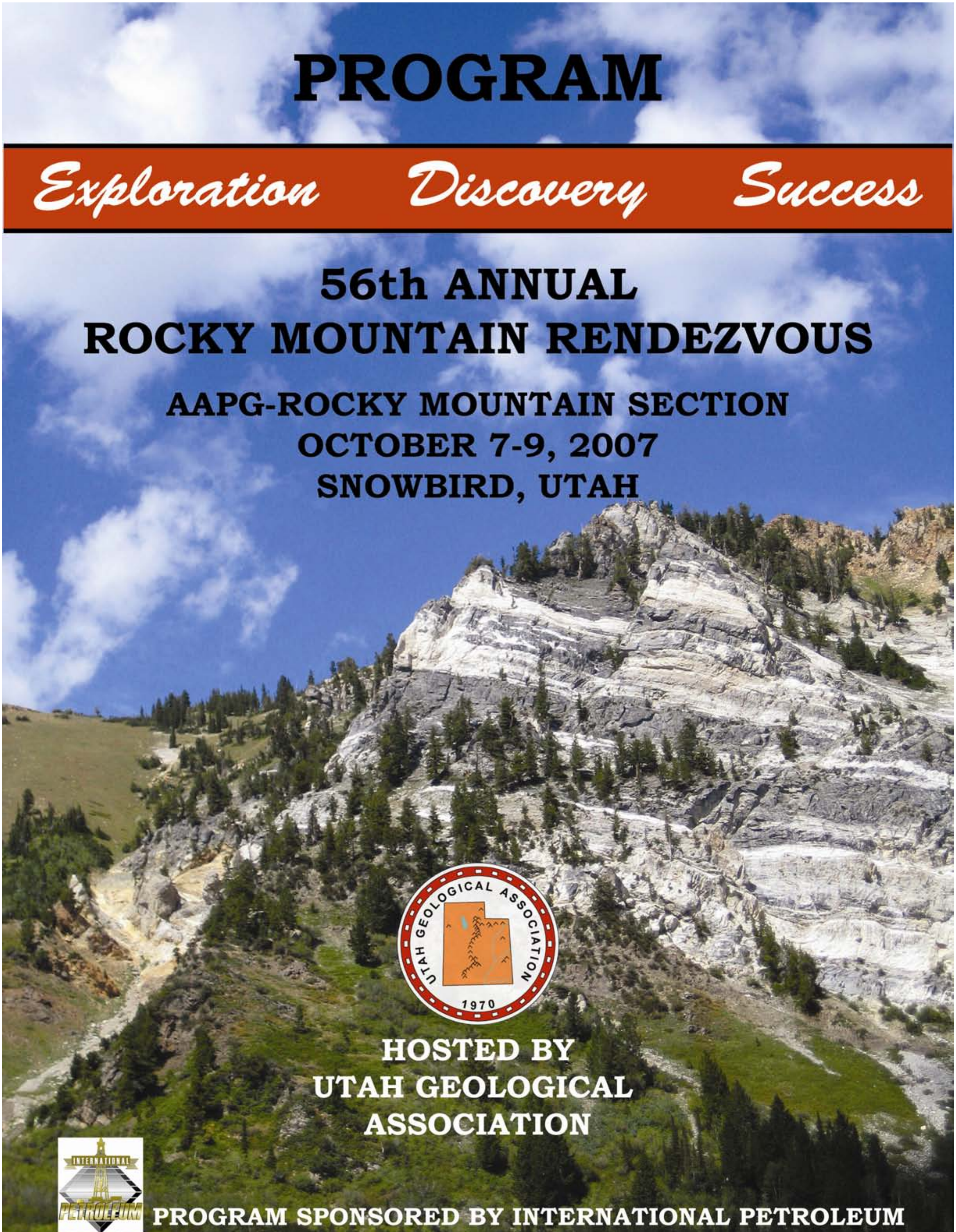
PROGRAM

Exploration Discovery Success

56th ANNUAL
ROCKY MOUNTAIN RENDEZVOUS

AAPG-ROCKY MOUNTAIN SECTION
OCTOBER 7-9, 2007
SNOWBIRD, UTAH



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UTAH GEOLOGICAL ASSOCIATION

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Exhibit Hall	Craig Morgan
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Program Design: Cheryl Gustin
Cover photo by Michael Vanden Berg showing Cambrian and Mississippian carbonates bisected by faults, Little Cottonwood Canyon, Utah

Welcome to Snowbird and the 2007 Rocky Mountain Section Meeting

On behalf of the Rocky Mountain Section of AAPG and our host, the Utah Geological Association, I welcome you to our 56th annual meeting! Thank you for coming to this beautiful place for our annual rendezvous. I am sure you will be rewarded by a vibrant exchange of information and ideas to fuel your important work of exploration, discovery, and success in the Rockies for the coming years.

The organizing committee for the 2007 RMS meeting worked hard to prepare an excellent combination of short courses, field trips, and oral-poster-core technical presentations to feed your intellectual appetite and entertain you. The Committee is a great group of people and I hope you will take a moment to thank them during the meeting. A public forum and our all convention luncheon speaker, Chuck Stanley of Questar, will address the challenges of natural gas development on public lands. The technical program is packed with great presentations. I hope you plan to stay through the end of the program on Tuesday because we have some great talks, rocks, and posters offered on Tuesday afternoon. A closing reception will be held in the exhibits/poster/core area late Tuesday to entice you to stick around!

The Alta-Snowbird area was the site of considerable interest by early miners seeking their fortunes in precious metals. In fact, several historic mines still dot the hillside. I hope you find riches in the association with your fellow members, the technical exchange of ideas from the meeting presenters, and the activities you engage in while you are here.

Thanks again for coming and enjoy!

Paul B. Anderson
General Chair

Schedule of Events

All events will be held at the Snowbird Resort unless otherwise noted. Transportation for all tours and field trips will depart from the Cliff Lodge at the Snowbird Resort unless otherwise noted.

Friday, October 5

7:00 a.m .... Field Trip #1: Structural Geology of the Central Utah Thrust Belt (*Departs from the Utah Department of Natural Resources building and returns to the Cliff Lodge at Snowbird on Sunday afternoon)*

Saturday, October 6

8:30 a.m. – 4:00 p.m .... "Rocks in Your Head" Teacher workshop (*held at the Utah Geological Survey)*
10:00 a.m. – 3:00 p.m .... Short Course #1: Depositional Environments, Diagenesis, and Hydrothermal Alteration of the Mississippian Leadville Limestone Reservoir, Paradox Basin, Utah: A Core Workshop (*held at the Utah Core Research Center, Utah Geological Survey)*
1:00 p.m. – 5:00 p.m .... Short Course #2 (Session 2): Geological Aspects of Shale Gas Exploration, Exploitation, and Development

Sunday, October 7

8:30 a.m. – 3:00 p.m .... Field Trip #2: Uplift and Evolution of the Central Wasatch Range, Utah
10:00 a.m. – 3:00 p.m .... Short Course #2 (Session 1): Geological Aspects of Shale Gas Exploration, Exploitation, and Development
12:00 p.m. – 8:00 p.m .... Registration
1:00 p.m. – 3:00 p.m .... Public Forum: Energy Development on Public Lands: Finding Common Ground; Keynote Speaker: Dr. Charles G. Groat
2:30 p.m. – 4:30 p.m .... Guest Hospitality Suite
4:30 p.m. – 5:30 p.m .... Opening Session: Welcome and Awards
5:30 p.m. – 7:30 p.m .... Icebreaker and Opening of Exhibit Hall

Monday, October 8

6:30 a.m. – 7:30 a.m .... Speakers Breakfast
6:45 a.m. – 8:00 a.m .... AAPG House of Delegates Breakfast
7:00 a.m. – 5:00 p.m .... Registration
7:30 a.m. – 5:00 p.m .... Guest Hospitality Suite
8:00 a.m. – 5:00 p.m .... Exhibit Hall
8:00 a.m. – 5:00 p.m .... Core Poster Session: Signature Cores of the Rocky Mountain Region
8:00 a.m. – 11:35 a.m .... Poster Session: Rocky Mountain Structural Analysis
8:00 a.m. – 11:35 a.m .... Technical Session: Emerging Shale Gas Resources of the Rockies
8:00 a.m. – 11:35 a.m .... Technical Session: Uinta Basin – Expanding Oil and Gas Opportunities
8:00 a.m. – 11:35 a.m .... Technical Session: Sevier and Cordilleran Thrust Belt Revisited
8:30 a.m. – 5:00 p.m .... Guest Activity: Park City Luxury Home Tour
9:30 a.m. – 10:15 a.m .... Morning Break
11:45 a.m. – 1:15 p.m .... All Convention Luncheon; Keynote Speaker: Charles B. Stanley, Questar Corp.
1:30 p.m. – 5:00 p.m .... Poster Session: Rocky Mountain Investigations
1:30 p.m. – 5:00 p.m .... Technical Session: Resource Play Technologies
1:30 p.m. – 5:00 p.m .... Technical Session: Petrophysical Case Studies in Unconventional Reservoirs
3:00 p.m. – 3:30 p.m .... Afternoon Break
5:45 p.m. – 8:30 p.m .... Oktoberfest Celebration

Tuesday, October 9

6:00 a.m. – 8:30 a.m .... RMS-AAPG Executive Committee Breakfast
6:30 a.m. – 7:30 a.m .... Speakers Breakfast
7:00 a.m. – 12:00 p.m .... Registration
8:00 a.m. – 5:00 p.m .... Guest Hospitality Suite
8:00 a.m. – 5:00 p.m .... Exhibit Hall
8:00 a.m. – 5:00 p.m .... Core Poster Session: Signature Cores of the Rocky Mountain Region
8:00 a.m. – 11:35 p.m .... Poster Session: Sedimentation and Depositional Systems
8:00 a.m. – 11:35 a.m .... Technical Session: Shale Gas Secrets – Lessons from other North American Shale Gas Plays (EMD)
8:00 a.m. – 11:35 a.m .... Technical Session: Geophysical and Structural Advances in the Rockies
8:00 a.m. – 11:35 a.m .... Technical Session: Advances in Rock Mechanics and Hydraulic Fracturing – Case Studies (SPE)
9:30 a.m. – 10:15 a.m .... Morning Break
11:45 a.m. – 1:45 p.m .... View From the Top: Snowbird Geology Lunch via the Tram
2:00 p.m. – 5:00 p.m.......... Poster Session: Stratigraphic Studies of Utah and Colorado
2:00 p.m. – 4:10 p.m.......... Technical Session: Uinta Basin – Stratigraphic Studies
2:00 p.m. – 4:10 p.m.......... Technical Session: Studies in Stratigraphy and Sedimentation
4:10 p.m. – 5:00 p.m.......... Closing Reception

Wednesday, October 10

7:30 a.m .... Field Trip #3: Classic Geology and Reservoir Characterization Studies of Central Utah *(Returns 6:00 p.m. Friday, October 12)*

Photo of the Triassic Moenkopi Formation at Capitol Reef National Park, Utah, courtesy of Michael Vanden Berg.

General Information

Registration Hours

Cliff Lodge, Coat Room, Level B
Sunday, Oct 7......... 12:00 p.m. - 8:00 p.m.
Monday, Oct 8 .... 7:00 a.m. - 5:00 p.m.
Tuesday, Oct 9 .... 7:00 a.m. - 12:00 p.m.

Speaker Breakfast

Maybird Room
Monday, Oct 8 .... 6:30 a.m. - 7:30 a.m.
Tuesday, Oct 9 .... 6:30 a.m. - 7:30 a.m.

All oral and poster presenters should attend the complimentary breakfast at 6:30 a.m. in the Maybird Room on the morning of their session. Not all Session Chairs will be attending the speaker breakfast, so please communicate directly with your Session Chair outside of this venue.

Speaker Ready Room

Red Pine Room
Sunday, Oct 7......... 3:00 p.m. - 6:00 p.m.
Monday, Oct 8 .... 3:00 p.m. - 6:00 p.m.

Oral presentations must be submitted the day before your scheduled presentation. AV technicians will only be present between 3:00 p.m. and 6:00 p.m. on Sunday and Monday to load your media onto the conference computers and assist in accessing your files.

Judges Information

All poster and oral session judges should pick up your packets at the judges desk next to the registration tables. There will not be a judges breakfast this year, instead we have opted to provide a nicer judges appreciation gift in lieu of the breakfast. For information please contact Carl Kendell at: carl.kendell@flyingj.com.

Exhibition Hours

Ballroom II, Mezzanine Lobby, Golden Cliff, Atrium Overlook
Sunday, Oct 7......... 5:30 p.m. - 7:30 p.m.
Monday, Oct 8........ 8:00 a.m. - 5:00 p.m.
Tuesday, Oct 9 .... 8:00 a.m. - 5:00 p.m.

Exhibition Areas

Vendors in service to the petroleum industry are looking forward to the 2007 AAPG Rocky Mountain Section meeting in Snowbird, Utah. You will have the opportunity to investigate and see demonstrated the latest in a wide range of products and services that cover all areas of the industry.

Sunday's Icebreaker, as well as Tuesday's Closing Reception, will be held in and near the exhibit areas. Food and drinks will be available during these times while you learn about the latest in products and services, purchase the most current geological publications, see core posters from many of the Rocky Mountain reservoirs, and network with friends and colleagues.

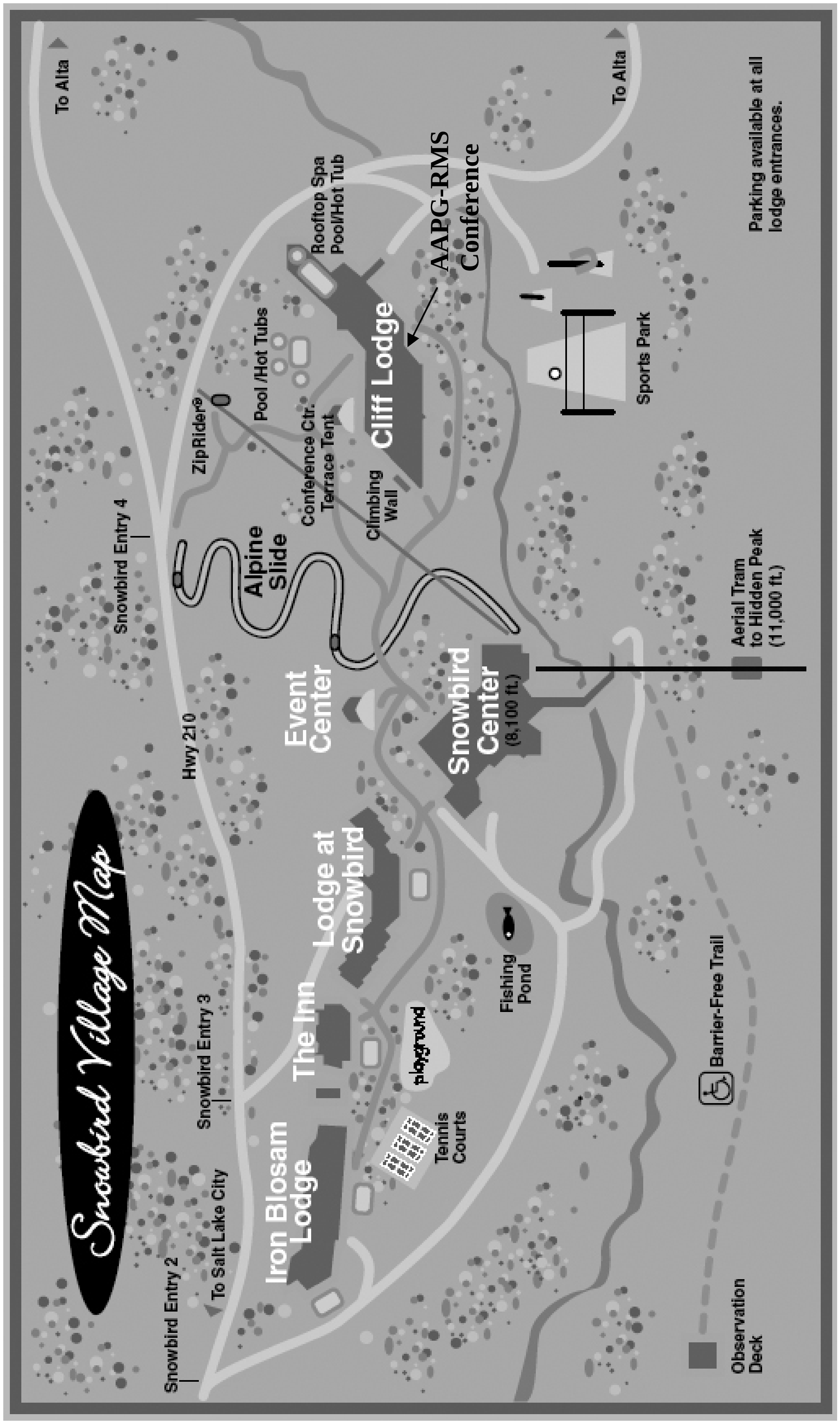
Note: A trade exhibition is not a safe place for children, so please be advised that no one under the age of 13 will be allowed to spend time in the exhibition areas.

Guest Hospitality Suite

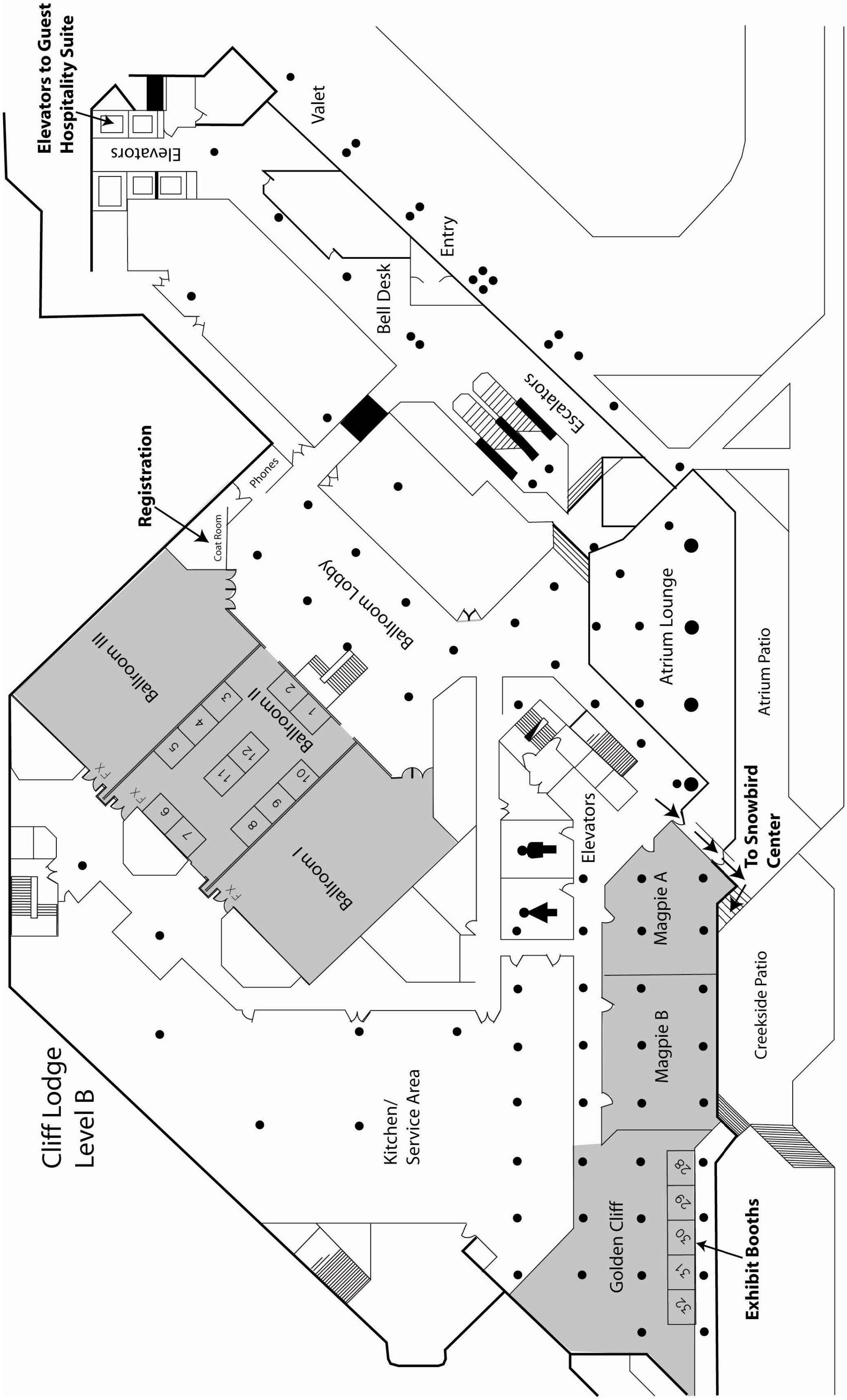
Summit Room, 10th Floor of Cliff Lodge
Sunday, Oct 7......... 2:30 p.m. - 4:30 p.m.
Monday, Oct 8........ 7:30 a.m. - 5:00 p.m.
Tuesday, Oct 9 .... 8:00 a.m. - 5:00 p.m.
Sponsored by Titan Energy Resources

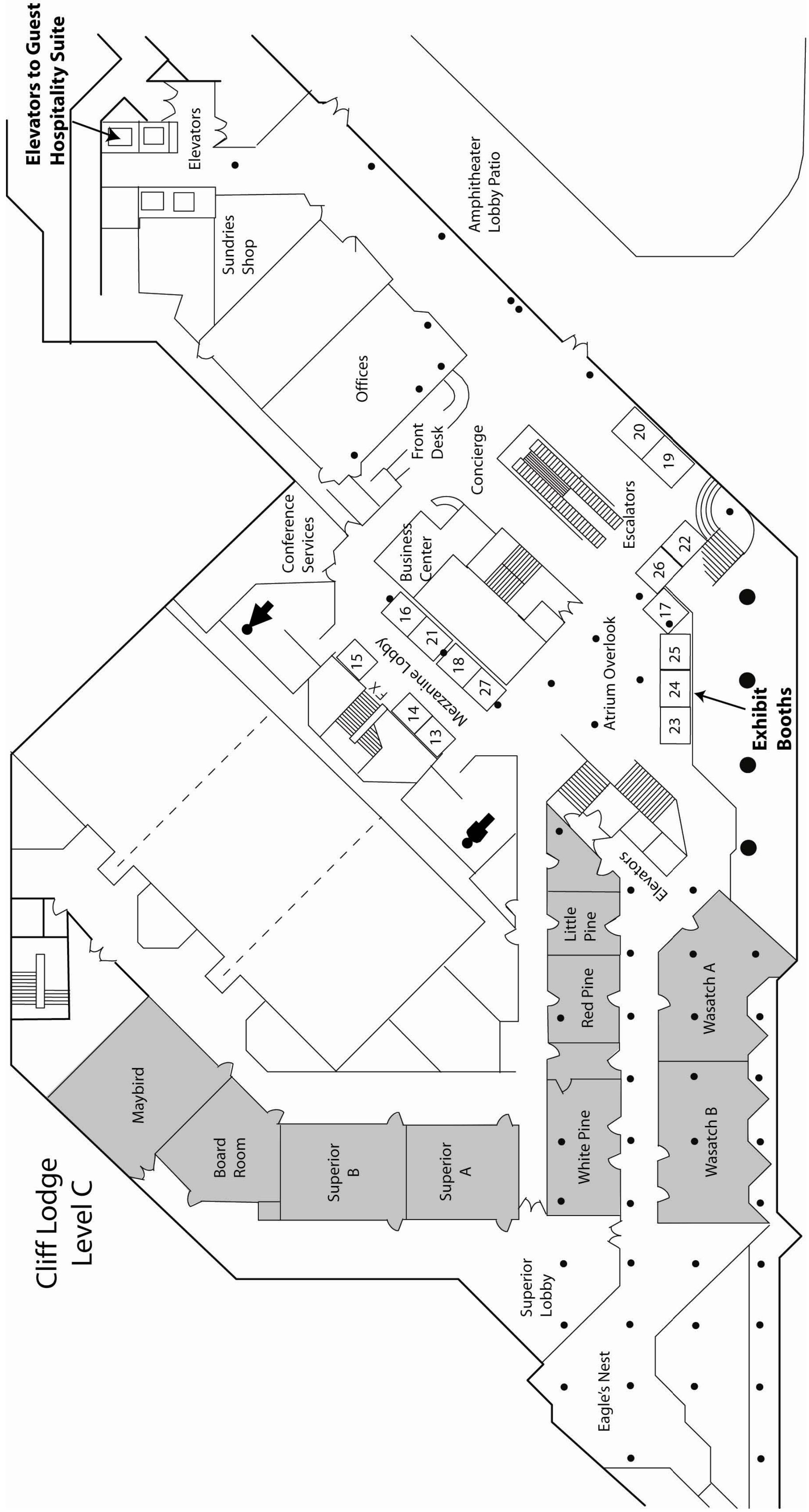
The Hospitality Suite is open to registered guests of professional attendees and is located next to the Cliff Spa on the 10th floor of the Cliff Lodge. Breakfast will be available Monday morning 7:30 a.m. to 9:30 a.m. and Tuesday morning 8:00 a.m. to 10:00 a.m. Snack bags for guest registrants will be available each day.

Snowbird Map



Floor Plan—Cliff Lodge




Cliff Lodge
Level C
Elevators to Guest
Hospitality Suite
Elevators
Amphitheater
Lobby Patio
Sundries
Shop
Offices
Front
Desk
Concierge
Escalators
Conference
Services
Business
Center
Mezzanine Lobby
Atrium Overlook
Exhibit
Booths
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Elevators
Little
Pine
Red Pine
White Pine
Wasatch A
Wasatch B
Maybird
Board
Room
Superior
B
Superior
A
Superior
Lobby
Eagle's Nest

Exhibitors

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Events

Public Forum

"Energy Development on Public Lands: Finding Common Ground"

Date: .... **Sunday, October 7, 1:00 p.m. – 3:00 p.m.**
Location: .... **White Pine Room**

Clearly, responsible development of fossil energy resources on public lands in the West is in the public interest. But in many instances energy development is seen as being in conflict with other vital natural resources and land values. Presently, too much time, effort, and money is being spent fighting the "opponents", be they the petroleum industry, environmental lobby, or the U.S. Bureau of Land Management, rather than working to identify common areas of agreement and ultimate cooperation. The objective of the forum is to foster better mutual appreciation of the concerns and problems of the various stakeholders, not create a venue for finger-pointing. A greater degree of cooperation in settling disputes related to energy development on public lands is in the interest of stakeholders and the Public.

The forum will have four speakers, a neutral observer defining the issues from various perspectives and one person representing each of the principal stakeholders - the federal land managers, the gas and oil operators, and the environmental lobby. A 90-minute period is scheduled for a brief introduction and for the four 20-minute presentations. This will be followed by 20-30 minutes of general comments and questions to the panelists from the audience. Refreshments will be available at the close of the forum to allow all participants, speakers and audience, to converse informally.

The forum is open to all interested persons; convention registration is not required. This event is a public outreach activity sponsored by the AAPG Rocky Mountain Section, the AAPG Division of Environmental Geosciences, and the AAPG Division of Professional Affairs.

Dr. Charles G. "Chip" Groat, Keynote Speaker
Director of the Center for International Energy and Environmental Policy, Director of the Energy and Earth Resources Graduate Program, holds the John A. and Katherine G. Jackson Chair in Energy and Mineral Resources in the Department of Geological Sciences, Jackson School of Geosciences, and Professor, LBJ School of Public Affairs at The University of Texas at Austin

Dr. Groat assumed the above positions in June 2005 after serving 6 ½ years as Director of the U.S. Geological Survey, having been appointed by President Clinton and retained by President Bush. Dr. Groat has been a member of the National Research Council Board on Earth Sciences and Resources and the Outer Continental Shelf Policy Board. He is a past President of the Association of American State Geologists and the Energy Minerals Division of the American Association of Petroleum Geologists. His degrees in geology are from the University of Rochester (A.B.), University of Massachusetts (M.S.), and The University of Texas at Austin (Ph.D.). His current interests focus on advancing the role of science and engineering in shaping policy and decision making, and on ways to increase the integration of science disciplines as a means to improve the understanding of complex resource and environmental systems.

Richard Watson, Panelist 1 - Representing federal land managers
Senior Physical Scientist with the U.S. Bureau of Land Management and EPCA Inventory Project Manager

Mr. Watson's interests include federal lands energy policy and the use of geospatial techniques as a means to analyze oil and gas resources in the public domain. He is a former private industry wellsite geologist with experience in many Rocky Mountain basins. Mr. Watson holds a B.S. in geology with distinction from the University of Mississippi.

Stephen Bloch, Panelist 2– Representing the environmental interest
Staff Attorney, Southern Utah Wilderness Alliance

Mr. Bloch is a Staff Attorney for the Salt Lake City-based Southern Utah Wilderness Alliance (SUWA) - Utah's largest conservation organization - and has worked for SUWA for nine years. Mr. Bloch represents SUWA and other local, regional, and national conservation organizations in administrative appeals and federal court litigation with an emphasis on energy development. Mr. Bloch has litigated several geophysical exploration and oil and gas leasing cases in federal courts in Salt Lake City and Washington, D.C. He is a graduate of the University of Utah College of Law (1997) and lives in Salt Lake City with his wife and two children.

Paul Matheny, Panelist 3 - Representing oil and gas operators
Vice President of the Rockies Region for Questar Exploration & Production Company

During Mr. Matheny's 19 years with Questar he has worked in exploration and development of the Rocky Mountains, California, and the Gulf Coast. In addition, he has worked in Questar's A&D and has served as General Manager of the Pinedale, Uinta Basin, and Legacy divisions. Prior to joining Questar he worked for Gulf Oil and internationally for Ampolex. Mr. Matheny earned a B.S. in Geology from New Mexico State University and a M.S. in Geology from the University of Utah.

Opening Session and Awards

Date: .... **Sunday, October 7, 4:30 p.m. – 5:30 p.m.**
Location: .... **Ballroom 1**

Join us for the official kick-off to the 2007 RMS-AAPG meeting! Introductory remarks will be given by Paul Anderson, our conference General Chair, and Tom H. Morris, President of our host society, the Utah Geological Association, and geology Professor of Brigham Young University. We will also hear from our AAPG national leaders and the Rocky Mountain Section Executive Committee.

