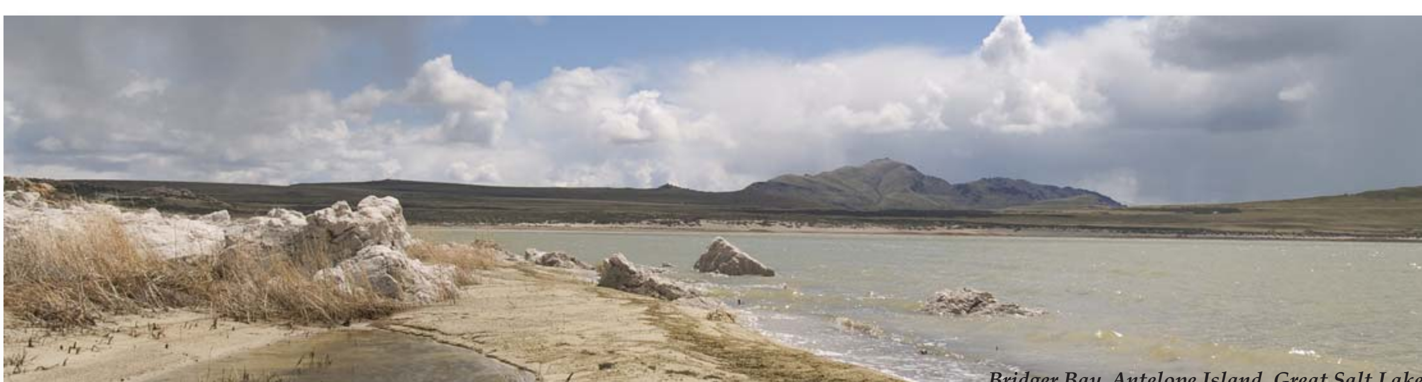
Instructors: David Eby – Eby Petrography & Consulting, Inc.; Thomas Chidsey – Utah Geological Survey; Michael Vanden Berg – Utah Geological Survey

Location: Utah Core Research Center

Fee: Professionals = $225, Students = $100 (check with the registration desk for course availablity)

Sponsor: Utah Geological Survey and Eby Petrography & Consulting, Inc.

Description: Recent discoveries in Early Cretaceous microbialites of the deepwater offshore of Brazil (pre-salt Santos Basin reservoirs) as well as other large oil deposits in microbialites (including some emerging oil resource plays) reveal the global scale and economic importance of these distinctive carbonates. Evaluation of the various microbial fabrics and facies, associated petrophysical properties, diagenesis, and bounding surfaces are critical to understanding these reservoirs. The workshop will consist of three modules with lectures and core exercises that involve representative microbial fabrics and related features from the Tertiary Green River Formation and various Utah Paleozoic reservoirs. Participants will describe and breakout rock types, package and define cycles, and identify pore types and reservoir quality. This workshop is designed for geoscientists with interests in exploration and development of microbial carbonate reservoirs and who wish to examine a large collection of cores containing Utah microbial carbonates applying the results to the areas they are working.



Bridger Bay, Antelope Island, Great Salt Lake

FIELD TRIPS

A special note for all field trips: hiking and climbing will be associated with most events. Sturdy shoes are recommended, plus outerwear that is water and wind repellant. The weather can be highly variable during September, with wide temperature ranges, including rain and snow. Individual field trip leaders will advise attendees on special conditions associated with their excursions. Safety will be strongly emphasized.

Inquire early in the meeting at registration to check on availability of post-meeting trips. All field trips depart from and return to the Hilton.

Field Trip #1 – The San Rafael Swell: Geologic Centerpiece of Utah

Dates: Friday, September 20 – Saturday, September 21

Leaders: Tom Morris – Brigham Young University; Scott Ritter – Brigham Young University; Robert Ressetar – Utah Geological Survey

Sponsor: Utah Geological Association

Description: This two-day trip will examine the Permian through Paleogene geologic history of Utah by traversing the stunning landscapes of the San Rafael Swell. Exposures along all flanks of this doubly-plunging asymmetrical Laramide uplift allow geoscientists to examine facies changes and structural features over hundreds of square miles. Highlights will include lively discussions on the latest interpretations of several famous formations including the Ferron Sandstone, Entrada Sandstone, Navajo Sandstone/Page Sandstone/Temple Cap Formations, Sinbad Limestone, and Manning Canyon Shale. Additionally, we will discuss the Temple Mountain structure, tar sands and oil typing in the San Rafael Swell, and attributes of the Woodside field for CO_2 sequestration.

Field Trip #2 – The Greatest Story Ever Told by Nine Miles of Rock: Exploring the Geology of Little Cottonwood Canyon, Wasatch Mountains

Date: Sunday, September 22, departs at 8:00 AM

Leader: Ron Harris – Brigham Young University

Sponsor: Utah Geological Association

Description: Mountains harbor many geological clues of how Earth works, but it is the canyons slicing through them that open the doors of discovery. Our journey of discovery will focus on Little Cottonwood Canyon, which reveals perhaps the greatest story ever told by nine miles of rock! The story unfolds like a journey back through time, through the relics of former worlds encrypted in the crag. It is the story of the geological evolution of western North America all compressed into one canyon. A story of clashing together and ripping apart of tectonic plates, of granitic fire and glacial ice, of gold and silver veins, of climate change, and destructive earthquakes. The canyon is also a repository of fossil remains that showcases some of Earth's earliest single-celled life forms, the Cambrian explosion and the progressively more complex forms that followed. The field trip will include some easy hikes and culminates in a tram ride to an 11,000 foot high overlook of the region. Also included is a geological guide book for the canyon with more than one hundred color illustrations that help you synthesize and interpret the geology for yourself.

Field Trip #3 – Great Salt Lake and Pleistocene Lake Bonneville – Free Trip for Students and Young Professionals

Date: Sunday, September 22, departs at 9:00 AM

Leaders: Mark Milligan – Utah Geological Survey; Genevieve Atwood – Earth Science Education; Robert Baskin – University of Utah

Sponsor: This trip is free for participants because of a very generous donation by the AAPG Foundation

Description: This trip explores Antelope Island to examine geomorphic features of shorelines of Pleistocene Lake Bonneville and modern Great Salt Lake. Although Utah is the second driest state in the nation, Quaternary lakes play a prominent role in the geology of Utah's west desert. During Ice-Age conditions of the late Pleistocene, most of western Utah was covered by Lake Bonneville, a freshwater lake up to 1000 feet deep with an area of approximately 19,800 mi2. Deposits and shorelines of Lake Bonneville account for much of the surficial geology of the Wasatch Front and are exceptionally exhibited on Antelope Island. With changing climate at the end of the last glacial cycle, Lake Bonneville receded into isolated basins, the largest of which contains present-day Great Salt Lake. Since historic time (1830s- present), Great Salt Lake has fluctuated up to about 12 feet above and below its historic average elevation of 4200 feet. Such fluctuations have economic, biologic, industrial, and political impacts. Specifically, from 1982–87, the elevation of the lake surface rose about 11.5 feet and equaled the lake's historic high stand level reached during the 1860s-1870s. The lake doubled its surface area causing millions of dollars in damage to highways, railroads, and other public and private resources. The fieldtrip will stop at the wonderful Antelope Island visitor center, as well as the beach at Bridger Bay for possible swimming (freshwater showers are available on site) and examination of modern microbial carbonate communities (depends on lake level).

Field Trip #4 – Geology of Nine Mile Canyon – Wasatch and Green River Formations

Date: Wednesday, September 25

Leader: Lauren Birgenheier – University of Utah

Itinerary: Departs from the Hilton at 6:30 AM and returns to the Hilton around 7:30 PM

Fee: $260 (check with the registration desk for trip availability)

Sponsor: Utah Geological Association

Description: Nine Mile Canyon in central Utah is a true geological and archaeological treasure, hosting spectacular exposures of the Paleocene and Eocene age deposits, as well as petroglyphs. This trip will focus on the sedimentology and stratigraphic architecture of the fluvial-lacustrine Wasatch and Green River Formations throughout the canyon. The goals are 1) to provide an outcrop based overview of these key reservoir and source rocks in the Uinta Basin, and 2) discuss the controls on deposition that help us better predict facies distribution and stratigraphic stacking patterns throughout the basin. Key subtopics include Wasatch Formation fluvial reservoir architecture, the lower Green River (Uteland Butte and Carbonate Marker Bed) as an emerging shale oil play, lacustrine carbonates, Sunnyside Delta deposition, and insights into oil shale distribution.

Field Trip #5 – Modern and Ancient Microbial Carbonates in Utah: Examples from Great Salt Lake and the Uinta Basin's Tertiary (Eocene) Green River Formation

Date: Thursday, September 26 – Saturday, September 28

Leaders: David E. Eby – Eby Petrography & Consulting, Inc.; Thomas C. Chidsey, Jr. – Utah Geological Survey; and Michael D. Vanden Berg – Utah Geological Survey

Itinerary: Departs from the Hilton at 8:00 AM and returns to the Hilton, or the Salt Lake International Airport, by approximately 11:00 AM, Saturday, September 28

Optional: Post-field trip re-examination of cores at the UGS Core Research Center from Short Course #4 – Microbial Carbonate Reservoirs from Utah – Core Workshop

Fee: $700 (check with the registration desk for trip availability)

Sponsors: Utah Geological Survey and Eby Petrography & Consulting, Inc.

Description: Utah is unique in that representative modern and ancient outcrop analogs of microbial reservoirs are present. Great Salt Lake is an excellent analog to the Eocene-age Lake Uinta facies represented by the Green River Formation in the Uinta Basin and microbial, shallow saline lake reservoirs worldwide. Day 1 will be an investigation of microbialites (stromatolites and thrombolites) as well as associated carbonate grains (ooids, coated grains, peloids, and lithified intraclasts) actively forming in and around Great Salt Lake. Next we will visit an outcrop of the Jurassic Twin Creek Limestone at the western end of the Uinta Mountains. Participants will traverse a stratigraphic section through the Twin Creek to identify a variety of shallow marine, microbial facies and rock fabrics that correspond to the core from nearby Pineview oil field. Day 1 will end in Vernal, Utah. Day 2 will be an excursion to outcrops of the Green River Formation. We will visit spectacular Green River sections that display microbialite-rich intervals (stromatolites, thrombolites, and oncolites) as well as the famous Mahogany bed (oil shale). The Green River also includes grainstones (containing lacustrine oolites, pisolites, and ostracods), dolomites, and other carbonate facies associated with the microbialites. Participants will observe vertical cycles and significant boundaries as well as lateral facies changes. Day 2 will again end in Vernal. Day 3 will be the return to Salt Lake City before noon. For those interested in conducting a re-examination of the cores from the workshop (Short Course #4 – Microbial Carbonate Reservoirs from Utah – Core Workshop), we will have them available at the Utah Core Research Center after the field trip.

PSI
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TECHNICAL PROGRAM

Keeping with the theme "Energy Elevated," an outstanding and diverse technical program has been prepared for the 2013 Salt Lake City Rocky Mountain Section Meeting. Everyone will find something of value to elevate their exploration, development, and geologic research efforts.

The technical program consists of over 130 oral and poster presentations covering diverse topics such as: lacustrine basins and microbial carbonates, tight oil and gas plays, geothermal resources, emerging plays and new discoveries, source rocks, and carbon capture, utilization, and storage. A special session will provide historical and geologic overviews of the old but still producing great oil and gas fields in the Rockies. Classic geologic topics include stratigraphy, sedimentation, structural geology, and—so nobody forgets their geologic roots—outcrop analogs. Eight core posters (four each day) will be located in the Exhibit Hall providing a chance to examine core from some of the newest and hottest play areas, such as the Bakken, Niobrara, and Green River Formations. An energy policy forum will explore and discuss environmental, economic, and cultural impacts of unconventional oil and gas development in the west. A gas marketing forum will also be offered covering gas marketing basics, transportation infrastructure, supply and demand, technological effects, and foreign price imbalances. These forums will afford the opportunity for attendees to interact with panels of leading policy and gas marketing experts. Finally, several of the technical presentations will be made by students based on their research and studies. These young geologists represent the future of petroleum exploration and will provide new insights and concepts we can all learn from.

Thus, the technical program combines something new, old, innovative, and unique that can elevate everyone's understanding of energy demands and challenges, all while meeting in the beautiful mountain setting of Salt Lake City.

Tom Chidsey
Technical Program Chair

Great Oil and Gas Fields of the Rocky Mountains: A Historical Perspective

Monday Morning Oral Session I
Alpine
Session Chairs: Thomas Chidsey and David Eby
Sponsors: MJ Systems and Encana

8:40 AM Greater Aneth Field, Paradox Basin, Southeastern Utah
Thomas C. Chidsey, Jr., David E. Eby*

9:00 AM Discovery of the Weber Sandstone and Development of the Raven Creek Anticline at Rangely Field, Colorado
Ryan Grimm, Leigh Owens, Carlos Collantes, Laura Murray, Marina Borovykh, Tashika Charles, Ed Bucher, Roy Cramer*

9:20 AM History of Gas and Oil Development of the San Juan Basin, New Mexico and Colorado
James E. Fassett

9:40 AM Geology of Eagle Springs Oil Field, Railroad Valley, Nevada
Jerome Hansen, Carl Schaftenaar*

10:00 AM **Break**

10:40 AM History of the Cedar Creek Anticline, Southeast Montana
John D. Davis

11:00 AM History of Geologic Investigations and Oil Operations from Teapot Dome, Wyoming
Tom Anderson

11:20 AM Wyoming's Historical Oil Fields I: Still Producing (A Lot) After All These Years
Ranie Lynds, Rachel N. Toner, Alan J Ver Ploeg*

11:40 AM Wyoming's Historical Oil Fields II: Still Producing (A Lot) After All These Years
Ranie Lynds, Rachel N. Toner, Alan J Ver Ploeg*

**denotes presenting author; abstracts listed alphabetically by first author beginning on p. 38*

Unconventional Resource Plays I

Monday Morning Oral Session II
Canyons A&B
Session Chairs: Mark Longman and Steve Schamel
Sponsors: MJ Systems and Encana

8:40 AM Eagle Ford - Colorado Connection: Cenomanian to Coniacian in Southwestern North America
Thomas E. Ewing

9:00 AM Quantitative Geologic Analysis of Mancos Shale Core Improves the Geologic Model of the Play
Roberto Suarez-Rivera, Eric Edelman, Patrick Gathogo, David Handwerger*

9:20 AM A Facies and Sequence Stratigraphic Model for the Mancos Shale, Uinta Basin: Identifying Unconventional Horizontal Targets
Lauren Birgenheier, Brendan Horton, Laini Larsen, Andrew D. McCauley, John McLennan, Robert Ressetar*

9:40 AM Mancos Shale In-situ Stress Estimation and Fracture Simulation Across the Uinta Basin
Trevor Stoddard, Lauren Birgenheier, John McLennan, Justin Wriedt*

10:00 AM **Break**

10:40 AM Current Understanding of the Sedimentology, Stratigraphy, and Liquid-Oil Potential of the Pennsylvanian Cane Creek Shale of the Paradox Formation, Southeastern Utah
Peter Nielsen, Craig D. Morgan, Michael Vanden Berg*

11:00 AM Influence of the Pronghorn Member of the Bakken Formation on the Drilling and Production Potential of the Upper Three Forks in McKenzie County, Williston Basin, North Dakota
Mark Millard, Murray Dighans, Greg Hilton*

11:20 AM Stratigraphy of the Three Forks Formation and Implications for Exploration
Alyssa L. Franklin

11:40 AM Geologic Controls on Oil Production from the Niobrara Formation, Silo Field, Laramie County, Wyoming
Carrie Welker, Tom Anderson, Lisa Stright*

Stratigraphy and Sedimentation – 8:40 AM to 12:00 Noon

Monday Morning Poster Session I
Topaz/Lobby
Sponsors: Utah Office of Energy Development, USTAR, Utah Trust Lands (SITLA)

1 Curious Proximal Facies: Transgressive Overprinting in the Ferron Sandstone
*Ryan King, Paul B. Anderson**

2 Discharge Controls on River Sinuosity: Analysis of a Small Modern Stream
Guangming Hu,Marjorie A. Chan, Ziqiang Yuan*

3 Fluvial Sequence Stratigraphy and Depositional Systems of the Tertiary Duchesne River Formation, Northern Uinta Basin, Northeastern Utah
Takashi Sato, Marjorie A. Chan*

4 Point Pattern Analysis of Channel Organization from the Cretaceous John Henry Member of the Straight Cliffs Formation, Kaiparowits Plateau, Southern Utah
Wassim Benhallam, Cari L. Johnson, Luke Pettinga, Lisa Stright*

5 Reservoir-scale Facies and Stratigraphic Architecture of the Middle and Upper Williams Fork Formation, Upper Philadelphia Creek, Douglas Creek Arch, Colorado
John L McFadden, Jr., Rex D. Cole, Matthew J. Pranter*

6 Sedimentary Provenance, Transport, and Mixing of Cretaceous Fluvial and Marginal Marine Strata in the Straight Cliffs Formation, Southern Utah: Insights from Detrital Zircon Geochronology
Tyler S Szwarc, Cari L. Johnson*

7 The First Absolute Ages and Chronostratigraphic Framework for the Muddy Portion of the Jurassic Entrada Sandstone in South-Central Utah
Toby S. Dossett, George Jennings, Thomas H. Morris*

8 Facies and Diagenesis of the Park City Formation, Wind River Basin, Sheep Mountain Anticline, Fremont County, WY
Daniel G Hallau, J. Frederick Sarg*

9 Paleozoic Correlations in the Northern San Rafael Swell Area, Carbon and Emery Counties, Utah
Craig Morgan, Gerald Waanders*

10 Recognition of the Stratigraphic Heterogeneity of Late Paleozoic Eolian Erg Margin Deposits for Improved Oil Recovery: Weber Sandstone, Rangely Field, Colorado
Ryan P. Grimm

11 Sedimentology and Reservoir Characteristics of the Lower Triassic (Smithian) Sinbad Formation, San Rafael Swell, Utah
Scott Ritter, Colton Goodrich, Caleb Osborn*

12 Using Channel Morphometrics and MPS to Improve Reservoir Model Accuracy: An Example from Greater Monument Butte Field, Uinta Basin Utah
Darrin Burton, Bobby Sullivan, Kurtus Woolf*

13 Tar Sand Triangle Bitumen Deposit, Garfield and Wayne Counties, Utah
Steven Schamel

14 Gilsonite Veins of the Uinta Basin, Utah
Taylor Boden

15 Evaluation of Frac Sand Potential in Utah
Andrew Rupke, Taylor Boden*

Tight/Shale Oil Core Posters – 8:40 AM to 5:00 PM

Monday Core Posters
Grand Ballroom
Sponsor: Utah Geological Survey

A Carbonate Mudrock Microporosity Classification and Characterization through Core Examination: Upper Cretaceous Niobrara Formation, Denver-Julesburg Basin, Colorado & Wyoming
Peter D. Pahnke, Tom Anderson, Scott Ritter*

B Detailed Sedimentology and Stratigraphy of the Remington 21-1H Cane Creek Shale Core, Pennsylvanian Paradox Formation, Southeastern Utah: Implications for Unconventional Hydrocarbon Recovery
Peter Nielsen, Craig D Morgan, Michael Vanden Berg*

C Reservoir Characterization of the Uteland Butte Formation in the Uinta Basin
Jason Anderson, John Roesink*

D Reservoirs of the Bakken Petroleum System: A Core-based Perspective
Julie A LeFever, Richard D. LeFever, Stephan Nordeng*

Geothermal Resources

Monday Afternoon Oral Session I
Alpine
Session Chairs: David Hawk and Walt Snyder
Sponsor: EMD

1:20 PM Geothermal Potential of Deep Sedimentary Basins in the United States
Tom Anderson

1:40 PM The Geothermal Power Potential of Hot Stratigraphic Reservoirs
Rick Allis, Joseph N. Moore*

2:00 PM Geothermal Discovery in the Black Rock Desert of Western Utah
Mark Gwynn, Rick Allis, Robert Blackett, Christian Hardwick*

2:20 PM Investigating Geothermal Resources in the Black Rock Desert, Utah, using MT and Gravity
Christian Hardwick, Rick Allis, David Chapman*

2:40 PM The Blackfoot Volcanic Field, Southeast Idaho: A New Structural Paradigm for Hidden Geothermal Resources in the Northeastern Basin and Range
John A. Welhan, Dean L Garwood, Michael O. McCurry*

3:00 PM **Break**

3:40 PM Characterization of a Basin and Range Type Geothermal System in Southeast Oregon, the Paisley Geothermal System
Kyle A. Makovsky, Roy Mink, Walter Snyder*

4:00 PM Re-evaluation of Available Thermal Energy of the Lower Cretaceous Formations in the Denver Basin: Colorado and Nebraska
Anna M. Crowell, William D. Gosnold*

4:20 PM Analysis of Borehole Temperature Data from the Mt. Princeton Hot Springs Area, Chaffee County, Colorado
Paul Morgan

4:40 PM Co-Produced Geothermal Power
William D. Gosnold, Anna M. Crowell*

Unconventional Resource Plays II

Monday Afternoon Oral Session II
Canyons A&B
Session Chairs: John McLennan and Roger Bon
Sponsors: MJ Systems and Encana

1:20 PM Assessment of Undiscovered Resources in the Bakken Formation of the U.S. Williston Basin, North Dakota and Montana
Stephanie B. Gaswirth, Troy Cook, Kristen R. Marra*

1:40 PM Assessment of Undiscovered Resources in the Three Forks Formation of the U.S. Williston Basin, North Dakota and Montana
Kristen R. Marra, Troy Cook, Stephanie B. Gaswirth*

2:00 PM Clay sensitivity of Lowstand Gravity Flow Deposits of the Douglas Creek Member of the Green River Formation, Greater Monument Butte Field, Uinta Basin, Utah
Bobby Sullivan, Darrin Burton, Margaret Lessenger, Kurtus Woolf*

2:20 PM Development of a Fractured Reservoir Model for the Mesaverde Formation to Support Hydrofracturing Design, Natural Buttes Area, Uinta Basin, UT
Paul La Pointe, Hope Sisley*

2:40 PM Basin-Scale Sequence Stratigraphy and Distribution of Depositional and Mechanical Units in the Middle and Upper Williams Fork Formation, Piceance Basin, Colorado
Michele Wiechman, Jennifer Aschoff*

3:00 PM **Break**

Source Rocks

Monday Afternoon Oral Session III
Canyons A&B
Session Chairs: Jeff Quick and Ammon McDonald
Sponsors: MJ Systems and Encana

3:40 PM Utilizing the Delta Log R method for Determining Total Organic Carbon of the Niobrara Formation, B Bench, Denver-Julesburg Basin, Colorado
Madeline K. Beitz, Robert Cunningham, Lisa E. LaChance*

4:00 PM Programmed-Pyrolysis Derived Petroleum Yield Determinations Calibrated with Hydrous Pyrolysis: A Case Study of Green River Source Rocks
Tim E. Ruble, Michael D. Lewan*

4:20 PM Recognition and Significance of Primary and Recycled Kerogen in Upper Cretaceous Source Rocks, Denver and Powder River Basins, USA
Christopher D. Laughrey, Jack D. Beuthin, Jackie Holt, Wayne Knowles*

4:40 PM Source Rock Potential of the Icebox Formation, Winnipeg Group (Ordovician), North Dakota
Timothy Nesheim, Stephan Nordeng*

Energy Policy Forum – 1:20 PM to 5:00 PM

Seminar Theater
Moderator: Edith Allison, Director AAPG GEO-DC
Sponsors: AAPG GEO-DC and the Division of Professional Affairs (DPA)

Lacustrine Basins: Modern and Ancient – 1:20 PM to 5:00 PM

Monday Afternoon Poster Session I
Topaz
Sponsors: Utah Office of Energy Development, USTAR, Utah Trust Lands (SITLA)

1 Earliest Record of Plant Preference in Caddisfly Larval Case Armor and of Caddisfly/Stromatolite Symbiosis from the Early Cretaceous Shinhudag Formation, Mongolia
Cory Dinter, Kurt Constenius, Cari L. Johnson, Mark Loewen*

2 In-Place Oil Shale Resources in the Saline Mineral and Saline-Leached Intervals, Piceance Basin, Colorado
Justin E. Birdwell, Michael E. Brownfield, Ronald C. Johnson, Tracey J. Mercier*

3 Preservation of Primary Lake Signatures in Carbonates of the Eocene Green River Wilkins Peak-Laney Member Transitional Zone
John T. Murphy, Tim K. Lowenstein*

4 Sandstone Deposition in the Eocene Green River Formation of Eastern Uinta Basin, Evacuation Creek: Depositional Environments and Reservoir-Scale Architecture
*T. Ryan O'Hara, Kati Tänavsuu-Milkeviciene, J. Frederick Sarg**

5 Temporal and Spatial Variations in Lacustrine Depositional Controls from the Middle to Upper Green River Formation, Central and Western Uinta Basin, Utah
Leah Toms, Lauren Birgenheier, Michael Vanden Berg*

6 The Esmeralda Basin: A Proven Intra-continental Lacustrine Rift Play along the Walker Lane Shear Zone, Western Nevada

Andrew B. Cullen, James H. Henderson*

7 Where Have the Mahogany Oil-Shale Beds Gone? Possible Evidence of Large-Scale Slumping at Sand Wash, Uinta Basin, Utah

David Keighley, Michael Vanden Berg*

Microbialites in the Rockies – 1:20 PM to 5:00 PM

Monday Afternoon Poster Session II

Lobby

Sponsors: Utah Office of Energy Development, USTAR, Utah Trust Lands (SITLA)

8 Depositional History and Lateral Variability of a Microbial Carbonate, Three Mile Canyon and Evacuation Creek, Eastern Uinta Basin, Utah

Michael Swierenga, J. Frederick Sarg, Kati Tänavsuu-Milkeviciene*

9 Geochemistry of Lacustrine Microbialite of the Eocene Green River Formation

M'bark Baddouh, Brian L. Beard, Alan R. Carroll, Clark M. Johnson*

Outcrop Analogs – 1:20 PM to 5:00 PM

Monday Afternoon Poster Session III

Lobby

Sponsors: Utah Office of Energy Development, USTAR, Utah Trust Lands (SITLA)

10 Characterization of Tensleep Reservoir Fracture Systems Using Outcrop Analog, Fracture Image Logs and 3D Seismic

Tom H. Wilson, Alan Brown, Valerie Smith*

11 Sedimentology and Fluvial Architecture of the Upper Williams Fork Formation, Plateau Creek Canyon, Piceance Basin, Colorado

Ryan J. Sharma, Rex D. Cole, Penny E. Patterson, Matthew J. Pranter*

12 Subsurface to Outcrop: Linking Rock Physics and Depositional Environment to Seismic Reflectivity Data, Kaiparowits Plateau, Utah

Karenth l. Dworsky, Cari L. Johnson, Lisa Stright, Tiziana Vanorio*

Environmental Research – 1:20 PM to 5:00 PM

Monday Afternoon Poster Session IV

Lobby

Sponsors: Utah Office of Energy Development, USTAR, Utah Trust Lands (SITLA)

13 Finding and Protecting Energy Assets with 21st Century Geochemical Tools

David Seneshen

14 Geological Controls on Formation Water Salinity Distribution, Southeastern Greater Natural Buttes Field, Uinta Basin, Utah

Tuba Evsan, Marc Connolly, Matthew J. Pranter*

15 Radiometrics and High Resolution Magnetotellurics in the Exploration for Oil and Gas

Robert W. Olson

Lacustrine Basins: Modern and Ancient

Tuesday Morning Oral Session I
Alpine
Session Chairs: Jeremy Boak and Helen Sadik-MacDonald
Sponsors: MJ Systems and Encana

8:00 AM Laguna Mar Chiquita (Argentina): A Possible Modern Analog for Lacustrine Source Rocks in Thick-Skinned Foreland Basins
Michael M. McGlue, Geoffrey S. Ellis*

8:20 AM Structural Controls on the Development of Eocene Lake Gosiute and Lake Uinta, Southwest Wyoming, Northwest Colorado, and Eastern Utah
Ronald C. Johnson

8:40 AM The Response of Fluvial Systems in the Uinta Basin, Utah to Extreme Global Warming Events During the Early Eocene Climatic Optimum
Evan Jones, Piret Plink-Björklund*

9:00 AM Lower Green River Formation Depositional Environments in the Uinta Basin, Utah
Kurtus Woolf, Darrin Burton, Bobby Sullivan*

9:20 AM **Break**

9:40 AM Facies Re-Interpretations of Sunnyside Delta Sandstone in Nine Mile Canyon, Uinta Basin, Utah: The Perils of Model-Driven Geology
David Keighley, Stephen Flint*

10:00 AM Microbial Fossils, Phosphatization, Heavy Rare Earth Element and Uranium Enrichment: Early Diagenesis of an Upper Green River Formation Oil Shale, Uinta Basin, Utah
David Keighley, Chris McFarlane, Tim E. Ruble*

10:20 AM Geochemistry of the Green River Formation, Piceance Creek Basin, Colorado
Jeremy Boak, Jufang Feng*

10:40 AM Siliceous Cementation of Mesozoic Strata in the Four Corners Area: Evidence for Lacustrine Carbonates in the Jurassic, Morrison Fm. and Silcretes in the Cretaceous, Burro Canyon Fm.
Kim J. Miskell-Gerhardt

Outcrop Analogs

Tuesday Morning Oral Session II
Canyons A&B
Session Chairs: Mike Pinnell and Bob Biek
Sponsors: MJ Systems and Encana

8:00 AM The Polygonal Fault System of the Niobrara Formation
Nicholas D. Kernan

8:20 AM Digital Characterization of Lower Ismay Phylloid Algal Mounds in the San Juan River Gorge, SE Utah
Scott Ritter, Colton Goodrich, Lincoln Reed*

8:40 AM Outcrop-to-Subsurface Correlation of Isolated Fluvial Sandstones, Grand Hogback, Piceance Basin, Colorado
Bryan McDowell, Piret Plink-Björklund*

9:00 AM Ground-truthing a Predictive Model for Locating Fossil Vertebrate Localities in the Eocene of Wyoming
Robert Anemone, Brett Nachman, Charles W. Emerson*

9:20 AM **Break**

New Resource Plays

Tuesday Morning Oral Session III
Canyons A&B
Session Chairs: Doug Sprinkel and Grant Willis
Sponsor: International Petroleum, Inc.

