AAPG
Rocky Mountain Section

2022 AAPG Rocky Mountain Section Annual Meeting

NEXT
HORIZONS

THE FUTURE OF ROCKIES GEOLOGY

DENVER • JULY 24-27, 2022

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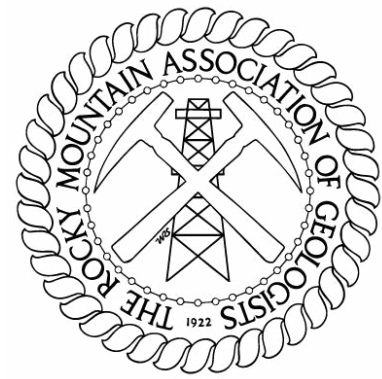OIL & GAS III

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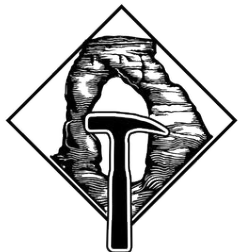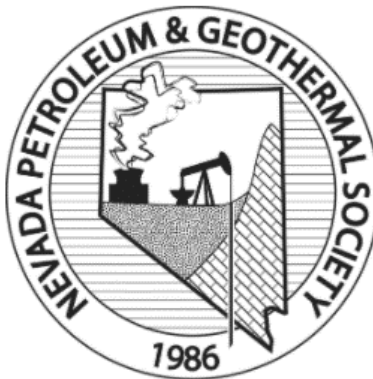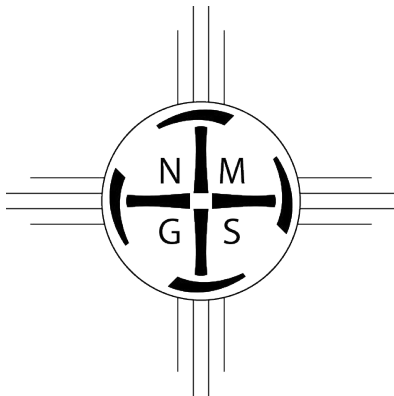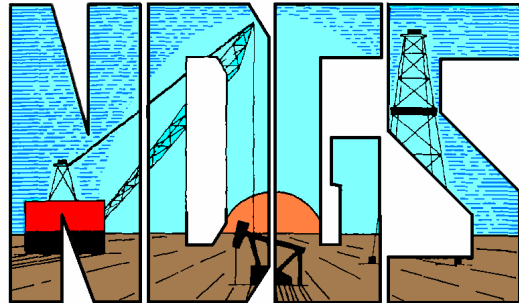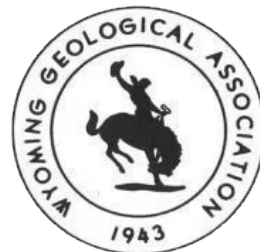
Attendee Safety

The safety of RMS-AAPG attendees, staff, and volunteers is our highest priority. We are planning a fully in-person meeting and expect all attendees to abide by the current CDC COVID guidance and regulations, including all City and County of Denver Public Health Orders.

Welcome to the Rocky Mountain Section of the American Association of Petroleum Geologists Annual Meeting! We are excited to have you back in Denver for the first time since 2014! Given COVID concerns, this is the first in-person RMS meeting since Cheyenne, WY in 2019. We have an excellent program for you and are looking forward to everything the conference has planned. The Next Horizons theme was chosen as geoscience continues to morph into the ever-expanding needs of energy sources, from petroleum and critical minerals to geothermal and CCUS.

Our Sponsorship (Chantel Maybach and Erika Davis) and Exhibits (Kat Pfeiffer) committees were instrumental in raising money for this year's RMS-AAPG conference. Indeed, the Sponsorship Committee raised more money for this conference than any meeting in the previous 10 years. We would like to express sincere gratitude to our sponsors and exhibitors.

Our committees have worked tirelessly to provide outstanding technical content for the meeting. The Technical Committee (Justin Birdwell, Jesse Melick and Lisa Stright) received 95 abstracts that were organized into 6 themes and 15 sessions of 64 talks and 24 posters. Our Field Trip Committee (Clayton Schultz and Lily Horne) arranged excursions to explore the stratigraphy and reservoir quality of the Niobrara Formation, Paleozoic and Mesozoic sequence stratigraphy along the Front Range, an east-to-west structural transect across Colorado, and a visit to Corral Bluffs, a world-class paleontological site featured in a recent episode of NOVA. Our Short Course Committee (Anita Thapalia and Holly Lindsey) has organized five classes: applications of hydrology in the petroleum industry, sequence stratigraphy of unconventional resource plays, exploration and production of non-hydrocarbon gasses and liquids, Python and its uses in geoscience workflows, and application of petroleum geology skills in the geothermal industry. Our Core Workshop Committee (Jerry Bellian, Jason Flaum and Howard Feldman) has organized an excellent two-day course examining core from a number of formations across the western U.S. including Bakken (Williston Basin), Cane Creek (Paradox Basin), Mowry, Frontier (Green River Basin), Wolfcamp/Leonard (Midland Basin) and Eagle Ford (Texas Gulf Coast).

The Social Events Committee (Matthew Bauer) has organized a number of fun networking and social events including a walking tour of Downtown Denver with stops at local breweries, a behind-the-scenes tour of History Colorado Center, a tour of The Anschutz Collection at The American Museum of Western Art, and the President's Reception at the Denver Museum of Nature and Science (DMNS). The committee has also arranged for Dr. James Hagadorn, Curator of Geology at DMNS, to deliver a talk on the Devonian-Carboniferous extinction event as recognized in Colorado at the All-Convention Lunch on Monday. We are looking forward to seeing you at these events!

The Publicity Committee (Chris Matson and Carolina Mayorga) worked exceptionally hard to get the word out for this meeting. They not only designed this booklet you're currently flipping through, but they also designed the website, coordinated email blasts to RMS members and affiliated societies, arranged for advertisements in print media and kept up with social media posts. The Awards and Judging Committee (Tofer Lewis and Ellen Wilcox) designed the specs for an app to judge oral and poster presentations and worked with a group of Colorado School of Mines students to build the application and make it available to all conference attendees. The Finance Committee (Jeff Zawila) worked with all other committees to construct and maintain a meeting budget. Our management company, Conference Direct (Michelle Gentzen and Ellen Husch), oversaw all of the contracts and logistics with the Hyatt (meeting room layout, A/V, food and beverages) and set up registration for the meeting.

The conference also coincides with the 100th anniversary of our host society, the Rocky Mountain Association of Geologists (RMAG). We have a session dedicated to 100 years of geology in the Rocky Mountains, and a talk specific to the history of RMAG will be delivered at the President's Reception at the Night at the Museum event. RMAG serves the Rocky Mountain geoscience community and offers monthly luncheon talks, short courses, symposia, core workshops and field trips, as well as the monthly Outcrop newsletter and the quarterly Mountain Geologist with peer-reviewed publications. Current RMAG President, Rob Diedrich, and Executive Director, Bridget Crowther, have lent their experience and support for the 2022 RMS-AAPG meeting rounding up volunteers and providing the signage that you see around the venue. If you're not a member or your membership has lapsed, you can sign up at their booth in the Exhibition area. Please join us in celebrating the RMAG centennial and become a member today.

Our hats are off to our committees for all of the hard work that they have accomplished to make this a top-notch RMS-AAPG conference. It couldn't have happened without you! We have a great meeting planned and look forward to seeing everyone in Denver!

Thomas Hearon and Larry Rasmussen
RMS-AAPG Co-Chairs, 2022

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Clayton Schultz

Lily Horne

SHORT COURSE CHAIRS

Anita Thapalia, PhD, PG

Holly Lindsey

CORE WORKSHOP CHAIRS

Jerry Bellian, PhD

Jason Flaum, PhD

HOSPITALITY CHAIR

Mathew Bauer, PG

SCHEDULE OF EVENTS

Friday, July 22, 2022

8:00 am	Field Trip: Stratigraphy and Reservoir Quality of the Mancos-Niobrara section as seen in Pagosa Springs and Durango (northern San Juan Basin). **Dates: July 22nd, 23rd, and 24th**

Saturday, July 23, 2022

8:00 am - 5:00 pm	Short Course: Application of Petroleum Geology Skills to the Geothermal Industry
8:00 am - 5:00 pm	Short Course: Python for Geoscientists
8:00 am - 5:00 pm	Short Course: Sequence Stratigraphy of Unconventional Resource Plays. **Days: July 23rd and 24th**

Sunday, July 24, 2022

8:00 am	Field Trip: Corral Bluff – an Exceptional Fossil Record from after the Cretaceous/Paleogene Mass Extinction
8:00 am - 4:00 pm	Short Course: Exploration and Production of Non-Hydrocarbon Gases and Fluids: Energy Minerals
8:00 am - 4:00 pm	Short Course: Hot Topics in Hydrology for the Petroleum Industry
1:00 pm - 5:00 pm	RMAG Presents – Block and Brews Tour
5:30 pm	Ice Breaker

Monday, July 25, 2022

9:00 am	Guest Event: History of Colorado Collections Tour – History Colorado Center
12:00 pm	All Convention Lunch
12:00 pm - 2:00 pm	Guest Event: History Colorado Collections Tour
5:00 pm - 6:00 pm	Social Hour – Exhibition Hall (Centennial Ballrooms A-D)
7:00 pm - 9:00 pm	President's Reception: Night at the Museum, Denver Museum of Nature and Science

Tuesday, July 26, 2022

6:30 am - 8:00 am	RMS-AAPG Executive Committee Meeting
12:00 pm - 2:00 pm	Guest Event: Western Museum of Art Tour
5:00 pm - 6:30 pm	Networking Reception – Exhibition Hall (Centennial Ballrooms A-D)
6:00 pm - 8:00 pm	Student and Young Professional Networking Event, Tivoli Brewing Company

Wednesday, July 27, 2022

Field Trip: Front Range Sequence Stratigraphy Field Trip. Dates: July 27th and 28th

Registration: Centennial Ballroom Foyer

Sunday, 7/24 7:00 am – 7:00 pm
Monday, 7/25 7:00 am – 6:00 pm
Tuesday, 7/26 7:00 am – 5:00 pm
Wednesday, 7/27 7:00 am – 1:00 pm

Speakers/Judges Prep Room: Agate A & B

Monday, 7/25 7:00 am – 6:00 pm
Tuesday, 7/26 7:00 am – 5:00 pm
Wednesday, 7/27 7:00 am – 2:00 pm

All Convention Lunch: Mineral A-C

Monday, 7/24 11:45 am

Exhibition: Centennial Ballrooms A-D

Monday, 7/25 8:30 am – 6:00 pm
Tuesday, 7/26 8:30 am – 5:00 pm
Wednesday, 7/27 8:30 am – 1:00 pm

Oral Sessions: Centennial Ballrooms E and G &F

Monday, 7/25 8:00 am – 5:00 pm
Tuesday, 7/26 8:00 am – 5:00 pm
Wednesday, 7/27 8:00 am – 1:00 pm

ALL Poster Sessions: Centennial Ballroom H

Professional: Monday, 7/25 8:00 am – 5:00 pm
Student: Tuesday, 7/26 8:00 am – 5:00 pm

Spouse Hospitality: Granite A

Sunday, 7/24 2:00 pm – 4:00 pm
Monday, 7/25 8:00 am – 10:00 am
Tuesday, 7/26 8:00 am – 10:00 am
Wednesday, 7/27 8:00 am – 10:00 am

Accommodations

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• Multilingual staff
• Car rental desk
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• Assistive listening devices
• Safe-deposit boxes at front desk
• Laundry and dry cleaning (fees apply)
• Valet and self parking (fees apply)

RESTAURANTS & BARS
• Altitude Restaurant – upscale three-meal comfort food
• Peaks Lounge – inviting rooftop cocktail lounge
• Strata Bar – high-energy lobby level bar
• Perks Coffee & More – 24-hour drinks, snacks and more
• In-room dining
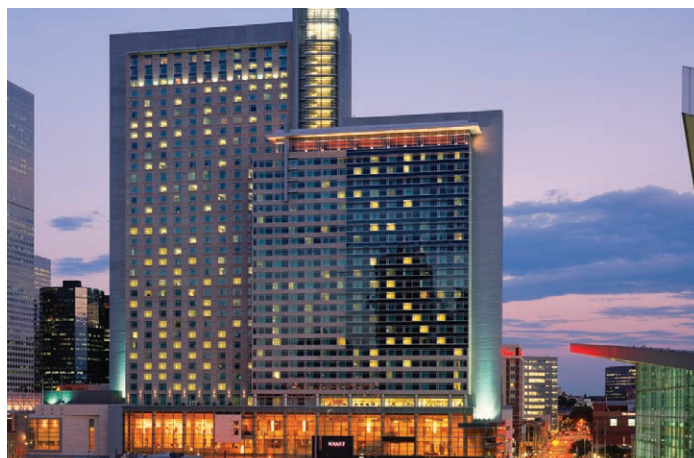
RECREATIONAL FACILITIES
• 6,700 square-foot health club including an indoor lap pool, changing rooms, outdoor whirlpool, and sun deck
• Spa Universaire

LOCATION
Situated in the heart of downtown Denver, Hyatt Regency Denver at Colorado Convention Center offers spectacular views of the Rocky Mountain front range and the city's dramatic skyline. Adjacent to Colorado Convention Center and just one block from shopping at 16th Street Mall, this contemporary luxury hotel is close to some of the city's most popular historic, cultural, and entertainment venues, including the Denver Center for the Performing Arts, Pepsi Center, Sports Authority Field at Mile High, and the State Capitol.

DIRECTIONS
From Denver International Airport (approximately 23 miles): Take Peña Blvd to I-70 West. Take I-70 West to I-25 South; exit at Colfax Avenue (exit #210a) Take a left off the exit ramp, heading east to Welton Street. Turn left onto Welton Street. Proceed 3.5 blocks and turn left onto 15th Street. Make an immediate left into Hyatt Regency Denver's circle drive.
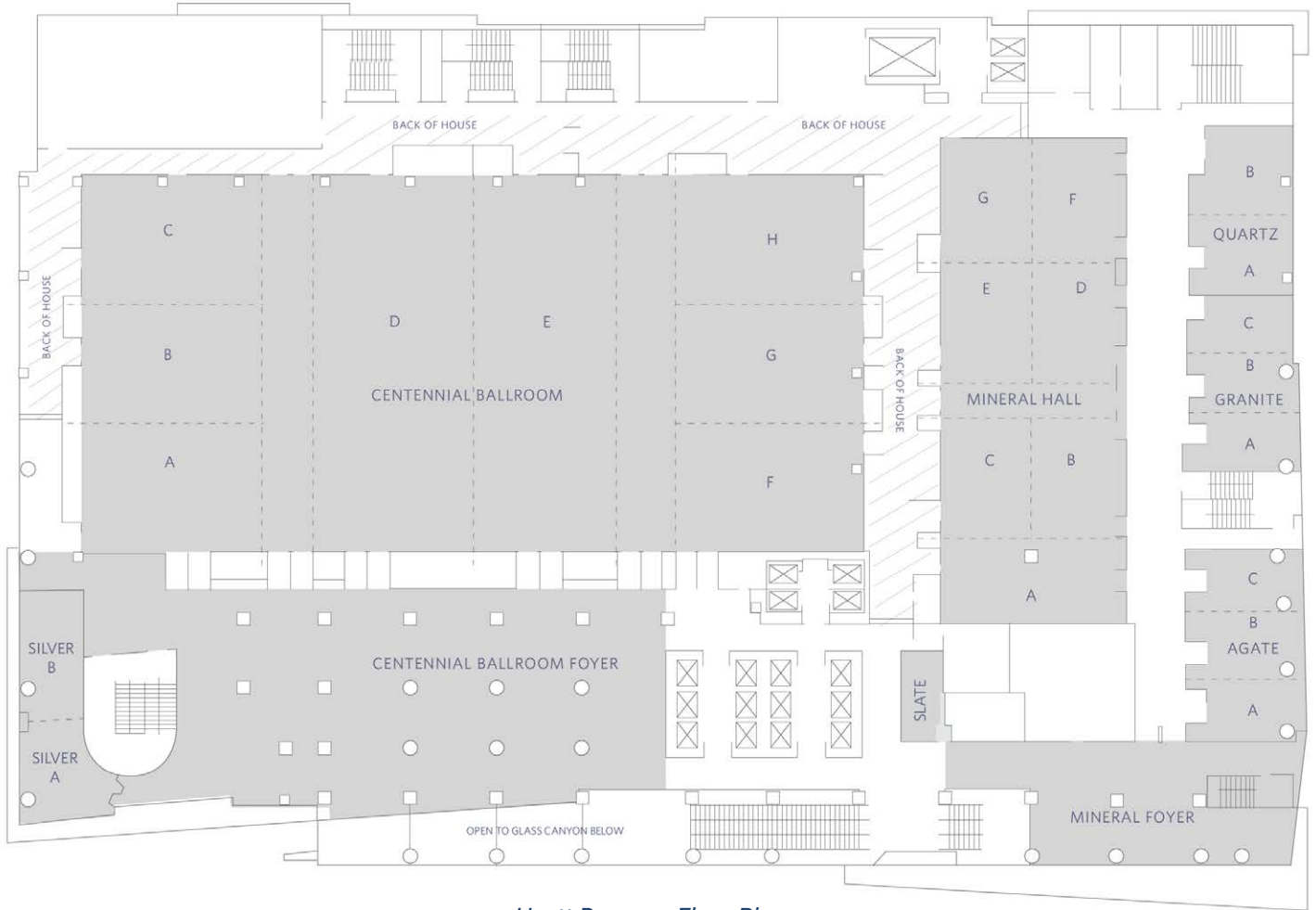
Hyatt Regency Floor Plan

Ballroom Layout

EXHIBITION HALL LAYOUT

Eagle Ford Core

14'-7"

10'-6"

10'-6"

10'-6"

Exit Doors

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Centennial Foyer

Cane Creek Core

Bar

Company	Booth Number
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GeoMark	5
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Rogii	11
Weatherford	2
Extreme Wireline	3
Diversified	47
RevoChem	46
Columbine	1
Stone Quilt Designs	23
CO School of Mines	49
Raptor Consulting	14
US Coring	13
University of Wyoming	48
TracerCo	24
Schlumberger	45
Canamera	36
Selman Associates	34
King Canyon Buffalo	22 + 21
GVERSE-Geographix	33

Thank You Core Laboratories
for lanyards, hand lenses, and grain size cards!

*Core material graciously provided by
the US Geological Survey and the Utah Geological Survey*

Block and Brews Tour

Presented by RMAG

Cost: Free with RSVP
Sunday, July 24, 1:00 PM - 5:00 PM

Explore the stone that built Denver on this guided 2.5 mile walking tour with stops along way to wet your whistle with your fellow geologists.

Ice Breaker

Exhibition Hall – Centennial Ballrooms (A-D)

Cost: Free
Sunday, July 24, 5:30 PM

Kick off the conference catching up with old friends and making new ones. Hosted bar, hors d'oeuvres, and live bluegrass by our very own Plots and Rocks.

All Convention Lunch

Mineral A-C

Cost: $60
Monday, July 25, 11:30 am - 1:00 pm

Featuring Lecture from Dr. James Hagadorn, Denver Museum of Nature and Science: Rocky Mountain Extinction at the Devonian-Carboniferous Transition

President's Reception: Night at the Museum

Denver Museum of Nature & Science

Cost: $75
Monday, July 25, 7:00 pm - 10:00 pm

An evening at the Denver Museum of Nature & Science. Awards, lecture on the 100 year anniversary of RMAG, and collection tours. Hors D'oeuvres & (2) drinks included followed by a cash bar. Transportation will not be provided - we suggest an Uber or Lyft to and from the Hyatt.

Student and Young Professional Networking Event

Tivoli Brewing Company

900 Auraria Pkwy Suite 240, Denver, CO 80204
Tuesday, July 26, 6:00 pm - 08:00 pm

Get to know your fellow Students and Young Professionals at Tivoli Brewing Co, Denver's OG Brewery founded in 1859! The event will provide networking opportunities and highlight different paths into industry. A $20 food and beverage credit will provided for those that sign up during meeting registration.

Environmental change and mass extinction at the Devonian-Carboniferous transition, Colorado.

Speaker: James Hagadorn, PhD
Location: Mineral A-C
Cost: $60
Date: Monday, July 25, 11:30 am - 1:00 pm

Featuring Lecture from Dr. James Hagadorn, Denver Museum of Nature and Science.

Abstract:

Paired chemostratigraphic and biostratigraphic data suggest that the Devonian - Carboniferous boundary and the Hangenberg extinction event are recorded in the Dyer Formation of the White River uplift region of northwestern Colorado. The lower member of the unit, the Broken Rib Member, represents a normal marine carbonate platform succession. In the Flat Tops region, the Broken Rib Member is prolifically fossiliferous, containing a diverse record of infaunal, epifaunal, and nektonic organisms ranging from microscopic epifaunal algae to enormous armored fish. The overlying Coffee Pot Member of the Dyer Formation contains the signature element of the end-Devonian mass extinction—the Hangenberg isotopic excursion. This signal is recorded in depauperate carbonates dominated by micritic dolostone and limestone with rare oolite and microbialite. Like many Paleozoic carbonates, the Dyer contains rare fine clastic stringers and laminae composed of silt-sized angular quartz grains, and thin horizontally stratified clastic lags of granule- to pebble-sized chert and quartz. Abundance of reworked Paleoproterozoic and Mesoproterozoic detrital zircons in these clastics together with evidence for meteoric diagenesis suggests that these strata were deposited during lowstands when Cambrian sandstones like the Sawatch Quartzite were exposed and reworked into the system.

Notes

2022 ROCKY MOUNTAIN SECTION AAPG AWARDS

Current awards will be presented, and previous two years of award winners will be celebrated during the President's Reception on Monday night at the Denver Museum of Nature and Science. (Tickets required).

Robert J Weimer Lifetime Contribution Award

RANDI S. MARTINSEN

To recognize outstanding contributions to the practice of geoscience in the Rocky Mountains.

RMS-AAPG Distinguished Service Award

KIMBERLEE MISKELL GERHARDT, PH.D.

To recognize long-term beneficial service to the science and RMS-AAPG.

Julie A. Lefever Memorial Award

DONNA S. ANDERSON, PH.D.

To recognize those who have done and exceptional job at sharing geoscience knowledge with the science community and/or general public.

John D. Haun Landmark Publication Award

JANE E. ESTES-JACKSON
& DONNA S. ANDERSON, PH.D., EDITORS

Revisiting and Revitalizing the Niobrara in the Central Rockies, RMAG, 2011
To recognize the authors or editors of a book or publication that has had exceptional influence on developing new hydrocarbon plays within the Rocky Mountain Region.

Outstanding Young Professional Award

NATHAN LA FONTAINE

To recognize significant contributions by an individual with less than five years of experience.

Teacher of the Year Award

KRISTY COON

Naples Elementary School, Vernal, UT
The Teacher of the Year (TOTY) award is intended to honor and encourage excellence in geosciences education.

SHORT COURSE #1:
APPLICATION OF PETROLEUM GEOLOGY SKILLS TO THE GEOTHERMAL INDUSTRY

DATE: Saturday, July 23, 2022
TIME: 8:00 am to 5:00 pm
LOCATION: Geothermal: Granite C
INSTRUCTOR: Benjamin Burke, MBA, PhD, CTO of Transitional Energy

About this course:
This course introduces the technical professional who is familiar with oil and gas exploration, development and production workflows to the field of geothermal power generation and its direct use in a lecture-based format with supplementary material and R code. The concepts covered in this one-day course involve power generation and direct use cases, subsurface evaluation, and facilities engineering considerations in sedimentary basins.

Who should attend?
Geoscientists, geochemists, engineers, geotechnical professionals, land professionals, and executives who have an interest in learning about similarities and differences between oil and gas and geothermal workflows should attend this course, as well as anyone who is interested in learning how their thermal resources can be monetized. Lectures will be aimed at the technically minded while being not specific to geoscience. Supplementary material and code will allow geoscientists and engineers to take a deeper dive into the material.

SHORT COURSE #2:
PYTHON FOR GEOSCIENTISTS

DATE: Saturday, July 23, 2022
TIME: 8:00 am to 5:00 pm
LOCATION: Python: Granite A
INSTRUCTOR: Matthew Bauer, PG

About this course:
Practical Python for Earth Scientists is a hands-on course intended to introduce basic concepts and give working examples of python code that can be used in daily geoscience workflows. No prior knowledge of python or other programming languages is necessary to attend this course.

Who should attend?
This course is tailored for geologists, geophysicists, petrophysicists, petroleum engineers, production engineers, landmen, and anyone else that would like to gain skills in practical python programming, data mining, and machine learning. While this course will use examples from the petroleum industry, any earth scientist will benefit from learning about geospatial and subsurface data analysis.

SHORT COURSE #3:
SEQUENCE STRATIGRAPHY OF UNCONVENTIONAL RESOURCE PLAYS

DATE: Saturday, July 23, 2022
TIME: 8:00 am to 5:00 pm
LOCATION: Sequence Strat: Quartz A
**INSTRUCTOR**: Ali Jaffri, PhD

About this course:
This course introduces participants to the sedimentology of unconventional reservoirs and then covers sequence stratigraphic applications. Due to the homogeneous nature and limited thickness of most unconventional resource plays, seismic has very limited applicability. Therefore this is not a Seismic Stratigraphy course and the bulk of our time will be investigating these reservoirs using well logs (including borehole image logs), core and thin-sections. Each day of the course will be devoted to one play type with case-studies from popular oil and gas fields within North America. The instructor will provide a small collection of well logs and core photos, but we strongly urge participants to bring paper copies of their own data to work on. These data will not be shared with anyone and the instructor will only review the work done by participants.

Who should attend?
The audience for the course includes geologists, geophysicists and reservoir engineers who are involved in horizontal well planning and geosteering in unconventional reservoirs.
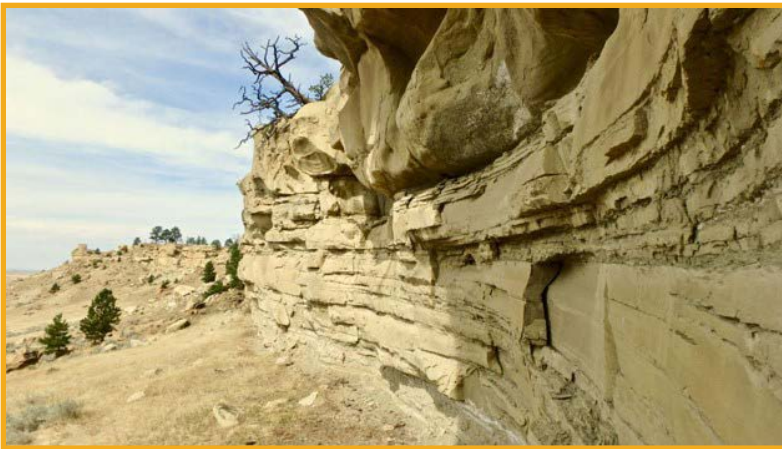
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SHORT COURSE #4:
EXPLORATION AND PRODUCTION OF NON-HYDROCARBON GASES AND FLUIDS: ENERGY MINERALS

DATE: Sunday, July 24, 2022
TIME: 8:00 am to 5:00 pm
LOCATION: Energy Minerals: Granite A
**INSTRUCTOR**: Steven Tedesco, PhD

About this course:
Learn how to add additional revenue to your production operations by leveraging produced gases and fluids. This short course covers several topics in energy minerals that can add additional revenue streams in hydrocarbon exploration and production. This hands-on course will cover critical minerals such as helium, lithium, and rare earth minerals extraction along with brine processing. We will discuss current produced fluid and brine processing methods prior to disposal back in the ground and the economic extraction of valuable energy minerals. We will also cover the basics of geothermal resources and crypto mining sources and economics. No prior knowledge of energy minerals production or exploration methods is necessary to attend this course.

Who should attend?
This course is geared for anyone that is interested in the exploration and production of energy minerals: geologists, geophysicists, development geologists, and production engineers. Anyone tasked with business development will benefit from learning about valuable additional cash flows and maximizing opportunity in the energy transition economy. While this course will use examples from the Petroleum and Helium industries, anyone eager to learn about mineral economics and analysis of gases and minerals will benefit.
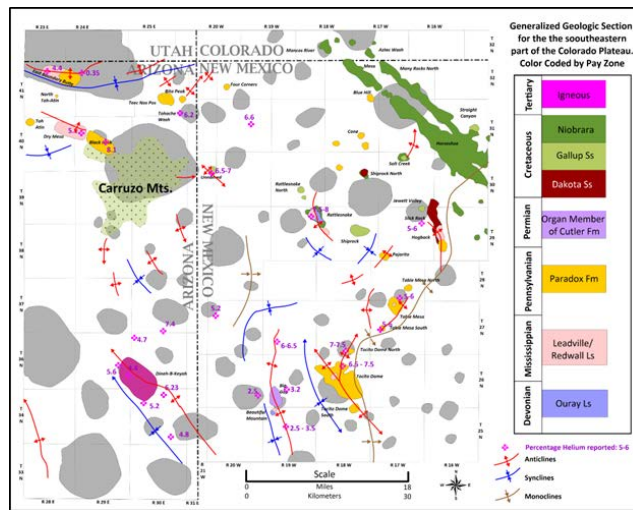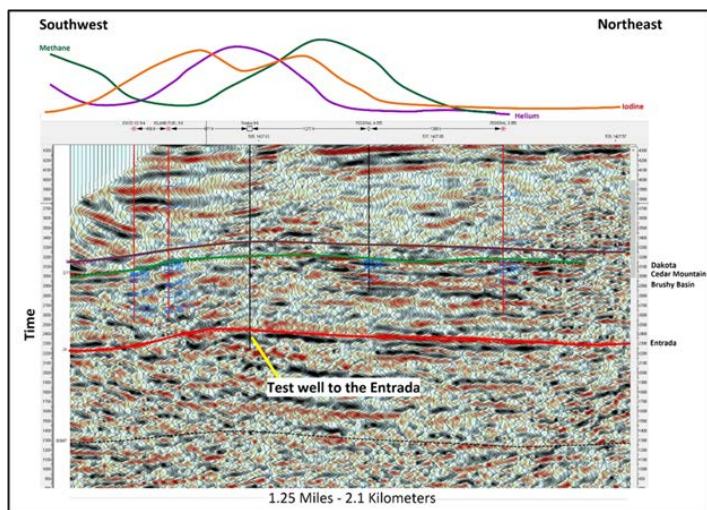
Notes

SHORT COURSE #5:
HOT TOPICS IN HYDROLOGY FOR THE PETROLEUM INDUSTRY

DATE: Saturday, July 23, 2022
TIME: 8:00 am to 5:00 pm
LOCATION: Hydrology: Quartz B
INSTRUCTOR: Dave Lipson, PhD

About this course:
Expand your skills to meet the increasing demand for quality ESG knowledge. This course will cover a range of topics that are important to Oil and Gas operators. We will begin with an introduction to water quality concerns, look at the issue of methane in water, consider the problem of supplying the large amounts of water needed for completions and how water law affects contamination and remediation. We will also look at emerging contaminants and practice applying existing skills to all these issues in a combined lecture and problem format.

Who should attend?
Geoscientists and engineers that need to deal with water quality and supply issues will benefit from this survey of the intersection of hydrology and oil and gas production. Anyone interested in transferring existing skills to the solution of hydrological problems will also benefit.

THANK YOU TO OUR SPONSORS

SUPPORTING THE STUDENT POSTER CONTEST PRIZES AND REDUCED OR FREE REGISTRATION FOR FIELD TRIPS AND SHORT COURSES

The 2022 AAPG Rocky Mountain Section Annual Meeting Field trips are brought to you by the host society: The Rocky Mountain Association of Geologists.