Forrest Terrell, Chair of the Awards/Judging Committee, will present the A.I. Levorsen Award, the Steve Champlin Memorial Award, and the Runge Award to the honorees from the 2006 RMS-AAPG Billings, MT annual meeting.

The award winners for the 2006 Rocky Mountain Section of AAPG annual meeting are:

A.I. Levorsen Award for Best Oral Presentaion

Geoffrey Thyne: ***Evaluation of Potential Impacts to Water Resources from Petroleum, Grand Mesa, Colorado***

The A.I. Levorsen Memorial Award was established as a result of contributions from many individuals and societies who wished to contribute a lasting memorial to Dr. A.I. Levorsen. A plaque is given at the RMS-AAPG annual meeting for the best paper, with particular emphasis on creative thinking toward new ideas in exploration.

Steve Champlin Award for Best Poster

Quentin German, Nichola Sommer, Matthew Pranter, Rex D. Cole: ***Analysis of Fluvial Sand-Body Characteristics and Dimensions in a High Net-to-Gross System, Upper Williams Fork Formation, Main and Plateau Creek Canyons, Piceance Basin, Colorado***

The Wyoming Geological Association sponsors the Steve Champlin Memorial Award for Best Poster. The award is presented to the poster author receiving the highest score at the RMS-AAPG annual meeting. The award was created to encourage poster authors to strive for excellence in their presentation and to foster the one-on-one discussion of geology for which Steve Champlin was well known. First created in 1986, it is hoped that this award will carry on Steve's spirit of friendly cooperation for the exploration of our natural resources.

All divisions of the RMS-AAPG, EMD, DEG, and SEPM are eligible for this award. A plaque will be presented to the winner or to the senior author in case of multiple authors. The only restriction is that the display and the oral presentation must not be part of a professional presentation that is for sale or is part of a sales presentation. The award is for scientific endeavor, and for the courage to display a new concept before your peers and to defend the concept under their scrutiny.

John Runge Award for Best Student Presentation

Hanna Ross, M. D. Zoback: ***Sub-Hydrostatic Pore Pressure in the Powder River Basin, Wyoming and Montana, and Implications for Re-injection of Coalbed Methane Produced Water***

The Runge Award recognizes professional and scientific excellence in the student papers presented before the RMS-AAPG annual meeting, with particular emphasis on creative thinking toward new ideas in exploration. Established in 1975, the award is made to the student presenting the best paper as judged by a committee established for the evaluation of papers at each meeting. The qualifications of the author(s) are defined as follows:

1. The paper was prepared during the author's enrollment in a college or university.
2. The abstract was submitted to the Section during enrollment or no later than one year following the end of the last semester of enrollment of the author.
3. If more than one author participated on the paper, all authors must meet the above qualifications.

The award is a plaque given at the RMS-AAPG annual meeting and is provided by John S. Runge, petroleum geologist, Casper, Wyoming.

Icebreaker

Date: .... **Sunday, October 7, 2007: 5:30 p.m. to 7:30 p.m.**
Location: .... **Exhibit Areas (Ballroom II, Mezzanine Lobby, Golden Cliff , Atrium Overlook)**
Admission: .... **By badge only**
Sponsor: .... **Berry Petroleum Company**

The traditional Icebreaker will be held in the exhibit areas after the Opening Session on Sunday evening. Enjoy refreshments, mingle with friends and colleagues, and peruse the wares and services offered by exhibitors.

Closing Reception

Date: .... **Tuesday, October 9, 2007: 4:10 p.m. – 5:00 p.m.**
Location: .... **Exhibit Areas (Ballroom II, Mezzanine Lobby, Golden Cliff , Atrium Overlook)**
Admission: .... **By badge only**

This year we are closing the meeting with a mini party. Join us for refreshments in the exhibit areas and the Poster and Core/Poster Session rooms starting at 4:10 Tuesday afternoon. Be sure to purchase those last minute items from vendors, check out the posters and **real** rocks (core), and say farewell to friends, old and new.

Ticketed Events

All Convention Luncheon

"Natural gas in the Rockies- the Challenges and Opportunities of Resource Development on Pubic Lands"

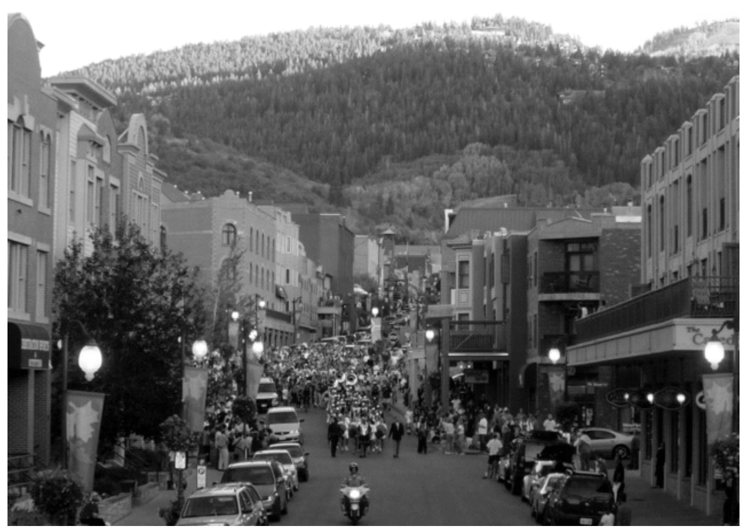
Speaker: .... **Charles B. (Chuck) Stanley, Questar Corporation**
Date: .... **Monday, October 8, 2007, 11:45 a.m. – 1:15 p.m.**
Location: .... **Cottonwood Room, Snowbird Center**
Fee: .... **$25.00 per person**
Sponsor: .... **Flying J**

Operations in the Rockies are problematic for a number of reasons. Please join us for an informative presentation from the corporate leader of one of the more active companies working the Cretaceous Basins of the Rockies. Mr. Stanley will be addressing a number of issues such as U.S. Bureau of Land Management restrictions, access issues, reserve analyses in tight gas sands, governmental affairs, etc. For any company working in the Rocky Mountains, this is a presentation not to be missed. Mr. Stanley is Executive Vice President of Questar Corporation and has served as a Director since 2002. He has responsibility for the company's Market Resources business segment and is President and Chief Executive Officer of each entity within that group -- Questar Market Resources, Inc., Questar Exploration and Production Company, Wexpro Company, Questar Gas Management Company (gas gathering and processing) and Questar Energy Trading Company (wholesale marketing and storage). Mr. Stanley began his career in 1981 as a research and field geologist for the Virginia Geological Survey, and then worked in oil and gas exploration and development for British Petroleum Co. He held positions with Maxus Energy Corp. and Coastal Gas International Co., and then went on to serve as President and CEO of El Paso Oil & Gas Canada, Inc., prior to joining Questar in 2002. He is a graduate of Virginia Polytechnic Institute and State University.

Park City Luxury Home Tour

Date: .... **Monday, October 8, 2007, 8:30 a.m. – 5:00 p.m.**
Location: .... **Bottom of the escalators, main entrance of the Cliff Lodge**
Fee: .... **$25.00 (includes transportation and homes tour guide fee)**

Join us for a tour of beautiful homes in the Park City area followed by lunch and sightseeing/shopping/gallery stroll on Park City's historic Main Street. Main Street is home to historic buildings that have been converted to art galleries, restaurants and unique shops. Take time to visit the Museum and read the historic plaques on the buildings during your walk. Lunch is on your own, a perfect opportunity to meet old friends and make new ones.



Historical downtown Park City, Utah

Oktoberfest Celebration

Date: .... **Monday, October 8, 2007: 5:45 p.m. – 8:30 p.m.**
Location: .... **The Snowbird Event Center (tent next to Snowbird Center)**
Fee: .... **$40.00 per person**
Sponsor: .... **Titan Energy Resources**

Please join us for a fun and relaxing evening of music, food, dancing, and visiting with friends, old and new, in the Oktoberfest tent at Snowbird during the 2007 RMS Section Meeting. Bring the entire family to this casual event. The evening will kick off with a social hour with local micro-brews, wine, and cocktails. Dinner will follow with Snowbird's traditional German Oktoberfest Buffet featuring grilled bratwurst, Bavarian style sauerkraut, beef rouladen, potato pancakes, green salad, and all the other fixings along with Apple Strudel for dessert. The evening will continue with a rousing performance by the local Bavarian band Salzburger Echo. Their performance in authentic costume is not only musically enjoyable and upbeat, but visually exciting as well!

Price includes dinner, beverages, and entertainment. The location for this event is a short walk from the Cliff Lodge convention center. Evenings in October, high in the Wasatch Range, can get a bit chilly, so dress accordingly.

Snowbird Geology Luncheon via the Tram

Date: .... **Tuesday, October 9, 2007: 11:45 a.m. – 1:45 p.m.**
Location: .... **Aerial Tram Deck (In the event of inclement weather, lunches will be available in the Cottonwood Room)**
Fee: .... **$15.00 per person**
Sponsor: .... **Petrobank Energy & Resources**

Please join us for a tram ride to the top of Hidden Peak and a geologic talk by local geologist Joe Gates. The tram will whisk you from the Snowbird Plaza (8100 ft. elevation) to the top of Hidden Peak at over 11,000 feet in a matter of minutes. The views from the tram are spectacular, so bring your camera. At the top, participants will enjoy a hearty mountain sack lunch while enjoying the geology talk and scenic splendor of the Wasatch Range. Participants will have the opportunity to take a couple of short hikes offering a closer look at the stratigraphy and thrust faulting found at the top of Hidden Peak. Afterwards, catch the tram back down for the afternoon technical sessions. The tram ride and short hikes will not be overly strenuous, but sturdier footgear and outerwear appropriate for the weather are recommended. Price of the event includes lunch, tram ride, and geology talk. In the event of inclement weather, the presentation will be at the base, with the option for those willing to brave the elements to ride the tram to the top.

Hidden Peak Tram, Snowbird, Utah

This event is open to all convention attendees, so feel free to meet your spouse for lunch!

Short Courses

Short Course # 1: Depositional Environments, Diagenesis, and Hydrothermal Alteration of the Mississippian Leadville Limestone Reservoir, Paradox Basin, Utah: A Core Workshop

SOLD OUT

Date: .... **Saturday, October 6, 2007, 10:00 a.m. – 3:00 p.m.**
Instructors: .... **David E. Eby (Eby Petrography & Consulting, Inc.) and Thomas C. Chidsey, Jr. (Utah Geological Survey)**
Location: .... **Utah Core Research Center, Utah Geological Survey**
Fee: .... **$60.00 (includes lunch, refreshments, and course notes)**
Limit: .... **20 persons**
Sponsors: .... **Utah Geological Survey, U.S. Department of Energy-National Energy Technology Laboratory, and Eby Petrography & Consulting, Inc.**

Who Should Attend

Geoscientists with interests in exploration and development of shallow-shelf carbonate reservoirs. This course is designed for geoscientists who wish to examine a large collection of carbonate core (both limestone and dolomite) presented within lithofacies, diagenetic, and petrophysical context.

Objectives and Content

The Mississippian Leadville Limestone has produced over 53 million barrels of oil and 845 BCF of gas in the Paradox fold and fault belt of the Paradox Basin, Utah and Colorado. The Leadville was deposited as an open-marine, carbonate-shelf system highlighted with crinoid banks, peloid/oolitic shoals, and small Waulsortian mounds. Various lithofacies changes and extensive diagenesis have created complex reservoir heterogeneity. Predating or concomitant with late dolomite formation are pervasive leaching episodes that produced vugs and extensive microporosity. Solution-enlarged fractures and autobreccias are also common. Late-replacement and saddle dolomites, as well as brecciation and sulfide mineralization, developed from hydrothermal alteration that greatly improved reservoir quality. The result can be the formation of large, diagenetic-type hydrocarbon traps. The reservoir characteristics, particularly diagenetic overprinting and history, can be applied regionally to other fields and exploration trends in the Paradox Basin and shallow-shelf carbonate reservoirs elsewhere.

Utah Core Research Center, Utah Geological Survey

Representative core from Utah's Lisbon field will be examined. All core displayed will be presented within the context of the regional paleogeographic setting. The core workshop will be organized into topical modules with participants performing a series of exercises using core, geophysical well logs, and photomicrographs from thin sections. These modules include describing reservoir vs. non-reservoir lithofacies; determining diagenesis, hydrothermal alteration, and porosity from core; recognizing barriers and baffles to fluid flow; correlating core to geophysical well logs; and identifying potential completion zones.

Short Course # 2: Geological Aspects of Shale Gas Exploration, Exploitation, and Development

SOLD OUT

Date: .... **Saturday, October 6, 2007 1:00 p.m. – 5:00 p.m. (Session 2)**
Sunday, October 7, 2007, 10:00 a.m. – 3:00 p.m. (Session 1)
Instructor: .... **Robert Bereskin (Bereskin and Associates, Inc.)**
Location: .... **Cottonwood Room, Snowbird Center**
Fee: .... **$100.00 [includes lunch (session 2 only), refreshments, and course notes]**
Limit: .... **30 persons per session**
Sponsors: .... **Williams Production Company and Lario Oil & Gas**

Who Should Attend

Geoscientists with interests in the exploration and development of shale gas reservoirs of western North America. The course is designed for geoscientists who wish to examine the basic lithofacies of shale gas reservoirs recognized in various Rocky Mountain region exploration plays and compare how they are expressed in well core and in the context of open hole geophysical logs.

Objectives and Content

Because shale gas drilling ventures represent a significant percentage of recent exploration endeavors, conclusions regarding shale producibility and formation evaluation are commonly tied to characteristic lithofacies. To date, four basic lithofacies have been recognized, and while intergradations of various rock types are common, these end-member lithofacies encompass domination by (1) siliclastic material, (2) argillaceous content, (3) authigenic silica, or (4) various carbonate constituents. This core workshop is intended to highlight the various lithofacies from various shale plays, located principally in Western North America. For the most part, all examples will originate from the Rocky Mountain region (including Utah specifically) and generally involve thermogenic generation of shale gas. It is the intent of the workshop to not only exhibit the slabbed core samples, but also to demonstrate the open hole log characteristics that can result from the diagnostic assemblage of minerals and pore types. While micropores are most logically characteristic of shale reservoirs, the abundance and arrangement of voids can result in shales becoming either good or poor producers with varying intrinsic permeabilities. Both thin section petrography and scanning electron microscopy are obviously important in any geologic dissection of shales, and such microscopic examples will accompany the slabbed core material during the session.

Upper Cretaceous Mancos Shale. Photo by Steven Schamel

Field Trips

Field Trip #1: Structural Geology of the Central Utah Thrust Belt

Date: .... **October 5-6, 2007**
Trip Leaders: .... **Daniel Schelling (Structural Geology International, LLC) and John Vrona (Wolverine Gas and Oil Corporation)**
Departure/Return: .... **Depart 7:00 a.m. from the Utah Department of Natural Resources Building, Salt Lake City and return to Snowbird at 7:00 p.m.**
Fee: .... **$250.00 (includes transportation, 2 box lunches, and lodging)**
Limit: .... **24 participants**
Sponsors: .... **Utah Geological Association and Petroleum Systems International, Inc.**

Complexly deformed mudstones and evaporites of the Arapien Shale exposed along the Rainbow Hills of central Utah

Since the discovery of the Covenant oil field by Wolverine Gas and Oil Corporation in December of 2003, there has been renewed interest in the structural geology and evolution of the central Utah thrust belt, within which the Covenant field is located. During this two day geological field excursion, participants will have a chance to examine and discuss the Cretaceous through Paleocene contractional structural systems of the central Utah (Sevier) thrust belt, the Oligocene through Recent structural systems of the Basin and Range tectonic province, and possible "diapiric" deformational systems related to mobilisation of the Jurassic Arapien Shale. Structural reactivation, structural overprinting, and the role of the Arapien Shale in the development of both contractional and extensional structures will be discussed, along with the structural evolution of the Jurassic Arapien Basin, the Cretaceous thrust belt, and the eastern margin of the Tertiary Basin and Range province of central Utah. Discussions will be centered around exposed geologic features that provide clues to the structural architecture and evolution of central Utah, and balanced structural cross-sections constructed across the deformation front of the thrust belt. Where possible and appropriate, seismic data will be shown to support structural interpretations. During the second day of the field excursion, we will stop at the Covenant oil field to discuss the structural setting and geologic characteristics of the field and their implications for hydrocarbon exploration in central Utah.

Field Trip # 2: Uplift and Evolution of the Central Wasatch Range, Utah

Date: ....**October 7, 2007**
Trip Leaders: ....**William Dinklage, Michael Bunds, and Daniel Horns (Department of Earth Science, Utah Valley State College)**
Departure/Return: .....**Depart from Snowbird at 8:30 a.m. and return to Snowbird at 3:00 p.m.**
Fee: ....**$50.00 (includes transportation and box lunch/drink/snack)**
Limit: ....**47 people**
Sponsor: ....**Utah Geological Association**

Scarps of the Wasatch fault (in shadows on the near ridge) cut Pleistocene glacial moraines at the foot of the Wasatch Range

The Wasatch Range provides a dramatic and scenic backdrop to Utah's urban corridor, with peaks rising to heights of over 11,000 feet. This close juxtaposition of high mountains and metropolitan centers is almost unique in the United States. The Wasatch is an eastward-tilted fault block range, bound on the west by the Holocene Wasatch fault. As a result of the tilting, the west side of the range has been uplifted about 10,000 meters (6 miles) relative to the east side over the past 17 to 30 million years. Because of this uplift, deep canyons have been carved into the west side of the range. These canyons provide a window into the Earth's crust and the geologic past. We will explore many aspects of the geology of the Wasatch Range, including an early Paleozoic transgressive sequence, Tertiary granitic rocks of the Alta and Little Cottonwood stocks (and the metamorphic aureoles associated with them), spectacular Alpine glacial landforms, and the world-class scarps associated with the Wasatch fault zone along the dramatic western escarpment of the range.

Field Trip # 3: Classic Geology and Reservoir Characterization Studies of Central Utah

Date: ....**October 10-12, 2007**
Trip Leaders: ....**Thomas H. Morris (Brigham Young University), Craig Morgan (Utah Geological Survey), Marc T. Eckels (The Wind River Companies), and Scott M. Ritter (Brigham Young University)**
Departure/Return: .....**Depart from Snowbird (main entrance) at 7:30 a.m. and return to Snowbird at 6:00 p.m.**
Fee: ....**$350.00 (includes lodging, lunches, refreshments, 2007 UGA Guidebook "Geology of Central Utah", and a short "core workshop" in the field)**
Limit: ....**45 people**
Sponsor: ....**Utah Geological Association**

The classic geology of central Utah, including the San Rafael Swell, the Waterpocket Fold at Capitol Reef National Park, and the Central Utah Thrust Belt, will be overviewed on this field trip. The trip will emphasize four recent reservoir characterization studies including the Sinbad Limestone Member of the Triassic Moenkopi Formation, and the classic Jurassic erg systems of the Wingate, Entrada, and Navajo sandstones. The Jurassic erg systems have again demonstrated their potential to serve as quality subsurface hydrocarbon reservoirs with the recent development of the Covenant oil field in central Utah and the new high BTU gas production from both the Entrada and Wingate sandstones within the Uinta Basin. Details of potential flow units, baffles, and barriers will be discussed in light of current facies analysis and structural complexities. At Capitol Reef we plan to do an optional two-mile round trip hike to Hickman Bridge and from there discuss the landscape evolution of the Fremont River gorge in light of recent studies. Our final afternoon will feature two items: 1) a miniature core workshop examining core from the Covenant field and 2) field stops and discussion of the Central Utah Thrust Belt play by Doug Sprinkel for whom the 2007 UGA Guidebook is dedicated.

Technical Program

October 8 – Monday Morning Oral

Uinta Basin-Expanding Oil and Gas Opportunities

Co-Chairs: Edmund R. Gustason, and Jim Borer
Location: Ballroom I
Sponsors: EOG Resources Inc., Hess Corp., and Samson Resources

8:00 ..... **Introductory Remarks**
8:10 ..... **M. A. Kirschbaum, T. Cook, R. F. Dubiel, T. M. Finn, P. G. Lillis, E. A. Johnson, R. C. Johnson, P. H. Nelson, L. N.R. Roberts, S. B. Roberts:** A Review of the U.S. Geological Survey 2002 Geologic Assessment of Resources in the Uinta Basin
8:30 ..... **E. R. Gustason:** The Impact of New Technology and Deep Drilling on Oil and Gas Development in the Uinta Basin
8:50 ..... **G. Hinds:** Development of Conventional and Unconventional Reservoirs: West Tavaputs Plateau, Uinta Basin, Utah
9:10 ..... **J. A. May, R. W. Falk, D. S. Anderson, A. Grau:** Outcrop-to-Subsurface Correlation of the Blackhawk Formation, Uinta Basin: Sequence Framework, Shoreline Trends, and Gas Production
9:30 ..... **A. Ragas, L. MacMillan, S. Stancel, J. Cuzella:** Controlling Factors on Productivity in the Love Area, Natural Buttes Field, Uinta Basin, Utah
9:50 ..... **Break**
10:15 ... **J. M. Borer:** Altamont Field, Northern Uinta Basin: Development Operations and Regional Correlation of the Wasatch and Green River Formations
10:35 ... **C. Morgan:** Enhanced Oil Recovery Potential in the Uinta Basin, Utah
10:55 ... **M. Dolan, A. Grau, K. Ferworn, S. W. Brown:** Calibrating Stable Carbon Isotopes of Reservoir Fluids as a Thermal Maturity Indicator
11:15 ... **A. Grau, J. D. Edman, M. Dolan:** An Operation Geologist's Venture into the Land of Geochemistry: Using Mud Gas Isotopes and Standard Geochemical Analyses to Identify Seals, Source Rocks, Gas Families, and Prospect Fairways in the Uinta Basin

Emerging Shale Gas Resources of the Rockies

Co-Chairs: Mark Longman and Michael L. Hendricks
Location: Ballroom III
Sponsors: Hess Corp. and Samson Resources

8:00 ..... **Introductory Remarks**
8:10 ..... **D. D. Reimers:** Western U.S. Basin Shale Trends
8:30 ..... **S. Schamel:** Utah Shale Gas: An Emerging Resource Play
8:50 ..... **M. L. Grummon:** Update on the Cane Creek Fractured Shale Play, Northern Paradox Basin, Grand County, Utah
9:10 ..... **J. A. LeFever:** Exploration Frontiers in the Bakken Formation, Montana and North Dakota
9:30 ..... **Break**
10:15 ... **R. E. Locklair, B. B. Sageman:** Enrichment of Organic Carbon and Carbonate in the Upper Cretaceous Niobrara Formation, Western Interior Basin: The Role of Siliciclastic Flux
10:35 ... **M. Deacon, R. E. Locklair, D. Hill, E. Miller, E. R. Gustason:** Shale Gas Potential of the DJ Basin, Wattenberg Gas Field, Denver Basin, Colorado
10:55 ... **D. Schmude, M. Tobey:** The Steele/Niobrara of Central Wyoming: Insights into Hydrocarbon Generation-Induced Regional Over-Pressure
11:15 ... **M. W. Longman, R. Newhart, S. Goodwin:** Lithology and Characteristics of the Upper Cretaceous Baxter Shale, Vermillion Basin, Northwest Colorado

Sevier and Cordilleran Thrustbelt Revisited

Co-Chairs: Thomas C. Chidsey, Jr, and Douglas A. Sprinkel
Location: Wasatch A&B
Sponsors: Hess Corp. and Samson Resources

8:00 ..... **Introductory Remarks**
8:10 ..... **J. C. Coogan:** Extensional Inversion of the Central Utah Thrust Belt: More than Just the Sevier Desert Detachment
8:30 ..... **D. A. Wavrek, J. Ali-Adeeb, J. C. Chao, L. E. Santon, E. A. Hardwick, D. K. Strickland, D. D. Schelling:** Paleozoic Source Rocks in the Central Utah Thrust Belt: Organic Facies Response to Tectonic and Paleoclimatic Variables
8:50 ..... **G. J. Hunt, T. F. Lawton, G. E. Gehrels:** Detrital Zircon Geochronology of Lower Cretaceous Conglomerates, San Rafael Swell—Wasatch Plateau, Central Utah
9:10 ..... **W. W. Little:** Using Alluvial Architecture to Define Stratigraphic Sequences in Foreland Basins, Upper Cretaceous Strata of the Kaiparowits Basin, Utah
9:30 ..... **G. B. Nielsen, M. Chan:** A Reinterpretation of Diagenetic Coloration Patterns in the Jurassic Navajo Sandstone, Zion National Park, Utah
9:50 ..... **Break**
10:15 ... **D. Keele, J. P. Evans, W. D. Liddel:** The Marriage of Eolian Rock Properties and Deformation of the Nugget Formation; Anschutz Ranch East Field: Northeast Utah and Southwest Wyoming
10:35 ... **T. H. Morris, A. Hansen, S. Carney, C. D. Morgan, T. C. Chidsey, Jr:** The Jurassic Navajo Sandstone as a Partitioned(?) Subsurface Reservoir: Comparing Reservoir Characteristics and Facies Between San Rafael Swell Outcrop and Covenant Field Core, Utah
10:55 ... **D. Bate, M. Davies:** An Improved Understanding of the Utah Hingeline with the Application of BlueQube™ Technology
11:15 ... **F. C. Moulton, M. L. Pinnell:** Central Utah Thrust Belt-Hingeline: This New Oil and Gas Province Has Enormous Potential

October 8 – Monday Morning Poster

Rocky Mountain Structural Analysis

Chair: James P. Evans
Location: Magpie A&B
Time: 8:00 a.m. – 11:35 a.m.
Sponsors: GeoX Consulting, Inc., Core Laboratories, and The Discovery Group Inc.

R. W. Clayton, W. W. Little: Thrust Belt Structures and Paleozoic Stratigraphy of the Scott Butte and Snaky Canyon Quadrangles, Southern Beaverhead Mountains, Idaho
M. Dropkin, K. Campbell, R. Ehrlich: Detailed Analysis of the Nesson Antiform Williston Basin, North Dakota
E. A. Helmke, D. R. Lageson: Structural Analysis of Pressure Solution Cleavage in the McCartney Mountain Fold-Thrust Salient, Southwest Montana
W. H. Hokanson, R. W. Clayton: Geologic Map of Snaky Canyon Quadrangle, Clark County, Idaho
S. Roemer, W. W. Little, R. W. Clayton: Complex Deformation of Paleozoic Strata due to Folding and Faulting in the Southern Beaverhead Mountains, Clark County, Idaho

October 8 – Monday Core Poster

Signature Cores of the Rocky Mountain Region

Chair: Richard Newhart
Location: Magpie A&B and Golden Cliff
Time: 8:00 a.m. – 5:00 p.m.
Sponsor: Encana Oil & Gas Inc.

Golden Cliff .... **K. Kaiser, E. Davis, R. Newhart, M. Longman, R. Koepsell:** Characteristics of the Upper Cretaceous Baxter Shale in the Vermillion Basin, Northwestern Colorado

L. A. Mauro, M. W. Longman: Anatomy of a Tight Gas Sand: Upper Lance Core from Pinedale Field, Green River Basin, Sublette County, Wyoming

Magpie A&B .. **M. D. Laine, T. C. Chidsey, Jr, D. A. Sprinkel, J. P. Vrona, D. K. Strickland:** Covenant Oil Field, Central Utah Thrust Belt: Possible Harbinger of Future Discoveries

M. D. Vanden Berg, D. E. Tabet: Utah's Oil Shale Deposits: Stratigraphy and Resource Evaluation

October 8 – Monday Afternoon Oral

Resource Play Technologies

Co-Chairs: G. Earl Norris and Brad Thompson
Location: Ballroom I
Sponsors: Hess Corp. and Samson Resources

1:30 ..... **Introductory Remarks**
1:40 ..... **K. Oren:** Collaboration Across all Domains for Optimized Unconventional Resource Development Programs
2:00 ..... **T. R. Albrecht, G. D. Thyne:** Distinguishing Impacts of Natural Gas Production on Water Quality, Piceance Basin, Colorado
2:20 ..... **S. P. Cumella:** Stratigraphic Trapping in the Rollins Sandstone of the Mesaverde Group, Mamm Creek Field, Piceance Basin, Northwest Colorado
2:40 ..... **P. Nandi:** Lost Circulation and Fractures in Wamsutter, Wyoming
3:00 ..... **Break**
3:30 ..... **S. Mark, M. Stoner:** Geo-Steering Horizontal Wells: Case Studies Demonstrate the Value of Fuzzy Logic Directional Steering Guidance
3:50 ..... **T. Bowman, D. Burch, E. J. Nelson, D. E. Roberts:** Increasing the Odds: Data Analysis of the Barnett Shale in the Fort Worth Basin
4:10 ..... **A. Karpov, C. Morris, C. Segondy, R. Naimi-Tajdar, J. Hebert, E.Boratko:** Gathering and Analyzing Vertical Permeability Data to Evaluate Horizontal Wells in North San Juan CBM
4:30 ..... **D. Handwerger, R. Suarez-Rivera, T. Sodergren, M. Milner, K. Greaves:** Application of n-dimensional Log Analysis in Predicting Reservoir Properties from Core Data in both Cored and Un- cored Wells in Tight Gas Reservoirs

Petrophysical Case Studies in Unconventional Reservoirs

Co-Chairs: Terri Olson and Randolph J. Koepsell
Location: Ballroom III
Sponsors: Hess Corp. and Samson Resources

1:30 ..... **Introductory Remarks**
1:40 ..... **L. E. Soto:** Study of Almond Reservoir Connectivity in Wamsutter Field
2:00 ..... **K. W. Shanley, R. M. Cluff, J. W. Robinson:** What's The Matter With The Ericson? Gas Shows, Calculated Pay, and Water!
2:20 ..... **M. Holmes, A. Holmes, D. Holmes:** A Method to Quantify Gas Saturation in Gas/Water Systems, Using Density and Neutron Logs – Interpretation of Reservoir Properties When Compared With Gas Saturations from Resistivity Analysis
2:40 ..... **P. H. Nelson:** Pore Throats and Pore Pressure: Pushing Gas into Small Spaces
3:00 ..... **Break**
3:30 ..... **G. Tracy, K. Kaiser, R. Newhart:** Petrophysical Evaluation of the Hiawatha Deep Unit #5 Well in the Vermillion Basin, Northwestern Colorado
3:50 ..... **A. P. Byrnes, J. C. Webb, R. M. Cluff:** Regional Petrophysical Properties of Mesaverde Low-Permeability Sandstones
4:10 ..... **D. Merkel:** Using Core Data to Develop and Calibrate Petrophysical Models in Tight Gas Sand
4:30 ..... **M. Miller, R. Lieber, E. Piekenbrock, T. McGinness:** Core Analysis Issues in Tight Gas Reservoirs

October 8 – Monday Afternoon Poster

Rocky Mountain Investigations

Co-Chairs: Russell Griffin and Scott Ritter
Location: Magpie A &B
Time: 1:30 p.m. – 5:00 p.m.
Sponsors: GeoX Consulting Inc., Core Laboratories, and The Discovery Group Inc.