9:40 AM Mowry Shale, Properties and Potential, Big Horn and Powder River Basins, Wyoming
Robert Sterling

10:00 AM Stratigraphy and Oil Resource Potential of the Mississippian Heath Formation, Central Montana, USA
Richard J. Bottjer

10:20 AM Central Utah Thrust Belt Exploratioin Is in Its Infancy
Michael Pinnell, Spiro Vassilopoulos, Floyd Moulton*

10:40 AM Differentiation of Mississippian-age Shale Units of Central and Eastern Nevada Using Petrophysical, Mineralogical, and Geochemical Characteristics
Don E. French, Jerome P. Walker, James H. Trexler, Patricia H. Cashman*

11:00 AM The Underappreciated Middle Mississippian (C2) Unconformity in the Great Basin: Its Tectonic and Stratigraphic Significance
James H. Trexler, Don E. French, Jerome P. Walker, Patricia H. Cashman*

Forum – Rocky Mountain Natural Gas: A Marketer's Perspective – 8:00 AM to 11:20 AM

Seminar Theater
Presenters: Curtis Chisholm and David Lillywhite, Summit Energy, LLC

Carbon Capture, Utilization, and Storage/Environmental Research – 8:00 AM to 11:20 AM

Tuesday Morning Poster Session I
Topaz
Sponsors: DEG, Utah Office of Energy Development, USTAR, Utah Trust Lands (SITLA)

1 Assessing the Carbon Sequestration Potential within the Bear River Formation of the Wyoming-Idaho-Utah Thrust Belt
Ronald M. Drake II, Matthew D. Merrill*

2 CO_2 Sequestration via Adsorption in Thermally Treated Coal Seams
Robert L. Krumm, Milind Deo*

3 Field Observations And Stable Isotopic Analysis Of Laterally Continuous Calcite Veins Associated With Fault Zones: Insight into Ancient Fluid Travel
Elizabeth Horne

4 Fundamental Analysis of Relative Permeability and Heterogeneity on CO_2 Storage and Plume Migration
Nathan Moodie

5 Subsurface Isopach Maps for CO_2 Sequestration: Woodside Field, East-central Utah
Brad G. Bishop, Thomas H. Morris, Walter A. Harston*

6 Uncertainty Quantification of Sequestrated CO_2 in CCUS project
Wei Jia, Brian McPherson*

Geothermal Resources – 8:00 AM to 11:20 AM

Tuesday Morning Poster Session II
Lobby
Sponsors: EMD, Utah Office of Energy Development, USTAR, Utah Trust Lands (SITLA)

8 Characterization of Brittle Structures in Basalts of the Western Snake River Plain, Idaho: Implications for Fracture Connectivity in a Potential Geothermal Reservoir
James A. Kessler, James P. Evans, Doug R. Schmitt, John Shervais*

9 Geothermal Alteration of Basalts of the Snake River Plain, Idaho
Christopher J. Sant, John Shervais*

10 Microbial and Inorganic Depositional Processes in Travertine: Tools for Investigating a Possible Blind Geothermal System in Caribou County, Idaho
Sara R. Ohly, Michael O. McCurry, John A. Welhan*

Structure – 8:00 AM to 11:20 AM

Tuesday Morning Poster Session III
Lobby
Sponsors: Utah Office of Energy Development, USTAR, Utah Trust Lands (SITLA)

11 3D Seismic Interpretation and Evaluation of Mechanism(s) that Cause Along-Strike Change in Vergence of Thrust Faults in the Green River Basin of Southwestern Wyoming, Birch Creek Seismic Survey
Scott Greenhalgh, John H. McBride, R. William Keach II*

12 Seismically-Derived Fracture Mapping for Unconventional Reservoir Exploitation
*Paul J. Miller, George C. Bunge**

13 Testing 3D Seismic Attribute Strategies for Subtle Fault Mapping
John McBride, R. William Keach II, Clayton K. Chandler*

Tight/Shale Gas Core Posters – 8:30 AM to 5:00 PM

Tuesday Core Posters
Grand Ballroom
Sponsor: Utah Geological Survey

A An Integrated, Core-focused Facies and Stratigraphic Model of the Mancos Shale, Uinta Basin
Lauren Birgenheier, Laini Larsen, Andrew D McCauley, John McLennan, Robert Ressetar, Brendan Horton*

B Manning Canyon Shale in the Northern San Rafael Swell: A Potential Natural Gas Resource Play?
Steven Schamel, Jeffrey Quick*

C Bluebell-Altamont Field: Core from the Fractured Green River-Wasatch Reservoir, Uinta Basin, Utah
Paul Baclawski, John South, John Lorenz, Scott Cooper*

D Mowry Shale, Properties and Potential, Big Horn and Powder River Basins, Wyoming
Robert Sterling

Microbialites in the Rockies

Tuesday Afternoon Oral Session I
Alpine
Session Chairs: Rick Sarg and Jason Blake
Sponsors: MJ Systems and Encana

2:20 PM Microbialites of the Eocene Green River Formation as Analogs to the South Atlantic Pre-Salt Carbonate Hydrocarbon Reservoirs
Stanley M. Awramik, H. Paul Buchheim*

2:40 PM The Origin of Lacustrine Carbonates and Microbialites in Lake Basins
Elizabeth H. Gierlowski-Kordesch

3:00 PM Microbialite Distribution in a Lacustrine Rift Basin, Great Salt Lake, Utah
Robert L. Baskin

3:20 PM Paleocurrent Control of Facies Heterogeneity in Microbial Buildups and Stromatolites; Late Carboniferous (Moscovian) Hermosa Group, Southeastern Utah
Gary L. Gianniny, Amanda P. Peterson, Daniel J. Powers, Shannon M. Boesch*

3:40 PM Oncolites, Laminated Algal Deposits and Conglomerates in the Canyon Mountains -- An Overlooked,but Important Stratigraphic Indicator
James M. Stolle

Stratigraphy and Sedimentation

Tuesday Afternoon Oral Session II
Canyons A&B
Session Chairs: Paul Anderson and David Tabet
Sponsors: MJ Systems and Encana

2:20 PM Distinguishing Between Salt-Related and Algal Structures: A 3D seismic Example from the Northwest Denver Basin
Antara Goswami, Katie Joe McDonough, Brian W. Horn*

2:40 PM Correlation, Age, and Regional Distribution of the Nugget Sandstone and Glen Canyon Group, Utah
Douglas A. Sprinkel, Bart J. Kowallis, Paul H. Jensen*

3:00 PM New Insights into the Timing of Exhumation of the Uinta Basin and Mountain-Front Retreat of the Uinta Mountains, Utah
Douglas A. Sprinkel, Warren Sharp, Steven Schamel*

3:20 PM Geology and Seismic Interpretation of the Cisco Springs Area, Uncompaghre Uplift, Grand County, Utah
Steven A. Tedesco

Carbon Capture, Utilization, and Storage/Environmental Research

Tuesday Afternoon Oral Session III
Seminar Theater
Session Chairs: Rich Esser and Prashanth Mandalaparty
Sponsor: DEG

2:20 PM Monitoring, Verification and Accounting (MVA) Applied to CO_2-EOR Projects
Ronald W. Klusman

2:40 PM Facies and Reservoir Characterization of the Permian White Rim Sandstone, Black Box Dolomite, and Black Dragon Member of the Triassic Moenkopi Formation for CO_2 Sequestration at Woodside Field, East-central Utah

*Walter Harston, Thomas H. Morris**

3:00 PM Hydraulic Fracturing - Using Geology & Planning To Avoid Environmental Impacts

James M. Kerr, Jr., Angus McGrath, Thomas Fendler*

3:20 PM Mechanical Stratigraphy and Stress History of Cap-Rocks Analysis of Exhumed Analogs in Central and South-Eastern Utah and Implications for CCS

Elizabeth S. Petrie, James P. Evans*

Unconventional Resource Plays – 2:20 PM to 5:00 PM

Tuesday Afternoon Poster Session I

Topaz/Lobby

Sponsors: Utah Office of Energy Development, USTAR, Utah Trust Lands (SITLA)

1 Estimating Total Organic Carbon Content in the Cretaceous Mancos Shale

Ryan Hillier, Lisa Stright, Robert Ressetar*

2 Geologically Constrained Electrofacies Classification of Fluvial Deposits: An Example from the Cretaceous Mesaverde Group, Uinta and Piceance Basins

Daniel Allen, Matthew J. Pranter*

3 Log-Interpreted Reservoir Potential from Cretaceous Mancos Shale in the Uinta Basin

Trevor Stoddard, Lauren Birgenheier, Ryan Hillier, Laini Larsen, John McLennan*

4 Modeling Hydraulic Fracture Interactions with Natural Fractures

Ravindra Bhide, Milind Deo, John McLennan, Trevor R. Stoddard*

5 Prediction of Organic Maturation by Vitrinite Reflectance Regression in Units of the Mancos Shale, Uinta Basin, Utah

Jeffrey Quick, Andrew D. McCauley, Robert Ressetar*

6 Sedimentological and Stratigraphic Controls on Reservoir Architecture and Connectivity in a Variable Fluvial System: Mesaverde Group, Greater Natural Buttes Field, Uinta Basin, Utah

Ellen Wilcox, Edmund R Gustason III, Matthew J. Pranter*

7 Spatial Properties of Natural Fractures in the Mancos Shale, Eastern Utah

Ziqiang Yuan, John M. Bartley, Lauren Birgenheier, Andrew D. McCauley*

8 Evaluating the Impact of Mineralogy on Reservoir Quality and Completion Quality of Organic Shale Plays

Helena Gamero-Diaz, Camron K. Miller, Richard Lewis, Carmen C. Contreras-Fuentes*

9 Regional Stratigraphy, Elemental Chemostratigraphy, and Organic Richness of the Niobrara Formation, Piceance Basin, Colorado

Aya El Attar, Marc Connolly, Matthew J. Pranter*

10 Structural, Stratigraphic, and Diagenetic Factors Influencing Hydrocarbon Accumulations in the Bakken Petroleum System at the Elm Coulee Field, Williston Basin, MT

Henriette V. Eidsnes, Ellen R. Fehrs*

New Resource Plays – 2:20 PM to 5:00 PM

Tuesday Afternoon Poster Session II
Lobby
Sponsors: Utah Office of Energy Development, USTAR, Utah Trust Lands (SITLA)

11 Exploration in Southwestern Idaho: Will Idaho Finally Produce?
Dean L. Garwood, John A. Welhan*

12 Hydrocarbon Potential of the Chainman Shale, Western Utah
S. Robert Bereskin, Thomas C. Chidsey, Craig D. Morgan, John McLennan*

Earth Science Education – 2:20 PM to 5:00 PM

Tuesday Afternoon Poster Session III
Lobby
Sponsors: Utah Office of Energy Development, USTAR, Utah Trust Lands (SITLA)

13 Development of a New Geology Field Book for Utah
Shelby L. Johnston, Preston S. Cook, Thomas H. Morris, Jeffery M. Valenza*

14 Student Perspectives on Earth Science Data Management for the 21st Century
J. Anna Farnsworth, Marjorie A. Chan, Hannah Durkee, Marko Gorenc, William Hurlbut, Mallory Millington, Brittney Thaxton*


Little Cottonwood Canyon, Wasatch Mountains

ABSTRACTS

Listed alphabetically by first author

Geologically Constrained Electrofacies Classification of Fluvial Deposits: An Example from the Cretaceous Mesaverde Group, Uinta and Piceance Basins

Daniel Allen (University of Colorado, Boulder), Matthew J. Pranter (University of Oklahoma)*

This study establishes a set of distinct, core-defined electrofacies that represent the fluvial architectural-elements of the middle and upper Mesaverde Group of the Piceance and Uinta basins. Evaluation of electrofacies classification techniques in testing wells suggests that the electrofacies can be accurately predicted in non-cored wells. This allows for wire-line log curve interpretations which are timely, reproducible, and objective. Two different electrofacies classification techniques are utilized in this study: a k-nearest neighbor approach (KNN) and a probabilistic clustering procedure (PCP). Study data come from 1668 samples with known architectural-element classifications determined from the analysis of cores (N=9) with each sample having 4 available measured properties (wire-line log curves). The sampling population is divided into two groups: one for training and one for testing the capability of the trained classifier to correctly predict classes. A novel method involving a well-log indicator flag which pairs the results of the electrofacies classifications with thickness criteria, is applied to further refine classification results. The applicability of the geologically constrained electrofacies classification is demonstrated through batch prediction and mapping of electrofacies in wells (N=~200) throughout the study area. Initial testing yielded overall accuracies (number of correctly predicted samples/total testing samples) of 64% and 62% in the KNN approach and the PCP approach respectively. Testing was conducted again using a new facies realization which was created by combining two geologically similar facies. This yielded improved overall accuracies of 75% and 73% in the KNN approach and PCP approach, respectively. The top performing classification outcome was chosen for the application of the well-log indicator flag approach which increased the overall accuracy to 84%. While both classifiers produced similarly reasonable results, the KNN technique outperformed the PCP technique. In both the KNN and PCP techniques, the combination of wire-line log curves GR and RHOB proved to be the most useful assemblage tested. These curves are common in the study area, and their presence presents the opportunity for further geologic investigations utilizing these electrofacies classification methods.

The Geothermal Power Potential of Hot Stratigraphic Reservoirs

Rick Allis (Utah Geological Survey), Joseph N. Moore (Energy & Geoscience Insitute)*

Stratigraphic reservoirs with high permeability and temperature at economically accessible depths are attractive for power generation because of their large areal extent (> 100 km2) compared to the fault-controlled hydrothermal reservoirs (< 10 km2) found throughout much of the western U.S. A preliminary screening of the geothermal power potential of sedimentary basins in the U.S., assuming present day drilling costs, a levelized cost of electricity over 30 years of ? 10c/kWh, and realistic reservoir permeability, indicates that basins with heat flows of more than about 80 mW/m2, reservoir temperatures of more than 175°C, and reservoir depths of less than 4 km are required. Such reservoirs could sustain power plants of ~100 MWe in scale. These criteria put the focus for future geothermal power generation on high heat flow regions of California (e.g., the Imperial Valley and regions adjacent to The Geysers), the Rio Grande rift system of New Mexico and Colorado (especially the Denver Basin), the Great Basin of the western U.S., and high heat flow parts of Hawaii and the Alaska volcanic arc. The two major challenges to development are the identification of the hottest basins and characterizing the permeability at economically drillable depths. The lower Paleozoic carbonate units beneath the eastern Great Basin are known to be locally very thick (up to 5 km), commonly have high permeability, and cover a very large area. This region represents the most attractive area for development of stratigraphic geothermal reservoirs.

Reservoir Characterization of the Uteland Butte Formation in the Uinta Basin

Jason Anderson (Bill Barrett Corp.), Daniel Pritchard (Bill Barrett Corp.)*

Following recent success of horizontal drilling, the Uteland Butte Member has received much attention as a horizontal target. The Uteland Butte is known as the basal carbonate of the Green River Formation. The Uteland Butte Member covers a majority of the Uinta Basin. The Uteland Butte, is correlative, has good reservoir properties and is located in an established oil and gas field. Under Bill Barrett Corporation's (BBG) acreage, the main target is a dolomite comprised of 10% quartz, 25% calcite, 63% dolomite and 2% total clay. The dolomite has an average porosity of 20% and the permeability averages 0.076 md based on core samples. The interval ranges in thickness from 3' to 8' across the basin being the thickest towards the center of the basin. The over and underlying rock is comprised mostly of highly fractured limestone, which contains oil and gas as well. The fracture count in surrounding rock can be as high as 14 fractures per 3'. This fracture network in combination with the reservoir properties has made the Uteland Butte an attractive target to operators in the basin. BBG, Newfield Exploration (NFX), LINN Energy (LINE) and QEP Resources (QEP) are the most active in the basin. Like other unconventional horizontal targets the Uteland Butte member has 'sweet spots'. Areas with thicker dolomite and higher temperature and pressure regimes tend to be the most successful. A few operators in the basin have applied for 1280 acre drilling units which will enhance the exploitation of the resource.

History of Geologic Investigations and Oil Operations from Teapot Dome, Wyoming

Tom Anderson (Energy & Geoscience Institute)

Teapot Dome has a rich, sometimes infamous history. Currently operated by the U.S. Department of Energy (DOE), the field still produces about 200 barrels of oil per day (BOPD) from several hundred active wells, but in its heyday, it produced 6000 BOPD, and over 1300 wells were drilled. Cumulative production is about 30 MMBO, primarily from the Cretaceous Shannon Sandstone, Wall Creek (Frontier) Sands, and the Pennsylvanian/Permian Tensleep Formation. Minor production also comes from the Cretaceous Dakota and Muddy Formations. From an unconventional perspective, significant production has come from the Niobrara and Steele Shale Formations, all in vertical wells and influenced by the presence of natural fractures. The structure was initially discovered and named by geologist C.H. Wegemann in 1911, as a probable oil-bearing anticline on trend with the giant Salt Creek Field. Soon after that (1915) it was established as Naval Petroleum Reserve No. 3, and placed off-limits for development. The Teapot Dome Scandal during the Harding administration of the 1920's involved leasing and drilling the reserve. But the eventual outcome of the scandal was the U.S Supreme Court invalidating the leases and re-establishing the site as a reserve once more. Nevertheless, there are remnant vestiges today of the development during the 1920's, including concrete foundations, fireplaces, sidewalks, excavations, and old pipes. The federal government eventually authorized full field development in the 1970's. High-resolution, low-altitude aerial photography obtained at this time was indexed and incorporated into a GIS system, and this provided a basis for surface geologic mapping initiatives as well as locating historical sites from the abortive development of the 1920's. Field staff have created a historic map of the 1920's 'camps' (townsites) in the Teapot Dome oil field area. The author, a petroleum geologist who previously worked at the site, conducted numerous scientific studies of Teapot Dome, including collaborations with academic research partners. This includes subsurface interpretation and modeling in support of field operations, research studies, and enhanced oil recovery opportunities, including carbon dioxide injection. Detailed surface geological mapping was also included in this effort. One project was mapping the Quaternary terraces, both erosional and depositional, and relating those terrace ages to expected soil conditions as well as historic cultural sites.

Geothermal Potential of Deep Sedimentary Basins in the United States

Tom Anderson (Energy & Geoscience Institute)

Geothermal energy development has a promising future as part of a broad energy supply mix to meet growing demand in the United States and globally. Currently developed hydrothermal systems are a significant energy source, but these systems have limited geographic extent. Research is underway, including ongoing pilot projects, to evaluate the potential for EGS, or Engineered Geothermal Systems, to drill into hot crystalline rock, and create fractured reservoirs suitable for water injection and production cycles. However, a challenge to the economics of these systems is the drilling and fracturing cost. Co-production of geothermal energy associated with oil operations has been demonstrated successfully at Teapot Dome, where produced water is of sufficient quantity and adequate temperature to generate electricity with binary/hybrid systems. However, this approach has yet to be embraced by the oil industry. A potential new path toward expanded geothermal energy production is to use known porous and permeable reservoir rocks in appropriate sedimentary basins, where those packages of rocks have sufficient temperature, thickness, porosity, and permeability, existing at depths that are not so great that drilling costs make the potential system uneconomic. This presentation describes a DOE-funded project to identify, screen, and model these potential systems, incorporating geology, engineering, and economic modeling disciplines. From a geologic perspective, 17 basins in the western U.S. have been examined. Stratigraphic columns were compiled, including unit depths and thicknesses, along with thermal profiles. Target reservoir sections at appropriate depths and temperatures have been evaluated with respect to porosity and permeability, primarily from available core data, supplemented with wire-line log analysis. For screening purposes, thresholds of < 4 km depth and > 125 °C temperatures were applied to meet economic targets. Results indicate that many of those basins should be excluded, for example, the Bighorn Basin of Wyoming has favorable porous and permeable reservoir rocks and good temperatures for geothermal energy production, but these occur at nearly 6 km, too deep for economic drilling costs. The temperature at the 4 km threshold is only 100-110 °C, in the marginal range for binary geothermal power systems. Based on this work, basins meeting the criteria are the Williston, Denver, Great Basin, Fort Worth, Sacramento, Gulf Coast, and Imperial Valley.

Ground-truthing a Predictive Model for Locating Fossil Vertebrate Localities in the Eocene of Wyoming

Robert Anemone (Western Michigan University), Brett Nachman (University of Texas), Charles W. Emerson (Western Michigan University)*

Remote sensing and other tools and methods from the geographic information sciences have the potential to revolutionize how paleontological fieldwork is performed. We trained a neural network to analyze remotely sensed imagery and multiple GIS data and analytical layers in order to recognize different land cover classes, including productive localities, in Eocene deposits of the Great Divide Basin of southwestern Wyoming. Post hoc accuracy testing indicated that the model was able to recognize the spectral signatures of productive localities and four other land cover classes with a high degree of accuracy (84% correctly classified). Our predictive model was constrained by geology (limited to outcrops mapped as Wasatch formation), by topography (minimum required slope was 5%), and was limited to pixels which resembled known localities at the 98% probability level. Ground truthing of the model took place during the summer 2012 field season. The first area we surveyed yielded characteristic Eocene fossils (turtle, fish, crocodile, gastropod, bivalve) in deposits whose lithology (paper shales and stromatolites) suggested a lacustrine origin. We confirmed that these deposits have been mistakenly mapped as Wasatch formation and should instead be attributed to the Green River formation. In the second area, the lithology was clearly fluvial and the rocks were typical of the Wasatch formation (sandstones and mudstones). The area indicated by our model as having a high priority of being fossiliferous was in fact a large outcrop of heavily eroded sandstone that yielded typical Eocene terrestrial mammals, including Hyracotherium and Hyopsodus.

Microbialites of the Eocene Green River Formation as Analogs to the South Atlantic Pre-Salt Carbonate Hydrocarbon Reservoirs

Stanley M. Awramik (University of California, Santa Barbara), H. Paul Buchheim (Loma Linda University)*

The 2000-meter-thick Eocene Green River Formation stretches across 350 km of Wyoming, Colorado, and Utah, and contains what may be the richest record of lacustrine microbialites. Most microbialites occur in laterally extensive biostromes that have the facies association of ooids/flat-pebble conglomerate, microbialite, and kerogen-rich laminated mudstone. The facies association forms pronounced stacking patterns or parasequences with microbialite biostromes that were deposited on a low- gradient lake bottom. Multi-meter-size bioherms occur in the northwest corner of Green River Basin and are found over an aerial extent of over 2000 km2. The bioherms are composed of clusters of meter-scale stromatolites and tufa. The 10-30 m thick bioherms are composed of stacked, 1-3 m-thick successions of oolite and grainstone, microbialite, wackestone, and carbonate mudstone. The various microbialite facies associations and even spring-associated facies occur in specific stratigraphic relationships and their basinal and stratigraphic occurrence can be predicted. They are related to lake phase (under-filled, balance-filled or over-filled), water depth and energy, basinal location (margin to lake center), lake-bottom gradient (low to high gradient), and lake chemistry (calcium saturation, salinity). The Green River Formation is probably the best analog for the large lake systems that formed with the opening of the South Atlantic. The Green River lakes were saline-alkaline (bicarbonate lakes) as indicated by trona evaporates and the stevensite clays (both only occur in saline-alkaline lakes). Volcaniclastics are locally abundant. And now that we have found abundant 'arborescent shrubs' associated with Green River microbialites, we are confident that the Green River Formation will continue to provide many additional and significant insights into better understanding the pre-salt lacustrine systems.

Bluebell-Altamont Field: Core from the Fractured Green River-Wasatch Reservoir, Uinta Basin, Utah

Paul Baclawski (Devon Energy), John South (Fronterra Integrated Geosciences), John Lorenz (FractureStudies LLC), Scott Cooper (Consulting Geologist)

Bluebell-Altamont Field (along with the adjacent Cedar Rim Field) covers an area of about 500 sq-mi and has produced over 300 MMBO and 500 BFCG from Tertiary age Wasatch and Green River formations. From the core of the basin along the north side of the field, stacked reservoirs pinchout updip to the south from sandstones and carbonates into open lacustrine mudstones, forming major transgressive wedges. These wedges create multiple opportunities for stratigraphic traps in the over-pressured accumulation. Core description and analysis from eleven cores and of several formation image logs have documented the existence of two fracture domains in the reservoir interval: one striking approximately N20-45W and another striking approximately N90E, with the change in orientation generally occurring in the lower part of the Lower Green River interval (about the TGR3 level). Fractures are generally confined to brittle sandstones and carbonates terminating or becoming narrower where the lithology becomes more clay-rich. These naturally occurring fractures range in width from <.1 mm to >5 mm. They are generally lined with calcite, which occludes all or some of the original fracture, but also provide a mechanism to retain the remaining fracture aperture at reservoir conditions. Apparent fracture spacing from core is a few feet although image log data indicates that closer spaced fractures are common in the subsurface. Given these parameters, calculated fracture porosity in the pervasively fractured sandstones and limestones is at least 1% and results in large effective drainage areas and high recovery factors from this porosity system. It appears that the tight (<4% porosity, <.01 md) matrix in the Wasatch and Lower Green River reservoir contributes a negligible amount to the recoverable reserves in the field.

Geochemistry of Lacustrine Microbialite of the Eocene Green River Formation

M'bark Baddouh (University of Wisconsin-Madison), Brian L. Beard (University of Wisconsin-Madison), Alan R. Carroll (University of Wisconsin-Madison), Clark M. Johnson (University of Wisconsin-Madison)*

Microbialite of the Wilkins Peak member of the GRF forms mound-like structures of about 6-12m thick each, separated by carbonate grainstone. They are exposed in the Little Mesa region in the northwest part of the Green River Basin. Previous studies have reported that the mounds are associated with calcified caddisfly cases, encrusted logs, and ostracods. We report C, O, and Sr isotope data for 27 samples from the Little Mesa, Wyoming. The δ13C values range from -1.77 to 3.37 with an average 1.58 ‰ VPDB (n=27), a typical range for lacustrine rocks, and δ18O values range from -7.20 to -3.10 with an average -4.80 ‰ VPDB (n=27), consistent with moderately high lake water evaporation rates, but not previous interpretations that snowmelt was a major water source. Stable isotope data also show strong positive correlation (R2=0.85), which related to lake morphology, climate and geographic setting. In addition, covariant trend of the stable isotopes confirms hydrological closure of the lake and presence of long-term stability of the water source composition and hydrological characteristics (Talbot, 1990). The 87Sr/86Sr ratios range from 0.71022 to 0.71140 with an average of 0.71102 (n=27). These 87Sr/86Sr ratios represent the lowest yet measured for the deposits of Eocene Lake Gosiute in Wyoming, but are similar to those of the Paleocene-Eocene Flagstaff formation in central Utah (Gierlowski-Kordesch et al., 2008). The Sr isotopes also show strong positive correlation with both δ13C (R2=0.83), and δ18O (R2=0.74). These data shows that water source evolved from less radiogenic to more radiogenic values or probably a mixing between two end-members water sources. In general, these observations are consistent with stratigraphic evidence that GRF microbialite was deposited during a major transgression of Lake Gosiute, and show that lake level rise was caused by increased import of less radiogenic waters.

Microbialite Distribution in a Lacustrine Rift Basin, Great Salt Lake, Utah

Robert L. Baskin (University of Utah)

Great Salt Lake (GSL) provides an ideal location for examining environmental and chemical influences on the heterogeneity of microbialite distributions in a lacustrine rift basin. A variety of microbialite morphologies have been observed in GSL, including giant, ramified columnar forms (tens of meters in diameter and height) to smaller benthic forms (meters in diameter and height) to widespread biofilms. While the larger columnar forms seem to be limited to a specific area of the lake, the benthic forms are pervasive in the shallower waters and appear to be controlled by depth-related factors such as light penetration and/or wave-base energy. The influence of tectonic controls on microbialite distribution throughout GSL is evidenced by the abrupt occurrence of microbialites in areas of structural microtopographic highs. The relation between these highs and corresponding onlapping sediments trapped in hanging wall lows is repeated in many of the surveyed transects and likely occurs throughout the lake. Some microbialite growth appears very recent, occurring after Pleistocene Lake Bonneville; whereas in other areas, large ramified columnar forms appear long-lived, keeping pace with sediment accumulation. Examination of tectonic and chemical influences on the occurrence and distribution of microbialites in GSL provide insight into understanding fossil distributions and if distributions are related to evolution of the biological components of microbialite formation or variant environmental conditions.

Utilizing the Delta Log R method for Determining Total Organic Carbon of the Niobrara Formation, B Bench, Denver-Julesburg Basin, Colorado

Madeline K. Beitz (Drillinginfo, Inc.), Robert Cunningham (ChargeSearch, LLC), Lisa E. LaChance (Drillinginfo, Inc.)*

The Niobrara Formation was deposited in the Western Interior Seaway during the late Cretaceous Coniacian-Santonian stages which coincided with high eustatic sea-level. In the Denver-Julesburg Basin study area, the Niobrara Fm occurs as a mixed shale/marl/carbonate sequence comprised of parasequences interbedded with organic-rich shale/marl units. These parasequences are developed as the three primary carbonate (chalk) benches. Total thickness of the Niobrara Fm ranges from two hundred feet to four hundred feet. Weight percent Total Organic Carbon (TOC) was calculated for the B Bench of the Niobrara Fm using the Delta Log R method of Passey et al. (1990) within third-party well interpretation software. The study includes 129 wells that had both deep resistivity and sonic logs available digitally. The B Bench of the Niobrara formation was the focus of the study because recent drilling has indicated this zone to be a primary target for unconventional resource development. The methodology for Delta Log R calculation of TOC involved overlay and base-lining of the resistivity and sonic logs and consideration of Niobrara thermal maturity patterns. Zonal statistics (maximum, minimum, mean) for Delta Log R predicted TOC were calculated for the B Bench and the results were gridded over the study area using the top and bottom of the B Bench as a zone. The resulting mean values range from 2 % to 8 % in the study area and reflect both thermal maturity and deposition controls. This work aligns with and extends the published source characteristics for the Niobrara Fm.

Point Pattern Analysis of Channel Organization from the Cretaceous John Henry Member of the Straight Cliffs Formation, Kaiparowits Plateau, Southern Utah

Wassim Benhallam (University of Utah), Cari L. Johnson (University of Utah), Luke Pettinga (ConocoPhillips), Lisa Stright (University of Utah)*

The John Henry Member (JHM) of the Straight Cliffs Formation exposed along the Kaiparowits Plateau provides a record of ~6 my of coastal plain to marginal marine deposition. Understanding the mechanisms influencing stratigraphic trends throughout the basin requires elucidating the controls responsible for spatial changes in alluvial architecture. In particular, base-level driven change in accommodation is commonly hypothesized to be a major downstream control on fluvial systems. In this study, we test this hypothesis using the record of fluvial deposition preserved in the JHM that is coeval with known shoreline shifts in shoreface equivalents. Correlating the fluvial succession in the JHM with the mapped shoreline requires characterizing the spatial organization of channels across the multiple depositional units within the fluvial JHM. To this end, point pattern analysis techniques are applied on a dataset of fluvial channel sand bodies from the JHM. These techniques describe the channels' spatial organization as clustered, uniform, or random. The resulting variation in spatial organization is then correlated with relative sea-level fluctuations from the shoreline stratigraphy. Although a correlation may be established, this approach does not rule out the influence of other controls on the alluvial architecture. Three point patterns analysis techniques are used: quadrat method, nearest neighbor method, and K-function. Results indicate all depositional units are consistently classified by the three techniques. The correlation with onlap curves suggests channel clustering broadly corresponds to a basinward-shifting shoreline. Conversely, uniformity or randomness correlates with landward shifts of the shoreline. Furthermore, a moving window spatial analysis suggests the point pattern's history of spatial organization correlates even with the small scale fluctuations in relative-sea level.

Hydrocarbon Potential of the Chainman Shale, Western Utah

S. Robert Bereskin (Bereskin and Associates, Inc.), Thomas C. Chidsey, Jr. (Utah Geological Survey), Craig D. Morgan (Utah Geological Survey), John McLennan (University of Utah)*

Examination and sampling of a ~500 m surface section from the Confusion Range of western Utah indicates that the Chainman Shale (Mississippian) possesses clear potential for hydrocarbon production. Although very good stratigraphic and geochemical work has been accomplished in the past, application of relatively new geologic and engineering perspectives has confirmed reservoir potential, particularly in the lower 300 m of the formation. Although geochemical measurements are uniformly modest (1-2 wt % TOC), modern laboratory analysis reveals adequate mudrock porosity (3-9% effective) and oil saturation for largely liquid hydrocarbon production. In fact, one surface sample surprisingly contained substantial amounts of mobile oil (8%). Of the four major unconventional reservoir types recognized (organic siltstone, argillaceous mudstone, calcareous mudstone, and siliceous mudstone), the siliceous mudstone and organic siltstone most likely represent the sweet spot lithologies in this geologic instance. If some gross assumptions are made, including a normally pressured well at 1600 m drilling depth, a 30% water saturation, a 20% recovery factor, estimations of recoverable oil on an 80-acre spacing would amount to 270,000 BO over a 20 year lifespan. This estimate is based on surface mapping and geochemical testing exclusively.

Modeling Hydraulic Fracture Interactions with Natural Fractures

Ravindra Bhide (University of Utah), Milind Deo (University of Utah), John McLennan (University of Utah), Trevor R. Stoddard (University of Utah)*

Natural and hydraulically induced fractures will propagate and/or deflate when subjected to sufficient tensile and shear stresses. They will also mutually interact. Any numerical exercise predicting the effect of these mechanical interactions on an integrated fracture network relies on the fracture growth criterion that is adopted. Presented here are the results of a set of simulations carried out using weakly coupled geomechanical simulations for an evolving hydraulic fracture intersecting a prescribed natural fracture network. The simulations have been carried out using a crack opening displacement incremental propagation criterion to represent evolutionary extension, opening and pressurization of pre-existing fractures discretely incorporated in a rock matrix. This allows a natural fracture network to be entered a priori and a hydraulic fracture system to progressively evolve by interacting with these natural fractures. There is episodic growth rather than instantaneous pressurization of each entire intersected fracture. Beyond the nature of the natural fractures, other parameters considered in these numerical calculations include stress field and injection parameters. Realistic field scenarios are explored.

In-Place Oil Shale Resources in the Saline Mineral and Saline-Leached Intervals, Piceance Basin, Colorado

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The Eocene Green River Formation of the Piceance Basin in western Colorado contains most of the high-quality oil shale resource in the western United States. According to a recent analysis by the U.S. Geological Survey of the potentially recoverable resource as a function of oil-shale grade, the basin contains about 920 and 352 billion barrels of potential oil resource using oil-yield cutoffs of 15- and 25-gallons per ton (GPT), respectively. Much of this rich oil shale is associated with the saline minerals nahcolite and halite or intervals in which these minerals have been leached by groundwater. This impacts the potential for oil shale resource extraction as nahcolite must be co-produced or preserved. Furthermore, the presence of vugs and breccias in the leached zones can effect groundwater movement and potentially affect the implementation of in-situ oil shale extraction technologies. To facilitate the assessment of potentially recoverable resources associated with the major mineral facies of the Piceance Basin, oil-shale zones were delineated into mineralogical-stratigraphic intervals, specifically: (1) the illitic zone, which predates the deposition of saline minerals; (2) the saline zone; (3) the leached zone; and (4) other overlying oil shale zones. The oil shale resources in each interval were further sorted according to oil-shale grade. Of the 352 billion barrels of potentially recoverable oil resources associated with high-grade (<25 GPT) oil shale, the amounts present in the illitic, saline and leached intervals were 11%, 33% and 54%, respectively. Very little high-grade oil shale was associated with the overlying oil shale zones. These results highlight the importance of investigating the association between saline minerals and organic richness in the Piceance Basin oil shale, both to understand the geological setting and to facilitate resource development.