RMAG
ROCKY MOUNTAIN
ASSOCIATION
OF GEOLOGISTS

Pre-Conference

Stratigraphy and Reservoir Quality of the Mancos-Niobrara section as seen in Pagosa Springs and Durango (northern San Juan Basin)

DATES: Friday, July 22 - Sunday, July 24
INSTRUCTORS: Walter Nelson and Mark Leckie
COST: $700
STUDENT COST: $400

Includes travel from Denver and lodging in Durango.

Three-day field trip focused on understanding the regional changes in the Niobrara through the Western Interior Seaway. Trip will run between Denver and Durango, with overnight stays in downtown Durango. On the way to the San Juan Basin, we will first examine the Codell Sandstone, Juana Lopez, and lower Niobrara section in Pueblo before observing tremendous lateral changes from the Front Range to the Pagosa Springs area. From there we will observe more lateral changes in the lower Niobrara and Carlile sections as we work our way up-section and westward to focus in on stratigraphic changes in the Mancos and the characteristics of the prolific reservoir zones currently being explored across the basin. Trip participants will be able to view the full Niobrara marine cycle as represented in the Mancos Shale between Pagosa Springs and Durango. We will take the swift and scenic route through Buena Vista on the way back, with options for some brief geological and/or cultural stops if the group prefers.

Corral Bluff - an Exceptional Fossil Record from after the Cretaceous/Paleogene Mass Extinction

DATES: Sunday, July 24
INSTRUCTORS: Tyler Larson, James Hagadorn,
                             Gussie Maccracken
COST: $75
STUDENT COST: $50

Includes travel from Denver and lunch in the field.

Sixty-six million years ago a 10-kilometer-wide asteroid slammed into Earth and caused the extinction of more than 75% of life on Earth, including the dinosaurs. This was the single worst day for life on Earth. How and when life rebounded in the aftermath of the extinction has been shrouded in mystery due to a poor fossil record immediately after the mass extinction. An extraordinary new discovery at an area called Corral Bluffs, east of Colorado Springs, preserves a remarkably complete fossil record from this interval, illustrating how mammals, turtles, crocodiles, and plants rebounded after Earth's darkest hour. This field trip will focus on providing a progress report on how fossils, structures, and strata from the Cretaceous-to-Paleogene D1 Sequence at Corral Bluffs impact on our understanding of how Earth and life history changed during this interval.

Post-Conference

Front Range Sequence Stratigraphy Field Trip

DATES: Wednesday, July 27 and Thursday, July 28
INSTRUCTORS: Ali Jaffri
COST: $950

Includes travel from Denver, two nights lodging, and field snacks and refreshments.

This field trip runs between Fort Collins and Golden, Colorado and covers sequence stratigraphy of both siliciclastics and carbonates. Outcrops of Cretaceous marginal marine sandstones that host hydrocarbons in the Denver-Julesburg Basin provide an opportunity for participants to understand reservoir connectivity and compartmentalization. Arid carbonates of the Permian Ingleside-Owl Canyon Formations are an excellent reminder that not all sequence boundaries are associated with karstification and enhanced reservoir quality. Having taught sequence stratigraphy courses across the globe for over a decade we see a pattern in data interpretation pitfalls. The goal of this course to ensure that participants do not repeat sequence analysis mistakes that are rampant in our industry.

Who should attend: This course is meant for all who wish to develop a better understanding of sequence stratigraphy and factors that control distribution, quality, connectivity, and compartmentalization in shallow marine siliciclastic and carbonate reservoirs. The course assumes no prior knowledge of sequence stratigraphy, which is why we strongly urge engineers to enroll.

MONDAY, JULY 25

Time	Room	Session
8:35: am - 10:15 am	Centennial Ballroom E	Opening Plenary - Welcome to RMS 2022
10:15 am		**BREAK**
10:35 am - 11:15 am	Centennial Ballroom E	Remembering Bob Weimer and his Contributions to Rockies Geology
10:35 am - 11:15 am	Centennial Ballroom F, G	Technological & Analytical Tools for Energy Development
11:50 am		**LUNCH** *(All Convention Luncheon, Tickets Required)*
1:35 pm - 3:15 pm	Centennial Ballroom E	Petroleum Systems in the Rocky Mountain Region
1:35 pm - 3:15 pm	Centennial Ballroom F, G	Geological characterization and petroleum targets of the Green River Formation, Uinta Basin
3:15 pm		**BREAK**
3:40 pm - 4:30 pm	Centennial Ballroom E	History of Petroleum Geology in the Rockies
3:40 pm - 4:30 pm	Centennial Ballroom F, G	Geological characterization and petroleum targets of the Green River Formation, Uinta Basin
ALL DAY	Centennial Ballroom H	Professional Posters

TUESDAY, JULY 26

Time	Room	Session
8:35: am - 10:15 am	Centennial Ballroom E	The Cane Creek Petroleum Play, Paradox Formation, Utah
8:35: am - 10:15 am	Centennial Ballroom F, G	Carbon Capture, Utilization, and Sequestration in the Rockies
10:15 am		**BREAK**
10:35 am - 11:15 am	Centennial Ballroom E	The Cane Creek Petroleum Play, Paradox Formation, Utah
10:35 am - 11:15 am	Centennial Ballroom F, G	Carbon Capture, Utilization, and Sequestration in the Rockies
11:50 am		**LUNCH**
1:35 pm - 3:15 pm	Centennial Ballroom E	Applications of Geochemistry to Petroleum Systems
1:35 pm - 3:15 pm	Centennial Ballroom F, G	Geothermal Energy Resources in the Rockies and Beyond
3:15 pm		**BREAK**
3:40 pm - 4:55 pm	Centennial Ballroom E	Stratigraphy & Sedimentology
3:40 pm - 4:55 pm	Centennial Ballroom F, G	Using Machine Learning to Supplement Geology
4:55 pm		**BREAK**
ALL DAY	Centennial Ballroom H	Student Posters

WEDNESDAY, JULY 27

Time	Room	Session
8:35: am - 10:15 am	Centennial Ballroom E	Innovative Workflows for Energy Geoscience
8:35: am - 10:15 am	Centennial Ballroom F, G	Assessment of Energy Resources
10:15 am		**BREAK**
10:35 am - 11:15 am	Centennial Ballroom E	Applications of Geochemistry to Petroleum Systems
10:35 am - 11:15 am	Centennial Ballroom F, G	Structural Geology & Salt Tectonics

TECHNICAL PROGRAM

MONDAY MORNING ORAL SESSIONS

Opening Plenary - Welcome to RMS 2022!
Centennial Ballroom E
Session Chairs: Larry Rasmussen, Thomas Hearon

8:35 am **Welcome to the 2022 Rocky Mountain Section AAPG Meeting!**
Anna Phelps

9:00 am **100 Years! Celebrating RMAG's Past, Present & Future**
Rob Diedrich

9:25 am **The best strategies for effective cross-over training for geoscientists seeking to diversify**
Susan Nash

9:50 am **Niobrara Production from the Lowry-Bombing Range Area Denver Basin, a Deep-Basin, Continuous, Paleostructural Trap**
Steve Sonnenberg

Remembering Bob Weimer and his Contributions to Rockies Geology
Centennial Ballroom E
Session Chairs: Matt Silverman, Steve Sonnenberg

10:35 am **Integrating industry concepts with university learning: Attempting to combine classroom learning and workplace training**
Marron Bingle-Davis

11:00 am **Dakota Group Fluvial Systems of the Colorado Front Range: Provenance, Geochronology, and Paleogeographic Significance**
Mike Blum

11:25 am **Ten Million Years of Dakota Sandstone**
David Sawyer

Technological & Analytical Tools for Energy Development
Centennial Ballroom F,G
Session Chairs: Kevin Wutherich, Alan Lindsey

10:35 am **Using Drilling Data to Characterize Reservoirs**
Kevin Wutherich

11:00 am **Well Music: Translating Well Data to Music for a New Perspective**
Alan Lindsey

11:25 am **Field-Based Removal of Hydrogen Sulfide from Carbon Dioxide and Natural Gas Sample Streams without Geochemical Alteration**
Douglas B. Decker

MONDAY AFTERNOON ORAL SESSIONS

Petroleum Systems in the Rocky Mountain Region
Centennial Ballroom E
Session Chairs: Timothy Nesheim, Ron Broadhead

1:35 pm   **Codell continuous oil accumulation in the northern Denver Basin as defined by resistivity, density, and SP logs**
Steve Cumella

2:00 pm   **Examination of the unconventional resource potential of the Mississippian Madison Group within the Williston Basin**
Timothy O. Nesheim

2:25 pm   **Using Seismic Characterization to Support a New Horizontal Program at Jonah Field, WY**
Cory H. Christie

2:50 pm   **The offshore Mancos play in the San Juan Basin: productive carrier beds within the Mancos total petroleum system**
Ronald F. Broadhead

Geological characterization and petroleum targets of the Green River Formation, Uinta Basin
Centennial Ballroom F,G
Session Chairs: Riley Brinkerhoff, Ryan Gall

1:35 pm   **Characterization of an Unconventional Resource, Uteland Butte member, Lower Green River Formation, Uinta Basin, Utah**
Lucas J. Fidler

2:00 pm   **Using Pore System Characterization to Subdivide the Burgeoning Uteland Butte Play, Green River Formation, Uinta Basin, Utah**
Riley Brinkerhoff

2:25 pm   **Outcrop characterization and depositional model of the Uteland Butte member, Green River Formation, Uinta Basin, Utah**
Ryan Gall

2:50 pm   **Detailed geochemical characterization of the lower part of the Green River Formation in south-central Uinta Basin, Utah**
Justin E. Birdwell

3:15 PM   **BREAK**

3:40 PM   **Strain segregation between ductile and brittle stratigraphy–Characterizing the Sand Wash Fault System, Uinta Basin, Utah**
Riley Brinkerhoff

4:05 PM   **Depositional Architecture of a Turbiditic Sandstone Complex, Lower Green River Formation, Uinta Basin, Utah**
Matthew A. Jones

4:30 pm   **Molecular and bulk geochemical indicators of early thermal maturation in the Mahogany zone oil shale of the Green River Formation, Uinta Basin, Utah**
Justin E. Birdwell

MONDAY AFTERNOON ORAL SESSIONS *Continued*

History of Petroleum Geology in the Rockies
Centennial Ballroom E
Session Chairs: Matt Silverman, Mitchell Grimm

3:40 PM   **Ninetta Alia Davis: First Female President of RMAG**
Robbie R. Gries

4:05 PM   **History of Petroleum Development in Utah**
Thomas C. Chidsey, Jr.

4:30 PM   **From the Civil War to the Jazz Age: Isaac Canfield's 60-year career as an oil dowser**
Daniel J. Plazak

MONDAY POSTER SESSIONS

Professional Posters
Centennial Ballroom H
Session Chair: Justin Birdwell

Placards will be posted at each poster display indicating the times when the presenter must be available to discuss their poster with attendees. Each presenter is asked to be available to attendees for a minimum of 90 minutes over the course of the day their poster is displayed.

All Day   **Geologic characterization of the newly acquired State 16-2 Cane Creek research core, Pennsylvanian Paradox Formation, northern Paradox Basin, southeastern Utah**
Michael D. Vanden Berg

All Day   **Comparison of geochemical properties and mineralogical data from core and cuttings samples**
Justin E. Birdwell

All Day   **New USGS Assessment of Continuous Oil Resources of the Bakken and Three Forks Formations in the Williston Basin (North Dakota and Montana, USA)**
Kristen R. Marra

All Day   **Temperature mapping within the onshore oil and gas production region of the U.S. Gulf Coast Basin**
Justin E. Birdwell

All Day   **The Department of Energy's Advances Towards a Sustainable CM/REE Supply Chain**
Savannah L. Rice

All Day   **Defining the onset of oil generation in the Bakken Formation using thermal maturity series obtained from nonisothermal experiments and an extended kinetic method.**
Stephan H. Nordeng

All Day   **Advanced Aspects Of Groundwater Flow And 3D Geologic Models In The Oil Shale Basins, Jordan**
Paul G. Quinn

All Day   **Differences in oil shale organic matter across Eocene Lake Uinta inferred from Fischer assay data**
Justin E. Birdwell

All Day   **Paleoseismites in San Juan Basin fluvial sedimentary rocks indicate syndepositional seismicity in the Paleocene and Eocene**
Kevin M. Hobbs

All Day   **Using Physics to Prevent Oil & Gas Production Problems**
Brian Clemishire

All Day   **Fast-tracking conventional reservoir development and carbon management within the footprint of unconventionals**
Susan Nash

TUESDAY MORNING ORAL SESSIONS

The Cane Creek Petroleum Play, Paradox Formation, Utah 1
Centennial Ballroom E
Session Chairs: Mike Vanden Berg, Elliot Jagneki

8:35 am	**Sedimentology and Reservoir Characterization of the Emerging Cane Creek Play, Paradox Formation, Northern Paradox Basin, Southeastern Utah** *Elliot Jagniecki*
9:00 am	**Value Creation in the Northern Paradox Basin – paradoxical or not?** *Gregor Maxwell*
9:25 am	**Core Characterization of the Cane Creek Interval in the Paradox Formation from the State 16-2 Well** *Thomas J. Paronish*
9:50 am	**Subsurface constraints on Paradox Basin thermal history from borehole (U-Th)/He thermochronology within the Cane Creek petroleum play, southeastern Utah** *Eugene Szymanski*
10:15 am	**BREAK**
10:35 am	**Fracture Characterization of the Cane Creek Play, Paradox Formation, Southeastern Utah: A Multi-Scale Approach Incorporating the Geology and Petrology of Core and Well Cuttings** *Patrick N. Gathogo*
11:00 am	**Using Viscoplastic Stress Relaxation Theory on Core Measurements to Determine the Least Horizontal Principal Stress** *Kevin Lynn McCormack*
11:25 am	**Mining Brines: A New Exploration and Production Model for the Minerals Extraction Industries** *Thomas B. Smith*

Carbon Capture, Utilization, and Sequestration in the Rockies 1
Centennial Ballroom F,G
Session Chairs: Breck Johnson, Eugene Szymenski

8:35 am	**Integrated Reservoir Characterization for Hydrocarbon Exploration & Production, CO2 Sequestration, and Critical Mineral Resource Exploration & Production** *Calvin C. Reppe*
9:00 am	**Mitigating Geologic Risk Uncertainty for Carbon (CO2) Sequestration in Multiple Subsurface Targets in the Iron Springs District, Iron County, Utah** *Eugene Szymanski*
9:25 am	**Feasibility Study of Utilizing Water Disposal Wells to Inject Carbonated Water into Selected Formations in Oklahoma for the Purpose of CO2 Storage** *David Nnamdi*
9:50 am	**CCUS Risk Evaluation in the San Juan Basin Using Rock Volatiles Stratigraphy - Identification of Fractures and Lateral Migration Pathways and Implications for CO2 Injection and Storage** *Christopher M. Smith*
10:15 am	**Break**
10:35 am	**State of stress in southeastern Utah** *No'am Z. Dvory*
11:00 am	**TBD**
11:25 am	**Quantifying Rock Characteristics in the San Andres Formation that Promote CO2 Sequestration, Permian Basin, USA** *Mitchell T. Schneider*

TUESDAY AFTERNOON ORAL SESSIONS

Applications of Geochemistry to Petroleum Systems 1
Centennial Ballroom E
Session Chairs: Justin Birdwell, Stephen Nordeng

1:35 pm	**An Integrative Approach to Geochemical Production Allocation in the Northern Denver Basin Using Quantitative Chromatographic Fingerprinting** *Luke A. Arnsberger*
2:00 pm	**Optimizing Field Development in the Powder River Basin Using Geochemical Fingerprinting Technology** *E.M. Bergin*
2:25 pm	**Focused Investigation, Insights and Impact of Fluid-Filled Storage Volume; A Case Study in the Niobrara-Codell of the DJ Basin** *J. Alex Zumberge*
2:50 pm	**Correlations Between Petroleum Systems and Serpentinization** *Monte Swan*

Geothermal Energy Resources in the Rockies and Beyond
Centennial Ballroom F,G
Session Chairs: Emilie Gentry, Karen Lechtenberg

1:35 pm	**The Identification and Characterization of Sedimentary Geothermal Play Types on the Texas Gulf Coast for Power Generation** *Eric Stautberg*
2:00 pm	**Volatiles Analysis of Cuttings from the FORGE 58-32 Well-"Logging" High Temperature Wells, Evaluating Communication Pathways, and Implications for Completions in Enhanced Geothermal System Wells** *Christopher M. Smith*
2:25 pm	**Advancement of Geothermal Resources and Research in Utah, USA** *William Hurlbut*
2:50 pm	**Geothermal Resource and Synthetic Geothermal Reservoir Feasibility Study of Wyoming** *Emilie N. Gentry*

Stratigraphy & Sedimentology
Centennial Ballroom E
Session Chairs: Jesse Melick, Kevin Hobbs

3:40 pm	**New Horizontal Play Targeting Fluvial Sandstones in a Basin-Centered Gas System around Jonah Field, WY** *John C. Hoopes*
4:05 pm	**Paleohydraulic Analysis of Meandering River Deposits, Petrified Forest National Park, Arizona** *Thomas P. Martin*
4:30 pm	**Stratigraphic Framework of the Deadwood Formation of North Dakota** *Jeffrey W. Bader*

Using Machine Learning to Supplement Geology
Centennial Ballroom F,G
Session Chairs: Michael Harty, Thomas Martin

3:40 pm   **Using Data Analytics to Explore "J" (Muddy) Channel Sandstones in the Denver-Julesburg Basin and Test a ML Exploration Technique**
R. Mark Maslyn

4:05 pm   **Automating Raster Well Log Preparation with Python: Depth Registration, Straightening, and Track Identification**
Matthew W. Bauer

4:30 pm   **Data Analytics and Machine Learning to Predict Sedimentary Architecture**
Lisa Stright

TUESDAY POSTER SESSIONS

Student Posters
Centennial Ballroom H
Session Chair: Lisa Stright

Placards will be posted at each poster display indicating the times when the presenter must be available to discuss their poster with attendees. Each presenter is asked to be available to attendees for a minimum of 90 minutes over the course of the day their poster is displayed.

All Day   **Future of Core-scale analysis: Machine-Learning**
Thomas P. Martin

All Day   **Feasibility Study of Utilizing Water Disposal Wells to Inject Carbonated Water into Selected Formations in Oklahoma for the Purpose of CO2 Storage**
David Nnamdi

All Day   **Facies, Stratigraphy, and Reservoir Heterogeneity of the Upper Wolfcamp Formation (Wolfcamp A Equivalent) in the Glass Mountains of West Texas**
N.M. Dusak

All Day   **Hyperspectral Scan Imagery and XRD Identification of Carnallite as a Potash Source in Brines Associated with Ordovician and Silurian Formations in the Williston Basin, North Dakota**
M.A. Vasquez

All Day   **Modeling of Channel Stacking Patterns Controlled by Near Wellbore Modeling**
Luis C. Escobar Arenas

All Day   **Reservoir Quality on the Lewis Shale for horizontal drilling**
Ligia Carolina Mayorga-Gonzalez

All Day   **Insights into mudstone sedimentology, organic richness, and anoxia at the opening of the Cretaceous Interior Seaway: The Lower Cretaceous Skull Creek Formation, Colorado**
Patrick M. Sullivan

All Day   **Depositional setting and paragenesis of silica nodules from the Middle Jurassic Curtis Formation on the eastern flank of the San Rafael Swell, central Utah**
Eric Stautberg

All Day   **Comparison of the Upper Cretaceous Greenhorn Formation in cores from the Denver-Julesburg Basin; implications Ocean Anoxic Event 2 in the Western Interior Sea**
Christopher C. Matson

All Day   **Influences on mechanical properties of the Upper Wolfcamp (XY) of the Delaware Basin, west Texas, and their relationship with facies and facies architecture.**
Israel A. Jaramillo

All Day   **Quantifying Rock Characteristics in the San Andres Formation that Promote CO2 Sequestration, Permian Basin, USA (see also CCUS oral session)**
Mitchell T. Schneider

All Day   **Machine learning prediction of slope channel facies using outcrop analog data, Tres Pasos Formation, Magallanes Basin, Chile**
Patrick Ronnau

WEDNESDAY MORNING ORAL SESSIONS

Innovative Workflows for Energy Geoscience
Centennial Ballroom E
Session Chairs: Chris Matson, Riley Brinkerhoff

8:35 AM	**Multidisciplinary Approach to Niobrara Gas Development in an Overlooked High Temp, High Pressure Reservoir: A Southeast Piceance Case Study** *Barrett A. Lavergne*
9:00 AM	**A core competency: Digitalizing core data for better energy-resource and mineral prediction** *Zane R. Jobe*
9:25 AM	**Case Study of Optimizing Oil Recoveries and Parent-Child Relationships in the Gallup Sandstone, San Juan Basin, New Mexico** *Matt P. Slowinski*
9:50 AM	**Pitfalls of Model-Driven Unconventional Development – The Stratigraphic Trends that Drive Oil & Gas Productivity in Divide County, North Dakota** *Riley Brinkerhoff*

Assessment of Energy Resources
Centennial Ballroom F,G
Session Chairs: Wylie Walker, K.C. Oren

8:35 AM	**Chemical Tracers for Empirically-based Resources Assessment and Data Driven Valuations throughout an Asset's Life** *K.C. Oren*
9:00 AM	**Fast-tracking conventional reservoir development and carbon management within the footprint of unconventionals** *Susan Nash*
9:25 AM	**Market Evidence of Reserve Adjustment Factors and Risk Adjusted Discount Rates in a North American Unconventional Play** *Nicholas D. Kernan*
9:50 AM	**Importance of Probability Distributions on Volumetric Characterizations in Resource Assessment** *David M. Advocate*

Applications of Geochemistry to Petroleum Systems 2
Centennial Ballroom E
Session Chairs: Justin Birdwell, Stephen Nordeng

10:35 AM	**Methodology to Estimate Thermal Maturity from Petrophysical Calculations of Gas/Oil Ratios** *Michael Holmes*
11:00 AM	**Organic Petrography of the Ordovician Red River Kukersite Tight Oil and Gas Play, Williston Basin, North Dakota, U.S.A.** *Wayne Camp*
11:25 AM	**Estimating total organic carbon content in Green River Formation oil shales using elemental data and multivariate analysis** *Tengfei Wu*

Structural Geology & Salt Tectonics
Centennial Ballroom F,G
Session Chairs: Jesse Melick, Kyle Bracken

10:35 AM **Preliminary assessment of arch-top lineaments in Laramide arches, Wyoming–Montana (USA), and Ga-scale tectonic significance**
Jeffrey W. Bader

11:00 AM **The Sage Breaks scour event and its influence on layer-bound normal faulting within the Niobrara and Turner formations, Southern Powder River Basin, Wyoming**
Kyle, A. Bracken

11:25 AM **TBD**

Notes

Importance of Probability Distributions on Volumetric Characterizations in Resource Assessment

ADVOCATE, DAVID M., Retired Geologist; Kenneth C. Hood, Retired Geologist

Before making investment decisions for hydrocarbon opportunities, explorationists need to realistically evaluate chance of geologic and commercial success. Proper characterization of volume uncertainty, typically using statistical methods to evaluate parameters required for a hydrocarbon accumulation (porosity, net-to-gross, etc.), is essential. Use of past venture analysis has documented the tendency of industry to systematically overestimate the expected mean accumulation size and underestimate the volume range for undrilled prospects. Often such optimistic expectations result from improper characterization of the range and variance of volumetric input parameters.

The preferred choice of probability types used has long been a topic of debate and typically include Lognormal, Normal, Triangular, Beta, Uniform, and Gamma. When assigning distribution type and range, one must consider what each distribution represents. For parameters such as reservoir thickness or porosity, which have spatial or stratigraphic variations in measured values, the distribution represents uncertainty in the mean value for the evaluation unit. Generally, the distribution should be narrower than the range of individual measurements, but if biased, the range could be wider than or offset to measurements. For parameters such as closure area and height that will ultimately be a single measured value, the input distribution represents the range and probability of potential values. The granularity of the volumetric equation can vary, such as gross rock volume as a single aggregate parameter or as multiple input components. Use of multiple components is preferable to enable better control over the uncertainty distribution. Fluid contacts are complex and may be poorly represented by a simple distribution.

In this presentation, we discuss strengths and weaknesses of various options and argue that the Beta distribution is well suited for most symmetrical and asymmetrical volumetric inputs. By using modified inputs, the Beta distribution can be defined using minimum, maximum, mode, and dispersion (λ) parameters. Increasing parameter variance within the defined range is crucial, as the range may be limited by low-end cutoffs (e.g., minimum porosity cutoff) and high-end physical limits (e.g., net-to-gross less than 1). Because naturally unbounded distributions (e.g., Lognormal) must be truncated, the bounded Beta distribution is more intuitive and can reasonably represent the appropriate level of skewness. We discourage using intermediate input values (e.g., P90 and P10 rather than min and max) and allowing software to extend the range, as this approach can result in unforced errors (extending ranges outside of allowable range) and obscure the ability to learn as prospects are drilled. It is preferable to follow a well-defined workflow to ensure that the range is sufficient rather than depending on software to correct for user underestimation of the range.

Assessment of Energy Resources, Wednesday, July 27, 9:50 AM

An Integrative Approach to Geochemical Production Allocation in the Northern Denver Basin Using Quantitative Chromatographic Fingerprinting

ARNSBERGER, LUKE A., Dolan Integration Group; Patrick Travers; Dolan Integration Group; Benjamin C. Burke; Casco Consulting; Megan Essig; Dolan Integration Group; Alexander S. Moss; Dolan Integration Group; Michael P. Dolan; Dolan Integration Group

Geochemical fingerprinting techniques have increased in analytical ease and decreased in cost over the last decade as a tool for characterizing produced fluids. Specifically, the adoption of comprehensive methods with increased statistical rigor makes Whole Oil Gas Chromatography (WOGC) a highly cost competitive approach for allocating produced oil reservoirs. Using WOGC peak ratios to allocate produced oils is a well-established alternative to conventional production logging techniques. However, several challenges have limited the scope of its application in the past: an inability to compare raw data taken from laboratories using different analytical methods and software outputs, and the laborious manipulation of data required to compare results from different studies.

This study proposes a systematic, statistics-based mixing model using WOGC peak height ratios to solve production allocation problems. Within the model, an algorithm consolidates raw geochemical data, solves mixing equations with variable input parameters, and identifies possible endmember production streams. The model uses height ratios between neighboring peaks across the entire chromatogram, rather than only comparing a few manually selected peak pairs. Each ratio's importance in satisfying a set of linear mixing equations is weighted by statistical variance, allowing for an accurate, high-resolution characterization of mixed production oils. Error profiling provides a quantifiable means of justifying endmember selection and assessing soundness.

This method was applied to a set of 198 oils from wells producing in Hereford Ranch Field in Weld County, Colorado. The wells range from 5,800 to 7,800 ft in vertical depth and target 5 pay zones, with primary zones being the Niobrara Shales and the Codell Sandstone. HCA and PCA multivariate statistical analyses on 117 common WOGC peak ratios exhibited significant resource and production data differences across the dataset. The proposed method defined endmembers representing the two major pay zones and geochemically characterized zone contributions in production samples throughout time. The analysis of synthetic oil mixtures that range from a pure combination of assumed endmembers to a combination of unrelated oils provided quality assurance and quality control to these characterizations.

The proposed method aims to utilize a maximal amount of information from WOGC analysis without compromising efficacy or being a "black box". The algorithm provides the functionality necessary for the long-term integration and comparison of fingerprinting results across different studies and different laboratories. The case study demonstrates how correlating production data with mixing model results may characterize source contribution and draw-down of production wells over time. The results provide insight into how the proposed fingerprinting technique may inform allocation and spacing decisions as well as increase development efficiency for operators.

Applications of Geochemistry to Petroleum Systems, Tuesday, July 26, 1:35 PM

Preliminary assessment of arch-top lineaments in Laramide arches, Wyoming–Montana (USA), and Ga-scale tectonic significance

BADER, JEFFREY W., North Dakota Geological Survey; Jacob O. Thacker, New Mexico Bureau of Geology and Mineral Resources; Abdelmalek Abes, University of North Dakota; Yasser Laichaoui, University of Sciences and Technology; Houari Boumediene, Algeria

Lineaments within basement exposures in Wyoming and Montana may provide clues for fault reactivation during the Late Cretaceous–Paleogene Laramide orogeny. They are km-scale and occupied by erosional valleys within Archean granitic and high-grade metamorphic rocks atop Laramide arches. Some lineaments are previously mapped as dikes and faults. The nature and origin of these features have received little attention and have not been analyzed with modern tools or in the context of plate tectonics. It is suspected their formation is likely related to: 1) lithology; 2) regional strain during Precambrian and/or Laramide tectonism; and/or 3) localized strain. We present a geospatial analysis of lineaments from the Beartooth Mountains (MT-WY) using ENVI and GIS software to assess genetic relationships, possible origins, and possible implications for tectonics, natural resources, and geomorphic response.

Beartooth Mountains lineaments range in length from < 1 km to 35 km. Straight geometries across peak and valley topography suggests that the lineaments are planar sub-vertical features (joints and/or faults). Four orientations are apparent: NE-SW, WNW-ESE (dominant), and ENE-WSW, NW-SE (less dominant). These orientations are comparable but not exclusive to Proterozoic dikes mapped at scale 1:125,000 in the southeast part of the range. A Precambrian age of formation for the features is suggested by the similarity between Precambrian dike orientations, and apparent lack of such features in Cambrian and younger sedimentary cover (e.g., Beartooth Butte).

Orientations are consistent with formation as conjugate fractures/faults formed under NE–SW (latest Neoarchean) and NW–SE (Paleoproterozoic) contraction inboard of Precambrian convergent margins, and at the very least suggest that a basement structural framework was established on this part of the Wyoming Province during the Precambrian. Evidence for dextral ductile shear along NE–SW structures also suggests a Precambrian origin for these features. However, reactivation of this structural framework appears likely, as faults of similar orientation to lineaments accommodated movement during the Laramide, most notably along trends that are oriented WNW-ESE (ESE-striking segment of Beartooth thrust and the Nye Bowler fault zone) and NE-SW (SSW-striking segment of Beartooth thrust and the Fromberg fault zone). Brittle deformation, possibly attributable to Laramide orogenesis, is also indicated where faults along these trends cut Precambrian intrusions. Continued work will assess similar features in Laramide ranges across Wyoming to develop a regional-scale model of the structural framework and its possible role on fault reactivation from Precambrian to present.

Structural Geology & Salt Tectonics, Wednesday, July 27, 10:35 AM

Stratigraphic Framework of the Deadwood Formation of North Dakota

BADER, JEFFREY, W., North Dakota Geological Survey

The North Dakota Geological Survey (NDGS) is currently conducting studies of the Cambro-Ordovician Deadwood Formation (Deadwood) because of the increased interest in carbon dioxide storage in underground saline aquifers. These studies are being performed to develop a detailed stratigraphic framework for the Deadwood in the Williston Basin. Three detailed cores are presented with one consisting of a complete core across the entire Deadwood interval from Oliver County, North Dakota (NDIC #37672–J-ROC1 1). Four subsurface cross-sections utilizing these cores for control are also presented.

The Deadwood Formation consists of marginal and shallow marine sedimentary units; dominantly thick, porous, and permeable sandstone and limestone that are present at great depths and thus are ideal for carbon dioxide sequestration. The Deadwood represents two 3rd-order depositional sequences deposited in an overall 2nd-order transgressive-regressive cycle in the Late Cambrian and Early Ordovician Periods. In general, the lower sequence (member A) represents the initial sea-level rise during the Cambrian and consists of fluvial-deltaic and eolian deposits that give way to more marginal marine (member B) and nearshore progradational deposits (members C-F) that shallow upwards as represented by 4 parasequences of the highstand normal regression of the upper sequence.

Stratigraphy & Sedimentology, Tuesday, July 26, 4:30 PM

Automating Raster Well Log Preparation with Python: Depth Registration, Straightening, and Track Identification

BAUER, MATTHEW W., Colorado School of Mines

Raster well logs require manual processing prior to utilization for interpretation by a geologist. While logs vary in format by vendor they generally share a similar format of header, left track, depth track, right track, and footer. By locating these components of the log within the raster image we can automate the normally manual workflows of depth registration, straightening, and track identification.