M. Holmes, A. Holmes, D. Holmes: Comparison of Total and Effective Water Saturations as a Way to Verify the Validity of Effective Porosity Calculations
C. S. Painter, R. S. Martinsen: Another Look at Hartzog Draw Stratigraphy, Powder River Basin, Wyoming
T. L. Perkes, W. W. Little: Petrographic Analysis of Campanian Sandstones, Kaiparowits Formation, South-Central Utah
D. M. Seneshen, T. C. Chidsey, Jr, C. D. Morgan, M. D. Vanden Berg: New Techniques for New Discoveries – Results from the Lisbon Field Area, Paradox Basin, Utah
C. N. Stroup, P. K. Link, S. U. Janecke, C. M. Fanning: Eocene to Oligocene Paleodrainage of Southwest Montana: Evidence from Detrital Zircon Populations

October 9 — Tuesday Morning Oral

Geophysical & Structural Advances in the Rockies

Co-Chairs: Kenneth Grubbs and R. William (Bill) Keach
Location: Ballroom III
Sponsors: Hess Corp. and Samson Resources

8:00 ..... **Introductory Remarks**
8:10 ..... **W. R. Roux:** West Tavaputs, Uinta Basin - A Story of Persistence
8:30 ..... **J. C. Lorenz, P. Yin:** Fracture Distributions in the Tensleep-Equivalent Casper Sandstone at Flat Top Anticline, Wyoming: Implications for Reservoirs
8:50 ..... **S. P. Gay, Jr:** Basement Fault Control of Offshore Cretaceous Sandbars in the Powder River Basin, Wyoming
9:10 ..... **B. J. Black, M. Milliken:** Understanding The Complex Geometry of Extensional Faulting in a Compressional Laramide Structure: Teapot Dome, Wyoming
9:30 ..... **S. Carney, C. Morgan, M. Vanden Berg:** Structural Analysis of Aneth Field, Paradox Basin, Southeastern Utah: A Carbon Storage Study Site of the Southwest Regional Partnership for Carbon Sequestration
9:50 ..... **Break**
10:15 ... **V. G. Rigatti, T. LeFevre, R. Newhart, K. Kaiser, S. Goodwin, R. Parney:** The Vermillion Basin of SW Wyoming/NW Colorado: Structural Styles and Seismic Pore Pressure Prediction Through Over-Pressure
10:35 ... **J. E. Tully, D. R. Lageson, J. C. Coogan:** New Structural Interpretation of the Elk Range Thrust System, Southwest Colorado
10:55 ... **W. Pearson, R. Inden:** Sweet Spot Localization of Production from Fractured Shales
11:15 ... **D. Bate, M. Davies:** The Application of BlueQube™ Technology to Exploration in the Rocky Mountain Foothills

Advances in Rock Mechanics and Hydraulic Fracturing-Case Studies (SPE)

Co-Chairs: John McLennan and Rex Hansen
Location: Wasatch A&B
Sponsors: Hess Corp. and Samson Resources

8:00 ..... **Introductory Remarks**
8:10 ..... **I. Palmer:** Effectiveness of Horizontal Wells in Coalbed Methane Plays
8:30 ..... **D. Cramer:** Lessons Learned in Vintage Bakken Vertical-Well Completions Provide Answers to Pay Location & Quality and Stimulation Optimization
8:50 ..... **T. Olsen, T. Bratton, R. Koepsell, A. Donald:** Natural Fracture Quantification for Optimized Completion Decisions
9:10 ..... **T. Bratton:** Anisotropic Earth Models Improve Completion Design
9:30 ..... **Break**
10:15 ... **M. C. Vincent:** Understanding Waterfracs
10:35 ... **I. Gil, M. Sanchez, P. Young, S. Kleiner:** Discrete Element Modeling (DEM) Improves Fundamental Understanding of Microseismicity Data and Provides Capabilities for Predicting Events
10:55 ... **R. Suarez-Rivera, C. Deenadayalu, D. Handwerger, S. Green:** Laboratory Experiments of Hydraulic Fracturing Help Investigating Conditions for Fracture Branching and Fracture Conta
11:15 ... **D. Magill, M. Ramurthy, P. D. Nguyen:** Preventing Proppant Flowback from Stimulated Zones

Shale Gas Secrets - Lessons From Other North American Shale Gas Plays (EMD)

Co-Chairs: Creties Jenkins, Bob Bereskin and David Tabet
Location: Ballroom I
Sponsors: Encana Oil & Gas Inc., Hess Corp., and Samson Resources

8:00 ..... **Introductory Remarks**
8:10 ..... **M. H. Tobey, T. M. Smagala, D.E. Schmude:** Elements of Successful Thermogenic Shale Gas Plays
8:30 ..... **J. F. W. Gale, J. Holder, R. M. Reed:** Natural Fractures in the Barnett Shale: Why They Are Important
8:50 ..... **M. Milner, B. Marin, D. Handwerger:** Characterizing Unconventional Reservoirs: an Informal Mudstone and Shale Classification Based on Core
9:10 ..... **B. Coffey:** Gas Resource Potential of the Woodford Shale, Arkoma Basin, Oklahoma
9:30 ..... **J. M. Forgotson:** Caney Shale, Arkoma Basin, Oklahoma
9:50 ..... **Break**
10:15 ... **C. Miller, R. Lewis, K. Bartenhagen:** Design and Execution of Horizontal Wells in Gas Shales Using Borehole Images and Geochemically-Enhanced Formation Evaluation
10:35 ... **R. F. LaFollette:** The Barnett Shale Play of North Texas - Points to Ponder in 2007
10:55 ... **B. Faraj, J. Duggan:** Devonian Shale Gas Potential of the Southern Tier of New York
11:15 ... **D. J.K. Ross, R. M. Bustin:** Evaluating the Shale Gas Resource Potential in Western Canada

October 9 – Tuesday Morning Poster

Sedimentation and Depositional Systems

Chair: William W. Little
Location: Magpie A&B
Time: 8:00 a.m. – 11:35 a.m.
Sponsors: GeoX Consulting Inc., Core Laboratories, and The Discovery Group Inc.

D. S. Anderson, M. M. Carr: 3-D Architecture of Crevasse Splay and Point-Bar Bodies: From Outcrop to Geologic Model
G. S. Billman, W. W. Little: Correlation of Mississippian and Pennsylvanian Strata in the Southern Beaverhead Mountain Range, Idaho
A.P. Byrnes, J.C. Webb, R.M. Cluff: Regional Petrophysical Properties of Mesaverde Low-Permeability Sandstones
S. Jiang: Stratigraphic Reservoir Exploration in Liaozhong Strike-Slip Depression, Bohai Bay, China
P. H. Nelson, P. K. Trainor, T. M. Finn: Gas and Water Production in the Wind River Basin, Wyoming

October 9 – Tuesday Core Poster

Signature Cores of the Rocky Mountain Region

Chair: Richard Newhart
Location: Golden Cliff and Magpie A&B
Time: 8:00 a.m. – 5:00 p.m.
Sponsor: Encana Oil & Gas Inc.

Golden Cliff .... **T. C. Chidsey, Jr, D. E. Eby, M. D. Laine, J. T. Dempster:** Why Modelers Need to Look at the Rocks! - Examples from Greater Aneth Field, Paradox Basin, Utah**.**
M.W. Longman, R. Koepsell, S. Sturm: Use of Cores and Image Logs to Interpret Depositional Environments of Sandstones in the Dakota Group at South Baxter Field, Sweetwater County, Wyoming

Magpie A&B........... **E. R. Gustason, S. Schamel:** River Gas of Utah No. 1 Core: Window into the Mancos Shale Gas

October 9 – Tuesday Afternoon Oral

Studies in Stratigraphy and Sedimentation

Co-Chairs: Richard Newhart and David Lambert
Location: Ballroom III
Sponsors: Hess Corp. and Samson Resources

2:00 ..... **M. D. Milliken, B. Black:** Core Interpretation Allows a New Perspective on Tensleep Sandstone Correlations at Teapot Dome Field, Natrona County, Wyoming
2:20 ..... **R. Sacerdoti, P. Plink-Bjorklund:** Rangely Turbidites and Their Linkage to Coeval Shallow-Water Succession, Rangely, Colorado
2:40 ..... **J. P. Skinner, P. Plink-Bjorklund:** Wave- and River-Influenced Deltaic Clinoforms of the Chimney Rock Sandstone, Flaming Gorge Reservoir, Utah
3:00 ..... **B. A. Black, B. Dirks:** The Rio Grande Rift - A New Oil and Gas Province in New Mexico
3:20 ..... **C. Myer, C. Dehler:** Paleogeography, Climate and the Carbon Cycle of the Mid-Neoproterozoic Red Pine Shale, Uinta Mountains, Northeastern Utah
3:40 ..... **A. Chamberlain:** Hunting Great Basin Elephants with Serial Transect Mapping

Uinta Basin-Stratigraphic Studies

Co-Chairs: Edmund R. Gustason, and Jim Borer
Location: Ballroom I
Sponsors: Hess Corp. and Samson Resources

2:00 ..... **E. M. Kingsbury, P. K. Link, C. M. Dehler, C. M. Fanning:** Neoproterozoic Uinta Mountain Group of Kings Peak Quadrangle, Utah: A Marine-Fluvial Interface?
2:20 ..... **J. L. Aschoff, R.J. Steel:** Anatomy of an Extensive, Low-accommodation Clastic Wedge: Insights from Isopach Maps and Regional Correlation in the Uinta-Piceance Basins
2:40 ..... **B. J. Willis:** Stratigraphy of Tide-Influenced River Deltas in the Sego Sandstone
3:00 ..... **R. Steel:** Fluvio-Lacustrine Facies and Sequence Stratigraphy, Eocene Uinta Basin
3:20 ..... **R. C. Johnson:** The Outflow of Eocene Lake Gosiute Into Lake Uinta and its Affects on Sedimentation in Lake Uinta in the Piceance Basin of Western Colorado
3:40 ..... **N. Harcourt, D. Keighley:** Origin of the Deformed Basal Uinta Formation in Eastern Utah (Uinta Basin): Progradational Delta Clinoforms of a Lake Highstand or Ephemeral Fluvial Sheetfloods of a Lake Lowstand?

October 9 – Tuesday Afternoon Poster

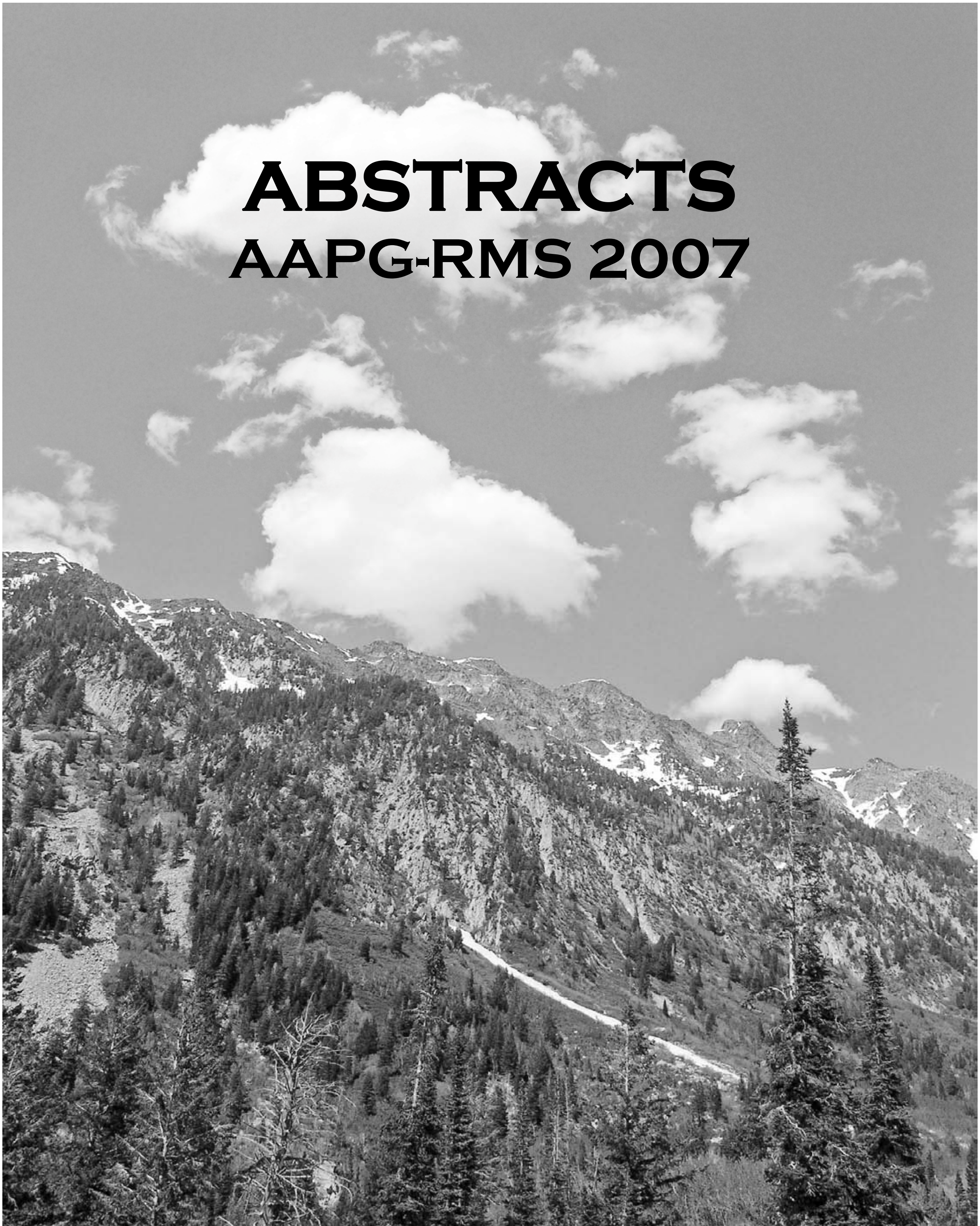
Stratigraphic Studies of Utah and Colorado

Chair: Russell Griffin
Location: Magpie A&B
Time: 2:00 p.m. – 4:10 p.m.
Sponsors: GeoX Consulting Inc., Core Laboratories, and The Discovery Group Inc.

S. P. Cumella: Stratigraphy and Petrophysics of Gas-Producing Parasequences in the Rollins Sandstone of the Mesaverde Group, Mamm Creek Field, Piceance Basin, Northwest Colorado
K. Duncan, R. Langford: Stratigraphic and Depositional Controls on Fluid Migration Through Eolian Sandstones - Comparing Outcrop with Reservoir
P. La Pointe, R. D. Benson, C. Rebne: Multivariate Modeling of 3D9C Data for Constructing a Static Reservoir Model of Algal Mounds in the Paradox Basin, Colorado
M. L. Pinnell, F. Moulton: Central Utah: A Photographic Essay and Update on Geology and Drilling in America's Most Exciting New Oil and Gas Exploration Province
D. Rybczynski, C. Dehler, A. Brehm: Subdividing the Undifferentiated Eastern Uinta Mountain Group, Northeastern Utah

Little Cottonwood Canyon, Utah

ABSTRACTS
AAPG-RMS 2007



Distinguishing Impacts of Natural Gas Production on Water Quality, Piceance Basin, Colorado

Albrecht, Tamee R.[1], Geoffrey D. Thyne[1] (1) Colorado School of Mines, Golden, CO

Semi-arid western Colorado has vulnerable water resources, but is experiencing rapid growth in petroleum exploration and production activities. An increasing trend in average groundwater methane concentration is correlated to the increasing number of gas wells in the Mamm Creek area suggesting that increased well drilling has impacted water quality. Isotopic data shows that some methane is thermogenic, but other samples are derived from CO_2-reduction of CO_2, possibly from the production interval. More detailed statistical analysis of hydrochemical data produced other criteria to detect impact including elevated Fe-Mn, Na-Cl-SO_4 or Na-HCO_3-Cl water chemistry. Samples with high Fe-Mn as well as elevated benzene and methane concentrations are found primarily at methane seeps where reducing conditions dominate. Other impacted samples appear to be influenced by produced water from the gas-production interval. Inverse geochemical modeling shows that the impacted samples can result from mixing normal groundwater with 2-8% produced water. The absence of benzene in some impacted samples is probably due to rapid natural degradation. Reactive transport modeling shows that benzene travels less than 50 meters in 6 years under aquifer conditions. These models can be used to help regulate the density of petroleum development in areas where groundwater resources are actively utilized. This study demonstrates that there are discernable impacts from petroleum activities on water resources in the Mamm Creek field, although impacts are generally below actionable levels. Methane and salinity appear to be better indicators of subtle impacts, whereas benzene and high Fe-Mn define larger impact events.

3-D Architecture of Crevasse Splay and Point-bar Bodies: From Outcrop to Geologic Model

Anderson, Donna S.[1], Mary M. Carr[1] (1) Colorado School of Mines, Golden, CO

Crevasse splay bodies are likely effective reservoirs in many thick tight-gas fluvial successions, yet they are incompletely recognized and lack the same level of dimensional data as point bars and channelbelts. North of Rangely Colorado, a 160-acre 3-D outcrop area exposes 200 feet of the nonmarine part of the lower Iles Formation (Neslen Formation of the Uinta basin, Utah). The outcrop contains an upward stratigraphic change from isolated, stacked crevasse channel/splay sandstone bodies to those of isolated, paired point bars within a laterally migrating 1500-ft wide, sinuous meanderbelt.

A largely deterministic 3-D model of the outcrop shows critical differences in shape, facies architecture, areal distribution, and rock volume between crevasse splays and point bars. It also shows a lack of vertical and lateral connectivity among four crevasse-splay and four point-bar bodies. All sandstone bodies show similar “average” statistics: they contain the same types and gross proportions of grain sizes and facies classified by sedimentary structures, with high net-to-gross sandstone (over 90%), similar gross rock volumes (1000 to 1500 acre-ft), and average thicknesses (about 18 ft). By contrast, the map-view dimensions and geometries and the internal facies architecture and proportions are completely different due to dissimilar, yet linked, depositional processes. In addition, individual point bars are in poor lateral communication within the meanderbelt, whereas individual crevasse-splay bodies are laterally widespread and internally more contiguous. The geometry and connectivity of these bodies has critical implications when considering whether well down-spacing is tapping new reserves or simply draining existing reserves faster.

Anatomy of an Extensive, Low-accommodation Clastic Wedge: Insights from Isopach Maps and Regional Correlation in the Uinta-Piceance Basins

Aschoff, J.L.[1], R.J. Steel[1] (1) Jackson School of Geosciences, University of Texas at Austin, Austin, TX

Despite recent advances in foreland basin research, the response of clastic wedges to tectonics remains contentious. Several studies demonstrate that clastic wedge progradation is coincident with structural development, whereas others show that progradation lags behind. Delineating architectural and geometric variation within clastic wedges can help resolve these discrepancies because different wedges may record tectonics differently. Three distinct clastic wedges are present in Campanian strata exposed at the southern Uinta-Piceance Basin margin. The upper and lower clastic wedges are thicker (>0.6 km), less extensive (130-150m), and have rising-shoreline trajectories characteristic of higher-accommodation settings. The middle wedge is thinner (< 0.3km), much more extensive (>250km), and has flat-to-falling shoreline trajectories characteristic of lower-accommodation settings. We describe the anatomy of the middle clastic wedge because it is anomalously-extensive, architecturally-complex, and developed very rapidly (250 km progradation in <500 ky). Units within the middle clastic wedge include the Sego Sandstone, Neslen Formation, Anchor Mine Tongue, Bluecastle Tongue and Iles Formation. This wedge consists of 8-12, thin (10-25 m), 50-100 km-long, transgressive-regressive sandstone tongues. Regressive tongues have narrow (10-20 km), fluvial-dominated proximal zones, wide (25-50 km), tidally-influenced central zones with numerous incisions, and narrow (10-20 km), mixed-energy distal zones. Transgressive tongues are thinner (<20 m) and less extensive than regressive tongues. They typically have narrow, fluvial-dominated proximal zones (<20 km), broad (25-50 km), tidally-influenced central zones, and broad (>50 km), wave-dominated distal zones. We highlight clastic wedge variability, and propose that different clastic wedges record tectonics differently-some may be syntectonic and others post-tectonic.

An Improved Understanding of the Utah Hinge Line with the Application of BlueQube™ Technology

Bate, Duncan[1], Mark Davies[2] (1) ARKeX Limited, Cambridge, United Kingdom (2) ARKeX Ltd, Cambridge, United Kingdom

The Utah hinge line area is an area with proven hydrocarbon potential. The discovery of the Covenant field, by Wolverine in 2003, has generated a great deal of interest in the area.

Many structural trap targets exist between the Covenant field and the analogous production to the North. However, the area is structurally complicated and the cost of seismic data prohibitive in many cases. BlueQube technology will help target these structural traps and improve the future placement of seismic surveys, well locations and increase the probability of success in the area.

A coarse grid of 2D seismic over some parts of the hinge line exists, including the Covenant field. However, the complexity of the area and sparse coverage means that there are many unanswered questions. The Tertiary cover, the salt lenses in the Arapien shale and the volcanic cover all mean that structural interpretation of the thrust belt is difficult.

The BlueQube data set includes airborne gravity gradiometry and a selection of other complementary geophysical data sets. Feasibility modelling of Covenant field shows that there is sufficient

density difference between the Navajo Sandstone and the overlying Arapien Shale to be able to identify structural closures within the thrust belt using gravity gradient data. Proving the technique over the known structure of Covenant field will show how BlueQube technology can be deployed in other areas to the north and south and aid future exploration in the Hinge line.

Early results from the survey will be presented.

The Application of BlueQube™ Technology to Exploration in the Rocky Mountains Foothills

Bate, Duncan[1], Mark Davies[2] (1) ARKeX Limited, Cambridge, United Kingdom (2) ARKeX Ltd, Cambridge, United Kingdom

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Early results from the survey will be presented.

Correlation of Mississippian and Pennsylvanian Strata in the Southern Beaverhead Mountain Range, Idaho

Billman, Gary S.[1], William W. Little[2] (1) Brigham Young University-Idaho, Rexburg, ID (2) Brigham Young University-Idaho, Rexburg, ID

Reconnaissance mapping in the southern Beaverhead and Lemhi Mountain Ranges of southeastern Idaho has shown inconsistency in the identification of stratigraphic units, particularly for the Upper Mississippian through Lower Pennsylvanian interval. Most workers agree on the presence of the Mississippian Scott Peak and Pennsylvanian Snaky Canyon Formations, but there has been considerable uncertainty regarding the units between them. For example, Skipp et al. (1979) show the Bluebird Mountain and Big Snowy Formations to occupy this interval; whereas, in another report (Skipp et al 1980) they suggest that the Big Snowy Formation is not recognizable in the area, and Huh (1967) places the South Creek and Surrett Canyon Formations in this position. Recent mapping by Brigham Young University-Idaho students on the Scott Butte Quadrangle at the southern end of the Beaverhead Mountain Range indicates that each of these units is present in that area and that problems in identification are due to deformation associated with Sevier orogenic compression and subsequent Basin and Range extension, which have truncated, overturned, and, in some cases, altered the thicknesses of these units.

The Rio Grande Rift - A New Oil and Gas Province in New Mexico

Black, Bruce A.[1], Bill Dirks[2] (1) Black Oil, Farmington, NM (2) Tecton Energy, LLC, Houston, TX

In 1985, the first oil production from the Rio Grande Rift was marketed from the Santa Fe Embayment of the Rio Grande Rift in north central New Mexico. It would be 22 years before this non - economic discovery (at $8.00 a barrel) would eventually prove to be an economic success. The story leading to this first producing well, and its eventual re-completion and payoff is a story more than three and a half decades in the making.

USGS Bulletin 2184, published in 2001, supports the theory that the Albuquerque Basin also contains a large basin-centered gas deposit in the rift. In 2005-06 Tecton Energy, LLC, working with Black Oil invested $7MM to prove this concept and extend the potential limits of the deposit northward into the Santa Fe Embayment. The commercially successful Tecton Black - Ferrill #1, and subsequent activities, has opened a new oil and gas province in the Rio Grande Rift. The recent activities suggest a multi-TCF and multi-hundred million-barrel oil accumulation potential within the downthrown areas of the rift.

Several sub-basins in the rift have abundant source rock, a favorable history of maturity and extensive reservoir systems. Structural complexities, including Laramide thrusting, and complex stratigraphy will account for a portion of the trapped oil and gas. Post-Oligocene subsidence has been the most important factor allowing coeval maturation of the Cretaceous source and a dramatic reduction in permeability of Tertiary and Cretaceous sandstones. This has effectively created a barrier for rapidly expelling hydrocarbons.

This discovery is a prime example of frontier exploration. It is a lesson in cooperation between different disciplines, and the foresight and courage of investors who can look beyond the obstacles we increasingly face today in frontier exploration. Perhaps, most importantly, it is a lesson in both mental and monetary persistence.

Understanding the Complex Geometry of Extensional Faulting in a Compressional Laramide Structure: Teapot Dome, Wyoming

Black, Brian J.[1], Mark Milliken[1] (1) Rocky Mountain Oilfield Testing Center, Casper, WY

Teapot Dome is a doubly plunging anticline, formed during the Laramide orogeny. It is one of several structures aligned along a northwest to southeast trend in the southern end of the Powder River Basin. The structure consists of an asymmetric fold with a steep flank on the west, bounded by a deep seated blind reverse fault. Over 1300 wells have been drilled into the structure providing an extensive database to work from. Previous work at Teapot Dome identified a series of normal faults in the shallow units that cross the structure almost perpendicular to the axis of the anticline. Recent surficial mapping, fault trenching, and subsurface log interpretation, have provided new understanding the faulting geometry. This work has shown that there is a very complicated network of normal faulting and fracturing that significantly influences oil production. In many cases, the faults do not line up in a sub-parallel array as interpreted previously. Instead, many of the larger normal faults cross the field in a curvilinear manner. Also, some faults are aligned parallel to the axis of the structure, rather than perpendicular to it. The normal faults seen in shallower units of the anticline appear to be related to older normal faults that are seated in the basement. These deeper faults existed prior to Laramide deformation and may have been active during deposition of the lower Cretaceous units. These pre-existing deeper faults may have contributed to a distinct change in the trend of the anticlinal axis that formed during Laramide deformation.

Altamont Field, Northern Uinta Basin: Development Operations and Regional Correlation of the Wasatch and Green River Formations

Borer, Jim M.[1] (1) El Paso Corporation, Denver, CO

The 500 mi^2 Altamont-Bluebell-Cedar Rim field in the northern Uinta Basin has produced over 290 MMBO and 500 MMMCFG from the Tertiary Wasatch and Green River formations. Infill wells and recompletions have good EUR potential, however challenges include: 1) reservoir complexity; 2) high drilling, completion and maintenance costs; 3) complex field history/data and 4) the refining market. The best production occurs in the marginal lacustrine facies tract, which includes a high percentage of shoreface, distributary mouth bar, and deltaic sandstones and carbonates. These facies exhibit lower clay content, better sorting and greater continuity than deposits in the southern offshore facies tract and northern alluvial/fluvial (red bed) facies tract. From north to south, stacked reservoirs pinch out structurally updip into offshore/open lacustrine mudstones, forming a major (3500') regressive-transgressive wedge. This configuration creates multiple opportunities for stratigraphic traps in the basin-centered, overpressured continuous accumulation. Natural fractures are essential for enhancing production of the tight (Wasatch, 3-6% porosity, <.01 md permeability; Green River, 7-8% porosity, 0.5-4 md permeability) matrix and control production/depletion anomalies. Quantitative log analysis is difficult due to the thin bedding, mixed lithology, low matrix porosity, variable water resistivities and fractures. Drilling and recompletion decisions are made largely based on offset production analogy, using maps and cross sections to analyze perforation history and zonal production. Completion strategies include both multi-stage acid jobs and recent proppant fracs. A regional grid of cross sections illustrate stratigraphic and paleogeographic variations in the field and provide a framework for assessing hydrocarbon potential throughout the basin.

Increasing the Odds: Data Analysis of the Barnett Shale in the Fort Worth Basin

Bowman, Thomas[1], Donald Burch[1], Eric J. Nelson[1], Dwight E. Roberts[1] (1) Aspect Abundant Shale LP, Denver, CO

The Barnett Shale is a gas play in the Fort Worth basin whose appeal is that it is paradoxically both low in risk and high in reward. The risk is low because there is little doubt that gas exists in enormous volumes in the Barnett Shale source rock, estimated as much as 150 BCF per square mile, at depths between 7,000 ft and 8,500 ft. Reward is great because fracture stimulation technologies and, recently, horizontal drilling, have already yielded more that 2.6 TCF of gas and 8.46 million barrels of hydrocarbon liquids from the Barnett Shale.

The discovery well for the Newark East (Barnett Shale) Gas Field was Mitchell Energy's Slay #1 in southeast Wise County, Texas, completed in December of 1981. Since 1981, over 5,600 wells have been drilled in the Barnett Shale, including over 2,000 horizontal wells. With the consistently increasing activity in the Fort Worth Basin some analysis shows that, while many wells are profitable and some operators are significantly more successful than others, a tremendous amount of the Barnett Shale wells will possibly loose money.

Determining where and how an operator is successful in the Barnett Shale depends on a thorough analysis of the information available. This analysis and comparisons for the Barnett Shale in the Fort Worth Basin allows for some generalizations to be formulated, and allows for some explanations to be presented that will increase the overall drilling and completion success throughout the play.

Anisotropic Earth Models Improve Completion Design

Bratton, Tom[1] (1) Schlumberger, Greenwood Village, CO

Isotropic earth models have been the standard in the industry for more than 30 years; not because isotropy was a good assumption, but because 3-dimensional anisotropic logging measurements were unavailable. Today, 3D anisotropic measurements are available, and the derived anisotropic earth models are beginning to impact completion design. To illustrate the improvements, case studies from tight gas-sand plays in the Rocky Mountains will be presented. These case studies show how to identify and quantify anisotropy and how this new information should be used to improve the completion design.