An Integrated, Core-focused Facies and Stratigraphic Model of the Mancos Shale, Uinta Basin

Lauren Birgenheier (University of Utah), Laini Larsen (University of Utah), Andrew D McCauley (University of Utah), John McLennan (University of Utah), Robert Ressetar (Utah Geological Survey), Brendan Horton (Chevron Corporation)*

A major challenge to successful hydrocarbon production from the Upper Cretaceous Mancos Shale in the Uinta Basin is the identification of prospective horizontal drilling target reservoir facies and production 'sweet spots.' This core-poster presentation will attempt to illustrate relationships between core-defined lithofacies and the data from a range of analytical techniques in order to develop a work plan that explorationists can use to locate and predict target horizons in the 4000-ft thick Mancos. Although in outcrop the Mancos Shale appears fairly homogenous, detailed core descriptions reveal a variety of mineralogic compositions and sedimentary structures and textures that suggest non-uniform geomechanical properties. The core analysis also defines several depositional facies in prodelta, mudbelt, and sediment-starved shelf environments. We have further characterized these facies using thin section, x-ray diffraction, x-ray fluorescence, and QEMSCAN analyses, among others. Results indicate distal sediment-starved shelf deposits have the best combination of hydrocarbon production, storage capacity, geomechanical properties, and reservoir potential. In contrast, the petrophysical data suggest that the proximal mudbelt facies, with its higher water saturations and lower TOC and carbonate contents, is less prospective for hydrocarbon production. Log-based sequence stratigraphic correlations indicate that the distal sediment-starved shelf deposits formed in late transgressive and early highstand sequence sets, whereas the proximal mudbelt facies represent late highstand and lowstand sequence set deposition. These results point towards a methodology whereby explorationists can rank potential Mancos targets for drilling, stimulation, and completion.

A Facies and Sequence Stratigraphic Model for the Mancos Shale, Uinta Basin: Identifying Unconventional Horizontal Targets

Lauren Birgenheier (University of Utah), Brendan Horton (Chevron Corporation), Laini Larsen (University of Utah), Andrew D. McCauley (University of Utah), John McLennan (University of Utah), Robert Ressetar (Utah Geological Survey)*

The Mancos Shale is unusually thick (~4000 ft., Uinta Basin), regionally extensive and ubiquitous across the Rocky Mountain region, relatively low TOC (average 1-2 %, max 6.7%) and carbonate poor (average 18% carbonate, 41% clay, and 41% detrital silica). Effective development of the Mancos play will require an accurate, detailed sedimentologic and stratigraphic characterization with the aim of locating and predicting prospective horizontal target reservoir facies and production sweet spots. To date, such analyses have been lacking. Using detailed core description from wells in the Uinta Basin, along with thin section, x-ray diffraction, x-ray fluorescence, and QEMSCAN analysis, a facies model has been developed. This model diagnoses prodelta, mudbelt, and sediment starved shelf environments within the broadly offshore Mancos system. Geochemical, geomechanical, and petrophysical evaluation suggest the distal sediment starved shelf deposits contain relatively fine-grained facies with higher calcite and TOC content. These facies offer the most prospective combination of hydrocarbon production, storage capacity and reservoir potential to fracture in a brittle fashion. Core analysis and basin-wide detailed log correlation suggest that desirable target reservoir facies (distal sediment starved shelf deposits) are found in the late transgressive sequence set and early highstand sequence set. In contrast, a petrophysical water saturation study of Mancos wells in the Uinta Basin suggests that proximal mudbelt facies have characteristically higher water saturations. This implies that these relatively coarser grained (higher detrital quartz sand and silt content), lower TOC and lower carbonate content would resist successful hydrocarbon production. These proximal mudbelt facies correlate to late highstand and lowstand sequence set deposition. Basin-wide log chronostratigraphic correlation defines key subunits within the Mancos and constrains the most prospective horizontal targets to three discrete transgressive intervals in the lower Mancos. Here, a regionally significant depositional and sequence stratigraphic framework is identified that can be tied to lithologic properties. This is critical for resource play evaluation and completion of the Mancos Shale in the Uinta Basin as well as for other similar offshore deposits of the Cretaceous Western Interior Seaway.

Subsurface Isopach Maps for CO2 Sequestration: Woodside Field, East-central Utah

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Geologic sequestration is a geo-engineering solution employed to mitigate the increasing concentration of anthropogenic CO_2 gasses in the atmosphere, thus reducing their effect on climate change. Woodside Field, a doubly plunging anticline is identified as the potential injection site for CO_2 sequestration. The field is located on the east flank of the San Rafael Swell in east-central Utah. The potential reservoir consists of the Permian White Rim Sandstone and the Black Box Dolomite. The Black Dragon Member of the Triassic Moenkopi Formation will act as the seal for the structural trap. Subsurface mapping of these units was necessary to determine the potential capacity and competence of the reservoir and seal system. Isopach maps of the reservoir units were constructed by correlating scintillometer data from measured outcrops to the subsurface type well log. Stratigraphic and structural representations were created through correlation of the type log to eight additional well logs. The thickness of the White Rim Sandstone varies from 525 ft. at the south end of the anticline to 380 ft. to the north. The Black Box Dolomite is 35 ft. thick on its east flank and thickens to 75 ft. on the west side. The Black Dragon Member is 280 ft. thick approximately at the center of the field and thins to the southeast to 185 ft. Overburden maps were constructed to obtain the formation temperatures and hydrostatic pressures at depth to determine CO_2 densities. These maps provide hard data that constrain volumetric calculations of storage and sequestration capacity under a variety of scenarios and assumptions.

Geochemistry of the Green River Formation, Piceance Creek Basin, Colorado

Jeremy Boak (Colorado School of Mines), Jufang Feng (Colorado School of Mines)*

The Green River Formation of Colorado, Utah and Wyoming constitutes one of the richest and thickest petroleum source rock deposits in the world. Although Lakes Uinta and Gosiute, where these sedimentary rocks were deposited, were unusual, even extreme, in their chemistry, the rocks provide clues to the conditions required to produce and preserve such source rocks. We have analyzed major and trace element chemical data from current work (82 samples) and previous work by the U. S. Geological Survey (172 samples), integrating them with stratigraphic and mineralogical studies conducted at Colorado School of Mines. A rise in Na_2O and Na/Al occurs in the basin center during the Transitional Lake Stage, coincident with sharp reduction in clay mineral content and rise in dawsonite and later nahcolite content. This change reflects a transition from mesosaline to hypersaline conditions. Na_2O drops near the top of the Rapidly Fluctuating Lake Stage reflecting a dissolution zone in which nahcolite was removed across a stratigraphically transgressive surface. Na_2O and Na/Al remain elevated because of the presence of authigenic albite. Dawsonite and quartz abundance decrease at the top of the R5 zone, reflecting increase in silica activity with continued hypersaline conditions. A wide variety of metal ratios and other chemical measures of redox potential devised mainly for marine systems support the long-held conclusion that the Colorado portion of Lake Uinta was stratified, with a deep zone (basin center samples) that was persistently at least dysoxic, and commonly anoxic, and a shallow zone (basin margin samples) that was less persistently dysoxic. Whereas a moderately strong correlation of Fe to Al indicates an origin in clastic constituents (clay and oxide/hydroxide minerals), calculated values of Ca/[Ca+Mg+Fe*] (where Fe* represents Fe not in pyrite) for basin center samples match carbonate mineralogy, and the Mg/[Mg+Fe*] indicate ferroan dolomite with XFe of ~0.2 as the dominant reservoir for Fe. Metal/Al ratios show enrichment with respect to the same ratio in average shale, in the following general order: Mo>Cu>U>V>Co. These data, along with thick organic rich zones and the presence of buddingtonite support the presence of chemical stratification, brackish-mesosaline-hypersaline conditions and dysoxia/anoxia from Garden Gulch Member onward. Potentially fresh water conditions found in part of the section in the basin margin may have been relatively local.

Gilsonite Veins of the Uinta Basin, Utah

Taylor Boden (Utah Geological Survey)

Gilsonite is a solid hydrocarbon that forms a swarm of subparallel, northwest-trending, near-vertical, laterally and vertically extensive veins in the Uinta Basin of Utah and Colorado. The Uinta Basin hosts the world's largest deposits of gilsonite, and is the only place where gilsonite is economically produced in large quantities. Gilsonite was sourced from the Mahogany oil shale zone of the Eocene Green River Formation and is hosted in the Tertiary Wasatch, Green River, Uinta, and Duchesne River Formations. The veins formed in two stages associated with thermal maturation of the Mahogany oil shale. Overpressuring deep in the Uinta Basin expelled large quantities of thermal water from the reservoir rocks and hydrofractured the overlying and underlying strata. Subsequently, thick, liquid gilsonite was expelled from the reservoir rocks, forcing open the existing fractures in the overlying and underlying strata. The gilsonite later solidified in these fractures, probably primarily through cooling and polymerization. This study included examination and mapping of 59 veins, vein systems, and isolated vein outcrops totaling more than 120 miles in length. In addition, we collected 1474 Global Positioning System data points with associated attribute data, obtained field data from previous geologic mapping by the U.S. Geological Survey and U.S. Bureau of Land Management, and examined recent National Agriculture Imagery Program high-resolution color aerial photography. A total of 71 significant veins, vein systems, and vein extensions were documented in our study, having a total combined vein length of more than 170 miles. Gilsonite has a wide variety of uses including asphalt paving mixes and coatings; chemical components in metallurgical, adhesive, coating, binder, ink, and paint products; and in metal foundry and oil well drilling and well completions. Even though significant amounts of the approximately 45-million-short-ton original gilsonite resource have been mined, millions of tons of the valuable resource still remain. This resource tends to be in the deeper parts of the veins and in thinner, more remote veins that will likely be more expensive to mine than veins mined in the past. At the recent industry production rate of 60,000 to 80,000 tons per year, gilsonite could continue to be mined in the Uinta Basin for decades.

Stratigraphy and Oil Resource Potential of the Mississippian Heath Formation, Central Montana, USA

Richard J. Bottjer (Cirque Resources LP)

The Heath Formation of central Montana is an emerging tight oil play. Historically studied for oil shale mining potential, these organic-rich beds are the primary source rocks for more than 100 MMBO of oil produced from the Tyler Sandstone and other reservoirs in central Montana. The late Mississippian Heath Formation is the highest stratigraphic unit in the Big Snowy Group and is unconformably overlain by the Pennsylvanian (and/or latest Mississippian) Tyler Formation. The Heath exceeds 450 feet in thickness in areas of little basal Tyler erosion. Internally the Heath can be informally subdivided into, in ascending order, a lower 'shale', the Van Dusen Zone, Potter Creek Coal, Forest Grove Limestone, Cox Ranch Oil Shale, Heath Limestone, and an upper 'shale'. Oil shows and saturations are present throughout the entire Heath Formation. The Potter Creek and several other thin coals indicate humid conditions were present in near shore areas in older parts of the Heath. Intertidal to supratidal dolomites with up to 18 percent porosity interbedded with nodular anhydrites in the Heath Limestone indicate hot, arid conditions dominated near shore areas in the middle part of the Heath. Oil production from the Heath Formation was discovered in 1919 at Devil's Basin Anticline. Recent horizontal and vertical completions in the Heath Formation have initial potentials up to 447 BOPD and demonstrate the economic potential of the Heath. With Oil-In-Place estimates ranging from 6.6 to 22.4 MMBO/section and total Oil-In-Place of more than 14.0 BBO there is sufficient oil potential to warrant additional drilling and testing.

Using Channel Morphometrics and MPS to Improve Reservoir Model Accuracy: An Example from Greater Monument Butte Field, Uinta Basin Utah

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Reservoir characterization focuses on rock and fluid properties, and how they vary about a field. Often engineers and geologists spend little time characterizing the size and arrangement of reservoir bodies which can be critical to accurately modeling fluid flow. In the Greater Monument Butte Field, oil is primarily produced from lacustrine-deltaic channel sand-bodies. In the field, channel characteristics were estimated using core, wireline logs, outcrop, and modern analogs, and were used to make realistic representations of channel thicknesses, widths, and sinuosity. These images were used to train muti-point statistical (MPS) realizations of reservoir facies. Accurate facies realizations decreased the uncertainty about connectivity between injectors and producers, and provided the basis for potential in-fill drilling in some parts of the reservoir.

Greater Aneth Field, Paradox Basin, Southeastern Utah

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Greater Aneth, Utah's largest oil field, was discovered in 1956 and has produced over 465 million bbls. Located in the Paradox Basin of southeastern Utah, Greater Aneth is a major stratigraphic trap. The primary reservoir is the Desert Creek zone of the shallow marine, Pennsylvanian (Desmoinesian) Paradox Formation. Carbonates in the Desert Creek are sealed by the organic-rich, overlying and underlying Gothic and Chimney Rock shales, respectively, that are also the hydrocarbon source rocks. The net reservoir thickness of the Desert Creek zone at Greater Aneth is 50 ft over a 48,260-ac area. Porosity averages 10% in interparticle, vuggy, moldic, and intercrystalline networks enhanced by fractures; permeability averages 10 mD, ranging from 3 to >100 mD. The drive mechanism is fluid expansion and solution gas; original water saturation was 24%. The initial reservoir field pressure was 2170 psi. The produced oil is a dark green, paraffinic, sour crude. The API gravity of the oil ranges from 40º to 42º. Greater Aneth field is a complex reservoir consisting of limestone (oolitic, peloidal, and skeletal grainstone and packstone, and phylloid-algal bafflestone and microbial boundstone) and finely crystalline dolomite. These lithotypes represent a variety of depositional environments (open-marine shelf, shallow-marine beach and shoal, phylloid-algal mound, low-energy restricted shelf) that produce significant reservoir heterogeneity. Several facies indicate microbial activities including sediment bindings and thrombolitic/stromatolitic structures with relief. Fractures are relatively common and there is evidence (hydrothermal dolomite and brecciation) of minor but important faults that may affect fluid flow. Cores reveal additional potential seals within the Desert Creek (mudstone and very fine grained sandstone units). Currently, there are 449 producing wells in the field. Waterflood operations are used in all four field units – the largest waterflood program in Utah. Production was greatly increased due to carbon dioxide flooding (the only one in Utah) beginning in 1985 and an extensive horizontal drilling program in the 1990s, where northwest-southeast-directed horizontal wells were drilled perpendicular to fault/fracture zones. The combination of carbon dioxide flooding and horizontal drilling, along with a better understanding of the reservoir heterogeneity, could extend the life of Greater Aneth for decades to come.

Re-evaluation of Available Thermal Energy of the Lower Cretaceous Formations in the Denver Basin: Colorado and Nebraska

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We have obtained new data that have allowed us to revise our previous estimate of available thermal energy in the Lower Cretaceous formations of the Denver basin. We also have determined that at least a second-order polynomial correction is most accurate, if not a piecewise-defined function. Our previous linear correction is overly generous and as a result, we have re-analyzed the Harrison, Kehle, and Forster correction equations. Statistical analysis of the three existing corrections shows that the Harrison and Kehle equations agree closely with respect to depth, which can be characterized by the equation: ?Tcf = 2x10-6x^2 – 0.0082x + 14.7325. We have therefore corrected the bottom-hole temperatures using the Harrison correction, utilized ArcGIS to obtain volume of the target formations and average temperature, and used the available heat equation (Q = ?CPV?T) to determine thermal heat in place. The estimate of the recoverable energy in place was determined from Sorey et al. (1982) for a sedimentary basin with the characteristics of the Denver Basin, and is different than what can be obtained by a binary plant with current technology. The available energy in place, listed by target temperature range is: 90°C and up = 6.10 x 10^11, 100°C and up = 3.85 x 10^11, 110°C and up = 1.06 x 10^11, 120°C and up = 2.73 x 10^10, and 130°C and up = 2.00 x 10^9.

The Esmeralda Basin: A Proven Intra-continental Lacustrine Rift Play along the Walker Lane Shear Zone, Western Nevada

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We demonstrate a widespread working petroleum system in western Nevada, which challenges conventional wisdom that, owing to complex tectonics and Cenozoic volcanism, the region's petroleum potential is marginal. Oil samples from a well in the Gabbs basin and an active oil seep in the Columbus basin share biomarkers signatures (sterane-hopane ratios, sterane-sterane ratios, gammacerane, and oleonane) indicating expulsion from a Tertiary algal source deposited under anoxic hypersaline conditions. We interpret these data as evidence for an organic-rich lacustrine facies in the Oligo-Miocene Esmeralda Formation. Although oil-prone source rocks in the Esmeralda Formation have not been reported, shallow bituminous coal seams (20ft thick) prove conditions favorable for preservation of organic-rich units. The Esmeralda coal Ro (0.54) is consistent with a high geothermal gradient measured in wells (60ºC/km). The Columbus and Gabbs basins lie in the central Walker Lane shear zone. Gravity modeling indicates both basins have >12,000ft of sediment. Because Walker Lane was not active during deposition of the Esmeralda Formation, the presence of lacustrine-sourced oils in both basins (70mi apart), suggests a large deep stratified lake once existed in a single basin, the Esmeralda Basin. Subsequent development of the Walker Lane shear zone segmented the Esmeralda Basin into the currently configured sub-basins. The Esmeralda Formation is primarily filled with interbedded tuffaceous sandstone, shale, volcanics, and diatomite beds. In the Gigante-1, on the Cobble Questa anticline, strong sample and mudlog shows (up to C5) in several overpressured intervals (~10ppg MW) demonstrate the opportunity for stacked pays. The Esmeralda Basin represents an inverted intra-continental lacustrine rift play. Although play POS=1, commercial and prospect risks include trap size, reservoir quality, and producibility of waxy, high pour-point oils.

History of the Cedar Creek Anticline, Southeast Montana

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Oil was discovered on the Cedar Creek Anticline in the Gas City Oil Field in 1951. Thirteen fields on the anticline have produced over a half billion barrels of oil from about 2700 wells. The Cedar Creek Anticline is a collection of structural traps, inter-connected by various faulting styles, including some subsets of fracture pattern overprinting. Located in southeast Montana, the anticline stretches 115 miles southeast from Glendive, Montana to Buffalo, South Dakota. The primary producing carbonate reservoirs include the Ordovician Red River, the Silurian Stoney Mountain and Interlake Formations, and Mississippian Mission Canyon Formation. The primary source rocks are the organic shales in the Cambrian Winnepeg Formation, Ordovican Lower Red River Formation, and lower Lodgepole Formation. All of the producing reservoirs, except the Mission Canyon, are intercrystalline and interpartical dolomites, and were deposited in supratidal, intertidal, and subtidal environments. The Mission Canyon reservoirs are mostly limestone. Shell Oil was the major explorer and developer of these fields from 1950 to 1998, and commenced water flooding and infill drilling from 1959 to 1984. Shell sold their intersts to Encore in 1999, whose focus was infill drilling for new oil. Denbury Resources Inc. bought Encore's interest in 2010, and current activities are centered on optimizing water flood patterns in prepation to commence CO2 floods in 2016. CO2 will be suppied via the 406 mile Denbury pipeline, under construction, starting from CO2 fields at Riley Ridge, and Lost Cabin Creek fields in Wyoming, and ending at Gas City, Montana.

Earliest Record of Plant Preference in Caddisfly Larval Case Armor and of Caddisfly/Stromatolite Symbiosis from the Early Cretaceous Shinhudag Formation, Mongolia

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Caddisfly larval cases have long been recognized in Cenozoic rocks and increasingly in the Mesozoic. Their association with stromatolites in lacustrine reefs is documented as early as the Aptian. We report on caddisfly larval cases as framework within lacustrine stromatolites from the Early Cretaceous Shinhudag Formation of Mongolia. The association occurs in a synrift succession that is Berriasian to Valanginian in age based on palynology (145.5 5 ± 4.0 Ma and 140.2 ± 3.0 Ma). Thin-sectioned samples reveal finely laminated stromatolites intercalated with straight round caddisfly larval cases of uniform size. The cases are filled with diagenetic calcite spar and display preferential armoring dominated by plant material, including woody tissue. Minor armor components include ostracod carapaces, ooids and quartz grains. Matrix surrounding the cases is largely micrite, with minor ooids and detrital silt. Plant material is rare except as case armor. This is the first documented occurrence of fossil caddisfly cases showing preferential choice of plant material for case armor, as is seen in living representatives of the family Phryganeidae. The stromatolite/caddisfly-bioherms suggest that they were deposited near the shore of a shallow, relatively alkaline lake. Likely the lake was periodically starved for calcite. These stromatolites might have formed when increased inflow brought in calcium-rich waters. Wave action and photosynthesis from the cyanobacteria of the stromatolites resulted in a carbonate-precipitating environment forming the stromatolite bioherms. The stable platform of the stromatolites provided an attachment site for the caddisflies in a well-oxygenated environment due to wave action, preferable to the shifting ooid forereef and backreef environments. The rare occurrence of the caddisfly/stromatolite reef association at only the greatest expansion of the lake within the formation is consistent with patterns and reefs present in the Laney Member of the Eocene Green River Formation. This represents the earliest occurrence of plant-preferring caddisfly larvae and the first documented occurrence of stromatolite bioherm/caddisfly symbiotic interactions.

The First Absolute Ages and Chronostratigraphic Framework for the Muddy Portion of the Jurassic Entrada Sandstone in South-Central Utah

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The Jurassic Entrada Sandstone in south-central Utah is comprised of a mud-dominated, tidally-influenced siliciclastic shoreline system. Regional correlation is difficult because eolian sands from the Entrada erg system interfinger with the tidal deposits in the south and east, creating dramatic facies changes. Additionally, the thickness of the Entrada Sandstone increases nearly threefold from the northeast to the southwest. Chronostratigraphically significant surfaces created by volcanic ash deposits allow us to correlate stratal packages from various locations. Sections of the Entrada Sandstone surrounding the San Rafael Swell and Escalante, Utah have been measured. Samples from ash deposits in these sections have been collected in order to separate out minerals for 40Ar/39Ar ages and chemical correlation. Using the ages obtained from these minerals and preliminary electron microprobe analysis of biotites, candidate chronostratigraphic packages have been identified. These packages, in conjunction with updated models, reveal depositional relationships and aid in the paleogeographic interpretation and reconstruction of the Entrada Sandstone at different instances in time.

Assessing the Carbon Sequestration Potential within the Bear River Formation of the Wyoming-Idaho-Utah Thrust Belt

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The United States Geological Survey (USGS) was directed by the 2007 Energy Independence and Security Act to assess the potential geologic storage resources for carbon dioxide (CO2) within the United States. Utilizing its probabilistic methodology for a national CO2 geological sequestration assessment, the USGS has assessed the storage potential of the shale and sandstone dominated Cretaceous Bear River Formation within the Wyoming-Idaho-Utah (W-I-U) thrust belt. The basic assessment unit used in the USGS methodology is the Storage Assessment Unit (SAU), which consists of a storage formation and an overlying regional seal formation. The SAUs are defined by geologic criteria that include rock properties, formation depth, and regional extents of the storage and seal formations. The methodology requires that the storage formation be at depths from 3,000-13,000 ft below ground surface. This minimum depth requirement ensures that CO2 will remain in a supercritical phase. Within the W-I-U thrust belt, a significant portion of the Cretaceous Bear River Formation fits within this depth interval. However, in several instances, thrusted Bear River Formation overlies a repeated deeper section of Bear River Formation and rock properties indicate that CO2 could be stored at depths greater than 13,000 ft, in a separate 'deep' SAU. These thrusted and stacked SAUs yield increased potential storage. The storage formation and overlying seal are required to be continuous and regional in extent. Within the W-I-U thrust belt, there are thick, regionally extensive, marine shales (Aspen and Mowry Shales) which could inhibit the flow of buoyant CO2 into overlying strata. In some cases, the stratigraphy includes the stacked seals of the Aspen and Mowry Shales. During this assessment, the seal was evaluated for leakage potential and a minimum seal thickness of about 75 ft was defined to ensure integrity. This minimum seal thickness extends over the entire Bear River Formation SAU. These criteria were used to delineate boundaries for the Bear River Formation regular and deep SAUs within the W-I-U thrust belt. The assessed storage formation is porous and permeable and has the required overlying regional seal that meets the requirements of the assessment methodology. This USGS carbon sequestration assessment has shown that there is potential for CO2 sequestration within the structurally complex Cretaceous Bear River Formation of the W-I-U thrust belt.

Subsurface to Outcrop: Linking Rock Physics and Depositional Environment to Seismic Reflectivity Data, Kaiparowits Plateau, Utah

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The Cretaceous John Henry Member provides excellent outcrop exposures of fluvial, paralic, and marine stratigraphy across the Kaiparowits Plateau in southern Utah. Previous outcrop studies link fluvial deposits in the east to shoreline facies in the west. There have only been a handful of studies of the transitional facies in the center of the plateau; the purpose of this study is to begin to address this data gap by synthesizing a newly acquired 2-D seismic line with available core from a nearby borehole (< 100 m from seismic line). To make a more accurate interpretation of seismic reflection data, an understanding of the elastic rock properties of each facies is required. Grain and bulk density, P- and S- wave velocity, Helium porosity and Klinkenberg-corrected permeability were acquired from 60 core plugs. The plugs statistically represent 9 different marginal marine and fluvial facies. Thin-sections from 15 samples and QEMSCAN analysis were used to obtain mineralogy and clay content. The results from core plug measurements demonstrate variability between the mudstone and shale facies, and the sandstone-dominant facies. Porosity and velocity values from the mudstone and shale facies have small ranges (7-13%; 1950-3985 m/s); whereas the sandstone facies are more dispersed (9-37%; 1400-4230 m/s). The permeability of mudstone and shale facies was too low to measure (< 1 mD); conversely, the sandstone facies had considerable permeability ranges (1-1140 mD). Clay content, clay type and organization, as well as variations in mineralogy are indicators of scatter in the velocity, porosity and permeability values of the sandstone facies. These rock physics analyses used in conjunction with identified depositional environments from the core enable a more accurate interpretation of the acquired seismic data.

Structural, Stratigraphic, and Diagenetic Factors Influencing Hydrocarbon Accumulations in the Bakken Petroleum System at the Elm Coulee Field, Williston Basin, MT

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The Bakken Petroleum System at the Elm Coulee field is an upper Devonian to lower Mississippian system consisting of the upper Three Forks, Bakken, and lower Lodgepole formations. Six distinct facies have previously been identified in the middle Bakken: the A, B, C, D, E, and F facies. These facies have been re-examined in six representative cores from the Elm Coulee field. All facies were identified and described except for the C and D facies. The main purpose of this research is to identify factors influencing hydrocarbon accumulation at Elm Coulee field. A study focusing on the structural and stratigraphic components of the Bakken Formation and Prairie Salt Formation at Elm Coulee addresses the basement structural trends and their influence on the Bakken pay interval and possible salt dissolution in the Prairie Salt. The latter is significant in explaining whether the anomalous thickness of the middle Bakken member is due to salt dissolution during Bakken deposition. Salt dissolution could have been initiated by basement structural faults and fractures acting as migration pathways for liquids, which could have provided an inflow of subsurface water to the Prairie Formation causing collapse of overlying beds and compensation infill. 3-D seismic has been used to map basement faults, create isochron maps to identify thickness anomalies, and to identify the seismic characteristics of the Bakken Petroleum System. Further, Elm Coulee has higher dolomite content than other fields. Because of this Elm Coulee features a different reservoir rock than other fields: the 'B facies' in the Middle Bakken Member. Characterizing the diagenetic history of the dolomite present should afford a better understanding of the secondary porosity and permeability, both of which control the reservoir rock at Elm Coulee. Diagenesis has produced pore space that acts as microfractures, which has led to increased production. A better understanding of this diagenetic evolution would provide an analog for similar unconventional reservoirs. Petrographic work, XRD and XRF analysis, isotope data, and SEM work will be used to constrain major diagenetic events and characterize the Elm Coulee dolomite as the product of one or more dolomite models.

Regional Stratigraphy, Elemental Chemostratigraphy, and Organic Richness of the Niobrara Formation, Piceance Basin, Colorado

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The Upper Cretaceous Niobrara Formation in the Rocky Mountain region is an emerging hydrocarbon play. A subsurface stratigraphic study shows the elemental composition and organic richness variability of the Niobrara interval in the Piceance Basin, Colorado. The Niobrara and equivalent strata consist primarily of interbedded calcareous shale and shaley limestone facies. This study is based on an analysis of open hole wireline logs (primarily gamma-ray and resistivity curves) from ~300 wells across the study area. Based on well-log signatures, a stratigraphic framework was constructed and lithostratigraphic units were defined and correlated throughout the study area. X-ray fluorescence data were collected from cuttings (at 10- and 30-ft intervals) from 10 wells (16430 ft total footage) across the basin. The stratigraphic variation of the elements and their ratios allowed the definition of seven major geochemical zones. Total Organic Carbon (TOC) was calculated for 70 wells using a sonic-resistivity overlay analysis technique (Delta Log R) calibrated to measurements from published TOC data. TOC varies laterally and stratigraphically throughout the study area: average TOC maps highlight areas of high organic content, and TOC profiles identify organic-rich zones as they relate to lithostratigraphic units. Relative changes in rock brittleness within the Niobrara were also interpreted using whole-rock geochemical data coupled with TOC profiles: organic (TOC)- and clay-mineral rich intervals are considered mechanically ductile, while more silicon and calcium enriched rocks are considered mechanically brittle.

Geological Controls on Formation Water Salinity Distribution, Southeastern Greater Natural Buttes Field, Uinta Basin, Utah

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Use of conventional petrophysical evaluation techniques at Greater Natural Buttes Field in the Uinta Basin is challenging. One reason for this is that sandstone gas reservoirs of the Upper Cretaceous Mesaverde Group have variable fluid saturation along with low matrix porosity and permeability. For petrophysical analysis, the study interval was divided into seven stratigraphic zones based on net-to-gross ratio and variation in resistivity. Pickett plot analysis was conducted for these zones in each well to determine formation water resistivity. Because many Mesaverde Group sandstones do not exhibit 100% water saturation, Pickett plot analysis often relied on interpreting irreducible water saturation. Moreover, water resistivity was used with formation temperature to determine formation water salinity. Temperature data from production logs show that the Wasatch Formation and Mesaverde Group have higher geothermal gradients than formations that are stratigraphically above. Therefore, formation temperature was estimated using these gradients which are consistent through the study interval. Total, irreducible, and free-water saturation were determined in order to evaluate the relationship between movable water saturation and salinity variations. Water saturation calculations based on the Archie equation are higher than values based on the Waxman and Smits equation due to bound water associated with shale and clay. Petrophysical analysis indicates more fresh water is present in the eastern part of the study area, while salinity increases and water saturation decreases stratigraphically upward. This may be due to natural fractures enhancing imbibition of fresh water into deeper zones creating the observed variability in salinity and water saturation. Basement faults are believed to create these natural fractures impacting gas and water production across parts of the field.

Eagle Ford - Colorado Connection: Cenomanian to Coniacian in Southwestern North America

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Preliminary reconstructions of early Late Cretaceous paleogeography suggest a complex series of events for organic mudrock deposition in southwestern North America. In middle Cenomanian time, shelf carbonate deposition in Texas suddenly ceased with formation of a major hardground and/or exposure surface. About the same time, Dakota clastic shorelines were being transgressed in New Mexico. In late Cenomanian and earliest Turonian time, marine transgression reached a peak. Clastics from the emerging Cordillera were trapped far westward. The deepwater Ojinaga trough connected northward to the Rio Salado tongue of the Mancos and ultimately to the Graneros and Greenhorn section to the north, and bounded the Eagle Ford shelf platform on the west. In middle Turonian time, a rapid shoreline progradation in New Mexico formed the Tres Hermanos regression, a zone of remarkably stable character and thickness suggesting a forced regression. At the same time, the Lozier Canyon section records a significant unconformity, perhaps on the flanks of the San Marcos Arch. The San Vicente section contains a few clastic grains but major clastic progradation was probably stopped by the Ojinaga trough. In the late Turonian, renewed transgression resulted in the D-Cross member of the Mancos, possibly time-correlative with the Langtry member of the

Eagle Ford. However, a major deltaic headland developed in southern New Mexico causing progradation of Gallup shorelines and deposition of the thick Crevasse Canyon Formation. This headland sealed the north end of the Ojinaga trough and possibly inhibited the circulation of anoxic waters in and out of the Western Interior Basin. This disruption of circulation may be partly responsible for gradual lithologic changes from Eagle Ford to Austin (oxygenated facies) in Texas, and a partial separation of Austin from Niobrara facies during Coniacian-Santonian time. Additional work is needed on key outcrop sections in west Texas and New Mexico to confirm this conjecture.