This study uses the mean values across the x and y axes of the image array to locate the log components and classify log run from header sections. Within log run sections the locations of the left edge of the left track can be aligned with dynamic time warping (DTW) with the offset adjusted thereby straightening the log image. By identifying the location of the depth tract this portion of the image can be cropped, segmented, and enlarged to increase the accuracy of digitization of depths with optical character recognition (OCR). Log curve names and scales for the left and right tract are identified with a similar process of cropping the tract header, digitizing the text with OCR, and searching an alias list with a Levenshtein Distance string match. This information can then be used to construct a depth registration file for the log image which also identifies separate logging runs and the log scale. Log tracks referenced within the raster images can be used by geologic interpretation software to show a desired log tract rather than the whole log width.

Preliminary results using array mean values across each axis have

yielded significant progress to automating the workflow compared to previous attempts. Work continues to improve the classification of log and header tracts on logs with a higher percentage of black pixels such as concrete bond logs. This automated workflow has wide application for making large log datasets usable without manually straightening and depth registering them prior to use.

Using Machine Learning to Supplement Geology, Tuesday, July 26, 4:05 PM

Optimizing Field Development in the Powder River Basin Using Geochemical Fingerprinting Technology

BERGIN, E. M., Anschutz Exploration Corporation; Jin, M; RevoChem; Liu, Y; Wu, J; Liu, F

Thousands of hydrocarbon compounds naturally occur in produced oil and oil extracted from core or cuttings samples. These compounds carry a tremendous amount of information on reservoir properties and subsurface fluid flow. In this study, we present a methodology based on high-resolution GCXGC geochemical data collected from cuttings and produced oil samples, to provide quantitative zonal contribution and vertical drainage height information, identify shared contribution between stacked wells, decipher the effectiveness of believed frac barriers, and optimize landing selections.

Water-based mud cuttings samples were collected and used to extract geochemical fingerprint data to establish a vertical baseline to identify where each formation showed a distinct geochemical pattern. A group of geochemically derived Reservoir Characterization Indices (RCI) were also calculated to provide key reservoir properties such as permeability and oil saturation. Time-lapse produced oil samples were then collected from multiple producers landed in different targets of the Niobrara and Turner formations. These oil samples were allocated back to the appropriate contributing zones using regression models, based on the geochemical fingerprint data established from the vertical baseline wells, to reveal the temporal and spatial variation of the effective drained rock volume (DRV) of each well. The probability of inter-well fluid communication between well pairs is also calculated based on the similarity of the geochemical fingerprints of the produced oils.

A case study in the southern Powder River Basin demonstrates how Anschutz integrated the data into spacing, landing, and reservoir workflows. The three main takeaways so far are: 1) limited fluid communication is observed between Niobrara-landed wells and the offset Turner-landed wells in the study area, leading to different infill and well management decisions, 2) Turner wells showed limited upward drainage from the Niobrara, indicating either limited upward frac growth or frac closure, 3) Data from wells landed within different benches of the Upper Niobrara all showed contribution from the entire Upper Niobrara interval, but the contribution from the higher bench diminished through time, leading to a review of landing targets, 4) P80 drainage frac heights of Niobrara producers varied between ~155' to 235' while frac heights for Turner producers are smaller at ~100' to 190'. Results from this study were validated with pressure, completions, and tracer data, and confirmed that geology, adjacent well placement, and well completions all have impacts on drainage profiles in both formations.

Results from this studies has facilitated the optimization of future landing zones and well spacing, and may lead to improved economic recovery of stacked plays in the Powder River Basin.

Applications of Geochemistry to Petroleum Systems, Tuesday, July 26, 2:00 PM

Integrating industry concepts with university learning: Attempting to combine classroom learning and workplace training

BINGLE-DAVIS, MARRON J., Sunshine Valley Petroleum Corp & Casper College; Mike A. Bingle-Davis; Kirkwood Oil & Gas

Transitioning from the university setting to industry is a daunting proposition. The suggestion that you will learn what you need on the job is a common theme and can be overwhelming. Universities are great at conveying fundamental concepts to students, but many have fallen short when it comes to teaching certain techniques and knowledge that are utilized in the workplace. The university system emphasizes traditional geology classes, like mineralogy or sed/strat, which are necessary; However, strict traditional geological education is often not enough preparation for industry careers. Integration of basic geologic concepts and tools and techniques used in industry is the key to better preparing students for after graduation. Teaching workplace standards like building cross-sections and making maps in conjunction with geology fundamentals like mineral chemistry and sedimentary structures will leave students with not only concepts but also applications. Recently this concept was applied to a mineralogy class with a lesson on physical properties of minerals. The lecture incorporated typical concepts like hardness and crystal habit, but also included economic minerals and how their properties influence how they are utilized. In the lab, students first learned how to identify mineral properties and then matched hand samples with associated products based on these properties. The feedback was encouraging on both the lecture and lab and will be further developed in other classes. This integration methods provides students with not only a base knowledge of geology but a smoother transition into actual workplace practices.

Remembering Bob Weimer and his Contributions to Rockies Geology, Monday, July 25, 10:35 AM

Comparison of geochemical properties and mineralogical data from core and cuttings samples

BIRDWELL, JUSTIN E., U.S. Geological Survey; Jason A. Flaum, U.S. Geological Survey; Stanley T. Paxton, U.S. Geological Survey

Evaluation of mudstone properties is an important step in characterization and assessment of source rocks and other petroleum system studies. Generally, cuttings material is more likely to be available than core, and though cuttings are usually collected at relatively low resolution (10's of feet), they can still provide useful analytical results, although some information on variability at finer scales is lost. However, the degree to which well cuttings represent the variations in different mudstone properties or show differences between stratigraphic packages is not often evaluated. During drilling of a shallow (178 to 650 feet) borehole through the Cenomanian-Turonian in the Texas outcrop belt near Dallas using an air hammer drilling system, care was taken to

collect representative cuttings every 10 feet through roughly 450 feet of strata. Samples were also collected roughly every two feet from a core drilled approximately 20 feet from where the cuttings were obtained. The studied interval focuses on the informal upper and lower parts of the Eagle Ford Shale. In an initial survey of core properties, samples were taken every two feet for evaluation. Total organic carbon (TOC) content, programmed pyrolysis parameters, major and trace elements concentrations, and X-ray diffraction mineralogy were determined on both the core samples and aliquots of the cuttings. A rough comparison of the average values from the core samples corresponding to intervals for which cuttings were collected showed reasonable agreement. Bulk organic parameters, as well as major and trace elements in the averaged core intervals and cuttings were generally well correlated (R^2 ~0.6−0.9), but mineral phase concentrations showed lower correlation coefficients (R^2 ~0.4). Further evaluation compared samples sorted into stratigraphic packages identified in the core. A combination of lithologic descriptions, focusing on bedding thickness and continuity, sedimentary structure, and dominant component grains, as well as analytical results, particularly bulk organic geochemistry and trace element concentrations, were used to identify three dominant depositional facies in the core. Starting at the base of the studied interval, the facies include argillaceous deltaic (Facies 1), argillaceous prodeltaic (Facies 2), and calcareous/organic-rich offshore/hemipelagic (Facies 3) mudstones. Core and cuttings samples were assigned to a facies and average concentrations of organic, elemental, and mineralogical parameters were compared. Excellent agreement was observed for most parameters ($R^2 \geq 0.9$), though differences in mineralogy between core and cuttings indicate greater variability at smaller scales than is evident in the bulk organic and elemental data. The results show that although cuttings provide geochemical information at lower stratigraphic resolution than can be obtained with core samples, they can provide reliable information when core material is not available.

Professional Posters, Monday, July 25

Detailed geochemical characterization of the lower part of the Green River Formation in south-central Uinta Basin, Utah

BIRDWELL, JUSTIN E., U.S. Geological Survey; Ryan D. Gall, Utah Geological Survey; Michael D. Vanden Berg, Utah Geological Survey

Lacustrine and fluvial-deltaic mudstones in the lower part of the Eocene Green River Formation in the Uinta Basin, particularly the informal Uteland Butte member (UB), represent the only significant oil production from an unconventional lacustrine petroleum system in North America. Since development of the UB by horizontal drilling and hydraulic fracturing, several other stratigraphic units with production potential have been identified and developed, including the underlying lacustrine Wasatch and the overlying Castle Peak and Carbonate Marker (Black Shale) units. Previous studies have presented results on immature UB mudstones from outcrop on the eastern margins, but data availability for core samples from more distal areas with low thermal maturity has been limited. To address this, samples were collected from a core drilled in the south-central region of the Uinta Basin (north of Nine Mile Canyon) for geochemical and mineralogical characterization. The Petes Wash well (U 13-06 GR), drilled by EOG Resources in 2007 was sampled roughly every foot between 5520 and 5650 feet.

The sampled interval contained approximately 44 feet of upper UB mudstones, including C- and D-shale marker beds and dolomitic "pay zones" described in previous studies and another 52 feet of organic- and carbonate-rich lower UB mudstones split by 26 feet of sandstone and feldspar-rich siltstone that is unique to the south-central part of the basin. Total organic carbon (TOC) content of the upper interval of the core was between 1% and 4% in most samples (average 2.2%, n = 53) and, based on programmed pyrolysis parameters (hydrogen index, HI ~600 mg/g; Tmax ~450°C). The lower interval of the core is slightly more organic-rich (TOC 1% to 5%; average 2.4%, n = 53) with similar but somewhat higher HI values. The sandstone unit TOC values were less than 1% (n = 24) with HI-Tmax values indicative of a different organic matter source or poorer preservation conditions than for the over- and under-lying mudstones. Mineralogy of the lower sampled interval is dominated by dolomite and illite. The UB in the area where the core was collected contains a variety of carbonate phases, including calcite, Mg-rich calcite, dolomite, and rare ankerite, along with lower concentrations of quartz and illite. The sandstone unit contains mostly quartz and illite, but high feldspar concentrations were observed in the middle of the unit. Major element concentrations were consistent with the identified mineral phases. Evaluation of the total rare earth element concentrations, Si/Zr ratios, and trace metal enrichment factors indicate fluctuating detrital input and redox conditions through the sampled strata, implying highly variable conditions. These results highlight some of the variability in distal areas of the Uinta Basin tight oil lacustrine resource play.

Geological characterization and petroleum targets of the Green River Formation, Uinta Basin, Monday, July 25, 2:50 PM

Molecular and bulk geochemical indicators of early thermal maturation in the Mahogany zone oil shale of the Green River Formation, Uinta Basin, Utah

BIRDWELL, JUSTIN E., U.S. Geological Survey; Katherine L. French, U.S. Geological Survey; Michael D. Vanden Berg, Utah Geological Survey

Characterization of early catagenic processes in the lacustrine strata present in the Uinta Basin is key to understanding the onset of oil generation as well as the origin and extent of unconventional petroleum resources like tar sands and gilsonite. To investigate changes related to early maturation, Mahogany zone oil shale samples from the Eocene Green River Formation were examined in five wells along an east-to-central basin transect that have a maturity level of less than a vitrinite reflectance (Ro) of ~0.7%, which is below oil generation onset of type I kerogen. Samples of the Mahogany zone oil shale were analyzed for bulk organic geochemistry. Samples varied from 20 to over 100 from each individual core. A subset of samples (13) were then selected for analysis of solvent extractable hydrocarbon biomarkers to evaluate what compounds are sensitive to the early, pre-oil stage of catagenesis. These results were compared to data on oils typed to the Mahogany zone, Fischer assay data, and biomarker results for gilsonite and tar sand bitumen determined in previous studies. Bulk parameters from programmed pyrolysis analysis (e.g., Tmax and hydrogen, oil saturation, and production indices) show trends with burial depths that are consistent with previous examinations of thermal maturity in the Green River Formation in the Uinta Basin. Carotenoids like β-carotane and the acyclic isoprenoids

pristane and phytane show similar sensitivity to thermal maturity to indicators like Tmax determined from programmed pyrolysis but these particular biomarkers could also have been affected by variations in depositional environment or organic matter source. However, other molecular parameters like the C_{29} $\beta\beta/(\alpha\alpha+\beta\beta)$ sterane ratio, C_{31} hopane 17α,21β 22S/(22S + 22R) ratio, and C_{31} 2α+β methylhopane index also show similar trends consistent with differences in thermal maturity from east to west identified in previous work. These results provide information on the subtleties of early Mahogany zone maturation that may have played a role in charging tar sand deposits in the southern basin and gilsonite veins in the east. Considering the very low porosity and high organic matter content of the Mahogany zone shale, these early stages of thermal maturation may have led to early expulsion of what would usually be considered bitumen and not "oil" based on the physical properties (high density and viscosity) of this material and may be a source of the non-crude oil petroleum resources found in the Uinta Basin.

Geological characterization and petroleum targets of the Green River Formation, Uinta Basin, Monday, July 25, 4:30 PM

Temperature mapping within the onshore oil and gas production region of the U.S. Gulf Coast Basin

BIRDWELL, JUSTIN E., U.S. Geological Survey; Scott A. Kinney, U.S. Geological Survey; Rand D. Gardner, U.S. Geological Survey; Lauri A. Burke, U.S. Geological Survey; Marc L. Buursink, U.S. Geological Survey; Nicholas J. Gianoutsos, U.S. Geological Survey

The extensive petroleum exploration and development activity that has occurred in the onshore Gulf Coast Basin of the southern United States (U.S.) over the last 100 years provides an invaluable source of information for evaluating geothermal resources. In petroliferous basins, most reported temperature data are bottom-hole temperatures (BHT) recorded during borehole logging. BHT values combined with their corresponding depths can be used to help evaluate source rock thermal maturity in petroleum system analysis and to investigate subsurface thermal regimes to identify potential geothermal resources. Using BHT and depth data for wells in the Gulf Coast region, 3-D temperature and thermal gradient maps were constructed. Data queries from oil and gas wells in the onshore U.S. Gulf Coast Basin were compiled from the IHS Markit™ database. Approximately 50,000 BHTs and corresponding depths were binned into 3,448 square-cells, each with an area of 93 km2 (36 mi²), from the Texas-Mexico border to the Florida Panhandle and from the coastline into central Arkansas. Data density was generally good, with only 664 cells being limited to a single BHT-depth data pair. Relatively high-density data, defined as containing 10 or more data pairs, were available for over 20% of the cells (770). Although issues regarding the veracity of and uncertainty in reported BHTs are a concern due to temperature differences between the reservoir and the drilling fluid, differences in well characteristics and drilling technology used, and the thermal diffusivity of the reservoir, the very large number of measurements available provides some reassurance that the observed trends are valid. BHTs were corrected for a subset of wells using the Waples correction developed for the Gulf of Mexico, which requires time-since circulation (TSC) values. By plotting the measured and corrected BHTs for this subset of wells, we developed a generalized correction factor that was then applied to the remaining datapoints

for which TSC was not available. Using basin modeling software, isothermal surfaces were constructed for 90°C (194°F) and 150°C (302°F), which represent the transitions from low to moderate and moderate to high temperature geothermal resources, respectively, as defined in recent geothermal assessments by the U.S. Geological Survey. These maps provide a starting point for evaluating geothermal resource potential in the onshore U.S. Gulf Coast Basin. Initial evaluation of the mapped area shows that approximately 36,000 km² (14,000 mi²) are estimated to have temperatures ≥ 150°C at a depth range between 1,500 and 3,000 m (~5,000 to 10,000 ft). These results are comparable to previous efforts to evaluate thermal gradients and subsurface temperatures in the U.S. Gulf Coast region.

Professional Posters, Monday, July 25

Differences in oil shale organic matter across Eocene Lake Uinta inferred from Fischer assay data

BIRDWELL, JUSTIN E., U.S. Geological Survey; Scott A. Kinney, U.S. Geological Survey; Tracey J. Mercier, U.S. Geological Survey; Ronald C. Johnson, Retired Geologist

Over 300,000 Fischer assay measurements from ~1,000 wells in the Piceance Basin display stratigraphic and geographic variability of organic matter deposited in oil shale in Eocene Lake Uinta. These data provide potentially detailed information on the depositional environment during different stages of lake history and in different parts of the lake. Fischer assay measurements originally made to determine the variability in oil yield to assess the resource include specific gravity values of liquid pyrolysates, which we utilize here as an indicator of variations in organic matter properties. The average specific gravity of Piceance Basin oils generated by Fischer assay was previously shown to decrease with depth from the Mahogany zone (~0.93) to the base of the Garden Gulch Member of the Green River Formation (~0.88), an equivalent shift in API gravity of ~10° over approximately 2,000 feet in depth in the basin center. This change in density has been attributed to decreasing kerogen oxygen content with increasing burial depth and thermal maturity, based on a limited set of kerogen analyses. The shallow burial depths across the Piceance Basin, as well as similar trends in deeper and shallower wells however suggest that thermal maturity differences, which range in terms of vitrinite reflectance from approximately 0.3% in shallow areas to just under 0.5% in the lowermost Garden Gulch zone, cannot explain the observed specific gravity trend. Oil specific gravity also varies geographically across the basin within particular oil shale zones, with lighter oils generated by shales deposited in or near the basin center and heavier oils being derived from shales collected near the basin margins, though there are differences between values observed in eastern and western areas. Notably, shales from the western edge of the basin generate particularly heavy pyrolysate oils relative to other marginal areas throughout the depositional record of the Green River Formation. Fischer assay oil specific gravity values were compiled for a diverse set of thermally immature oil shales with different kerogen types and from different depositional environments deposited across geologic time from the Cambrian to the Eocene. The specific gravity values were then compared to elemental data collected on kerogen isolates from the oil shales. Results of this comparison did not show a correlation with kerogen oxygen content but did indicate that total heteroatom content (NSO) may drive changes

in pyrolysate specific gravity. This suggests that a combination of organic matter source and paleoenvironmental conditions across Piceance Basin during deposition of the Green River Formation are reflected in pyrolysate properties.

Professional Posters, Monday, July 25

Dakota Group Fluvial Systems of the Colorado Front Range: Provenance, Geochronology, and Paleogeographic Significance

BLUM, MIKE, Earth, Energy and Environment Center, University of Kansas; Caroline Nazworth Doerger, Chesapeake Oil; Abdullah Wahbi, Saudi Aramco

Bob Weimer made first-order contributions to understanding of Cretaceous rocks of the Colorado Front Range and, more broadly throughout the Laramide Rockies. In this presentation we build on his timeless work by summarizing new detrital-zircon (DZ) U-Pb provenance and geochronology data from the Cretaceous Dakota Group, and outline the significance of Dakota Group strata to Cretaceous sediment routing.

The Front Range Dakota Group rests on the sub-Cretaceous unconformity, and represents fluvial, deltaic, and shallow-marine strata deposited in the Sevier foreland basin backbulge. We analyzed the DZ U-Pb signatures of the Early Cretaceous Lytle and Plainview units, and the mid-late Cretaceous Muddy sandstones to help define provenance and sediment routing, and provide maximum depositional ages (MDAs). Lytle and Muddy fluvial systems had headwaters in the Sevier fold-and-thrust belt and magmatic arc, consistent with previous interpretations. However, samples from Purgatoire and Canon City represent a slightly different source terrain from samples at Dinosaur Ridge and Fort Collins, which indicates two long-lived west-derived river systems. Moreover, we obtained MDAs of ca. 148-150 Ma from the underlying Jurassic Morrison Formation, and ca. 98-100 Ma from Muddy sandstones: both units were deposited during periods of high flux in the magmatic arc, syndepositional zircons are common, and MDAs are consistent with biostratigraphic ages. The Lytle and Plainview are Barremian through early Albian in age from biostratigraphic data, a time period that corresponds to a magmatic lull, hence syndepositional zircons are uncommon and we did not obtain useful MDAs.

Our Dakota Group study is part of a broader effort to understand Early Cretaceous sediment routing to the Alberta foreland. Early DZ U-Pb studies proposed that the Barremian to Aptian McMurray Formation in Alberta represents the trunk stream of a continental-scale south-to-north flowing river system. We test this model with DZ U-Pb analyses from the McMurray, as well as the basal Cretaceous Cheyenne sandstone of western Kansas and Lakota sandstone of the Black Hills in South Dakota, and Dakota Group sandstones of eastern Nebraska and Kansas. DZ U-Pb signatures of the Cheyenne and Lakota are statistically indistinguishable from the McMurray signature in east central Alberta, and represent a mixture of Lytle sandstones of the Front Range, and the classic east-derived Appalachian DZ U-Pb signature in Dakota Group strata of eastern Nebraska and Kansas. These data refine previous interpretations of a continental-scale river system, with headwaters that stretched from the Sevier fold-and-thrust belt and magmatic arc to the Appalachians: this river system was the Amazon or Mississippi of its time, and predated Latest Cretaceous

to Paleocene continental-scale drainage reorganization that routed water and sediment from southern North America to the Gulf of Mexico.

Remembering Bob Weimer and his Contributions to Rockies Geology, Monday, July 25, 11:00 AM

The Sage Breaks scour event and its influence on layer-bound normal faulting within the Niobrara and Turner formations, Southern Powder River Basin, Wyoming

BRACKEN, KYLE, A., Occidental Petroleum Corporation; Jessica Vahling; Occidental Petroleum Corporation

The Sage Breaks Shale (Carlile Shale) in the southern Powder River Basin ranges in thickness from 0 to over 300 feet due to a significant scouring event that occurred during the Late Turonian Age of the Cretaceous Period. Stratigraphic analysis reveals a complimentary depositional relationship between the Sage Breaks Shale and the unconformably overlain Niobrara Formation, where accommodation space created by the scoured Sage Breaks Shale is filled with a thickened section of Niobrara Marl. This variable stratigraphic package of shale and marl hosts a system of layer-bound (polygonal) normal faults similar in origin and distribution to those found in the Niobrara Formation of the Denver Basin, Colorado. Detailed interpretation of 3-D seismic and horizontal well log data reveals a selective pattern in fault development in relation to the scoured areas, where fault density, displacement, throw gradient, and fault length vary with the thickness of the Sage Breaks Shale. Faults within the scour zone are larger and commonly extend beyond the Niobrara and Sage Breaks formations to offset the underlying Turner Sandstone and overlying Steele Shale. These "scour-zone-faults" are characterized by broad throw distribution profiles and shallow throw gradient. Faults outside of the scour-zones are smaller, less frequent, and mostly restricted to the Niobrara and Sage Breaks formations. Fault analysis from horizontal wells drilled in the Niobrara and Turner formations provides additional evidence that vertical fault growth from the Niobrara Formation to the Turner Formation is controlled by the thickness of the Sage Breaks Shale. Fault initiation point, relative timing, and mechanical stratigraphy provide possible explanations for the observed relationship and are all considered to play an important role in the development of this fault system.

Structural Geology & Salt Tectonics, Wednesday, July 27, 11:00 AM

Strain segregation between ductile and brittle stratigraphy–Characterizing the Sand Wash Fault System, Uinta Basin, Utah

BRINKERHOFF, RILEY, Wasatch Energy; John McBride, Brigham Young University; Sam Hudson, Brigham Young University; Douglas A. Sprinkel, Aztec Geoscience; Ron Harris, Brigham Young University; Kevin Rey, Brigham Young University; Eric Tingey, Brigham Young University

The Sand Wash fault zone is a segmented and discontinuous fault system that strikes northwest to southeast in the central part of the Uinta Basin. It is approximately 34 kilometers long with an uncommonly wide damage zone, typically 100 to 200 meters wide. Due to recent, rapid, and large-scale incision by the Green River and its tributaries, the Sand-Wash fault zone is well exposed in several

closely spaced canyons. These canyon exposures allow mapping of the lateral relationships through panoramic photographs and surface kinematic descriptions.

Most movement on the Sand Wash fault zone occurred in the late Eocene. Evidence for fault timing includes strata-bound, syndepositional movement which occurred during Lake Uinta time (55 to 43 Ma BP) resulting in debris flows, slump blocks, and small (>150 meters diameter) sag basins filled with poorly organized sediments. After lithification, elongate grabens formed with up to 33.5 meters of horizontal extension. Two styles of deformation are present. Brittle rocks, such as sandstone and limestone beds, are intensely fractured and faulted, whereas clay-rich and organic-rich rocks are largely unfractured and unfaulted, with variably folded beds that have experienced some layer-parallel slip. Laterally, deformation is distributed up to 100 meters from the fault core, which is uncommonly large for faults with short lengths and little displacement. Vertically, displacement is concentrated in brittle sandstone and carbonate beds and rare in clay- and hydrocarbon-rich units, such as the Mahogany oil-shale zone of the Eocene Green River Formation. The Mahogany oil-shale zone mostly displays ductile flow (granular flow) commonly forming small décollements between overlying and underlying units. Vertical displacement on separate fault segments is generally less than 5 meters and decreases down section, dying out completely around the top of the Mahogany oil-shale zone.

In this presentation we show evidence for syndepositional deformation along the Sand Wash fault zone, strain partitioning along décollement surfaces, fault surfaces that experience multiple deformational phases, pop-up blocks, and graben development. We also show that deformation on the fault zone is related to extension above a neutral surface of a larger fold. This larger fold is associated with a basement-rooted fault zone that moved during Laramide tectonism with the reactivation of the Uncompahgre uplift. The Sand Wash fault zone appears to have many similarities to the larger, and more deeply buried, Duchesne fault zone 25 kilometers to the north, and the more deeply eroded Cedar Ridge fault zone located 30 kilometers to the south. The high-resolution fault model, developed herein, is thus a good proxy for other complex fault zones in the Uinta Basin. Our model will be useful to oil and gas operators as they develop horizontal wells across this and other complex fault zones in the basin.

Geological characterization and petroleum targets of the Green River Formation, Uinta Basin, Monday, July 25, 3:40 PM

Using Pore System Characterization to Subdivide the Burgeoning Uteland Butte Play, Green River Formation, Uinta Basin, Utah

BRINKERHOFF, RILEY, Wasatch Energy; Michael D. Vanden Berg; Utah Geologic Survey; Mark Millard; Novelstone Geologic Consulting;

Over 240 horizontal wells with highly variable production results have been drilled in the Uteland Butte member (UBm) of the lower Green River Formation in the Uinta Basin, Utah. The best wells have each produced more than 300,000 barrels of oil in the first 12 months of production, with conservative EURs above a million barrels. Conversely, the poorest UBm wells have initial production rates of less than 10,000 barrels of oil in the first year and will never recoup their drilling costs. Pore pressure, oil

viscosity, and frac size are recognized as important controls on well productivity. Less understood, but of equal importance, is the variability in reservoir types across the UBm play. The UBm can be divided into sub-plays by district using the dominant pore systems in each area. We defined four distinct sub-plays within the Uinta Basin: 1) intergranular-dominated porosity, 2) intercrystalline-pore-dominated dolomite, 3) mixed intercrystalline-organic porosity, and 4) organic porosity. Reservoirs in the intergranular-dominated porosity sub-play are mostly present in the form of nearshore siliciclastic and carbonate bars, such as ooid and ostracod shoals, fluvial mouth bars, and nearshore siliciclastic bars. The normal pressure and charge in these reservoirs are due to hydrocarbon migration out of the deeper basin. Source rocks in this sub-play have an average maturity too low for mainstage oil generation for these lacustrine shales, which produce highly viscous black wax with very low GORs. To date, horizontal wells drilled in this sub-play have not been economically successful. The intercrystalline-pore-dominated sub-play consists of thin, laterally continuous, high-porosity dolomites that act as the best reservoirs. This sub-play has an average VRo of 0.6 to 0.8, still too low for mainstage oil generation in these rocks and produces a migrated black wax with low GORs. The mixed intercrystalline-organic porosity sub-play is largely self-sourced and significantly overpressured. Maturities in this sub-play ranges from 0.8 to 1.0 VRo. This sub-play produces a yellow to gray wax with moderate GORs. Finally, the organic-porosity-dominated sub-play is highly overpressured and completely self-sourced. There is relatively little reservoir-quality dolomite, the limestones are more argillaceous, and the organic-rich carbonate shales are thicker. The productive reservoir in this sub-play consists of organic porosity largely contained in bitumen that has been expelled at lower maturity, then continued to thermally degrade with higher maturity, converting to zones of interconnected organic porosity. Maturities range from 1.0 to 1.2 VRo and the hydrocarbons produced are a bright yellow wax with relatively high GORs. By recognizing the important differences these pore systems exert on best development practices and then accurately mapping them across the basin, operators, interest owners, and regulatory agencies can more efficiently plan operations.

Geological characterization and petroleum targets of the Green River Formation, Uinta Basin, Monday, July 25, 2:00 PM

Pitfalls of Model-Driven Unconventional Development – The Stratigraphic Trends that Drive Oil & Gas Productivity in Divide County, North Dakota

BRINKERHOFF, RILEY, Wasatch Energy; Tim Nesheim, North Dakota Core Center; Mark Millard, Novelstone Geologic Consulting

In the early development of unconventional oil and gas plays, it is often deemed economically necessary to begin large-scale development before a complete understanding of the play's geology is established. Unfortunately, perm variability related to stratigraphic complexities almost invariably creates significant pressure differences in the targeted reservoirs. These higher perm rocks drain preferentially, producing the bulk of the fluids recovered from early wells. The higher perm, lower pore-pressure zones attract much of the frac energy of later infill wells, making subsequent development difficult or completely uneconomic. Early quantification of the contributing stratigraphic intervals is essential

to help operators develop the resource more efficiently. Models of the producing zones are often created to identify which reservoir rocks contribute to each well's production. Unfortunately, these models almost always prove to be overly simplistic and much too small compared to later measured pore-pressure data.

In 2011 operators began to target the stratigraphic pinch-out of the best dolostones in the first bench of the Three Forks Formation in Divide County in the extreme NW corner of North Dakota. The best production of the area was eventually established from the thinnest Three Forks reservoirs from which the large volumes of oil produced from these wells could not be reconciled to the limited reservoirs mapped in the pinch-out. This study utilized core-facies mapping from the large core inventory available at the ND Core Repository to build a comprehensive stratigraphic model to explain Bakken/Three Forks production trends found across the margins of the Williston Basin. The combination of reservoir pressure, facies mapping, geochemistry, and production data all points to the existence of a large stratigraphic trap within the Middle Bakken that correlates with horizontal well productivity trends in both the Three Forks and Middle Bakken. The trap extends from SE Saskatchewan into Divide-Williams counties (NW North Dakota) where the lowest water cuts and best production per lateral foot is found along the trap's NW-SE trend while water cut gradually increases and well performance decreases downdip towards the SE. This presentation will also show the extent of the trap, the internal character, evidence for its contribution to both Three Forks and Middle Bakken wells, evidence for its uneven depletion, how it fits with the low maturity data and what operators can do improve future infill wells.

Furthermore, the extent and internal character of the Middle Bakken strat trap can be used to explain the uneven depletion in the area, low thermal maturity of the Bakken shales, and provide operators with insights to improve future infill well development.

Innovative Workflows for Energy Geoscience, Wednesday, July 27, 9:50 AM

The offshore Mancos play in the San Juan Basin: productive carrier beds within the Mancos total petroleum system

BROADHEAD, RONALD F., Emeritus New Mexico Bureau of Geology and Mineral Resources/New Mexico Tech

Historically, the Offshore Mancos play of the San Juan Basin has produced oil from noncommercial to marginally commercial reservoirs formed by dark-gray marine shale with thin beds and laminae of fine-grained sandstone of limited permeability. During the last decade drilling with horizontal wells has resulted in substantially increased production. However, placement of the Offshore Mancos play within the Mancos total petroleum system has been poorly understood. Here, the Offshore Mancos play is interpreted as a carrier bed play within the Mancos total petroleum system.