Laboratory measurements on recovered core often show differences between the horizontal and vertical rock properties. The corresponding horizontal and vertical elastic moduli can now be measured with new sonic logging techniques. This is leading to improved correlations between logs and core. In addition, zone containment is often breached when sandstones are stimulated. Isotropic stress models applied to anisotropic formations do not predict either the correct stress or the correct stress contrasts between layers. A calibrated anisotropic stress model provides a stress profile which better defines zone containment and changes the perforating and staging strategy. The primary application for this method is improved completion design. The technical contribution to the industry is a better quantification of stress profiles in anisotropic formations.

Regional Petrophysical Properties of Mesaverde Low-permeability Sandstones

Byrnes, Alan P.[1], John C. Webb[2], Robert M. Cluff[2] (1) Kansas Geological Survey, Lawrence, KS (2) The Discovery Group, Inc, Denver, CO

Petrophysical properties of Mesaverde Group tight gas sandstones for the range of lithofacies present in the Washakie, Uinta, Piceance, Upper Greater Green River, Wind River, and Powder River basins exhibit consistent trends among lithofacies. Grain density for over 2400 samples averages 2.654±0.033 g/cc (±1sd) with grain density distributions differing slightly among basins. The Klinkenberg gas slip proportionality constant, b, can be approximated using the relation: b(atm) = 0.851 $kik^{-0.34}$. Regression provides a relation for *in situ* Klinkenberg permeability (kik): log kik = 0.282 Φi + 0.18 RC2 – 5.13 (±4.5X,1 sd), where Φi = *in situ* porosity, and RC2 = a size-sorting index. Artificial neural network analysis provides prediction within ±3.3X. Analysis of 700 paired samples indicates 90% of all samples exhibit porosity within 10%-20% variance. Permeability exhibits up to 40% variance from a mean value for 80% of samples.

Capillary pressure (Pc) exhibits an air-mercury threshold entry pressure (Pce) versus kik trend of Pce = 30.27 $kik^{-0.44}$ and wetting-phase saturation at any given Pc (for 350< Pc < 3350 psia air-Hg) and kik of Sw = A $kik^{-0.138}$ where A = -13.1*ln(Pcair-Hg)+117. Accuracy of the Leverett J function is poorer. Hysteresis Pc analysis indicates that residual nonwetting-phase saturation to imbibition (Srnw) increases with increasing initial nonwetting phase saturation (Snwi) consistent with the Land-type relation: 1/Snwr-1/Snwi = 0.8+0.2. Electrical resistivity measurements show that the Archie cementation exponent (m) decreases with decreasing porosity (Φi) below approximately 6% and can be generally described by the empirical relationship: m = 0.95-0.092 Φi +0.635 $\Phi i^{0.5}$. These relationships are still being investigated. The Mesaverde Project website is (http://www.kgs.ku.edu/mesaverde).

Regional Petrophysical Properties of Mesaverde Low-permeability Sandstones Poster

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Structural Analysis of Aneth Field, Paradox Basin, Southeastern Utah: A Carbon Storage Study Site of the Southwest Regional Partnership for Carbon Sequestration

Carney, Stephanie[1], Craig Morgan[1], Michael Vanden Berg[1] (1) Utah Geological Survey, Salt Lake City, UT

Aneth oil field is one of three pilot project sites selected by the Southwest Regional Partnership for Carbon Sequestration for CO_2 injection and monitoring. Surface and subsurface structural analysis of the site was done, in part, to characterize the oil-producing and potential CO_2 storage reservoir, the Pennsylvanian Paradox Formation, as well as identify possible pathways for CO_2 migration to the surface.

Surface fractures (deformation bands) and faults were mapped in the area to identify structural links between the surface and the reservoir at depth. We measured orientations of >1000 deformation bands and identified a few small, localized normal faults within the Jurassic Morrison Formation. Deformation bands appear randomly oriented and cannot be linked to any regional tectonic structures. Faults have small, vertical offsets (<5 m) and are likely shallow structures. These surface structures are probably a result of gravity-driven deformation.

Subsurface analysis included correlating and picking formation tops from over 200 well logs in the project area. Structure contour maps created at the reservoir level and cross sections between wells show a northeast-trending, high-angle fault that cuts through the Paradox Formation. The fault likely extends through younger Pennsylvanian strata, but dies out before entering Permian strata. Evidence of the fault is also seen in intense fracturing in the Paradox in core from a well near the fault.

These initial analyses indicate that surface and subsurface structures are not linked and migration of CO_2 from the reservoir to the surface is unlikely. Expanded analysis is needed to further characterize subsurface structures.

Hunting Great Basin Elephants with Serial Transect Mapping

Chamberlain, Alan[1] (1) Cordillera Resources, Inc, Eureka, NV

Serial transect mapping is an exploration method that involves deliberately populating predetermined transect lines with geologic constraints. This method is proving to be more efficient and cost effective than seismic or any other exploration method in the essentially uncharted Great Basin of western Utah and eastern Nevada.

Transects are planned to take advantage of well control, optimal exposures of Paleozoic rocks, the structural grain, and any other surface features and conditions. An experienced stratigrapher navigates along the transect lines and collects geologic data from rock exposures including structural, stratigraphic, biostratigraphic, and other geological data using a survey-grade GPS.

Upon completion of the fieldwork, structural models are constructed along the transect lines. These models are constrained with the newly collected geologic and well data, knowledge of structural style, and gravity, magnetic and any seismic data and models. Structural interpretation using structural modeling software in conjunction with these geological data and geophysical data and models where previous exploration methods have failed has revealed sizable structures that could contain significant quantities of hydrocarbons in this part of the Sevier Thrust Belt.

In this region, the quality of seismic imaging is generally poor in the pre-Tertiary strata, and consequently seismic interpretation is plagued with serious limitations. As an alternative to reflection seismic data, serial transect mapping is about one tenth of the cost of acquiring conventional seismic data, yet it provides superior constraints on structural models over the sparsely mapped ranges of the Great Basin.

Why Modelers Need to Look at the Rocks! – Examples from Greater Aneth Field, Paradox Basin, Utah

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Greater Aneth field, Utah's largest oil producer, has produced over 440 million bbls. The Aneth Unit, in the northwestern part of the field, was selected for a combined enhanced oil recovery (EOR) and CO_2 sequestration demonstration project; the projected production increase is 15,000 BOPD. Located in the Paradox Basin, Greater Aneth is a major stratigraphic trap. The primary reservoir is the Desert Creek zone sealed by the overlying Gothic shale, both within the Pennsylvanian Paradox Formation. Past well-log interpretations and published cross sections divide the Desert Creek into several correlatable reservoir subzones and units, as well as a few seals, across the field. However, caution is urged when using this type of information alone to generate reservoir models for EOR and CO_2 sequestration at Aneth and other fields.

Examination of available slabbed conventional cores from Aneth Unit wells reveals a more complex reservoir consisting of limestone (oolitic, peloidal, and skeletal grainstone and packstone, and algal boundstone/bafflestone) and finely crystalline dolomite. These lithotypes represent a variety of depositional environments (open-marine shelf, shallow-marine beach and shoal, algal mound, low-energy restricted shelf) that produce reservoir heterogeneity beyond what is determined from well logs. Fractures in cores are relatively common and there is evidence (hydrothermal [saddle] dolomite, brecciation) of minor but important faults that may affect fluid flow. Cores reveal additional potential seals within the Desert Creek (mudstone and very fine grained sandstone units). Finally, several units containing the bryozoan *Chaetetes* have good well-log porosity, but core observations show the porosity is ineffective.

Thrust Belt Structures and Paleozoic Stratigraphy of the Scott Butte and Snaky Canyon Quadrangles, Southern Beaverhead Mountains, Idaho

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Geologic mapping by faculty and students at Brigham Young University - Idaho has revealed a structurally-complex area involving Mississippian through Permian strata that have been subjected to folding (some overturned), thrust faulting, high-angle reverse faulting, and normal faulting at the southern end of the Beaverhead Mountains between the Idaho-Montana border and the Snake River Plain. This location is believed to be the north-westward extension of thrust faulting previously mapped in the Big Hole Mountains and Snake River Range to the south of the Snake River Plain; although, specific fault correlations have yet to be made. Structure of the southern Beaverhead Mountains is dominated by a northwest-striking normal fault that drops thrusted and complexly folded Pennsylvanian-Permian strata down to the west. The normal fault is thought to be Miocene in age because of its orientation parallel to the current mountain front. A second set of smaller normal faults with E- to ENE-strikes truncate or merge with the NW-striking normal fault and may be related to passage of the Yellowstone hot spot beneath the adjacent Snake River Plain during late Miocene time. In the Snaky Canyon Quadrangle, a thrust fault places the shallowly-dipping Lower Pennsylvanian to Upper Mississippian Bluebird Mountain Formation over the steeply-dipping Upper Mississippian to Lower Permian Snaky Canyon Formation. This thrust fault is in turn cut by a subvertical, NW-striking fault that forms an abrupt stratal boundary. The Mississippian South Creek Formation pinches out abruptly southward in the Scott Butte Quadrangle, and the shaly Mississippian Big Snowy Formation pinches and swells near faults and in folds.

Gas Resource Potential of the Woodford Shale, Arkoma Basin, Oklahoma

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The Woodford Shale (Lower Mississippian-Upper Devonian) has emerged as one of the most significant resource plays to develop in Oklahoma. The play area encompasses more than 1200 square miles, and lies within a 4 county area in eastern to southeastern Oklahoma. The play is defined to the west by the gas maturity level, and to east by the regional complexity of the Choctaw Thrust System. The Woodford Shale, as it is regionally termed, is an organic-rich mudstone by definition, consisting of predominantly silica and illite, with minor amounts of pyrite, and dolomite. The Woodford formation throughout the mid-continent is considered a world-class source rock, as it has provided the hydrocarbon source and seal for numerous major stratigraphic and structural conventional reservoir traps. Through outcrop, core and petrophysical measurements, the TOC values can exceed 15%, illustrating its potential as a hydrocarbon source. The emergence and refinement of the Barnett Shale play in the Fort Worth Basin of North central Texas lead Devon Energy to apply its drilling and completion experience to this resource shale candidate. Initial vertical drilling began in May of 2004, with vertical completion activities showing mixed to poor results. Devon's initial horizontal well was spud in January of 2005 with an initial production rate of 3000 MCFD. Development continued with the current completed well count at 31, with five rigs drilling in the focus area of Coal and Hughes counties, Oklahoma.

Extensional Inversion of the Central Utah Thrust Belt: More than Just the Sevier Desert Detachment

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The Sevier Desert detachment (SDD) is proposed as a low-angle Cenozoic normal fault that formed by inversion of slip along a former Cretaceous thrust fault, the Pavant thrust. Seismic imaging of Miocene-Pliocene growth strata above the SDD provides the most widely cited evidence for Basin and Range extension along the detachment. However, structural and stratigraphic reconstruction of the basin indicates that pre-Basin and Range extension accounts for over a third of the 45-50 km total SDD displacement constrained from hanging wall and footwall cutoffs and piercing points. Inversion of the Pavant thrust along the SDD is just one component of Oligocene and younger low-angle normal faulting that reactivated the Pavant and all major thrust systems to the east. Growth strata of the Oligocene Goldens Ranch Formation are particularly well dated and imaged across the relay zone between the Juab and Sevier grabens, where normal faults sole downward into Pavant footwall thrusts. Normal reactivation of the Paxton thrust occurred beneath the Sevier Valley south of the Gunnison Plateau, where the Sevier normal fault is interpreted to sole westward into the Paxton thrust system. Eastward rollover of the Oligocene Crazy Hollow and Aurora Formations and the thick overlying volcanic succession is evident along the east flank of the Pavant Range above the sole fault, although definitive evidence of growth is absent. Finally, growth strata in the Moroni Formation document Oligocene normal inversion of the Sanpete Valley backthrust along the west side of the frontal triangle zone east of the Gunnison thrust.

Lessons Learned in Vintage Bakken Vertical-Well Completions Provide Answers to Pay Location & Quality and Stimulation Optimization

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In the years before horizontal-well completion efforts (i.e., 1960-1988), stimulation treatments were commonly performed on vertical Bakken wells throughout the Williston Basin. The results of these treatments were mixed, from spectacular gains to catastrophic losses in productivity. Several factors have been identified which affect treatment response in the Bakken. Through the use of well history, treatment records, and laboratory data, this presentation will show the pay characteristics of adjacent lithologic intervals (basal Lodgepole through upper Three Forks) and explore ways in which fracture treatments influence Bakken reservoir performance. Some of the topics covered include: the condition of the wellbore area; rock mechanics; formation fluid properties; stimulation fluid systems such as water, acid, and oil; use of fluid loss additives and propping agents; and treatment size.

Stratigraphic Trapping in the Rollins Sandstone of the Mesaverde Group, Mamm Creek Field, Piceance Basin, Northwest Colorado

Cumella, Stephen P.[1] (1) Bill Barrett Corp, Denver, CO

Most gas production in the southern Piceance Basin is from the Williams Fork and Iles formations of the Mesaverde Group. In ascending order, the Iles Formation is comprised of three eastward-prograding marine parasequences sets, the Corcoran, Cozzette, and Rollins members. Across most of the southern Piceance Basin most operators avoid completing in the Rollins because it commonly produces water, due to its thick, laterally continuous nature and the fact that the northeast depositional strike of the Rollins shoreline is generally perpendicular to structural dip. However, in the Mamm Creek Field area, the Rollins produces gas from a series of marine shoreface parasequences that pinch out up dip across the northwest plunge end of the Divide Creek anticline where the northeast trend of the shoreline is sub-parallel to structural dip. Individual parasequences within the Rollins can be identified by flooding surfaces that are overlain by shale intervals that thicken seaward. These shales pinch out in a landward direction, but the tops of the parasequences can still be identified on well logs by cleaner sandstones overlain by higher gamma ray sandstones. The productive intervals of the Rollins parasequences are areas where the sandstone has relatively good porosity and permeability and a top seal is present (either an overlying shale or a burrowed, finer-grained sandstone with higher capillary pressure).

Stratigraphy and Petrophysics of Gas-Producing Parasequences in the Rollins Sandstone of the Mesaverde Group, Mamm Creek Field, Piceance Basin, Northwest Colorado

Cumella, Stephen P.[1] (1) Bill Barrett Corp, Denver, CO

The Rollins Sandstone Member of the Iles Formation produces gas from a series of marine shoreface parasequences that pinchout updip along the northwest plunge end of the Divide Creek anticline in the southeast Piceance Basin in northwest Colorado. Very high well density (10- and 20-acre) allows detailed correlation of upward-coarsening parasequences. In a distal setting, the tops of the parasequences are overlain by marine shale interbeds that thicken in a seaward direction. The shale interbeds pinchout in a landward direction, but in these areas the tops of the parasequences can be identified by a trough cross-stratified, low gamma-ray upper shoreface sandstone overlain by a burrowed, higher gamma-ray lower shoreface sandstone. Rollins shoreline orientation can be accurately determined by mapping the landward pinchouts of these shale interbeds. The productive intervals of the Rollins can be identified on open-hole logs by a combination of neutron-density cross over, high resistivity, and relatively low calculated water saturations. Productive intervals can also be identified by mud-log gas shows and gas seeps on borehole image logs. Maps of the productive portions of the Rollins parasequences show a series of shore-parallel lenses that shale out in a seaward direction.

Shale Gas Potential of the DJ Basin, Wattenberg Gas Field, Denver Basin, Colorado

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The Wattenberg Gas Field, in northeastern Colorado, has produced more than 2 TCFE from the Lower Cretaceous (Albian) J Sandstone and Upper Cretaceous (Turonian) Codell Sandstone. Approximately 700 feet of organic-rich, fine-grained, Cretaceous source rocks or “shales” occur stratigraphically below, within and above these main reservoirs. In ascending order, these shales include the Skull Creek Shale, Mowry Shale, Graneros Shale, Greenhorn Formation, Niobrara Formation, and Sharon Springs Member of the Pierre Shale. The shales are marine (Type II kerogen), have relatively high total organic carbon content (2-10% TOC), are thermally mature (> 0.8 Ro), are saturated with gas, and most have anomalously high pressure gradients. Approximately 60% of the wells in Wattenberg Field are faulted, but open fractures are rare.

Based on an integration of 2000 feet of core from several wells, historical production data and wire line logs from 7000 wells, as well as fall-off injection tests, microseismic analysis of hydraulic fractures, and production tests in several new wells, 700 feet of potential “gas shales” were reduced to two intervals, the Niobrara and Greenhorn formations. Although open fractures are rare, these rocks have high calcium carbonate content and are “fracable”. Unfortunately, the two most organic-rich and gas-saturated shales, the Sharon Springs member and the Graneros Shale, have a high clay content and could not be fracture stimulated. However, they probably form the top and bottom seals for this resource play.

Calibrating Stable Carbon Isotopes of Reservoir Fluids as a Thermal Maturity Indicator

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Organic thermal maturity indicators are used to determine the maximum level of maturity for a given rock unit. Thermal indicators such as measured vitrinite reflectance, thermal alteration index (TAI), and the Rock-Eval ™ parameter Tmax measure the rock unit directly and indirectly and require core or cuttings for analysis. Stable carbon isotopic analysis of mud gas, production gas and headspace gases provides the opportunity to measure the maturity of reservoir fluids. Measuring the maturity of reservoir fluids in conventional and unconventional plays allows for a more complete interpretation of the petroleum system elements such as source maturity, migration of hydrocarbons, and charge history and timing. In the case of shale gas plays understanding the maturity of the fluids can be a proxy for the maturity of the shale itself if there is no migration of the gas out of the rock, into the rock, or the gas within the source rock is a risiduum. Mud Gas Isotope Analysis (MGIA) is a technique that allows sampling of the mud stream gases while drilling to measure $d^{13}C$ isotopic concentrations of C1-5 components. $d^{13}C_{ethane}$ and $d^{13}C_{propane}$ are good thermal maturity indicators and can be derived from MGIA. These maturity parameters can be used qualitatively to understand relative maturity of the fluid/rock or, if calibrated to shale rocks, can be used as a robust quantitative thermal maturity parameter. Calibrations can be achieved using analogous systems from a global thermal maturity database or from basin and formation specific data. The objective of this talk is to provide information regarding limitations of global rock maturity data when calibrating basin and formation specific fluid maturity parameters. Also, the use of the gas maturity parameter in assessing conventional and unconventional hydrocarbon systems in the Rocky Mountains will be discussed.

Detailed Analysis of the Nesson Antiform Williston Basin, ND

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The Nesson antiform is a composite feature composed of a chain of horsts and associated intra-horst simple folds. Faults are vertical and probably cut Precambrian basement. The Larimide was a period of major uplift; but the Nesson area had broken into discrete blocks by the Mesozoic—each block having a different subsidence history. Presence of these sharp-edged thickness domains can be detected as early as the Devonian. At least three families of faults occur: 1) northeast across the trend, 2) southeast oriented faults and 3) medial faults parallel to the Nesson trend. The Nesson is thus subdivided into discrete fault bonded rhombs. Within some rhombs, the strata are arched. These results corroborate earlier concepts that the Nesson complex is a bundle of wrench faults localized over an ancient zone of crustal weakness. As many as 20 tops (Cretaceous-Ordovician) and more than 25,000 wells were used in the analysis. Data was screened algorithmically, ~5% was in error (errors included input error, incorrect KB, no correction to true vertical depth, incompetence). More than 40 Swath sections-were derived, each swath containing 100-300 wells ranging in length from 30 to 100 miles. Screened data combined with computer-assisted graphical analysis resolves structures down to a vertical relief of about 10 feet, control permitting. . These same procedures easily resolve subtle stratigraphic and structural features basin-wide and at depths more sparsely penetrated. The ubiquity of vertical faults basin-wide can complicate interpretation of seismic data.

Stratigraphic and Depositional Controls on Fluid Migration through Eolian Sandstones - Comparing Outcrop with Reservoir

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The Cedar Mesa Sandstone is located in the Needles District of Canyonlands National Park, Eastern Utah, was deposited in an ancient sand dune sea, and is an exhumed stratum that has been a host for migration of and alteration by fluids. The Cedar Mesa Sandstone has a complex depositional history and consists of red and white interbedded and intertonguing cross bedded eolian, thin bedded fluvial, pebbly and muddy pedogenic, and thin, muddy and sandy, pond strata. The focus of the research was to characterize size, orientation, and lithologies surrounding small scale pond and associated pedogenic lithologies that act as permeability barriers in both outcrop and reservoir rocks. The Cedar mesa Sandstone is a useful analog for the Weber Sandstone that is a Permian aged producing eolian reservoir in the Rangely Field, Colorado. Comparisons were made between the outcrops of the Cedar Mesa Sandstone, and core and wireline log patterns through the Weber Sandstone. This revealed the two formations have similar dune and pond sizes and lithologies but different dune and pond orientations. We conclude that geometric distribution of groups of ponds stacked within sandstones is predictable using outcrop and log observations, along with wind direction, to reconstruct the depositional dune topography and accumulation. Predicting where large dunes are located in the subsurface may aid in the selection of drilling targets while avoiding permeability barriers.

Devonian Shale Gas Potential of the Southern Tier of New York

Faraj, Basim[1], James Duggan[1] (1) Talisman Energy Inc, Calgary, AB

Deep structures in New York and Pennsylvania are drilled for Trenton-Black River (Ordovician) dolomite reservoirs where they often encounter "nuisance" gas in the Devonian shale succession, requiring careful planning and selection of casing schemes. Often a topic as a resource-type play, the shale gas potential of the the Hamilton Group and selected units of the Upper Devonian shales are under investigation. Mineralogical, geochemical and shale desorption data were collected from cores, cuttings and outcrop samples, in order to carefully characterize and delineate the reservoir and source rock potential of the shale package.

The thickness of the overall package in the Southern Tier of New York where the Upper Devonian crops out varies from a few hundred feet to 5000 feet. A detailed sequence stratigraphy is made difficult by a lack of extensive marker beds in the Upper Devonian succession. However, the well control and occurrence of favorable markers (Onondaga Fm. and Tully Fm.) make the Geneseo Fm. and Marcellus Fm. suitable candidates for horizontal drilling.

The lateral extent of the shales of the Appalachia Basin from New York to Kentucky suggests a vast, underexplored shale gas resource in the Southern Tier of New York and much of Pennsylvania where a thermogenic origin of dry gas is predicted. Gas in place (GIP) is large and range between 20 and 100 bcf/section. The Marcellus, Geneseo, and Rhinestreet contain up to 25% TOC with favorable mineralogies and pressures to consider a variety of stimulation techniques. High rate/volume, low sand completions technologies applied in shale basins elsewhere may yield results that are improved over conventional methods.

Caney Shale, Arkoma Basin, Oklahoma

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The Caney Shale, Chesterian age, was deposited in the Oklahoma part of the Arkoma Basin one of a series of foreland basins that formed progressively westward along the Ouachita Fold Belt from the Black Warrior Basin in Mississippi to basins in southwest Texas. The Arkoma Basin in Oklahoma is in the Southeast corner of the state north and northwest of the Ouachita Mountains. The Caney thickens toward the southeast from 90' at its northwest edge to 220' along the Choctaw fault in the south. It can be subdivided into 6 intervals based on characteristics of the GR, density and resistivity logs. The Caney dips southward from a depth of 3000' in northern McIntosh County, Oklahoma to 12,000' just north of the Choctaw thrust. Reported average TOC values for the Caney Formation range from 5% to 8%. The TOC values range from 3% to 8% for different members of the Caney. The R0 values range from 1.7 at the northwest edge of the gas window to 3.4 just north of the Choctaw thrust. TOC values show linear correlation with density. Mud log gas shows have a strong correlation with desorbed gas values that range from 120 to 150 SCF/T. Estimates of GIP for the Caney range from 30 to 40 BCF/ section. Only one Caney completion reported an IP over 1000 Mcf/d. Other vertical completions have ranged from 50 to 100 Mcf/d. The Williams Layman 1-27 horizontal completion declined from an IP of 822 Mcf/d to 180 Mcf/d in one year and could produce at 80-100 Mcf/d for an extended period.

Natural Fractures in the Barnett Shale: Why They Are Important

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Microseismic monitoring of hydraulic-fracture treatments in the Barnett Shale shows that fractures propagate in an array wider than that expected from knowledge of the present-day stress field. It has been suggested that this is because hydraulic fractures reactivate natural-fracture systems. To investigate this possibility, we analyzed the orientation, size, intensity, and sealing properties of opening-mode fractures in several Barnett Shale cores from the Fort Worth Basin.

Natural fractures in the Barnett Shale are common. They are narrow (< 0.05 mm), sealed with calcite, and present in en echelon arrays. They are typically steep (> 75°), and the dominant trend is WNW. Other sets trend N-S. The narrow fractures are mostly sealed and cannot contribute much to reservoir storage or permeability. The fracture population, however, may follow a power-law size distribution, where the largest fractures in the population are open. A mechanical rock property, the subcritical crack index, was measured for different lithofacies. This index, along with mechanical layer thickness, governs fracture clustering. The subcritical crack index for all lithofacies tested is high, indicating strong fracture clustering. These results suggest that large open fractures exist in clusters spaced several hundred feet apart.

We also tested the effect of calcite-sealed fractures on tensile strength of shale. Samples containing natural fractures have half the tensile strength of those without. The junction between the fracture-wall rock and cement is weak because the calcite cement grows mostly over noncarbonate grains, thus providing a mechanism for hydraulic reactivation of sealed natural fractures.

Basement Fault Control of Offshore Cretaceous Sandbars in the Powder River Basin, Wyoming

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Cutting a broad 25 mile wide NW-trending swath across the Powder River Basin are a series of oil fields that occur in Upper Cretaceous offshore sandbars. Stratigraphic units involved include Shannon, Sussex, Ferguson, Parkman, Tecla and Teapot. At first glance these fields would seem to fall in the “purely stratigraphic” category. However, of the 20 fields studied 13 lie over well-mapped basement faults , several of which I will show. The remaining 7 probably lie over basement faults that are not easily mappable with the magnetic methods employed.

Two depositional mechanisms have been proposed to explain the relationship of sandbars to basement faults. Swift and Rice (l984) suggested that fault movement created long, linear seafloor highs on which the winnowing action of bottom currents deposited porous sands. More recently, Denver geologists Horne and Inden have proposed instead that sands deposited as lowstand shorelines were reworked and preserved on the downthrown sides of seabed fault scarps following sealevel rise. Either mechanism calls on faulting as the control, so these bars cannot properly be considered “purely stratigraphic.”

Basement control on deposition of offshore sand bars is just one facet of “reactivation tectonics,” which is currently revising many long-standing, outmoded, or poorly-explained concepts of structural geology. Although these new geological revelations have been slow in acceptance, they will be accepted when it is realized how many geological phenomenon are better explained by reactivation of preexisting basement faults.

Discrete Element Modeling (DEM) Improves Fundamental Understanding of Microseismicity Data and Provides Capabilities for Predicting Events

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Microseismic data from hydraulic fracturing field operations were analyzed using a Discrete Element Model to understand fracture propagation processes in a complex environment. The case history presented is a thick gas reservoir package; composed of coal (adsorbed gas), shale absorbed and free gas), and tight, gas-charged sands. This rock package is located at rather shallow depths (less than 3000 ft). While the resource is good, economic and optimized producibility mandates developing an optimized stimulation program.

Current “standard” methods for microseismic interpretation have limitations such as inherent non-uniqueness, difficulty in identifying failure mechanisms (tensile vs. shear), the existence of events located away from the fracture fronts, and also the fact that up to 90% of rock failure may be aseismic. In the model presented, rock is represented by an assembly of individual particles that are bonded at their contact points. Seismic events are generated when these bonds break under stress and deformation; stored strain energy is transformed into kinetic energy which is recorded as (micro)seismicity. This model is capable of replicating not only different failure modes of rock under a given stress field (shear and tensile events) but the associated seism locations and amplitudes as well.

Stimulation treatments in the rock package were monitored. The stimulations have been numerically represented and the location and chronology of microseismic events have been matched. The simulations are qualitatively validated by comparing the simulated seismicity with the actual data. This provides indications of the effective fracture network extent and the consequent fracture system conductivity.

An Operation Geologist’s Venture into the Land of Geochemistry: Using Mud Gas Isotopes and Standard Geochemical Analyses to Identify Seals, Source Rocks, Gas Families, and Prospect Fairways in the Uinta Basin

Grau, Anne[1], Janell D. Edman[2], Michael Dolan[3] (1) EOG Resources Inc, Denver, CO (2) Geochemical Consultant, Denver, CO (3) Dolan Integration Group, Louisville, CO

The objective of this talk is to discuss methods of applied geochemistry that can be used by the average desk geologist to help characterize and understand petroleum systems in a practical scope that is useful to field characterization, development, and exploration. Using a case study and real data obtained in the Greater Natural Buttes Field of the Uinta Basin, several analytical techniques and interpretive methods will be presented that allow for a working geochemical model to be developed. Standard geochemical analyses such as measured vitrinite reflectance, thermal alteration index (TAI), and Rock-Eval ™ pyrolysis helped to characterize basin-wide maturity indicators and source rock quality. Mud Gas Isotope Analysis (MGIA), a technique that allows sampling of the mud stream gases while drilling, measures many components of gas chemistry including stable carbon isotopes of methane, propane, and ethane. Simple graphing techniques using MGIA data allows many useful interpretations including identifying gas “families”, observing seals, and providing evidence for migrated thermogenic gas accumulations. Specialized analyses, including Compound Specific Isotopic Analysis, helped to determine the association of gas and liquid hydrocarbons produced in a developing field. A variety of geochemical analyses, combined with guidance from a host of expert geochemists, resulted in the ability to identify important elements of the petroleum systems at Natural Buttes Field. Integration with other types of geologic characterization have allowed for better understanding of existing fields and exploration prospect fairways in the Uinta Basin.

Update on the Cane Creek Fractured Shale Play, Northern Paradox Basin, Grand County, Utah

Grummon, Mark L.[1] (1) Samson Resources, Denver, CO

Recent drilling in the northern Paradox basin has re-energized the Cane Creek Shale play. After the initial 1990's horizontal drilling campaign collapsed, several companies attempted to extend the same play concept farther south, while various others tried to establish resource type shale plays in the Paradox Salt throughout the basin.