Student Perspectives on Earth Science Data Management for the 21st Century

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Global information technology, tools, and access have rapidly changed our lives and how we communicate. Students of Generation Y are fully engaged in a digital age, and are looking to new technological innovations to conduct Earth science research. On the near horizon, EarthCube is a powerful, new National Science Foundation initiative with the goal of building a comprehensive data and knowledge management system in the Earth, atmospheric, and oceanic sciences for the 21st Century. Through this project, information and data will be integrated into a single, geovisualization portal, accessible through the internet to scientists in both academic and professional settings. Wide ranging datasets will include sedimentology/stratigraphy, hydrology, structure/ tectonics, paleobiology, petrology and geochemistry, paleoclimate, modeling, geophysics, EarthScope, and more. A small group of undergraduate and graduate students participated in creating a short, informational video about EarthCube to pique interest in this new initiative. This filming effort to communicate what EarthCube is about deepened our understanding and appreciation for the complexity of what is involved, and for the potential of what it can do. With the petroleum industry participation and partnership, multiple applications of Earthcube can include: searchable subsurface data integrated with outcrop geology, published literature and well completion reports, maps, imagery, and interpreted data at multiple scales. Earthcube will enable users to more easily and efficiently access data, promote integration across disciplines, and foster innovations in teaching and sharing Earth science data. It is anticipated that this will be a 10-year commitment to a highly collaborative process that engages scientists across many disciplines of geosciences, computer science, and cyberinfrastructure. Generation Y is enthusiastic to shape the future that will become an indispensible tool for better science. This can be a valuable pathway to new discoveries and explorations of resources and scientific questions.

History of Gas and Oil Development of the San Juan Basin, New Mexico and Colorado

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The San Juan Basin of northwest New Mexico and southwest Colorado is the second largest gas basin in the United States and contains the largest CBM field in the world. Through September 2009, cumulative gas production from nearly 40,000 wells in the basin was 45.3 TCFG; oil production was 281 MBO. The first commercial gas well in the basin was completed in 1921 at a depth of 1000 ft in the Farmington Sandstone Member of the Kirtland Formation. Because there was no large market for gas (no pipelines out of the basin then existed) further significant gas development did not take place. In the 1950s, with the completion of large pipelines out of the basin, the drilling and completion of additional gas wells exploded with gas production expanding outward from the basin's center in all directions until the limits of production were found at the periphery of the productive area by dry holes. This gas play was never based on any solid geologic information because gas production was from stratigraphic traps with no surface manifestation whatsoever, thus the discovery of this field was totally accidental. Gas development grew and matured into the 1970s, when the basin suddenly developed new life with the discovery of the enormous gas resources hidden in the coal beds of the Fruitland Formation. It is ironic that thousands of wells had drilled through Fruitland coal beds before it was discovered that CBM could be liberated by pumping water from the coal beds. Fracking horizontal wells in the organic-rich marine shales in the basin may be ushering in a resurgence of O&G production in the San Juan Basin.

Stratigraphy of the Three Forks Formation and Implications for Exploration

Alyssa L. Franklin (Colorado School of Mines)

The Three Forks Formation is a tight oil reservoir sourced by the Bakken Shale in the Williston Basin. This study seeks to analyze depositional controls of reservoir facies distribution across the basin and apply that understanding to evaluate the potential of extending the Three Forks play from North Dakota into Montana. This study was conducted by describing 23 cores: 14 from Montana and 9 from North Dakota along with interpreting digital logs from across the U.S. portion of the basin. Lithofacies indicate deposition in a wind-driven wave-dominated, storm-influenced, micro-tidal epeiric shelf that was partially restricted due to movement along the Punnichy Arch - Swift Current Platform complex. Landward facies equivalents include coastal plain to evaporitic mudflat deposits. Facies are observed in laterally expansive, continuous belts across the basin, often bound by correlative surfaces. They are interpreted to have been deposited on a broad, shallow epeiric shelf with minimal accommodation. This depositional geometry in fact prohibits progradation and instead results in highly punctuated and aggrading deposits. Subtle changes in eustatic sealevel results in dramatic facies shifts across the broad basin with minimal slope. This depositional geometry also resulted in the tripartite energy zonation with lower energy zones separated by a shoreline detached high energy zone (see Irwin, 1964; Poppelreiter and Aigner, 2003). The dominant energy in this system varies between wind-driven waves and storms with microtidality. Reservoir quality, source maturity, pressures, and entrapment mechanisms have been considered to identify prospective areas for the Three Forks play in Montana.

Differentiation of Mississippian-age Shale Units of Central and Eastern Nevada Using Petrophysical, Mineralogical, and Geochemical Characteristics

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Organic-rich rocks of Mississippian age, commonly identified as the Chainman Shale, can be subdivided over a large area into upper and lower units based on characteristics of wireline logs, mineralogy, and organic-carbon content. The boundary between the units is sharp; the lower unit has high resistivity with greater variability compared to that of the upper unit. Gamma ray curves also have greater intensity and variability in the lower unit compared to the upper. Changes in the log curves coincide with systematic variation in the source-rock characteristics. The lower unit has about twice the total organic carbon content and 5 times the pyrolysis yield as the upper unit. X-ray diffraction of surface samples and well cuttings shows that the lower unit has substantially more quartz than clay compared to the upper unit.

Dolomite and calcite are commonly present in the lower unit and absent from the upper, whereas kaolinite is common in the upper and rare in the lower unit. These differences are manifested in outcrops. The upper unit is softer and weathers as an expansive soil that is difficult to sample. The lower unit is brittle and weathers as light gray to light tan chips. The data indicate the units are separated by an unconformity that can be associated with the early Chesterian C2 unconformity of Trexler and others (this volume). The unit below the C2 unconformity is the likely source rock for 95% of the oil produced in Nevada and is a target for unconventional-resource development.

Evaluating the Impact of Mineralogy on Reservoir Quality and Completion Quality of Organic Shale Plays

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Geochemical logs are fundamental to the evaluation of organic shale plays because they provide mineralogy among other measurements necessary for the petrophysical and geological evaluation of these complex reservoirs. Mineralogy impacts reservoir quality (RQ) and completion quality (CQ), which ultimately governs shale well performance. sCore is a ternary-based classification scheme for organic mudstones that will be used in this paper to define relationships between mineralogy, RQ and CQ within various U.S. shale plays. Ternary plots are useful for discriminating rock types based on normalized proportions of three main end members: i) clay; ii) carbonate; and iii) quartz, feldspar, and mica. When shale RQ parameters, such as effective porosity, total organic carbon (TOC) content, matrix permeability, hydrocarbon saturation, etc., or CQ parameters, such as minimum closure stress, Thomsen's gamma, Mineral Brittleness Index (MBI), etc. are plotted on an sCore ternary diagram, one can make observations as to how mineralogy is impacting RQ and CQ in a particular shale play. The identification of lithofacies having superior RQ and CQ is important information for identifying 'sweet spots' and targeting both vertical and horizontal well completions. A strong correlation exists between mineralogy and CQ in most U.S. shale plays. More specifically, minimum closure stress, Thomsen's gamma and MBI appear to be driven by the mineralogy of organic mudstones. The correlation between mineralogy and RQ is not as strong. Organic mudstones have complex mineralogy, consisting of a mixture of intrabasinal and extrabasinal sources of siliciclastic and/or carbonate debris, affected by diagenetic processes, resulting in highly heterogeneous rocks especially in the vertical direction. RQ in U.S. shale plays appears to be driven by both compositional and textural components of organic mudstones. RQ, as determined by other data types, can be compared to the sCore ternary to aid in interpretation of sediment source. For example, low correlation between effective porosity and silica content may imply dilution via terrigenous input, while a high correlation indicates minimal dilution and more desirable rock.

Exploration in Southwestern Idaho: Will Idaho Finally Produce?

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Recent exploration efforts in Idaho have been focused on the western Snake River Plain, an approximately 64 km wide, northwest-trending tectonic basin. This structure formed over a short time period (10-12 Ma) and is filled with up to 3,500 meters of sand, silt, clay, ash, diatomite, freshwater limestone, conglomerate, and intercalated basalt flows (Wood and Clemens, 2002). Deep seismic exploration profiles, gravity anomalies, and geophysical logs indicate large fault blocks and facies changes that could create traps (McLeod, 1993; Wood, 1994; Porter, 2009) and ubiquitous thick clay interbeds afford potential seals for porous sandy reservoir rocks. Natural gas shows are common in deeper parts of the basin. Since 1907, there have been 68 exploration wells drilled in southwest Idaho. Many of these wells are less than 800 m deep, with limited well log information, and have gas shows as shallow as 100 m but have no economic production to date. Recent exploration started in 2010 with 11 new wells drilled resulting in five gas wells and two gas condensate wells in the Hamilton and Willow fields, near New Plymouth, Idaho. Older geophysical data has been reprocessed and supplemented by new 2-D and 3-D seismic surveys in the area. If these wells go into production, they would be the first commercial gas wells in Idaho.

Assessment of Undiscovered Resources in the Bakken Formation of the U.S. Williston Basin, North Dakota and Montana

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The U.S. Geological Survey has completed a geology-based assessment of the undiscovered, technically recoverable petroleum resources in the Devonian-Mississippian Bakken Formation of the U.S. Williston Basin, including North Dakota and Montana. The Bakken Formation was last assessed in 2008 and estimated to have a mean of 3.65 billion barrels (BBO) of recoverable, undiscovered oil. The 2013 assessment incorporates new production data, thermal maturity data, and geologic information to define continuous and conventional assessment units (AUs) in the Bakken Formation. Five continuous AUs are refined as a result of the large amount of new horizontal drilling production, particularly in the areas of the central basin, northeast Montana, and northwest North Dakota. The Parshall and Sanish fields have also been substantially developed since 2008, providing longer production histories and more robust estimated ultimate recovery (EUR) data. The Bakken Total Petroleum System (TPS) encompasses strata from the Devonian Three Forks Formation, Devonian-Mississippian Bakken Formation, and lower part of the Mississippian Lodgepole Formation that may contain Bakken-sourced oil. The TPS is defined by the postulated maximum extent of petroleum fluids within the Bakken and Three Forks Formations. The geologic model for the assessment of the Bakken Formation is that oil generated in the upper and lower Bakken shale members migrated locally into low-permeability and variable-porosity reservoirs of the middle Bakken member, the Pronghorn Member of the Bakken Formation, and dolomitized units of the underlying Three Forks Formation. Locally, oil was also retained in the low-porosity matrix and fractures of the upper and lower Bakken shale members.

Paleocurrent Control of Facies Heterogeneity in Microbial Buildups and Stromatolites; Late Carboniferous (Moscovian) Hermosa Group, Southeastern Utah

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The facies and fabric heterogeneity within ancient microbial carbonates are an important control on reservoir-scale variations in permeability and porosity. Three sequences within the exquisitely exposed outcrops of Late Carboniferous (Moscovian) limestones in the Goosenecks of the San Juan River, Southeast Utah, demonstrate that predictable variation in facies and microbial fabrics are shaped by trade wind-driven marine currents, tides, and possibly storms. Within a fourth order sequence of the third order Akah sequence, 5-15 meter-thick thrombolitic mounds prograded shoreward to the modern west and northwest. We infer these were formed by currents and wave action from the southeast, producing clinoform partitioning within buildups. These grain-dominated boundstones may be analogous to grainstone aprons which prograde shoreward from the windward margin of modern metazoan reef systems. Lower in the Akah sequence, thinner beds of 2.5-3.5m high digitate stromatolites form isolated 0.5-1.5m wide clusters of club shaped stromatolites inclined to the southeast (186 of 309 samples). This is consistent with asymmetrical growth into the current as documented in the modern of the Bahamas (Dill, 1997), and the ancient (Hoffman, 1967). Thirdly, the intricately digitate stromatolites of the underlying Barker Creek Sequence are the source of reworked, cemented microbial clasts which fill in 0.1 to 0.25m troughs between stromatolitic heads. These reworked and in situ stromatolitic facies overlie a very fine quartz sand, peloidal grainstone with bi-directional current ripples. Although both the thrombolitic mounds and the club-shaped stromatolites were shaped by currents from the southeast, they responded differently. The thrombolitic mounds prograded downwind to the west, while the club-shaped stromatolites grew into the current towards the southeast. This current direction is most consistent with easterly trade wind-driven oceanic currents. Thinner beds of digitate stromatolites, in shallower settings with more exposure, experienced early cementation and were reworked by tides and/or storms.

The Origin of Lacustrine Carbonates and Microbialites in Lake Basins

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Accumulation and distribution of lacustrine carbonates and microbialites in tectonic basins must be assessed according to controls on input of calcium-rich waters within lake systems, including surface water, groundwater, and precipitation. Controls on input of calcium ions into a lake environment are dependent on volume of carbonate bedrock (surface and subsurface) in relation to the lake body along with hydrology (dependent on tectonics and climate) that determines the mode of water input. Water input controls the distribution of all carbonates within a lake system. Carbonate lakes can be classified as dominantly, partially, or sparsely carbonate-rich. Dominantly carbonate lakes have more than 60-70% carbonate source rocks in the drainage area so that a complete array of carbonate facies occurs from littoral to profundal environments. Examples include the Eocene Shulu Sag deposits (Hebei Province, China), the Eocene Green River Formation (Wyoming, USA), the Las Hoyas Lake in the Serrania de Cuenca basin in central Spain, and the Cretaceous Apache Canyon Formation (Bisbee Basin, USA). Lakes associated with catchment areas containing both siliciclastic and carbonate bedrock (perhaps 40-60% carbonate) contain carbonate facies limited to groundwater or surface input areas, such as the Shoofly oolitic delta of a Pliocene lake in Idaho (USA) or littoral lacustrine facies of the deep water phase of the Miocene Horse Camp Formation (Nevada, USA). If the carbonate provenance is limited relative to the volume of siliciclastic rocks in the drainage area, then carbonates accumulate in less significant quantities, as in fine carbonate laminae in profundal regions. Significant accumulation of bioherms in all these lake types is the result of large quantities of Ca-rich groundwater entering a lake environment, dependent upon subsurface carbonate aquifers.

Co-Produced Geothermal Power

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Advances in binary energy conversion technology, i.e., small organic Rankine cycle engines, have generated interest in the potential for electric power generation from low-to-intermediate temperature fluids in deep sedimentary basins. Estimates of the power that could be produced have been based on calculations of the energy stored in permeable formations, formation properties relevant to reservoir productivity and on total fluid production data from oil and gas databases. These general estimates indicate that large quantities of power could be extracted from many intracratonic basins using co-produced fluids and fluids pumped from hot permeable formations. Estimates of the resource potential for the Williston basin are on the order of 1020 Joules which implies a resource potential of several GW of electrical power. However, the water-to-oil production ratio (WOR) for the Williston basin is low, 1.22:1 based on 8,013 working wells in 2013. Other than the Bakken, the Madison (Mississippian) and the Red River (Ordovician) formations produce the greatest fluid volumes from the basin. Power production for the top ten producing wells in the Madison and Red River formations based on an exit temperature of 160 °F (71.1 °C) and an ambient air temperature of 60 °F (15.6 °C) for an ORC with 6 percent efficiency are approximately 671 kW and 814 kW respectively. Repeating the calculations for the unitized Madison and Red River fields yields co-production potentials of 3 MW for the Madison and 4 MW for the Red River. Thus, actual power production from co-produced fluids in the Williston Basin may be several orders of magnitude less than was predicted in earlier estimates.

Distinguishing Between Salt-Related and Algal Structures: A 3D seismic Example from the Northwest Denver Basin

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Paleozoic deposits in the Denver Basin include evaporites as well as shallow-shelf carbonate and algal sediments, which form in restricted marine settings. Anomalous domal features observed in 3D seismic may represent (a) Permo-Pennsylvanian carbonate mound buildups, (b) evaporate dissolution/flowage, or (c) tectonic structures generated by differential movement along basement faults. Deep-seated domal algal mounds have been an exploration target in many US basins and are difficult to differentiate from salt-related features or basement structures in a seismic section, especially without well control. Some of the alleged 'algal' structures drilled in the northwest Denver Basin were later identified as salt. This paper is a practical exercise in experimentally selecting the best distinguishing parameters to reduce reservoir risk in carbonate exploration. For example, differential movement on basement faults may result in convergent/divergent strata which mimic mound 'growth'. Similarly, reflection coefficient alone is not a reliable parameter to evaluate a domal feature of unknown internal composition. Low density salt structures generate a seismic trough at the top in normal polarity data. However, porous carbonate mounds may also exhibit the same signature. These uncertainties are addressed using tactical analysis methods. We analyzed stratigraphic data, such as the nature and direction of onlapping sediments around the structure, and the internal and external architecture of the 'mound feature'. Geophysical attribute analyses aided us in reconstructing the stratigraphic evolution of the feature. Co-rendering attributes allowed us to map internal horizons and compare related parameters. A velocity model assisted in eliminating the possibility of salt-generated velocity anomalies at the level of subsalt reflectors. This approach is designed to reduce uncertainty in predicting reservoir facies and develop a potential exploration play type in Rocky Mountain basins.

3D Seismic Interpretation and Evaluation of Mechanism(s) that Cause Along-Strike Change in Vergence of Thrust Faults in the Green River Basin of Southwestern Wyoming, Birch Creek Seismic Survey

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The Birch Creek 3D seismic survey is located in southwestern Wyoming and lies just east of the western Cordilleran overthrust belt. This data set will provide insight to the interaction between Sevier and Laramide style deformation. The study area is part of what is known as the Idaho-Wyoming-Utah Salient, which has been studied extensively for the timing of thrust events. The Birch Creek survey shows multiple thrust events that appear to switch in their direction of vergence along strike. This abrupt change in vergence has not been well documented and the cause is not fully understood. Our study focuses on the mechanism(s) involved in the changing direction of vergence of thrust faulting. The objective is to accurately interpret thrust faults and evaluate the faulting mechanism(s) within the study area. As seen in the seismic data, these faults appear to be blind. Field work will be conducted to verify whether these faults project to the surface or not. Landmark Software and Services has provided state-of-the-art interpretation programs that we will use to visualize and evaluate these thrust events. This software will provide an elegant approach as we pursue and test various hypotheses.

Recognition of the Stratigraphic Heterogeneity of Late Paleozoic Eolian Erg Margin Deposits for Improved Oil Recovery: Weber Sandstone, Rangely Field, Colorado

Ryan P. Grimm (Chevron Energy Technology Company)

Complex interstratification of Late Paleozoic eolian dune sandstone reservoirs with associated non-reservoir interdune and alluvial deposits has created significant hurdles to enhanced recovery and production within the Weber Sandstone at Rangely Field, Rio Blanco County, Colorado. Relatively minor facies variations introduce important heterogeneities, influencing fluid-flow and production. Application of modern techniques of dryland process sedimentology and continental stratigraphy allows for depositional environment interpretation of archived cores and a new appraisal of reservoir architecture from core-calibrated wireline logs and available seismic data. Results from the description, analysis, and interpretation of 15,000 feet of core as well as new borehole image data define the recognition criteria for ten end-member depositional facies evident from vertical sequences. Reservoir facies are predominantly associated with four distinct eolian dune facies – Sandsheet, Dune Slipface, Slumped Dune, and Bioturbated Dune. Non-reservoir facies include four interdune facies - Paleosols, Dry, Wet and Massive interdune and two alluvial facies - Ephemeral channel and Overbank splay - are vertically and laterally interstratified with eolian facies. Comparison of facies with plug petrophysical data suggests strong poro-perm relationships with depositional facies. Vertical associations of facies can be qualitatively subdivided into greater than 25 chronostratigraphic sequences, ascribed to repetitive arid-pluvial shifts in regional paleoclimate and sediment availability. Although individual sequences are typically thin and subseismic, multiple sequences can be grouped into seismically perceptible packages, mappable on both seismic and vintage wireline log data across the study area. The updated stratigraphic architecture of the Weber Sandstone provides an initial facies distribution model for inter-well reservoir and flow barrier prediction, highlighting new opportunities from vintage log suites and a pilot seismic survey.

Discovery of the Weber Sandstone and Development of the Raven Creek Anticline at Rangely Field, Colorado

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Since the initial observations of C.A. White in 1875, the Raven Creek anticline has attracted prospectors to Rangely, Colorado. Early explorers generated numerous prospects along active oil seeps in the Mancos Formation at Rangely, leading to financial backing and discovery drilling into the shallow (400-700 ft) Cretaceous shales near the crest of the structure in 1901. Continued cable-tool drilling of the Mancos targeted oil-bearing fractures, expressed at the surface as calcite-filled veins. Cumulative Mancos production exceeded 4.7 MMbbl by 1954. Exploration wells targeting the Dakota Sandstone in the 1920's proved to be non-commercial, encountering high initial gas flows that quickly watered out, and common, sometimes spectacular, blowouts during drilling. The Weber Sandstone discovery well, the Raven A-1, was spudded in 1931 by the California Company. The discovered giant oil accumulation of 1.8 Billion STB remained trapped within Pennsylvanian-Permian eolian & dryland-fluvial sandstones, as field development was postponed until WWII demand created a drilling boom in Rocky Mountain production. Between 1944 and 1949, 473 wells were drilled on 40 acre spacing, with as many as 63 active rigs working year-round. Part of the success at Rangely was the application of diamond core bit technology, leading to faster penetration and longer bit life in the abrasive and well-lithified Weber sandstone. This drilling method also recovered over 109,000 ft of core from over 330 wells, providing a valuable archive for continued reservoir management. Production increased with pipeline capacity, to a maximum production rate of 82,000 BOPD in 1956. Following unitization in 1957, a variety of waterflood projects were implemented and expanded with 20 acre infill drilling in 1963. The additional wells and five-spot injection patterns successfully increased production by 14,000 BOPD in 1969. Tertiary recovery via CO2-WAG flooding began in 1986 and has significantly extended incremental production rates into the 21st century. The Weber Sandstone has produced over 840 MMbbl and continues to provide commercial production. The acquisition of 3D seismic in the field combined with modern logging and completion technologies offers multiple viable opportunities for future development.

Geothermal Discovery in the Black Rock Desert of Western Utah

Mark Gwynn (Utah Geological Survey), Rick Allis (Utah Geological Survey), Robert Blackett (Utah Geological Survey), Christian Hardwick (Utah Geological Survey)*

The Utah Geological Survey drilled 10 temperature-gradient boreholes in the Black Rock Desert of western Utah in 2011-2012. Seven of these wells and three others drilled in the 1970s show that the background heatflow in the Black Rock Desert is about 80-85 mW/m^2 and delineate a geothermal resource where temperatures greater than 150°C cover an area of about 350 km^2 at a depth of 3 km. The resource coincides with the axis of an actively extending basin containing late Tertiary-Quaternary sediments up to 3 km thick overlying Mid-Late Cambrian carbonate bedrock. An area of approximately 60 km^2 reveals temperatures above 200°C at 3 km depth. An abandoned oil exploration well confirms temperatures of 230°C at 3.3 km depth in the center of the thermal anomaly. The near-surface temperature gradient in the vicinity of this well is 105°C/km and the heat flow is 125 mW/m^2. The thermal anomaly may be associated with a cooling intrusion in the upper crust beneath Pavant Butte volcano, which last erupted about 15,000 years ago. Potential geothermal reservoirs likely exist in the near-horizontal carbonate strata between 3 and 4 km deep in the Black Rock Desert. These units are exposed in the adjacent Cricket Mountains west of the Black Rock Desert. If these carbonate bedrock formations are sufficiently permeable, a substantial deep geothermal resource may exist in the Black Rock Desert.

Facies and Diagenesis of the Park City Formation, Wind River Basin, Sheep Mountain Anticline, Fremont County, WY

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This study examines the Permian carbonates on Sheep Mountain Anticline in Fremont County, Wyoming, which sits on the southern margin of the Wind River basin. From a hydrocarbon exploration perspective, the Park City Fm. on Sheep Mountain represents a critical position between the landward Goose Egg shales and the basinward cherts and organic mudrocks. Most Park City Fm. hydrocarbon production to date is from anticlinal structures and is almost exclusively associated with Tensleep (Pennsylvanian) production. There is a possibility that the basin is largely underexplored with respect to Permian stratigraphic traps. While the world-class phosphate deposits of the Phosphoria Fm. have been extensively studied, an examination of less phosphate-rich facies helps elucidate the conditions under which this enormous phosphate resource was deposited. Four measured sections, petrographic analysis of ~60 thin sections, descriptions of over 200 hand samples, well log analysis of 10 nearby well logs, and handheld x-ray fluorescence have been used to interpret the depositional and diagenetic history of these rocks. Three 3rd order cycles of the Park City Fm. outcrop on Sheep Mountain, each of which represents a very different position on the homoclinal carbonate ramp. From youngest to oldest, the Ervay cycle is dominated by peloidal pack- & grainstones, the Franson cycle by echinoderm bryozoan brachiopod wacke- & packstones, and the Grandeur cycle by sandy and silty mud- to packstones. Silicification of bioclasts and bioturbation traces is common, and at least two silicification events are recorded. Phosphate precipitation appears to have been an early diagenetic event, and apparently occurs throughout the sea level cycle, notable during transgression and throughout the highstand. The preferential phosphate replacement of echinoderm fragments instead of bryozoans and brachiopods suggests a relationship between the Mg-content of calcite and phosphatization.

Geology of Eagle Springs Oil Field, Railroad Valley, Nevada

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In 1954, Shell drilled a seismically-defined four-way closure and discovered Nevada's first oil field, Eagle Springs. The well spud in Quaternary-Miocene valley fill sediments, and at 3355' (1023 m), a 95' (29 m) thick mass of brecciated Paleozoic carbonate was encountered which was determined to be a landslide deposit. Drilling continued through the valley fill until 6450' (1966 m), when oil was tested from porous, fractured Oligocene welded tuff below Unconformity A. Subsequent drilling established oil production from the lacustrine carbonates of the Eocene Sheep Pass Formation. During the 1960's, Texota drilled infill wells and Pennington extended the field to the east on a higher fault block. In the 1990's, Foreland drilled additional development wells, and discovered a new reservoir in brecciated limestone of the Permian Riepe Spring formation 0.5 miles (0.8 km) south of the main field. The oil is a black, 26-29° API gravity crude, pour point of 65-85°F (18-29°C), sourced from Mississippian Chainman and Tertiary Sheep Pass shales. Oil is trapped where the volcanic and carbonate reservoirs have been truncated by Unconformity A and sealed by clay-rich valley fill on a north-plunging nose. A 3D seismic survey was run over the field in 1993. Interpretation of the seismic is difficult, particularly in the eastern part of the field, due to the lack of sonic logs and the large lateral velocity change in the valley fill from slower velocity lake beds in the west to high-velocity fanglomerate adjacent to the range-bounding fault on the east. The 3D seismic was instrumental in the discovery of Ghost Ranch field, a landslide deposit in the valley fill in 1998. Eagle Springs has produced 5.5 MMBO, while Ghost Ranch has produced 616 MBO.

Investigating Geothermal Resources in the Black Rock Desert, Utah, using MT and Gravity

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Magnetotellurics (MT) and gravity, complemented by regional borehole information are the basis for assessing three geothermal areas: Crater Bench, Pavant Butte and, Thermo, located in the Sevier Thermal Anomaly within the Basin and Range Province of western North America. Recent geothermal studies on sedimentary basins in western Utah suggest the possibility of significant geothermal reservoirs at depths of 3 to 5 km. Our study areas are centered in or near such basins. Since 2010, we have added 263 MT stations and 371 gravity stations to the existing data coverage. Gravity anomalies and electrical resistivities provide estimates of depth to basement and buried structure geometry that may control upwelling of geothermal fluids. Resistivity models also help assess thermal characteristics in regards to the presence of hot fluids and/or clay-rich sediments within the basins. Depth-to-basement values vary from 1.5 to 3.4 km for the Crater Bench are and have a maximum basin depth of 3 km for the Pavant Butte area, including a region over 15 km wide with more than 2 km of sediments overlying basement rock. Independent 2D modeling of MT data are consistent with gravity anomaly models and structural interpretations. The Pavant Butte area displays resistivity values of less than 10 Ohm?m in regions within 1 km of the surface and extending to known basement depths. We attribute the large, hot-spring system (89°C) adjacent to Crater Bench to the upwelling of deep hydrothermal fluids along the margin of a buried horst block. Corrected temperatures encountered at the bottom of an oil and gas well near Pavant Butte were in excess of 220°C, whereas other wells in the area were significantly cooler (~100°C) at similar depths. Preliminary findings from a 2012 drilling program and geophysical surveys at Pavant Butte make for an attractive geothermal target, and resource potential appears to be significant.

Facies and Reservoir Characterization of the Permian White Rim Sandstone, Black Box Dolomite, and Black Dragon Member of the Triassic Moenkopi Formation for CO2 Sequestration at Woodside Field, East-central Utah

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Geologic sequestration of anthropogenic CO2 gasses is an engineering solution that potentially reduces CO2 emissions released into the atmosphere limiting their effect on climate change. This study focuses on Woodside Field as a potential storage site for captured CO2. The Woodside Anticline is a doubly-plunging anticline on the northeast flank of the San Rafael Swell. Particular focus will be on the Permian White Rim Sandstone, Black Box Dolomite and Black Dragon Member of the Triassic Moenkopi Formation as the reservoir-seal system for CO2 storage and sequestration at Woodside Field. The White Rim Sandstone, the primary storage target, is divided into three broad facies: a lower sand sheet facies, a middle eolian sandstone facies, and an upper reworked facies. Porosity in the White Rim Sandstone can be as high as 23% and permeability can reach 2.1 D. The White Rim Sandstone is up to 525 ft (160.0 m) thick at Woodside Field providing a significant volume of porous and permeable rock in which to store CO2. The Black Box Dolomite is the secondary potential reservoir for CO2 storage at Woodside Field. The Black Box Dolomite may be divided into four lithofacies: a caliche, a dolowackestone, a dolomitic sandstone, and a sandy dolowackestone. The combined thickness of these facies is up to 75 ft (22.9 m) at Woodside Field. Porosity can be as high as 29.2% and permeability up to 358 mD. The Black Dragon Member of the Triassic Moenkopi Formation will serve as the seal rock for the relatively buoyant CO2 stored in the underlying formations. Silty mudstones comprise 75% of this member at Black Dragon Canyon.

Mudstone beds have from 0.16 to 0.47% porosity. Minerals within these beds that may react with a CO2-rich brine include calcite, dolomite, alkali feldspar, glauconite, and plagioclase. The Black Dragon Member is up to 280 ft (85.3 m) thick at Woodside Field. Volumetric estimates for Woodside Field were calculated based on the 10th, 50th, and 90th percent probabilities (P10, P50, and P90). The White Rim Sandstone is the primary target reservoir and has capacity to store 2.2, 8.8, or 23.7 million metric tonnes (P10, P50, and P90, respectively) of CO2 within the structural closure of Woodside Field. The Black Box Dolomite may additionally store 0.5, 1.8, or 4.5 million metric tonnes, respectively. Combined they have the capacity to capture up to 28.3 million metric tonnes (P90) of CO2.

Estimating Total Organic Carbon Content in the Cretaceous Mancos Shale

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The Late Cretaceous Mancos Shale is a prospective shale-gas reservoir located in the Uinta Basin in eastern Utah. To assess the hydrocarbon potential of the Mancos, the quantity of organic matter, measured by percent of total organic carbon (%TOC) within the shale matrix and pore space, must be determined. The %TOC can be estimated through a petrophysical approach called the ?logR method. The ?logR method uses wireline logs, geochemical data, and thermal-maturity information to calculate an in-situ %TOC. Using the ?logR method, calculated %TOC values are often underpredicted in shale-gas systems that have reached thermal maturation values within the dry-gas window. However, the exact degree of thermal maturity is often uncertain due to subjective visual characterization in vitrinite reflectance analysis. To compensate for the uncertainty associated with thermal maturity, petrophysicists have incorporated adjustment parameters into the ?logR equations to achieve an optimal match between observed and calculated %TOC values. These parameters create an improved match between calculated and observed %TOC values, but they do not address the underlying geologic relationship between thermal maturity and %TOC. Vitrinite reflectance values in the Uinta Basin indicate portions of the Mancos Shale are within the dry-gas window. We present an improved ?logR workflow that incorporates results from one-dimensional burial history modeling in order to more accurately characterize thermal maturity. This method optimizes input parameters, including the aforementioned adjustment parameters and thermal maturity model results, to obtain an improved fit between calculated and measured %TOC values. This optimization indicates that of all of the parameters, thermal maturity is the most dominant in accurately predicting %TOC. Adding thermal-maturity models into a modified ?logR workflow can achieve a more robust method for calculating %TOC in shale-gas systems that are within the dry-gas maturation window.

Field Observations And Stable Isotopic Analysis Of Laterally Continuous Calcite Veins Associated With Fault Zones: Insight into Ancient Fluid Travel

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The capability to store CO2 in subsurface geologic reservoirs is a proposed technique that will reduce the amount of human-generated CO2, a greenhouse gas, from accumulating in the atmosphere. By examining bedrock sites where evidence for ancient carbonate deposition, and where we see natural CO2 leaks, we can understand how fluid flow in the subsurface behaves in relation to faults and fractures. Understanding fluid flow in a natural system improves our understanding of risks involved in the storage of CO2 in subsurface reservoirs. We focus on two different outcrops of Mesozoic rocks associated with active CO2 leaks. The field locality for this work is in the Salt Wash Graben SE Utah, adjacent to the Ten-Mile fault, a normal fault with hundreds of meters of offset. Field observations at this location allow an understanding of crosscutting relationships of laterally extensive carbonate veins and travertine deposits associated with the Salt Wash fault zone. Maps of cross-cutting relationships in outcrop are used to understand timing of mineralization along with petrographic analysis of host rock and vein mineralization of calcite veins to understand relationships between host rock and mineralization. Both stable carbon and oxygen isotope analysis are used to understand changes in the fluid reservoir composition. Preliminary stable carbon isotope analyses give 13C values between 3.9-6.0 per mil; variations may indicate change in fluid source, relative timing of mineralization, and depth of mineralization. Stable carbon isotope analysis is important because they serve as geochemical markers related to source fluids.