Unconventional reservoirs of the Offshore Mancos play are stratigraphically equivalent to updip conventional reservoirs deposited nearer to the shoreline and are also equivalent to downdip source rocks matured to peak oil generation. Offshore Mancos facies include a proximal facies to the southwest, a medial facies, and a distal facies to the northeast. Oil production has been obtained from the proximal and medial facies

Mancos shales contain oil generative kerogens that are within the upper oil window near conventional reservoirs in the south and have been matured to peak oil generation downdip of and to the northeast of the Offshore Mancos reservoirs. Uniform API gravities of light sweet produced oils that transcend thermal maturity variations of Mancos shales indicate that oils generated in downdip mature source rocks migrated updip through the carrier bed sandstones of the Offshore play and into the conventional reservoirs. Residual oil saturations are consistent with the concept of migrating oils moving updip through only a small number of interconnected pathways within a carrier bed.

Petroleum Systems in the Rocky Mountain Region, Monday, July 25, 2:50 PM

Organic Petrography of the Ordovician Red River Kukersite Tight Oil and Gas Play, Williston Basin, North Dakota, U.S.A.

CAMP, WAYNE K., Retired, Anadarko Petroleum; Juergen Schieber; Maria Mastslerz; Timothy O. Nesheim

An organic petrographic study was conducted to supplement previously published geochemical data as part of an evaluation of a conceptual Upper Ordovician kukersite tight oil and gas play in the Williston Basin, North Dakota. The kukersite interval of the lower Red River member is an organic-rich (average 3.8 wt% TOC) dolomitic limestone that has been documented as the source rock for hydrocarbons produced from porous dolomite zones in the overlying upper Red River member in conventional structural and stratigraphic traps. Basin modeling studies of the Red River petroleum system suggest that only a small fraction of the generated petroleum has been produced from the conventional fields, and that a significant resource may remain trapped within low permeability carbonates associated with the kukersite source rock in the lower Red River member. The maceral composition of the kukersite is predominately oil-prone algal and amorphous kerogen where thermally immature (bitumen reflectance (BRo) <0.30% BRo) that grades to 100% solid bitumen by 0.63% BRo and pyrobitumen at BRo > 1.5%, and completely fills the mineral interparticle pore space in the studied samples. Only a few nanopores were observed in the organic matter by SEM examination, including the gas mature samples (up to 3.50% BRo). The organic matter in the thermally mature samples often exhibited a volatile response when probed by the electron beam, indicating that the general lack of observed organic matter pores may be due to the presence of altered residual oil.

Applications of Geochemistry to Petroleum Systems, Wednesday, July 27, 11:00 AM

History of Petroleum Development in Utah

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Utah's petroleum development history extends back more than 130 years. Over the decades, many lessons have been learned from past exploration efforts and resulting production. This history has led Utah to be consistently ranked in the top 15 states in production since the 1960s.

In 1891, the Bamber & Millis 1 was drilled and although a dry hole, it was the first well in Utah to specifically target hydrocarbons. That same year, natural gas was accidentally discovered just east of Great Salt Lake while drilling a water well. Gas from nearby wells was transported to Salt Lake City in a wooden pipe, marking Utah's first use of local gas or oil.

Wildcats in the early part of the 20th century targeted large surface anticlines and areas with oil seeps. Discoveries included Rozel Point (1904), Virgin (1907), Mexican Hat (1908), and Cane Creek (1925). These fields produced only small amounts of oil; Mexican Hat still pumps a few BOPD.

Utah's first commercial gas field, Clay Basin, was discovered in 1927 in the southern Green River Basin. As a result, pipelines were constructed to transport gas from Clay Basin, and other new fields in southwestern Wyoming, to northern Utah during the late 1920s and early 1930s. In 1948, the first truly commercial oil field, Ashley Valley, was discovered in eastern Utah (it has produced over 21 MMBO). Not long after, major discoveries opened the large basins where most of the activity continues today: Bluebell (1949), Redwash (1951), and Natural Buttes (1952) fields in the Uinta Basin, and Boundary Butte field (1948), Utah's largest oil field Greater Aneth (1956), and Lisbon field (1960) in the Paradox Basin.

In 1951, the Cretaceous Ferron Sandstone proved gas productive with the discovery of Clear Creek field on the Wasatch Plateau. Ferron coalbeds proved productive with the 1992 discovery of Drunkards Wash field, now part of the "Ferron CBM fairway," which has produced over 1.5 TCFG.

The discovery of Pineview field in 1975 led to major finds in the Utah-Wyoming thrust belt during the late 1970s and early 1980s after years of drilling failures. Heavy oil was discovered in Great Salt Lake during an "offshore" drilling program from 1978 to 1981. The 2004 discovery of Covenant field in the central Utah thrust belt turned that region from one of speculation to proven potential.

In 1982, a then-new experimental drilling program was initiated in Grassy Trail field, a small Triassic Moenkopi Formation oil producer in east-central Utah. The new technique was horizontal drilling. Horizontal drilling is now the standard practice for wells targeting the oil potential of the Cane Creek shale in the Pennsylvanian Paradox Formation of the Paradox Basin and the Eocene Green River Formation of the Uinta Basin.

Over 1.7 billion BO and 14 TCFG have been produced in Utah. The exploration efforts, development practices, and successes of the past provide a great legacy for Utah's future hydrocarbon potential and development.

History of Petroleum Geology in the Rockies, Monday, July 25, 4:05 PM

Using Seismic Characterization to Support a New Horizontal Program at Jonah Field, WY

CHRISTIE, CORY H., Jonah Energy; William R. Drake, Jonah Energy ; Greg Gromadzki, Jonah Energy; John Hoopes, Jonah Energy

The Jonah Field in Sublette Co., WY is a prolific gas producer that has historically been exploited with tightly spaced vertical wells that mainly targeted gas-saturated sand bodies in up-dip areas of compartmentalized fault blocks of the field. Today the same stacked fluvial sands of the Lance Formation are being tested outside of the historical field boundaries using modern horizontal drilling and completion techniques. Leveraging 3D seismic is critical for well planning and execution in the structurally and stratigraphically complex play fairways with limited well control. However, reliance on a vintage seismic data set in an area where subseismic facies changes and fracture swarms are common can lead to poor well placement and unanticipated drilling hazards. With the goal of testing remote areas and optimizing horizontal well locations for DSU development, ~150 square miles of seismic was reprocessed using pre-stack depth migration to better identify and characterize subsurface complexities. At a regional scale, the new depth volume allows updated characterization of large-scale features such as field-bounding faults and broad stratigraphic architecture. At an operational scale, the volume has proved indispensable for well planning and geosteering by accurately delineating bedding dips, structural geohazards, and stratigraphic variations. Our fault prediction methodology has proved to be accurate in areas where previous fault interpretation was unreliable or not possible, and previously unencountered stratigraphic hazards can be mapped for predictive purposes. Although limits to seismic resolution remain a challenge in and around Jonah Field, the high-quality depth volume is an example of a cost-effective tool for fairway delineation, strategic DSU development, and optimal well placement in a structurally and stratigraphically challenging system.

Petroleum Systems in the Rocky Mountain Region, Monday, July 25, 2:25 PM

Using Physics to Prevent Oil & Gas Production Problems

CLEMISHIRE, BRIAN, Enercat Technology Inc.; Monte Swan, Enercat Technology Inc.; Adela Porter, Devon Energy

Oil and gas production problems are primarily physical as opposed to chemical, and are caused by static-electrical intermolecular forces between molecules as oil exits reservoirs through perforations and rises in wells. As temperature and pressure decrease physical problems such as paraffin, scale, asphaltene, heavy oil, and emulsion develop. The EnercatTM Tool weakens the intermolecular forces preventing these problems from developing, and it stabilizes production while often increasing it resulting in decreased down time and workovers. Enercat tools are made of an aluminum alloy that requires no external power source. The tools must be installed deep in the well bore below the fluid level so they are able to properly condition the production fluids, minimizing or preventing undesirable changes in the fluids as they travel up the riser. The tool emits a vibrational frequency that weakens the instantaneous dipoles of alkane molecules at the quantum scale, which in turn weakens the London Dispersion Forces the primary cause of the paraffin crystallization and deposition. The frequency

also travels on hydrogen bonds past perforations into the reservoir decreasing hydrogen bond strength also at the quantum scale, which decreases interfacial tension. This decrease drives the reservoir toward water wet often enhancing production 30-40%. An ongoing field-wide case study of 40 wells in the Delaware Basin's Bone Spring 2nd Sand is an recent example of how the Enercat downhole tool prevents severe paraffin crystallization and deposition in wells that did not respond to chemical methods. After up to 400 days without chemical treatments there has been no paraffin deposition. Another ongoing field-wide case study of 22 wells in the Bemis-Shutts Oil Field's Kansas City and Arbuckle Formations and Hugoton Oil Field's Morrow Formation all in the Central Kansas Uplift has showed after 1.5 to 2.5 years no paraffin and an average increase in production of 40%. These wells normally required hot oiling every 3 months and pulls every 6 month.

Professional Posters, Monday, July 25

Codell continuous oil accumulation in the northern Denver basin as defined by resistivity, density, and SP logs

CUMELLA, STEPHEN P., consultant

A continuous Codell Sandstone oil accumulation is present in the northern Denver Basin downdip from water-wet Codell. The Codell oil accumulation can be defined by resistivity, spontaneous potential (SP), and density logs. Updip from the oil accumulation, average deep resistivity of the Codell decreases to below 4 ohm-m, SP response increases, and density porosity increases. Codell sandstones are continuous across the transition from downdip oil to updip water, so the updip seal does not seem to be caused by a stratigraphic trap. The transition corresponds to a change in thermal history; the area of the oil accumulation was subject to much higher heat flow than the updip wet area. This thermal maturity may have had an impact on clay diagenesis and quartz cementation resulting in reduced porosity and permeability in the more thermally mature part of the Codell. This paper presents a wireline log-based workflow that can be used to identify and map regional changes in thermal maturity that control hydrocarbon accumulations and sweet-spots in low-permeability rocks such as the argillaceous Codell Sandstone.

Petroleum Systems in the Rocky Mountain Region, Monday, July 25, 1:35 PM

Field-Based Removal of Hydrogen Sulfide from Carbon Dioxide and Natural Gas Sample Streams without Geochemical Alteration

DECKER, DOUGLAS B., Dolan Integration Group; Michael Dolan, Dolan Integration Group; Patrick Travers, Dolan Integration Group;

The project goal is to develop a system to remove hydrogen sulfide (H_2S) from gasses without altering the stable isotopic composition of the remaining gas. This will allow robust studies of systems where H_2S has previously prevented geochemical and stable isotopic analysis. There are no commercially available products that can scrub H_2S from carbon dioxide (CO_2) without fractionating the isotopic composition. Our testing using commercially available products designed to scrub H_2S from hydrocarbon gasses showed isotopic changes outside statistically acceptable deviations. We have designed, built, and are extensively testing a proprietary portable scrubber system to remove H_2S from gasses with CO_2, hydrocarbons C_1 through n-C_5, and air without altering $\delta^{13}C$ values of the remaining analytes.

Stable isotopes are important natural tracers and can provide vital information about subsurface systems involving sequestered CO_2, oil and gas, and coal related gasses. Monitoring the isotopic composition of injected CO_2 is becoming more increasingly utilized as a monitoring tool for carbon capture and storage projects. In these systems, H_2S is a common naturally occurring hazard. Currently, high concentrations of H_2S in samples prevent accurate analysis and even sample acceptance at most laboratories. Preliminary data from our scrubber system testing show we have found a novel solution to remove H_2S without affecting stable isotopic composition.

Our scrubber system uses a packed column with a substrate that changes colors when expended. The column is transparent so the substrate remains visible during all stages of operation. The entire scrubber system is made of inert, corrosion resistant materials that are compatible with natural gas, CO_2, and H_2S. Using a Gas Chromatography Combustion Isotope Ratio Mass Spectrometer (GC-C-IRMS) system, we are conducting a series of experiments to verify the efficacy of our scrubber system with gasses containing different combinations and concentrations of CO_2, H_2S, and hydrocarbons C_1 through n-C_5 in conjunction with GC analysis to identify compositional effects.

Testing our system using pure CO_2 has shown we are able to process CO_2 without any statistically significant fractionation or alteration of the $\delta^{13}C$ stable carbon isotope composition. This capability alone is something that is not currently commercially available and is useful in a wide range of applications where stable isotopic analysis provides critical information about the system. Based on preliminary data, this represents a significant improvement in H_2S removal from samples intended for geochemical and isotopic analysis. Additionally, it prevents the hazards of both shipping and handling of samples containing hazardous concentrations of H_2S in the laboratory.

Technological & Analytical Tools for Energy Development, Monday, July 25, 11:25 AM

100 Years! Celebrating RMAG's Past, Present & Future

DIEDRICH, ROBIN P., RMAG

In 1922, the first AAPG regional meeting was held in Denver, hosted by a newly formed organization called the Rocky Mountain Association of Petroleum Geologists. 100 years later, RMAG is still going strong and is one of the largest, and most active, geological societies in the United States. This presentation will feature highlights of RMAG's history as we celebrate the association's centennial year. We will consider what the future holds as RMAG continues to serve our geoscience community in the next century.

Opening Plenary - Welcome to RMS 2022, Monday, July 25, 9:00 AM

Facies, Stratigraphy, and Reservoir Heterogeneity of the Upper Wolfcamp Formation (Wolfcamp A-Equivalent) in the Glass Mountains of West Texas

DUSAK, N.M., Department of Geology & Geophysics, Texas A&M University; Eric Peavey, Texas A&M University Dept. of Geology and Geophysics; Michael Pope, Texas A&M University Dept. of Geology and Geophysics; Art Donovan, Texas A&M University Dept. of Geology and Geophysics; Juan Carlos Laya, Texas A&M University Dept. of Geology and Geophysics

The Upper Wolfcamp Formation, which includes most of the classic Early Permian (Artinskian-Kungurian) Skinner Ranch Formation, is exposed along the Glass Mountains in Brewster County, Texas. These outcrops comprise the southern part of the Ouachita Fold-and- Thrust Belt and have exposures that have remained largely unstudied by geologists for the past 50+ years. This study of the Skinner Ranch Formation (Upper Wolfcamp; Wolfcamp A-equivalent) uses an outcrop-based sequence stratigraphic and chemostratigraphic analysis to identify distinct chemo/litho facies within a regionally correlative framework for improved reservoir characterization of organic-rich mudrock successions. Moreover, modern advances in chemostratigraphy through integration of Energy Dispersive – X-Ray Fluorescence (ED-XRF), Fourier Transform Infrared (FTIR) Spectroscopy, and FTIR Total Organic Carbon (TOC) content helps improve understanding of depositional constraints on reservoir quantity (spatio-temporal variations) and quality (compositional, TOC richness) within this mixed carbonate-siliciclastic system.

Five facies are recognized from the integration of geochemical and petrographic thin section analysis of mudstone, siltstone, and limestone within the Poplar Tank Member of the Upper Wolfcamp Formation. This includes Facies 1 (skeletal wackestone/packstone/grainstone; Avg. TOC 0.7 wt.%), Facies 2 (calcareous silty mudstone; Avg. TOC 1.7 wt.%), Facies 3 (argillaceous shale/mudstone; Avg. TOC 0.9 wt.%), Facies 4 (siliceous mudstone/siltstone; Avg. TOC 1.6 wt.%), and Facies 5 (siliceous shale/siltstone; Avg. TOC 0.1 wt.%). Depositional heterogeneity and stratigraphic cyclicity of the of the Upper Wolfcamp Formation is expressed via vertical distribution of facies and constituent elemental proxies within alternating patterns or couplets of turbidites, debris flows, and hybrid event beds.

Among the key recent learnings included are: (1) seismic-scale geometries of lowstand conglomerate beds within the Decie Ranch Member and Sullivan Peak Member include gravity flow deposits of toe-of-slope debris flow aprons and mixed hybrid event beds of channelized sands, (2) Facies 1 and 2 have high values of redox-sensitive proxies and low values of detrital proxies within the carbonate-rich facies, indicating deposition within anoxic/suboxic conditions during the late TST and early HST, (3) Facies 3 and 4 low redox proxy values and high detrital proxy values indicate oxic/suboxic environments during early-to-mid TST and mid-to-late HST, and (4) intermittent deposition of carbonate debrites and turbidites alternating with siliceous/argillaceous mudstone deposition within HSTs is indicative of distal fringe deposition within mixed carbonate-siliciclastic sea-floor fans. This outcrop study improves understanding of spatio-temporal variation, and lithologic and geochemical heterogeneity, of basin-floor strata that comprise the unconventional source rock plays of the Wolfcamp A Formation.

Student Posters, Tuesday, July 26, 5:30 PM

State of stress in southeastern Utah

DVORY, NO'AM Z., University of Utah; Carlos Vega-Ortiz, University of Utah; John McLennan, University of Utah; Brian McPherson, University of Utah

The Paradox basin in southeastern Utah is an emerging play for carbon dioxide subsurface storage and hydrocarbon development. Knowledge of the principal stress directions and the relative stress magnitudes is important for predicting the slip potential of natural fractures during hydraulic fracturing stimulation. Similarly, at least qualitative knowledge of the stress tensor is required to forecast the potential of fault reactivation during continuous injection for water disposal or carbon storage. Previous studies showed that the Paradox basin's stress state varies from extension (normal faulting) in the west to mild compression in the east. The presence of outcropping salt structures and interbedding evaporites in the local stratigraphy adds complexity to the stress distribution mechanisms. However, stress state resources in this area are limited and excluding one point, the relative stress magnitudes were obtained from outside the basin's perimeter. Furthermore, the updated North America stress map does not include any stress orientation data within this basin. The lack of quantitative constraints on relative principal stress magnitudes and the large gaps in knowledge of horizontal principal stress orientations created challenges for predicting fault slip potential. In the current study, we integrate recent and legacy well data and continuous seismic records to identify critically stressed faults, characterize the SH_{max} orientation and estimate the local principal stress magnitudes. We identified two stress measurements/calculations in the mid-northern part of the basin. Petal fractures from core data analysis, breakouts from FMI interpretation and fast shear azimuth interpretation show an SH_{max} orientation of ~N50°-N70°. While these values require additional validation this directional trend aligns with previous measurements that show that west of the Wasatch fault zone and east, toward the Colorado Plateau, the SH_{max} orientation changes from N-S to E-W. These measurements also suggest that the northern part of the basin, where major faults are perpendicular to the maximum compressive stress orientation, could have relatively lower seismic risk for carbon storage. However, major faults in the central-eastern part of the basin are oriented parallel or with an angle of 30° to the SH_{max} orientation; this is a scenario

which might favor triggered earthquakes depending on the relative principal stress magnitudes.

Carbon Capture, Utilization, and Sequestration in the Rockies, Tuesday, July 26, 10:35 AM

Modeling of Channel Stacking Patterns Controlled by Near Wellbore Modeling

ESCOBAR ARENAS, LUIS C., Colorado State University; Patrick Ronnau, Colorado State University; Lisa Stright, Colorado State University; Steve Hubbard, University of Calgary; Brian Romans, Virginia Tech

Reservoir models of deep-water channels rely upon low-resolution but spatially extensive seismic data, high vertical resolution but spatially sparse well log data and geomodeling methods. The results cannot predict architecture below seismic resolution or between well logs. Usually, the data and interpretations that provide constraints for modeling workflows do not capture sub-seismic scale architecture. Therefore, standard modeling methods do not generate models that include details that can impact hydrocarbon flow and recovery, and constraining models to well and seismic data is problematic. Employing >5000 m of measured sections in the Upper Tres Pasos Fm. is feasible to predict deep-water channel architecture, specifically channel stacking patterns with 1D information analogous to well data. This research performed near-wellbore modeling to generate multiple scenarios of channel stacking patterns constrained by machine learning. These results anchor points to correlate deep-water channels between wellbores using surface-based modeling.

Machine learning workflows generate channel position probabilities (i.e., axis, off-axis, margin) within a measured section given the interpreted top/bases of channel elements. These probabilities constitute the input for Monte Carlo simulations capturing channel element stacking patterns at the measured section locations. More constraints can be added to make stacking patterns more realisitic (e.g., minimum distance a channel migrates from the previous channel, constraining to transition probabilities). The most likely 2D stacking pattern scenarios defined channel centerline points, and volumes of the individual channel elements can be generated connected them. The volumes will depict the complex transition from thick-bedded sandstones in the axis to thin-bedded sandstones and mudstones in the margins.

Surface-based modeling offers a way to depict reservoirs of hydrocarbons, water or low-enthalpy geothermal systems in which small-scale heterogeneity needs to be captured explicitly by bounding surfaces because it impacts fluid flow, improving our forecasts of resources exploitation. Furthermore, predicting heterogeneity controlled by depositional architecture is critical for transport and storage capacity in CO_2 reservoirs. The dataset provided and the advent of these flexible and accurate methods to depict the subsurface offer the opportunity to overcome the historical limitations of grid-based models and allow us to assess multi-scale architecture that controls fluid flow. This research aims to show the results of modeling of deep-water channels, which includes a 1D identification of facies, 2D arrangement of stacking patterns and 3D connectivity/compartmentalization in the inter-wellbore region.

Student Posters, Tuesday, July 26, 5:30 PM

Characterization of an Unconventional Resource, Uteland Butte member, Lower Green River Formation, Uinta Basin, Utah

FIDLER, LUCAS J., XCL Resources, LLC; Joshua T. Sigler, XCL Resources, LLC; Matthew A. Jones, XCL Resources, LLC

Horizontal oil production in Utah's Uinta Basin has grown dramatically over the past decade with development activity primarily focused in the prolific Uteland Butte play. The Uteland Butte member (UB) is an informal member of the Eocene Green River Formation and is primarily comprised of organic shales, limestones, and dolostones deposited in Lake Uinta during a freshwater period immediately following the Paleocene/Eocene Thermal Maximum. Estimated Ultimate Recoveries from UB wells range from 50,000 to 1,500,000 barrels of oil. Previous outcrop and subsurface studies have observed discrete depositional belts and associated subplays within the UB based on the relative percentages of carbonate content and intragranular vs. organic-matter (OM)-hosted porosity. The dramatic variation in well EURs is partially attributable to the variation of multiple geologic factors associated with these depositionally-driven subplays including depositional facies, source rock quality, maturity, pore pressure, and fluid mobility. The Uteland Butte Organic subplay (UBO) is the northernmost of the productive subplays and is characterized by the presence of highly-overpressured, organic-rich lacustrine source rocks and secondary carbonate beds. This study presents the results of an integrated petrophysical, core, and geochemical analysis to characterize the UBO. Sedimentological and stratigraphic description of core confirmed the presence of prolific source rocks within the UBO along with significant carbonate and dolostone content. Subsequent laboratory analyses verified the presence of significant volumes of mobile hydrocarbon stored in OM-hosted porosity within mature Type-I kerogen. Wireline logs were calibrated to core analyses and utilized to evaluate depositional facies throughout the UBO and further delineate the extents of organic porosity within the UB. These findings were immediately utilized to refine lateral placement in existing development benches and were also paramount in the decision to test and develop additional resource within the Uinta Basin.

Geological characterization and petroleum targets of the Green River Formation, Uinta Basin, Monday, July 25, 1:35 PM

Outcrop characterization and depositional model of the Uteland Butte member, Green River Formation, Uinta Basin, Utah

GALL, RYAN D., Utah Geological Survey; Brinkerhoff, Riley, Wasatch Energy Management, LLC; Birdwell, Justin E., U.S. Geological Survey; Vanden Berg, Michael, Utah Geological Survey

The informal Uteland Butte member of the Eocene Green River Formation, ranging in thickness from 15 to 65 m, represents the first widespread transgression of Lake Uinta across the Uinta Basin, Utah. This study assesses the outcrop expression of the Uteland Butte member along an 85-km transect in the western and central Uinta Basin, from Soldier Summit to Desolation Canyon, using detailed measured sections, organic and inorganic geochemical data, and outcrop gamma ray logs. Eighteen lithofacies were identified and comprise seven depositional facies associations interpreted to represent lacustrine, palustrine, and deltaic depositional settings. Five 4- to 12-m-thick shallowing upward depositional cycles are identified across the study area. Each depositional cycle is defined by a >1.5-m-thick basal clay-rich interval and is capped by a thicker carbonate-rich interval. Clay-rich intervals consist of finely laminated

organic-rich (3%–16% TOC) mudstone (profundal to sublittoral lacustrine) and/or silty mudstone (deltaic). Carbonate-rich intervals are composed of complexly interbedded bivalve wackestone, ostracodal limestone, laminated to massive dolomite, and coal (littoral lacustrine to palustrine). The western outcrop belt correlates to the more distal central Uinta Basin using well logs and cores and to previously published outcrop sections from the far eastern Uinta Basin. Each of the five clay-carbonate shallowing upward cycles identified in outcrops are present across the Uinta Basin, which signifies an allogenic control that resulted in distinct clay- or carbonate-rich lake phases. We interpret climate to be the dominant control and driver of the depositional cyclicity. During relatively humid periods, increased fluvial input of siliciclastic sediment and fresh water into the basin resulted in higher relative lake levels and clay distribution across proximal and distal lake settings. In contrast, more arid periods resulted in decreased fluvial input and evaporative conditions that gradually lowered relative lake levels and favored basin-wide carbonate accumulation and subsequent dolomitization. Climatically driven depositional cycles within the Uteland Butte member likely reflect, to a lesser degree, the climatically driven depositional cycles of fluvial and lacustrine sedimentation observed at broader member and formation levels of Paleocene–Eocene stratigraphy in the Uinta Basin. Importantly, this sub-member-level study showcases how variation of fluvial input can impact lacustrine sediment accumulation at basin scales.

Geological characterization and petroleum targets of the Green River Formation, Uinta Basin, Monday, July 25, 2:25 PM

Fracture Characterization of the Cane Creek Play, Paradox Formation, Southeastern Utah: A Multi-Scale Approach Incorporating the Geology and Petrology of Core and Well Cuttings

GATHOGO, PATRICK N., Rock Microscopy LLC; Lauren Birgenheier, University of Utah; Elliot Jagniecki, Utah Geological Survey; Raul Ochoa, University of Utah; Michael Vanden Berg, Utah Geological Survey;

Fracture analysis is an important component of reservoir rock characterization primarily because of the potential for enhanced migration of hydrocarbon along natural fractures that are open in-situ. The actual permeability ranges for an unconventional 'fracture play' are often anomalously higher than expected for porosity-based permeability predictions. Most fracture evaluation studies have so far depended on core and/or wellbore image logs for verification. This study presents a unique approach that integrates cuttings-scale microfractures with core-scale fractures using petrology interpretations. Also incorporated in this study are results from whole core X-ray CT (computed tomography) and wellbore image logs. This study focuses on the recently drilled State 16-2 (vertical) and State 16-2LN-CC (horizontal) wells in Grand County, Utah, with the target being the Cane Creek production zone of the Paradox Formation. Cuttings from three legacy vertical wells are also included in the study to represent the three main Cane Creek production areas in the Paradox Basin.

Core-based observations provide perhaps the best geological context for fracture geochronology. Fracture sets from the same structural event or geological timeframe generally show consistent orientation patterns and diagenetic mineralization. However, fracture geometry and mineralization may also show local variations depending on lithological attributes such as mineralogy and porosity/permeability as well as the composition of interstitial/pore fluids. Whole core CT reveals the volumetric interactions between fractures and rock facies that have unique composition and microtextural features including stylolite.

Cuttings-based microfractures are reasonably correlated with fractured sections of the core based on similarities in petrology features that include diagenetic mineralization of both the fractures and the microfractures. Initial findings indicate local interactions between some of the mineralized microfractures and microstylolites that are at various stages of development. As an example, organic-filled microstylolites that are incipient stage occur in tangential contact with mineral-filled microfractures. Many forms of isolated microstylolites are also evident in some cuttings where they are commonly lined or filled with organic material. These types of features are typical in many fracture plays. Drilling-induced microfractures and associated deformation features that characterize the cuttings also show good correlation with petrology-based rock facies and may therefore be good indicators of geomechanical behaviors such as fracturability and elasticity.

The Cane Creek Petroleum Play, Paradox Formation, Utah, Tuesday, July 26, 10:35 AM

Geothermal Resource and Synthetic Geothermal Reservoir Feasibility Study of Wyoming

GENTRY, EMILIE N., Petrolern; Batir, Joseph; Petrolern; Kitz, Kevin; Kitzworks; Soroush, Hamed; Petrolern

Wyoming is an epicenter for energy resources across the energy spectrum – coal, oil, gas, uranium, and wind. Additionally, there are surface expressions of hot springs and geothermal resources across the state, most recently assessed in 2012 as part of the National Geothermal Data System compilation project. Previous studies suggest there are limited low-enthalpy geothermal resources available for development, not including the Yellowstone super volcano. While there are geothermal energy opportunities, no public studies are available that assessed the best pathway for economic development of these resources in Wyoming.

Here, we summarize the geothermal potential of Wyoming, assess new geothermal utilization technology options, and estimate its effectiveness to decarbonize Wyoming energy production. This study generates a plan for geothermal development and opportunities focusing on known resources in the state using commercial technology to advance Wyoming's energy strategy. Furthermore, we explore innovative technologies such as Synthetic Geothermal Reservoirs (SGR) to increase Wyoming's renewable energy penetration potential.

In general, the geothermal resource across the state is limited to low enthalpy that would be best suited for direct use applications. There are approximately 1000 wells with bottom hole temperature greater than 200 °F where modular Organic Rankine Cycles may be able to generate electricity, if there are sufficient water production rates. A previous example of this in Wyoming was the Rocky Mountain Oilfield Testing Center that generated an average of 175 kW net power. Still, given the low temperature nature of the resource in Wyoming, this is considered niche power potential.

As an alternative to traditional geothermal energy production, this research evaluates the feasibility of utilizing a Synthetic Geothermal Reservoir (SGR) to store the state's abundant wind resource as

thermal energy in the subsurface. SGRs use the subsurface as a medium for thermal energy storage collected from various renewable sources such as wind energy or concentrated solar power to reliably produce on-demand electrical power, using the recovered heat. In this way, SGRs can provide weather-independent, renewable, baseload energy, without the traditional geothermal geographic constraints of initially hot rock. Instead, the hot geothermal reservoir is engineered by deploying the WY petroleum workforce and wind energy resources. Wyoming's wind resource is cross examined with potential SGR locations and the change in wind utilization is calculated. Results suggest SGR can turn off-peak wind generation into baseload geothermal power, which can provide WY with a unique way to "Drill to a Decarbonized Energy Future".

Geothermal Energy Resources in the Rockies and Beyond, Tuesday, July 26, 2:50 PM

Ninetta Alia Davis: First Female President of RMAG

GRIES, ROBBIE R., Gries Energy Partners, LLC.

Aspiring for something better than an ordinary woman's life with career choices limited to stenography, bookkeeping or teaching, Ninetta Alia Davis set a goal of earning $100,000 ($2.4MM in 2020 dollars) a year and selected the profession of geological engineering and set her sights on a future in the oil business with a goal of owning her own company. The Great Depression, family care, and, likely, prejudice against women would offer challenges and ultimately defeat her dream, but not her spirit.

Ninetta Davis entered the Colorado School of Mines (CSM) at age 16 and was awarded her degree in petroleum engineering in 1920. She was the second woman to graduate from CSM, and after her graduation, no other woman graduated from the CSM geology department until 1961. A prohibition of women attending Mines had insinuated itself into the school though its charter stated, "The School of Mines shall be open to any inhabitant of the Territory of Colorado without regard to sex or color." That charter was quietly set aside and ignored for four decades.

In 1920 Ninetta went to work for $150 per month at Midwest Refining Company in Casper, Wyoming. Midwest (the fourth largest producer of gasoline in the US). Casper was a rough boom town. Four years later, she moved to Fort Collins to work for Union Oil of California. However, Union closed the office, circa 1929, leaving her jobless at the very onset of the Great Depression. Ninetta, resilient and resourceful as ever, took a job in Denver as a bookkeeper in the back office of a department store for $15/week just to get by, and was thankful to have the position.