Organic rich source rocks interbedded with modest reservoir quality sandstones and carbonates comprise a typical Paradox Salt clastic break. The Cane Creek is the thickest and best developed of these, but is not otherwise unique. Salt both above and below clastic breaks provides critical sealing capacity that preserves over-pressure generated during hydrocarbon maturation. Commercial production requires well bore communication with un-mineralized open natural fractures. Matrix porosity adds significantly to reservoir storage capacity. Many dry holes, both vertical and horizontal, can be ascribed to seal failure or the absence of open natural fractures.

Horizontal wells targeting fractured Cane Creek shale met with spotty success. Two fracture-stimulated vertical wells were commercial failures. Current operators' press releases provide evidence that the Paradox Shale play extends over a large portion of the northern Paradox basin. One company has begun using multi-stage frac treatments on 1,000-ft thick gross clastic reservoir intervals spread over 12 clastic intervals in vertical wells. Preliminary results indicate potential for combined flow rates from 4 to 12 MMCFGD and 500 BCPD.

River Gas of Utah No. 1 Core: Window Into the Mancos Shale Gas Reservoir

Gustason, Edmund R. "Gus"[1], Steven Schamel[2] (1) El Paso Exploration and Production Company, Denver, CO (2) GeoX Consulting Inc, Salt Lake City, UT

Nearly 1700 feet of uppermost Tununk Shale, Ferron Sandstone and Lower Blue Gate Shale members of the Mancos Shale was continuously cored in the River Gas of Utah No. 1 well, located in the Drunkards Wash CBM field (section 36, T14S, R9E). The upper Tununk Shale is dark gray, slightly calcareous, bioturbated, silty claystone with some streaky laminated silty claystone. The lower 200 feet of the Lower Blue Gate is dark gray, bioturbated, silty claystone and streaky laminated silty claystone. The upper 800 feet of the Lower Blue Gate Shale Member is dark gray, calcareous claystone and silty claystone that grades upward into streaky to lenticular bedded silty claystone. Bentonite beds and calcite concretions are common. A few subvertical fractures occur throughout the core but, in general, the core contains few fractures. Abundant trace fossils, including Planolites, Chondrites, Anconichnus, Terebellina, Thalassinoides, and Teichichnus and ammonites and inoceramid bivalves indicate an oxygenated, normal marine shelf environment with abundant organic input. Over 1,000 feet of the Lower Blue Gate Shale has TOC (type II and mixed type II-III kerogen) greater than 1.0%, 680 feet has TOC greater than 1.5%, and nearly 200 feet has TOC greater than 2.0%. Thermal maturity, as estimated from the rank of nearby Ferron coals, is 0.6-0.7% Ro (high-volatile B bituminous). The Lower Blue Gate Shale may be a significant gas reservoir north of the Book Cliffs and beneath the Wasatch Plateau.

The Impact of New Technology and Deep Drilling on Oil and Gas Development in the Uinta Basin

Gustason, Edmund R.[1] (1) El Paso Exploration & Production, Denver, CO

Since the first commercial gas well in the Uinta Basin was established at Ashley Valley in 1925, economic oil and gas development has been driven by several factors besides commodity prices. This paper summarizes the impact of using new technology and drilling deeper targets on the development of oil and gas resources in the Uinta Basin over the past 80 years

Like most basins in the Rocky Mountains, oil seeps led to the exploitation of shallow structures that were, in turn, drilled to deeper reservoirs. For example, recent deepening in Red Wash and Natural Buttes has found significant new gas reserves in the Cretaceous Mesa Verde, Blackhawk, and Mancos intervals.

However, in addition to exploring for deeper targets, continued economic success in the Uinta Basin will require the application of new technologies in old fields. New formation evaluation tools, cores, image logs, detailed outcrop studies, and comprehensive reservoir characterization studies have helped operators better understand the impact of fractures, reservoir architecture, and permeability anisotropy for in-fill drilling and enhanced oil recovery in existing mature fields, such as Bluebell-Altamont, Monument Butte and Natural Buttes. Acquisition and interpretation of 3D seismic has improved success and economics in both structurally complex areas such as Peter's Point. In areas where thin, but widespread sandstone reservoirs occur, operators are drilling horizontal wells. Cooperative development of new technologies among operators and service companies will, hopefully, continue to improve geological and engineering efficiencies and lead to continued economic success during the next decade and beyond.

Application of n-dimensional Log Analysis in Predicting Reservoir Properties from Core Data in both Cored and Un-cored Wells in Tight Gas Reservoirs

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Tight gas shales present interesting challenges to the interpretation of reservoir properties using logs. Unfortunately, none of these is easily addressable using conventional log analysis techniques. Most of the challenges stem from the fact that in unconventional reservoirs, the porosities are typically 7-8% or less, and the rock matrix has highly variable intrinsic properties associated with variability in silica, carbonate, the presence of other minerals, and most importantly, clay. As a result, the amount of variability in log responses caused by the rock matrix is high, and overwhelms the amount of variability associated to the materials of interest (gas, oil and water in the pore space). The latter is at best a secondary effect when compared with the variability of >90% of the volume investigated by logging tools – the matrix. To address these issues, we have employed n-dimensional cluster analysis techniques to define zones of statistically similar or dissimilar bulk log response, over multiple log dimensions, in an effort to separate the log signatures into zones of consistent material properties. These zones can then be integrated with core data to produce continuous vertical profiles of reservoir and mechanical properties measured in the lab. Additionally, using pattern recognition techniques, we can then identify these zones in other, non-cored wells throughout the field and use the zonal models to predict the reservoir and mechanical properties with a much higher degree of accuracy and interpret log responses in terms of petrologic and geologic properties. This leads to much better understanding of the gas in place as well as the fraction of the reservoir that is most producible.

Origin of the Deformed Basal Uinta Formation in Eastern Utah (Uinta Basin): Progradational Delta Clinoforms of a Lake Highstand or Ephemeral Fluvial Sheetfloods of a Lake Lowstand?

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The early to middle Eocene stratigraphic succession in the Uinta Basin can be roughly divided into a lower coarse grained unit (Wasatch Formation), medial fine grained interval (Green River Formation), and upper, mixed fine-coarse grained and locally evaporitic unit (Uinta Formation). Lithofacies interpretations are of an alluvial intermontane basin containing a major lake of fluctuating size and depth.

The presence of saline facies in the upper part of the succession in the west of the basin has generally lead to the conclusion that 'Lake Uinta' gradually dried out as the basin was infilled. However, in the east it was thought possible that there existed inclined lake-delta-front foresets on a decameter-scale. This interpretation would indicate that there was gradual coarse-clastic infilling of a deep lake that preceded the onset of drier conditions.

Interpretation of basal Uinta Formation strata in the east, and the nature of its contact with underlying shale and oil shale of the Green River Formation, is complicated by deformation on various scales. The localized nature of the deformations indicates their syndepositional origin as soft-sediment deformation features. At the meter scale, beds may be dewatered and large flame structures punctuate the contact. At the decameter scale, domal and diapiric mudstone structures can be viewed.

Currently, the working hypothesis is that the decameter scale "foresets" are actually related to the large-scale domal structures, and the beds were originally flat-lying sheetflood deposits now partly dewatered and tilted after loading and intrusion. This suggests that the large Uinta Lake at the time of oil shale deposition subsequently experienced a major base-level fall before any of the observed coarser grained units were deposited.

Structural Analysis of Pressure Solution Cleavage in the McCartney Mountain Fold-Thrust Salient, Southwest Montana

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The McCartney Mountain salient is a distinct convex-east segment of the Sevier fold-thrust belt in southwest Montana, lying east of the Pioneer batholith and west of basement-cored Laramide uplifts. Prominent features of the central part of the salient include the in-sequence Sandy Hollow thrust fault (displacing Permian over Lower Cretaceous strata) and syncline-anticline pairs in the hanging wall and footwall that display complex intra-formational duplexes and parasitic detachment folds at all scales. Pressure solution cleavage (PSC) occurs in the argillaceous carbonate members of the Cretaceous Kootenai and Triassic Dinwoody Formations throughout the area. PSC has been systematically mapped and characterized according to morphology, domainal spacing and orientation for all exposed outcrops of a distinctive yellowish dolomitic unit in the lower carbonate member of the Kootenai. This PSC exhibits planar morphology with domainal spacing at the mm-cm scale, classified as strongly spaced-cleavage to slaty-cleavage. Structural orientation data divides the PSC into three populations. S1 is localized and fans with respect to axial surfaces of mesoscopic folds. S2 is defined by axial planar PSC that trends N-S, dips east and is inferred to have formed during late stage shortening (parallel to regional fold axes). S3 is recognized by E-W trending PSC that dips within 10° of vertical, cross cutting hanging wall and footwall folds in the area. Later tectonic influences such as: a) impingement against foreland Laramide structures, b) Late Cretaceous magmatic inflation of the fold-thrust belt, and/or c) Eocene exhumation and extension, could provide mechanisms for S3 development.

Development of Conventional and Unconventional Reservoirs: West Tavaputs Plateau, Uinta Basin, Utah

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In early 2002, Bill Barrett Corporation purchased approximately 46,000 gross acres in three Federal Units in the Nine Mile Canyon area of the Southern Uinta Basin. At the time of the purchase, the field was producing 1.4 MMCFD from approximately 11 wells. The purchase also included three federal permits, an ongoing Environmental Assessment and an antiquated polypipe gathering system. The company immediately applied to shoot an 83 square mile 3D seismic program and to expand the EA as well as renaming the project to the West Tavaputs Plateau to better reflect the area of operations.

Historical producing horizons at West Tavaputs include the primarily fluvial reservoirs of the Blackhawk, Price River and North Horn formations along with shallow production from the alluvial and lacustrine reservoirs in the Green River-Wasatch transition zone. The project area also contained two deep tests that had resulted in a small amount of gas production from the Dakota formation. By applying CO2-assisted fracture treatments and stacking completions, the company has been able to overcome the previously marginal economics from the normal to slightly over pressured reservoirs. Also, by utilizing 3D seismic, Bill Barrett Corporation has been able to define sweet spots within the complex structural and stratigraphic controlled shallow reservoirs. The 3D was also instrumental in identifying deeper potential which resulted in the discovery of significant reserves in the Navajo formation. Presently, the company has drilled over 80 Mesaverde depth wells and six Navajo wells. Production has grown to over 90 MMCFD and continues to increase, despite a very difficult regulatory and operating environment.

Geologic Map of Snaky Canyon Quadrangle, Clark County, Idaho

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The Snaky Canyon Quadrangle is located at the southern end of the Beaverhead Mountains in eastern Idaho between the Idaho-Montana border and the Snake River Plain. Detailed geologic mapping by BYU-Idaho faculty and Field Camp students reveals a clear exposure of an unnamed Sevier thrust fault that places Lower Pennsylvanian to Upper Mississippian Bluebird Mountain formation over the steeply-dipping Upper Mississippian to Lower Permian

Snaky Canyon formation. The thrust is cut by a subvertical fault with down-to-the-west displacement, with the largest thrust exposure on the upthrown side. Two distinct exposures of the thrust are also present on the down-thrown side. Mapping also reveals previously unmapped exposures of the Mississippian Big Snowy formation along the subvertical fault.

A Method to Quantify Gas Saturation in Gas/Water Systems, Using Density and Neutron Logs – Interpretation of Reservoir Properties When Compared With Gas Saturations from Resistivity Analysis

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A standard approach to evaluate gas effects on porosity logs is the "density/neutron cross over" response. In the presences of gas, bulk density is reduced, and the neutron log is suppressed.

The degree of cross over can be related quantitatively to gas saturation, so long as accurate knowledge of matrix lithology is available. In the calculations presented in this paper, porosity calculations (lithology corrected) for the density and neutron logs are compared with the cross plot density/neutron porosity. This latter calculation requires no input of matrix properties and, in gas/water systems, is relatively insensitive to fluid content.

Differences between the individual porosity log calculations and cross plot porosity yield quantified estimates of gas saturation for each log individually. These estimates, when compared with standard resistivity modeling of gas saturation can be used to gain insight into gas reservoir characteristics:

If gas saturations agree, the conclusion can be drawn that all sources of petrophysical data are consistent, and the model is robust. Agreement also suggests that all sources of data are equally affected by the wellbore environment, i.e. the porosity logs have not been influenced by invasion.

If, as is common, gas saturations from porosity logs are significantly less than that derived from resistivity analysis, a number of possible explanations exist:

Matrix properties are inaccurate.

There has been pervasive invasion by mud filtrate, with extensive flushing of gas away from the wellbore.

The calculations of shale volume are inaccurate – for example presence of kaolin that a gamma ray measurement might not detect.

Presence of fresh water sands, with high values of water resistivity that have been mistaken for gas-bearing sands when analyzed by resistivity modeling.

Examples from tight gas sands of the Rocky Mountains are presented, to show variable reservoir responses as outlined above.

Comparison of Total and Effective Water Saturations as a Way to Verify the Validity of Effective Porosity Calculations

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Ransom proposed that the following equality holds for standard oil and gas reservoirs.

In place hydrocarbons in total porosity = In place hydrocarbons in effective porosity

Or:

$\Phi_T*(1-S_{WT})=\Phi_E*(1-S_{WE})$

Porosity * Hydrocarbons = Porosity * Hydrocarbons

Where:

Φ_T = Total Porosity

S_{WT} = Total Water Saturation

Φ_E = Effective Porosity

S_{WE} = Effective Water Saturation

This relationship implies that there are no hydrocarbons in the shales.

Knowing total porosity, total water saturation and effective porosity, effective water saturation can be calculated.

Effective porosity is calculated from total porosity, shale volume, and porosity reading in shale.

$\Phi_T=\Phi_E+V_{SH}*\Phi_{SH}$

Where:

V_{SH} = Shale Volume

Φ_{SH} = Shale Porosity

If either of the last two terms in inaccurate, the value of effective porosity will be inaccurate.

It can be shown that if either shale volume is overestimated and/ or shale porosity is overestimated, then calculations of effective porosity are too low. As a consequence, values of S_{WE} are too low or even negative.

Examination of a large number of reservoirs shows that traditional choices of shale porosity often give negative values of effective water saturation. The incorrect choice of shale porosity will often not be obvious if only total water saturation is considered.

A plot of total vs. effective water saturation can help in the proper choice of shale porosity. A correct choice will result in data with similar values of shale volume aligned linearly, with different slopes converging to a single point where both total and effective water saturation is one. An incorrect choice will lead to significant dispersion of the alignments.

Examples from a variety of reservoirs are included.

Detrital Zircon Geochronology of Lower Cretaceous Conglomerates, San Rafael Swell—Wasatch Plateau, Central Utah

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U-Pb ages of detrital zircon grains collected from four samples of Lower Cretaceous Cedar Mountain (Neocomian-Albian) and San Pitch (Aptian-Albian) Formations in central Utah exhibit discrete, distinctive peaks on age-probability plots. Detrital zircons were ultimately derived from Precambrian, Paleozoic, and Mesozoic igneous rocks. Paleoproterozoic grains (2475-1651 Ma; 62 of 100 grains) dominate the basal Cedar Mountain Formation in Salina Canyon. In contrast, the type Buckhorn Conglomerate on the San Rafael Swell and Member C of the San Pitch Formation in Salina Canyon contain mostly Mesoproterozoic grains (1579-1000 Ma; 61 and 64 of 100 grains, respectively). A population of Ordovician-Mississippian grains in the type Buckhorn Conglomerate indicates substantial contributions from Paleozoic and/or Mesozoic source rocks. Our data indicate that the basal Cedar Mountain Formation in Salina Canyon and the type Buckhorn Conglomerate were deposited by two different river systems, separated either geographically or temporally, or both. We postulate that clasts in the Buckhorn Conglomerate were derived from Paleozoic quartzarenites, the Triassic Chinle Formation and Permian and Jurassic eolianites. The San Pitch Formation clasts, which lack Paleozoic grains, may have been derived primarily from the Cambrian Prospect Mountain Quartzite and older rocks.

Our data are consistent with progressive unroofing of siliciclastic units from the Sevier thrust belt. They corroborate and refine exposure gates for inverted clast stratigraphies documented in carbonate clast conglomerates of the foreland basin. Future work on these geochronologically distinctive quartzite-clast conglomerates should further elucidate correlations, which remain ambiguous, among conglomeratic strata of the foreland.

Stratigraphic Reservoir Exploration in Liaozhong Strike-Slip Depression, Bohai Bay, China

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Great success of stratigraphic reservoirs exploration has been achieved through using lacustrine sequence stratigraphy in Chinese onshore basins in recent years, which mainly focuses on large scale extensional faulted basins, the stratigraphic reservoir exploration is just on its initial stage in offshore basins in China. Liaozhong Depression is one typical oil and gas rich offshore basins, the famous Tan-Lu stike-slip fault influences its structure and sedimentation, the stratigraphic exploration has not made progress since ESSO failed drilling one stratigraphic traps in 1999, but almost all the structures have been drilled in this depression at present, which stimulates the stratigraphic traps exploration in Liaozhong depression, this paper introduces how the Tan-Lu strike-slip fault and the extensional faults control the sequence stratigraphic framework , then predicts the subtle stratigraphic traps distribution within the sequence stratigraphic framework, the result shows the distribution of these stratigraphic traps are related to system tracts and slope break, they are mainly located on the third and forth order sequence boundaries, and have good reservoir forming conditions based on the analysis of sedimentary environment, migration pathways and reservoir forming simulation, recent drilling of one stratigraphic traps proved the the prediction, it not only indicates stratigraphic reservoirs are the new exploration frontier in this depression but also demonstrates the other similar depressions or basins influenced by Tan-Lu strike-slip fault in east China have great potential in stratigraphic traps exploration.

The Outflow of Eocene Lake Gosiute Into Lake Uinta and its Affects on Sedimentation in Lake Uinta in the Piceance Basin of Western Colorado

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The Eocene Green River Formation, where exposed near the mouth of Yellow Creek in western Colorado, provides evidence of outflow from in Lake Gosiute of western Wyoming and northwestern Colorado into Lake Uinta of western Colorado and eastern Utah. Throughout much of their histories, the two lakes were separated by the Axial Arch, however, Lake Gosiute, apparently drained southward across the arch into Lake Uinta late in its history, entering Lake Uinta near the present-day mouth of Yellow Creek. This outflow, which caused Lake Gosiute to evolve from saline to fresh water, caused a major expansion of Lake Uinta represented by the base of the Mahogany oil shale zone. Because of this outflow, the normally rich Mahogany oil shale zone grades into organic-poor rocks in the vicinity of Yellow Creek, and cannot be recognized. Coarse volcaniclastic sediments, sourced from the Absaroka volcanic field in central Wyoming, flooded into Lake Uinta starting about 150 ft above the base of the Mahogany zone at Yellow Creek, implying that Lake Gosiute was filled in by that time. Many of these volcanoclastic wedges grade into thin airfall tuffs toward the center of Lake Uinta.

The Yellow Creek area was a locus of sand and silt deposition starting much earlier than Mahogany time, implying that outflow from Lake Gosiute followed a previously established drainage system that flowed southward into Lake Uinta. Outflow must have reached the upper part of this drainage through a low somewhere along the Axial Arch, possibly near Cross Mountain.

Characteristics of the Upper Cretaceous Baxter Shale in the Vermillion Basin, Northwestern Colorado

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The overpressured Coniacian to Campanian-aged Baxter Shale overlies the Frontier Sandstone and is about 2500 ft thick. This dark-gray shale forms the reservoir in a developing shale gas play in the Vermillion Basin of northwest Colorado and southwest Wyoming. Cores were cut in the Baxter Shale in the Hiawatha Deep #5 well at depths of 12,343 to 12,390 ft and 12,951 to 13,005 ft. The cores reveal lithologies ranging from relatively pure, laminated shales to thin (<1 inch), planar to rippled, interbedded very fine sandstones, siltstones, and shales interpreted as hyperpycnal deposits. The laminated shales contain 0.5 to 2% total organic carbon. Burrowing is rare or absent suggesting that most deposition occurred under anoxic conditions on a relatively deep sea floor.

The shale-rich and siltstone-rich intervals both contain quartz (28 to 45%), calcite (6 to 28%), dolomite (4 to 18%), plagioclase (4 to 13%), authigenic pyrite (0.5 to 3.5%), and traces of other minerals. Clay content ranges from 12.8 to 37%, dominated by illite (5-23%) and chlorite (6 to 12%).

Core plugs from shales and siltstones have from 3.6 to 6% measured porosity and crushed-rock pressure-decay permeabilities of 52 to 115 nanodarcies. With such low permeability, natural fractures may play an important role in production. The natural fractures present in the core are of four types: 1) single-stage calcite-filled vertical; 2) single-stage oblique calcite-filled; 3) oblique partially open; and 4) multi-stage (or reactivated) oblique calcite-filled. Healed natural fractures reveal a distinctive "electrical halo" response on the image log that can be tied to healed fractures seen in the core.

Gathering and Analyzing Vertical Permeability Data to Evaluate Horizontal Wells in North San Juan CBM

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Coalbed methane resources have become an important part of the natural gas supply. A large fraction of the gas is adsorbed on internal coal surfaces and pressure must be reduced to produce the gas through the cleats and fractures. Horizontal wells can offer certain advantages in CBM development compared to vertical wells: high initial gas rate, pressure reduction over a larger drainage area and reduced surface impact. However, coal vertical permeability and layer connectivity need to be high enough to ensure the entire coal interval is effectively drained by the horizontal lateral. Gathering data on vertical communication within and/or between coal layers is critical to justify horizontal wells, select an optimal number of horizontal laterals, and choose a completion strategy.

In addition to obtaining formation openhole logs, several wells were tested using wireline formation testers for pressure, permeability, permeability anisotropy, fluid identification, and lateral continuity of barriers to vertical flow. These tools are able to collect a large amount of data at multiple depths thus helping to quantify changes in rock and fluid properties along the wellbore, to define hydraulic flow units, and to understand the reservoir architecture. The use of formation imaging data helps place the tool probes and/or packers at optimum formation and depth locations, thereby reducing risk and operating time, easing interpretation, and maximizing data and sample recovery. This methodology represents a new approach to the evaluation of coalbed methane reservoirs.

Application of the wireline formation tester techniques in the Fruitland coal of the North San Juan Basin in Colorado is illustrated with data acquired in several wells. Formation tester measurements were then incorporated into a numerical simulation model. This model was used to analyze the performance of horizontal versus vertical wells and select optimal drilling and completion strategy depending on CBM reservoir parameters.

The Marriage of Eolian Rock Properties and Deformation of the Nugget Formation; Anschutz Ranch East Field: Northeast Utah and Southwest Wyoming

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The Nugget Formation in the Anschutz Ranch East field, northeast Utah and southwest Wyoming, provides an exceptional example of how eolian rock properties have a considerable influence on the style of structural deformation. Both new and existing subsurface data were integrated for an overall characterization of sedimentologic and diagenetic heterogeneities, which demonstrate relationships with different styles of structural compartmentalization in reservoirs. The Anschutz Ranch East field is a large asymmetric anticlinal trap in the Utah-Wyoming thrust belt. Three cores were analyzed in order to investigate brittle deformation in eolian facies; dune, toe of a dune, and interdune. Selected cores are located along the back limb of the main structure and are nearly perpendicular to the fold axis. Each eolian facies appears to have an associated style of deformation that generally occurs within this tectonic setting. Within the dune facies, deformation bands are the most common style of deformation, unless a fault is present. When faults are present open fractures and breccia occur. In the toe of a dune facies, open fractures are more prevalent; however deformation bands are still very frequent. The primary style of brittle deformation observed in interdune facies is breccias and closed fractures. This relationship between facies and rheology also correlates with porosity. These results support a hypothesis that high porosity rocks tend to be weaker and develop deformation bands, while in low porosity rocks, rock strength is greater and will deform brittlely.

Neoproterozoic Uinta Mountain Group of Kings Peak Quadrangle, Utah: A Marine-Fluvial Interface?

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The Neoproterozoic Uinta Mountain Group (UMG) is a well-known but little studied unit that occupies the core of the Uinta Mountains. Traditionally the UMG has been referred to as “Mesoproterozoic”, but this is incorrect: three samples of siltstone from the lower and middle UMG contain detrital zircons of about 770 Ma (Fanning and Dehler, 2005, GSA National Meeting Abstract, v. 37, no. 7, p. 42).

New 1:24,000 scale mapping in the Kings Peak quadrangle of the High Uintas Wilderness indicates that the central part of the UMG represents a marine shoreline and estuary system sourced from the east. These eastern coarse-grained sandstones represent a rapidly aggrading west-flowing braided river system, containing Mesoproterozoic- and Grenville-aged Laurentian detrital zircons that filled a half-graben south of a boundary fault along the reactivated Cheyenne Belt.

Spectacularly exposed stratigraphic relationships in cirque walls display an incised valley with tens of meters of relief, cut into a marine(?) sandstone of the formation of Deadhorse Pass and filled with onlapping siltstone of the Gilbert Peak shale member. These relationships suggest a shoreface to fluvial plain stratigraphic interface. The <770 Ma age constraint, plus Neoproterozoic microfossil assemblages, supports the ChUMP (Chuar-Uinta Mountain- Pahrump) correlation, which hypothesizes the existence of a Neoproterozoic interior seaway. The UMG contains the eastern fluvial-marine transition into this seaway. These sediments may record brackish geochemical and paleobiological conditions just prior to the Sturtian glaciations. Geologic mapping and stratigraphic analysis are ongoing.

A Review of the U.S. Geological Survey 2002 Geologic Assessment of Resources in the Uinta Basin

Kirschbaum, Mark A.[1], Troy Cook[1], Russell F. Dubiel[1], Thomas M. Finn[1], Paul G. Lillis[1], Edward A. Johnson[1], Ronald C. Johnson[1], Phillip H. Nelson[1], Laura N.R. Roberts[1], Stephen B. Roberts[1] (1) U.S. Geological Survey, Denver, CO

The U.S. Geological Survey (USGS) completed an assessment of the undiscovered oil and gas potential of the Uinta Basin in 2002 as required by the Energy Policy and Conservation Act Amendment of 2000. The assessment was derived from geologically based hypotheses concerning the quantities of oil and gas that have the potential to be added to proved reserves in the U.S. The USGS defined hydrocarbon source rocks, reservoir rocks, and hydrocarbon traps and seals for five Total Petroleum Systems that included seventeen conventional and continuous (unconventional) oil and gas assessment units within the Uinta Basin.

The greatest potential for additional gas was estimated to be within continuous accumulations sourced from marine shale of the Mancos Shale and from coal of the Mesaverde Group. These source rocks are thermally mature, with vitrinite reflectance values exceeding 0.75% Ro in much of the Uinta Basin. Reservoirs are mainly low-permeability Cretaceous and Tertiary fluvial and shoreface sandstones.

Drilling completions in the five years since the assessment include about 1,650 oil and gas wells producing approximately 12 million barrels of oil and 0.4 trillion cubic feet of gas. A high proportion of new gas wells are from the continuous accumulation at Natural Buttes field, an increase predicted in the 2002 assessment.

Multivariate Modeling of 3D9C Data for Constructing a Static Reservoir Model of Algal Mounds in the Paradox Basin, CO

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A 3D9C survey was carried out over a six square mile portion of the Roadrunner and Towaoc Fields on the Ute Mountain Ute reservation in southwestern CO. This survey was jointly funded by the US DOE and the Southern Ute tribe's Red Willow corporation to promote development of Ismay algal mound plays in the Paradox Basin within the Ute Mountain Tribal lands and elsewhere in the Paradox Basin. Multicomponent data was utilized to better delineate the external mound geometry as well as to estimate internal mound reservoir parameters like matrix permeability, saturation and porosity.

Simple cross-plotting of various multicomponent attributes against reservoir properties did not provide the desired predictive accuracy, in part due to sub-optimal frequency content which degraded attributes derived from the shear wave data. However, a multivariate statistical analysis greatly improved the predictive accuracy. These multivariate regressions were then used to prescribe reservoir properties for a static reservoir model, which in turn formed the basis for a dynamic reservoir simulation model of the project area to assess the usefulness of the multivariate relations developed. This poster illustrates the workflow used to carry out the multivariate modeling, key maps of the reservoir properties that were derived, the static model, and results from the dynamic simulation used to assess the usefulness of the approach. Results from wells drilled based on the seismic data are also presented.

The Barnett Shale Play of North Texas - Points to Ponder in 2007

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The Barnett Shale of the Fort Worth Basin is a play with a long history of experimentation, success, and failure. From drilling of the first well in the play in 1981, through April 5, 2007, over 6,500 vertical, deviated, or horizontal Barnett tests or producers have been drilled. Over that time period, vertical wells predominated for 20 years or more, and were then supplanted by horizontal well drilling technology.

Study of public data pertaining to the North Texas Barnett play indicates that there is no simple, one-size-fits-all recipe for success in the Barnett. There are different reasons for Barnett successes and failures in different parts of the play. Technologies used successfully in one area may fail miserably in another. Barnett successes and failures result from the intersection of reservoir quality, well architecture, geohazards, completion, and stimulation processes. Reservoir quality and geohazards vary according to geographic position. Barnett production patterns analyzed using GIS methods show clear evidence of sweet, and not-so-sweet spots. Frac barriers, hydrocarbon liquids, and water all have their effects of Barnett production. Well architecture can be the difference between completing a better or poorer Barnett well. Different well completion and stimulation types have been attempted throughout the history of the Barnett play.

Over time, two technologies have been critical to Barnett success; horizontal drilling and slick water fracturing. Two other technologies that may prove to be beneficial going forward are simultaneous fracturing of horizontal wells, or simo-fracs, and ultra-light weight proppants.

Covenant Oil Field, Central Utah Thrust Belt: Possible Harbinger of Future Discoveries

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After over 50 years of exploration in the central Utah thrust belt, or “Hingeline,” the 2004 discovery of Covenant oil field proved that this region contains the right components (trap, reservoir, seal, source, and migration history) for large accumulations of oil. Covenant has produced over 3 million bbls of oil and no gas from the Jurassic Navajo Sandstone; the field averages 5500 BOPD. The OOIP is estimated at 100 million barrels; the estimated recovery factor is 40 to 50%.