Discharge Controls on River Sinuosity: Analysis of a Small Modern Stream

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Normal river patterns suggest that slope gradient produces braided river channels upstream of a meandering river channel. A study of a small modern river system in the Uinta basin of Utah shows that discharge can influence channel sinuosity and morphology to produce initial meandering patterns that change later to braided patterns in the downflow direction. On a relatively flat (about 1-2°), modern, sandy pediment surface with scattered boulders, the small stream is informally divided into 3 portions: upstream, midstream, and downstream. The upstream segment is a high sinuous geometry dominated by both erosion (cutbanks) and deposition (point bars). The midstream is dominated by deposition (more small bars). The downstream section shows multistage erosional terraces, in the relatively straight channel system. Since the slopes of all three segments are consistently low, the key controlling factor of the channel patterns is the discharge. In the upstream, flood discharge occurs with large amplitude variation, and strong power that erodes the cutbank to produce sinuosity. Here, sand laterally accretes to form point bars. In the midstream segment, the current power decreases to form the braided river. A strong flood can cut off the point bar completely, which causes the channel to widen with a quickly corresponding current power decrease. Then, sediment from the upstream portion is unloaded in the midstream segment. Unloaded clastics can protect the bank in the midstream, and the current with low power reduces the erosion to the bank, which keeps the channel to a low sinuous geometry in the midstream. After the water drops its load, becomes 'clear' and reaches downstream, the lower current power is helpless to reform the river geometry. Thus, the downstream channel segment keeps a lower sinuous geometry, even straight partially. Simultaneously, little fine clastics (e.g. mud, silt) are deposited and multistage erosional terraces are formed during the flood regression. This stream example demonstrates the subtleties of stream flow and the importance of discharge. Similar effects are modeled in some experimental stream tables. Although it is difficult to scale this example up to large river systems that carve the geomorphic landscape, this shows how river geometries can vary from the traditional patterns attributed to gradient.

Uncertainty Quantification of Sequestrated CO2 in CCUS project

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CO2 sequestration can be achieved in the Enhanced Oil Recovery (EOR) process by many trapping mechanisms, including hydrodynamic trapping, residual trapping, and solution trapping. We evaluated the total amount of sequestrated CO2 and the role/importance of each trapping mechanism for a CCUS site. However, given the uncertainty of subsurface properties, such as permeability and porosity, uncertainty quantification (UQ) is necessary for estimating the amount of trapped CO2. As it is computationally expensive to follow the approach of Monte Carlo simulation and conventional geocellular simulation, we applied the Polynomial Chaos Expansion (PCE) methodology to reduce computation cost while still maintain accuracy. Geostatistics techniques were applied to generate stochastic realizations based on well logs and seismic survey. While small amount of realizations were simulated with conventional geocellular simulator to develop reduced order models (ROMs) by applying PCE methodology, rest realizations were simulated through the established ROMs to generate probability distribution function (PDF) of the amount of sequestrated CO2. Our results suggest that while the role of each trapping mechanism is not affected by parameter uncertainty, the uncertainty of the amount of trapped CO2 cannot be neglected and must be taken into consideration.

Structural Controls on the Development of Eocene Lake Gosiute and Lake Uinta, Southwest Wyoming, Northwest Colorado, and Eastern Utah

Ronald C. Johnson (U.S. Geological Survey)

This study examines the relations between tectonism and the development of Eocene Lake Gosiute, which occupied the Greater Green River Basin in southwest Wyoming and northwest Colorado, and Eocene Lake Uinta, which occupied both the Uinta Basin of northeast Utah and the Piceance Basin of western Colorado. About 52-53 Ma, both lakes began to form as relatively small, externally drained, fresh-water lakes, then evolved into much larger internally drained saline lakes. This unusual evolution could have been the result of: 1) movement on surrounding uplifts that elevated spill points until external drainage was lost, or 2) regional sagging that led to drainage reversals and ultimate loss of external drainage. The first implies that lake elevations were above sea level, whereas the latter implies lake elevations below sea level. Evolution of brines in the lakes, however, appears to be inconsistent with invasion of sea water. Interestingly, as Lakes Uinta and Gosiute formed they transgressed across comparatively minor structural arches that, based on isopach maps, had been active prior to transgression but became largely inactive during saline lake deposition. Uplift on these arches resumed sometime after the lakes were filled in. The progressive infilling of the lakes by volcaniclastic debris from the Absaroka volcanic field also may have been partially controlled by structural activity. Infilling began about 49-50 Ma in the northern Green River Basin and progressed southward, filling in Lake Gosiute and then the Piceance Basin part of Lake Uinta. Lake Uinta persisted in the Uinta Basin until about 43-44 Ma. Subsidence patterns largely mimic this infilling pattern, with subsidence diminishing first in the northern Green River Basin and last in the Uinta Basin.

Development of a New Geology Field Book for Utah

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We are assisting in the development of a guidebook for the Geology 210 Field Studies class at Brigham Young University. Our focus is on creating a visually impactful reference book that will help students comprehend the dynamic geologic history of Utah. The majority of our time and research have been directed towards the creation of paleogeographic reconstructions of eight different phases in Utah's geologic past. The first phase covers the Paleozoic Era and the paleogeographic map depicts the offshore deposits characteristic of that era. The second phase is comprised of Triassic period, and the map shows the depositional environment of the Moenkopi. The third period covers Jurassic period. We created two maps for phase three: the first represents the depositional environment of the Navajo Formation and the second shows the depositional environment of the Entrada Formation. The forth phase focuses on the Cretaceous. The map shows the Cretaceous Interior Seaway and the multiple deltas of the Ferron Sandstone. The fifth phase is dedicated to the Laramide Orogeny and Eocene lakes, with the map showing Lake Flagstaff and the Laramide uplifts. Phase six covers slab rollback and related volcanism during the Miocene, as illustrated by the map. The sixth phase comprises the initiation of extension and the advent of the basin and range. For this phase, we modified an existing geologic map to highlight basin fill associated with extension. Finally, the seventh phase covers the Pleistocene and Lake Bonneville. Since it is impossible to illustrate all aspects of Utah's geologic history in a short book, we have selected eight significant geologic events that are well represented in the National Parks visited by the class. We will outline the project's progress, highlighting our maps and figures, research, creative techniques, and collaboration with faculty.

The Response of Fluvial Systems in the Uinta Basin, Utah to Extreme Global Warming Events During the Early Eocene Climatic Optimum

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The Wasatch and Green River Formations in the Uinta Basin contain fluvial sandstones that record terrestrial sedimentation coincident with Paleocene-Eocene Thermal Maximum (PETM) and six post-PETM hyperthermal climate change events. The Uinta Basin was one of a series of lacustrine basins isolated by Laramide uplifts in the Rocky Mountain region during the Early Eocene, and this project will better constrain the relative influence of both tectonic and climatic forcing on fluvial systems that fed sediment and water to these endorheic basins. This dataset combines quantitative petrographic analysis with carbon isotope analysis taken along measured stratigraphic sections in the southern margin of the Uinta Basin. This work shows that peak negative isotope excursions, related to pulses of greenhouse climate, correlate to regional flushing of sediment from catchment areas and progradation of fluvial systems into the lacustrine basin. This correlates to deeper channel incision, lateral and vertical amalgamation of channels, and delivery of relatively compositionally and texturally immature sediment to the basin. Understanding the compositional and textural maturity of these fluvial sandstones will provide insights into the response of chemical weathering rates, physical erosion rates, and the seasonality of sediment and water discharge to a series of global warming events. Climate change during the PETM was initiated by a release of over 2,000 gigatonnes of CO2 into the atmosphere, comparable in magnitude to that which could occur in the coming centuries from anthropogenic sources, and understanding the terrestrial response to extreme climatic forcing is important for predictive climate change modeling. Further, if terrestrial records of chemical weathering rates differ substantially from proxies developed from marine sediments, carbon-cycle dynamics during the Early Eocene Climatic Optimum must be reconsidered.

Facies Re-Interpretations of Sunnyside Delta Sandstone in Nine Mile Canyon, Uinta Basin, Utah: The Perils of Model-Driven Geology

David Keighley (University of New Brunswick), Stephen Flint (University of Manchester)*

Numerous workers over the years have studied the interbedded carbonate, shale, and sandstone interval that forms part of the middle Green River Formation in Nine Mile Canyon of the Uinta Basin, Utah. The fine-grained, generally low-calcareous sandstones in question contain internal bounding surfaces that have variable dip angle and direction together with abundant asymmetric and less common symmetric cross lamination. They interbed on a 10 to 20 m scale with coarsening upward carbonate beds (oolitic, oncolitic and fossiliferous grainstone, algal mats, micrite) and an oil shale, and truncate calcareous grey shale and red-maroon paleosols. Most workers have interpreted the sandstone to be mostly fluvio-deltaic (at various or unspecified positions on the lacustrine delta top), and to include in-channel bars. Recently, detailed study of two such sandstones along one, ~1.5km-long, canyon wall has resulted in their re-interpretation as a terminal mouth bar deposit lakeward of a river-dominated delta. This latter suggestion is rejected based on numerous pieces of evidence. The lower sandbody is exposed on more than one canyon wall and so can be confidently mapped over 2.5 km of outcrop as a low sinuosity NW flowing channel sandstone with down-stream accreting bars and side bars adjacent to ~5 m deep channel margins. The upper sandbody is more sheetlike but across 9 km of canyon walls locally downcuts through mature red paleosols. Neither observation is consistent with a terminal bar lakeward of a river-dominated delta. Also, the carbonate interbeds are indicative of a high energy shoreface which equates with models showing the E Uinta basin to be in an exposed down-fetch position. Any rivers emptying into a lake at such an exposed location would have mouth bars extensively reworked. As such, if mouth bars were to be present, those associated with a wave-dominated, not river-dominated, delta would be more appropriate and consistent with Walther's Law.

Microbial Fossils, Phosphatization, Heavy Rare Earth Element and Uranium Enrichment: Early Diagenesis of an Upper Green River Formation Oil Shale, Uinta Basin, Utah

David Keighley (University of New Brunswick), Chris McFarlane (University of New Brunswick), Tim E. Ruble (Weatherford Laboratories)*

Nearly 300 samples of shale and oil shale from outcrop and core of the Parachute Creek Member, Green River Formation (GRF), in the Uinta Basin have been analyzed using inductively-coupled-plasma mass spectrometry (ICP-MS). Some beds of oil shale are found to be relatively enriched in phosphorus, uranium, and rare-earth elements (REE). Spider plots of REE abundance have allowed for a tentative inorganic geochemical correlation of particular oil shale beds between outcrops spaced 80 km apart. One such phosphatic oil shale, from outcrop 128 m above the base of the Mahogany Oil Shale Zone (MOSZ) at Buck Canyon in the SE of the basin, also contains micro-slump-like structures. This shale has been analyzed by bitumen extract gas chromatography (GC), gas-chromatography mass-spectrometry (GC-MS), scanning electron microscopy (SEM), x-ray diffraction (XRD), and laser ablation (LA) ICP-MS. GC and GC-MS indicate both algal and bacterial derived biomarkers are typical of other GRF oil shale formed in an offshore stratified closed lake, suggesting that elemental enrichments are not mediated by an unusual biocommunity. XRD has identified abundant calcium fluorapatite (CFA) and carbonate, minimal silicate and zeolite. Microcrystalline CFA phases are imaged in SEM as filling pores, replacing grains, and fossilizing aggregates of well-preserved globular microbes. Most other organic matter is imaged as amorphous stringers, implying that, comparatively, the fossilized microbes had not degraded and possibly were alive until the phosphatization event. LA-ICP-MS indicates a persistent negative Eu anomaly suggesting an anoxic hypolimnion and substrate conditions. The working hypothesis is that phosphate-storing chemotrophic coccoid bacteria preferentially adsorbed heavy REE on their cell walls in a very shallow anoxic substrate. Slumping caused changes in pore-water conditions that killed the microbes. Phosphorus released into porewaters reached saturation, quickly precipitating (precursor) CFA that incorporated U and REE into its lattice.

Where Have the Mahogany Oil-Shale Beds Gone? Possible Evidence of Large-Scale Slumping at Sand Wash, Uinta Basin, Utah

David Keighley (University of New Brunswick), Michael Vanden Berg (Utah Geological Survey)*

The Mahogany Oil Shale Zone (MOSZ) of the Green River Formation (GRF) contains numerous beds of high-oil-yield shale that form part of the largest such resource in the world. The zone can be correlated across the Uinta Basin and adjacent Piceance Creek Basin, forming one of the most reliable marker beds in the GRF. Several previous authors have noted that some of the oil shale beds contain small-scale recumbent folds or convolute bedding, indicating instability in the pre-lithified organic layers. Preliminary work in the Sand Wash area of the Uinta Basin indicates much larger scale instability, with the MOSZ being folded, brecciated, or completely absent from the succession. Underlying argillaceous beds of up to 15 m thickness contain recumbent folds, brecciation, dewatering structures and structureless beds. Seismicity may be invoked as the trigger for the liquefaction or fluidization of poorly lithified sub-MOSZ beds, which resulted in the foundering and slumping of the overlying, more competent bed that was the precursor of the oil-shale. Alternatively, further west, interbedding of shoreface sandstone within the MOSZ simply may point to an interpretation of overloading by these sands on underlying unstable beds.

The Polygonal Fault System of the Niobrara Formation

Nicholas D. Kernan (Colorado School of Mines)

For close to one hundred years geologists have known about randomly oriented normal faults in the outcrops of Niobrara Formation in Western Kansas. These faults have dips close to forty-five degrees or less and a few hundred feet of displacement. They have been interpreted as being slump features due to salt dissolution within underlying Permian strata. Recently, 3D seismic data in the Denver Basin has helped identify a polygonal fault system within the Niobrara. Polygonal faults are layer bound extensional features that develop in fine grained deep water sequences. Faults mapped in outcrop were related to faults interpreted on seismic over the Wattenberg and Silo fields of Colorado. We interpret the faults in Kansas outcrops to be an extension of the polygonal fault system identified in the subsurface Niobrara and not related to salt dissolution. This would be the first outcrop of a polygonal fault system documented in North America. Theories behind polygonal faulting are still debated, as such, this research aims to further the overall understanding of how these fault systems initiate and develop. The paragenesis and fracture history of the Niobrara formation was investigated using petrographic and seismic interpretation, together with field and core descriptions. A primary focus was put to understanding potential causes for the nucleation and development of the polygonal fault system. Observations suggest that volumetric contraction, due to early burial dissolution, could have made the Niobrara formation susceptible to polygonal fault nucleation. Subsequent burial, compaction, and water expulsion would have then caused these faults to develop. The role of bioturbation in polygonal fault development is also considered.

Hydraulic Fracturing - Using Geology & Planning To Avoid Environmental Impacts

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The collection of accurate geologic, geochemical, and hydrogeologic data and the proper planning of the drilling program through completion and production can help identify background conditions and avoid environmental impacts commonly associated with hydraulic fracturing. Once a prospect is identified, it is important to understand the geology above the target zone and any connection to current or future groundwater resources; collectively known as well pad risk evaluation or analysis. The drilling program, including casing setting depths, should be planned to take into account potable water bearing zones, identification of saline zones and shallow gas zones that maybe encountered during drilling. Additional considerations such as the collection of geochemical groundwater parameters and/or depth discrete gas samples during drilling may be warranted depending upon the location of the well pad. Cement bond logs and pressure tests should be run to verify proper casing installation and integrity. Pre-drill and post-drill monitoring and sampling programs should be developed to determine baseline conditions and protect against future liability. Personnel should be available to respond to public inquiries of water quality concerns if there is a perception of impacts related to drilling activities. Well head testing, SPCC Plans, Facility Response Plans (if required), and Spill Response Planning and Drills should conducted to avoid and/or minimize environmental impacts. Finally, a team with the proper Incident Command System (ICS) training and experience should be identified that can immediately respond in the event that a release related to drilling, hydraulic fracturing or production activities occurs.

Characterization of Brittle Structures in Basalts of the Western Snake River Plain, Idaho: Implications for Fracture Connectivity in a Potential Geothermal Reservoir

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The western Snake River Plain is a region of high crustal heat flow and has the potential for commercial geothermal energy development. High-temperature crystalline reservoirs commonly have connected fracture networks and other discontinuities that provide the primary fluid storage and permeability (Type I fractures). The DOE/ICDP Snake River Scientific Drilling Program drilled a borehole near Mountain Home, Idaho to a depth of ~1,800 m (6,000 ft) with 85 - 90% slimhole core recovery to assess the potential for geothermal energy development. An artesian flow zone was encountered in basalt at a depth of 1,608 m (5,276 ft) in the MH-2 borehole with fluid temperatures above 140°C. Analysis of geomechanical behavior of rocks requires an understanding of basic physical and elastic properties under dynamic in-situ stress conditions. We conduct unconfined uniaxial stress experiments on core samples to measure static elastic properties and tensile strength over a ~305 m (1,000 ft) interval of the borehole above and including the geothermal reservoir. We compare the static elastic properties to the dynamic elastic properties calculated from full wave train downhole sonic data. The comparison demonstrates that the method to calculate dynamic elastic properties is effective in the case that core is not available for analysis. Natural fractures, induced fractures, and breakouts are mapped in acoustic televiewer data. Fracture density is calculated and compared to lithological and mechanical stratigraphy, defined by the physical properties, elastic properties, and strength measurements. The stratigraphic relationships indicate that a ~45 m (150 ft) section of weak, non-brittle, low-permeability, highly altered basalt may act as a caprock to the geothermal reservoir at depth. The induced fracture and breakout data will be used to conduct a stress analysis to identify the magnitude and direction of each of the three principal stress directions that describe the stress tensor. The results of fracture characterization, mechanical stratigraphy, lithological stratigraphy, and stress analysis will used as conditions of a discrete fracture network (DFN) model using the FracMan® code. FracMan® can build a deterministic model from fracture data measured in the borehole and stochastically model realizations of the fracture network on the reservoir scale. The model will allow us to make a first-order estimate of fracture permeability and fluid flow directions in the reservoir.

Curious Proximal Facies: Transgressive Overprinting in the Ferron Sandstone

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The Turonian-Coniacian Ferron Sandstone, near Emery, Utah, is subdivided on the basis of regressive-transgressive deltaic cycles. The fourth parasequence set (Kf-4) of the Ferron Sandstone has an overly thickened landward sandstone. This study provides evidence that this thickened portion of the Kf-4 sandstone, in the Bear Gulch area, consists of a landward stepping, or initial relative sea level rise before the progradational cycle began. Recognition of these landward palimpsest facies has likely been hindered by modification associated with transgressive erosion, and deep biogenic overprinting by subsequent distal shoreface environments. The Kf-4 sand body in the Bear Gulch area can be broken into two very distinctive facies associations that are interpreted as a lower wedge of palimpsest nearshore facies, and the overlying distal shoreface deposits that shallow upward. The proximal palimpsest deposits are composed of a highly complex arrangement of facies showing a wide range of environmental conditions. Sedimentary structures are mostly high-energy structures such as planar tabular or trough cross-beds and low angle dipping planar bedding with parting lineations. Periods of rapid sedimentation are suggested by the presence of equilibrichnia traces. However, the occurrence of multiple dinosaur track horizons and an intra-sand surface with vertical tree casts, indicate exposure, perhaps for significant periods of time. Ophiomorpha and Teredolites still lend to the environment being in proximity to marine conditions. A rapid shift is seen both upward and laterally into heavily bioturbated facies and finer grain size, representing a shift to deeper shoreface conditions. Traces can be highly diverse including Ophiomorpha, Diplocraterion, and Rosselia. The sandstone grades upwards into trough cross-beds and planar beds of the upper shoreface and foreshore. However, in many parts of the study area the upper portions of this shoreface are not present due to subsequent fluvial incision. The complex juxtaposition of these facies provides a cautionary tale to subsurface stratigraphers and reservoir engineers.

Monitoring, Verification and Accounting (MVA) Applied to CO2-EOR Projects

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Previous geochemical measurements at three operational or proposed CO2-EOR projects; Rangely, CO, Teapot Dome, WY, Weyburn, SK are presented as indicators of effectiveness of selected MVA methods. Seasonal fluxes and soil gas concentrations of carbon-containing gases have been determined by the author at Rangely and Teapot Dome. Similar measurements were made at Weyburn by a group led by the British Geological Survey. Methane and light hydrocarbon measurements will be more effective than CO2 for monitoring of EOR projects, whereas CO2 measurements have dominated proposals at pure sequestration projects. Measurement of inert gases as indigenous tracers in soil gas and shallow ground waters for monitoring will be effective in both pure sequestration and CO2-EOR projects. Isotopic measurements provide stronger data necessary for verification. In climates with strong seasonal variations, carbon-containing gas fluxes can vary by a factor of ten and shallow soil gas concentrations by a factor three, primarily due to seasonality of shallow biological processes. Winter or dry season measurements allow improved recognition of a deep source component. Modeling of CH4 and light alkane vertical migration at Rangely indicated an estimated improvement of the signal:noise ratio by a factor of five during winter measurements. A first-order estimate of deep source gas leakage at Rangely is <170 tonnes of CO2 and 400 tonnes of CH4 annually. Trace CH4 leakage at Teapot Dome was detected over faults. An IPAC-sposored study over an alleged localized leak at Weyburn used carbon-contiaining gases to verify the absence of leakage at this location. The results support the particular strength of isotopic measurements on inert gases in shallow groundwater for purposes of verification.

CO2 Sequestration via Adsorption in Thermally Treated Coal Seams

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Underground Coal Thermal Treatment (UCTT) is a technology being investigated at the University of Utah as a means of producing light hydrocarbons by heating unmineable coal seams. Using the groundwork put forth by Enhanced Coal Bed Methane (ECBM) research, it was hypothesized that thermally treated coal seams could serve as a long term repository for anthropogenic carbon dioxide. It was also proposed that the thermally treated coal would have adsorptive properties somewhere between a fresh coal and an activated carbon. The increased adsorptive capacity of the treated coal should result in sequestration capacities greater than ECBM counterparts.

Development of a Fractured Reservoir Model for the Mesaverde Formation to Support Hydrofracturing Design, Natural Buttes Area, Uinta Basin, UT

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The role of natural fractures in the stimulation and production of tight sand and shale reservoirs has been the subject of numerous investigations. Newly-developed geomechanical multiphase models provide a more comprehensive way to understand the interaction between the induced hydrofractures and the natural fracture system and optimize development. A conceptual model for the origin of the natural fracture system in the Mesaverde Formation of the Uinta Basin was developed to test this technology. This conceptual model was then implemented as a Discrete Fracture Network (DFN) model, and the DFN model was validated by comparing the model to subsurface fracture data, and the model's simulated microseismic response to measured microseismicity. Field studies of fracturing in the Mesaverde Formation and other formations within the Uinta Basin, supplemented by subsurface fracture image log data and core were used to develop a conceptual model for the origin and variability of natural fractures in the Uinta Basin. They indicated that there were two families of natural fractures, one related to structural folding, and a second related to in-situ hydrofracturing produced by excess fluid or gas pressures in the rock during hydrocarbon generation and burial. This model was then evaluated in the Natural Buttes area and predicted fracture geometry that matched image log data. A well-scale DFN model was created and used to simulate the growth and interaction of the hydraulic fracture with the natural fracture system. The microseismicity of the model compared well with the measured microseismicity of a nearby well, validating the conceptual model of fracturing and providing a new means to study the interaction between the natural fracture system and the hydrofracturing process.

Recognition and Significance of Primary and Recycled Kerogen in Upper Cretaceous Source Rocks, Denver and Powder River Basins, USA

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Petroleum source beds in the Denver and Powder River basins include the Mowry Shale, the Frontier and Greenhorn Formations, and the Niobrara Formation. These sediments were deposited during transgression and basin deepening, and have relatively high total organic carbon comprised mostly of hydrogen-rich type II or mixed-type II/III kerogen. Bituminite is the principal maceral. Inertinite, semi-fusinite, solid bitumen, sporinite, alginite, and vitrinite occur in variable, but subordinate, quantities. Optical parameters consistently yield bimodal thermal maturation results suggesting the presence of primary and recycled kerogen. Recycled kerogens are more mature than primary macerals. Vitrinite occurs as finely comminuted dark gray particles dispersed throughout mineral matrix. Primary vitrinite is uncommon to rare and sporadic. It consists of relatively large Telocollinite particles. Primary vitrinite reflectance values yield accurate thermal maturation estimates corroborated by several ancillary maturity parameters. Recycled vitrinite, derived from the erosion of older sedimentary rocks, consists of small, angular to irregularly shaped and broken Telocollinite particles, finely dispersed Vitrodetrinite debris, and Collodetrinite. Reflectance measured on recycled Telocollinite consistently indicates peak/late oil generation. Alginite and sporinite also occur as primary and recycled kerogen. Respective fluorescence and TAI measurements made on primary alginite and sporinite yield maturation estimates compatible with those derived from other thermal indicators. Fluorescence and TAI results from recycled alginite and sporinite, however, do not agree with other maturity indicators. TAI and fluorescence of recycled kerogen do match the reflectance of recycled Telocollinite. We postulate that recycled kerogen was derived from older source beds that were buried to depths adequate for peak oil-generation, then uplifted and eroded along fronts of the Sevier Orogeny thrust system. Recognition of primary and recycled kerogen is critical for accurate resource assessment in these rocks, particularly with regard to determining the type and thermal maturity of source beds.

Reservoirs of the Bakken Petroleum System: A Core-based Perspective

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The high level of activity in the Bakken Petroleum System has resulted in significant increase in available data. Log data is unreliable in determination of reservoir properties and has prompted the increased level of coring in an attempt to understand the reservoir. Nine potential reservoirs have been identified within the petroleum system. Production is well established from some, limited from others, and waiting to be tested in others. The informal members within the Three Forks Formation provide four potential reservoirs consisting of brecciated dolo-mudstones, an interbedded sequence of claystones and dolomitic mudstones, with each reservoir capped by an anhydrite or an argillaceous mudstone. These were deposited on a prograding carbonate shoreline, largely in tidal flat or supratidal settings. The Bakken Formation unconformably overlies the Three Forks. Its basal member, the Pronghorn consists of Skolithus sandstones, silty- to sandy-dolomitic mudstones, brachiopod-bearing lime mudstones, and a cherty limestone with the reservoir facies limited to the sandstone and dolomitic mudstone facies representing shoreface to nearshore deposits. Mixed carbonates and siliclastics of the Middle Member comprise the next reservoir in the system representing variable shallow environments. Black organic-rich shale of the Upper Member is considered as one of the source beds, as well as a reservoir. Immediately overlying the Bakken is the Lodgepole Formation. The basal nodular-bedded, crinoidal-rich limestone, as well as its dark organic-rich limestone may provide two additional targets. The unconventional nature of the reservoirs requires wells to be fracture stimulated to produce. Cored sections provide a window into the effectiveness of the stimulation procedures.

Wyoming's Historical Oil Fields I and II: Still Producing (A Lot) After All These Years

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Oil production began in Wyoming in 1884 with the drilling of the discovery well for the Dallas Dome field in central Wyoming. Since then, oil production has occurred from over 49,000 wells in 1,410 fields. The top five most-productive oil fields in Wyoming, including Salt Creek (696.4 million barrels of oil, MMBO), Oregon Basin (481.3 MMBO), Elk Basin (472.9 MMBO), Lost Soldier (270.5 MMBO), and Hamilton Dome (269.1 MMBO), were discovered before 1918. Wyoming's oil fields are the result of a fortuitous overlap of geology and paleogeography. The hydrocarbon sources include the organic-rich shallow-marine shales of the Permian Phosphoria Formation as well as the Upper Cretaceous shales deposited as part of the Western Interior Seaway. Folding and faulting associated with Laramide-age tectonics formed the basin-margin anticlinal traps that today hold the bulk of Wyoming's conventional oil fields. The most prolific oil producing formation in Wyoming is the Pennsylvanian Tensleep Sandstone; a marginal marine sandstone interbedded with nearshore limestones and shales. Oil has also been recovered in significant quantities from the Upper Cretaceous Frontier Formation, Cody Shale, and Mesaverde Group/Formation. The Dallas Dome discovery well sparked interest in Wyoming's oil fields, and Salt Creek was soon discovered in 1889 on the southwest flank of the Powder River Basin. The Salt Creek field is an asymmetric anticline that has produced far more than any other field in Wyoming. At nearly 3.8 million barrels of oil in 2012, Salt Creek is still the second largest oil producer in the state, in part due to tertiary recovery methods such as enhanced oil recovery with carbon dioxide (CO2-EOR), which began in 2004. Wyoming's historical oil fields have helped define an industry. Many of the methods associated with secondary and tertiary recovery techniques (six fields in Wyoming are currently under CO2-EOR), as well as advancements in drilling and production technologies, were developed in these historic fields and resulted in increased field longevity. In 2012, 128 years after discovery, the Dallas Dome field produced 75,628 barrels of oil. The lessons learned from these historic oil fields helped pave the way for Rocky Mountain oil production as well as oil production around the world. Engineering and geological knowledge gained from these fields will also help guide the future success of those involved in new and 'unconventional' frontiers of the oil business.

Characterization of a Basin and Range Type Geothermal System in Southeast Oregon, the Paisley Geothermal System

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Two types of geothermal systems dominate in the western United States, those related to Pliocene and younger magmatism and those related to Basin and Range extension. Basin and Range type geothermal systems are evidenced by high surface heat flow values, low concentrations of magmatic contaminants (e.g., SO4, As, and B), and by their strong dependence on the regional and local structural framework. The Paisley geothermal system shares many aspects similar to Basin and Range geothermal systems. High regional heat flow values averaging 150 mW/m2 are evidence of an elevated regional geothermal gradient. Geologic mapping has revealed structures related to the Basin and Range Province and also to the High Lava Plains. Upwelling of thermal waters in Summer Lake Basin is controlled by a structural transfer zone connecting two en echelon normal faults. Thermal water in the Paisley geothermal system has been determined to be Pleistocene age based on stable isotopes signatures. Recharge to the thermal reservoir is driven dominantly by topographic flow, with residence times on the order of 1000's of years; however, another interpretation is that there is no reservoir and the water simply takes 1000's of years to reach the production zone in the thermal wells from its recharge area in the topographically high areas southwest of Paisley (i.e., long hydrologic flow-paths). Aqueous geochemistry demonstrates that the Paisley geothermal system is not magmatic in origin, with low values of magmatic SO4, As, B, and high values of HCO3 and Na. Geothermometers were used to calculate potential reservoir temperatures between 95 °C – 166 °C. These results were independently checked by X-ray diffraction studies of alteration mineral assemblages from the production zones of two wells drilled by Surprise Valley Electrification; revealing similar temperatures for the stability field of mineral assemblages present in the wells.

Assessment of Undiscovered Resources in the Three Forks Formation of the U.S. Williston Basin, North Dakota and Montana

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In 2008, the U.S. Geological Survey (USGS) used a geology-based assessment methodology to estimate a mean of 3.65 billion barrels of oil of undiscovered resources in the Bakken Formation in North Dakota and Montana. This assessment was limited to the Bakken Formation and 50 feet of strata below the lowermost shale, which includes the informal Pronghorn member of the Bakken Formation and/or the uppermost Three Forks Formation where the Pronghorn is thin or absent. Since 2008, significant drilling and production have occurred within multiple intervals of the Three Forks, warranting the first USGS assessment of the Three Forks Formation. The Three Forks includes supratidal to intertidal units consisting of interbedded gray-green dolomitic mudstones, pink to tan silty dolostones, and variable anhydrite. The Three Forks is stratigraphically divided into lower and upper units, or four distinct 'benches', and is sourced from the overlying, organic-rich Bakken shales. Production is primarily from horizontal drilling into the upper Three Forks, although variable oil saturations have been identified throughout the formation to expand present-day drilling in both the upper and lower units. The 2013 assessment utilizes the geographic extent of the Three Forks Formation and overlying Bakken shales to define continuous and conventional assessment units (AUs). Within the continuous AUs, sweet spots are identified based on areas of maximum hydrocarbon generation (as determined by hydrogen index (HI) values), maximum formation pressures, and structural enhancements. The Pronghorn member is assessed with the Three Forks Formation as it is in fluid communication with the underlying Three Forks reservoirs. The newly revised assessment of technically recoverable, undiscovered oil and gas resources of the Bakken and Three Forks Formations will be available in 2013.