In 1934, she joined the U.S. Geological Survey (USGS) as a specialist in sub-surface geology of oil fields in the western states. She became active in the Rocky Mountain Association of Petroleum Geologists which was founded two years after she entered the oil business. Ninetta served as Secretary-Treasurer, as First Vice-President, and, in 1941, became the first woman to be President—a year they were preparing to host the AAPG 1942 Annual meeting.

In 1944, Ninetta left the USGS and returned to her first love, petroleum geology, joining Shell Oil when they opened a new office in Denver. Her projects included producing complete regional studies, cross sections, isopachs, current drilling activity, penetration charts and much more. Fifteen years later,

in 1959, she was required to quit, because of her age (60). She was not happy.

Ninetta Alia Davis never became a millionaire, but she had a richly rewarding professional and volunteer career. Before the term "networking" was coined, Ninetta aptly used this process to continue as a geologist and re-entered the industry after a 19-year hiatus. Though knowledge of her role in RMAG was lost for decades, she blazed the trail for many future female RMAG presidents, beginning 54 years later with Susan Landon in 2001. In the last 20 years seven women have been president of RMAG.

History of Petroleum Geology in the Rockies, Monday, July 25, 3:40 PM

Advancement of Geothermal Resources and Research in Utah, USA

HARDWICK, CHRISTIAN L., Utah Geological Survey; William Hurlbut, Utah Geological Survey; Kayla Smith, Utah Geological Survey; Eugene Szymanski, Utah Geological Survey; Stefan Kirby, Utah Geological Survey

Utah is one of only seven states that generates electricity from geothermal resources, contributing about 1% to Utah's total electricity mix. Utah geothermal power plants have a capacity of 73 megawatts (MW), which is only 0.1% of the total estimated undeveloped potential of 49,400 MW. Multiple avenues of research are underway in Utah to characterize this valuable and under-utilized energy resource. 1) Research on produced waters in the Uinta Basin indicates that about 97% of the 776 wells analyzed exceed standard direct-use temperature requirements (>120°F/50°C) and 5% of those are capable of geothermal electric power production (>285°F/140°C), providing an avenue to utilize wastewater and repurpose existing well infrastructure all through the area. 2) Research conducted on sedimentary-hosted geothermal systems throughout western Utah and the eastern Great Basin identifies unconventional reservoirs with temperatures of 350°–400°F (175°–200°C) at depths of 10,000–13,000 feet (3–4 km) that are capable of supporting several power plants in excess of 100 MW, providing a significant contribution to state energy portfolios. 3) In 2018, DOE committed $220 million to research and development at the Utah Frontier Observatory for Research in Geothermal Energy (FORGE) site in Milford, Utah, which is actively working to successfully produce geothermal electricity from hot, low-permeability crystalline rock and demonstrate new technologies, many from the oilfield, for enhanced geothermal systems (EGS). 4) In 2021, as part of the DOE INnovative Geothermal Exploration through Novel Investigations Of Undiscovered Systems (INGENIOUS) project, the UGS began work supporting a multidisciplinary geothermal play fairway analysis of the Great Basin to develop input datasets and analysis techniques to target blind geothermal systems. 5) Low-temperature (U-Th)/He thermochronology is being employed to derive geological time-temperature histories in areas of interest for investigating the age, spatiotemporal evolution, and longevity of modern and ancient subsurface geothermal anomalies to explore for hidden resources in the Great Basin of Utah. Overall, these research programs will help advance geothermal exploration and development in Utah, making use of its massive undeveloped geothermal resource potential while assisting to decarbonize the energy sector, help support rural communities, and generate new economic opportunities across the state.

Geothermal Energy Resources in the Rockies and Beyond, Tuesday, July 26, 2:25 PM

Paleoseismites in San Juan Basin fluvial sedimentary rocks indicate syndepositional seismicity in the Paleocene and Eocene

HOBBS, KEVIN M., New Mexico Bureau of Geology and Mineral Resources; Jacob O. Thacker; New Mexico Bureau of Geology and Mineral Resources

Paleoseismites in eastern and central San Juan Basin are observed in Paleocene–Eocene fluvial siliciclastic sedimentary rocks proximal to the basin-bounding Nacimiento fault and up to 50 km inboard, near the basin axis. Features include clastic dikes, convolute and overturned bedding, diapir-like structures, vents, anastomosing vein-like structures, and potential thixotropic bowls the early Paleocene (ca. 66.0 Ma) Ojo Alamo Sandstone, early to middle Paleocene (ca. 65.8 – 62.3 Ma) Nacimiento Formation, and early Eocene (ca. 56.0 Ma) Cuba Mesa Member and Regina Member of San Jose Formation. The lithologic compositions most affected are fine- to medium-grained feldspathic arenites and mud-clast conglomerates. Mud-clast conglomerates seem especially likely to become injectites: they make up less than 1% of the Regina Member of San Jose Formation yet comprise approximately 50% of injectites in that member. Convolute bedding is often truncated by overlying beds, indicating soft-sediment deformation occurred at or near the surface before deposition of overlying strata. While these features are most prevalent near the Nacimiento Fault on the eastern basin margin, the presence of clastic dikes in Eocene sediments near the basin axis suggests that significant basin-central syndepositional seismicity occurred during accommodation associated with Laramide flexure. Basinwide, clastic dike measurements thus far reveal two major strike orientations: 055° (dominant) and 160°(subsidiary). The dominant clastic dike orientation is sub-parallel to prior estimates of Cretaceous–Paleogene WSW-ENE intraforeland (i.e., Laramide) shortening at the local to regional scale. Cross-cutting planar features that strike 020° may post-date the clastic dikes, but their relationship is not yet clear. The presence of paleoseismites in earliest Paleocene (Puercan North American Land Mammal Age) through early Eocene (Clarkforkian–Wasatchian age) indicates that seismicity occurred for at least approximately 10 million years in the Paleogene San Juan Basin, consistent with stratigraphic evidence of tectonism at this time. The presence of San Juan Basin paleoseismites could suggest early Cenozoic intraforeland earthquakes on the order M ≥ 5 that disrupted sedimentary structures prior to lithification. These preliminary data suggest a 10 m.y. episode of intermittent seismicity associated with the Cenozoic structural and depositional evolution of the San Juan Basin during the Laramide orogeny. Results from this work will be integrated into regional studies on the paleoenvironmental, depositional, and Laramide tectonic development of the area.

Professional Posters, Monday, July 25

Methodology to Estimate Thermal Maturity from Petrophysical Calculations of Gas/Oil Ratios

HOLMES, MICHAEL, Digital Formation; Antony M. Holmes, Digital Formation; Dominic I. Holmes, Digital Formation

Thermal maturity is routinely calculated from analysis of vitrinite reflectance (Ro), and is important in the understanding of the type of hydrocarbons – oil vs gas – that will be produced. However, in areas where Ro has not been run, and where there are no producing wells, there is no current method of predicting thermal maturity from other available data.

There are direct relations between vitrinite reflectance and Gas/Oil Ratios (GOR). A prior publication of Holmes (SPWLA 1990), describes a petrophysical method of calculating GOR using density, neutron, and resistivity well log responses. Correlation of GOR with Ro has been defined by Dow (1977) and Jarvie et al (2015).

The basis for quantifying the degree of gas saturation from petrophysical analysis is the effect of gas on density and neutron log responses. Gas increases porosity on the density log, and reduces porosity on the neutron log (the so called "density/neutron cross-over effect"). Care must be taken to apply the correct lithology, since this must be known to calculate porosities from both logs. If available, descriptions from core or cuttings data should be examined. Also, responses of density, neutron, and Pe logs using a Matrix Identification Plot (comparison of apparent matrix density and Apparent Matrix Volumetric Cross Section) should be examined. Total hydrocarbon saturation is determined from a standard porosity vs Resistivity (Pickett) plot. By subtracting gas saturation, oil saturation is available, allowing for the calculation of gas/oil ratio.

In this publication, we have analyzed eight Niobrara wells from the Denver – Julesburg Basin, which have a large range of GOR as determined from production data. All wells have the requisite log suite to calculate GOR. We demonstrate good comparison between the two sets of GOR. We also have vitrinite reflectance data on all wells, provided by Grant Zimbrick of the Dolan Integration Group.

From the vitrinite reflectance data, values of GOR are shown to be significantly lower than actual GOR. This suggests that the hydrocarbons have migrated from levels of higher thermal maturity. For these wells, the most likely explanation is lateral migration from a fairly close "hot spot".

These findings are significant for a number of reasons. Thermal maturity can be estimated from petrophysically generated GOR, even if no Ro data are available. If Ro information does exist, comparisons can be made with petrophysically determined GOR, to analyze the likely provenance of the hydrocarbons. A knowledge of thermal maturity is required to calculate volumes of total organic carbon (TOC) from well logs. These calculations are equivalent to "organic porosity" which is a significant source of unconventional reservoir hydrocarbons.

Applications of Geochemistry to Petroleum Systems, Wednesday, July 27, 10:35 AM

New Horizontal Play Targeting Fluvial Sandstones in a Basin-Centered Gas System around Jonah Field, WY

HOOPES, JOHN C., Jonah Energy LLC; Cory Christie; Geophysicist, Jonah Energy LLC; William R. Drake; Geological Advisor, Jonah Energy LLC; Greg Gromadzki - G&G Manager, Jonah Energy LLC

New horizontal wells around Jonah Field of the northern Greater Green River Basin support the presence of a prolific basin-centered gas system outside of the historical field extents. Jonah Field is located along the deepest point between the Pinedale Anticline and the LaBarge Platform and produces primarily from vertical wells in Upper Cretaceous Lance Formation sandstones. Braided and

stacked fluvial sandstone channels generally range in thicknesses from 10 to 150 ft. and in width from 100 to 1500 ft. Silt, mudstone, shale, overbank, floodplain, and lacustrine facies, however, interweave throughout the sandstone intervals and are typically considered unproductive and potential stratigraphic hazards. Historical development of the Jonah Field has been most successful in structural highs of fault blocks. These structural features further act as discontinuities that truncate the already complex geometry of the sandstone reservoirs. Earlier development has generally avoided down-dip and east of these faults, due to several factors: 1) diminished vertical well productivity, 2) lower net to gross reservoirs and thicker shales, 3) higher risk of structural hazards, and 4) increased drilling depths in the syncline between Jonah Field and the Pinedale Anticline. Importantly, lower EURs of vertical wells drilled in this down-dip portion of the field are mainly due to lesser net sand footages rather than unfavorable gas saturations. Today, a new horizontal drilling program tests the viability of the synclinal margin of Jonah Field as well areas outside the classic field-defining faults. Despite challenging stratigraphic and structural complexities in these areas, long-reach horizontal wells have yielded excellent results. We attribute the early success of this new Rockies horizontal play to careful well-planning and targeting, stratigraphic traps, and widespread basin-centered gas saturation.

Stratigraphy & Sedimentology, Tuesday, July 26, 3:40 PM

Sedimentology and Reservoir Characterization of the Emerging Cane Creek Play, Paradox Formation, Northern Paradox Basin, Southeastern Utah

JAGNIECKI, ELLIOT A., Utah Geological Survey; Michael Vanden Berg, Utah Geological Survey; Raul Ochoa, Dept. of Geology & Geophysics, University of Utah; Lauren P. Birgenheier, Dept. of Geology & Geophysics, University of Utah

The Pennsylvanian Paradox Formation of the northern Paradox Basin, southeastern Utah, is composed of ~30 cycles of thick salt (200–300 ft) interbedded with intervals of siliciclastics (<120 ft thick). The successions are interpreted as resulting from rhythmic sea level changes driven by glacial and interglacial climatic cycles in the southern hemisphere of the Pangean continent. During periods of glacial retreat and subtropical-arid climate, marine incursions via a northern tidal inlet, coupled with fluvial drainage and eolian processes, deposited siliciclastic and sulphate evaporites in a sabkha-type environment. Glacial maxima ceased open-marine connection and initiated closed-basin evaporative conditions that led to substantial salt deposition. Siliciclastic cycle 21, the Cane Creek (CC), is a targeted emerging resource/fracture play with a total oil production of ~10 MMBO and up to 215 MMBO of undiscovered resource. The CC is informally divided into three distinct zones. The upper A and basal C zones are composed of fabric-destructive and wavy bedded anhydrite, dolomitic mudstone, and organic-rich algal laminated mudstones (source rock). The middle B zone is low-permeability sandstone-siltstone (reservoir), generally wave rippled and burrowed. Collectively, these zones represent parasequences that internally contain meter-scale shallowing upward 5th-6th order cycles, similar to the progradation of shallow-marine sabkha tidal deposits of Abu Dhabi (Persian Gulf). New core obtained from the research stratigraphic well State 16-2 in the White Sands unit, northern Paradox Basin, shows typical anhydrite assemblages in the A zone but thicker reservoir packages (~40 ft) in the B zone compared to the central (~35 ft) and southern (~30 ft) areas. The C zone contains less anhydrite and more siltstone/sandstone, implying less restriction and increased sediment supply near a tidal inlet and/or by fluvial input from the Uncompahgre Plateau. Although reservoir packages are thicker in the north, they have low permeabilities (0.009–0.202 mD) and variable porosities (6%–17%) due to clay content, occluded macerals, and diagenetic anhydrite-dolomite-quartz-halite cements. Intergranular microporosity is scantly observed from planar light petrography but notable under scanning electron microscopy. Therefore, naturally occurring and possibly stimulated fractures may be essential for hydrocarbon recovery. Source rock analyses from northern core/cuttings also indicate deeper burial, positioned within the dry/wet gas window (VRo ~1.8), with laminated organic-rich mudstones that contain up to 15 wt% TOC. In comparison, the central (oil productive) and southern play areas have lower maturity (VRo 1.1 and 1.5, respectively). This initial depositional and reservoir characterization screening of the northern CC provides new insights to understanding depositional play extent, reservoir quality predictability, and rationale for burial history and structural controls.

The Cane Creek Petroleum Play, Paradox Formation, Utah, Tuesday, July 26, 8:35 AM

Influences on mechanical properties of the Upper Wolfcamp (XY) of the Delaware Basin, west Texas, and their relationship with facies and facies architecture

JARAMILLO, ISRAEL A., Department of Geology and Geological Engineering, Colorado School of Mines; Leslie Wood, Department of Geology and Geological Engineering, Colorado School of Mines; Zane Jobe, Department of Geology and Geological Engineering, Colorado School of Mines

Accurate evaluation of rock mechanical properties is critical for predicting the fracture behavior of rocks during hydraulic stimulation. Submarine-lobe deposits are major targets for the exploration and production of hydrocarbons in the X and Y intervals of the Upper Wolfcamp (XY). Event-beds (e.g., mass-transport deposits, debrites, turbidites, and hybrid event beds) are the building blocks of these submarine fans, yet, very few studies have performed rock mechanical analysis or examined the mechanical stratigraphy of these deposits at the event-bed scale. Schmidt hammer rock strength evaluation of event beds in core has been integrated with core-derived facies and key surface analysis, and petrophysical log analysis to assess relationships between sedimentary characteristics and rock fracture behavior. The objectives of this research are to identify key stratigraphic compositional factors controlling mechanical properties in the XY intervals, document the vertical scales at which these properties vary, and consider the impact of these properties on the development of hydraulic fractures. Five primary facies defined by mud content in the XY have been identified and numerous subfacies are decided based on secondary variables (ie., mud clast percentages, degree of bioturbation, dolomitization, etc.). Results will be discussed and modeled to predict the mechanical properties, and hydraulic stimulation potential of the XY reservoir facies will be put forth.

Student Posters, Tuesday, July 26, 5:30 PM

A core competency: Digitalizing core data for better energy-resource and mineral prediction

JOBE, ZANE R., Colorado School of Mines; Nick Howes, Water Institute of the Gulf

Core taken from boreholes is used to characterize many subsurface earth-resources, including hydrocarbon, mineral, and water extraction, geothermal energy development, carbon sequestration, hydrogen storage, and for geotechnical and paleoclimate characterization. Although these disciplines often have different objectives, many of the analyses performed on core are the same – however, there is little communication of sharing of best practices between disciplines. Furthermore, the storage of core and the associated analytical data is often haphazard and not in a digital framework. Given that core is expensive to collect and is the only data type that fully characterizes the heterogeneity in the complex rock types we study, it is imperative that the subsurface community develops a wide-ranging framework to store and analyze core data. Cross-disciplinary collaboration (e.g., between the mining and oil/gas sectors) will be crucial for economies of scale when scanning and digitalizing core data, ensuring future access to this irreplaceable resource that is not only used for resource characterization, but also for training the next generation of subsurface geoscientists.

This talk will provide an overview of the many tools available to help digitalize core, creating data that can be accessed anywhere for viewing, interpretation, and analysis. These tools are unlocking warehouses full of dusty core boxes, providing valuable high-resolution data that can be used for earth-resource characterization in a multitude of geological settings. Core scanners provide 3D lidar and/or CT scans of the core, high-resolution photography, quantitative geochemistry (using e.g., XRF, magnetic susceptibility, multi/hyperspectral imaging), and geomechanical properties. Plugs and thin sections from the core can be photographed for viewing in a 'virtual microscope' and scanned using automated mineralogy techniques to provide quantitative constraints on mineralogy, grain-size, ore-grade, and porosity. Other analytical data (e.g., core descriptions, four-acid assays, plug-based permeability) can be embedded in a depth-registered framework to be compared with scanned core data to allow for statistical comparisons and machine-learning enabled predictions of discipline-specific properties.

Innovative Workflows for Energy Geoscience, Wednesday, July 27, 9:00 AM

Depositional Architecture of a Turbiditic Sandstone Complex, Lower Green River Formation, Uinta Basin, Utah

JONES, MATTHEW A., XCL Resources, LLC.; Sigler, Joshua T, XCL Resources, LLC; Fidler, Lucas J., XCL Resources, LLC; Posey, Tanner A., Epoch Geoservices, LLC; Parker, Dusty L., Epoch Geoservices, LLC

The Green River Formation of Utah records multiple episodes of Eocene lacustrine deposition within the Uinta Basin. Numerous members of the Lower Green River formation (LGR) have been successfully exploited for oil production utilizing horizontal drilling and hydraulic fracturing techniques over the last decade. One such member is the informal Castle Peak member of the LGR. The Castle Peak member produces from over 50 laterals within the Uinta Basin with Estimated Ultimate Recoveries (EURs) from these lateral ranging from 50,000 to 1,000,000 barrels of oil. The most prolific Castle Peak laterals are located within the Central Basin subregion, where a series of sand-dominated turbidites, informally referred to as the Bar F sandstone, have been identified. Due to a relatively limited number of legacy wellbore penetrations within the Central Basin subregion, the lateral extent and aspect ratio of individual turbiditic beds and bedsets within the Bar F sandstone are relatively poorly understood. This study attempts to utilize well logs, cuttings, and geosteering profiles from a high-density development drilling pattern to resolve the depositional architecture of the Bar F sandstone. To conduct this analysis, bedset-scale correlations were made across numerous clastic depositional bodies for every well drilled within a development cube. These high-resolution log correlations were combined with lateral geosteering profiles to develop a 3D framework for individual bedsets. To further confirm correlations and interpretations, drill cuttings were analyzed to compare elemental concentrations across the numerous bodies encountered during development drilling with the intent of evaluating changes in provenance. Additional evidence for compartmentalization was evaluated utilizing high-resolution mud gas ratios from vertical and lateral wellbores. This study distinguishes multiple lenticular, turbiditic complexes within the Bar F sandstone depositional fairway and proposes a generalized relationship between Bar F sandstone thickness and Castle Peak lateral productivity.

Geological characterization and petroleum targets of the Green River Formation, Uinta Basin, Monday, July 25, 4:05 PM

Market Evidence of Reserve Adjustment Factors and Risk Adjusted Discount Rates in a North American Unconventional Play

KERNAN, NICHOLAS D., Division of Minerals Evaluation, U.S. Department of the Interior

There is a significant lack of information on how the U.S. oil and gas industry handles investment risk when valuing mineral rights. The most useful tool currently available is the Society of Professional Evaluation Engineers' (SPEE) annual survey that asks industry experts to share their opinion concerning Reserve Adjustment Factors (RAF) and Risk Adjusted Discount Rates(RADR) for different reserve categories. Be it large mergers and acquisitions or small royalty purchases, little has been done to observe direct market evidence of RAFs or RADRs. This investigation gathered information on the sale of mineral rights in two regions of the Oklahoma and then conducted discounted cash flows to establish the un-risked fair market value (FMV) of the mineral rights at the date they were transacted. We compare these un-risked FMV's to the actual sale price, and use the difference between the two to make assumptions on the industries perspective of investment risk. As would be expected, we observe progressive de-risking over the life-cycle of mineral rights, with large risk adjustments prior to initial drilling when reserves would be categorized as possible or probable. Then smaller risk adjustments as appraisal wells are drilled and the majority of reserves are proved-undeveloped. Once a production unit is fully drilled-out and the reserve category is Proved Developed Producing (PDP) there is almost no risk adjustment and a standard 10% discount rate is often applied. Our findings serve as an example for how oil and gas evaluators can

approach RAFs and RADRs in a way that is more consistent with the real-property appraisal and encourage oil and gas evaluators to seek market driven risk adjustments and discount rates when estimating FMVs.

Assessment of Energy Resources, Wednesday, July 27, 9:25 AM

Multidisciplinary Approach to Niobrara Gas Development in an Overlooked High Temp, High Pressure Reservoir: A Southeast Piceance Case Study

LAVERGNE, BARRETT A., Trifecta Geo Solutions; Salar Nabavian, Gunnison Energy; Keith Jagiello, Petro Data Integration

Early Piceance Basin test wells were completed in the Niobrara, a formation at the base of the Mancos group, beginning in 2009. These first wells were completed on projects which had assets primarily focused on the Williams Fork and Illes Formation. With the last widely known horizontal Niobrara activity circa 2015, the opportunity to incorporate recent technology became possible. To the southeast, little focus had been made on the underlying Mancos, where an overlooked high-pressure reservoir exists. In the early 2010's a few groups drilled test wells in the Niobrara in this area, beginning the uncharted development of the Niobrara in the Southeast Piceance.

This paper discusses the multidisciplinary approach needed to define a prospective resource, from concept to completion, using recent technology. Several evaluation steps were taken to achieve a reliable subsurface model. Along the way, challenges of limited data and model constraints were encountered, which the development team was able to successfully manage.

Available well data was processed and normalized with an appropriate model for petrophysical properties. An early development in the analysis suggested lithologic changes from the "main trend" differentiating the southern development area. Another determining factor used to define the project area was the learnings of the deep and high pressure mapped intervals from offset well data. Other log data including image logs and acoustic information was also a critical part of the subsurface geo model.

A vertical test well near the proposed project area revealed important gas production by zone using a normalized proppant per foot metric. This metric tied to the subsurface geologic model and gave the management team confidence to propose a plan in a focused target window.

3D Seismic information was acquired in the ideal project area identified from the subsurface model to identifying localized faulting and geohazards. Also, the seismic was a critical component of zone placement and geosteering of the planned well. The seismic quality allowed for the advanced processing of seismic volumes, which proved useful when drilling.

Outside of the subsurface evaluation, there was a wide scale logistics and surface infrastructure need, a challenging endeavor in a remote mountain setting. The installed infrastructure was critical to executing one of the largest completions in the basin to date, allowing implementation of recent technology in a geologic derived target window, for the first time in the area. Initial results suggest this well is expected to be one of the best performing wells in the Piceance, with a 6 hr IP test of 30+ MMCFD. It is hoped that the development roadmap for this overlooked resource can be replicated, as the horizontal Niobrara play in the Southeast Piceance has a great deal of future potential.

Innovative Workflows for Energy Geoscience, Wednesday, July 27, 8:35 AM

Well Music: Translating Well Data to Music for a New Perspective

LINDSEY, ALAN, Vesmir

Oil and gas wells are time machines. As they drill, they uncover the history of planet Earth at a given locale, much as tree rings record the history a tree experiences. These wells record millions of years, and now we can artistically express their experience; the lives, the deaths, the droughts, and the floods that the instruments and fossils reveal.

Almost 100 years ago the Schlumberger brothers kicked off well logging by creating long linear graphs of electrical resistivity. Gamma ray, density, spontaneous potential, and more were added through time and used to compare measurements and stratigraphy from one well to another.

While traditional well logs use a visual approach, Leonardo da Vinci, in 1490, used a tube inserted into the water to detect ships by ear. During World War I, the need to detect submarines prompted more research into the use of sound, with an operational passive sonar system in use by 1918.

Well data and musical data as seen in MIDI displays look very similar. How about translating well data into music? What new insights might we gain from well data by experimenting with auditory perception?

This talk explores techniques and results of using log and paleo data to generate music from wells in southern Louisiana and offshore Texas. The approach is called sonification; the use of non-speech audio to represent information.

In the southern Louisiana recordings, the SP curve plays Bass, the Sonic curve is on Flute, and the Density curve plays Clarinet. A percussive beat sounds every ten feet, with special beats marking fifties, hundreds, and thousands of feet. The musical texture has a jazz quality to it and varies dramatically from the sandy deltaic intervals to the distal shaly section.

The paleo data from offshore Texas results in music that is haunting. Each of the species plays a pitch track and a rhythm track where the faster rhythm equals higher counts for that species. The first time that counts are heard for a given species is the last time it lived at that location.

The sonification approach may also be useful for interpretive purposes, comparing the same intervals across many wells in a field, for example, or for monitoring while drilling.

This novel approach provides a totally different way to experience well data that will leave you in awe of the planet we live on and the secrets that oil and gas wells reveal.

Student Posters, Tuesday, July 26, 5:30 PM

The Use of Hydroelectric Energy for Transportation Propulsion in the Rocky Mountain Region

MANGOLD, DAVID H., Colorado School of Mines

The Use of hydroelectric energy in addition to geothermal and other renewable energy sources can be used excessively in the near future for transportation propulsion in the Rocky Mountain Region.

The use of hydroelectric power for propulsion by a railroad began in the early Twentieth Century in Montana and Idaho. Generating facilities were constructed to power what became an extensive system to convert the coal powered steam railroad to electric propulsion. Using improved technology for power generation: low head hydro and in stream hydro, significant power can be generated for propulsion for all surface modes of transportation. Modern technology and engineering designs can significantly expand the generation of hydroelectric power.

The first significant large-scale implementation of hydropower in the region was by the Chicago, Milwaukee, St. Paul Railroad. The construction began in 1914 and the new power system was fully operational in 1917. This success led to additional implementations of railroad electrifications over the next two decades. The Pennsylvania Railroad electrification project is the most notable and the modern example of higher speed passenger rail transportation in the United States, the Amtrak Northeast Corridor remains partially powered by hydro-electric power.

In the future and beyond there are continued planned electrifications of high-speed passenger rail corridors, transit lines and highway vehicle transition to battery electric propulsion is already underway. In California construction of the California High Speed rail system is in construction and planned to operate with predominantly renewable energy.

Opportunities exist in the Rocky Mountain Region to develop significant hydroelectric energy using innovative systems using available water resources as identified by the US Department of Energy. The positive environmental and economic benefits of renewable energy transportation propulsion systems will significantly benefit the region. No new dams would be needed therefore avoiding the negative environmental impacts. Electricity can be used to propel automobiles, trucks, transit systems and trains, operating on corridors where hydroelectric power is readily available. Propulsion using this clean, efficient, and sustainable electrified transportation infrastructure would provide an alternative to fossil fuel powered transportation. This new system to move the people and commerce of the Rocky Mountain Region will allow a prosperous future.

Technological & Analytical Tools for Energy Development, Monday, July 25, 11:00 AM

New USGS Assessment of Continuous Oil Resources of the Bakken and Three Forks Formations in the Williston Basin (North Dakota and Montana, USA)

MARRA, KRISTEN R., USGS; Chris J. Schenk, USGS; Sarah E. Gelman, USGS; Tracey J. Mercier, USGS; Cheryl A. Woodall, USGS

The U.S. Geological Survey (USGS) recently completed a new quantitative, geology-based assessment of continuous oil resources in the Bakken and Three Forks Formations in the U.S. portion of the Williston Basin. The Bakken and Three Forks Formations are part of the Bakken Total Petroleum System, which includes strata from the Upper Devonian Three Forks Formation, Upper Devonian to Lower Mississippian Bakken Formation, and the lowermost section of the Lower Mississippian Lodgepole Formation. Oil generated within the two organic rich upper and lower Bakken shale members has locally migrated into the informal middle member and the lowermost Pronghorn Member of the Bakken Formation, as well as into dolomitized intervals of the underlying Three Forks Formation. Currently, more than 17,500 wells have been drilled into the Bakken and Three Forks, where horizontal laterals primarily target the informal middle Bakken Member and upper and middle units of the Three Forks Formation. Wells with the highest production and greatest estimated ultimate recoveries (EURs) typically occur where increased shale thickness, higher thermal maturity, and overpressure facilitate increased oil saturations into various reservoir facies.

The USGS previously assessed the Bakken Formation in 1995, 2008, and 2013, whereas the Three Forks Formation was initially assessed in 2013. In the 2013 assessment, the Bakken Formation was assessed at a mean of 3.65 billion barrels of oil (BBO) and the Three Forks was assessed at a mean of 3.74 BBO, for a combined reported mean estimate of 7.4 BBO. The USGS assesses undiscovered, technically recoverable resource volumes, which are based on current drilling and technology practices. The quantitative assessment is completed by evaluating the uncertainty about the productive area, the drainage areas, the EURs, the percentage of untested area, and future success ratios for each geologically defined assessment unit (AU). For 2021, a total of 9 continuous Bakken and 7 continuous Three Forks AUs were defined. The estimated mean total is 4.29 BBO, with approximately 1.95 BBO attributed to the Bakken Formation and 2.34 BBO attributed to the Three Forks Formation. The decrease from the 2013 estimates is related to the substantial increase in drilling across the basin, where more than 10,500 additional wells were drilled in the Bakken and Three Forks Formations since the previous assessment. Overall, variations in drainage areas, differences in EURs across the basin, and the percentage of untested area (related to the amount of current drilling) had the biggest impact on the assessment values. Despite the change in the mean resource estimates for the Bakken and Three Forks Formations, the Williston Basin represents a significant oil resource for the United States and remains second behind the Permian Basin in terms of domestic onshore estimated oil resource volumes.

Professional Posters, Monday, July 25

Future of Core-scale analysis: Machine-Learning

MARTIN, THOMAS P., Colorado School of Mines; Zane Jobe, Colorado School of Mines

Core analysis has changed dramatically in the past 5 years with the open-source nature of machine learning algorithms, multi-sensor data acquisition, and cheap cloud computing. This improvement in both software and hardware is allowing for multi-scale, multi-parameter interpretations and predictions on new core, and legacy archives around the world at scale. Much of this technology was developed for the hard rock mining industry, and now is being

applied to sedimentary systems and hydrocarbon bearing intervals. This poster will give an overview of the state of the art for these techniques, and highlight future research directions, with a particular emphasis on the Minalyze system at Colorado School of Mines. While these technologies offer promise of what the future of automated core analysis is, we will also examine pitfalls of using such technology for sedimentary system analysis and interpretation.

Student Poster Session, Tuesday July, 26

Paleohydraulic Analysis of Meandering River Deposits, Petrified Forest National Park, Arizona

MARTIN, THOMAS P., Colorado School of Mines; Zane Jobe, Colorado School of Mines; Clark Gilbert, Colorado School of Mines; Patrick Sullivan, Colorado School of Mines

The Lithodrendon Wash 'Bed', in the Devils Playground area of Petrified Forest National Park, is part of an almost completely exposed section of the Triassic Chinle Formation. This specific unit has been studied previously for its intact 3D exposures of preserved point bar strata in both the vertical and plan-view dimensions. Using measured sections, interpreted satellite imagery, and sedimentary structure measurements this study reconstructs channel dimensions and paleo-discharge measurements for the Lithodrendon Wash Bed. Other contextual data, including an extensive fossil record, detrital zircon geochronology, paleoclimate data, and sedimentological research, is used to further constrain our interpretations and calculations of fluvial conditions of the Lithodrendon Wash 'Bed'.