The Covenant trap is an elongate, symmetric, northeast-trending anticline, with nearly 800 ft of structural closure and bounded on the east by a series of splay thrusts in a passive roof duplex. The eolian Navajo Sandstone reservoir is effectively sealed by mudstone and evaporites in the overlying Jurassic Twin Creek Limestone and Arapien Shale. Oil analysis indicates a probable Mississippian source – oil derived and migrated from rocks within the Hingeline region. Cores from the Navajo Sandstone display a variety of eolian facies (dune, interdune, lake/playa, fluvial/wadi), fracturing, and minor faults which, in combination, create reservoir heterogeneity. Reservoir sandstone is 97% frosted quartz grains (bimodal grain size), with some quartz overgrowths and illite. The net reservoir thickness is 424 ft over a 960-ac area. Porosity averages 12%; permeability is ≤100 mD. The drive mechanism is a strong water drive; water saturation is 38%. A thorough understanding of all the components that created Covenant field will determine whether it is a harbinger of additional, large oil discoveries in this vast, under-explored region.

Exploration Frontiers in the Bakken Formation, Montana and North Dakota

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Early exploration provides the framework for the current Bakken play. Numerous studies assessed optimum shale thickness, TOC, and wireline log resistivity relationship to thermal maturation. Maps were constructed showing the aerial distribution of the onset of hydrocarbon generation and areas of intense hydrocarbon generation in the Upper and Lower Bakken shales. Results show the shales range from 28 to 55 ft and are predominantly illite (up to 42%), organic material, silt-and clay-sized quartz, calcite, feldspar, and pyrite. No discernable trends in the major and heavy element geochemistry are observed. TOCs of up to 30% suggests large in place reserves remain ranging from 200 to 415 billion barrels. Bakken exploration has relied heavily on available technology. Formation damage was minimized using slightly under-balanced inverted mud systems. Vertical wells were fracture stimulated, whereas horizontal wells relied on naturally occurring fractures. Horizontal wells in the Upper Bakken Shale wells met with moderate success as the combination of low oil price, improper spacing, and poor EUR's ended the first phase of horizontal Bakken exploration.

Current horizontal wells target the middle member, consisting of a sequence of low porosity, low permeability dolomite, silty dolomite, sandstone, and shale. Wells in the silty dolomite facies in Elm Coulee Field, Montana averaged 500,000 BOPW. The average pay thickness is 10 ft. To date, North Dakota well results are highly variable as drilling and completion practices adjust to account for lithologic variability in the Middle Bakken Member.

Using Alluvial Architecture to Define Stratigraphic Sequences in Foreland Basins, Upper Cretaceous Strata of the Kaiparowits Basin, Utah

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As basin subsidence and eustatic sea level fluctuations each affect the production of accommodation space and can form similar vertical successions for a given locality, tectonic and eustatic models based on interpreted relationships between alluvial architecture and rates of accommodation production have been developed for Upper Cretaceous strata of the Kaiparowits Basin, south-central Utah to try and determine whether or not eustatic and tectonic effects can be differentiated from one another in a foredeep basin setting. These strata comprise three tectonically-generated second-order sequences that record migration of the Western Interior Foredeep axis as the Sevier Thrust Belt approached from the west. Each sequence consists of four parts that demonstrate distinctive styles of alluvial architecture associated with varying rates of basin subsidence and together make up an approximately 2 km-thick succession dominated by nearly continuous fluvial deposition. It is believed that regional distribution patterns defined by these changes in architecture, particularly for the capping unit of each sequence, can be used to distinguish between tectonic and eustatic forcing mechanisms. Such interpretations have significance in determining the placement of sequence boundaries in terrestrial successions of foreland basins.

Enrichment of Organic Carbon and Carbonate in the Upper Cretaceous Niobrara Formation, Western Interior Basin: The Role of Siliciclastic Flux

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The Cretaceous is characterized by intervals of widespread organic carbon enrichment in marine sediments and relatively high sea levels. The Upper Cretaceous is noted for expansive deposits of coccolith-rich sediment that accumulated in deep ocean basins, flooded shelves, and epicontinental seaways to produce calcareous oozes, chalks and marls. Both organic-rich and carbonate-rich marine sediments were deposited in the Western Interior basin of North America during the Late Cretaceous. Although there are many organic-rich units in the Cretaceous offshore section of the Western Interior, there are relatively few that are both organic-rich and carbonate-rich. The Upper Turonian-Lower Campanian Niobrara Formation has the highest average carbonate content of the Cretaceous section and is also one of the most organic-rich. The confluence of high TOC (source rock) and high carbonate content (brittleness) plays a key role in making the Niobrara Fm. an economic gas play. Understanding the controls on and variability in carbonate and TOC may help in the development of better production models for other post-Paleozoic gas shales. In this study, we characterize organic and carbonate content of the Niobrara Fm. and evaluate the primary depositional controls on enrichment. Accumulation rates are also calculated via frequency analysis of rhythmic bedding identified throughout the formation. We also focus on the role of siliciclastic supply as a source of dilution. Siliciclastic flux is evaluated in terms of sediment supply, transport pathways, and depocenters. Mud flux in the offshore is further scrutinized in the context of relative sea level change and multi-millennial changes in climate.

Lithology and Characteristics of the Upper Cretaceous Baxter Shale, Vermillion Basin, Northwest Colorado

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The Coniacean to Campanian Baxter Shale, a stratigraphic equivalent of the Niobrara, Mancos, and Hilliard formations, was deposited in hundreds of feet of water in the Western Interior Seaway about 90 to 85 million years ago. It consists of about 2500 ft of dominantly siliceous, illitic, and calcareous shales that contain regionally correlative coarsening-upward sequences of quartz- and carbonate-rich siltstones several tens of feet thick. Planktonic foraminifers and chalk-rich copepod fecal pellets are locally common in the shales between the siltstones.

Bioturbation ranges from non-existent to minor in most of the Baxter, suggesting anoxic bottom conditions. The siltstones range in thickness from a single layer of grains to ~3 cm. The thinnest planar siltstone beds represent dominantly hypopycnal flow whereas thicker beds contain ripple laminae and were deposited by bottom currents. Total organic carbon content ranges from 0.5 to 2% in the shales and from 0.25 to 0.75% in the siltstones. Measured porosities in both shales and siltstones range from 3 to 6% with matrix permeabilities of 100 to 1500 nanodarcies.

In the Vermillion Basin at depths >10,000 ft, the Baxter Shale has vitrinite reflectance values approaching 2.0% and is in the gas generation window. The 2500 ft of shale between the Blair and Frontier sandstones is overpressured with gradients ranging from 0.6 to 0.8 psi/ft. Fracture stimulation of the gas-bearing Baxter with up to 10 stages averaging about 300 ft thick allows vertical wells to be completed with IPs of 1 to 3 MMCFGPD, but one recent well was completed for >9 MMCFGPD. Production is commonly commingled with that from the underlying Frontier and Dakota sandstones. Baxter production comes mainly from silt-rich intervals and naturally fractured shales after hydraulic fracture stimulation, although most of the natural fractures are filled with calcite.

Use of Cores and Image Logs to Interpret Depositional Environments of Sandstones in the Dakota Group at South Baxter Field, Sweetwater County, Wyoming

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The Lower Cretaceous Dakota Group is 230 ft thick in the area of South Baxter Field, southwestern Wyoming and was continuously cored in the South Baxter #27. The unconformable contacts with the underlying Jurassic Morrison Formation and the overlying mid-Cretaceous Mowry Shale were recovered in the core along with three sandstone packages that form important reservoirs in the field. Additionally, high-resolution image logs reveal a variety of features in the sandstones including crossbed dip angle and direction, root structures, scour surfaces, pyrite nodules, shale rip-up clasts, and natural and induced fractures.

The sandstone package at the base of the Dakota is 21 ft thick and is composed of medium- to fine-grained chertarenites in a fining-upward fluvial channel deposit. Porosity ranges from 16 to 28%. Measured oil saturations were only 7 to 25% and low resistivities of 3 to 10 ohm-m indicate the interval is water bearing.

A sandstone package about 40 ft thick in the middle Dakota consists of stacked fining-upward fluvial channel sands, each about 5 to 10 ft thick. These sandstones are medium- to very fine-grained with more quartz grains (~80 to 90%) and less chert (5-7%) than the basal sandstone. Porosity ranged from 11 to 26% but low resistivities suggest this interval is water bearing.

The sandstone package capping the Dakota is 43 ft thick with a 10-ft-thick fining-upward fluvial package at the base overlain by 33 ft of sandstone composed of 6- to 8-ft-thick amalgamated parasequences. These sandstones are very fine- to medium-grained cherty sublitharenites. As with the other sandstones, vector plots generated for this interval from the image log suggest a generally northerly sand transport direction off the ancestral Uinta Mountains. There is a sharp contact between this blocky sandstone and the overlying organic-rich deep marine shale of the Mowry.

Fracture Distributions in the Tensleep-Equivalent Casper Sandstone at Flat Top Anticline, Wyoming: Implications for Reservoirs

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Natural fractures and fracture corridors are pervasive within the Tensleep-equivalent Casper sandstones that crop out at Flat Top Anticline, six miles north of Medicine Bow in southeastern Wyoming. The pattern of oil-staining in the sandstones is not influenced by the distribution of fractures, but ornamentation and the sequence of fracture-face coatings, consisting of both mineralization and micro-gouge, suggest extension fractures that were commonly reactivated in shear to create low-permeability planes. Less oil is present in the reduced pore space immediately adjacent to the sheared fractures, and such features would compartmentalize and control flow patterns in similar reservoirs. The fracture system includes an older fracture set that strikes NNE-SSE, oblique to the ENE-WSW axis of the anticline, and a younger fracture set that is nearly parallel to that axis. Fracture strikes and spacings vary with position around the anticline. More widely spaced fracture swarms mark fault zones that trend sub-parallel to the older set of fractures. The two-set fracture system was the compound response of poorly cemented Casper strata to initiation and growth of the anticline near the toe of the hanging wall of a thrust fault. NNE-directed horizontal compression (oblique to the present anticlinal axis) caused initial uplift and the older set of extension fractures; extension during folding formed the younger set of fractures parallel to the hinge of the fold. Both sets of fractures were sheared during continued NNE translation of the thrust plate. Initial anhydrite fracture cementation has converted to calcite in the near-surface environment.

Preventing Proppant Flowback from Stimulated Zones

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Post stimulation proppant flowback has been a major issue in both conventional and unconventional reservoirs. In coalbed methane (CBM) wells that are on pumps this could lead to wellbore downtimes as the pumps can get sanded off. This is very costly as not only the operator is losing production but also replacing the pumps repeatedly can be expensive. The solution to this uncontrolled sand production is to clean the well with a workover rig; identify the zone (or zones) from which the sand is being produced, isolate the zone (or zones) and pump a remedial proppant flowback control treatment. This proprietary low viscosity proppant consolidation treatment can be pumped via either jointed tubing or coil-tubing technology, regardless of interval length or number of intervals, without affecting or reducing the conductivity of the proppant pack. It coats the individual grains of proppant and locks them in place.

Ten wells (8 CBM) with different downhole conditions in the San Juan and Raton basins, where frac sand production was a major problem, were treated with this technology and in all of them proppant flowback stopped. This study will discuss the criteria for identifying candidates; optimal placement; lessons learned and the successful results from these 10 treatments.

Geo-Steering Horizontal Wells: Case Studies Demonstrate the Value of Fuzzy Logic Directional Steering Guidance

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The success of horizontal drilling in Cretaceous reservoirs is initiating many new development programs throughout the Rocky Mountain basins. The productive zones are often thin, and the ultimate performance of a well is usually dependant upon the number of feet through which the lateral wellbore travels through the zone.

Geo-steering a horizontal well in real-time is geological interpretation at its most stressful. The objective of geo-steering interpretation is to describe the stratigraphic location of the wellbore as drilling progresses. This task is complex because the known 3-dimensional curving wellbore must be resolved with the unknown 3-dimensional curving and often faulted reservoir. Modern geo-steering requires depth-accurate formation evaluation measurements acquired with Logging While Drilling (LWD) tools. The most common such tool measurement in the Rocky Mountains is gamma ray. Modern geo-steering involves correlating LWD signal data with a type log to discern the stratigraphic location of the wellbore.

Software that performs the mathematics necessary for geo-steering has been available for many years, but there are new techniques that take the interpretation to a new level. Technical Hole Deviation (THD) is the mathematical unification of planned versus actual directional well paths. THD quantifies how a directional well path differs from its planned trajectory, and provides much greater detail than is supplied by the directional company. When THD data are combined with the geo-steering interpretation through Fuzzy Logic processing, genuine steering guidance is provided. The benefits of this additional insight have been recognized in several recent wells.

Anatomy of a Tight Gas Sand: Upper Lance Core from Pinedale Field, Green River Basin, Sublette County, Wyoming

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Upper Cretaceous Lance and Upper Mesaverde sandstones are the major producing intervals in Pinedale field. Gas is produced from stacked fluvial sandstones and siltstones. The productive interval in the Lance Formation is approximately 4000 ft thick; the productive interval in the Upper Mesaverde is about 1200 ft thick. The Lance Formation lies below the arkosic sandstones of the lower Fort Union Formation and above the sublitharenite sandstones of the Mesaverde Group.

The upper Lance was cored from 9010 to 9130 ft in the Mesa 4CB-20D well. The shallower part of the core penetrated approximately 60 ft of stacked fluvial channels containing mud rip-up clasts, massive to cross-stratified, very fine- to medium-grained chertarenite sandstones, and flakes of organic material. The deeper part of the core contains a mix of overbank mudstones and siltstones, crevasse splay deposits, and floodplain shales.

Lance sandstones are composed of 79-86% quartz, 0-4% feldspar, 3-6% carbonate, and 6-14% clay minerals, mainly illite and chlorite. Rock fragments are dominantly chert and carbonate clasts derived from Upper Paleozoic deposits. Plutonic, volcanic, and metamorphic rock fragments are absent, which indicates that Precambrian basement rocks were not exposed in the source terrain during Lance deposition.

Measured core porosities in the sandstones range from 3.1 to 12% and average 7.4%. Klinkenberg permeabilities in the sandstones range from 0.001 to 0.094 md with a median value of 0.01 md. Measured gas saturations in the sandstones range from 1.4 to 63.7% and average 41.4%. Sandstones in the cored interval were perforated and hydraulic fracture stimulated and contribute to the well's initial production of 9,577 MCFGPD.

Outcrop-to-Subsurface Correlation of the Blackhawk Formation, Uinta Basin: Sequence Framework, Shoreline Trends, and Gas Production

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Whereas superb outcrops of the early Campanian Blackhawk Formation along the Book Cliffs in eastern Utah have been the topic of over 100 papers, little has been published on distribution of the Blackhawk in the subsurface to the north and northeast. Dense well spacing in Natural Buttes Field of the eastern Uinta Basin, combined with recent exploration drilling in the western Uinta Basin, provide dip and strike control on the subsurface configuration. Depositional patterns and chronostratigraphic relationships identified from outcrop tie directly to well logs.

Members of the Blackhawk - Spring Canyon, Aberdeen, Kenilworth, Sunnyside, Grassy, and Desert - represent 4th-order sequences. Their paleogeographic distributions and parasequence stacking patterns reflect changes in accommodation and sediment supply. During early Blackhawk time, accommodation was constantly increasing, albeit at varying rates. The Spring Canyon and Aberdeen members thus display progradational to retrogradational stacking of shoreface and coastal-plain deposits. During late Blackhawk time, accommodation continued increasing, though at an ever-slowing rate that was periodically punctuated by decreasing accommodation. Consequently, the Kenilworth, Sunnyside, Grassy, and Desert members display progradational to retrogradational parasequence sets separated by one or more high-frequency sequence boundaries. In addition, shoreline trends rotated to the north-northeast, contrary to some published projections.

The subsurface framework promotes understanding of the controls on Blackhawk gas production. To date, greatest production comes from distal parts of the upper two parasequences of the Grassy Member in the Natural Buttes area. Fluvial-to-shoreface parasequences of the Sunnyside, Kenilworth, and Aberdeen members have produced gas at lesser rates in the central and western Uinta basin.

Using Core Data to Develop and Calibrate Petrophysical Models in Tight Gas Sands

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Rocky Mountain tight gas sand reservoirs typically have complex mineralogy in the reservoir rock in the form of sandstone, mica, feldspars, and carbonates. Moreover shale is often some combination of the clays illite, smectite, kaolinite, and chlorite. The measured signal from most logging tools originates from the rock matrix, which in the case of these tight gas sands is often both complex and poorly defined.

Selective coring and core analysis can be used to understand various tool log responses in order to develop and calibrate petrophysical models. However this requires rigorous planning that ranges from 1) specifying core bit and mud type, to 2) shipping, plugging and preserving core, to 3) specifying what conventional and special core analysis is to be performed. This protocol is particularly important in tight gas sand core analysis because some analysis needs to be done at native state conditions while conventional core analysis can be done at restored state (after the core is cleaned and dried).

With a selected logging suite and proper core analysis, evaluation of complex tight gas sandstone reservoirs can be accomplished. Examples will be shown how core analysis techniques ranging from tritiated mud, analysis at multiple net confining stresses, NMR, capillary pressure, mercury injection, XRD, and SEM can be used in the generation of an integrated petrophysical model.

Core Analysis Issues in Tight Gas Reservoirs

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Increased focus in tight gas reservoirs has stirred a debate concerning potential uncertainties in determining gas in place and recoverable gas. There are questions concerning the reliability (accuracy and reproducibility) and applicability of routine and special core analysis measurements to the in-situ rock. Small pore volume and the low flow capacity make these rocks particularly sensitive to measurement errors and make it difficult to reproduce in-situ conditions. A survey of some recent literature provides a glimpse at the state of the art in low permeability core analysis procedures. Recently, it has been shown that the most commonly used unsteady-state technique over estimates permeability. The differences are most significant for permeability less than 0.01 md. Legacy data for rocks with permeability of less than 0.01 md will be biased high, potentially by up to an order of magnitude. Multiphase permeability measurements show a wide variability of permeability reduction with changes in wetting phase saturation. Modeled gas recovery varies by more than 30 percent based on these data. Differences in irreducible water saturation from capillary pressure curves exist depending on test method. Uncorrected high-pressure mercury injection data often inaccurately characterizes capillary pressures at irreducible water saturation. Formation water salinity can show significant variability (+/- an order of magnitude) when reconstructed from a Dean Stark analysis. Water resistivity and saturation in core is difficult to measure in rocks with low total pore volume. Archie saturation exponent can vary depending on analysis technique. Single point versus multipoint resistivity index measurements and test duration can have a large effect on saturation exponent. These tests can take weeks/months instead of days to become stable. The prudent evaluation of low permeability rocks worldwide requires the ability to understand and limit these and other sources of petrophysical uncertainty.

Design and Execution of Horizontal Wells in Gas Shales Using Borehole Images and Geochemically-Enhanced Formation Evaluation

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Horizontal drilling is a key technology used worldwide in conventional and unconventional reservoirs to maximize and speed the recovery of hydrocarbons. Most conventional reservoirs within the United States have been exploited, and the focus is now on the development of unconventional plays. Organic shales, the hydrocarbon source for conventional reservoirs, have become a viable target resource for gas. The poor reservoir characteristics of shales make them ideal candidates for horizontal drilling development. This paper will focus on new technologies and strategies for horizontal well placement within gas shales.

These projects require interaction between geologists, engineers, and petrophysicists to develop an integrated approach to the design and execution of horizontal wells. Key reservoir parameters and evaluation packages have been established for gas shale deposits.

Borehole images and geochemical data have become the standard evaluation technique for gas shales. Geochemical logs provide a gamma-ray-independent clay content and a matrix density that corrects for the complex lithology of shales. These data are used along with borehole images to identify shale layers with the optimal mineralogy for reservoir performance and drillability. Borehole images allow one to identify and define the orientation of bedding, drilling-induced and natural fractures, and faults. These data are used to determine the drilling azimuth and inclination angle for the horizontal well.

These techniques have been successfully applied to many horizontal wells within the continental United States. Several examples will be presented. Sharing new technologies and strategies for horizontal well employment should allow operators to become more successful in these ventures.

Core Interpretation Allows a New Perspective on Tensleep Sandstone Correlations at Teapot Dome Field, Natrona Co., Wyoming

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Interpretation of core from the Pennsylvanian-Permian Tensleep and Permian Goose Egg Formations has resulted in an upgraded stratigraphic hierarchy at Teapot Dome. In well 48-X-28, 353 ft of core were analyzed and carefully interpreted, including thin section work. The coring project provides data on the sealing character of the overlying Goose Egg rocks, and vertical and horizontal permeability heterogeneities in Tensleep sandstone units. The basal Opeche sandstone of the Goose Egg contains dead oil and is partially fluvial in origin. Its lower contact is a major unconformity on the Tensleep "A sandstone." At Teapot Dome and elsewhere, the Opeche sandstone is often miss-correlated with the Tensleep A sandstone. Core and formation imaging logs have allowed more effective top and base definitions and facies correlations. Some traditional Tensleep units, such as the "B Dolomite", have been redefined to correlate with sequence boundaries. Tensleep outcrops confirm the repetitive nature of sequences. A typical sequence consists of cross-bedded eolian dunes eroded during a marine advance, and then overlain by marine dolostones, algal mats, and dolomitic marine sandstones. Subareally exposed marine units (exposure surfaces) suggest lowstand sequence boundaries. Overlying the marine units are dune and interdune sandstones. Tensleep sequence boundaries defined by log character can be correlated among other wells within the western Powder River Basin region.

Characterizing Unconventional Reservoirs: an Informal Mudstone and Shale Classification Based on Core

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Reservoir characteristics of shales and mudstones are strongly influenced by the three parameters: 1) depositional mineralogy, 2) organic content and maturity, and 3) matrix composition. These parameters also affect log response and mechanical properties. A suite of analytical methods developed to measure these parameters has led to an informal classification of shales and mudstones based on core measurements. This ‘shale toolkit' ideally includes core description and geology, thin section petrology, X-ray diffraction, scanning electron microscopy, and geochemistry. With data thus gathered, a three-layered classification of shales and mudstones is possible. Layer one, depositional mineralogy, considers the ratio of different sized detrital materials, and mimics in concept most traditional classification schemes for fine-grained clastic rocks. Layer two considers organic content as an essential component, and characterizes its abundance, source and thermal history. Layer three characterizes the composition of the shale or mudstone matrix, that is, material less than 4 microns (clay). In general, observations identify three common matrix mineralogies resulting from a combination of original (depositional) and diagenetic elements. Siliceous mudstones, argillaceous mudstones, and calcareous/dolomitic mudstones form major subdivisions of matrix composition; several intermediate and variant compositions are also important.

Enhanced Oil Recovery Potential in the Uinta Basin, Utah

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The Eocene Green River Formation is a major oil producer in the Uinta Basin. Currently, water flooding is the only enhanced oil recovery (EOR) technique being used in the basin. The Red Wash/ Wonsits Valley and the Greater Monument Butte fields produce from the Green River Formation and are currently in water flood. Red Wash discovered in 1951, has an estimated ultimate recovery (EUR) of 106 MMBO, neighboring Wonsits Valley discovered in 1962, has an EUR of 48 MMBO, and Monument Butte, discovered in 1981, is still being developed. The three fields were developed on 40 acre-spacing. In the Monument Butte Northeast unit (part of the Monument Butte field) the density of the well spacing was increased from 40-acre spacing to 20-acre (a 40-acre five-spot pattern). The greater well density is expected to increase the EUR from 8 % of original oil in place to 12 %.

Chevron, in the 1980s, attempted pilot CO2 floods at two locations in Wonsits Valley field and two locations in Red Wash field. The Red Wash locations had almost immediate breakthrough of CO2. Work on the CO2 floods was stopped due to the poor results at Red Wash and declining oil prices. The University of Utah is conducting a numerical simulation model for the Glen Bench field (a step out from Wonsits Valley field) and the Monument Butte Northeast unit to determine the potential increased recovery if the fields convert to CO2 flood, most likely a water alternating gas flood.

EOR has not been attempted in the Cedar Rim/Altamont/ Bluebell fields. This area is significantly deeper, has highly fractured reservoirs, and mostly does not have the well spacing density needed for conventional EOR. There is a tremendous volume of oil being left behind in this field complex that may require some innovative and unconventional EOR techniques.

The Jurassic Navajo Sandstone as a Partitioned (?) Subsurface Reservoir: Comparing Reservoir Characteristics and Facies Between San Rafael Swell Outcrop and Covenant Field Core, Utah

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Reservoir characterization and facies analysis of outcrop and core from the Jurassic Navajo Sandstone in east-central Utah indicate that impermeable barriers can divide the Navajo into upper and lower flow units. In outcrop on the west flank of the San Rafael Swell, the lower Navajo (50+ m) is heterogeneous and contains five different interdune facies that are interbedded with dune facies. Average porosity and permeability of interdune facies are relatively low and their lateral extent is variable, ranging from tens to thousands of meters. Thus, the lower part of the Navajo would contain numerous baffles to fluid flow and serve as a lower quality reservoir in the subsurface. The upper Navajo section (200 m) is dominated by dune facies with relatively few interdune baffles, which are thin and "leaky." Hence, the upper Navajo should serve as a very high quality reservoir. The lower and upper Navajo are separated by an algal-influenced interdune unit that has very low permeability (average of 0.265 mD) and extends for several kilometers. Thus, in an oil field that has tight structural closure, this facies could act as a barrier to fluid flow and partition the Navajo into two distinct flow units.

Core from the Covenant field can also be divided into lower and upper Navajo units, which are both dominated by dune facies making high quality subsurface reservoirs. Ten meters of apparently tidal-influenced mudrocks separate these units, creating a barrier to fluid flow that potentially partitions the reservoir.

Central Utah Thrust Belt-Hingeline: This New Oil and Gas Province Has Enormous Potential

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The Wolverine Gas and Oil central Utah thrust belt-hingeline oil discovery made on May 3, 2004, opened a new and very large oil and gas exploration-production province. It ranges from the north near Pineview field 160 miles to Cedar City, Utah on the south. It is bounded on the east by thrusted sediments near Highway 89, then extends westward perhaps 50 miles to the central Delta desert area. The play is presently defined by at least ten producing wells, 120 dry holes, numerous thrusted outcrops of Mesozoic and older rocks, older and recent seismic, magnetic, and gravity data plus surface hydrocarbon seeps and satellite-defined hydrocarbon microseepage anomalies. The Jurassic Navajo Sandstone, always recognized as a world class 1,200 foot thick potential hydrocarbon reservoir, did not disappoint when Wolverine's KMR 17-1 well flowed 708 barrels of 40 gravity, water-driven, low-sulfur oil. Shallower Jurassic Twin Creek limestone is apparently productive, but not yet developed.

However, there were some surprises: (1) The Navajo Sandstone was 1,320 feet higher than mapped, (2) The production was oil, not gas, (3) Two Navajo Sandstones were present, and (4) Oil sourced from Paleozoic rocks was, at least in part, remigrated. We predict at least 30 structural anomalies will be drilled after several massive 3-D group and company seismic programs are completed along the four major, east vergent thrusts and a west vergent Laramide back thrust. Paleozoic reservoir rocks may eventually provide more reserves than Mesozioc rocks. Cretaceous and Permian shales may be significant source rocks. Recoverable reserves may exceed several billion barrels of oil and several tens of trillion cubic feet of gas.

Paleogeography, Climate and the Carbon Cycle of the Mid-Neoproterozoic Red Pine Shale, Uinta Mountains, Northeastern Utah

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The Red Pine Shale, Uinta Mountain Group, northeastern Utah, is an organic-rich sedimentary succession that records information on depositional environments, paleogeography, carbon cycling, and climate of northeastern Utah during Neoproterozoic time. Data suggests deposition in a marine deltaic system open to the west and south with at least two sediment sources. The carbon-isotope record shows a fluctuating carbon cycle that may indicate changes in regional climate. Six measured sections were described for facies analysis and sampled for carbon isotope and TOC analyses, and sandstone petrography. Five facies were identified including: shale, shale-and-sandstone, sandstone, slump-fold, and concretion facies. The shale facies represents a prodelta environment, the shale-and-sandstone facies represents the distal delta front, and the sandstone facies represents the delta front to delta plain. The slump-fold facies represents a proximal prodelta. The concretion facies also represents a prodelta setting and contains vase-shaped microfossils, a mid-Neoproterozoic (ca. 750 Ma) index fossil. Four measured sections in the southern range were correlated using marker beds. Using these correlations, a better understanding of facies architecture will be possible. A minimum thickness of exposed Red Pine Shale in this area is measured to 880m, and local mapping suggests a thickness of ~1200 m. C-isotope values range from -27.10 to -16.91 PDB (~20 m sample spacing) and display anomalies that have potential to be used as fingerprints for correlations, as well as for potential climate proxies. Preliminary TOC values are up to 5.91 weight percent. A higher resolution curve (~3 m sample spacing) is in progress.

Lost Circulation and Fractures in Wamsutter, WY

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Circulation losses are the biggest source of non-production drilling delays in Wamsutter, resulting in 426 days of downtime over 2001 to 2005 or roughly ten million dollars in wells costs. Analysis of these wells suggests that fractures play a large role. Wells experiencing circulation losses align spatially with field-wide directions of natural stress and are concentrated along sparsely distributed trends, suggesting that they could be related to regional faults/fractures. These wells take less pressure to induce fracturing during completions, indicating that they are inherently weaker. They also have lower rates of initial production, perhaps from depletion via fracture conduits. In comparison to wells which experienced no losses, the difference in pressure required to induce fractures is directly proportional to rock quality. Geologically, loss wells are restricted to only part of the Wamsutter field, underlying the northeast corner of the Washakie Basin, shown from drill stem tests to have high values of hydraulic head at reservoir depths. In total, these factors suggest that loss wells occur an area with significant over-pressures and containing fractures and faults, causing lost circulation problems while drilling. Normally pressured weaker rock at shallow depths is exposed to higher mud weights to combat overpressures and then fractures, providing a pathway for drilling mud to flow. Fortunately, the spatial distribution of fracture and fault trends allows the prediction of which wells might experience lost circulation. Analysis from wells drilled in 2007 show this method to be quite successful.

Gas and Water Production in the Wind River Basin, Wyoming

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We examine gas and water production from low-permeability reservoirs in the Wind River Basin, where water is commonly produced from most gas fields. Plots of gas production, water production, and water-gas ratio illustrate the variability of fluid production within fields (time dependence). Representative daily rates derived from these plots permit field-to-field comparisons (spatial dependence).

As an example of time dependence, plots of gas and water production from overpressured sandstones in the Upper Cretaceous Cody Shale in the Madden area show that water is produced from all intervals and that water production commences with gas production. Gas production usually decreases with time, but in some cases remains unchanged (within a factor of two) for as long as 13 years. In 11 cases of decreasing gas production with time, water decreases with time in 6 cases, remains unchanged in 3 cases or increases in 2 cases. The water-gas ratio increases, decreases, or remains unchanged with time, with no apparent dependence upon gas or water behavior. In brief, gas production rate, water production rate, and water-gas ratio over time are highly variable among wells and among production zones.