Testing 3D Seismic Attribute Strategies for Subtle Fault Mapping

John McBride (Brigham Young University), R. William Keach II (Brigham Young University), Clayton K. Chandler (Brigham Young University)*

Discovering and mapping fine-scale faults is a critical activity for carbon sequestration planning. Particularly important is assessing the risk of subtle faults or fractures that may continue from a potential sink upward through a potential seal. Further, if such faults or fractures can be shown to have propagated from seismogenic depths (e.g., from Precambrian 'basement'), then a risk of reactivation may exist. In order to assess the potential strengths and weaknesses of using geophysical data to study the problem of subtle faults, we use a publicly available 3D seismic reflection data set from the Illinois Basin where a deep Paleozoic interval for carbon sequestration has been identified. The Illinois Basin provides special challenges for carbon sequestration planning because geologic anomalies (e.g., faults) can be faint and easily missed using 2D seismic data or even 3D data if only conventional display strategies are used. Previous studies have suggested that many large-scale structures in the basin are facilitated by deep-seated faults, which have propagated up continuously from Precambrian rocks into the shallow Paleozoic section. However, the same cannot necessarily be said for small-scale faults in the basin. Using the 3D seismic data from the Illinois Basin, we employ a suite of seismic attributes to demonstrate how deep faults at the target sequestration interval may initially appear to propagate vertically through the Paleozoic (and uppermost Precambrian) section in conventional displays, but when mapped in detail are seen to be much more complex. We have computed attribute displays based on discontinuity, positive and negative curvature, amplitude change in X and Y directions, and seismic shaded relief. Our results show how sets of small-scale faults can apparently grow and die out in a vertical section, while skipping laterally up or down section, thus lacking significant vertical continuity. However, such faults can appear continuous when viewed without detailed analysis and without optimal display parameters and orientation. Our study provides a general strategy for assessing subtle fault continuity and a cautionary tale for concluding significant fault continuity where none may actually exist.

Outcrop-to-Subsurface Correlation of Isolated Fluvial Sandstones, Grand Hogback, Piceance Basin, Colorado

Bryan McDowell (Colorado School of Mines), Piret Plink-Björklund (Colorado School of Mines)*

In western Colorado, the Williams Fork Formation has proven to be a significant gas producer from isolated and amalgamated fluvial deposits. These isolated sandbodies are difficult to interpret in the subsurface due to their variable well log responses, overall complicated stratigraphic architecture, and high lateral and vertical variability. Outcrop studies along the Grand Hogback of Colorado have yielded four types of sandbodies in the Upper Williams Fork Formation based on their reservoir potential: (1) single-story, (2) multi-story, (3) laterally-amalgamating, and (4) crevasse/other. Outcrop GR curves were taken alongside stratigraphic sections (approx. 6 inch spacing) and used to create cumulative GR, K, U, and Th histograms and pseudo-GR curves to compare to subsurface well data. This data set shows distinct differences between sandbodies, notably: (1) highest radioactivity associated with crevasse splays/channels, (2) lowest radioactivity associated with multi-story channels, and (3) a range of data associated with single-story sandbodies. These differences appear interrelated with lithofacies content and the stratigraphic architecture of individual sandbodies. The focus of this study is to test the validity and accuracy of this method for subsurface expression and interpretation related to hydrocarbon production. We attempt to use a combination of outcrop GR measurements, stratigraphic sections, sandbody geometry, and nearby well data to differentiate sandbody types and lithofacies in the subsurface using wireline logs and simple statistical methods to aid future exploration in the Upper Williams Fork Formation.

Reservoir-scale Facies and Stratigraphic Architecture of the Middle and Upper Williams Fork Formation, Upper Philadelphia Creek, Douglas Creek Arch, Colorado

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This study explores the fluvial style and stratigraphic variability of the middle and upper Williams Fork Formation at the reservoir scale using high quality outcrops in upper Philadelphia Creek, Douglas Creek Arch, Colorado. The Late Cretaceous, upper interval (Kmvu) of the Mesaverde Group of the Douglas Creek Arch, is represented by a complex succession of crevasse splays and single-story, multistory, and amalgamated channel bodies that serve as outcrop analogs to laterally equivalent natural gas reservoirs in the Piceance and Uinta basins. Net-to-gross (N:G) ratios (generally >40% sandstone) present of this interval show direct ties to the stratigraphic framework and provide a predictive tool for subsurface reservoir characterization. Outcrop measured sections (N=6; 1,505 ft [458.7 m]) from Upper Philadelphia Creek were used to determine the characteristics and spatial relationships of lithofacies and architectural elements present in the study interval. Sections were spaced approximately 660 ft (201.2 m) apart to mimic the 10-acre well spacing commonly used by producers in the Piceance Basin. Spectral-gamma-ray (SGR) data were collected along measured section paths every foot in order to determine architectural element and lithofacies SGR signatures. Field descriptions, global-positioning-system (GPS) traverses, laser-ranging (LiDAR) data, and ground-based photomosaics were used to map and document the abundance, stratigraphic position, and dimensions of single-story and multistory channel bodies and crevasse splays. These data, in conjunction with recorded paleocurrent values and measured sections, are used to characterize the complex relationship between low-sinuosity braided and high-sinuosity meandering river deposits present in the middle and upper Williams Fork Formations.

Laguna Mar Chiquita (Argentina): A Possible Modern Analog for Lacustrine Source Rocks in Thick-Skinned Foreland Basins

Michael M. McGlue (U.S. Geological Survey), Geoffrey S. Ellis (U.S. Geological Survey)*

Laguna Mar Chiquita (~31°S, 63°W; Argentina) provides an outstanding opportunity to examine the relationships between depositional processes and organic matter accumulation in a modern thick-skinned foreland basin lake. Because of its tectonic origins and the prevailing mesic climate of the Argentine Pampas, the hydrologically-closed, saline Laguna Mar Chiquita serves as a potential present-day analog to underfilled lake phases of the petroliferous Eocene Green River Formation of the western United States. Depositional environments in Laguna Mar Chiquita were determined through: (1) bathymetric surveying; (2) particle size, mineralogical, and organic geochemical analyses of a grid of modern lake-bottom sediment samples (n=61); and (3) assessment of published limnological datasets. Trends in sediment composition and grain size suggest the presence of open-lake, sublacustrine delta, and lake-margin depositional environments. The muds of the open-lake environment are relatively rich in organic matter (average weight % of total organic carbon = 2.9) and characterized by Type II kerogen (average hydrogen index = 220 mg hydrocarbon/g total organic carbon). The lateral variability of organic facies is minimal. Lake-wide, the quality of organic facies is constrained primarily by siliciclastic dilution and early diagenesis, which are a function of depositional environment and water-column oxidation in the shallow (low accommodation) basin, respectively. Over short time intervals (10[sup]2[/sup] - 10[sup]4[/sup] years), modern analog data suggest that climatically-driven water-level fluctuations influence source-rock potential in thick-skinned foreland basin lakes. Over time intervals >10[sup]5[/sup] years, contraction and lateral migration of the basin flexural profile control stratal-stacking patterns and the potential for hydrocarbon play development.

Influence of the Pronghorn Member of the Bakken Formation on the Drilling and Production Potential of the Upper Three Forks in McKenzie County, Williston Basin, North Dakota

Mark Millard (SM Energy Company), Murray Dighans (SM Energy Company), Greg Hilton (SM Energy Company)*

The Pronghorn is a recently renamed member of the Bakken formation in the Williston Basin, North Dakota. Recent work by Johnson (2013) divided the pronghorn in 4 distinct facies across the Williston Basin. While the lower facies of the Pronghorn have been associated with recent production in the basin, the uppermost facies (Pronghorn Shale), described as grey shale with laminations of siltstone to fine-grained sandstone, appears to have a negative impact on production. The Pronghorn Shale is most prominent in central McKenzie County, reaching a maximum thickness of 35 ft. Mineralogical characteristics of the shale, predominately the large presence of clays, have a significant effect on the oil saturation and productivity of the underlying Three Forks. Wireline based maps, and recent production data aid in understanding the influence of Pronghorn Shale deposition on oil migration into the Upper Three Forks. Pronghorn deposition also had an influence on the deposition of the overlying Middle and Lower Bakken source and reservoir intervals. In addition, the presence of the Pronghorn Shale in Central McKenzie Co. introduces complications while attempting to set casing and drill horizontal wells in the Upper Three Forks. Specific examples, along with mitigation methods are also discussed in this presentation.

Seismically-Derived Fracture Mapping for Unconventional Reservoir Exploitation

Paul J. Miller (Schlumberger Ltd.), George C. Bunge (Schlumberger Ltd.)*

Knowledge of the pre-existing natural fracture orientations and of the in-situ stress regime has particular relevance for optimal well planning and completions in unconventional reservoir plays. Surface seismic data offers the potential to provide this information, enabling field development planning prior to the onset of the drilling campaign. At the ´meso´ scale, where fractures are of a sufficient size to cause discontinuities in the seismic image, though are not necessarily clearly resolvable, Ant-Tracking can offer a solution. This provides a means of rapidly obtaining detailed, automatic unbiased fault and fracture interpretation from seismic amplitude data which integrated with fracture information derived from well log measurements and/or microseismic data, enables a detailed understanding of geometries associated with fault/fracture networks. It is particularly powerful in terms of capturing small-scale, often subtle discontinuities which normal interpretation cannot realistically capture. At the ´micro´ scale, below the limit of seismic resolution in terms of imaging, of even subtle discontinuities, we can utilize seismic anisotropy. Shear waves generated by the interaction of incident P-wave energy propagating through a fractured media, are polarized into a fast component – along the dominant fracture direction, and a slow component perpendicular to it. Pre-stack simultaneous AVOAz inversion provides estimates of this shear wave anisotropy with potentially more detail of the vertical variations because of the sensitivity of shear to interface contrasts rather than an average cumulative response of overlying strata associated with velocity based P-wave anisotropy. This information can be used to infer the fracture density and the orientation of the dominant fracture direction. We present examples of these techniques from several unconventional plays in North America.

Siliceous Cementation of Mesozoic Strata in the Four Corners Area: Evidence for Lacustrine Carbonates in the Jurassic, Morrison Fm. and Silcretes in the Cretaceous, Burro Canyon Fm.

Kim J. Miskell-Gerhardt (Consulting Geologist)

Turner and Fishman (1991)* postulated ephemeral alkaline lacustrine environments in the Jurassic, Brushy Basin member of the Morrison Formation of SW Colorado based on the alteration of volcanic ash layers in a concentrically zoned succession ranging from smectite to zeolite to authigenic feldspar from margin to center. The current study of the upper Brushy Basin member differs by examining chert layers with clear microbial carbonate precursors, rather than volcanic ash. These cherts have laminated (stromatolitic) textures and minor (<5 cm) mounded morphologies. Rip-up clasts on bedding surfaces indicate storm-induced destruction and transport of algal mats. Individual deposits are limited in extent but such beds are found throughout Canyons of the Ancients National Monument north to Lake McPhee. This distribution suggests small, scattered carbonate lakes in an arid environment during the late Jurassic. Associated sediments consist of green, illitic and smectitic shales and minor silica-cemented sandstones. There are no associated organically-enriched mudstones, eliminating any source potential. Regionally the cherts sit about 40' below a heavily silica-cemented sandstone in the Early Cretaceous, Burro Canyon formation. Silicification along this upper horizon ranges from softer to harder quartzite, with minor alteration to chalcedony. Soil development on top of silicified beds is indicated by root penetration and indistinct pedogenic structures. Blocks of very angular quartzite carried as bedload in overlying fluvial conglomerates indicates early (intra-Cretaceous) cementation. These quartzites are interpreted as silcretes, or siliceous paleosols, formed during a widespread hiatus very late in the early Cretaceous. They occur throughout the study area noted above, as well as in north-draining washes of the Uncompahgre Plateau and in the Blanding region of SE Utah. If this unit is present in the subsurface it would negatively impact reservoir quality in conventional Burro Canyon / Dakota oil and gas plays. Both the Brushy Basin cherts and the Burro Canyon Quartzites were first noted by archaeologists looking for flakable stone quarry sites, without realizing the geologic significance. *Turner, C.E. and N.S. Fishman, 1991. Jurassic Lake T'oo'dichi': A large alkaline, saline lake, Morrison Formation, eastern Colorado Plateau. GSA Bull. V. 103, pp. 538-558.

Fundamental Analysis of Relative Permeability and Heterogeneity on CO2 Storage and Plume Migration

Nathan Moodie (University of Utah)

Relative permeability is a critical flow parameter for accurate forecasting of long-term behavior of CO2 in the subsurface. In particular, for clastic formations, small-scale (cm) bedding planes can have a significant impact on multiphase CO2-brine fluid flow, depending on the relative permeability relationship assumed. Such small-scale differences in permeability attributable to individual bedding planes may also have a substantial impact on predicted CO2 storage capacity and long-term plume migration behavior. Relative permeability model calibration in this study was accomplished by analyzing previously-published laboratory-scale measurements of relative permeability of Berea sandstone. A core-scale model of the flow test was created in TOUGHREACT to elucidate the best-fit relative permeability formulation that matched experimental data. Among several functions evaluated, best-fit matches between TOUGHREACT flow results and experimental observations were achieved with a calibrated van Genuchten-Mualem function. Using best-fit relative permeability formulations, a model of a small-scale Navajo Sandstone reservoir was developed, implemented in TOUGHREACT with the ECO2h module. The model was one cubic meter in size, with eight individual lithofacies of differing permeability, instigated to mimic small-scale bedding planes. The model assumes that each lithofacies has a random permeability field, resulting in a model with heterogeneous lithofacies. Three different relative permeability functions were then evaluated for their impact on flow results for each model, with all other parameters maintained constant. Results of this analysis suggest that CO2 plume movement and behavior are directly dependent on the specific relative permeability formulation assigned, including the assumed irreducible saturation values of CO2 and brine. Model results also illustrate that, all other aspects held constant, different relative permeability formulations translate to significant contrasts in CO2 plume behavior.

Analysis of Borehole Temperature Data from the Mt. Princeton Hot Springs Area, Chaffee County, Colorado

Paul Morgan (Colorado Geological Survey/Colorado School of Mines)

Mt. Princeton Hot Springs are a group of thermal springs in an accommodation zone in the Sawatch Fault, the western bounding fault of the Upper Arkansas (half) graben in the northern Rio Grande rift. The springs include Hortense Hot Spring, the hottest spring in Colorado with a temperature of about 82°C. A cluster analysis of the chemistry of the waters of the springs indicated that two thermal reservoirs may be feeding the springs. AMAX Exploration drilled 31 thermal gradient holes in the Upper Arkansas Valley in the mid-1970s to investigate the geothermal potential of the area for power production, but abandoned the prospect. Contours of the geothermal gradient based on these data leave the anomaly open to the west, including the highest contours of the anomaly. Five additional temperature gradient holes were drilled in 2009 by Mt. Princeton Geothermal LLC. Drilling problems prevented penetration to the planned depth in the two western holes but the western margin of the anomaly was probably defined. More interesting was the penetration of an isothermal zone in one of the holes at 65°C, slightly hotter than the outflow temperature of the main Mt. Princeton Hot Springs. The topography in the Mt. Princeton area is rugged. On a small-scale, geothermal gradients from individual boreholes form an irregular contour pattern. Much of this irregularity correlates with topographic irregularities. A crude approximation has been used to remove the effects of topography: at each borehole site the elevation of the surface and the geothermal gradient was used to calculate the elevation of the 65°C isotherm (assuming 1-D vertical heat flow). These elevations were then contoured as the top of the warm (65°C) Mt. Princeton Hot Spring aquifer. These contours were much smoother than the geothermal gradient contours and were found to dip gently from the west to Mt. Princeton Hot Springs, where they intersected the surface, and then plunged steeply below the valley to the east. A hotter (82°C) aquifer from Hortense Hot Springs could not be contoured as this aquifer was not penetrated by any of the drill holes. Geothermometry of the Hortense and Mt Princeton Hot Spring waters indicates reservoir temperatures of ~150°C, mixing with a cold meteoric component in the ratio of 1 part hot with 2 to 3 parts cold.

Paleozoic Correlations in the Northern San Rafael Swell Area, Carbon and Emery Counties, Utah

Craig Morgan (Utah Geological Survey), Gerald Waanders (Waanders Palynology Consulting)*

A thick sequence of upper Paleozoic strata has been penetrated by wells in Carbon and northern Emery Counties, Utah. They represent deposition on a shallow marine shelf during much of the Mississippian. The Pennsylvanian saw the rise of the ancestral Uncompahgre Highlands and associated downwarp forming the Paradox Basin. The Paradox structural basin extended into Carbon County where interbedded sandstone, shale, carbonates, and evaporites were deposited in a restricted basin. Separating the Paradox Basin from the open marine environment to the west was the Emery shelf. During the Pennsylvanian, much of the Upper Mississippian was eroded from the Emery shelf and Pennsylvanian strata were never deposited or were deposited and later eroded from the high. The maximum unconformity places Wolfcampian Elephant Canyon Formation on Kinderhookian to Osagean Redwall Limestone, representing a gap of about 40 myr.

Preservation of Primary Lake Signatures in Carbonates of the Eocene Green River Wilkins Peak-Laney Member Transitional Zone

John T. Murphy (Binghamton University), Tim K. Lowenstein (Binghamton University)*

Important changes in carbonate mineralogy, texture, and stable isotope composition occur at the transition from the Wilkins Peak Member (WPM) to the Laney Member (LM) in the Eocene Green River Formation, Wyoming, which reflect evolution of inflow waters, lake waters, and paleoenvironments. Pristine, unaltered laminae of primary aragonite and calcite at the base of the LM were identified by powder x-ray diffraction, transmitted light microscopy, and scanning electron microscopy. Criteria for identifying primary lacustrine aragonite include its purity, preservation of prismatic needle-like crystals 5-10?m in length, micro-lamination defined by crystal size variation, and poor cementation. ?18O values from aragonite laminae are low, suggesting they formed from (1) lake waters sourced by high altitude foreland rivers (e.g. Carroll et al., 2008) and/or (2) the lakes contained fresh water that underwent little evaporative concentration. Primary precipitated calcite also forms laminae that are monominerallic, poorly cemented, with no diagenetic overprints. Calcite crystals are well developed blocky polyhedra, ~10?m in size. ?18O values of primary calcite are higher than the primary aragonite, suggesting changes in lake water temperature, salinity, source, or evaporation. Primary aragonite and calcite in the Laney Member may have precipitated during 'whiting' events, analogous to modern day Pyramid Lake, Nevada, for aragonite (Galat and Jacobsen, 1985) and Lake Zurich, Switzerland, for calcite (Kelts and Hsu, 1978). In contrast to the calcite and aragonite of the basal LM, the top of the underlying WPM is predominantly dolomite with lesser calcite and evaporites, deposited during underfilled, evaporative lake conditions. Pure dolomite laminae contain a range of crystal sizes (5-50?m) and textures, indicating multiple generations of diagenetic crystallization. Laminae of calcite comprise interlocking mosaics with cement overgrowths of crystals ranging between 20 to 70?m. These laminae also contain dolomite crystals up to 60?m in size. Carbonate ?18O values from the upper WPM are variable, perhaps from diagenetic overprinting. The results from this study show that understanding the lacustrine versus diagenetic origin of Green River carbonate minerals is important before using them for paleoclimate interpretations.

Source Rock Potential of the Icebox Formation, Winnipeg Group (Ordovician), North Dakota

Timothy Nesheim (North Dakota Geological Survey), Stephan Nordeng (North Dakota Geological Survey)*

The Icebox Formation (middle Winnipeg Group) has been long viewed as a petroleum source rock within the Williston Basin. While several studies have examined the source rock potential of the Icebox Fm. in Saskatchewan's portion of the Williston Basin, limited work has been published in North Dakota. Extending throughout most of North Dakota, the Icebox Formation is typically ~130 ft. thick while reaching burial depths of over 14,500 ft. The Icebox Fm. contains sandy to sandstone intervals and becomes partially to fully oxidized towards the east, but primarily consists of green to grey to black shale deposited in a marine shelf environment. Thermal modeling reveals that the Icebox Fm. may be thermally mature beneath ~22,000 sq. miles of western North Dakota as well as parts of the Montana, South Dakota, and Saskatchewan. Overall, the Icebox Formation averages as a fair quality source rock while containing an excellent quality source rock interval near its base. Based on 249 measurements off of drill cuttings from 18 wells, the Icebox Fm. in North Dakota averages 0.55 wt. % TOC. Individual well averages, however, range from 0.23 to 1.63 wt. % TOC, with the highest well averages located in the central portions of the state where the Icebox Fm. is neither thermally mature nor oxidized. Also, a core sampled from the Taylor Field (southwestern North Dakota) contains a 3-4 ft. black shale interval near the base of the Icebox section that averages 3.5 wt. % TOC and an S2 of 18.9 mg/g (type I kerogen). Mapping the sonic-resistivity log cross-plot signature of this shale interval, it appears to be regionally extensive and reach thicknesses of 8-10 feet.

Current Understanding of the Sedimentology, Stratigraphy, and Liquid-Oil Potential of the Pennsylvanian Cane Creek Shale of the Paradox Formation, Southeastern Utah

Peter Nielsen (Utah Geological Survey), Craig D. Morgan (Utah Geological Survey), Michael Vanden Berg (Utah Geological Survey)*

The Utah Geological Survey recently received a three-year, U.S. Department of Energy grant to examine the liquid-oil potential of the Cane Creek shale in the Pennsylvanian Paradox Formation of the Paradox Basin, southeastern Utah. Examination of the depositional environment, stratigraphy and lateral extent, geochemistry and mineralogy, fracture spacing, thermal maturity and burial history, and geomechanical properties will help maximize liquid-oil production through the determination of 'sweet spots' and help define optimal completion strategies. The Cane Creek shale records an early stage of a transgressive-regressive sequence (cycle 21) in the Paradox Formation. The Cane Creek is informally divided into three zones, in ascending order the C, B, and A. The thickness of the Cane Creek varies from 0 to 160 feet within the basin. Depositional thickening occurred on downthrown fault blocks, and thinning on upthrown blocks. Extreme thickness variations are also caused by diapiric salt movement and reverse faults associated with salt-diapiric anticlines and synclines. The unit has a northwest-southeast depositional strike and generally thins towards the southwest. The B zone is considered the source and reservoir and has an average TOC of 15%. Production from the Cane Creek shale is generally related to traps caused by diapiric anticlines or to high positions on fault blocks. The Cane Creek is highly overpressured, ranging between 5000 and 6200 psi, which is probably the result of hydrocarbon generation between very impermeable upper and lower anhydrite and halite seals. The unit generally has a porosity of 1–2% and matrix/fracture permeability between 39 and 400 mD. Oriented cores from the Cane Creek show that generally the B zone fracture system trends northeast-southwest, matching the regional trend. The U.S. Geological Survey estimates the total undiscovered oil at 103 MMB and gas at 2473 BCF in the Cane Creek shale. The most successful vertical well, 1 Long Canyon, encountered a thick section of highly fractured Cane Creek and has produced over 1.1 million barrels oil to date. The Kane Springs Federal 27-1 was the first horizontal well drilled in the Paradox Basin and has produced over 50,000 BO from the Cane Creek. Several other vertical and horizontal wells have been drilled or are scheduled to be drilled.

Detailed Sedimentology and Stratigraphy of the Remington 21-1H Cane Creek Shale Core, Pennsylvanian Paradox Formation, Southeastern Utah: Implications for Unconventional Hydrocarbon Recovery

Peter Nielsen (Utah Geological Survey), Craig D Morgan (Utah Geological Survey), Michael Vanden Berg (Utah Geological Survey)*

The Cane Creek shale records an early stage of a developing transgressive–regressive cyclic sequence (Cycle 21) in the Middle Pennsylvanian Paradox Formation, southeastern Utah. The Cane Creek is informally divided into three zones. These are; in ascending order, the lower C, middle B, and upper A. The lower C zone typically consists of interbedded silty carbonate and anhydrite. The middle B zone, the primary source and reservoir for oil and gas, consists of interbedded gray to black shale, occasional fine-grained quartz, and silty to sandy carbonate. The upper A zone typically consists of alternating beds of silty carbonate and gray to black shale with laminated or nodular anhydrite. Upper and lower seals, provided by the thick anhydrite and halite, bracket the B zone. Very low permeability in the B zone inhibits oil migration in unfractured rock. Historical data from wells, either logged through or completed in the Cane Creek shale, suggest a good potential source of hydrocarbons. However, many wells completed in the Cane Creek have limited production or experience significant production declines after a few months following completion. The Utah Geological Survey, as part of a three-year, U.S. Department of Energy project, is examining core and cuttings from the Cane Creek shale to maximize its liquid-oil production potential. In particular, we will examine the depositional environment, stratigraphic and lateral extent, frequency and abundance of fracturing, thermal maturity and geochemistry, and geomechanical properties. In this core poster session, we present the Remington 21-1H Cane Creek core, which displays the typical stratigraphic sequences of A, B, and C zones.

Sandstone Deposition in the Eocene Green River Formation of Eastern Uinta Basin, Evacuation Creek: Depositional Environments and Reservoir-Scale Architecture

T. Ryan O'Hara (Colorado School of Mines), Kati Tänavsuu-Milkeviciene (Statoil), J. Frederick Sarg (Colorado School of Mines)*

Lacustrine basins across the globe contain large resources due to the occurrence of rich source rock and adjacent clastic reservoir facies. In the Uinta basin the Eocene Green River Formation is productive from several fields in the basin such as: Altamont-Bluebell, Red-Wash, and Monument Buttes. The reservoir characteristics of these fields are dissimilar and can be explained by the contrasting depositional settings and subsequent diagenetic histories. Outcrop studies in Evacuation Creek in eastern Uinta basin offer insight into a relatively understudied portion of the Uinta basin. Evacuation Creek is located near the Colorado-Utah border on the western flank of the north-south trending Douglas Creek Arch. This study is based on detailed description of two sandy siliciclastic units of the marginal-lacustrine Green River Formation, profiled along a 2.5 mile outcrop in the R6 zone of the Rising Lake Stage of Tänavsuu-Milkeviciene and Sarg (2012). Facies analysis is used to interpret the overall depositional setting. Deposition within the study interval ranges from alternating oil shale-microbialites during low sediment input phases to sandy clastic input during rising lake levels when sediment supply was greater and deltaic style deposition dominated. The sandstone intervals in this study area are complex. Described facies associations include mouth bars, delta front, distributary channels, and oil shale-microbialites. These units are mapped across the study interval with high resolution panoramic photography. Depositional environments contain evidence for high sedimentation rates, which include slump and slide features like plastic transportation of sandstone blocks out into the distal delta front resulting in 'Cinnamon Roll' features. Mouth bars are sharp-based and vary from a single phase of development that prograded rapidly to multiphase mouth bar deposition that contain wave and wave-modified current ripple lamination, and coarsening upward sequences. Single phase mouth bars prograde directly onto distal delta front and contain local slides of mouth bar blocks within the laterally extensive bar form. Delta front facies contain ripple facies in proximal settings, and planar to laminated facies from sediment plume settling in distal settings. Distributary channels contain predominantly trough cross-bedded facies in broad, sharp-based packages.

Microbial and Inorganic Depositional Processes in Travertine: Tools for Investigating a Possible Blind Geothermal System in Caribou County, Idaho

Sara R. Ohly (Idaho State University), Michael O. McCurry (Idaho State University), John A. Welhan (Idaho Geological Survey)*

Travertine can be used as a proxy for hydrocarbon-forming microbial environments, as well as for geothermal exploration. Travertines from the Blackfoot Volcanic Field (BVF) in southeast ID were studied to determine depositional history and possible geothermal origin. Compositional variations in $CaCO_3$ were used to infer travertine origin and water-rock interaction history, and petrographic microfacies studies allowed reconstruction of depositional history. Compositional data were gathered using SEM-EDS, XRD and solution ICP-MS. Morphological trends were determined by combining field observations with petrography and SEM-EDS. Travertines were grouped into 3 subtypes based on color, mineralogical, and morphological properties: white travertine (WT), red type 1 travertine (RT1), and red type 2 travertine (RT2). WT deposits are characterized by calcite shrubs and regions of secondary microcrystalline calcite with low to moderate intergranular, interparticulate, or moldic porosity. RT1 travertines contain alternating layers of Fe-stained calcite and hematite (and possibly oxyhydroxides) with trace fluorite. RT1 textures include clusters of skeletal calcite and aggregated rhombs with fenestral porosity. RT2 deposits include brecciated aragonitic botryoids cemented together with micritic calcite, with interparticulate pores partially filled with Fe/Mn oxyhydroxides, or peloids composed of micritic calcite and detrital clasts with meniscate cement. WT and RT1 travertines have trace element signatures indicative of water-rock interaction with highly porous Pleistocene basalts that cover most of the BVF. RT2 travertine signatures reflect older regional volcanics. CaCO3 in RT1 and RT2 travertines contains up to 5% Fe+Mg+Mn+Sr+Ba. WT travertine carbonates have concentrations of these elements of <1%. WT morphology indicates the presence of pond, proximal and distal slope facies with sparse laminated stromatolitic areas. Microtextures are suggestive of microbially influenced precipitation in ponds and laminated portions, and abiotic precipitation on slopes. RT1 and RT2 travertines are dominated by vent and apron facies, and microfacies indicate a predominantly abiotic precipitation mode. Depositional processes in BVF travertines appear to be controlled by proximity to vents. Areas proximal to vents with higher dissolved CO2 and flow rates tend to show abiotic features, and distal areas have evidence of microbial contributions to precipitation as well.

Radiometrics and High Resolution Magnetotellurics in the Exploration for Oil and Gas

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Total count radiometrics has been used in oil and gas exploration since the early 1950s. improved instrumentation has allowed the identification of the individual gamma emitting radioelements (Windowed Radiometrics)(WR). The increased concentration of uranium and the decreased concentration of potassium over a microseeping hydrocarbon accumulation at depth reflects the geochemistry of these two elements. Line processing of the WR data often shows a periodic mutual divergence of the concentrations of these two elements when compared to regional background (the potassium - uranium couplet: the K - U Couplet). This suggests some catalytic cracking of hydrocarbon liquids in the reservoir. This identifies the radiometric anomalies as surface oil and gas shows. Very similar to mud log shows in a vertical borehole. Aerial data can cover a large area quickly but is surface only. The correct call rate for radiometrics on previously mapped prospects is approximately 75% to 80% for positive and 60% to 80% for negative. The modern Controlled - Source ElectroMagnetic (CSEM) systems used offshore by ExxonMobil and others generate the input energy source at specified frequencies. CSEM data processing may'stack out' electromgnetic phase, thus possibly losing fluid content information. The input energy source for High Resolution Magnetotellurics (HRMT) is generated by the interaction of the solar wind with the earth's electric and magnetic fields. This input energy source contains all frequencies. The HRMT system must tune to the necessary frequencies. Both of these electromagntic systems investigate depth as a function of frequency. HRMT is point specific. The recorded HRMT data maintain frequency and phase. WR data can give location, approximate size and an indication of liquid hydrocarbons at depth (the K - U Couplet). HRMT data can give size, depth and thickness (frequency) as well as fluid content (phase: oil-gas-water). These two technologies together can provide the basic information for the initial economic analysis of the prospect without the cost of drilling a hole. The HRMT success rate is 49% for commercial production. The do-not-drill prediction rate is 100%.

Carbonate Mudrock Microporosity Classification and Characterization through Core Examination: Upper Cretaceous Niobrara Formation, Denver-Julesburg Basin, Colorado & Wyoming

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Multiple efforts at describing and classifying pore types in mudrocks have been made (Slatt & O'Brien, 2011, Loucks et al., 2012). These efforts have been focused primarily on the Barnett, Woodford, Bossier and Pearsall formations, which are silica-rich and mainly gas producing unconventional reservoirs. Carbonate rock pore type classifications have been proposed by Choquette & Pray (1970), Lucia (1995) and recently by Lønøy (2006). While these classifications have been successful in characterizing conventional reservoirs, little knowledge exists regarding pores in carbonate-rich mudrocks. The Loucks et al., 2012 classification is consistent with previous schemes used in conventional carbonate reservoirs as well as descriptive and simple to use. This study focuses on fundamental pore characteristics and looks to extend conventional carbonate classifications to the Rocky Mountain Region Niobrara Formation. The Niobrara is a self-sourced tight petroleum resource play producing oil and natural gas from low permeability chalks and marls. Located throughout much of the Rocky Mountain Region, it was deposited along the eastern margin of the Western Interior Seaway during a major Late Cretaceous marine transgression (Longman et al., 1998). The Niobrara is divided into two members: the Fort Hayes Limestone and the Smoky Hill Member. The Smoky Hill is the thicker portion, consisting of three interbedded chalk bench and organic-rich marl sequences appropriately named A, B, & C. The B Bench is currently the main production target. Having been referred to as North America's 'next Bakken', the Niobrara is an evolving resource still in the early stages of understanding and development lacking investigation of key reservoir parameters. Thus, the Niobrara is a perfect candidate for this study. A detailed description of Niobrara pore types contributes to the overall understanding of how to best develop this emergent economic resource and provides a platform of study for the investigation of similar carbonate-rich resource plays. Data for this study come from core and outcrop samples collected from locations throughout the Denver-Julesburg Basin. Here the major focus is on core from Colorado's prolific Wattenberg Field. Pore type characterization incorporates petrography using thin section, QEMSCAN®, SEM and FIB-SEM analyses. SEM and FIB-SEM samples were prepared using Argon-ion milling techniques intended to create a polished surface devoid of major surface variations.