We collected 12 measured sections, 300+ thickness of trough cross stratified beds, and 30+ channel-belt thickness measurements to help constrain the fluvial deposit dimensions. We also utilized satellite imagery to estimate planform metrics (e.g., radius of curvature). These independently measured datasets are used as inputs to existing empirical formulas to predict channel width and discharge of the fluvial system. Results derived from cross-sectional and plan-view data show strong correlation (<10% difference), highlighting the exceptional exposure of this system.

With the constrained parameters from the paleohydraulic reconstruction of the Lithodrendon Wash Bed, is it possible to use these as inputs into various fluvial modeling programs. We chose MeanderPy, as it's an open-source with a python interface. Today, no program can fully model a rivers dynamic environment, from hydraulics to stratigraphy, but many programs can model specific parts of that system. With MeanderPy, the planform patterns are the focus of the program, with bulk stratigraphic modeling and superposition a secondary feature. We demonstrate that we can recreate the Lithodrendon Wash bed patterns and can model what it may have looked like during, before, and after time of deposition.

The Lithodrendon Wash bed in Petrified Forest National Park is a world-class fluvial exposure where the plan form and vertical exposures of the rock record are preserved and mappable. Recent field work confirms the connection in the rock record between these two measurements tied to the river discharge. Modeling this system using MeanderPy with field collected parameters provides additional insights into stratigraphic construction and fluvial history.

Stratigraphy & Sedimentology, Tuesday, July 26, 4:05 PM

Using Data Analytics to Explore "J" (Muddy) Channel Sandstones in the Denver-Julesburg Basin and Test a ML Exploration Technique

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Some geologic features including river systems can form branching hierarchical network patterns. A trend in storing hierarchical data is to use a NoSQL hierarchical database. Graph databases are an example of a NoSQL database that can model this data category. Graph databases consist of nodes representing entities, with connecting edges representing relationships. Channel sandstones can be modeled as edges with the channel segment starting / ending points and direction. Locations where two channels intersect are modeled as nodes. Once the data is in a graph database data analytics can derive additional information. Different graph specific data analytics can be applied to derive insights and potentially aid exploration. The example described in this presentation uses published data from the Cretaceous "J" (Muddy) Sandstone channels of the Dakota Group of the Denver-Julesburg Basin stored in a graph database, and after applying data analytics, illustrates the results. The "J" Sandstone is the uppermost member of the Cretaceous-age Dakota Group in the Denver-Julesburg Basin of Colorado, Nebraska and Kansas. This unit was deposited in channels eroded into underlying Cretaceous sediments during a regressive shoreline phase. It consists of two members: the basal Fort Collins Member, where present, includes deltaic and marine sediments and overlying Horsetooth Member which includes fluvial channel and estuarine sandstones. A published "J" Sandstone channel sandstone map indicating the directions of water flow and the channel network pattern in the Denver-Julesburg Basin was digitized and stored in a graph database. Individual channel sandstone segments identified in the published mapping were digitized and stored as edges in the graph database, while channel intersections were identified and stored as nodes connected by channel segment edges. Although there are several categories of data analytics that could be applied to this type of data, Google's PageRank was selected because its use for analyzing link flow between websites can be compared to analyzing intersecting flows in channel networks. The PageRank algorithm applied to incoming website links was originally developed by Google to numerically score search results. In simplified terms, the importance of a website is related to the number of external websites that have links to the site being ranked. Sites with greater numbers of incoming links are assumed to be more important and receive higher scores. The numeric ranking of each site is propagated through the nodes in the network and combined by the algorithm with other node's numeric scores to produce a PageRank value. The "J" Sand example uses a similar approach to search result ranking, but instead uses counts of upstream tributary channels as inputs to the algorithm to compute PageRank values. Higher PageRank scores may indicate areas with greater channel flow and exploration potential.

Using Machine Learning to Supplement Geology, Tuesday, July 26, 3:40 PM

Comparison of the Upper Cretaceous Greenhorn Formation in cores from the Denver-Julesburg Basin; implications Ocean Anoxic Event 2 in the Western Interior Sea

MATSON, CHRISTOPHER C., Colorado School of Mines; Stephen A. Sonnenberg, Colorado School of Mines

Despite considerable study of the Cenomanian-Turonian Boundary (93.9 ± 0.15 Ma) in North America, the timing of massive volcanic events and their relationship Ocean Anoxic Event 2 (or OAE 2) remains difficult to resolve. Beginning in the late Turonian, a severe, global environmental perturbation is expressed as an extreme, positive carbon isotopic excursion of $\delta^{13}C > 3 - 7‰$ VPDB. Widespread organic matter burial, development of marine anoxia, pronounced increases in sea surface temperature, elimination of many benthic foraminifera, and elevations in proxy pCO_2 concentration all occur within a few thousand years. These conditions persist into the early Turonian but are not uniform throughout the ~600 – 800 ka duration of OAE 2. A transitory cooling phase known as the Plenus Cold Event echoes cool conditions and more negative $\delta^{13}C$ values immediately prior to OAE 2. Critically, well studied sections, including the Global Boundary Stratotype Section and Point (GSSP) and the USGS Portland 1 core near Pueblo, CO suffer from depositional hiatuses during these initiation and early phases of OAE 2. This study assesses the depositional conditions and stratigraphic completeness of the Upper Cretaceous Greenhorn Formation from unpublished cores in the more distal Denver-Julesburg Basin. Core descriptions, aided by compositional, geochemical, and isotopic datasets, establish that the Greenhorn Formation is more complete in these more distal areas when correlated to existing proximal-distal transects of the Basin. Detailed study of more distal cores is therefore warranted to determine the contribution and timing of massive volcanism to the development of marine anoxia during OAE 2.

Student Posters, Tuesday, July 26, 5:30 PM

Value Creation in the Northern Paradox Basin – paradoxical or not?

MAXWELL, GREGOR, Zephyr Energy plc; Dave List, Zephyr Energy plc; Bilu Cherian, Premier Oilfield Group; Olubiyi Olaoye, Premier Oilfield Group; Bruce Houtchens, Zephyr Energy plc

Zephyr Energy plc operates a 25,000 acre lease holding in the northern Paradox Basin that targets hydrocarbon potential within the Paradox Formation. The Company recognised the possibility for commercial hydrocarbon production from several of the Paradox Formation clastic reservoir zones based on observations suggesting continuous oil and gas accumulations, favourable matrix reservoir quality, significant overpressure and natural fracture permeability that had the ability to deliver substantial offset production, based on analogue wells from the Cane Creek reservoir in the nearby Cane Creek Unit.

The Company acquired a 40 sq. mile, wide-azimuth 3D seismic survey which imaged the Layered Evaporite Sequence (LES) of the Paradox Formation well. These data were used to map the interbedded salt and clastic horizons and the structural framework, to predict natural fracture potential, and to help well plan and guide geosteering once drilling operations commenced.

In 2020, in partnership with the NETL sponsored 'Improving Production in the Emerging Paradox Oil Play' project team, the Company drilled a vertical pilot hole that was cored and extensively logged. Preliminary subsurface models were built using newly gathered and offset data from the pilot hole to evaluate possible outcomes from various completion strategies. A side-tracked 4500' horizontal well that targeted the Cane Creek reservoir zone was then drilled. This horizontal well was drilled entirely within the Cane Creek reservoir and was hydraulically stimulated across 14 stages and subsequently tested. The stimulation and completed design were based upon pre-drill geomechanical and reservoir simulation models due to the lack of nearby analogue comparison wells. These models were updated with (mud logging data, through bit wireline log data and results from a diagnostic formation integrity test (DFIT)) and re-integrated with the 3D seismic and the earth and simulation models at various stages of the data gathering process.

Upon well testing, the data showed high well deliverability of a wet gas/condensate fluid with reservoir pressures close to 10,000 psia and with limited pressure drawdown witnessed during initial production. The well test was considered a success and may suggest the potential for a new commercial play in this part of the basin. This paper will describe the steps that led to the drilling of the well, the first horizontal well completed by modern stimulation in this part of the basin, the well results, the well implication for the potential of the Cane Creek reservoir and other stacked reservoir zones within the Paradox Formation that appear to be analogous to it.

The Cane Creek Petroleum Play, Paradox Formation, Utah, Tuesday, July 26, 9:00 AM

Reservoir Quality on the Lewis Shale for horizontal drilling

MAYORGA-GONZALEZ, LIGIA CAROLINA, Colorado School of Mines; Stephen Sonnenberg

The Lewis Shale is a turbidite system encompassing sandstones, siltstones, and organic-rich shales deposited during the last Western Cretaceous Seaway transgression. It is informally subdivided into three members; a lower member (characterized by high clay and organic matter content), a middle member or Dad sandstone member (a mixture of siltstones, shales, and sandstones), and an upper member (with decreasing amounts of sandstone and greenish-grey shales. Its lithological characteristics vary depending upon its location within the depositional basin (eastern Greater Green River Basin).

The present study is in Sweetwater and Carbon counties in Wyoming. Investigated data include three cores in the Great Divide Basin and one on the Wamsutter Arch provided by MorningStar Partners/Southland Royalty. These cores contain various lithologies, including shales, siltstones, and sandstones, representing the Lewis Shale's lithologic heterogeneity and complexity. This formation is considered an unconventional reservoir due to its low porosity and permeability and the need to use hydraulic fracturing to obtain hydrocarbons at commercial rates. In addition, the area around the cores is relatively undeveloped for horizontal wells.

The objective of this work is to develop a high-resolution reservoir characterization. Reservoir quality and diagenesis are intrinsically related. For this purpose, some of the analyses performed

include X-ray Fluorescence (XRF), X-ray Diffraction (XRD), Field Emission-Scanning Electron Microscopy (FE-SEM), and routine core analyses (RCA).

Well-log data obtained from the Wyoming Oil and Gas Conservation Commission (WOGCC) were used to perform correlations, build maps of the different cored intervals, and evaluate its internal characteristics and reservoir quality. Core description, XRF analyses, thin sections and XRD were taken in areas of interest.

Several authors have described some of the petrophysical properties of the Lewis Shale. However, there are no petrophysical models in the sandstone intervals tying together log and core data to the author's knowledge. The petrophysical characteristics of these four cores displayed the same level of heterogeneity as the facies described. Samples have high variation in water saturation values and, in general, very low porosity and permeability. Samples classified as finely laminated silty sandstones displayed better reservoir properties than the other facies, even the clean, massive sandstones. This proves that the cleanest sandstones are not always the best reservoirs.

Chlorite and clay content have a meaningful impact on reservoir properties. Thus, affecting the porosity calculation. Chlorite also helped preserve porosity and permeability in some of these facies by coating quartz grains, which may explain why the finely laminated silty sandstone facies have better reservoir characteristics than the clean sandstones.

Student Posters, Tuesday, July 26, 5:30 PM

Using Viscoplastic Stress Relaxation Theory on Core Measurements to Determine the Least Horizontal Principal Stress

MCCORMACK, KEVIN L., University of Utah

Over roughly the past ten years, a concept called viscoplastic stress relaxation theory has been developed with direct implications for measuring the in situ stresses regarding the long-term deformation of clay and organic rich rocks. The theory was advanced by using laboratory measurements of shales that are subjected to a constant axial stress over the course of months. The result of this constant load is that the rock slowly strains. In the earth, it is the strain that is relatively constant, and over geologic time, the stresses acting on these rocks relax. By making the assumption of a nearly isotropic stress state at the time of diagenesis, we can mathematically model the viscoplastic relaxation and hence the modern-day stresses. A method has previously been developed a method for normal faulting regimes that incorporates direct measurements of the least horizontal principal stress at depth and an anisotropic velocity model to characterize that stress in the Denver-Julesburg Basin in Colorado, although the location only matters insofar as the faulting regime present. An anisotropic velocity model is rare, and typically only corresponds to sites where microseismic monitoring has taken place. The novelty of the present work is that I have determined certain values of the least horizontal principal stress by using geomechanical laboratory measurements of the horizontal Young's modulus, which allows me to circumvent the need for the anisotropic velocity model. The stress profile that is generated by this method is valid only for depths at which core was taken and the geomechanical measurements were performed such that there are discrete points along the depth profile rather than a continuous

model. Nonetheless, this innovative approach has elucidated the state of stress in the recently drilled State 16-2 research well and subsequent lateral (State 16-2LN-CC) in the Paradox Basin. A hydraulic fracturing stimulation was performed in the lateral at a TVD of 9,701 feet and there were six valid measurement points for the least horizontal principal stress – three above the stimulation and three below. The least principal stress appears to be higher around the depth of the stimulation and lower both above in the same Cane Creek formation and below in a different clastic formation. This implies that the stimulation likely generated large hydraulic fractures because the injection pressure would have had to be high relative to the rock above and below. This is a desired effect for stimulation, although the operators had little data that could inform the state of stress prior to stimulation. In the future, this new method has the potential to inform the state of stress for any project that has access to clay and organic-rich core from the interval of interest.

The Cane Creek Petroleum Play, Paradox Formation, Utah, Tuesday, July 26, 11:00 AM

Geological Modeling of Carbon Dioxide Storage in Osage County, Oklahoma

MILAD, BENMADI M., Adjunct Lecturer and Postdoctoral Research Associate in Petroleum and Geological Engineering at the University of Oklahoma; Rouzbeh Ghanbarnezhad Moghanloo, Associate Professor at OU; Jamal Daneshfar, Ph.D. student at OU

This study aims at identification of sweet spots for potential CO_2 storage projects in Arbuckle Group in Osage County, Oklahoma. Osage county has been very silent in terms of seismicity despite a huge volume of water disposal that has being taken in place over decades that makes this county unique in the state. A total of 124 well logs and existing core datasets were used to build a 3D geological model. Existing injection data were used to validate the geological model. Three criteria were used to examine the safe and permanent CO_2 subsurface storage, including presence of a minimum supercritical depth (>2500 ft) for the target formation, sufficient thickness of porous and permeable rock to store CO_2, and presence of an impermeable caprock.

These criteria were considered for the Arbuckle group in Osage county and turns out that the west side of Osage meets the criteria and potentially can store between 35 to 96 million metric tons of CO_2. Two sweet spots at west and northwest part of the county were identified. Interestingly, there is an active CO_2 EOR into the shallower formation in the same part of county that takes its CO_2 from the nitrogen fertilizer plant in Coffeeville, Kansas and can reduce the cost of potential storage projects since the CO_2 infrastructure (including pipelines and compression units) already exist in the region; the existing CO_2 EOR project can be considered as the contingency plan, in case needed in the future. The significance of this study demonstrates huge potential for storing CO_2 in Arbuckle formation in Osage county permanently and cost-efficiently that can reduce carbon emission from the fertilizer plant and other CO_2 sources in the region.

Carbon Capture, Utilization, and Sequestration in the Rockies, Tuesday, July 26, 11:00 AM

Fast-tracking conventional reservoir development and carbon management within the footprint of unconventionals

NASH, SUSAN, American Association of Petroleum Geologists

This presentation details a methodology and workflow designed to optimize blocks of acreage that have existing unconventional operations. The strategy uses analytics and novel approached for data management and secure data sharing at the heart of the operation, with an emphasis on free and low-cost sources of information and applications that can be used in an as-needed way to reduce risk while evaluating the prospectivity of conventional targets whose oil and gas have often been generated by the unconventional source (and now reservoir). In addition to exploration tools, the process integrates drilling and completion optimization, and also provides a road map for ongoing operations that integrates water management, methane utilization, induced seismicity prevention, and supply chain optimization.

Assessment of Energy Resources, Wednesday, July 27, 9:00 AM

The best strategies for effective cross-over training for geoscientists seeking to diversify

NASH, SUSAN, American Association of Petroleum Geologists

Geoscientists must be agile in a quickly changing world. Not only do they need to identify emerging areas of opportunity, they need to possess the tools and skills that can be deployed across a range of jobs and careers. This presentation details the strategies kinds of knowledge and skills needed by geoscientists and engineers who are seeking to diversify, and how a blend of self-study, guided training, and project-based collaboration can both bolster resumes, and also allow one to start contributing in a meaningful way to new areas. We will look at what learning theory and neuroscience tell us about the best strategies for designing and taking training, and will examine a few case studies to see the processes in action.

Opening Plenary - Welcome to RMS 2022, Monday, July 25, 9:25 AM

Fast-Track

NASH, SUSAN, American Association of Petroleum Geologists

The goal of this presentation is to evaluate the possible methods of converting high and low-volume natural gas that is currently stranded, flared, or shut in, waiting for a pipeline into ammonium fertilizer. There are a number of competing technologies and approaches, and they can be assessed in terms of the availability of inputs, infrastructure, and the specific needs of the market. In the case of ammonium nitrate fertilizer, some additives might be highly desirable in the production process depending on the market. Gas reservoirs, with pressures, geochemistry, and the nature of the associated reservoir fluids can also allow the deployment of different types of chemical plants. Further, produced water can be a part of the solution as well, as the water can be used in the process rather than being injected or hauled off. This approach represents a blended solution that takes advantage of the foundational skills possessed by geoscientists, which include reservoir modeling, reservoir characterization, chemistry, data analytics, project management and supply chain issues. A skid-mounted, mobile ammonium nitrate plant located at the wellhead or in the gas gathering plant could be quickly commissioned and start producing fertilizer quickly and safely. It represents a solution for crisis situations in times of shortages of agricultural inputs.

Professional Posters, Monday, July 25

Examination of the unconventional resource potential of the Mississippian Madison Group within the Williston Basin

NESHEIM, TIMOTHY O., North Dakota Geological Survey; Stephen H. Nordeng, University of North Dakota; Chioma J. Onwumelu, University of North Dakota;

The Mississippian Madison Group has historically produced more than 4.6 billion BOE (~90% oil) from over 32,000 vertical and horizontal wells spanning more than a dozen stratigraphic reservoir targets across both the US and Canadian portions of the Williston Basin. Initial geochemical fingerprinting studies during the 1970's proposed that Madison reservoirs were sourced by the underlying Bakken Formation. However, numerous ensuing geochemical investigations over the past few decades have concluded that Madison reservoir oils were instead primarily self-sourced by one or more sets of Madison petroleum source beds and not by the underlying Bakken Formation.

Recent work integrating core data with wireline logs has revealed the presence of petroleum source rock intervals within the upper Lodgepole/Tilston Interval and Bluell subinterval, which are both proximal to basin center and stratigraphically positioned near the base and middle of the stacked Madison reservoir subunits. Both the upper Lodgepole/Tilston and Bluell source rock intervals contain TOC values of 1-5% (by weight), plot along Type I/II kerogen signatures (hydrogen index versus oxygen index), reach gross thicknesses of 40 feet or more, extend at least for 10's of miles laterally in the subsurface, and appear to have reached the peak oil generation window (Tmax values of 436-456 °C).

Additionally, the overall permeabilities of the numerous Madison reservoirs collectively decrease moving from the basin margins (where most of the historical conventional Madison production has occurred) towards basin center, proximal to the Madison source rock intervals. Furthermore, Madison exploration and development in the late 1970's to early 1980's within the Mondak field area (west central North Dakota) included vertical wells with perforations that spanned upward of several hundred feet (gross), targeted multiple stacked Madison reservoirs with sub-millidarcy permeability and utilized hydraulic fracture stimulation for well completions.

Considering the conventional production volumes along the basin margins, the presence of at least two thermally mature source rock intervals, and the presence of low-permeable reservoirs proximal to basin center and the previously noted source rock intervals, the Mississippian Madison Group may contain substantial unconventional resource potential.

Petroleum Systems in the Rocky Mountain Region, Monday, July 25, 2:00 PM

Feasibility Study of Utilizing Water Disposal Wells to Inject Carbonated Water into Selected Formations in Oklahoma for the Purpose of CO_2 Storage

NNAMDI, DAVID, University of Oklahoma; Jamal DaneshFar, University of Oklahoma; Rouzbeh Moghanloo, University of Oklahoma;

This paper examines the practical and economic feasibility of utilizing existing water disposal wells, with focus on areas with low seismicity events recorded, to sequester CO_2 and benefit from the 45Q tax code.

The UIC (Underground Injection control) program in Oklahoma regulates the activity from class II permits and monitors the injection rates/ volume/ pressure. Based on UIC-2019 record, there are about 11, 000 UIC wells which are utilized to inject about 2 billion barrels of saltwater annually (an average rate of 500 B/D) into underground geological formation(s).

As operators within Oklahoma still experience high water cuts with produced water being re-injected back into underground formation(s), this presents an excellent opportunity for Carbonated Water Injection (CWI).

Injection of carbonated water for EOR projects has been well documented. In our study, we adopt concept of carbonated water for the purposed of CO_2 storage: mixing of captured CO_2 with (slightly processed) produced water at the surface and injecting it into underground formation. We use a simulation approach to evaluate cost to benefit analysis of carbonate water injection for the purpose of geological storage of CO_2. We select counties with the least observed seismicity events over the last decades and identify existing disposal wells in those areas. Next, we select the geological formations that are suitable for the CO_2 storage based on the state's storage catalogue. We use SIMCCS® to conduct simulations of various scenarios.

The amount of CO_2 dissolved in water is a function of pressure, temperature, and salinity. Based on our initial evaluation, we can dissolve about 156 SCF in one barrel of salt water based on average pressure, temperature, and salinity of Oklahoma UIC wells. This will yield sequestration of an average 75 MCF per day of CO_2 stored in target formations through each disposal well with average rate of 500 B/d injection rate per day. To meet the IRS-45Q tax credit eligibility requirement of capturing & storing 100,000 metric tons of CO_2 (~ 2BCF) annually, about 75 wells spread across clusters are required for individual operators.

Our results indicate that the economic gain of storing CO_2 through carbonated water injection is significant and can be considered as considerable cash flow generator for oil and gas operators in the state. The tax credit revenue will easily surpass the related expenses incurred due to surface facility modification for handling and mixing process of fluids, monitoring the acidity of carbonated water and the cost of corrosion treatment for tubular.

This study outlines a novel methodology for CO_2 sequestration via CWI. In addition, we demonstrate the economic benefit of utilizing existing UIC class II permits wells for this purpose without having to incur extra costs and time to apply for class VI permits.

Carbon Capture, Utilization, and Sequestration in the Rockies, Tuesday, July 26, 9:25 AM

Defining the onset of oil generation in the Bakken Formation using thermal maturity series obtained from nonisothermal experiments and an extended kinetic method

NORDENG, STEPHAN H., University of North Dakota; Chioma Onwumelu

The early development of the Bakken Petroleum System recognized the critical importance of the relationship between production and the onset of oil generation. This study presents an additional metric that appears capable of establishing whether or not a specific well has reached the point of oil generation. We use nonisothermal kinetic experiments of natural and experimentally matured examples of the Bakken, that when evaluated using an extended kinetic method, show the development and evolution in kinetics that suggest a means of evaluating the point at which oil generation is initiated. Two endmember sets of kinetic trends are present based on 78 analyses consisting of splits of single samples, multiple samples from individual cores and single core samples from wells distributed across the North Dakota portion of the Williston Basin. Two end member trends or maturation series are evident as linear compensation effects between the activation energy (Ea) and natural logarithm of the frequency factor (A). The end members are distinguished on the basis of the slope of the compensation effect that in both cases are significantly different than a compensation effect caused by statistical aberrations in the data. Nonlinear intermediate examples are bowed upwardly or downwardly with the limbs distributed parallel to subparallel to the trends produced by the end member examples. From these analyses and their geographic relationship to production, it would appear that the critical kinetic parameters that accompany oil generation occur at the point where the two linear compensation effects intersect. This point tends to also correspond with the point of inflection that is associated with the nonlinear compensation effects. Calibration of Rock Eval Tmax to the extended kinetics data is obtained by mapping Tmax onto Ea-ln(A) space and noting the corresponding point of intersection between immature and mature compensation effects.

Professional Posters, Monday, July 25

Chemical Tracers for Empirically-based Resources Assessment and Data Driven Valuations throughout an Asset's Life

OREN, K.C., GeoStar Energy Partners; Patrick Hayes, Tracerco

Direct measurements of zonal production whether in multi-stage unconventional horizontal wells or multi-zone conventional vertical and directional wells are essential to a true understanding of an asset's value. Over the past 15 years chemical tracer innovations have advanced for measuring targeted producing formations and horizontal well zone contributions for reservoir characterization and asset assessments. Mid-life asset management and infield development can be further characterized for enhancing production while minimizing capital investment in depleted acreage and focusing on best ROI. And for later life asset development, chemical tracers are critical for EOR project management by understanding injector-producer relationships to understand enhanced recovery performance and further maximizing capital returns.

There are many reasons for surface recovery of "in-situ" measurements of production data using chemical tracer

technology providing a wide-variety of production assessments throughout the life-cycle of an asset.

In unconventional wells that are hydraulically stimulated in multiple staged intervals across a long reach horizontal wellbore, geologic and other reservoir characteristics will have a direct impact on a well's overall production. Using chemical tracers, a resource's staged productivity can be monitored for a correlated understanding of drilling parameters, stratigraphy and geologic composition, and completion techniques over time. Tracers provide a better understanding of the resource and changes in different completions technologies that are used to liberate hydrocarbons can be directly measured and understood towards making improvements in D&C best practices while enhancing a resource's ultimate valuation.

Likewise, in conventional wells with multiple producing zones through vertical penetrations of comingled interval hydrocarbon production, tracers can be used to provide details of formation zone productivity to understand individual zone contributions of oil, gas and water. Again, chemical tracer measurements are valuable in managing the targeted resource stacked pay for optimizing production and a truer asset valuation over time.

As a resource development evolves, chemical tracers can be applied for continuing in-fill development assessments and understanding depletion, interwell-communications and, ultimately, identifying the best well candidates for late life asset development and field recovery enhancement investments using secondary- and tertiary-recovery techniques.

This paper will focus on how tracer technologies are used over the life-cycle of full-field development of hydrocarbon assets, both oil and gas reservoirs, including different EOR techniques in conventional and unconventional petroleum assets. Case studies in different US basins are included to illustrate the application of tracer technology available today.

Assessment of Energy Resources, Wednesday, July 27, 8:35 AM

Core Characterization of the Crane Creek Interval in the Paradox Formation from the State 16-2 Well

PARONISH, THOMAS J., National Energy Technology Laboratory; Dustin Crandall, National Energy Technology Laboratory; Terry Mckisic, NETL Support Contractor; Sarah Brown, NETL Support Contractor; Johnathan E. Moore, NETL Support Contractor; Natalie Mitchell, NETL Support Contractor; Eric Edelman, University of Utah; Brian McPherson; University of Utah

The State 16-2 well was drilled in Emery County, Utah as part of a U.S. Department of Energy funded field project run by the University of Utah and Zephyr Energy to explore and improve production in the emerging Cane Creek shale of the Paradox oil play (DE-FE0031775). The computed tomography (CT) facilities and multi-sensor core logger at the National Energy Technology Laboratory were used to collect non-destructive data and characterize the lithology and structure of the State 16-2 core to better understand the reservoir quality and fracture network to effectively produce this play.

The core includes roughly 110 feet from a depth of 9,638 to 9,748 feet encompassing the Cane Creek interval and the top of #22 halite cycle. Low-resolution CT images were acquired of the core,

along with gamma density, p-wave velocity, magnetic susceptibly, and handheld X-Ray fluorescence measurements every 6 cm. Several sections of core were also analyzed with high-resolution CT imaging to interrogate internal structures. Sidewall and horizontal core plugs were examined with a steady-state gas permeameter under effective pressures up to 4,500 psi to semi-quantitatively examine the impact of stress-state on permeability.

The Cane Creek interval consists primarily of carbonate mudstone with 1 to 3-foot carbonate units throughout the cored section. These units lack fractures; however, they tend to have interbedded mudstone where structural movement occurred. Fractures exist in the mudstone intervals and most appear to be generated post-deposition, are mineralized, and vertical to subvertical with respect to bedding. The base of the Cane Creek interval has some interbedded zones of halite that have overturned bedding; an increase in the fracture intensity at the base of the formation was not observed.

Preliminary results from core plugs and selected intervals showed a wide variation in permeability, ranging over four orders of magnitude. High resolution CT imaging of gas flow experiments under effective pressures up to 4,500 psi reveal that micro-fractures adjacent to larger grains can dominate the flow through the cores under higher effective pressures.

The Cane Creek Petroleum Play, Paradox Formation, Utah, Tuesday, July 26, 9:25 AM

Focused Investigation, Insights and Impact of Fluid-Filled Storage Volume; A Case Study in the Niobrara-Codell of the DJ Basin

PERRY, STEPHANIE E., GeoMark Research Ltd.; J. Alex Zumberge, GeoMark Research; Kai Cheng, GeoMark Research

For decades subsurface characterization experts have relied on calibration of fluid-filled storage volume (porosity and saturation) from laboratory analysis performed on crushed rock samples and results tied to geological and petrophysical property models. Lack of further innovation to advance the application of the crushed rock technique to accurately quantify rock properties across maturity, organic-enrichment and lithological variation resulted in a prevalent disconnect between petrophysically calibrated models (wireline based) and original oil-in place versus the prediction of recoverable hydrocarbons at the wellhead (both hydrocarbon and water phases). In this study we present an innovated and integrated rock and fluid laboratory work flow that resolves the identified past challenges with laboratory property quantification, particularly porosity and saturations. Further, the technique resolves the known laboratory loss of fluids from investigated rock volume as samples are prepared by crushing the material for complimentary methods to be applied and measurements performed. Last, the integrated work flow integrates both open and closed retort application, geochemical total organic carbon and programmed pyrolysis investigation as well as nuclear magnetic resonance to result in increased accuracy and understanding of the rock and fluid properties of investigated rock volume. With the improvement in quantification, petrophysical wireline based models can be corrected for the quantification of lost fluid elucidating the understanding and perspectives of prospective unconventional target zones. The laboratory data integration to the wireline evaluation and geological context results in an opportunity to bridge the gap between the subsurface characterization to an

improved predictive wellhead performance understanding. In this case study we highlight and discuss learnings from four wells, spanning the maturity variation in the DJ basin from dry gas to black oil while comparing and contrasting the Niobrara-Codell development stack in each location. Then, linking the modified and innovated laboratory technique to production performance of the relevant horizontal wells, demonstrating how the subsurface to wellhead, static to dynamic behavior interaction can be understood.

Applications of Geochemistry to Petroleum Systems, Tuesday, July 26, 2:25 PM

From the Civil War to the Jazz Age: Isaac Canfield's 60-year career as an oil dowser

PLAZAK, DANIEL J., self-employed

Isaac Canfield started his oil-industry career in Titusville, Pennsylvania in the 1860s, during the Civil War. His oil career ended with his death in 1924, when the nation was enthralled with jazz and bootleg gin. In between, Canfield discovered the second and third oil fields in Colorado (Florence in 1881, and Boulder, the first oil discovery in the Denver basin, in 1902). He also chose the location for the discovery well of the Electra field in Texas, and has a reasonable claim to have drilled the first (though non-commercial) oil well in New Mexico in 1906. He did all his oil exploration by dowsing with a forked stick he called ""the bobber.""

Canfield and his bobber were not infallible by any means. He drilled many dry holes, perhaps more dry holes than producers. But he never gave up, and by the time of his death had accumulated a record of discoveries that most geologists would envy.

History of Petroleum Geology in the Rockies, Monday, July 25, 4:30 PM

Advanced Aspects Of Groundwater Flow And 3D Geologic Models In The Oil Shale Basins, Jordan

QUINN, PAUL G., Ambet LLC; Omar Alyed

Oil-shale deposits have been identified in the Jordan Basins. Geophysical and Geological Investigations have been conducted on the Oil Shale basins. The availability, natural dynamics and interaction between surface water and groundwater resources are understood and will be important to understanding integrated hydrologic impacts from development of oil shale resources on the Oil Shale Basins. Development will require groundwater to access and process oil shale deposits. The removal of this water and subsequent disposal of it will likely impact both groundwater and surface water. Understanding these impacts requires detailed knowledge of both the surface hydrology and subsurface hydrogeology of the basin system and their interaction. Natural ground water recharge within the basin aquifer is derived from precipitation whereas ground-water discharge is to either ephemeral or, perennial streams. The geohydrologic units considered in these models in geologic Formations that are unconfined and confined units. These deposits directly influence flows between surface water and groundwater. Hydraulic conductivity of the basin aquifer is related to lithology and the degree of fracturing. This presentation discusses development of a conceptual model, and inputs necessary to construct a fully integrated surface water-groundwater hydrologic model of existing conditions of the Oil Shale Basins: El Lajjun and Attarat.