To examine spatial dependence, average daily fluid production rates after two years of production are plotted on log-log plots of water and gas rates for a number of fields in the basin. Gas and water rates vary by more than ten-fold from well to well within fields. In five "tight" gas fields, gas production ranges from 300 to 10,000 mcf/day, water production ranges from 1 to 100 barrels per day, and the water-gas ratio ranges from 1 to 30 barrels per mmcf. The water-gas ratio does not appear to depend upon thermal maturity.

Pore Throats and Pore Pressure: Pushing Gas into Small Spaces

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Data from tight-gas reservoirs indicate that gas has invaded pore space with apertures less than one micrometer. How did sub-micron pore space become charged with gas? I review published investigations of low-permeability, tight-gas rocks and consider the pressures required to displace water with gas. In evaluating the initial gas charge, pore-throat size is the key parameter, not permeability.

Siliciclastic rocks can be characterized in terms of their pore-throat-size distributions, which are commonly measured with mercury injection. In very fine and fine-grained sandstones, grain size ranges from 62 to 250 micrometers (µm); corresponding pore-throat sizes measured in one sample set range from 3 to 30 µm. However, in low-permeability tight-gas sandstones, pore-throat sizes are considerably smaller, ranging from 0.03 to 1 µm (for comparison, 0.5 µm is the smallest size of clay particles defined on the sedimentological phi scale). The distribution of pore-throat sizes in shales extends to less than 0.01 ìm.

Gas first entering the pore space must overcome capillary pressure, which is inversely proportional to pore-throat size. Gas-water interfacial tension is a function of pressure and temperature. At the temperature and pressure conditions of maximum burial depth of 13,000 feet for the base of the Mesaverde Group in the Piceance Basin, a pore-throat size of 1.0 (0.1) ìm requires gas pressure of roughly 20 (200) psi to displace water. Capillary pressure data from the fluvial section of the Mesaverde Group show that water saturations would be reduced to less than 60 percent by gas pressure of 300 psi, a value considerably less than the present-day overpressure of approximately 3,000 psi at the base of the Mesaverde. Consequently, gas charging is attributed to conditions at maximum burial.

Diagenetic Coloration Patterns in the Jurassic Navajo Sandstone of Zion National Park, Utah

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Coloration patterns in the Jurassic Navajo Sandstone of Zion National Park are examined using geospatial, petrographic and geochemical analysis. In the northern Kolob Plateau, the Navajo Sandstone is dominantly red colored with a uniform pigmentation resulting from thin, iron oxide grain coatings. These grain coatings formed during early diagenesis to produce the "primary" sandstone color.

In contrast, Navajo Sandstone of the main Zion Canyon was previously divided into three informal subunits: white (upper), pink (middle), and brown (lower). Analysis of these subunits indicates a more complex diagenetic history than previous interpretations suggested, with multiple episodes of iron oxide depletion (bleaching) and enrichment (cement precipitation). The white and pink subunits are characterized by a combination of prevalent bleaching, areas of remnant primary sandstone, small concretionary lenses and brightly colored, secondary mineralization. The brown subunit represents a separate episode of iron oxide enrichment and is characterized by widespread dark spotty cement concentrations. The upper contact of this brown subunit is regionally extensive as a subhorizontal surface. In Zion Canyon, a narrow zone (~10 m) of concentrated bleaching occurs immediately above the brown subunit.

Widespread bleaching in the upper Navajo Sandstone ends abruptly in the Kolob Plateau, but narrow, well-defined bleaching bands locally follow high-permeability units in the lower Navajo Sandstone throughout the central park and into the Kolob Plateau. These narrow bands indicate horizontal movement of fluids. Multiple episodes of subsurface fluid movement on both regional and local scales contributed to the distinctive coloration variations of Zion National Park.

Natural Fracture Quantification for Optimized Completion Decisions

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Natural fracture enhanced formations are one of the key parameters for commercial production from many of the unconventional gas reservoirs in North America. Natural fractures can enhance system permeabilities one to two orders of magnitude over matrix permeabilities, and enable economic production from unconventional sources. However these natural fracture systems can be very prone to damage from cementing and fracturing fluids, which can cause completion difficulties and greatly temper the productive potential from these wellbores.

This paper presents a process for quantifying the natural fracture azimuth and porosity through fracture characterization logs, and uses this information to optimize the cementing and fracturing systems in order to minimize invasion damage and maximize the productive potential of these natural fracture systems. A customized natural fracture leakoff control package based on specific characterization of the natural fracture systems and properties can greatly reduce both the frac fluid invasion damage as well as decrease near wellbore frac gradient increases due to poroelastic leakoff effects. The result is naturally fractured reservoirs that can come much closer to their full productive potential with less secondary damage and near wellbore flow constrictions. In this paper we present example applications from the Piceance basin and the Greater Green River basin, presenting production data, fracture analysis as well as micro seismic evaluation.

Collaboration Across all Domains for Optimized Unconventional Resource Development Programs

Oren, KC[1] (1) Landmark, Denver, CO

The development of unconventional resources prior to the end of the last century was overlooked for many reasons – most of which were due to lack of understanding of these complex and challenging reservoirs along with the lack of mainstream technologies necessary to develop them. Now, with the arrival of what have become widely available advanced drilling systems, as well as quickly evolving innovations in completions practices, the exploitation of unconventional resources has moved to the forefront with promises of significant contributions to worldwide oil and gas supplies.

Collaboration among the geoscientists and reservoir engineers has been critical in understanding these complex reservoirs and enabling recent breakthroughs allowing these unconventional resources to be developed. But often overlooked is the key role that the drilling and evaluation domains have brought into the mix to enhance overall resource production while reducing drilling, completions and operating costs.

This paper will detail one workflow where an earth model developed by integrated geosciences and engineering teams is used to design an unconventional greenfields development project. By working in a collaborative environment, the team can quickly optimize reservoir target positioning, work through different surface location scenarios and minimize costs while avoiding various “hazards” including sensitive environmental areas and restricted surface owner's off-limits locations.

Once the targets and surface pad locations are defined, then individual wellbore designs can be considered further reducing the drilling and completions costs and maximizing the design integrity of the overall field development program.

Optional: The paper will then discuss how continued collaboration throughout the implementation phase of the drilling and completions program can enhance definition of the earth model and enable near real-time re-design – “on-the-fly” – of the field development plan. Team collaboration environments and report-time planning processes will be highlighted.

Another Look at Hartzog Draw Stratigraphy, Powder River Basin, WY

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Hartzog Draw, a large oil and gas field, within the Powder River Basin, Wyoming, produces from the Campanian Shannon Sandstone. The Shannon has been the focus of numerous papers and much oral debate, yet there is little consensus regarding its origin and depositional setting. Furthermore, the current operator within Hartzog Draw has encountered difficulties with water flooding the Shannon. Although the water floods appear successful at first, before too long the reservoir abruptly ceases to accept further flooding, and this could indicate a lack of understanding of the Shannon Sandstone's stratigraphy in Hartzog Draw.

A new data set of over 50 cores from Hartzog Draw has been made available and it allows us to closer examine the reservoir's stratigraphy and its possible subtleties that could be causing unsuccessful water flooding. We performed detailed descriptions of these cores, created cross sections across the length and width of the Hartzog Draw and studied samples of the Shannon Sandstone in thin section. Throughout the study particular attention was paid to possible attributes that could cause a cessation of water intake such as barriers causing compartmentalization and the presence of expansive clays. We believe that these descriptions could help current oil and gas producers to better understand the nature of the reservoir's architecture and overcome current complications. In addition to helping overcome present production complications, we believe that our new insight into the detailed stratigraphy of the Shannon Sandstone can be applied to better understanding the long-debated history of its deposition and preservation.

Effectiveness of Horizontal Wells in Coalbed Methane Plays

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This topic addresses how wellbore damage (skin) and horizontal well geometry can affect production from horizontal CBM wells.

Based on field performance from several basins, horizontal wells often give more than 4 times greater gas production than vertical wells. This result depends strongly on near-wellbore damage (i.e., positive skin factor), but the effective skin in a horizontal well is moderated by the well geometry. Sources of positive skin are reviewed.

As well as skin factor, horizontal/vertical gas production depends on diameter, length, permeability, and seam thicknesses accessed by both horizontal and vertical wells. We will report on a study of these factors, and which have the most influence, using a pseudo-steady-state model.

The impact of wellbore flow effects, including friction pressure, hydrostatic pressure, and multiphase flow, when coupled with wellbore geometry was also examined. This model predicts that small wellbore diameters and small build radii give better production at lower reservoir pressures, and gives quantitative differences in gas rates. Also we show that undulations and down dip wells can reduce production substantially. This means longer horizontal wells can lose their production advantage at low reservoir pressure.

Finally, smaller wellbore diameters are stronger, and therefore more stable during drilling and production, and we demonstrate how this translates to safe operating conditions (i.e., without wellbore collapse and fines production). The use of liners is suggested whenever possible, to avoid loss of effective length in the event of well collapse.

Sweet Spot Localization of Production from Fractured Shales

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Definition of intervals that qualify as good shale gas or oil targets are determined by laboratory analyses, but where to drill the high-graded candidates and recover economic hydrocarbons relies more upon mapping, and on an understanding of fracture distribution. It appears from existing production that Rocky Mountain fractured shale production bears a relationship to either major wrench faults, or the intersections of these and more localized fault systems, and thus zones of more intense fracturing.

Interpretations of filtered aeromagnetic data readily illustrate faulting, and thus the potential for extensive fracturing in fields that produce from Cretaceous shales, the Williston basin Bakken Shale, and Pennsylvanian shales of the Paradox basin, where prolific production from the Cane Creek Shale lies along a prominent N-NE oriented fault.

The Puerto Chiquito Field in the San Juan Basin has produced over 25 MMBO from the Niobrara Formation along a N-S system of faults. The field appears to be limited in extent by NE oriented shear zones. Numerous other fractured shale fields in the San Juan, Powder River Basin (Mowry Shale), and other basins bear similar relationships.

Bakken production in the Williston Basin is associated with rejuvenated regional wrench faults. The thick dolomite of the Bakken middle member in Richland Co., Montana that sets up the 100 MMB Elm Coulee Field follows a set of NW oriented regional faults. Likewise numerous rapid changes in isopach trends and thickness occur along major regional faults. Other excellent production from the Bakken, such as EOG's Parshall Field on the east side of the basin, occurs along a major NE oriented fault system.

Petrographic Analysis of Campanian Sandstones, Kaiparowits Formation, South-central Utah

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A Petrographic analysis of fluvially-deposited sandstones from the Kaiparowits Formation of south-central Utah shows an abrupt increase in the relative abundance of feldspar and lithic fragments at approximately 70 meters from its base. This compositional change is likely due to the introduction of new sediment source areas as the Sevier Thrust Belt advanced from the west. The compositional transition appears to also coincide with a change in alluvial architecture associated with rapid basin subsidence in front of the advancing Sevier Thrust Belt. Petrographic data suggest that these sandstones are genetically related to fluvially deposited Upper Cretaceous sandstones of the Mesaverde Group exposed in the Book Cliffs and Price Canyon of eastern Utah, where Lawton (1983, 1986) observed a similar vertical petrofacies change from quartz-rich sandstones in the Bluecastle Tongue of the Castlegate Sandstone to orthoclase- and lithic-rich sandstones in the Farrer Formation. Petrographic data obtained in this study, along with paleodrainage data and the correlation of changes in alluvial architecture within the Kaiparowits Formation and the Mesaverde Group, indicate that the Mesaverde Group is the downstream equivalent of the Kaiparowits Formation.

Central Utah, A Photographic Essay and Update on Geology and Drilling in America's Most Exciting New Oil and Gas Exploration Province

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Oil and gas in the Central Utah Thrust Belt was sourced, at least in part, from Mississippian age rocks in the thicker, western facies of the Utah portion of the western North American Hingeline. The timing of this action may have been early initial hydrocarbon migration, and entrapment in broad, fairly flat, pre-Sevier structures or stratigraphic traps. Subsequent migration filled Sevier structures. Similar early migration in Canada resulted in gigantic pre-Sevier oil accumulations in stratigraphic traps which were later exhumed and exposed as the famous trillion barrel tar sand deposits. Later gas migration provided over 40 trillion cubic feet of gas to Canada's Sevier age structures. In Utah, Cretaceous rocks may be important as a secondary source in the northern and southern portions of the province. Permian and other formations may also prove to be important source rocks. Drilling activity has created both excitement and disappointment. Laccoliths, overturned synclines, 50 foot caves, missing reservoir rock, misplaced structural crests on 2-D seismic data, salt in all the wrong places and other surprises have been encountered. Surface igneous rocks cover over 3,000 square miles of prospective, structured area, sequestering some of the most promising trends. Area of interest encompasses 12,500 square miles with an average Navajo Sandstone penetration of one well per 370 square miles, and an average Mississippian penetration of one well per 1780 square miles.

Controlling Factors on Productivity in the Love Area, Natural Buttes Field, Uinta Basin, Utah

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The Greater Natural Buttes Field (GNB) of the Uinta Basin, northeastern Utah, currently produces over 200 MMCFG per day, primarily from the late Cretaceous Mesaverde Group and early Tertiary Wasatch Formation. Productive units are comprised of stacked, highly lenticular, tight, fluvial sandstones, interbedded with non-marine, organic-rich siltstones and shales, and occasional thin coal seams. GNB was discovered in 1955 and has an aerial extent of approximately 400 square miles.

A WNW trending fairway, deemed the “sweet spot” in GNB, is located through T9S R21-22E and T10S R23E. This area contributes significantly to the overall production of the field. As part of efforts to fully exploit GNB, thirty-six wells were drilled in a fringe area to the south, the “Love Area” (T11S R21E). These wells were drilled sporadically since 1960, but most (22) were drilled in 2006. Production results for these wells are marginally economic, with a few exceptions.

In the Love Area, the number of sandstone bodies of the Wasatch and Mesaverde, especially those that are gas-charged, decrease to the south. The low net-to-gross sandstone ratio may provide a type of large-scale regional stratigraphic trap. Also, regional vitrinite reflectance indicates a decrease in thermal maturity north to south across GNB into the Love Area. These factors and the influence of structural elements on gas migration and trapping in GNB may explain productivity in the Love Area and help define the economic limit of the Greater Natural Buttes Field.

Western U.S. Basin Shale Trends

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Completions in the Rocky Mountain basins of the U.S. have shown a steady increase over the past five years. The largest overall increases have been in the Williston, Uinta, Piceance, San Juan, and Green River basins. Contributing to this increase are the completions in shale formations in certain of these basins. Analysis of exploration data shows the successes in shale gas exploration has contributed to this increased activity. The Williston, Uinta, Green River, and San Juan are the main gas producing basins and this trend is continuing as shale completions in the first quarter of 2007 are slightly higher than the same period last year.

The increased shale success in the Rocky Mountain basins has resulted in an increase in total overall gas production for most western basins over the past five years. The Williston, Green River, Uinta, and Piceance basins show the greatest increase in production and this increase in drilling and production should continue though out 2007 and beyond. The increase in natural gas prices coupled with recent improvement in production technology shale drilling should help spur further increases in other shales in these western basins.

The Vermillion Basin of SW Wyoming/NW Colorado: Structural Styles and Seismic Pore Pressure Prediction through Over-Pressure

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The Vermillion basin is a sub-basin of the Greater Green River basin and includes the Canyon Creek, Trail, Kinney, E & W Hiawatha, & Sugarloaf fields. The basin straddles the Wyoming/ Colorado state lines and includes Sweetwater County, Wyoming and Moffat County, Colorado.

This sub-basin of the Greater Green River basin lies just to the northeast of the eastern terminus of the Uinta Mountain front and exhibits transpressional tectonics with evidence of recent extension. The area is characterized by SW-NE trending anticlines cored by compressional faults. The folds exhibit steep fore-limbs and gentle back-limbs, and some areas exhibit large back thrusts.

The first discovery of gas in the Vermillion basin was made by Questar predecessor Mountain Fuel Supply Company in 1927 at Hiawatha Field in NW Colorado. Since that time several prolific fields have been discovered and the area has produced approximately 1 TCFG and 8 MMBO. To date most of the production has come from shallow Mesaverde sandstones, however there is an emerging play targeting the deeper Dakota, Frontier and Baxter formations. There is a regional over-pressure cell in the lower part of the Baxter Formation through the Frontier (3,000-4,000 ft thick) that requires mud weights in the 12-15 ppg range to drill.

Within the Vermillion basin there is approximately 200 square miles of 3D seismic, composed of 3 separate surveys acquired over the last 12 years. The data has been merged and processed into one continuous volume of good-excellent quality (Nominal 30 fold with 110 * 110 bin spacing). Source is a mix of Vibroseis and Dynamite data and recently reprocessed in 2006. In addition to standard processing (stack, migration, PSTM) of the merged 3D volumes, the data has also been processed to generate a 3D pore pressure volume.

Complex Deformation of Paleozoic Strata due to Folding and Faulting in the Southern Beaverhead Mountains, Clark County, Idaho

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The geologic map of the Scott Butte 7.5 Minute Quadrangle at the southern end of the Beaverhead Mountain Range, Idaho is a compilation of field work preformed by undergraduate students participating in the advanced field geology course at Brigham Young University–Idaho during Summer 2006, supplemented by earlier unpublished research of others. Mapping has revealed complex relationships involving Paleozoic carbonate and clastic strata that have been subjected to folding, thrust faulting, high-angle reverse faulting, and normal faulting associated with Sevier compression, Basin and Range extension, and passage of the area over the Yellowstone hotspot. Geologic relationships have been further complicated by Tertiary volcanism, both basaltic and rhyolitic, and a thick alluvial cover that blankets the valley floor. Mapping in the southern Beaverhead Mountain Range is part of an ongoing project to correlate tectonic structures across the Snake River Plain with similar features in the northern part of the Big Hole Mountains. Part of the significance of this mapping involves surface exposures of geologic features that are common to Thrust Belt hydrocarbon reservoirs and, therefore, could serve as a model for further exploration.

Evaluating the Shale Gas Resource Potential in Western Canada

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Unconventional gas resources in Canada are estimated to be in the order of several thousand TCF, a significant component of which is in gas shales. Realisation of these resources requires ingenuity, technology and comparatively high gas prices.

Through much of western Canada and parts of eastern Canada potential gas shales exist in strata ranging from Ordovician to Late Cretaceous in age. Although vast resources of gas undoubtedly exist in these shales the amount of producible gas remains unknown and currently there is no gas production specifically attributed to gas shales in Canada. A significant component of the gas produced from shallow tight formations in eastern Alberta and adjacent Saskatchewan are fed from strata best defined as gas shales. In these gas shales larger reserves in place exist than have been attributed by use of conventional methods of reservoir analyses. If these reservoirs are evaluated as having a gas shale component, larger reserves could be booked and a more efficient development program with further down spacing would be warranted. The greatest potential for gas shale development in Canada is currently perceived to be in north eastern British Columbia where recent Crown land prices have locally exceeded $1000/ha. These mainly Devonian aged shales have been many characteristics in common with the highly productive Barnett Shale in the Fort Worth Basin.

West Tavaputs, Uinta Basin - A Story of Persistence

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The remote West Tavaputs Plateau area has experienced sporadic exploration and intermittent drilling for the past 50 years. Despite well-recognized hydrocarbon potential, the remoteness of the site, rough topography and access to markets all helped suppress more thorough development.

In 2002, Bill Barrett Corporation (BBC) acquired 13 wells producing 1.4 MMCFGD and 46,622 gross acres in the Stone Cabin, Jack Canyon & Peter's Point federal units and adjacent areas located in Carbon County, Utah, Southwest Uinta Basin, for approximately $8 MM. Production in 2002 was from the Tertiary North Horn Formation (Lower Wasatch) and a minor amount from the Wasatch. The Company believed there was further potential from the North Horn and possibly from the deeper Price River (Mesaverde).

This presentation focuses on the early exploration seismic acquisition and drilling on the project and also provides an update on drilling and production. In April 2002 the Company applied for a 3D seismic permit with the BLM for a 83 square mile survey. Two years later the Company received a favorable Decision Record in July 2004.

The objective of the survey was the structural configuration of deeper Cretaceous Dakota / Cedar Mtn Formations and the Jurassic Entrada, Navajo, and Wingate Formations. The secondary objective was the shallower Price River (Mesaverde) Formation. Given the length of time from May 2002 to July 2004 to acquire a Federal permit the original estimate of $4.2MM for survey cost ultimately ballooned to over $8MM.

Subdividing the Undifferentiated Eastern Uinta Mountain Group, Northeastern Utah

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Although geologists recognize six separate formations throughout the western Uinta Mountain Group (UMG), only the basal unit of the eastern UMG has been formally named (Jesse Ewing Canyon Formation), leaving close to 95% of eastern UMG undivided. Detailed geologic mapping (1:12,000 scale) is underway to subdivide and correlate the seemingly homogenous, 4 to 7 km-thick Neoproterozoic (~770-780 Ma) eastern UMG along the margins of Browns Park, northeastern Utah. The eastern UMG consists of dominantly sandstone interbedded with subordinate shale and conglomerate. Common sedimentary structures include a diversity of crossbedding, pebble lags, symmetric and asymmetric ripplemarks, mudcracks, and soft-sediment deformation. Paleoflow directions range from south-southwest in some facies, to bimodal (northwest and southeast) in others.

Preliminary divisions within the Swallow Canyon quadrangle (eastern Uintas) include a $\leq$ 70 m-thick shale interval, termed the formation of Outlaw Trail (fOT; De Grey, 2005). The lateral extent of this interval is currently being evaluated northwestward (towards Goslin Mountain) and northward across the Browns Park graben (Willow Creek Butte quadrangle) to aid in regional correlation; refining previous thickness estimates and paleoenvironmental and paleogeographic interpretations. Preliminary field and air photo interpretation show previously unmapped northwest-trending normal faulting along the western margin of Browns Park may offset the fOT at several locations. Furthermore, one or more of these structures may juxtapose the fOT with a thick shale interval (~100's of meters) from another yet unknown part of the UMG. Geologic mapping in conjunction with measured sections, petrography, and paleocurrent analysis are being applied to resolve these problems.

Rangely Turbidites and Their Linkage to Coeval Shallow-Water Succession, Rangely, Colorado

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Isolated sand bodies within the Mancos shale of the Western Interior Basin are exposed below the Castlegate sandstone in the Rangely Anticline. These sand bodies have previously been interpreted as shoreface deposits associated with the Castlegate Formation. Detailed stratigraphic analysis has identified these deposits as turbidites. One of the objectives of this project is a further detailed analyses of the turbidite beds with the aim to document the architecture of this turbidite system, establish the type of feeder system (i.e. river-fed hyperpycnal flow turbidites vs. failure-initiated turbidites), and establish the paleo-water depth (i.e. deposition below or above the wave base). Considering the latter special attention is paid to signs of wave- or tide- influence in the turbidite beds. The second objective is to resolve the timing of the Rangely turbidite sandbody deposition, and whether it is associated with lowstand, falling-stage or highstand systems tract in the coeval shoreline complex. Previous correlations suggest that the Rangely turbidites are associated with the Desert interval of the Blackhawk Formation. Subsurface data and outcrop correlations are used to link the shallow-water deposits to the Rangely turbidites. Through linking the Rangely turbidites to their source, we hope to further understand what causes some systems to have an "attached" highstand, falling-stage and lowstand system, whereas in other systems the lowstand deposits are detached from their highstand shorelines.

Utah Shale Gas: an Emerging Resource Play

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In 2007 several proven and potential shale gas plays in Utah are poised to make a significant contribution to natural gas production. Spurred by improving market conditions for natural gas and the availability of appropriate fracture stimulation technology, exploitation of Upper Cretaceous Mancos Shale gas has begun already and potential Paleozoic shale gas reservoirs (Hermosa Group and Manning Canyon) are being evaluated. Favorable gas tests from Mancos Shale completions, good DSTs, large to very large mud gas readings, and widespread gas shows all demonstrate the strong potential for development of this shale gas reservoir. Whereas most of the good indications are in the upper part of the 3,000-3,800 ft thick Mancos Shale, principally in the Prairie Canyon Member, favorable indications were found in all of the other shaly and silty units, the Lower Blue Gate, Juana Lopez and Tununk Members. At present, Mancos shale gas is being produced from a small number of wells in the Greater Natural Buttes and Flat Rock fields. In all instances, this is "add-on" gas, supplementing production from conventional sandstone reservoirs. The only remaining impediment to major development of the Mancos Shale gas resource is determination of operators to complete wells in the formation. Where sufficiently mature, the Hermosa Group black shales in the Paradox basin and the Manning Canyon-Doughnut Shale in the western Book Cliffs have strong potential for shale gas, but serious evaluation is just beginning.

The Steele/Niobrara of Central Wyoming: Insights into Hydrocarbon Generation-Induced Regional Over-Pressure

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The Steele/Niobrara and its equivalent units are important source rocks throughout the Rocky Mountain region. In central Wyoming the interval is in its early life cycle of maturation and hydrocarbon generation, and in certain areas, sub-surface over-pressuring within this package is associated with a maturation thresh hold for hydrocarbon generation and saturation. Vitrinite reflectance data demonstrate relationships between present day thermal maturity / top of overpressure and an increase in the paleo-thermal gradients below top of overpressure at several locations. The former relationship is believed be related to kerogen conversion and hydrocarbon expulsion. The latter relationship is believed to be related to the thermal conductivity of hydrocarbon saturation within the over-pressured interval. The data infer that the maturation of the source interval is relatively recent, and that hydrocarbon generation is dynamic present day. The data also suggest that hydrocarbon over-pressure cells within this petroleum system can be inferred from well cuttings where there is little pressure or mud log data. At one location studied, there is evidence that a paleo over-pressure boundary has breached, and moved down section.

Thin section, fluid inclusion, and kerogen conversion kinetics work was undertaken to help understand the processes associated with the development of the overpressure seals within the Steele-Niobrara section. At one well, a larger fracture cross-cut with later open fractures, and open veins of all sizes were observed within the overpressure boundary, possibly suggesting periodic breaching and healing.

New Techniques for New Discoveries – Results from the Lisbon Field Area, Paradox Basin, Utah

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Exploration for Mississippian Leadville Limestone-Hosted hydrocarbon reservoirs in the Paradox Basin is high risk in terms of cost and low documented success rates (10% based on drilling history). The potential for more hydrocarbon reserves is enormous, but the high cost of seismic exploration methods in environmentally sensitive areas deters small independents from exploring for Leadville hydrocarbon reservoirs. This study was therefore initiated over the Lisbon and Lightning Draw Southeast fields to evaluate the effectiveness of low-cost surface geochemical methods for predicting productive and non-productive Leadville carbonate reservoirs. The main conclusions of the study are:

(1) Low-cost surface geochemical methods are effective for distinguishing between productive and non-productive parts of Leadville reservoirs.

(2) Important variables for distinguishing productive from non-productive areas are light alkanes and aromatics (C1-C6), heavy aromatics (C30+), uranium, vanadium, cadmium, molybdenum, and lead.

(3) Productive "Lisbon-type" microseepage signatures, based on discriminant analysis of C1-C12 hydrocarbon data, are observed over the recently discovered Leadville Lightning Draw Southeast gas

condensate field southwest of Lisbon. Compositional signatures over the Lightning Draw field also predict productive parts of Lisbon.

(4) Hydrocarbons (C1-C6), hydrogen and carbon dioxide are anomalous in free gas samples over productive parts of Leadville reservoirs.

What's The Matter With The Ericson? Gas Shows, Calculated Pay, and Water!

Shanley, Keith W.[1], Robert M. Cluff[1], John W. Robinson[2] (1) The Discovery Group, Denver, CO (2) North Ranch Resources, Littleton, CO

The Ericson Formation is a clean, quartzose, sheet-like sandstone that underlies the gas productive Almond Formation throughout the Washakie basin. The majority of wells that penetrate the Ericson have indications of gas pay including 6-11% porosity, resistivity in excess of 50 ohm-m, neutron-density gas cross-over, and mudlog shows. Saturation calculations using appropriate electrical properties and Rw values indicate "gas pay" with saturations similar to producing intervals in the Almond. Nearly all Ericson completions, however, result in high water volumes and minor gas.. Commercial production from the Ericson is largely restricted to structural closures.

We suggest the Ericson is at, or near, residual gas saturation with high relative permeability to water and low relative permeability to gas. Calculated water saturations (40-60%) are approximately correct as corroborated by gas shows during drilling; there is gas in the pore-space, however, the gas does not form a connected column and lacks capillary pressure. Basin history suggests the Ericson was either gas-charged as part of a large accumulation, or served as a migration pathway during the Late Cretaceous to Early Tertiary. Late Tertiary uplift resulted in structural re-adjustment, gas re-migration, and imbibition leaving the Ericson at residual saturation across large portions of the Washakie Basin. Imbibition and scanning capillary pressure data suggests residual gas saturation in tight-gas reservoirs range from 25% to 80% water saturation (Sw).

The high net/gross and widespread nature of the Ericson, reduce the opportunities for significant stratigraphic and fault-related traps and explain the structural control of virtually all significant Ericson accumulations. Minor accumulations will continue to be found, however, they will be difficult to distinguish from residual gas saturation. These difficulties in recognizing residual gas saturation exist in other sheet-like sandstones such as the Castlegate Sandstone, in the Uinta Basin, and the Rollins, Corcoran, and Cozzette Sandstones in the Piceance Basin.

Wave- and River Influenced Deltaic Clinoforms of the Chimney Rock Sandstone, Flaming Gorge Reservoir, Utah

Skinner, Jay P.[1], Piret Plink-Bjorklund[2] (1) Colorado School of Mines, Denver, CO (2) Colorado School of Mines, Golden, CO

The Chimney Rock Sandstone is an Upper Cretaceous sandstone deposited in near shore deltaic, and estuarine environments in the Western Interior Basin. The Chimney Rock Sandstone outcrops in a 15 km long, near continuous exposure near Flaming Gorge Reservoir, Utah. Previous work has shown that the wave-dominated highstand, falling stage or forced regression, and lowstand deltas can be distinguished based on the stacking patterns and shoreline trajectory. The deltaic clinoforms consist of shoreface deposits, fluvially-dominated mouth bars, delta front deposits and distributary channel deposits. One of the objectives of this study is to study in detail the deltaic clinoforms, to develop sedimentologic and early diagenetic criteria for recognition of the HST, FRST and the LST clinoforms, as well as to distinguish the fluvial-dominated mouth bar deposits and upper-shoreface deposits. The detail study will compare the lithology changes, clinoform steepness, sandbody geometry, degree of amalgamation, net to gross ratios, and local permeability barriers. The study suggests that there are more mud-rich intervals in parts of the delta that have more fluvial domination, and more clean sand-rich intervals in the wave dominated areas of the delta. The degree of amalgamation is also expected to change with the systems tract. The tops of the clinoforms show significant cementation that could be preferentially related to a specific systems tract. The second aim of the project is to apply the criteria developed in outcrops to subsurface data, and determine if the delta system exposed in outcrops has equivalent attached or detached lowstand deposits further seaward.