Mechanical Stratigraphy and Stress History of Cap-Rocks Analysis of Exhumed Analogs in Central and South-Eastern Utah and Implications for CCS

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Top-seal failure of subsurface waste storage systems such as those proposed for the mitigation of anthropogenic CO2 accumulation can occur when pre-existing optimally oriented fault and fracture systems are reactivated or when new fractures are induced due to increased fluid pressures. The presence of discontinuities in seal lithologies affects their mechanical and hydrogeologic properties; migration of fluids or gas through mm- to cm-scale discontinuity networks can result in focused fluid flow within and across a caprock. We examine the mechanical and fracture stratigraphy of Paleozoic and Mesozoic analogues of failed cap-rocks exposed in central and south-east Utah to understand the nature and distribution of fluid flow pathways in various sealing lithologies. Each seal type has experienced a unique depositional and tectonic history, all are heterolithic, low permeability (0.001 to 0.12 D), and show evidence of fluid flow across the cap-rock through open-mode and shear fractures. We combine outcrop analysis with the unique loading history and resultant uniaxial strain model at each locality to understand the timing of fracture initiation and paleo-tectonic stress orientation, if it differs from the current dominant crustal stress orientation. Burial history models evaluated in this study suggest that most formations reach a maximum burial depth > 1.6 km and experience an overburden stress of up to 50 MPa. As lithostatic load increases with burial depth the potential for initiation of natural hydrofractures increases because the excess pressure above the hydrostatic gradient required for failure decreases. Once zones of weakness have been established within the cap-rock they exist as loci for future deformation and fluid flow.

Central Utah Thrust Belt Exploratioin Is in Its Infancy

Michael Pinnell (Consulting Geologist), Spiro Vassilopoulos, Floyd Moulton (Consulting Geologist)*

Recent worldwide research has demonstrated that each salient of major thrust belt hydrocarbon entrapment can be unique in source rock, reservoir rock, trapping mechanism, time of hydrocarbon migration and sealing properties. Central Utah's Thrust Belt (CUTB) follows this pattern. To date, only Navajo Sandstone reservoir rocks in hanging wall, thin skinned, thrust bend folds have been extensively tested in this promising trend. By way of comparison, the Peruvian thrust salient of the Andean Thrust Belt has at least five unique structural trapping mechanisms as well as several ages of source beds and reservoir rocks. Insufficient exploration in Central Utah precludes us from even knowing if such a variety of entrapment exists. It is known that very thick sequences of Mississippian age source rocks, immediately west of, and in part within the CUTB, have yielded extremely large volumes of hydrocarbons. It is also known that hydrocarbons migrated into CUTB area structures both before and after Sevier age thrusting. Therefore, it can be inferred that hydrocarbons are trapped in the thousand-foot thick Mississippian carbonate reservoir rocks pervasive in the region in very large, simple, but deeper hanging and foot wall folds seen on seismic data. Giant fields from this same horizon in Wyoming and Canada have been known for decades. These structures have not yet been tested in Utah. Covenant Field is a large, gas-free oil seep having re-migrated from a pre-thrust, hydrocarbon filled foreland structure, possibly contained in Mississippian carbonates. It should be west of Covenant and contain oil, gas and condensate. Similar accumulations are known in Wyoming, Canada and Peru. This feature has not yet been drilled in the CUTB. Other similarly large anticlines appear on seismic data and are also untested. Additional non-commercial oil seeps are known on trend. Most likely, they are derived from untested, deeper, commercial accumulations. The transitional trend between Mississippian carbonate platform facies to the east and foreslope facies, and the Deseret-Chainman starved basinal facies on the west, run through the Central Utah Thrust Belt. Strato-structural traps and reefs may be present. Other basins with a similar lithologic sequence are prolific oil and gas producers like the Permian Basin of West Texas. This transition in Central Utah, masked below complex thrusting and Tertiary fill, has never been explored.

Prediction of Organic Maturation by Vitrinite Reflectance Regression in Units of the Mancos Shale, Uinta Basin, Utah

Jeffrey Quick (Utah Geological Survey), Andrew D. McCauley (University of Utah), Robert Ressetar (Utah Geological Survey)*

The Upper Cretaceous Mancos Shale in the Uinta Basin of Utah, with a thickness approximating 4000 ft and burial depths ranging to >15,000 ft, presents challenges in indentifying optimal zones for well completion and stimulation. One technique that may aid in ranking potential Mancos target zones is predicting the organic maturation of selected Mancos subunits. To do this, we compiled vitrinite reflectance (%Ro) data for the Mancos and other Uinta Basin strata, and by regression analysis obtained a formula to predict %Ro based on location and structural depth (elevation). The formula, which is subject to change as additional data are added, has the form: %Ro = 14.9X + 33.2Y – 80.1Z + 0.0847X2 – 0.264Y2 + 29.3Z2 – 0.364XY – 2.48YZ – 642.3 where: X = UTM easting/100,000 Y = UTM northing/100,000 Z = 1,000,000/(300,000 + elevation [ft]) As an example of this technique's application, we identified an ~100-ft-thick informal unit within the lower Blue Gate Member of the Mancos as a potential reservoir target, based on its stratigraphic position and log signature. Along a transect from the basin's southeastern margin to its center, burial depths to the top of the target unit range from 3300 to 13,900 ft. Using the above formula, we predict %Ro to vary from 0.84 (peak oil) in the southeast to 1.47 (dry gas) in the central basin near Ouray, Utah. We predict the transition from oil to gas generation (%Ro = 1.2) to occur about 12 miles north of the Flat Rock and Hill Creek North fields. Finally, we have used the formula to predict the depth to a given %Ro value at various locations. These data combined with geologic structure maps illustrate which stratigraphic units are at the same level of maturation across the basin.

Digital Characterization of Lower Ismay Phylloid Algal Mounds in the San Juan River Gorge, SE Utah

Scott Ritter (Brigham Young University), Colton Goodrich (Brigham Young University), Lincoln Reed (Brigham Young University)*

The spectacularly exposed middle Pennsylvanian phylloid algal mounds in the vicinity of Eight-Foot Rapid on the San Juan River have been lauded as outcrop analogs of hydrocarbon-producing carbonate mounds in the Greater Aneth Field and dozens of satellite fields in the Paradox Basin, Utah for many years. Owing to the nature of the exposures, standard outcrop techniques (measured sections and outcrop photography) applied to the Eight-Foot Rapids mound field to-date do not meaningfully characterize, nor quantify critical reservoir parameters. A LIDAR-based survey provides a continuous, high-resolution survey of the outcrops along a 2.7 kilometer-long stretch of the San Juan River. Modeling of selected horizons within the Lower Ismay depositional sequence permit calculation of volumes of key stratigraphic units. Stochastic modeling of the surface defined by the tops of the mounds can be used to determine the shapes of the individual mounds and the spacing of the mounds over a four square mile area. Such models indicate that mounds are relatively equant in footprint, suggesting that current alignment of phylloid algal fragment accumulations (mounds) was not a major process in their genesis. The dominant component of carbonate mounds is non-aligned fragments (blades) of the phylloid genus Eugonophyllum. However, the upper parts of selected mounds are characterized by the occurrence of relatively complete thalli of Eugonophyllum and decimeter-scale in situ Chaetetes heads, indicating a change in depositional conditions/ ecology during the latter stages of mound development. Intermound depressions ranging in size from 30 to 40 meters in diameter and up to 6 meters deep were filled with grain-rich carbonate sediment that displays an shallowing-upward change in marine biota within individual intermound pools.

Sedimentology and Reservoir Characteristics of the Lower Triassic (Smithian) Sinbad Formation, San Rafael Swell, Utah

Scott Ritter (Brigham Young University), Colton Goodrich (Brigham Young University), Caleb Osborn (Chevron)*

The Sinbad constitutes the maximum flooding and turn-around phases of the thick depositional (approximately 200 m) sequence that includes the underlying Black Dragon Formation and at least part of the overlying Torrey Formation. Vertically, the Sinbad Limestone comprises three units, each characterized by a distinctive association of sedimentary facies: (A) a basal storm-influenced, open-marine unit comprised of mixed mollusk-dominated skeletal/non-skeletal limestone microfacies (B) a medial storm-dominated, restricted-marine unit comprised of hummocky crossbedded siliciclastic/peloidal microfacies, and (C) a capping peritidal crossbedded oolitic dolograinstone unit. Lateral variation is most pronounced in the medial unit, where storm-deposited beds thin and pinch out over lateral distances of one to a few tens of meters. Individual beds and microfacies display a large degree of lateral homogeneity and regional persistence in the lower and upper stratigraphic units. Diagenetic fabric elements indicate that the Sinbad Formation was altered by marine, meteoric, and burial diagenetic processes. The upper member of the Sinbad has been pervasively dolomitized throughout the study area. All three units have been replaced by dolomite in section 2 in the southeastern part of the San Rafael Swell. Hydrocarbon-lined interparticle and separate vug (largely molds) pores (1-5%) characterize the skeletal-oolitic limestones with permeability ranging from 0-100 md. Low permeability/porosity characterizes the middle silicilastic unit. The best reservoir qualities (permeability 400 md) occur in portions of the dolomitized oolitic grainstones that form the upper 2 to 3 m of the Sinbad Limestone.

Programmed-Pyrolysis Derived Petroleum Yield Determinations Calibrated with Hydrous Pyrolysis: A Case Study of Green River Source Rocks

Tim E. Ruble (Weatherford Laboratories), Michael D. Lewan (U.S. Geological Survey)*

Total organic carbon (TOC) and programmed pyrolysis data are easily determined and widely applied to assess unconventional shale-oil targets. These data may be used to map and constrain the generative potential, kerogen type, and thermal maturity of source rocks at the well- to basin-scale. In addition, by making some assumptions regarding the original TOC and hydrogen index of thermally immature source rocks, yield calculations can be applied to estimate the extent of petroleum generation and the volumes and expulsion efficiency of mature source rocks. In this study, we used Green River shale samples and various programmed pyrolysis parameters to estimate the volumes of oil generated from a temperature series of hydrous pyrolysis experiments. These experiments were conducted for 72 hours at temperatures between 160? to 365?C, which represents a maturity range from pre-bitumen generation to the end of oil generation. Spent source rock material and solvent extracted samples were both analyzed by programmed pyrolysis and the calculated oil generation yields were compared. These calculated oil yields were also calibrated against measured oil volumes recovered from the various hydrous pyrolysis experiments. Although hydrous pyrolysis oil yields at the end of oil generation are similar to the calculated estimates, these measured oil yields are significantly lower than those predicted at the earlier stages of oil generation. In contrast, comparison of total product yields from hydrous pyrolysis (bitumen+oil+gas) shows good correlation with programmed pyrolysis derived calculated oil yields across the entire maturation range. These relationships indicate that calculated yields from programmed pyrolysis need to be calibrated to hydrous pyrolysis yields for more realistic determinations of oil charge in evaluating conventional and unconventional oil plays.

Evaluation of Frac Sand Potential in Utah

Andrew Rupke (Utah Geological Survey), Taylor Boden (Utah Geological Survey)*

Demand for and production of frac sand (or proppant sand) has increased in the U.S. in recent years in response to the increased use of hydraulic fracturing to produce oil and gas. The source for much of the U.S. frac sand supply is the Midwest and the South, and production from the West is limited. Because transportation costs for frac sand can be a substantial percentage of the overall cost, a western source of frac sand could be beneficial to producers in western oil and gas fields. The Utah School and Institutional Trust Lands Administration provided the Utah Geological Survey with funding to investigate frac sand potential in Utah. For our study, a number of geologic units in Utah were examined and tested for their frac sand suitability including (but not limited to) Quaternary eolian deposits, Cretaceous Castlegate Sandstone, Jurassic Thousand Pockets Tongue of the Page Sandstone, Jurassic White Throne Member of the Temple Cap Formation, Jurassic Navajo Sandstone, and Permian White Rim and Cedar Mesa Sandstones. We gave priority to potential units that are relatively close to rail. Sieve analyses, roundness and sphericity evaluation, and semi-quantitative chemical analyses using XRF were performed at the Utah Geological Survey to evaluate frac sand suitability. We also noted friability of consolidated units during sample collection. Initial evaluation indicates that grain sizes from a few geologic units may be suitable for the 40/70 (ASTM sieve size) and 30/50 frac sand size designations. In most cases, the units with these favorable size fractions possess roundness and sphericity of the primary size fraction (most commonly material passing no. 40 and retained on no. 50) within acceptable limits. Semi-quantitative analyses also indicate relatively pure quartz sand in many samples, although some processing may be required to upgrade the purity to a marketable product. Preliminary results suggest the geologic units having the best potential are the White Throne Member; the Navajo, White Rim, and Cedar Mesa Sandstones; and some Quaternary eolian deposits. Although preliminary results indicate some potential, additional testing, particularly crush resistance, which measures the sand's strength to withstand downhole pressures, will need to be performed on potential deposits and geologic units.

Geothermal Alteration of Basalts of the Snake River Plain, Idaho

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This project analyzes basaltic core from the Kimama well, north of Burley, in the Snake River Plain of Idaho. The objectives of this project are to establish zones of geothermal alteration and analyze the potential for geothermal power production using sub-aquifer resources on the axial volcanic zone of the Snake River Plain. Thirty samples from 1,912 m of core were sampled and analyzed for clay content and composition using X-ray diffraction. Observations from core samples and geophysical logs are also used to establish alteration zones. Mineralogical data, geophysical log data and physical characteristics of the core suggest that the base of the Snake River Plain aquifer at the axial zone is located 960 m below the surface, much deeper than previously suspected. Swelling smectite clay clogs pore spaces and reduces porosity and permeability to create a natural base to the aquifer. Increased temperatures favor the formation of smectite clay and other secondary minerals to the bottom of the hole. Below 960 m the core shows signs of alteration including color change, formation of clay, and filling of other secondary minerals in vesicles and fractured zones of the core. The smectite clay observed is Fe-rich clay that is authigenic in some places. Geothermal power generation may be feasible using a low temperature hot water geothermal system if thermal fluids can be attained near the bottom of the Kimama well.

Fluvial Sequence Stratigraphy and Depositional Systems of the Tertiary Duchesne River Formation, Northern Uinta Basin, Northeastern Utah

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An upward-coarsening, continental sequence of lacustrine through fluvial systems is both a common and important target for hydrocarbon exploration. The juxtaposition of lower organic-rich lacustrine source rock and the overlying coarse-grained fluvial sandstone reservoir creates favorable conditions for upward hydrocarbon migration and accumulation. The Eocene to earliest Oligocene strata of the Uinta Basin exhibits this same upward coarsening sequence which includes the Green River, Uinta and Duchesne River formations in ascending order. The Duchesne River Formation represents the last 'Lake Uinta' intermontane basin fill, comprised primarily of braided and meandering fluvial deposits. The formation also contains significant tar sands in Asphalt Ridge (e.g. alluvial facies) of the eastern Uinta Basin, likely sourced from the organic-rich lacustrine Green River shales. Duchesne River depositional facies are: alluvial fan conglomerates, fluvial channel sandstones, flood plain mudstones, and lacustrine carbonates. Complex depositional systems and drainage patterns result from multiple clastic sources of the Uinta Mountains in the north, Split and Blue Mountain in the northeast, and the Sevier orogenic belt to the west. The extensive exposures are conducive to studies of: (1) fluvial sequence stratigraphy, (2) correlation and distribution of depositional facies, and (3) controls on the facies distribution (e.g. tectonics, climate). Collectively, the Duchesne River example has important applications for exploring similar subsurface fluvial reservoir systems, and for understanding the history of the late-stage basin filling.

Tar Sand Triangle Bitumen Deposit, Garfield and Wayne Counties, Utah

Steven Schamel (GeoX Consulting, Inc.)

The bitumen in the Tar Sand Triangle deposit is reservoired in a several-hundred-foot-thick eolian sandstone, the White Rim Sandstone (Lower Permian). Across an area of 84 square miles, the thickness of the bitumen-impregnated sandstone exceeds 100 ft. The strata are gently dipping and otherwise unstructured. Average porosity and permeability of the sandstone reservoir are in the range 15-20 % and 200-500 md, respectively. The oil saturation is consistently low, averaging 30-35%. The bitumen has an API gravity less than 8º at the surface and just over 10º in core. It has a high asphaltene and sulfur content, and it is saturate-poor. Although very viscous at reservoir temperatures, the bitumen is a few orders of magnitude less viscous than the Uinta Basin heavy oils. This study estimates a total in-place bitumen resource between 4.25 to 5.15 billion barrels in a deposit less than 200 square miles in size. However, at a commercially viable resource minimal threshold equal and greater than 60 MBO/ac, the in-place bitumen resource is estimated to range between 1.30 and 2.46 billion barrels in an area of 30 to 52 square miles, respectively. The Tar Sand Triangle deposit has several drawbacks that will make commercial bitumen recovery operations difficult and expensive, but not impossible. These include the relatively low grade of the resource and the apparent low oil saturations; the generally poor quality of the oil due to high sulfur content and high viscosity at reservoir temperatures; the difficult access by existing unimproved roads, all of which pass through the Glen Canyon NRA; potentially complicated and/or expensive process water access; the lack of petroleum service vendors and other support services in southeast Utah; and the proximity to environmentally-protected and visually stunning public lands.

Manning Canyon Shale in the Northern San Rafael Swell: A Potential Natural Gas Resource Play?

Steven Schamel (GeoX Consulting, Inc.), Jeffrey Quick (Utah Geological Survey)*

Across broad areas of northern and west-central Utah the Upper Mississippian is represented by two interbedded formations, the Manning Canyon Shale and the Great Blue Limestone. The Manning Canyon Shale contains minor carbonates and locally abundant organic matter, whereas the carbonate-rich Great Blue Limestone generally lacks appreciable organic matter and silisiclastic constituents. The Manning Canyon Shale is a regionally significant, potential hydrocarbon source rock. Wells completed in Manning Canyon Shale at the north end of the San Rafael Swell near Price, Utah, have shown enticing, albeit sub-commercial, natural gas flow rates. This study describes core from a vertical well in this area (Carbon Canal 5-12), which was completed in Manning Canyon Shale during early 2008 by Shell E&P Inc. Shortly after completion, testing of this well showed production rates of 78 Mcf/d and 667 Bw/d over a 63 hour period. The produced gas contained 93% methane, 4% ethane, 1.4 % nitrogen, and just 0.5% carbon dioxide, with a heating value of 1,052 BTU/scf. Down-hole fiber-optics indicated that most of the flow was from between 9124 ft to 9350 ft, roughly corresponding to the lower half of the cored interval. The 546 ft core (8805-9351 ft depths) includes the upper two-thirds of the Manning Canyon Shale and 101 ft of the overlying Oquirrh/Round Valley Formation. Nearly 90% of the Manning Canyon part of the core consists of carbonaceous shale and limestone, which is typically silty with laminar features. The remainder is largely non-carbonaceous, nodular and micritic limestone. The inorganic constituents includes sub-equal parts of quartz as silt grains and minor siliceous sponge spicules, carbonate as lime mud, microbioclasts and skeletal debris, and clay. Total organic carbon (TOC) ranges from <1% to >60% and is present as microscopic grains, macroscopic plant parts, and four thin coal beds. Despite abundant TOC, the generation potential (S1+S2) is poor to fair (0.1-6 mg HC/g rock), consistent with the high maturity (dry gas stage) and abundant inertinite (fossil charcoal) indicated by petrographic analyses. Nonetheless, inflated sealed core sample bags suggest that the Manning Canyon Shale retains some quantity of adsorbed natural gas and may have shale-gas reservoir characteristics.

Finding and Protecting Energy Assets with 21st Century Geochemical Tools

David Seneshen (Vista Geoscience)

Organic and inorganic geochemical analyses of various sample media are used to reduce risk in oil & gas exploration and development. More specifically, the tools help to focus land acquisition, seismic surveys and drill targets in petroleum exploration. Similar geochemical tools are used for documenting baseline environmental conditions before and after development of an energy resource to prevent potential litigation and complaints down the road. The results of geochemical exploration surveys are presented from the following areas: (1) Albion-Scipio Oil Field (Michigan) – Crude oil microseeps in focused the drilling of commercial oil wells in the 4,000-foot deep, Ordovician Trenton hydrothermal dolomite reservoir. (2) Roncott Bakken Oil Field (Saskatchewan) – Crude oil microseeps are evident over and around the field and in several townships surrounding Roncott. (3) Covenant Oil Field (Utah) – Oil microseeps and wet gas anomalies over the Covenant oil field. Baseline environmental surveys are done before and after the development of an energy resource to document groundwater quality and natural hydrocarbon seeps. This documentation is important for avoiding future potential litigation and complaints from landowners and regulatory agencies. Groundwater from domestic and stock wells near proposed oil and/or gas wells are tested for dissolved C1-C7 hydrocarbons, carbon and deuterium isotopes of detected hydrocarbons, cations and anions, and pathogenic and non-pathogenic bacteria to document general water quality before and after stimulation of an oil and/or gas reservoir. Examples of baseline environmental surveys from the DJ and Ration Basins will be presented. Forensic isotopic evidence from shallow aquifers and produced water in the DJ Basin will be shown to emphasize the lack of fluid mixing between oil and gas reservoirs and shallow groundwater aquifers.

Sedimentology and Fluvial Architecture of the Upper Williams Fork Formation, Plateau Creek Canyon, Piceance Basin, Colorado

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This study addresses the sedimentology and stratigraphy of the upper Williams Fork Formation (Upper Cretaceous) in the southwestern Piceance Basin based on exceptionally well exposed outcrops in Plateau Creek Canyon, 10 mi (16 km) northeast of Palisade, Colorado. The upper Williams Fork Formation is a relatively high net-to-gross (>50% sandstone) fluvial sequence deposited during the regression of the Western Interior Seaway. Seven stratigraphic sections covering a total of 1300 ft (400 m) were measured and described in order to evaluate the sedimentology and stratigraphy of the 600 ft (180 m) study interval. In addition, high-resolution photo-panoramas were acquired from the opposing cliffs to describe and quantify characteristics of the large-scale amalgamated channel complexes. The study interval consists of two informal members: a lower, low net-to-gross interval containing channel-complex deposits embedded in overbank mudstones and thinly bedded sandstones; and an upper, high net-to-gross interval dominated by sandstone-rich, laterally and vertically amalgamated channel complexes that form laterally extensive sheet-like units with apparent widths of up to 1 mi (1.6 km) and thicknesses averaging 30-40 ft (9-12 m). The channel complexes in both members are characterized by sharp erosional bases, multiple internal fining-upward sequences, a predominance of trough-crossbedding, extensive internal erosion, and sparse accretionary bedding. They are interpreted as deposits of low-sinuosity braided to meandering fluvial systems, similar to the modern Platte River of eastern Nebraska. The occurrence of similar channel-complex deposits in both members suggests that the fluvial style remained relatively constant across the study interval and that the increase in sandstone content and amalgamation of sandstone bodies toward the top of the interval reflects changes in preservation rather than a change in the depositional environment. The study interval is capped by a highly amalgamated sandstone body that is approximately 70-100 ft (21-30 m) thick and a variegated paleosol horizon, both of which have apparent lateral continuity of at least 10-20 mi2 (26-52 km2). These units are succeeded by quartz-gravel conglomerates and sandstones of the Ohio Creek Conglomerate, which marks the top of the study interval.

Correlation, Age, and Regional Distribution of the Nugget Sandstone and Glen Canyon Group, Utah

Douglas A. Sprinkel (Utah Geological Survey), Bart J. Kowallis (Brigham Young University), Paul H. Jensen (Arch Coal Company)*

The Nugget Sandstone is exposed and has been drilled in the Sevier thrust belt of northern Utah and around the flank of the Uinta Mountains. The Glen Canyon Group, which consists of the Wingate Sandstone/Moenave Formation, Kayenta Formation, and Navajo Sandstone, is exposed and has been drilled on the Colorado Plateau and in the central and southwestern sectors of the Utah Sevier thrust belt. The Nugget Sandstone is not included as a formation of the Glen Canyon Group, and thus two terms are used for similar strata above the Triassic Ankareh-Chinle Formations and below the Middle Jurassic formations throughout Utah. There has been some uncertainty as to the correlation of the Nugget Sandstone with either all or part of the Glen Canyon Group, especially in the eastern Uinta Mountains, the Uinta Basin, and parts of the Sevier thrust belt in central and southwestern Utah. Aetosaur and dinosaur tracks preserved in the Nugget Sandstone in the eastern Uinta Mountains and in exposures throughout the Glen Canyon Group include similar assemblages in approximately the same stratigraphic positions, strongly suggesting they are correlative. In addition, well log interpretation suggests that the Nugget Sandstone correlates with the entire Glen Canyon Group and that the Kayenta Formation either pinches out or transitions from fluvial to eolian deposition under the Uinta Basin and along the thrust belt in the Provo salient and southward to the Mineral Mountains area. Therefore, the term Nugget Sandstone should be used where the Kayenta Formation is not present or recognized and the section consists entirely of eolianite. Glen Canyon Group should be used where the Kayenta is recognized. The age of the Nugget Sandstone is Late Triassic to Early Jurassic, which is similar to the Glen Canyon Group, and places the Triassic-Jurassic boundary within the Nugget Sandstone and not at its base as previously thought.

New Insights into the Timing of Exhumation of the Uinta Basin and Mountain-Front Retreat of the Uinta Mountains, Utah

Douglas A. Sprinkel (Utah Geological Survey), Warren Sharp (Berkeley Geochronology Center), Steven Schamel (GeoX Consulting, Inc.)*

Timing of Laramide uplift of the Uinta Mountains and coeval deposition of the Uinta Basin is fairly well known. However, new geologic mapping and isotopic dating suggest that the timing of the post-Laramide erosion that profoundly altered the landscape within the Uinta Basin is younger than previously thought. The Uinta Basin is a strongly asymmetric intracratonic depression formed during Late Cretaceous to Paleogene time by crustal loading beneath the rising Uinta Mountains anticlinorium. Pre- and synorogenic strata within the basin dip uniformly northward towards the Uinta Basin boundary fault, which borders the deepest part of the basin and cuts rocks as young as the late Eocene Duchesne River Formation. Crustal stability replaced basin subsidence and Uinta Mountains uplift about 30 million years ago (Oligocene). Consequently, an extensive, gently sloping surface (pediment) called the Gilbert Peak erosion surface developed around the flanks of the highland and extended into at least the northern part of the Uinta Basin, leaving only the higher parts of the range above the surface. Streams flowed away from the highlands in a radial pattern and across the surrounding broad plain. The Oligocene Bishop Conglomerate was deposited on the Gilbert Peak erosion surface and the south-dipping Duchesne River and older formations. Tectonic activity resumed about 15 to 10 million years ago as extension lowered the eastern Uinta Mountains, faulted the Gilbert Peak erosion surface, and altered the drainage pattern. A poorly to unconsolidated gravel deposit unconformably overlies the Bishop Conglomerate. The gravel deposit cuts into the underlying Bishop and locally removes it so that the gravel rests directly on the Gilbert Peak erosion surface and underlying pre-Bishop formations. Present-day outliers of this gravel deposit suggest that much of Ashley Valley was covered by the Bishop Conglomerate and this gravel deposit. A uranium-series age obtained from the innermost, densely laminated calcium-carbonate coatings on cobble-sized clasts collected from the gravel deposits indicates the minimum age of the deposit is about 187 ± 11 ka. This suggests that much of the erosion of sedimentary strata and mountain-front retreat along the south flank of the Uinta Mountains occurred in less than 500,000 years. The rapid erosion and downcutting in the Uinta Basin may be linked to the timing of capture of the Green River near or at Lodore Canyon, Colorado.

Mowry Shale, Properties and Potential, Big Horn and Powder River Basins, Wyoming

Robert Sterling (Cirque Resources)

The Cretaceous Mowry Shale is a prolific source rock for quite a few of the Cretaceous reservoirs in many Rocky Mountain basins, including the Big Horn Basin. A few wells have been completed out of the Mowry Shale as a bailout zone because of the shows seen while drilling through it. In the Powder River Basin there was more production encountered in vertical wells, but once again mainly as a bailout after conventional reservoirs proved nonproductive. The Mowry Shale has been the subject of several concerted exploration programs over the last couple of years in the Powder River and Big Horn Basins. Recent horizontal drilling has had mixed results A better undersanding of what makes the reservoir and the best technological solutions are necessary to advance this play to commerciality . The Mowry is a siliceous shale that ranges in gross thickness across the basins from 120 to over 400 feet. Amorphous silica content ranges from 45% to as high as 70%. There are areas in the basin where very fine grained turbidites are interbedded with siliceous shales in the Mowry. TOC content ranges from 1.1% to as high as 4.0%, but there is a relationship between lower TOC values and higher thermal maturity. There are both type II and type III kerogens present in the Mowry. The USGS has evaluated the Mowry Shale as a possible basin centered, or continuous, oil accumulation in both the Big Horn and Powder River basins. Overall reservoir characterization for the basin centered Mowry Shale is slightly different than the areas that have historically produced from the Mowry Shale in the Rocky Mountain region. Within the hydrocarbon generation window, expulsion microfractures contribute to the overall matrix of reservoir pore space, along with interparticle porosity and 'large crack' fracture porosity. Horizontal drilling with effective completion technology will be key to making this play commercially successful.

Mowry Shale, Properties and Potential, Big Horn and Powder River Basins, Wyoming – Core Poster

Robert Sterling (Cirque Resources)

The Cretaceous Mowry Shale is a prolific source rock for quite a few of the Cretaceous reservoirs in many Rocky Mountain basins, including the Big Horn Basin. A few wells have been completed out of the Mowry Shale as a bailout zone because of the shows seen while drilling through it. In the Powder River Basin there was more production encountered in vertical wells, but once again mainly as a bailout after conventional reservoirs proved nonproductive. The Mowry Shale has been the subject of several concerted exploration programs over the last couple of years in the Powder River and Big Horn Basins. Recent horizontal drilling has had mixed results A better undersanding of what makes the reservoir and the best technological solutions are necessary to advance this play to commerciality . The Mowry is a siliceous shale that ranges in gross thickness across the basins from 120 to over 400 feet. Amorphous silica content ranges from 45% to as high as 70%. There are areas in the basin where very fine grained turbidites are interbedded with siliceous shales in the Mowry. TOC content ranges from 1.1% to as high as 4.0%, but there is a relationship between lower TOC values and higher thermal maturity. There are both type II and type III kerogens present in the Mowry. Data from two recent Mowry Shale cores are presented here. The Mariner Java State 16-1, located in the northern Powder River Basin in 16-T54N-R80W, was cored in the Mowry Shale and recovered 109' of core. The Cirque Federal 1-26H, located in the eastern portion of the Big Horn Basin in 26-T52N-R95W was cored as well in the Mowry Shale and recovered 82' of core. Analysis is presented on these two cores.

Log-Interpreted Reservoir Potential from Cretaceous Mancos Shale in the Uinta Basin

Trevor Stoddard (University of Utah), Lauren Birgenheier (University of Utah), Ryan Hillier (Montana State University), Laini Larsen (University of Utah), John McLennan (University of Utah)*

Mancos formation log data from several key wells in the Uinta basin have been analyzed and approximate reservoir potential assessed. One of the primary production concerns in the Uinta basin involves high water production rates. A workflow to accurately determine water saturation in shales using normalized resistivity logs has been created and general water saturation trends across the basin have been resolved to give estimates on production across the basin. In addition to water saturation a logging interpretation method to determine rock mechanics properties using triple combo logs have been used to estimate the rock mechanics properties across the basin. Passey's 'DlogR' method was also employed to estimate TOC within the Mancos unit in areas across the basin. All of the methods employed to reduce these various logs were used to create an overall estimate as to the amount of Mancos gas potential across the Uinta basin. With regard to estimated water saturations across the basin it was found that the Mancos B had the highest water saturation, with a low of 50% water saturation. Generally the water saturations in the northern portion of the basin were higher than in the south. All of the water saturation findings agree with high water production rates reported by operators. 'DlogR' analysis has shown that there are areas of TOC within the Mancos unit, on average between 0.5% to 4.0%. Currently the method for estimating shear and compressional slowness from triple combo logs is being used on those wells without sonic data to utilize the 'DlogR' method to determine how well the values estimated from density and neutron porosity overlap with resistivity curves compare with what the estimated DlogR overlap would be. The approximated sonic log was used to generate estimates as to the rock mechanic properties within the Uinta basin which were then extended to stress estimations in stratigraphic units across the basin. The estimated stresses across the basin were confirmed by operator well reports suggesting average fracture gradients of 0.88 throughout the Mancos stratigraphic unit. This research has indicated that within the Mancos in the Uinta basin there are areas of higher TOC, though typically it is accompanied with high water saturation and high fracture gradients. This suggests that additional research on optimal fracturing strategies needs to be completed to maximize production of the log estimated gas potential within the reservoir.