Professional Posters, Monday, July 25

Integrated Reservoir Characterization for Hydrocarbon Exploration & Production, CO2 Sequestration, and Critical Mineral Resource Exploration & Production

REPPE, CALVIN C., RC Allan; Ivana M. Stevanovic, PhD

Reservoir characterization is a multi-disciplinary analysis, that is essential to reduce the geologic and economic risks for any geologic play and basin in North America. The integrated reservoir characterization techniques are utilized in the evaluation, analysis, and identification of the specific geologic reservoir characteristics for any geologic play. Reservoir characteristics for each geologic play whether for hydrocarbons, CO_2 sequestration, or critical minerals may be similar in their approach, but are unique to each reservoir (play). The reservoir characterization analysis includes: 1) well log (raster and LAS), mud log, core, drill stem tests (DSTs), petrophysics, and sequence stratigraphy; 2) borehole temperature, API, gas oil ratios (GORs); 3) source rock and rock mechanics which includes organic and inorganic chemistry; and 4) seismic, fracture identification, structural, and 3D reservoir modeling. These techniques are then incorporated into an integrated reservoir characterization model and applied into the drilling, completion, and reservoir engineering. These techniques do not need to be costly, especially if already available geologic data is utilized and paired with a precisely modeled study.

A reservoir characterization was conducted for the Cretaceous Frontier/Turner sandstone reservoir in the Powder River Basin. The cost for the analysis (chemostratighy, proppant embedment, XRD, and organic and inorganic chemistry) was $75,000. This reservoir characterization was presented in 2014 at the Niobrara Conference. The same analyses were presented at this conference by a competitor for a cost of $500,000. Another reservoir characterization was conducted to reevaluate a failed exploration "resource play" in the Delaware Basin. The operator failed to identify the 'key' reservoir(s) that were identified by the historic DSTs. The operator drilled and completed 5 marginal wells in a shale interval that did not represent a reservoir. The operator walked away from a >$250 million investment and sold for <$1 million.

These integrated reservoir characterization techniques will significantly improve the economics of the geologic plays. A TEAM approach and working relationship that has the same goals will result in the identification and high grading of "sweet spots" for greater producibility and achieving the project economic benchmarks, i.e., rates of return (ROR), return on investment (ROI), net present value (NPV), and multiple revenue streams for the hydrocarbon, CO_2 sequestration, and critical minerals projects.

Carbon Capture, Utilization, and Sequestration in the Rockies, Tuesday, July 26, 8:35 AM

The Department of Energy's Advances Towards a Sustainable CM/REE Supply Chain

RICE, SAVANNAH L., Oak Ridge Institute for Science and Education (US Department of Energy); Anna Wendt, Department of Energy; Grant Bromhal, Department of Energy; Evan Granite, Department of Energy; Maryanne Alvin, National Energy Technology Laboratory

The US is import-dependent (>50% from foreign source) on 32 of the 35 critical minerals and import-reliant (100% from foreign source) for at least 14 critical minerals. The DOE established the Division of Minerals Sustainability to help address this problem as we move into a future with an increasing mix of clean energy technologies. The Division of Minerals Sustainability's vision and mission are focused on producing unconventional and secondary feedstocks containing critical minerals and carbon ore derived from previous mining operations, as well as other fossil energy-related byproduct streams, such as produced water from natural gas and oil operations. This approach will augment recycling efforts, which are projected to relieve the pressure on primary critical mineral supply but will not be sufficient to meet the demand required for electric vehicle and battery materials. Since 2014, the U.S. Department of Energy (DOE) Office of Fossil Energy and Carbon Management (FECM) and its national lab, National Energy Technology Laboratory (NETL), have been developing technologies to diversify the domestic supply and enable the reuse of coal waste and byproducts, particularly in the manufacturing of high value carbon products. These carbon products may include graphene, graphite, and carbon fibers. FECM and NETL launched the CORE-CM (Carbon Ore, Rare Earth, and Critical Minerals) initiative last year, aimed at catalyzing regional economic growth and job creation by addressing the upstream and midstream CM supply chain and downstream manufacturing of nonfuel, carbon-based products, to accelerate the realization of full potential for carbon ores and CMs within the U.S basins. 13 CORE-CM awardees across the US are currently working in their respective basins to regionally characterize their CM resource potential. FECM's RDD&D program activities for critical mineral production have demonstrated successful recovery of CMs from unconventional and secondary sources. Researchers have identified localities across the United States where coal by-products yield concentrations of rare earth elements deemed to be economically producible. The RDD&D program has identified opportunities for creating new critical mineral supply chains through upgrades to feedstock extraction, concentration, extractive metallurgy, reduction, and alloying. This includes three pilot-scale REE separation facilities that are producing kilograms of high-purity (~98%) Mixed Rare Earth Oxides (MREO). It also includes the pre-FEED studies for facilities designed to produce 1-3 metric tons/day of high-purity MREO. Over the next several years FECM will focus its efforts on building and strengthening sustainable critical mineral supply chains through unconventional and secondary sources that contain CMs and carbon ore. These efforts will work synchronously with strategies to support the commercialization of high-value carbon ore products to advance domestic clean energy manufacturing.

Professional Posters, Monday, July 25

Machine learning prediction of slope channel facies using outcrop analog data, Tres Pasos Formation, Magallanes Basin, Chile

RONNAU, PATRICK, Colorado State University; Lisa Stright; Department of Geosciences, Colorado State University; Stephen M. Hubbard; Department of Geoscience, University of Calgary; Brian W. Romans; Department of Geosciences, Virginia Tech

Deep-water slope systems hold significant economic importance as potential hydrocarbon reservoirs. Interpretation of channel architecture from well data is vital to locating zones of high reservoir connectivity for optimal well placement. Antecedent studies use machine learning (ML) to classify facies from measured sections (MS). In this study, > 5000 m of MS data from Cretaceous Tres Pasos Formation outcrops in the Magallanes Basin (southern Chile) are used to test ML detection of facies and channel architecture (i.e., element size and stacking hierarchy). This investigation expands from previous studies to incorporate data from outcrops that are up- and down-dip (up- and down-slope) from the Laguna Figueroa outcrop as well as incorporate additional statistics. The goal is predicting classes that are typically interpreted by a sedimentologist (i.e., facies and architectural) and improving ML interpretation performance with sedimentologic data.

Sedimentological features of each MS are recorded quantitatively in a relational database, including bed count, bed thickness distribution, grainsize distribution, element net to gross, and element amalgamation ratio. This is analogous to information collected from wellbore core. In the MS, facies and architectural position (axis, off-axis and margin) are manually interpreted and all aforementioned statistics grouped into these categories. Laguna Figueroa data (68 MS) with interpreted facies and positions serve as a training set for a neural network to avoid manually interpreting these categories in other MS (>100 additional measured sections). Through a series of algorithm architectures, prediction accuracy is improved until decision performance plateaus. Then, using the expanded database, ML interpretations are generated for each MS varying data density and spatial configuration between different MS. Due to non-uniqueness, the resulting predictions are cast as probabilistic realizations of facies and architectural position for each section. Furthermore, ML decision quality is assessed with confusion matrices for each facies and position classifier. Per class performance thus provides insight into relative feature importance and robustness of predictions.

Sedimentological data is often qualitative in nature and difficult to combine with ML workflows. This project optimizes the use of sedimentologic observations from outcrop analogs into ML predictions to improve subsurface interpretation. New drilling projects often suffer from limited availability of core data, making it challenging to interpret sedimentology directly from logging (1D data). This forces inference into reservoir characterization. These limitations necessitate more robust approaches to interpretation that incorporate aspects of analog datasets. ML, which is already employed in well log interpretation, represents a significant advantage over traditional manual interpretation, which is time intensive and can introduce error and bias.

Student Posters, Tuesday, July 26, 5:30 PM

Tectonic evolution of the Paradox Basin with insight from 3D seismic reflection data

RUNYON, BROOK, University of Arizona; Amanda N. Hughes, University of Arizona; Dave F. List, David List Consulting; Eugene Szymanski, Utah Geological Survey; Michael D. Vanden Berg, Utah Geological Survey; Elliot Jagniecki; Utah Geological Survey

The Paradox Basin in southeastern Utah and southwestern Colorado has a complex geologic history that includes multiple deformational events with structural styles that were influenced heavily by the presence of extensive Pennsylvanian-aged Paradox Formation evaporite deposits within the basin. While some strata and structures have exceptional outcrop exposure, limited seismic and well data have given only a partial view of the subsurface constraints needed to fully characterize the geologic history and processes that have occurred in the basin. Because of this, open questions remain regarding the local expression of regional deformation events and their influence on local petroleum systems.

To better characterize the geometry and timing of basin deformation, we have interpreted a 40-mi2 3D seismic volume located in the northern Paradox Basin, acquired to image a hydrocarbon-rich clastic interbed of the lower Paradox Formation known as the Cane Creek interval. Significant economic resources on the order of ~10 MMBO have been produced in the central and southern sectors of the Cane Creek play while the unconventional resource potential in the northern sector is actively being characterized. The Cane Creek has a complex subsurface geometry that without seismic data would not be characterized in well planning. A tectonic evolution of the basin informed by subsurface data provides higher resolution insight into the timing and geometry of structural deformation that will aid in the ongoing and future economic exploration of the Paradox Basin.

We place these subsurface observations in the context of the geologic history of the basin and demonstrate their implications through a series of seismic images, cross sections, volume amplitude extractions, isopachs, horizons, and fault interpretations. Basement-involved faults in the pre-salt formations exhibit strike-slip geometries, indicative of a pre-Pennsylvanian deformational event. We define the Green River anticline as a detachment fold, with distributed shortening deformation in its core within the Paradox Formation. Deformation in the lower Paradox Formation accommodates shortening through a series of fault-related folds, duplexes, and wedges separated by three main detachment intervals, while the upper Paradox Formation is more fold-dominated. The shortening magnitude within the lower Paradox is variable and influenced by the position of basement faults, reflecting the influence of pre-salt paleotopography on deformation of the overlying section. By evaluating lateral thickness changes of stratigraphic packages in the post-salt section, we further characterize the geometry, magnitude, and timing of structural growth. With the added value of subsurface data integrated with regional well constraints and surface geology, we can validate and constrain the timing and manifestation of regional geologic events within the Paradox Basin and aid in well planning and drilling for future hydrocarbon exploration.

Student Posters, Tuesday, July 26, 5:30 PM

Ten Million Years of Dakota Sandstone

SAWYER, DAVID, University of Colorado; Bradley S. Singer, University of Wisconsin; Brian R. Jicha, University of Wisconsin; Robert Buchwaldt, Boston University

Marginal marine deposits commonly called Dakota Sandstone were deposited at the edge of the Cretaceous Western Interior Seaway from Late Albian (104 Ma) throughout the Cenomanian stage to the Cenomanian-Turonian boundary (94 Ma). These sedimentary rocks thus straddle the Albian-Cenomanian boundary (100-100.5 Ma), as ratified by the IUGS with a GSSP at Mount Risou, southern France, based on first occurrence of marine planktonic foraminifera Thalmanninella globotruncanoides. Obradovich and Matsumoto used radioisotopic Ar geochronology to date bentonites with planktonic foraminifera biostratigraphy in Hokkaido, Japan. Many Western Interior deposits that had been called Lower Cretaceous beneath the top Mowry Shale Clayspur bentonite or "Fish Scales" marker were shifted into the lower 2-3 Ma of the Cenomanian (Late or Upper Cretaceous). John Obradovich and Bob Weimer embarked on a campaign to determine the age of rocks broadly called Dakota Sandstone in the early 1990s; Obradovich subsequently dated over 50 samples of Dakota Sandstone and equivalents in the northern Rockies ranging over 6 My; by including units correlated with the Dakota Sandstone where Mowry Shale is absent (in UT, NM, CO, & KS), Dakota Sandstone ranges up in age to the Cenomanian-Turonian boundary (OAE2), dated by the 40Ar/39Ar age of Neocardioceras juddi ammonite bentonite "B" at 94.08±0.06 Ma. Skull Creek Shale (104.69±0.07 Ma) and Kassler Member (103.9-104.0 Ma) of the Dakota Sandstone ages at Dinosaur Ridge in the Denver Basin were established by U/Pb dating of zircon. Ages for the Taft Hill and Vaughn Members in Montana (103.1-102.7 Ma) overlap ages for Crowsnest Volcanics in Alberta. The Muddy Sandstone in the Bighorn and Wind River Basins is tightly constrained at 101.3±0.1 Ma, distinctly older than the Newcastle Sandstone ages in the eastern Powder River Basin ranging from 99.8-99.5 Ma. The Albian/Cenomanian boundary in the Rockies probably occurs above the Muddy Sandstone in the Shell Creek Shale in the Bighorn (100.1 Ma) and Wind River Basins (99.7 Ma). Younger Dakota Sandstone ages in Colorado (99.4 Ma), and from Detrital Zircon ages on the uppermost Dakota Sandstone at Horsetooth Reservoir (100±2 Ma) and Dinosaur Ridge (99±2 Ma), show a 4 Ma unconformity between the Kassler and upper Dakota trackways on the east side of the Dakota hogback. The top Mowry age of 97.5 Ma in the Powder River Basin is older than Dakota Sandstone ages that correlate with the WIK ammonite zonation in Kansas (95.5 Ma), New Mexico (96.2-95.5 Ma), and Utah (94.3-94.1 Ma). Marginal marine facies of the Dakota Sandstone were repeatedly deposited across the Western Interior Cretaceous region for over 10 My; sequence boundaries interpreted as representing less than a few 100 ky, turn out to be regional unconformities of several My; correlations of the Dakota across sequence boundaries and interbasinally within the Rockies are uncertain if unconstrained by independent isotopic geochronologic evidence.

Remembering Bob Weimer and his Contributions to Rockies Geology, Monday, July 25, 11:25 AM

Quantifying Rock Characteristics in the San Andres Formation that Promote CO_2 Sequestration, Permian Basin, USA

SCHNEIDER, MITCHELL T., Colorado School of Mines; Zane Jobe, Colorado School of Mines; Jonathan Knapp, Bruker

The San Andres Formation is a conventional carbonate reservoir on the Central Basin Platform, Permian Basin. The San Andres has been a prolific producer of oil and gas, but vertical and lateral heterogeneity within and between fields make reservoir characterization and thus recovery difficult. Carbon dioxide (CO_2) flooding has long been used for enhanced oil recovery operations within the San Andres Formation, and some fields unintentionally sequester large volumes of CO_2. However, the rock characteristics that allow effective CO_2 sequestration (e.g., lateral geological heterogeneity, diagenetic evolution, pore-network dynamics, fluid-rock interactions) are still uncertain. There is a desire to transition these reservoirs into permanent CO_2 sequestration sites due to existing infrastructure and the history of CO_2 injection. Using thin-section data from several fields on the Central Basin Platform, we quantify heterogeneity within pore and pore throat networks using to provide a ranking for transitioning these reservoirs into permanent CO_2 sequestration sites.

We analyzed thin sections using field-emission scanning electron microscopy to document the mineralogy and porosity network at the micron scale. The resulting data documents pore dimensions, pore-lining minerals, and pore-network heterogeneity between different facies and stratigraphic intervals of the San Andres Formation. We integrate this thin section data with existing core-plug porosimetry and field-wide production data to quantify the CO_2 trapping capability of the San Andres Formation, and thus the viability for a particular field to be converted to CO_2 sequestration. This newly collected data can help make informed economic decisions on the future utilization of depleted carbonate petroleum reservoirs, not only in the Permian Basin, but globally.

Carbon Capture, Utilization, and Sequestration in the Rockies, Tuesday, July 26, 11:25 AM

Case Study of Optimizing Oil Recoveries and Parent-Child Relationships in the Gallup Sandstone, San Juan Basin, New Mexico

SLOWINSKI, MATT P., DJR Energy, LLC; Don Koenig, DJR Energy, LLC; Jack Rosenthal, DJR Energy, LLC; Devin Hunter, DJR Energy, LLC

Active horizontal development in the San Juan Basin provides valuable information about how older (parent) and newer (child) wells interact. The operator has performed a case study on the dynamics of reservoir pressure and impacts of operating strategies on horizontal Gallup Sandstone oil production. Operator seeks to validate development techniques to circumvent detrimental impact of offset depletion and consistently achieve forecast production. The Gallup Sandstone is an oil-rich, yet underdeveloped system. This study and ongoing work aim to maximize future oil production in the southern portion of the San Juan Basin.

A basin-wide petrophysical model was developed to quantitatively measure original-oil-in-place (OOIP). This carefully calibrated model dictates type curve risking based on observed recovery factors, while also informing well spacing, development plans and an assessment of parent well drainage. Operator drilled and completed 31 wells between 2019 and 2021 monitoring parent-child production and pressure data, comparing well outcomes to OOIP-based expectations. Using data from existing parent/child interactions, pressure and production rates were analyzed to develop correlations between parent well oil rates, casing pressures, and child well production.

Horizontal Gallup Sandstone wells are high-rate oil producers with subnormal initial pressure. The impact of parent wells in the San Juan Basin can be avoided with thoughtful development practices and pressure management during flowback. Operator found that 12-month oil production from child wells improves by up to 101% when parent wells maintained at least 60% of their initial flowing bottomhole pressure. These results infer safe pressure ranges to maximize production from child well completions. Regional OOIP mapping contextualizes observed production results.

Recent observations on limiting initial oil rates to maximize reservoir pressure and preserve child well locations are applicable in many plays. In oil-rich reservoirs with subnormal pressure, novel approaches should be considered via collaboration between geology and engineering teams. With extremely competitive economics and a substantial resource of untapped oil reserves, the San Juan Basin will be a key Rockies oil producer and is well worth continued study. Outside the San Juan Basin, maximizing child well results is paramount for operators who seek to improve recoverable oil volumes. This study provides a platform for operators to reconsider pressure management and development strategies.

Innovative Workflows for Energy Geoscience, Wednesday, July 27, 9:25 AM

Volatiles Analysis of Cuttings from the FORGE 58-32 Well- "Logging" High Temperature Wells, Evaluating Communication Pathways, and Implications for Completions in Enhanced Geothermal System Wells

SMITH, CHRISTOPHER M., Advanced Hydrocarbon Stratigraphy; Patrick S. Gordon, Timothy M. Smith, and Michael P. Smith

Cuttings from the Frontier Observation for Research in Geothermal Energy (FORGE) Phase 2 58-32 well at the Milford site in Utah were analyzed in late 2021 using rock volatiles stratigraphy (RVS). 58-32 was drilled as a test bed for enhanced geothermal system (EGS) activities targeting a granitoid encountered at ~3200 ft with temperatures ≥175°C present below ~6500 ft. The granitoid has little natural permeability and must be stimulated to provide an appropriate reservoir for EGS. Cuttings were analyzed from above the granitoid at 3000 ft to 7500 ft near TD; sampling was denser near the granitoid interface and the in three 2019 granitoid stimulations zones. RVS data provided unique insights into communication pathways along faults and fractures, showed strong correlations to porosity and fracture density-offering an opportunity to log the higher temperature sections of the well where wireline tools do not function, and demonstrated relationships that appear to have been predictive of the success of the 2019 stimulations.

RVS is an advanced geochemical technique that extracts, identifies, and quantifies 35+ entrained volatiles including water, sulfides,

noble gases, carbon dioxide, and molecular oxygen and nitrogen. The volatiles are extracted by a series of gentle (no heat or solvents used) vacuum extractions and measured on a unique cryo-trap mass spectrometry system developed and built by Advanced Hydrocarbon Stratigraphy; the ease with which volatiles are extracted provides information on the environments where they reside. Cuttings or core samples sealed at the well site can be used for RVS, but legacy materials, including low porosity rock types, can be effectively analyzed years after drilling; the 58-32 cuttings were 4+ years old when analyzed. Legacy samples are crushed during analysis opening tight pore spaces/exposing fresh surfaces and generating a mechanical strength index. RVS data were combined with other data from 58-32 including limited wireline data, an image log to TD, other cuttings data, and stimulation information. This combination allowed for validation of RVS signatures from other applications.

Major findings include: correlation of water content to porosity and fracture density-water, in small quantities, is present in what available porosity there is; the distribution of various sulfur species, CO_2, and helium show correlations to faults and fractures providing information on communication along these features; helium shows discrete build ups at some changes in minerology likely indicating tight rock features serving as baffles/seals. Perhaps most importantly water and mechanical strength measurements appear to be predictive of stimulation experiences; of the three 2019 stimulation zones the highest mechanical strength and lowest water content are observed in stimulation zone 3 which was considered not to be successfully stimulated due to a lack of critically stressed fractures. "

Geothermal Energy Resources in the Rockies and Beyond, Tuesday, July 26, 2:00 PM

CCUS Risk Evaluation in the San Juan Basin Using Rock Volatiles Stratigraphy - Identification of Fractures and Lateral Migration Pathways and Implications for CO2 Injection and Storage

SMITH, CHRISTOPHER M., Advanced Hydrocarbon Stratigraphy; William Ampomah, New Mexico Tech; Luke Martin, New Mexico Tech; Timothy Smith, Advanced Hydrocarbon Stratigraphy; Patrick Gordon, Advanced Hydrocarbon Stratigraphy; Michael Smith, Advanced Hydrocarbon Stratigraphy

As part of a DOE funded grant to examine the role of faults and other possible communication pathways which may allow injected CO_2 to escape its target storage zones New Mexico Tech (NMT) and Advanced Hydrocarbon Stratigraphy (AHS) have been working together in the San Jan Basin (SJB). The goal of the grant is to demonstrate the utility of new technologies for carbon capture and storage applications with the field work being done used to support NMT's CarbonSAFE program at the Farmington site. The field work will culminate in a well to be drilled later in 2022; while being drilled as a monitoring well, it will be completed such that it could serve as a US EPA Class VI well and inject CO_2 into the Jurassic aged Entrada and Bluff formations. Prior to drilling, Rock Volatiles Stratigraphy (RVS), developed by AHS was used on legacy cuttings from wells in the SJB and the Ute and Barker Dome fields to create an ~8 mile four well transect. RVS gently extracts, identifies, and quantifies over 40 volatile compounds from rock samples that can be fresh or several decades old; compounds include the C_{1-10} hydrocarbons (HCs), water, CO_2, and several sulfur species among others. The RVS analysis of the cuttings from the Jurassic section

of Kirtland 1, drilled in 1961, revealed previously unknown fractures containing HC liquids, most likely condensate. The fractures in the Jurassic were charged by three different pulses of increasingly mature HCs with the most mature charge possibly matching the API gravity of Paleozoic production from the relatively close Hogback Field. The SJB and the Ute Dome Field (UDF) are separated by the Hogback Monocline (HM) fault (which may possibly be a fault/fold system) with 3-7000' of displacement. The Paleozoic section of Stephenson 1, in the UDF less than a mile away on to the HM, aligns such that Paleozoic HC liquids on the HM could laterally charge the fractures in the Jurassic on the SJB side of the fault. The chemical composition of the HC liquids in the Paleozoic section Stephenson and Kirtland share similarities re-enforcing this mechanism. The Jurassic section of the Stephenson also shows HC liquid filled fractures that are vertically too removed to be charged by the Mancos shale in Stephenson but would reasonably be charged via lateral fractures from the Mancos in the "downthrown" SJB. These RVS data demonstrate lateral communication across the HC. Other RVS signatures from Stephenson document vertical gas migration. Other features of the transect will be discussed, but this study has uncovered a previously unknown potential migration conduit for CO_2 to escape the target injection zone along - lateral fractures in the Jurassic section of the SJB that lead back to the HM fault where CO_2 may come to reside in the shallower Dakota formation gas fields. It is yet unclear if the CarbonSAFE well will encounter these fracture networks – if the well has been drilled and RVS data are available these will be discussed too.

Carbon Capture, Utilization, and Sequestration in the Rockies, Tuesday, July 26, 9:50 AM

Mining Brines: A New Exploration and Production Model for the Minerals Extraction Industries

SMITH, THOMAS B., US Strategic Minerals Exploration, LLC; Thomas Smith PE, SPE; Robert Benson PhD

How can brine be mined? One first must understand what mining means. Mining, digging, chipping, or simply moving surface sediments has occurred in one form or another for as long as humans and other land mammals have existed on Earth. Fast forward to present - several NASA space programs have focused explicitly on mining or simply rock collecting on nearby asteroids and Mars. Why do we go to such great lengths to mine elsewhere when we have so many mines right here on our planet? Exploration is in our DNA!

What is a hybrid exploration approach? Hybrids result from mixing two different methods hoping to find a better, improved way of doing something. Why is this better? For one, the surface footprint of this type of brine mining operation is usually less than 10 acres in size. In our search for LiquidOre™ brines which contain valuable minerals, we use a rotary drilling rig typically used to drill for oil, gas, or geothermal water. Once we reach the brine reservoir, we again use tried and true equipment and methods to complete the well to produce the brine and deliver it to surface storage tanks. At that point, the processing step is variable and tailored to the specific minerals to be extracted from the brine. New projects aimed at extracting Lithium from brines are under various stages of planning and development throughout the world. Typical brine mining for Lithium using surface evaporation ponds requires a much larger mine site and is environmentally and logistically

challenged in all but a few areas of the world.

US Strategic Minerals Exploration and a host of other "out of the barrel" thinkers are currently developing processing technology to take CO_2 from the atmosphere and use it in a CCUS process with our LiquidOre™ brines to permanently store it as an alkaline earth carbonate product, such as aggregate commonly used for road base and in concrete. Demonstration scale testing is planned at a suitable in-field site where Calcium and Magnesium Chloride-rich brines are available to further evaluate the efficiency and economic viability of our ex-situ CCUS technology.

The Cane Creek Petroleum Play, Paradox Formation, Utah, Tuesday, July 26, 11:25 AM

Niobrara Production from the Lowry-Bombing Range Area Denver Basin, a Deep-Basin, Continuous, Paleostructural Trap

SONNENBERG, STEPHEN A., Colorado School of Mines

The Lowry-Bombing Range (LBR) field (Arapahoe County, CO) is productive from the Niobrara B and C chalks at vertical depths of 7300 to 7950 ft. Both the Niobrara B and C chalk beds range in thickness from 20 to 30 ft in the field area. Porosities in the B chalk range from 10 to 12%; porosities in the C chalk are approximately 10%. The LBR field is being developed by horizontal drilling.

Resistivity mapping in the Niobrara chalks show anomalously high resistivities in areas of Niobrara production. The high resistivities (> 50 ohms) are due to hydrocarbon accumulation/charge in the chalk beds (as evidenced by high residual oil saturations in cores). The high resistivities also coincide with mapped high vitrinite reflectance (Ro > 0.8) and high bottom hole temperatures on well logs and drill stem tests (geothermal gradient 1.9 to 2.5oF/100 ft).

The total Niobrara is thin in the LBR compared to surrounding areas and averages thickness of approximately 350 ft. Thinning occurs in the Niobrara A marl across the area. This thinning is interpreted to be due a paleostructure high being present in the LBR area. Paleostructure also appears to influence thicknesses in lower Cretaceous strata. This paleostructural feature is herein named the LBR High. The paleostructure trends W NW across the area and is approximately 25 miles wide and 60 miles in length. Present-day structure in the LBR is primarily due to the Laramide Orogeny and regional dip is to the west across the LBR area at approximately one-half a degree.

The marls between the chalk beds are regarded as source beds for oil found in the chalk beds. Source rock total organic carbon weight percent (TOC) and Tmax data for the Niobrara in LBR is as follows: A marl, 2-3.4 wt.%, 445°C; B marl, 2.58-3.74 wt.%, 445°C; C marl, 3.5-6.27 wt.%, 451°C; D marl, 0.8 wt.%, 450°C. Source rock data for the Carlile is as follows: TOC 1.5-2.2 wt.% and Tmax 453°C. The overlying Sharon Springs source bed has TOC's ranging from 2.5-4.0 wt.%. Thus, the Sharon Springs, Niobrara, and Carlile have good source rock potential (> 2 wt.%).

Production from horizontal wells is variable and ranges from 199 to 1613 BOPD. The best production is from longer reach laterals drilled in an east-west direction (~2-mile laterals). Maximum horizontal stress direction is interpreted to be NW SE.

Opening Plenary - Welcome to RMS 2022, Monday, July 25, 9:50 AM

Depositional setting and paragenesis of silica nodules from the Middle Jurassic Curtis Formation on the eastern flank of the San Rafael Swell, central Utah

STAUTBERG, ERIC, Colorado School of Mines; Marsha French, Colorado School of Mines; Mindy Solomon; Occidental Petroleum Corporation

In central Utah, outcrops of the Middle Jurassic Curtis Formation contain silica nodules with a distinctive botryoidal morphology (informally referred to a "grape agates") formed by a complicated paragenetic history. Interpretations of the Curtis Formation in central Utah commonly describe shallow marine to marginal marine depositional environments. In contrast, on the eastern flank of the San Rafael Swell, the Curtis Formation exhibits sedimentary structures and stacking patterns that suggest a terrestrial origin: Thinly bedded, ripple laminated sandstones and brown limestones are encased in thick siltstones and shales and represent deposition on an arid fluvial floodplain comprised of crevasse splays, evaporative ponds, and siliceous sinters. The complicated depositional and geochemical relationship between these facies explains why silica nodules can be found scattered over many square miles in this location.

To understand the spatiotemporal distribution of silica nodules in the Curtis Formation, two partial stratigraphic sections were measured, 30 hand samples were collected, and thin sections were made from five hand samples for petrographic and SEM analysis. Petrographic analyses of the brown limestone beds that host the silica nodules show a primary composition of coarse calcite and silt sized detrital quartz grains. Gypsum and celestite are two accessory minerals observed in thin section and hand samples from these limestone beds. Based on field relationships between depositional facies, the stratigraphic location of silica nodules, and mineralogy, it is suggested here that these silica nodules formed on an arid floodplain in siliceous sinters that became evaporative ponds when the hydrothermal flow into the siliceous sinters ceased.

In thin section, silica nodules in these beds exhibit two distinctive botryoidal morphologies: 1) a spherical crystal with radial growth rings of chalcedony and a euhedral quartz in the center and 2) a spherical crystal with bladed opal that radiates outward from a central nucleus. The multiple quartz phases observed within the botryoids suggest that each morphology formed in an environment with different silica concentrations. Botryoids composed of radial opal formed in an environment with higher silica concentrations as compared to the botryoids composed of chalcedony and euhedral quartz. Initial water chemistry in these siliceous sinters fostered the growth of spherical botryoids of opal-A and opal-CT. As the silica concentration decreased in the ponds, chalcedony and eventually euhedral quartz formed. When the silica rich hydrothermal fluids ceased flowing into the sinter, water chemistry switched from silica dominated to carbonate dominated and the ponds precipitated calcium carbonate, gypsum, and celestite marking the last phase of mineralization in these environments.

Student Posters, Tuesday, July 26, 5:30 PM

The Identification and Characterization of Sedimentary Geothermal Play Types on the Texas Gulf Coast for Power Generation

STAUTBERG, ERIC, Colorado School of Mines; Steve Sonnenberg, Colorado School of Mines

Sedimentary geothermal is an emerging energy sector with the potential to provide renewable baseload electricity to residential, commercial, and industrial markets above sedimentary basins. The Texas Gulf Coast contains reservoir temperatures necessary for electricity production, and Texas is the largest consumer of electricity in the United States with a high demand for dispatchable baseload electricity. Identifying and characterizing the major geothermal play types in this basin will help to reduce the exploration and development risks associated with these geothermal resources.