Study of Almond Reservoir Connectivity in Wamsutter Field

Soto, Luis E.[1] (1) BP, Houston, TX

Wamsutter is a giant tight gas field in Wyoming that covers over 2,500 square miles, and has produced over 4Tscf from 2,000+ wells. Around 85% of total production is coming from the prolific Almond Formation.

The Almond formation consists of shales, coals and sandstones bodies deposited in fluvial, coastal plain, lagoonal, tidal channel, and marine bars environments during the transgressive cycle of the late Cretaceous Interior Seaway in several

As in many fields, Wamsutter has gone through several down spacing processes from the initially developed at 640 acres, to it's current development at 80 acres. BP is evaluation a new down spacing scenario to maximize the recovery in the gas field.

Down spacing decisions have been mainly driven by drainage area evaluations. There fore reservoir connectivity has been incorporated as one of the most relevant parameters to focus on in a multidisciplinary effort attempting to develop a more comprehensive reservoir understanding. Ultimately, this evaluation will allow BP to determine to optimum well spacing for the most efficient field development.

The reservoir connectivity study corroborates unexpected pressure depletion recorded in the field at 40 to 80 acre spacing

This reservoir connectivity presentation covers the most significant aspect of the study. It will include results, methodology and the parameters affecting reservoir connectivity. Those parameters take account of depositional environment, reservoir architecture, sand body dimensions, sand to gross ratio and porosity permeability distributions. They were independently studied, integrated and evaluated using 3D stochastic and dynamic modeling techniques.

Sequence Stratigraphy of the Green River FM Fluvio-Lacustrine Clastic Tongues, Uinta Basin, USA

Steel, Ron1 (1) The University of Texas at Austin, Austin, TX

Fluvial clastic tongues interfinger (50-100km transits) with shallow-lacustrine carbonates and oil shales, in the well-exposed Eocene Green River Formation of the Laramide Uinta Basin. Analysis of some 13 such tongues, each a few 100ky in duration, shows that the fluvial system repeatedly regressed and was transgressed during the wet intervals of wet-dry Eocene stratigraphy. The fluvial sandbodies were terminal fluvial systems (channels and frontal floodplain splays) that prograded basinwards while lake level was low, but rising. Continued and accelerated lake-level rise caused the fluvial systems to be transgressed by carbonates. Lake level fell and lake facies shallowed to dessication during dry periods. Fluvial sandbodies can be shown to be amalgamated, thick and narrow (up to 60m and a few km respectively) in the proximal reaches of their transits, becoming more isolate, thinner and wider (5-20m and >10km, respectively) distally, as might be expected in terminal systems. The progradational aspect of the fluvial system frequently causes channels to be larger at the late stages of a cycle. Lake deltas are present only in the mid-stage of the wet period, and only in the most distal segments of some of the transits, when terminal fans briefly became fan deltas. Deltas are not developed during the transgressive phases. This type of basin is contrasted with deep lake basins, where turbidites are developed abundantly.

Eocene to Oligocene Paleodrainage of Southwest Montana: Evidence from Detrital Zircon Populations

Stroup, Caleb N.[1], Paul K. Link[1], Susanne U. Janecke[2], C. Mark Fanning[3] (1) Idaho State University, Pocatello, ID (2) Utah State University, Logan, UT (3) Australian National University, Canberra, Australia

Contrasting models have been proposed for paleodrainage within the north-striking Paleogene rift system in southwest Montana, in the western hanging wall of the Muddy-Grasshopper detachment. Models most notably disagree over whether northern or southern drainage within the rift basins persisted from the Eocene to Oligocene.

Detrital zircon populations from sandstones in and adjacent to the Paleogene Grasshopper, Anaconda and Nicholia Creek supradetachment basins have diverse provenance. Different sands contain a) Proterozoic (1400-1750 Ma) zircons recycled through the Belt Supergroup, b) mixed cratonally derived Archean, Paleoproterozoic, and Grenville zircons from nearby ranges, and c) Cretaceous magmatic zircons of two prominent populations (65-85 Ma and 90-110 Ma).

Axial Oligocene two-mica sandstones from the Grasshopper basin contain a 65-85 Ma grain population, likely sourced from local granites. Paleocurrents suggest derivation from the north-northwest. A second 90-110 Ma population is found in sandstones deposited in the intra-rift Grasshopper and Nicholia Creek basins, and in older middle-Eocene “Renova” sandstone from Mantle Ranch, MT, east of the rift zone. No known proximal ca. 100 Ma plutonic source exists in southwest Montana, but little U-Pb geochronology has been done in nearby ranges. These data require that regional fluvial systems drained not only plutons from the north and west, but also unknown ~100 Ma plutons, perhaps in the Pioneer Mountains.

Oligocene two-mica sandstones in the type Renova Formation near Whitehall, MT contain many 70-80 Ma Boulder batholith grains and confirm persistent eastward drainage from uplifts east of the rift basins, even where detachment vergence changes from top-west to top-east.

Laboratory Experiments of Hydraulic Fracturing Help Investigating Conditions for Fracture Branching and Fracture Containment

Suarez-Rivera, Roberto[1], Chaitanya Deenadayalu[1], David Handwerger[1], Sid Green[2] (1) TerraTek, a Schlumberger company, Salt Lake City, UT (2) TerraTek, a Schlumberger company, salt lake city, UT

Economic production of gas from micro- to nano-darcy permeability tight rocks, requires the generation of large surface area during hydraulic fracturing. Large surface area can be created by increasing the fracture geometry (height and length), or by increasing the fracture complexity (branching). Micro seismic monitoring during hydraulic fracturing in tight gas shales indicates narrow and often broad spread of microseismic events along the plane of fracture propagation. These results allow us to interpret the degree of fracture complexity. The overall resulting structure with single or multiple branches propagating in the direction of the maximum horizontal stress and often, smaller, cross cutting, branches propagating orthogonal to the former is referred to as the stimulation fairway. Given that branching significantly increases surface area during hydraulic fracturing, understanding the causes and consequences of branching, and most importantly, understanding whether these structures can be affected during pumping is of great technical relevance and economic importance for the unconventional gas industry. In this paper we present results of laboratory experiments of hydraulic fracturing on small- to large- scale samples to evaluate the sources of fracture branching. Experimental results suggest that interfaces and deviatoric stresses are required for branching. Under stress free conditions, once encountering the interface the fractures are either arrested, or turn to propagate along the direction of the interface. Under strong stress contrast, the fracture steps-over laterally to cross the interface. This process often results in multiple branches.

Elements of Successful Thermogenic Shale Gas Pays

Tobey, Mark H.[1], Thomas M. Smagala[2], David E. Schmude[3] (1) Organic geochemistry consultant, Castle Rock, CO (2) EnCana Oil & Gas (USA), Inc, Denver, CO (3) EnCana Oil & Gas (USA) Inc, Denver, CO

Finding the keys to unlock shale gas plays requires thorough investigation, experimentation, and persistence. These plays are as varied as “conventional” plays in terms of the nature of the “reservoir” and the completion practices which tap those “reservoirs.” Therefore, there is no one formula of attributes which guarantees success. Designing a effective extraction strategy will depend upon the specific attributes of the play, and the application of key learnings from other successful plays. There are common elements to successful shale gas plays, however, which can be evaluated up front to assess their potential and to reduce exploration risk. The hydrocarbon generative potential of the shale depends upon its organic enrichment and kerogen composition. The degree of thermal maturation, coupled with the kerogen type, quantifies the risk for hydrocarbon liquids, the potential for liquid-to-gas cracking, or the risk for hydrocarbon destruction. The shale porosity (rock matrix and total matrix which includes fracture density), organic enrichment, reservoir temperature / pressure, and shale thickness are parameters which contribute to the maximum gas storage capacity of the shale – original gas in place. The potential for remaining gas in place depends upon the timing of maturation, burial / tectonic history, and other factors. Gas delivery potential depends upon shale fabric, permeability, rock mechanical properties, stress environment, and reservoir pressure – and using that information to formulate the key to an effective completion. Individual plays also include additional components relevant to that play. These elements will be reviewed and put into context with productive shale gas plays.

Petrophysical Evaluation of the Hiawatha Deep Unit #5 well in the Vermillion Basin, Northwestern Colorado

Tracy, George[1], Kimberley Kaiser[2], Richard Newhart[2] (1) Schlumberger Oilfield Services, Greenwood Village, CO (2) Questar, Denver, CO

The Hiawatha Deep Unit #5 (HDU #5) is located in Sec. 15-T12N-R100W, Moffat Co., Colorado. The well was drilled into the Jurassic Morrison Formation and reached a total depth of 14,030 ft. Primary objectives in the HDU #5 were the Cretaceous Frontier and

Baxter formations. Both reservoirs were buried at depth sufficient to place the intervals in geo-pressure, providing an unconventional play in the Baxter Shale and stratigraphic traps in the Frontier.

Two cores were cut in the Baxter Shale in the HDU #5 at depths of 12,343 to 12,390 ft and 12,951 to 13,005 ft. Observed lithologies in the cores range from relatively pure, laminated shales to thin interbedded sandstones, siltstones, and shales. Laminated shales contain 0.5 to 2% total organic carbon. The mineralogy in the shale-rich and siltstone-rich intervals includes quartz, calcite, dolomite, plagioclase, authigenic pyrite and trace amounts of other minerals. Clays, which comprise 12.8 to 37% of total rock composition, are dominated by illite and chlorite.

The Schlumberger Platform Express, Dipole Sonic Imager and Formation Micro Imager were used to log the HDU #5. Petrophysical and rock-mechanic models incorporate the observed mineralogy and are calibrated to core analysis. Total organic carbon values from logs are calculated and a representative amount of kerogen is added into the model. With core-derived shale matrix permeabilities of 52 to 115 nanodarcies, traditional log-derived permeability results are inadequate and must be revised. The petrophysical model also includes a gas-in-place calculation that is calibrated to a known core Langmuir desorption/adsorption isotherm profile.

New Structural Interpretation of the Elk Range Thrust System, Southwest Colorado

Tully, Justin E.[1], David R. Lageson[1], James C. Coogan[2] (1) Montana State University, Bozeman, MT (2) Western State College of Colorado, Gunnison,

The Elk Mountains of southwest Colorado expose a thick Pennsylvanian-Permian succession that was displaced southwestward in Late Cretaceous-Early Paleogene time along the NE-dipping Elk Range Thrust System (ERTS). The ERTS trends southeast from Redstone to Taylor Canyon and includes the low-angle, en-echelon Elk Range and Brush Creek thrust faults. This thrust system represents the deeply eroded up-plunge core of a major Laramide tectonic feature in western Colorado, the Grand Hogback monocline. The ERTS forms the thrust-faulted southwestern margin of the Sawatch arch and is separated from the core of the uplift by a SW-facing, NNW-trending, reverse-faulted monocline of Precambrian through Mississippian rocks. The geometrically awkward arrangement of this basement-cored monocline immediately adjacent to the low-angle ERTS led previous investigators to propose gravitational sliding from the crest of the Sawatch arch. New mapping, balanced cross-sections and kinematic analyses demonstrate that the ERTS is basement-rooted and that the region evolved through two stages and two different styles of Laramide shortening: 1) southwestward displacement of the ERTS on low-angle basement-rooted thrust faults, followed by 2) high-angle reverse faulting along the western flank of the Sawatch arch that truncated the ERTS. As a result, the Precambrian core of the Sawatch Range uplift was juxtaposed against Paleozoic rocks of the ERTS hanging wall.

Utah’s Oil Shale Deposits: Stratigraphy and Resource Evaluation

Vanden Berg, Michael D.[1], David E. Tabet[1] (1) Utah Geological Survey, Salt Lake City, UT

With the recent increase in crude oil prices and concerns over diminishing conventional reserves, the Utah Geological Survey has been re-examining the state's oil shale resource. Past assessments concentrated on the Eocene Green River Formation's Mahogany zone in the southeastern part of the Uinta Basin. This lithologic horizon holds the richest oil shale deposits in Utah, but other significant stratigraphic zones, as well as other areas within the basin, warrant further study. We have broadened our investigation to include the entire Green River Formation's Parachute Creek Member, which is found throughout much of the Uinta Basin. Over 100 density and sonic logs from oil and gas wells in the basin have been digitized and tops to key oil shale horizons have been picked. Structure contour and isopach maps were created for each zone, including the R-8, R-7 (Mahogany zone), R-6, R-5, and R-4 rich zones and the A-groove, B-groove, L-5, and L-4 lean zones. Cores from selected rich and lean oil shale horizons will be on display with the poster. In addition, we have correlated available Fischer assay analyses to geophysical logs as a way to produce high-resolution shale oil yield logs. This technique provided data to map oil shale thickness and richness throughout the basin and create structure contour and isopach maps with shale oil yields of 15, 25, and 35 gallons per ton of rock.

Understanding Waterfracs

Vincent, Michael C.[1] (1) CARBO Ceramics, Inc, Golden, CO

It is safe to assume that our industry has never placed a truly "optimized" waterfrac. Most engineers will admit that we really don't have a good understanding of the created fracture geometry, the realistic proppant placement, or the resulting velocity of produced gas within these fracs. This presentation will touch on the following topics:

* Frac Geometry achieved in some waterfracs
* Proppant Transport - videos and settling rates with various particle sizes and densities
* Unpropped fractures - how much conductivity can we hope for?
* What happens to proppant in narrow fracs? Can I rely on standard crush measurements?

Additionally, this presentation will share a novel waterfrac design recently implemented, in which the operator reduced the total treatment size, incorporated several different proppant diameters, and altered the pumping rates to improve the well productivity. The first 5 wells with these smaller but improved treatments have been on-line for over 6 months, and are producing higher production rates than offset wells using the previous treatment design which used much higher proppant mass. While we still don't understand enough to truly optimize waterfracs, participants in this presentation should gain a useful mental model of what is going on in waterfracs so we can continue to make design improvements.

Paleozoic Source Rocks in the Central Utah Thrust Belt: Organic Facies Response to Tectonic and Paleoclimatic Variables

Wavrek, D. A.[1], J. Ali-Adeeb[1], J. C. Chao[1], L. E. Santon[1], E. A. Hardwick[1], D. K. Strickland[2], D. D. Schelling[3] (1) Petroleum Systems International, Inc, Salt Lake City, UT (2) Wolverine Gas and Oil, Corp, (3) Structural Geology International, LLC,

It was not long ago that the industry paradigm explained exploration failure in Central Utah due to inadequate source rock. Our recent studies, however, have proven the existence of hundreds of feet of Mississippian and Devonian source rock. Detailed examination of nearly 600 potential source rocks from the Permian-Devonian stratigraphic horizons in Central Utah reveal important points:

1. measured TOC in the Mississippian-Devonian horizons exceeding 2% are found in Black Canyon 1, WXC-Barton 1, Sunset Canyon Unit 1, Desolation Unit 1, Bishop Springs Unit 1, Antimony Canyon 1, Paxton 1, Thousand Lakes Mountain 2, Fishlake #1-1, and Tanner 1-27; 2. all Pennsylvanian horizons are below the 2% threshold, except for the Manning Canyon Formation; 3. all Permian horizons with TOC exceeding 2% (Moroni 1-A, Salina Unit 1, and Paxton 1) are interpreted to be stained with migrated hydrocarbons

(i.e., not indigenous organic matter); and 4. outcrop sample data reinforce conclusions from the subsurface dataset.

Understanding organic facies require the integration of tectonic and paleoclimatic variables. For example, the western margin of the Chainman Basin has influence from sediment influx from the Antler Orogeny (i.e., dysoxic facies; maximum TOC 6%) whereas the central area is an anoxic sediment starved depositional system (maximum TOC 16%). In contrast, the eastern margin is influenced by upwelling and contains phosphorites (i.e., upwelling facies; maximum TOC 4%). The practical significance of this latter point is that the upwelling will impart a distinct molecular signature that can lead to erroneous source rock correlations (e.g., Permian Phosphoria Formation). Palinspastic reconstructions are used to better define the distribution of source rock, organic facies, and stratigraphic correlations in the study area.

Stratigraphy of Tide-Influenced River Deltas in the Sego Sandstone

Willis, Brian J.[1] (1) Chevron, Houston, TX

The Buck Tongue transgression of the flat-topped Blackhawk-Castlegate clastic wedge left a broad shallow area within the Cretaceous Western Interior Seaway that enhanced tidal currents and dampened coastal waves. The Sego Sandstone records episodic regression of deltas into this shallow area of the seaway. Falls in sea level allowed tides to scour in front of prograding shorelines, forming regressive erosion surfaces separating offshore marine deposits vertically from coarser-grained deltaic deposits. Deltaic successions contain successively thicker and less bioturbated tidal bar deposits, which are cut locally by meters-thick distributay channels, more-heterolithic, upward-coarsening tidal scour fills, and deeply incised valley fills. Tops of progradational sandstones were deeply ravined, and in most areas delta top facies were completely removed.

The upper Buck Tongue - Sego - Neslen succession between Green River and Grand Junction is a forward stepping sequence set. Initial sequences are upward-coarsening shelf successions capped by prominent benches of HCS sandstone. In the lower Sego Sandstone four sequences contain successively broader sharp-based deltaic sandstones that are disconnected between western and eastern segments of the outcrop belt, and record progradation to two distinct tide-influenced deltas. The upper Sego sandstone records amalgamation of deposits of these two deltas as deposition shifted further eastward into Colorado. Past stratigraphic studies of the Sego Sandstone failed to adequately differentiate regressive erosion surfaces from lowstand “sequence boundaries”. A recent stratigraphic study by Wood (2004), which shows a progressive increase in the thickness of transgressive deposits westward cross this outcrop belt, is significantly less accurate than the earlier stratigraphic study of Young (1955).

Speaker Cross Reference

Speaker	Day/Time	Location	Session
Albrecht, T. R.	Mon/2:00	Ballroom I	Resource Play Technologies
Anderson, D. S.	Tues/8:00	Magpie A&B	Sedimentation and Depositional Systems
Aschoff, J.L.	Tues/2:20	Ballroom I	Uinta Basin-Stratigraphic Studies
Bate, D.	Mon/10:55	Wasatch A&B	Sevier and Cordilleran Thrustbelt Revisited
Bate, D.	Tues/11:15	Ballroom III	Geophysical & Structural Advances in the Rockies
Billman, G. S.	Tues/8:00	Magpie A&B	Sedimentation and Depositional Systems
Black, B. A.	Tues/3:00	Ballroom III	Studies in Stratigraphy and Sedimentation
Black, B. J.	Tues/9:10	Ballroom III	Geophysical & Structural Advances in the Rockies
Borer, J. M.	Mon/10:15	Ballroom I	Uinta Basin-Expanding Oil and Gas Opportunities
Bowman, T.	Mon/3:50	Ballroom I	Resource Play Technologies
Bratton, T.	Tues/9:10	Wasatch A&B	Advances in Rock Mech. & Hydraulic Frac.-Case Studies (SPE)
Byrnes, A. P.	Mon/3:50	Ballroom III	Petrophysical Case Studies in Unconventional Reservoirs
Byrnes, A.P.	Tues/8:00	Magpie A&B	Sedimentation and Depositional Systems
Carney, S.	Tues/9:30	Ballroom III	Geophysical & Structural Advances in the Rockies
Chamberlain, A.	Tues/3:40	Ballroom III	Studies in Stratigraphy and Sedimentation
Chidsey, T. C	Tues	Golden Cliff	Signature Cores of the Rocky Mountain Region
Clayton, R. W.	Mon/8:00	Magpie A&B	Rocky Mountain Structural Analysis
Coffey, B.	Tues/9:10	Ballroom I	Shale Gas Secrets- Lessons from other N. Amer. Shale Gas Plays
Coogan, J. C.	Mon/8:10	Wasatch A&B	Sevier and Cordilleran Thrustbelt Revisited
Cramer, D.	Tues/8:30	Wasatch A&B	Advances in Rock Mech. & Hydraulic Frac.-Case Studies (SPE)
Cumella, S. P.	Mon/2:20	Ballroom I	Resource Play Technologies
Cumella, S. P.	Tues/2:00	Magpie A&B	Stratigraphic Studies of Utah and Colorado
Deacon, M.	Mon/10:35	Ballroom III	Emerging Shale Gas Resources of the Rockies
Dolan, M.	Mon/10:55	Ballroom I	Uinta Basin-Expanding Oil and Gas Opportunities
Dropkin, M.	Mon/8:00	Magpie A&B	Rocky Mountain Structural Analysis
Duncan, K.	Tues/2:00	Magpie A&B	Stratigraphic Studies of Utah and Colorado
Faraj, B.	Tues/10:55	Ballroom I	Shale Gas Secrets- Lessons from other N. Amer. Shale Gas Plays
Forgotson, J. M.	Tues/9:30	Ballroom I	Shale Gas Secrets- Lessons from other N. Amer. Shale Gas Plays
Gale, J. F. W.	Tues/8:30	Ballroom I	Shale Gas Secrets- Lessons from other N. Amer. Shale Gas Plays
Gay, S. P.	Tues/8:50	Ballroom III	Geophysical & Structural Advances in the Rockies
Gil, I.	Tues/10:35	Wasatch A&B	Advances in Rock Mech. & Hydraulic Frac.-Case Studies (SPE)

Speaker	Day/Time	Location	Session
Grau, A.	Mon/11:15	Ballroom I	Uinta Basin-Expanding Oil and Gas Opportunities
Grummon, M. L.	Mon/8:50	Ballroom III	Emerging Shale Gas Resources of the Rockies
Gustason, E. R.	Mon/8:30	Ballroom I	Uinta Basin-Expanding Oil and Gas Opportunities
Gustason, E. R.	Tues	Magpie A&B	Signature Cores of the Rocky Mountain Region
Handwerger, D.	Mon/4:30	Ballroom I	Resource Play Technologies
Harcourt, N.	Tues/3:40	Ballroom I	Uinta Basin-Stratigraphic Studies
Helmke, E. A.	Mon/8:00	Magpie A&B	Rocky Mountain Structural Analysis
Hinds, G.	Mon/8:50	Ballroom I	Uinta Basin-Expanding Oil and Gas Opportunities
Hokanson, W. H.	Mon/8:00	Magpie A&B	Rocky Mountain Structural Analysis
Holmes, M.	Mon/2:20	Ballroom III	Petrophysical Case Studies in Unconventional Reservoirs
Holmes, M.	Mon/1:30	Magpie A&B	Rocky Mountain Investigations
Hunt, G. J.	Mon/8:50	Wasatch A&B	Sevier and Cordilleran Thrustbelt Revisited
Jiang, S.	Tues/8:00	Magpie A&B	Sedimentation and Depositional Systems
Johnson, R. C.	Tues/3:20	Ballroom I	Uinta Basin-Stratigraphic Studies
Kaiser, K.	Mon	Golden Cliff	Signature Cores of the Rocky Mountain Region
Karpov, A.	Mon/4:10	Ballroom I	Resource Play Technologies
Keele, D.	Mon/10:15	Wasatch A&B	Sevier and Cordilleran Thrustbelt Revisited
Kingsbury, E. M.	Tues/2:00	Ballroom I	Uinta Basin-Stratigraphic Studies
Kirschbaum, M. A.	Mon/8:10	Ballroom I	Uinta Basin-Expanding Oil and Gas Opportunities
La Pointe, P.	Tues/2:00	Magpie A&B	Stratigraphic Studies of Utah and Colorado
LaFollette, R. F.	Tues/10:35	Ballroom I	Shale Gas Secrets- Lessons from other N. Amer. Shale Gas Plays
Laine, M. D.	Mon	Magpie A&B	Signature Cores of the Rocky Mountain Region
LeFever, J. A.	Mon/9:10	Ballroom III	Emerging Shale Gas Resources of the Rockies
Little, W. W.	Mon/9:10	Wasatch A&B	Sevier and Cordilleran Thrustbelt Revisited
Locklair, R. E.	Mon/10:15	Ballroom III	Emerging Shale Gas Resources of the Rockies
Longman, M. W.	Mon/11:15	Ballroom III	Emerging Shale Gas Resources of the Rockies
Longman, M. W.	Tues	Golden Cliff	Signature Cores of the Rocky Mountain Region
Lorenz, J. C.	Tues/8:30	Ballroom III	Geophysical & Structural Advances in the Rockies
Magill, D.	Tues/11:10	Wasatch A&B	Advances in Rock Mech. & Hydraulic Frac.-Case Studies (SPE)
Mark, S.	Mon/3:30	Ballroom I	Resource Play Technologies
Mauro, L. A.	Mon	Golden Cliff	Signature Cores of the Rocky Mountain Region
May, J. A.	Mon/9:10	Ballroom I	Uinta Basin-Expanding Oil and Gas Opportunities

Speaker	Day/Time	Location	Session
Merkel, D.	Mon/4:10	Ballroom III	Petrophysical Case Studies in Unconventional Reservoirs
Miller, M.	Mon/4:30	Ballroom III	Petrophysical Case Studies in Unconventional Reservoirs
Miller, C.	Tues/10:15	Ballroom I	Shale Gas Secrets- Lessons from other N. Amer. Shale Gas Plays
Milliken, M. D.	Tues/2:00	Ballroom III	Studies in Stratigraphy and Sedimentation
Milner, M.	Tues/8:50	Ballroom I	Shale Gas Secrets- Lessons from other N. Amer. Shale Gas Plays
Morgan, C.	Mon/10:35	Ballroom I	Uinta Basin-Expanding Oil and Gas Opportunities
Morris, T. H.	Mon/10:35	Wasatch A&B	Sevier and Cordilleran Thrustbelt Revisited
Moulton, F. C.	Mon/11:15	Wasatch A&B	Sevier and Cordilleran Thrustbelt Revisited
Myer, C. A.	Tues/3:20	Ballroom III	Studies in Stratigraphy and Sedimentation
Nandi, P.	Mon/2:40	Ballroom I	Resource Play Technologies
Nelson, P. H.	Mon/2:40	Ballroom III	Petrophysical Case Studies in Unconventional Reservoirs
Nelson, P. H.	Tues/8:00	Magpie A&B	Rocky Mountain Investigations
Nielsen, G. B.	Mon/9:30	Wasatch A&B	Sevier and Cordilleran Thrustbelt Revisited
Olsen, T.	Tues/8:50	Wasatch A&B	Advances in Rock Mech. & Hydraulic Frac.-Case Studies (SPE)
Oren, KC	Mon/1:40	Ballroom I	Resource Play Technologies
Painter, C. S.	Mon/1:30	Magpie A&B	Sedimentation and Depositional Systems
Palmer, I.	Tues/8:10	Wasatch A&B	Advances in Rock Mech. & Hydraulic Frac.-Case Studies (SPE)
Pearson, W.	Tues/10:55	Ballroom III	Geophysical & Structural Advances in the Rockies
Perkes, T. L.	Mon/1:30	Magpie A&B	Rocky Mountain Investigations
Pinnell, M. L.	Tues/2:00	Magpie A&B	Stratigraphic Studies of Utah and Colorado
Ragas, A.	Mon/9:30	Ballroom I	Uinta Basin-Expanding Oil and Gas Opportunities
Reimers, D. D.	Mon/8:10	Ballroom III	Emerging Shale Gas Resources of the Rockies
Rigatti, V. G.	Tues/10:15	Ballroom III	Geophysical & Structural Advances in the Rockies
Roemer, S.	Mon/8:00	Magpie A&B	Rocky Mountain Structural Analysis
Ross, D. J.K.	Tues/11:15	Ballroom I	Shale Gas Secrets- Lessons from other N. Amer. Shale Gas Plays
Roux, W. R.	Tues/8:10	Ballroom III	Geophysical & Structural Advances in the Rockies
Rybczynski, D.	Tues/2:00	Magpie A&B	Stratigraphic Studies of Utah and Colorado
Sacerdoti, R.	Tues/2:20	Ballroom III	Studies in Stratigraphy and Sedimentation
Schamel, S.	Mon/8:30	Ballroom III	Emerging Shale Gas Resources of the Rockies
Schmude, D.	Mon/10:55	Ballroom III	Emerging Shale Gas Resources of the Rockies
Seneshen, D. M.	Mon/1:30	Magpie A&B	Rocky Mountain Investigations
Shanley, K. W.	Mon/2:00	Ballroom III	Petrophysical Case Studies in Unconventional Reservoirs

Speaker	Day/Time	Location	Session
Skinner, J. P.	Tues/2:40	Ballroom III	Studies in Stratigraphy and Sedimentation
Soto, L. E.	Mon/1:40	Ballroom III	Petrophysical Case Studies in Unconventional Reservoirs
Steel, R.	Tues/3:00	Ballroom I	Uinta Basin-Stratigraphic Studies
Stroup, C. N.	Mon/1:30	Magpie A&B	Rocky Mountain Investigations
Suarez-Rivera, R.	Tues/10:55	Wasatch A&B	Advances in Rock Mech. & Hydraulic Frac.-Case Studies (SPE)
Tobey, M. H.	Tues/8:10	Ballroom I	Shale Gas Secrets- Lessons from other N. Amer. Shale Gas Plays
Tracy, G.	Mon/3:30	Ballroom III	Petrophysical Case Studies in Unconventional Reservoirs
Tully, J. E.	Tues/10:35	Ballroom III	Geophysical & Structural Advances in the Rockies
Vanden Berg, M. D.	Mon	Magpie A&B	Signature Cores of the Rocky Mountain Region
Vincent, M. C.	Tues/10:15	Wasatch A&B	Advances in Rock Mech. & Hydraulic Frac.-Case Studies (SPE)
Wavrek, D. A.	Mon/8:30	Wasatch A&B	Sevier and Cordilleran Thrustbelt Revisited
Willis, B. J.	Tues/2:40	Ballroom I	Uinta Basin-Stratigraphic Studies

Notes

Notes

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