Mancos Shale In-situ Stress Estimation and Fracture Simulation Across the Uinta Basin

Trevor Stoddard (University of Utah), Lauren Birgenheier (University of Utah), John McLennan (University of Utah), Justin Wriedt (University of Utah)*

Accurate hydraulic fracturing simulations require an adequate knowledge of the in-situ stress state. The stress levels regulate vertical growth, spatial complexity, and treating pressures during hydraulic fracturing. With a few exceptions, stress information in the Mancos Shale in the Uinta Basin is sparse. Stress data were acquired from the literature, from diagnostic injection methodologies and from treatment records. These were contoured to a 4-dimensional volume to be utilized in optimizing Mancos Shale hydraulic fracturing operations across the Uinta Basin. Gradients estimated from treatment reports from instantaneous shut-in pressure (ISIP) values were compiled into a set of matrices along with breakdown pressure and average pressure for 103 wells across the Uinta Basin. Formation Micro-Imaging (FMI) log-based borehole breakout data from above and below the Mancos indicate a consistent NNE-SSW minimum in-situ principal stress direction. Limited diagnostic fracture injection test (DFIT) data provided representations of the minimum in-situ principal stress and aided in calibration of calculated values. A 4-dimensional volume presenting these values across the basin was generated using MATLAB© software. A logging-based approximation to estimate rock mechanics properties such as Young's modulus and Poisson's ratio (and the corresponding stresses) lithologically has also been incorporated to aid in property estimation for hydraulic fracture simulations in commercially available software. Using the MATLAB© created volume and contour slices the fracture gradients across the basin were used in hydraulic fracture simulations using commercially available software. The purpose is to infer relevant characteristics of stimulation treatments and how to best stimulate the Mancos Shale to optimize production. Natural discrete fracture networks (DFN) have been created in the Mancos using FMI logs and bootstrap statistics. The addition of the DFN to the production simulations within the hydraulic fracturing simulation software adds to the accuracy of the production predictions. A further correlation between the most prospective stratigraphic intervals and lithofacies will add consistency to these overall predictions, with the final goal being the ability to efficiently stimulate the Mancos Shale to maximize production.

Oncolites, Laminated Algal Deposits and Conglomerates in the Canyon Mountains --An Overlooked,but Important Stratigraphic Indicator

James M. Stolle (TGS)

When you have eliminated all which is impossible, then whatever remains, however improbable, must be the truth. Sherlock Holmes Quote-The Blanched Soldier. Central Utah and the complex stratigraphic relationships is certainly a test of this statement. Ideas to possibly eliminate: 1) The Canyon Mountains, at least the Cretaceous-Tertiary conglomeratic section, are all non-marine, probably just a variety of fluvial and/or alluvial fans.(It sure looks like it) 2) Plus, the red beds and conglomeratic section is an unlikely place for pollen and spore preservation. Surprisingly, we have recovered an initial collection of trilete, spores of various ages, and more curious, some marine dinocysts. In the same samples also recovered were freshwater algal evidence, including multicellular algal bodies, i.e.a coenobia of Pediastrum. Strike also the assumption about not being able to recover any pollen or spores. Phase two of palynology efforts is already underway, and the third and fourth phases will occur this summer for additional confirmation and results to report. A decision point must be evaluated, either the trilete spores, dinocysts, and algal remains are in-place. If so, we may be developing evidence of a Campanian-Maestrichtian stratigraphic age with lithologic evidence for extensive lake or ponding environments. However, the alternative explanation that it represents a re-working of Cretaceous and older units, and redepositing into a Paleocene-Eocene lake environment must be considered. More intriguing, is part of the section is a conglomerate section being dumped into a lacustrine environment. The transition from conglomerates to all varieties of algal limestones can occur within inches vertically and appears to be repeated many times. This generated the need for a 3-dimensional review of the outcrops, and expansion to other areas, and the type of environment really existed. Keep in mind this is within a few miles of the Pre-Cambrian section overriding the synorogenic section, probably just a bit younger and stratigraphically higher. Different areas and sections are reviewed. The algal laminated sections and oncolitic limestones in the Canyon Mountains may be a real indicator if indeed we show the palynology is indeed reflecting a re-worked section about the environment then present. The presence in the Canyon Mountains and also the Pavant Range pushes the western edge of Paleocene-Eocene deposition.

Quantitative Geologic Analysis of Mancos Shale Core Improves the Geologic Model of the Play

Roberto Suarez-Rivera (Schlumberger), Eric Edelman (Schlumberger), Patrick Gathogo (Schlumberger), David Handwerger (Schlumberger)*

Subtle properties in the micro-texture of organic-rich mudstone reservoirs dictate important conditions of hydrocarbon mobility, phase transformations and segregation of hydrocarbon components during production. Understanding these details requires observations at the nano-meter scale. In addition, and in particular for the Mancos shale, the depositional sequences vary at the scale of few millimeters. Therefore, the challenge in descriptive geology is to understand the microtexture at the nano-meter scale, its variability at a millimeter scale, and construct a detailed description of the geologic system along the section of interest, represented by hundreds of feet of core. The challenge is also to describe the core and its geologic variability in a quantitative manner, and be able to propagate the knowledge gained to other core sections, and other cores. In this paper, we describe continuous measurements of strength, thermal conductivity, rock hardness, XRF mineralogy and CT density, at millimeter resolution, and along the length of the core. These measurements allow us to define fundamental rock properties of texture and composition quantitatively. Given that texture and composition are the end result of complex geologic processes of deposition, diagenesis, interaction with micro-organisms, and varying geochemical conditions over time, rock units with similar texture and composition reflect the action of similar geologic processes. And these can be identified, mapped across the core, and subsequently recognized on other core sections or other cores using the same measurements. The identification of millimeter-scale rock units with similar and dissimilar texture and composition give us a powerful tool for understanding the geologic processes that produce them. The thickness and cyclic stacking patterns of these units provide quantitative information of the depositional system and its sequences. In Mancos shale cores, for example, the cyclic nature of the shale and silt sequences is apparent in the measurements. The method also differentiates transitional contacts from abrupt contacts, and provides additional information for developing a geologic model. Results allow us to define the geologic system quantitatively. They also allow us to scale up the variability observed at a millimeter scale, to averaged properties obtained at the sample scale, and used to characterize bulk core properties.

Clay sensitivity of Lowstand Gravity Flow Deposits of the Douglas Creek Member of the Green River Formation, Greater Monument Butte Field, Uinta Basin, Utah

Bobby Sullivan (Newfield Exploration), Darrin Burton (Newfield Exploration), Margaret Lessenger (Newfield Exploration), Kurtus Woolf (Newfield Exploration)*

The lower portion of the Douglas Creek member (LODC) of the Green River formation represents proportionally a high net to gross tight sandstone reservoir where distributed within the Greater Monument Butte Field. This interval has historically been recognized as a poor producing interval. Through detailed log correlation, core description, and outcrop studies, a sequence stratigraphic framework was developed for the LODC. Through core and log analysis , it was recognized that the LODC contained authigenic clays that are sensitive to freshwater. Through a pilot program, completion practices where modified by increasing KCl concentrations to determine formation sensitivity. The results from the pilot indicate that increased KCl concentrations corresponded with increased production and a subsequent increase EUR.

Depositional History and Lateral Variability of a Microbial Carbonate, Three Mile Canyon and Evacuation Creek, Eastern Uinta Basin, Utah

Michael Swierenga (Colorado School of Mines), J. Frederick Sarg (Colorado School of Mines), Kati Tänavsuu-Milkeviciene (Statoil)*

Marginal lacustrine carbonates of the Eocene Green River Formation form important reservoir rocks in the Uinta basin, yet are often underrepresented in studies. This study seeks to describe and interpret a microbial carbonate unit along a continuous three mile long outcrop in Three Mile Canyon, on the eastern edge of the Uinta basin, near the Utah-Colorado border. This canyon is a tributary of Evacuation Creek, an area well known for its excellent exposures of the Green River Formation. The units exposed in Three Mile Canyon are marginal lacustrine deposits of shale, deltaic sandstone, and littoral to sublittoral carbonates. The outcrop runs obliquely to the paleo-shoreline, giving insight into marginal-lacustrine depositional variability. The objectives of this study are to 1) identify and fully describe the facies of a thick microbialite unit in this study area, 2) measure and describe porosity, 3) describe the lateral variability of microbialite facies along the outcrop, 4) determine depositional history, 5) place this unit into the larger, existing stratigraphic framework developed for the Uinta basin, and 6) describe the diagenetic history of this microbialite deposit. To this end, rock samples and measured sections were taken at intervals along outcrop where lateral changes were observed. Samples were prepared for thin section and stable isotope analysis. Littoral carbonate facies include oolitic grainstone to packstone, intraclast rudstone, and skeletal grainstone. Microbialite facies include stromatolite, thrombolite, and dendrolite. These facies form an upward deepening cycle, transitioning from coated grains or intraclast rudestone to agglutinated microbialite, capped by fine-grained stromatolite. A sandstone unit underlies the microbial carbonate layer, indicating that deltaic sands provided a stable growth platform for microbial accumulations. Microbialite thickness is greatest where it directly overlays sandstone bodies, and large thrombolite to stromatolite heads are dominant. The microbialite layer persists laterally for kilometers beyond sandstone pinch-out, but quickly thins, transitioning from large-scale (several meter) laterally-linked stromatolite and thrombolite heads, to thin (cm-scale) planar laminations with smaller isolated microbial mounds. Graded pisoids and ooids commonly form the early core of mound, and fill between mounds. Porosity observed in outcrop is primarily interparticle and fenestral.

Sedimentary Provenance, Transport, and Mixing of Cretaceous Fluvial and Marginal Marine Strata in the Straight Cliffs Formation, Southern Utah: Insights from Detrital Zircon Geochronology

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Cretaceous strata of the Straight Cliffs Formation in southern Utah document fluvial to shallow marine deposition along the margin of the Western Interior Seaway. High sediment supply and prolonged subsidence in this part of the foreland basin allowed over 250 meters of Coniacian-Santonian sediment to accumulate, but the sources of this basin fill are poorly known. In order to better understand the sedimentary provenance of the Straight Cliffs Formation, 24 detrital zircon samples were collected from several prominent stratigraphic units throughout the Kaiparowits Plateau in southern Utah. Detrital zircons derived from fluvial sandstones (n=1004) yield primarily Paleoproterozoic ages near 1.7 Ga (65% of all fluvial zircons) and 1.4 Ga (13%). These ages, in addition to outcrop paleocurrent measurements, suggest the majority of sediment was sourced from Proterozoic intrusive igneous bodies exposed in the Mogollon highlands of central Arizona, and was transported northward in an axial river system. Additionally, Mesozoic zircons (2%) indicate these rivers drained Cordilleran volcanic arc sources. Subordinate populations of Grenville (6%), Paleozoic (2%) and Archean (2%) aged zircons were transported into the basin via minor tributaries draining the Sevier thrust belt to the west. Ages from shallow marine sandstones (n=425) provide evidence for the mixing of fluvial sediments with shoreface sands that were transported from the north by longshore currents. The dominant ages are still Paleoproterozoic (1.7 Ga, 42% of all shallow marine zircons; 1.4 Ga, 10%), but a prominent Grenville aged peak (1.1 Ga, 17%) with moderate Paleozoic (5%), Neoproterozoic (4%), and Archean (4%) ages indicate longshore drift transported Sevier thrust belt sediment southward and mixed it with the Mogollon and arc-derived sediment. Zircons from intertidal deposits (n=187) yield a combined age signature of the fluvial and shoreface rocks, signaling mild mixing of fluvial and shoreface sediments by tidal processes. This study demonstrates that an axial drainage system draining the Mogollon highlands was the dominant sediment transport mechanism in this part of the basin; despite the proximity of the Sevier thrust belt, the Mogollon highlands remained the primary sediment source for the Straight Cliffs Formation during Coniacian-Santonian time.

Geology and Seismic Interpretation of the Cisco Springs Area, Uncompaghre Uplift, Grand County, Utah

Steven A. Tedesco (Running Foxes Petroleum Inc.)

The Uncompaghre uplift in the Cisco Springs area, Grand County, Utah has a number of shallow oil and gas fields that produce from Cretaceous and Jurassic age sandstone reservoirs. The production is predominantly from the Dakota and Cedar Mountain sandstones that were deposited in a general northeast-southwest direction. The area is dominated by a plunging northwest trending structural anticline that is faulted on its southwestern side. Associated with this structure are numerous isolated single well producers, both structural, structural-stratigraphic and stratigraphic traps, that are in many cases are surrounded by numerous dry holes. The top of the structure is dominated by sub-economic to marginally economic gas wells and a series of oil wells lie in a graben structure that parallels the structural high to the west. Numerous cross-faulting and compartments that help define the present productive trend and potential additional locations. Some of these wells have produced over 40,000 barrels of oil and simple volumetric calculations suggest many of these wells are draining a much larger area. In 2009, approximately 17 miles of 2D were shot in order to better define these seemingly very erratic reservoirs. Seismic interpretation confirms that a number of channels on and off structure are narrow elongated channels that would be difficult to find using subsurface mapping methods alone. Seismic has also defined several channel trends off structure and demonstrated the very narrow nature of these reservoirs. The integration of seismic with subsurface data has revitalized an old area.

Temporal and Spatial Variations in Lacustrine Depositional Controls from the Middle to Upper Green River Formation, Central and Western Uinta Basin, Utah

Leah Toms (University of Utah), Lauren Birgenheier (University of Utah), Michael Vanden Berg (Utah Geological Survey)*

Upstream and downstream climatic and tectonic controls on fluvial-lacustrine systems contribute to the fluctuation of sediment and water entering lake basins. In addition, the relative balance between these controls affect the spatial distribution of deposited sediments and the resulting stratigraphic architecture seen in outcrop and core. The stratigraphy preserved in the lacustrine Eocene Green River Formation provides key insights into the evolution of ancient Lake Uinta and the controls influencing sediment deposition and facies distribution. Specifically, this study characterizes the sedimentology and stratigraphy of the middle to upper Green River Formation (C marker to the

Horsebench Sandstone) from outcrop and core in Gate Canyon, south-central Uinta Basin, and Indian Canyon, western Uinta Basin. The examined sections were deposited during the hyperthermal events that followed the Paleocene-Eocene Thermal Maximum, allowing specific investigation of how climate change may have influenced facies distribution, stratigraphic architecture, and lake evolution. Detailed outcrop and core descriptions along with paleocurrents, X-ray fluorescence data, and thin sections in both the central and western portions of the basin reveal distinct suites of facies from each region. The central portion of the basin contains both siliciclastic and carbonate facies whereas the western portion of the basin contains primarily carbonate facies with zones of saline mineral deposition. The lack of siliciclastic deposits near Indian Canyon suggests a much lower terrestrial sediment supply and a more profundal, hypersaline environment. In addition, littoral microbialites and carbonate grainstones present near Gate Canyon are largely absent to the west. This data suggests variations in the dominant depositional processes controlling each area. Overall, this study seeks to link these regions to provide a more comprehensive understanding of the evolution of Lake Uinta, highlighting the spatial and temporal changes in upstream and downstream controls across the basin.

The Underappreciated Middle Mississippian (C2) Unconformity in the Great Basin: Its Tectonic and Stratigraphic Significance

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In Nevada, the two Mississippian mudrock units that can be distinguished from geochemical and petrophysical log data correspond to lithotectonic units previously recognized from surface geology. Locally exposed paleosols, truncated sub-unconformity structures, synorogenic sediments, and contrasting depositional environments (or provenance) across the unconformity are all unequivocal evidence for mid-Mississippian uplift and erosion. However, the poor exposure and superficial similarity of the mudrocks above and below the C2 unconformity make it difficult to map at a regional scale. The new geochemical and petrophysical-log results enable us to locate the unconformity with outcrop or well-log data, and therefore to better evaluate the extent and tectonic significance of the units below and above it. Rocks below the unconformity include sedimentary rocks of the Antler foredeep that are as old as Kinderhookian and as young as middle Osagean, as well as strata associated with the Roberts Mountains allochthon. At the longitude of Eureka and Elko, these rocks are deformed into east-vergent folds and east-directed thrust faults, accommodating east-west shortening. In this Antler foredeep section, coarse-grained rocks have been mapped as Dale Canyon, Diamond Peak, and Melandco formations, and fine-grained rocks as Chainman Shale. However, this stratigraphic nomenclature must be revised because some formation names, particularly 'Chainman Shale' and 'Diamond Peak Formation', have been applied to rocks both above and below the C2 unconformity. We use the unique, previously defined term 'Gap Wash Formation' for mudrock below the C2 unconformity. The C2 unconformity is buried by synorogenic and post-orogenic sediments, as old as late Meramecian in age, that were shed eastward from the mid-Mississippian tectonic highland. Coarse-grained rocks of this section have been mapped as Tonka and Diamond Peak formations, and fine-grained rocks have been mapped as Chainman Shale. We retain the term 'Chainman Shale' for these mudrocks, because they include the type section of this unit. In middle Osagean-Meramecian time, ~30-40 million years after the Antler orogeny, Antler foreland was deformed, uplifted and eroded, forming the C2 unconformity. This unconformity was covered by late Meramecian to Chesterian overlap strata. It is essential to use correct stratigraphic terminology that distinguishes units below the C2 unconformity from those above it.

The Blackfoot Volcanic Field, Southeast Idaho: A New Structural Paradigm for Hidden Geothermal Resources in the Northeastern Basin and Range

John A. Welhan(Idaho Geological Survey), Dean L Garwood (University of Idaho), Michael O. McCurry (Idaho State University)*

The Blackfoot volcanic field (BVF), located on the western margin of the Idaho-Wyoming overthrust belt in southeast Idaho, is a Quaternary bimodal volcanic province consisting of extensive basaltic lava flows and rhyolite lava domes in a north-trending Basin and Range graben whose Tertiary normal faults cross-cut west-dipping Cretaceous thrust faults. During the geothermal exploration boom of the 1970s and 80s, the BVF was considered to have high geothermal resource potential but interest waned after a 2.5 km-deep geothermal exploration well drilled near the 58 Ka China Hat rhyolite dome did not encounter temperatures above 100 oC. The temperature information in that borehole, obtained from intermittent soundings during drilling, suggested that the volcanic heat source was already spent, possibly because of limited magma volume, rapid mid-crustal cooling or both. Recent re-examination of the petrology and geochemistry of BVF lavas (McCurry et al, 2012), however, suggests that a substantial magmatic heat source at depths of 12-14 km is not only likely but now appears to be necessary to explain the low-temperature geothermal activity and 3He and CO2 gas fluxes that characterize the southern end of the BVF (Lewicki et al, 2012). Considering the region's geohydrology and structural setting, we propose a new paradigm for hidden geothermal resources where the overthrust belt and eastern Basin and Range merge. Based on the inferred depths and geometry of large-scale thrust faults in this area and the ubiquitous shows of high-temperature geothermal fluids encountered at depths of 3-5 km in wildcat wells east of the BVF, it is possible that fluids heated by a magmatic body at depths of 10-15 km beneath the BVF may rise and move eastward along one or more thrust faults (or along carbonate strata within the thrust sheets) to feed hidden geothermal reservoirs within the overthrust belt. The acidic nature of magmatically influenced fluids would contribute solution-enhanced porosity and permeability to the host thrust faults / sheets and could promote lateral migration well away from the BVF. Such a mechanism would also explain the presence of high-temperature brines reported in wildcat wells east of the BVF and suggests that the geothermal resource potential of this part of the Basin and Range and overthrust belt needs to be reconsidered. Both legacy information and new heat flow data collected for the National Geothermal Data System will be presented.

Geologic Controls on Oil Production from the Niobrara Formation, Silo Field, Laramie County, Wyoming

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The Niobrara Formation, an interbedded source-rock and low-porosity chalk/limestone deposited during the Late Cretaceous in the Western Interior Seaway (WIS), is an important hydrocarbon play throughout the Rocky Mountain region. The interbedded chalks and marls contribute to the petroleum system potential of the Niobrara. Ductile marl units have higher organic carbon content, and act as both a source and seal while most reservoir capacity is in the brittle chalk benches. Silo Field, located in the Denver-Julesburg Basin in Laramie County, Wyoming, has been producing from the Niobrara Formation since 1981. Vertical wells were drilled in the 1980s, followed by horizontal drilling in 1990, and finally, horizontal drilling using modern technology began ~2009. Cumulative production to date is 10.8 MMBO and 9,751 MMCFG. At Silo Field, the Niobrara is ~300 ft. thick, is at depths between 7500-8500 ft., and consists of the lower Fort

Hayes Limestone and the upper Smoky Hill Member, which contains alternating chalk and marl sections. The middle B chalk bench is the main production target. Despite over thirty years of production history at Silo Field, it is not well understood why only a few wells are top producers while neighboring wells have very poor production rates. Though the Niobrara has been the topic of much previous research, little attention has been paid in analyzing relationships between geological trends and production data in a quantitative manner. Our objective is to identify geologic factors that contribute to productive wells or groups of wells ('sweet spots') at Silo Field. We will identify completion practices in order to differentiate whether successful production is due to geological variables like mineralogy, distance from faults, fracture intensity, interval thickness, and porosity; or to how wells were managed. We will present the correlation between production and geologic variables determined from core, well logs, cross-sections and maps, with an emphasis on the B chalk. Our goal is to build a predictive geologic model of spatial and stratigraphic heterogeneity to test whether a relationship exists between geologic variables and production. Results from this study may contribute to understanding other Niobrara plays in the Denver-Julesberg basin like the nearby Wattenberg and Hereford fields in Colorado, and may also define what makes the Niobrara Formation unique compared to other source rock reservoirs.

Basin-Scale Sequence Stratigraphy and Distribution of Depositional and Mechanical Units in the Middle and Upper Williams Fork Formation, Piceance Basin, Colorado

Michele Wiechman (Oxy, Inc.), Jennifer Aschoff (Colorado School of Mines)*

The Piceance Basin, northwest Colorado, is home to one of the most important basin-centered tight-gas accumulations in North America. A wide range of geologic controls are responsible for the variation in gas production from the heterogeneous, low-permeability reservoirs, but these are not well understood. This study focuses on potential stratigraphic and mechanical controls on tight-gas sandstone reservoirs in the middle and upper Williams Fork Formation by building a regional sequence-stratigraphic framework integrating outcrop and subsurface data. The database includes detailed stratigraphic profiles (12), outcrop gamma-ray profiles (10), two cores, detrital mineral compositional changes, detailed facies (27) and facies associations (8) descriptions and interpretations, paleocurrent data and well-logs. Fluvial facies are laterally extensive with channel type variations throughout the basin while marine and tidal facies show lateral discontinuity in the northwestern sections of the Basin. Five facies associations have been identified as having the best reservoir potential based on their internal heterogeneity and lateral extent, (1) high-sinuosity, meandering fluvial, (2) isolated, low-sinuosity anastomosed fluvial, (3)tidally influenced fluvial channels, (4) regressive marine shoreline, and (5) transgressive marine shoreline barrier system. Natural fractures, important components of production from fluvial sandstones within the Williams Fork, were indentified in six facies. These associations were (1) high-sinuosity, meandering fluvial, (2) isolated, low-sinuosity anastomosed fluvial, (3) undifferentiated floodplain, (4) tidally influenced fluvial, (5) estuarine systems, and (6) transgressive marine shorelines. Fractures seem to be controlled by facies composition and bedding character. Fracture and fracture swarm spacing is relatively proportional to bedding thickness, with thicker beds showing higher fracture spacing then thinner beds. Sandstones with high fractures concentrations are also found to have cementation trends that increase the sandstones brittleness.

Sedimentological and Stratigraphic Controls on Reservoir Architecture and Connectivity in a Variable Fluvial System: Mesaverde Group, Greater Natural Buttes Field, Uinta Basin, Utah

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The Mesaverde Group of the Greater Natural Buttes (GNB) Field in the Uinta Basin, Utah represents a succession of single-story channel, multistory channel, and crevasse splay deposits that form tight-gas sandstone deposits. Reservoir models of these deposits explore how sandstone-body connectivity varies by environment of deposition and stratigraphically. The Mesaverde Group, a 2000 – 2500 ft (610 – 762 m) thick system, is the main producing unit within the GNB field, located along the eastern flank of the Uinta Basin, Utah. Production from the Mesaverde Group is primarily within the lenticular and highly discontinuous stacked fluvial sandstones. Research has subdivided the Mesaverde Group into four intervals of distinct depositional environments, including estuarine-salt marsh, well-developed floodplain, mixed load braided and meandering stream environments. The ~23 mi study area is located along the eastern edge of the GNB field where the changing depositional environment preserves sandstone bodies with unique characteristics in the Mesaverde Group. To assess the stratigraphy and reservoir characteristics, data from 1650 ft (503 m) of core from 6 wells and well logs from 389 wells on a variable 10-ac [4-hectare] to 40-ac [16-hectare] spacing are used in conjunction with outcrop sandstone-body dimensional data from the surrounding area. Core descriptions covering all four intervals of the Mesaverde Group were used to determine key facies (fourteen), facies associations, and architectural elements (ten). A core-to-log comparison was used to develop criteria to calculate lithology logs from conventional well logs. The core interpretations and calculated lithology logs were compared to existing outcrop data and observations to evaluate stratigraphic variability within the area. Three-dimensional models of the Mesaverde Group provide estimates of the spatial variability for sandstone deposits within different depositional environments. The significance of what constitutes a reservoir-quality sandstone and its impact on static connectivity are investigated using various scenarios. One scenario models only single-story and multistory channel deposits as reservoir-quality sandstones while a second scenario models all sandstone deposits (channel deposits, crevasse splays, and sand bars) as reservoir-quality sandstones. The different scenarios explore the effect on static connectivity and potential impact on reservoir performance.

Characterization of Tensleep Reservoir Fracture Systems Using Outcrop Analog, Fracture Image Logs and 3D Seismic

Tom H. Wilson (West Virginia University), Alan Brown (Schlumberger), Valerie Smith (Schlumberger)*

We develop a model of the discrete fracture network in the Tensleep Sandstone reservoir, Teapot Dome, Wyoming, using design approaches and criteria that may have general applicability to characterization of naturally fractured unconventional reservoirs. Seismic discontinuities related to fracture zones and small faults are extracted from 3D seismic over the dome. Fracture image logs (Formation MicroImager (FMI) logs) provide information about open fracture trends, aperture and present-day orientation of SHmax. We also incorporate field observations of fracture height, length and spacing from Tensleep exposure in the Fremont Canyon area of southern Wyoming. The field analog was compiled from outcrop measured fracture trends and analysis of outcrop photos and WorldView satellite imagery. Fracture height distributions observed in Fremont Canyon on the NE flank of Granite Mountain anticline generally exhibit power law behavior. Decreased power in more intensely fractured zones suggests increased probability of greater fracture height. The power within fracture zones was about -1.6, while that in less intensely fractured zones was about -2.2. Spacing distributions exhibit power law response over a limited range of scales. The power is increasingly negative for larger spacings. Fracture intensity ranges from 0.02/m to 0.075/m. Fracture intensity within fracture zones varies from about 0.05/m to 0.06/m while that in less intensely deformed zones varies from about 0.025/m to 0.03/m. Geometric mean spacing varies from about 11 to 14 meters in fracture zones and from about 19 to 26 meters in less deformed zones. Geometric mean spacing, layer-by-layer, varies from about 10 meters to 27 meters. Length distribution determined from satellite imagery follows a power law (power -1.85), as does the distribution of discontinuity lengths measured in 3D seismic data over the dome (power -2.29). Aperture distributions obtained from FMI logs exhibit limited power law behavior for apertures larger than 0.05 mm, but, overall their distribution is more accurately characterized as log-normal. SHmax (present-day maximum horizontal compressive stress) determined from drilling induced fractures observed in fracture image logs trends ~N76W. The dominant open fracture trend in the Tensleep reservoir, inferred from image log interpretations, parallels SHmax. These fracture parameters combined with output from 3D seismic workflows are used to build a reservoir fracture model.

Lower Green River Formation Depositional Environments in the Uinta Basin, Utah

Kurtus Woolf (Newfield Exploration), Darrin Burton (Newfield Exploration), Bobby Sullivan (Newfield Exploration)*

The petroleum systems of the Eocene Lower Green River Formation are tied to lacustrine, marginal lacustrine, and fluvial-alluvial depositional settings. These depositional settings can be best identified and mapped spatially and temporally by integrating outcrop, core, and wireline logs. Maps of depositional environments are essential to de-risking exploration and field expansion and development activities. The five principle depositional environments of the Lower Green River Formation are: 1) deep lake, 2) shallow lake, 3) lacustrine delta, 4) lacustrine coastal plain, and 5) alluvial plain. Deep lake environments are characterized by laminated oil shales and fine-grained carbonates. These facies are typified by anomalously high neutron porosity, and low bulk density. Shallow lake environments are dominated by weakly-laminated to massive grey mudstones, and limestones, with occasional thin, high bulk density sandstones. Lacustrine deltas (both sand-prone, and mud-prone) grade from shallow lake muds to ripple-laminated sandstones to cross-bedded sandstones. The upward decrease in mudstone can be seen in the gamma-ray, neutron porosity, and bulk density profiles of deltaic intervals. Coastal plain mudstones have a greenish hue, and frequently contain organic matter. Channels in coastal plain settings are typically thin, isolated and heterolithic. Alluvial plain channels tend to be sandier, thicker, and less isolated than coastal plain channels. Alluvial mudstones are reddish with more abundant pedogenic features. The highest gamma-ray readings are most common in the alluvial plain setting, and are believed to correlate to well-developed paleosols. The vertical association of depositional environments in the Lower Green River indicates both high amplitude and high frequency lake level fluctuations. However, the macroscale trend shows a rapid deepening of the lake lower in the section, followed by a gradual filling of the lake, and a gradual flooding near the top. The Lower Green River depositional environments form key petroleum systems components. Oil shales in the deep lake settings are the major source rock, and coastal plain muds are a potential minor source. Deep and shallow lacustrine shales and tight carbonates form regional seals. Delta, coastal plain, and alluvial plain sands form the principal reservoirs. Deep lake mudstones and carbonates are also potential unconventional reservoirs.

Spatial Properties of Natural Fractures in the Mancos Shale, Eastern Utah

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The response of rocks to hydraulic fracturing is affected by the presence and geometrical properties of pre-existing natural fractures. Owing to poor outcrop, the presence and spatial properties of fractures in mudstones can be difficult to assess at the surface. This is particularly true for the Mancos Shale, which is a potential target for hydrocarbon production via hydraulic fracturing. We therefore examined the properties and spatial distribution of fractures imaged in formation image (FMI) logs through the Mancos Shale from six wells in the east-central part of the Uinta Basin. The locations and orientations of natural fractures were compared to depth, gamma-ray intensity, and borehole breakout orientation to investigate the spatial properties of the fractures and possible controls on their distribution related to lithologic and stress field characteristics. Imaged fractures strike 270° - 280° and 90% dip more than 60°. This orientation is approximately perpendicular to the in situ least horizontal stress trajectory indicated by borehole breakouts, which are rare within the Mancos Shale but are more common in overlying sandstone strata. This relationship predicts that induced hydraulic fracturing of the Mancos in this area will mainly result in propagation of existing fractures rather than the initiation of new ones. Fine laminations of siltstone and mudstone within the Mancos Shale results in a fairly uniform gamma ray character throughout the formation, which averages about 93 API. The highest and lowest API values in the Mancos, about 115 and 65 respectively, are only rarely present, with insufficient frequency for robust statistical evaluation. Fractures tend to be concentrated in portions of the shale with higher API values, although this trend is inconsistent across the study area. The abundance of fractures that dip < 80° generally increases with depth, suggesting a gradual transition from primarily tensile to shear fractures. However, the lower portions of the Mancos Shale are generally characterized by more mudstone rich facies, and some concentrations of shallowly dipping fractures are contained in particular, high API stratigraphic intervals. Both increasing confining pressure and lithologic changes could be controlling the character of these observed fractures.

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WHAT TO SEE AND DO IN SALT LAKE CITY

Salt Lake has a lot going for it that makes it appealing, and if you've never visited, you're in for a treat. Visitors consistently comment on how friendly, clean, and safe this destination is, with loads of outdoor recreation, shopping, and cultural opportunities available.

The city of over one million people rests in a valley at 4,330 feet. The majestic Wasatch Mountains surround the city and soar to a dramatic 11,000 feet. As the region's hub for commerce, transportation, medical services, research, higher education, and cultural attractions, Salt Lake is a vibrant, modern metropolis. The walkable downtown convention district features 170+ restaurants, cafes, brewpubs, and nightspots. There are two large shopping malls, art and history museums, IMAX theater, planetarium, professional sports teams, theater, opera, ballet, and symphony. Historic Temple Square offers numerous admission-free cultural attractions, including the Mormon Tabernacle Choir. A fare-free light rail line runs through the compact convention district, just a couple of blocks away from the Hilton.

On the edge of the downtown convention district, Memory Grove Park and City Creek Canyon provide scenic walking and biking trails. Further out from downtown, you can be experiencing all the great outdoors has to offer within 10-35 minutes: golfing, mountain biking, hiking in wilderness areas, trail running, picnics, and tram rides that top out on 11,000-foot mountain peaks. And that's just for starters. Utah is one of the most accessible outdoor destinations in the world, encompassing 85,000 square miles of nature's offerings, from the Rocky Mountains to the Southwestern desert.

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Covenant field, central Utah
photo by Thomas Chidsey, UGS

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