Currently, the main sedimentary geothermal play type identified on the Texas Gulf Coast is the Tertiary geopressured-geothermal sandstones of the Wilcox, Vicksburg, and Frio formations. In addition to these geopressured-geothermal systems, other sedimentary geothermal play types have yet to be identified. Cretaceous and Jurassic formations in South and East Texas should have the necessary reservoir properties to be used for power generation but have not yet been investigated thoroughly. Additionally, salt diapirs across the Gulf Coast are a potential source of geothermal energy due to their high thermal conductivity, but this concept has yet to be evaluated for resource potential.

Preliminary results show that South Texas is optimal for sedimentary geothermal exploration. Eocene Wilcox geopressured-geothermal sandstones are in relatively close proximity to multiple salt diapirs and Cretaceous formations with reservoir temperatures greater than 300°F. The proximity of multiple potential geothermal play types here provides an ideal location to compare the characteristics of each reservoir and resulting resource potential. This research project is focused on using oil and gas exploration techniques to answer essential questions about the use of hot sedimentary aquifers for power generation. How should these geothermal reservoirs be characterized? What are the key risks associated with different play types? What type of subsurface technology should we employ to develop these resources? Answering these questions will help progress sedimentary geothermal to become a major energy sector capable of providing renewable baseload electricity to markets in this region.

Geothermal Energy Resources in the Rockies and Beyond, Tuesday, July 26, 1:35 PM

Insights into mudstone sedimentology, organic richness, and anoxia at the opening of the Cretaceous Interior Seaway: The Lower Cretaceous Skull Creek Formation, Colorado

SULLIVAN, PATRICK M., Colorado School of Mines; Stephen Sonnenberg, Colorado School of Mines

The Skull Creek Formation is a succession of marine mudstones and sandstones within the Lower Cretaceous Dakota Group. The formation contains the earliest record of marine deposition and ocean connection in the Western Interior Seaway (WIS), yet its depositional environments, stratigraphic correlations, and paleogeographic evolution remain poorly understood. This study addresses those uncertainties and presents new sedimentological and geochemical data from four cores and 38 well logs in the central Denver Basin, integrating them into previous outcrop and subsurface studies of the Skull Creek Formation.

Three regional flooding surfaces divide the Skull Creek Formation into informal lower, middle, and upper units which record the paleogeographic evolution of the early WIS. The lower Skull Creek Formation was deposited in a restricted lobe of the Arctic ocean, contains predominately oxygenated, organic matter (OM)-poor basinal to lower slope facies and includes the Eldorado Springs Member, a northwest to southeast-oriented wave-dominated sandstone. The Eldorado Springs Member is the only documented coeval shoreline of the Skull Creek seaway in the Rocky Mountain Region. The middle Skull Creek Formation exhibits anoxic, OM-rich calcareous basinal facies and is hypothesized to represent the earliest connection between the Arctic and Tethyan lobes of the WIS. A unique bioclastic calcarenite facies in the middle Skull Creek Formation is interpreted to signal the onset of this seaway connection, and an associated increase in bottom current strength and biological productivity. These lithofacies persist into the upper Skull Creek Formation, indicating the WIS remained connected until the deposition of the overlying Muddy Formation.

Student Posters, Tuesday, July 26, 5:30 PM

Correlations Between Petroleum Systems and Serpentinization

SWAN, MONTE M., MagmaChem Research Institute; Troy Tittlemier; Stan Keith; Hans Konrad Johnson; Martin Hovland; Haakon Rueslatten

In 2001, during the AAPG Annual Convention in Denver, a major oil & gas company's research group asked the question: "When we do the accounting for supergiant giant oil & gas accumulations the books don't balance (not enough HC's in source rocks, Mg required for dolomitization and foreign metals in oil). Do you have any idea what we are missing?" A promising answer is the ultra-deep hydrothermal (UDH) process of serpentinization, which is the hydration of peridotite under supercritical conditions. It is an exothermic reaction causing 40% expansion of its protolith peridotite, accompanied by large volumes of hydrothermal heavy brines charged with kerogen and Mg released into basement fractures/faults. The correlation of low-grav/strong-mag is a unique characteristic of serpentinites and observed globally, indicating serpentinite diapirs at depth. Basement faults are associated with the diapirs and often with oil fields. The timing of oil generation can be predicted using this model in light of oil, kerogen and black shale Re/Os data and rock-eval pyrolysis data. Serpentinization is the deepest known penetration of water into the Earth, forming the the Serpentosphere, a 3-12 km thick near Earth-wide layer/shell of rock dominated by serpentine group minerals. It is initiated at oceanic spreading centers as lizardite and when subducted transitions to antigorite releasing hydrothermal brines. During rifting the antigorite of the continental Serpentosphere can be dehydrated to steatite (talc) also releasing hydrothermal brines. The Serpentosphere coincides with the seismic and gravity transition from crustal to mantle material, known as the Moho. Beneath the North Sea the top of the Moho lies as little as 2 km below the bottom of the North Sea Basin. Spider plots of 45 trace-elements in oils from numerous basins correlate closely with the same 45 trace-elements in serpentinites. Hydrothermal minerals such as talc, serpentine, and clinochlore are interlayered

with Permian Basin evaporites. During the hydration of the peridotite, simultaneously serpentinite and brine products are being made. The brine product then migrates to the upper crust crossing the sub-critical/super-critical boundary at about 11 km where the kerogen ionizes and is electrostatically attracted to hydrogen to ultimately alkylate into liquid oil. Diamondoids form in serpentinite brines and chemical muds at this transition. A spectacular example near King City, California is the New Idria 15-mile diameter mud volcano carrying 1% TOC and lying close to a major oil field. It erupted 5 cubic miles of chemical serpentinite mud (the Big Blue Formation) on the same timeline as the Monterey Shale. The UDH process of serpentinization suggests petroleum systems may be part of a much larger process than biogenesis in basins−serpentinization answers the question asked by a major oil company's research group during the 2001 AAPG Annual Convention in Denver and 'balances the books'.

Applications of Geochemistry to Petroleum Systems, Tuesday, July 26, 2:50 PM

Subsurface constraints on Paradox Basin thermal history from borehole (U-Th)/He thermochronology within the Cane Creek petroleum play, southeastern Utah

SZYMANSKI, EUGENE, Utah Geological Survey; Pete Reiners; University of Arizona

Thermochronological data have provided critical insight into the complex geologic history of the Paradox Basin by revealing multiple phases of basin subsidence, exhumation, and denudation tied to regional tectono-sedimentary and climatic events. Most public domain data are derived from outcrop samples which, while useful for landscape evolution study, may yield only limited insight into subsurface thermal conditions through time. Subsurface constraints are necessary to accurately characterize the geologic processes that have occurred in the basin, especially when defining the thermal history of emergent petroleum plays like the hydrocarbon-rich Cane Creek clastic interbed of the Pennsylvanian Paradox Formation. To account for this, we conducted down-hole detrital apatite and zircon (U-Th)/He thermochronology analysis of Jurassic-age and older strata in three wells (Threemile 43-18-H; Cane Creek 18-1; and State 16-2) located within the southern, central, and northern sectors, respectively, of the Cane Creek unconventional petroleum play. Success in the central and southern play regions has not yet been matched in the northern part of the play and the geological controls on the unconventional resource potential are not well understood. Our research intends to (1) assess whether the subsurface thermal history of the northern Paradox Basin differs significantly from other regions and (2) determine how individual thermal histories impacted oil and gas systems within prospective zones. (U-Th)/He thermochronology data were derived from 19 samples of well cuttings and 8 yielded data with analytical uncertainties acceptable enough to model numerically. Apatite (U-Th)/He age-[eU] trends indicate a three-stage thermal history for the Cane Creek play area. First, stratigraphic overburden development in the study area caused slow and steady heating in the subsurface through the Cretaceous with a rate increase ca. 100 Ma and peak ca. 70 Ma. This initial heating/burial phase was followed by thermo-tectonic quiescence from 60 to 6 Ma. The third stage is marked by rapid regional exhumation and cooling beginning ca. 6 Ma to modern day because of overburden removal—results indicate ~25°−30°C of cooling with removal of ~1−1.2 km of overburden—and this signal is observed in other published studies in the region. Partially

reset zircon He ages indicate that maximum paleo-temperatures within parts of the Cane Creek play reached ≤180°C during a relatively brief period ca. 70 Ma, which indicates potential impacts to petroleum system development. To account for some site-specific challenges presented to the (U-Th)/He thermochronology method from inherent rock mineralogy, subsurface thermal conditions, and analytical-grade apatite and zircon yield variability, research has expanded into fission-track thermochronology to provide a wider range of paleo-temperature modeling and more precise interpretations.

The Cane Creek Petroleum Play, Paradox Formation, Utah, Tuesday, July 26, 9:50 AM

Mitigating Geologic Risk Uncertainty for Carbon (CO_2) Sequestration in Multiple Subsurface Targets in the Iron Springs District, Iron County, Utah

SZYMANSKI, EUGENE, Utah Geological Survey; Michael D. Vanden Berg, Utah Geological Survey; Elliot A. Jagniecki, Utah Geological Survey; Austin Jensen, Utah Geological Survey; Nathan Moodie, The University of Utah Energy & Geoscience Institute

The Iron Springs District in southwest Utah lies at the eastern boundary of the Basin and Range Province as it transitions into the Colorado Plateau. The region comprises north-northeast-trending basement-cored uplifts and grabens that juxtapose thick sequences of Paleozoic and Mesozoic strata and extensive Eocene and younger volcanics, all of which have been heavily faulted. Although this area is potentially suitable for CO_2 sequestration for several reasons— the presence of multiple, world-class reservoir/seal packages at depths suitable for CO_2 storage and the absence of an active petroleum system which lowers the risk of occluded pore space and overpressure— considerable geologic risk is involved due to complex and poorly constrained subsurface conditions. To reduce uncertainty within the ~180-km^2 area, our subsurface characterization approach leverages new and existing geological and geophysical data for analysis of CO_2 storage capacity, reservoir and seal quality, drilling hazards, and economic contingency planning. Favorable injection targets include (1) eolian sequences of the Jurassic Navajo sandstone (ϕ: ≤15%; μ: ≤156 mD, historically), overlain by gypsiferous shale and limestone of the Carmel Fm. that was intruded by the Three Peaks quartz monzonite, and (2) the intensely fractured Permian Kaibab Limestone, overlain by the mudstone-dominated Triassic Chinle Fm. Control points include reprocessed 2D seismic lines, newly acquired gravity data, on-site outcrop exposures, and geophysical logs, core and cuttings from three nearby petroleum exploration wells. pXRF analysis of core and cuttings from the ARCO Three Peaks #1 well reveals several crosscutting, calcite-filled fracture sets and elevated Ca and S values in the Carmel Fm., providing evidence for paleo-fluid mobilization related to quartz monzonite intrusion ca. 22 Ma. Metasomatic fluids from anhydrite-carbonate beds in the Manganese Wash Mbr. of the overlying Temple Cap Fm. may have precipitated pore-occluding $CaCO_3$ and $CaSO_4$ in the uppermost Navajo Fm.—the entire reservoir quality remains under evaluation. Reprocessed 2D seismic data indicate some promising laterally continuous reflectors and several viable structural, stratigraphic, and volcano-stratigraphic trap styles within Sevier thrust belt structural duplexes. Published data from the Covenant oil field in Sevier County (~200 km away) show that max. permeability in upper Navajo lithofacies varies by several orders of magnitude (0.01—41 mD) between interdunal and massive facies. Terrestrial gravity surveys complement seismic time-

to-depth conversion and can delineate basin structure and laccolith extent. Preliminary calculations indicate that current reservoir targets can store industrial volumes of CO_2 and saline water geochemical models yield encouraging results to greenlight CO_2 injection. Ongoing petrographic work includes MICP analysis, thin section petrography, and electron microprobe analysis.

Carbon Capture, Utilization, and Sequestration in the Rockies, Tuesday, July 26, 9:00 AM

Geologic characterization of the newly acquired State 16-2 Cane Creek research core, Pennsylvanian Paradox Formation, northern Paradox Basin, southeastern Utah

VANDEN BERG, MICHAEL D., Utah Geological Survey; Elliot Jagniecki, Utah Geological Survey; Raul Ochoa, Dept. of Geology & Geophysics, University of Utah; Lauren P. Birgenheier, Dept. of Geology & Geophysics, University of Utah; Eugene Szymanski, Utah Geological Survey; Gregor Maxwell, Zephyr Energy plc; Dave List, Zephyr Energy plc; Eric Edelman, Energy & Geoscience Institute, University of Utah; Rich Esser, Energy & Geoscience Institute, University of Utah; Katie Cummings, Utah Geological Survey

The Cane Creek (CC) unit within the Pennsylvanian Paradox Fm. of the northern Paradox Basin, SE Utah, is often touted as one of the last remaining emerging unconventional tight oil plays in the U.S., with wells capable of producing up to 1500 BOE per day. However, the drilling history of the CC play has been fraught with challenges and disappointment. To help with this effort, the U.S. DOE awarded funding to the Energy & Geoscience Institute at the U. of Utah and the Utah Geological Survey to develop the tools and strategies necessary to tap into this underutilized resource, while minimizing environmental impact. One important project milestone occurred in Dec. 2020 with the drilling of the State 16-2 research well with industry partner Zephyr Energy. Drilled in the White Sands federal unit near the town of Green River, Utah, the well spudded in the Tununk Mbr. of the Cretaceous Mancos Shale and terminated near the base of the Paradox Fm. Cuttings were collected at 50-foot intervals starting at 1620 ft (Jurassic Carmel Fm.) down to the top of the Paradox Fm. (6250 ft). To obtain a more detailed geologic record of the upper Paradox, cuttings were collected at 10-foot spacing and 31 rotary sidewall cores were recovered from specific clastic units. Core of the CC unit (as well as the underlying salt and thin clastic 22) was taken from 9632–9728 ft. The new core shows typical anhydrite assemblages in the upper CC (A zone), but thicker siltstone/very fine sandstone reservoir packages in the middle B and lower C zones compared to CC cores in the central and southern parts of the play. This might imply that the northern area experienced less open-water restriction and increased sediment supply from a possible proximal tidal inlet and/or fluvial input from the Uncompahgre Plateau. Although reservoir packages are thicker in the north, they still have low permeabilities (0.009–0.202 mD) and variable porosities (6%–17%) due to clay content, occluded macerals, and diagenetic anhydrite-dolomite-quartz-halite cements. Intergranular microporosity is scantly observed from planar light petrography but notable under scanning electron microscopy. The core also displays significant fracturing, with one set (lower angle) filled with halite and a second set (higher angle) filled with calcite. Source rock analyses from the numerous, thin organic-rich mudstones (TOC up to 15 wt%) indicate deeper burial compared with play areas to the south, with maturity in the dry/wet gas window (VRo ~1.8). Zircon (U-Th)/He thermochronometers corroborate maximum paleo-temperature estimates (≤180°C) within parts of the CC play and date them to a relatively brief period ca. 70 Ma. This newly acquired core in the northern part of the basin will greatly enhance understanding of the lateral deposition and reservoir variations of the CC and provide new insights into understanding hydrocarbon play extent, reservoir quality, and rationale for overall burial history and structural controls.

Professional Posters, Monday, July 25

Hyperspectral Scan Imagery and XRD Identification of Carnallite as a Potash Source in Brines Associated with Ordovician and Silurian Formations in the Williston Basin, North Dakota

VASQUEZ, M. A., University of North Dakota; Stephan Nordeng, University of North Dakota; Lionel Fonteneau, Corescan Pty Ltd

In the past decade the demand for potash have been steadily increasing. Potassium or potash is a major constituent of most fertilizers on the market. Potassium deposits are found in the form of chemical or mineral compounds such as chlorides and sulfates. The geological environments associated with potash minerals are typically evaporites where minerals such as Sylvite (KCl); Carnallite ($KCl\ MgCl_2\ 6H_2O$); Kainite ($KCl\ MgSO_4\ 3H_2O$); Halite (NaCl) precipitate from evapoconcentrated brines. The Williston Basin in North Dakota contains several thick stratigraphic sections associated with evaporite and sabkha environments with the common occurrence of anhydrite, and rarely sylvite where evaporitic minerals have been identified.

A review of hyperspectral core scanning (Corescan© Hyperspectral Core Imager, HCI 3.2) of some 9800' of cores from the North Dakota portion of the Williston Basin found reflectance signatures that are consistent with the presence of carnallite $KCl\ MgCl_2\ 6H_2O$. Carnallite appears to be present as crusts lining pore space exposed in slabbed cores of laminated dolostones associated with nodular anhydrite. Carnallite with this association was found in several cores of the Red River (Ordovician) and Birdbear (Devonian) formations. Evaporation of interstitial pore filling brines appears to be the most likely source of the cations that precipitate as carnallite. XRD and ICP-MS of samples from cores with hyperspectral signatures indicating carnallite are consistent with this interpretation. To the authors knowledge, this is the first report of carnallite in the Paleozoic section of the Williston Basin in North Dakota. These results indicate that some brines associated with these formations may be a potential source of potash or dissolved potassium.

Student Posters, Tuesday, July 26, 5:30 PM

Estimating total organic carbon content in Green River Formation oil shales using elemental data and multivariate analysis

WU, TENGFEI, Oklahoma Geological Survey; Jeremy Boak, Hurricane Peak Geosciences, Littleton, CO; Justin Birdwell, U.S. Geological Survey

Relationships between total organic carbon (TOC) content and concentrations of major and trace elements, particularly redox-sensitive metals, are well documented in the source rock literature.

Over the last ten years, a range of studies using multivariate, neural networking, and machine learning approaches have been applied to source rock TOC prediction based on inorganic elemental concentration data. Another use of these models is identification of key elements that relate to organic enrichment due to their sensitivity to enhanced productivity or preservation conditions, or that reduce organic richness due to dilution. In this study, major and trace element concentration data from inductively coupled plasma (ICP) optical emission spectroscopy-mass spectrometry were related to TOC measured on the same thermally immature oil shale and mudstone samples from two cores collected in distal areas of the Eocene Green River Formation in the Piceance Basin (approx. 100 samples from each core). Several modeling approaches were tested, including multi-linear regression, random forest, and gradient boosting algorithms. Performance of the models was compared and evaluated in terms of mean square error, mean absolute error, and correlation coefficients between measured and predicted TOC values (R^2). Multi-linear regression showed a significant overfitting issue with low bias and high variance. The remaining three models also indicated some overfitting, but generated relatively high R2 values (≥ 0.66) in the test dataset. This indicates that ensemble tree methods perform better in general for predicting TOC from inorganic elemental data. Among the elements examined, Mo, P, Ti, Ni, and Cr were found to be the top predictors for TOC. This is consistent with results from hierarchical cluster analysis (HCA) applied to these datasets, which also showed many of these elemental associations with organic-rich samples. Results from additional modeling tests comparing different sample groupings, based on stratigraphic sorting or chemofacies clusters identified using HCA, will be presented. In general, the better performance of ensemble tree methods indicates that relationships between TOC and elemental proxies for redox, productivity, and dilution are non-linear.

Applications of Geochemistry to Petroleum Systems, Wednesday, July 27, 11:25 AM

Using Drilling Data to Characterize Reservoirs

WUTHERICH, KEVIN, Drill2Frac; Jason Glascock; Drill2Frac; Brian Sinosic; Drill2Frac; Bill Katon; Drill2Frac

In the world of unconventional horizontal wells, the pace of development and thin margins typically precludes the acquisition of geological or reservoir data from logs that would assist reservoir engineers and geologists. This information is now becoming more and more accessible from an unconventional source, the drilling data. Often overlooked and forgotten once a well has reached TD, there is a plethora of information contained within the drilling data that can guide petrotechnical experts to better understand and adapt their operations to the actual well properties.

In this presentation, we will discuss some of the key insights that can be obtained from drilling data including changes in lithology, inferring rock strength, identifying, and quantifying localized depletion caused by offset producers, fracture detection both natural and induced, and the identification of faults and geohazards. We will also explain how this information can be collected and ultimately used to make decisions on items like optimal drilling target, stacked pay development, well spacing, and the effect of various geohazards.

Several case studies will be presented that demonstrate the accuracy and applicability of this data, with focus on using the data to make actionable decisions, as well as some of the data limitations. At the conclusion of this talk, the importance of incorporating drilling data from every well to improve reservoir knowledge will become evident. Even more so when considering this data is readily available, on every well, and is obtained at a very low or no cost, and with no associated operational risks.

Technological & Analytical Tools for Energy Development, Monday, July 25, 10:35

for thermal energy storage collected from various renewable sources such as wind energy or concentrated solar power to reliably produce on-demand electrical power, using the recovered heat. In this way, SGRs can provide weather-independent, renewable, baseload energy, without the traditional geothermal geographic constraints of initially hot rock. Instead, the hot geothermal reservoir is engineered by deploying the WY petroleum workforce and wind energy resources. Wyoming's wind resource is cross examined with potential SGR locations and the change in wind utilization is calculated. Results suggest SGR can turn off-peak wind generation into baseload geothermal power, which can provide WY with a unique way to "Drill to a Decarbonized Energy Future".

Geothermal Energy Resources in the Rockies and Beyond, Tuesday, July 26, 2:50 PM

Notes

Presenter or Lead Author	Day	Time	Session
Advocate, David M.	Wed., July 27	9:50 AM	Assessment of Energy Resources
Arnsberger, Luke A.	Tues., July 26	1:35 PM	Applications of Geochemistry to Petroleum Systems
Bader, Jeffrey W.	Tues., July 26	4:30 PM	Stratigraphy & Sedimentology
Bader, Jeffrey W.	Wed., July 27	10:35 AM	Structural Geology & Salt Tectonics
Bauer, Matthew W.	Tues., July 26	4:05 PM	Using Machine Learning to Supplement Geology
Bergin, E.M.	Tues., July 26	2:00 PM	Applications of Geochemistry to Petroleum Systems
Bingle-Davis, Marron	Mon., July 25	10:35 AM	Remembering Bob Weimer and his Contributions to Rockies Geology
Birdwell, Justin E.	Mon., July 25	2:50 PM	Geological characterization and petroleum targets of the Green River Formation, Uinta Basin
Birdwell, Justin E.	Mon, July 25	4:30 PM	Geological characterization and petroleum targets of the Green River Formation, Uinta Basin
Birdwell, Justin E.	Mon., July 25	ALL DAY	Professional Posters
Birdwell, Justin E.	Mon., July 25	ALL DAY	Professional Posters
Birdwell, Justin E.	Mon., July 25	ALL DAY	Professional Posters
Blum, Mike	Mon., July 25	11:00 AM	Remembering Bob Weimer and his Contributions to Rockies Geology
Bracken, Kyle A.	Wed., July 27	11:00 AM	Structural Geology & Salt Tectonics
Brinkerhoff, Riley	Mon., July 25	1:35 PM	Geological characterization and petroleum targets of the Green River Formation, Uinta Basin
Brinkerhoff, Riley	Mon., July 25	3:40 PM	Geological characterization and petroleum targets of the Green River Formation, Uinta Basin
Brinkerhoff, Riley	Wed., July 27	9:50 AM	Innovative Workflows for Energy Geoscience
Broadhead, Ronald F.	Mon., July 25	2:50 PM	Petroleum Systems in the Rocky Mountain Region
Camp, Wayne	Wed., July 27	11:00 AM	Applications of Geochemistry to Petroleum Systems
Chidsey, Jr., Thomas C.	Mon., July 25	4:05 PM	History of Petroleum Geology in the Rockies
Christie, Cory H.	Mon., July 25	2:25 PM	Petroleum Systems in the Rocky Mountain Region
Clemishire, Brian	Mon., July 25	ALL DAY	Professional Posters

Presenter or Lead Author	Day	Time	Session
Cumella, Steve	Mon., July 25	1:35 PM	Petroleum Systems in the Rocky Mountain Region
Decker, Douglas B.	Mon., July 25	11:25 AM	Technological & Analytical Tools for Energy Development
Diedrich, Rob	Mon., July 25	9:00 AM	Opening Plenary - Welcome to RMS 2022
Dusak, N.M.	Tues., July 26	ALL DAY	Student Posters
Dvory, No'am Z.	Tues., July 26	10:35 AM	Carbon Capture, Utilization, and Sequestration in the Rockies
Escobar Arenas, Luis C.	Tues., July 26	ALL DAY	Student Posters
Fidler, Lucas J.	Mon., July 25	2:00 PM	Geological characterization and petroleum targets of the Green River Formation, Uinta Basin
Gall, Ryan	Mon., July 25	2:25 PM	Geological characterization and petroleum targets of the Green River Formation, Uinta Basin
Gathogo, Patrick N.	Tues., July 26	9:50 AM	The Cane Creek Petroleum Play, Paradox Formation, Utah
Gentry, Emilie N.	Tues., July 26	2:50 PM	Geothermal Energy Resources in the Rockies and Beyond
Gries, Robbie R.	Mon., July 25	3:40 PM	History of Petroleum Geology in the Rockies
Hagadorn, James	Mon., July 25	11:50 AM	LUNCH (All Convention Luncheon)
Hardwick, Christian L.	Tues., July 26	2:25 PM	Geothermal Energy Resources in the Rockies and Beyond
Hobbs, Kevin M.	Mon., July 25	ALL DAY	Professional Posters
Holmes, Michael	Wed., July 27	10:35 AM	Applications of Geochemistry to Petroleum Systems
Hoopes, John C.	Tues., July 26	3:40 PM	Stratigraphy & Sedimentology
Jagniecki, Elliot	Tues., July 26	8:35 AM	The Cane Creek Petroleum Play, Paradox Formation, Utah
Jaramillo, Israel A.	Tues., July 26	ALL DAY	Student Posters
Jobe, Zane R.	Wed., July 27	9:00 AM	Innovative Workflows for Energy Geoscience
Jones, Matthew A.	Mon., July 25	4:05 PM	Geological characterization and petroleum targets of the Green River Formation, Uinta Basin
Kernan, Nicholas D.	Wed., July 27	9:25 AM	Assessment of Energy Resources
Lavergne, Barrett A.	Wed., July 27	8:35 AM	Innovative Workflows for Energy Geoscience
Lindsey, Alan	Mon., July 25	11:00 AM	Technological & Analytical Tools for Energy Development

Presenter or Lead Author	Day	Time	Session
Marra, Kristen R.	Mon., July 25	ALL DAY	Professional Posters
Martin, Thomas P.	Tues., July 26	ALL DAY	Student Posters
Martin, Thomas P.	Tues., July 26	4:05 PM	Stratigraphy & Sedimentology
Maslyn, R. Mark	Tues., July 26	3:40 PM	Using Machine Learning to Supplement Geology
Matson, Christopher C.	Tues., July 26	ALL DAY	Student Posters
Maxwell, Gregor	Tues., July 26	11:25 AM	The Cane Creek Petroleum Play, Paradox Formation, Utah
Mayorga-Gonzalez, Ligia Carolina	Tues., July 26	ALL DAY	Student Posters
McCormack, Kevin Lynn	Tues., July 26	9:00 AM	The Cane Creek Petroleum Play, Paradox Formation, Utah
Nash, Susan	Mon., July 25	9:25 AM	Opening Plenary - Welcome to RMS 2022
Nash, Susan	Mon., July 25	ALL DAY	Professional Posters
Nash, Susan	Wed., July 27	9:00 AM	Assessment of Energy Resources
Nesheim, Timothy O.	Mon., July 25	2:00 PM	Petroleum Systems in the Rocky Mountain Region
Nnamdi, David	Tues., July 26	9:25 AM	Carbon Capture, Utilization, and Sequestration in the Rockies
Nnamdi, David	Tues, July 26	ALL DAY	Student Posters
Nordeng, Stephan H.	Mon., July 25	ALL DAY	Professional Posters
Oren, K.C.	Wed., July 27	8:35 AM	Assessment of Energy Resources
Paronish, Thomas J.	Tues., July 26	9:25 AM	The Cane Creek Petroleum Play, Paradox Formation, Utah
Phelps, Anna	Mon., July 25	8:35 AM	Opening Plenary - Welcome to RMS 2022
Plazak, Daniel J.	Mon., July 25	4:30 PM	History of Petroleum Geology in the Rockies
Quinn, Paul G.	Mon., July 25	ALL DAY	Professional Posters
Reppe, Calvin C.	Tues., July 26	8:35 AM	Carbon Capture, Utilization, and Sequestration in the Rockies
Rice, Savannah L.	Mon., July 25	ALL DAY	Professional Posters
Ronnau, Patrick	Tues., July 26	ALL DAY	Student Posters
Runyon, Brook	Tues., July 26	ALL DAY	Student Posters

Presenter or Lead Author	Day	Time	Session
Sawyer, David	Mon., July 25	11:25 AM	Remembering Bob Weimer and his Contributions to Rockies Geology
Schneider, Mitchell T.	Tues., July 26	11:25 AM	Carbon Capture, Utilization, and Sequestration in the Rockies
Schneider, Mitchell T.	Tues., July 26	5:30 PM	Student Posters
Slowinski, Matt P.	Wed., July 27	9:25 AM	Innovative Workflows for Energy Geoscience
Smith, Christopher M.	Tues., July 26	9:50 AM	Carbon Capture, Utilization, and Sequestration in the Rockies
Smith, Christopher M.	Tues., July 26	2:00 PM	Geothermal Energy Resources in the Rockies and Beyond
Smith, Thomas B.	Tues., July 26	11:00 AM	The Cane Creek Petroleum Play, Paradox Formation, Utah
Sonnenberg, Steve	Mon., July 25	9:50 AM	Opening Plenary - Welcome to RMS 2022
Stautberg, Eric	Tues., July 26	1:35 PM	Geothermal Energy Resources in the Rockies and Beyond
Stautberg, Eric	Tues., July 26	ALL DAY	Student Posters
Sullivan, Patrick M.	Tues., July 26	ALL DAY	Student Posters
Swan, Monte	Tues., July 26	2:50 PM	Applications of Geochemistry to Petroleum Systems
Szymanski, Eugene	Tues., July 26	9:00 AM	Carbon Capture, Utilization, and Sequestration in the Rockies
Szymanski, Eugene	Tues., July 26	10:35 AM	The Cane Creek Petroleum Play, Paradox Formation, Utah
Vanden Berg, Michael D.	Mon., July 25	ALL DAY	Professional Posters
Vasquez, M.A.	Tues., July 26	ALL DAY	Student Posters
Wu, Tengfei	Wed., July 27	11:25 AM	Applications of Geochemistry to Petroleum Systems
Wutherich, Kevin	Mon., July 25	10:35 AM	Technological & Analytical Tools for Energy Development
Zumberge, J. Alex	Tues., July 26	2:25 PM	Applications of Geochemistry to Petroleum Systems

2023 RMS-AAPG Annual Meeting
Bismarck, North Dakota • June 4-7 2023
Energy & Plains Solutions

- Petroleum Geology of the Rocky Mountain Region
- Carbon Capture-Storage, Lithium, & Deep Geothermal Resources
- Multi-day, pre-conference, Williston Basin core workshop
  -> Agenda to include Cambrian, Ordovician, Devonian, and Mississippian units

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ASSOCIATION
OF GEOLOGISTS

2022 AAPG-RMS Annual Meeting Host Society and Field Trip Sponsor

CHEERS TO 100 YEARS!

Congratulations to RMAG for serving the Rocky Mountain geoscience community for a century!

FEATURED UPCOMING RMAG EVENT

Powder River Basin Symposium & Core Workshop

Sept. 14-15, 2022
Sheraton Denver West, Lakewood

Join RMAG for this exciting symposium focusing on the geology and petroleum development of the Powder River Basin. Talks cover the **Mowry, Wall Creek, Turner, Frontier, Shannon,** and **Muddy.** The Core Workshop will feature a new unnamed Mowry core.

Early Bird Registration through July 31st!

$225/members; $275/non-members
After July 31: $275/members; $325/non-members

Register today at www.rmag.org

Visit us at booth 32 in the Exhibit Hall