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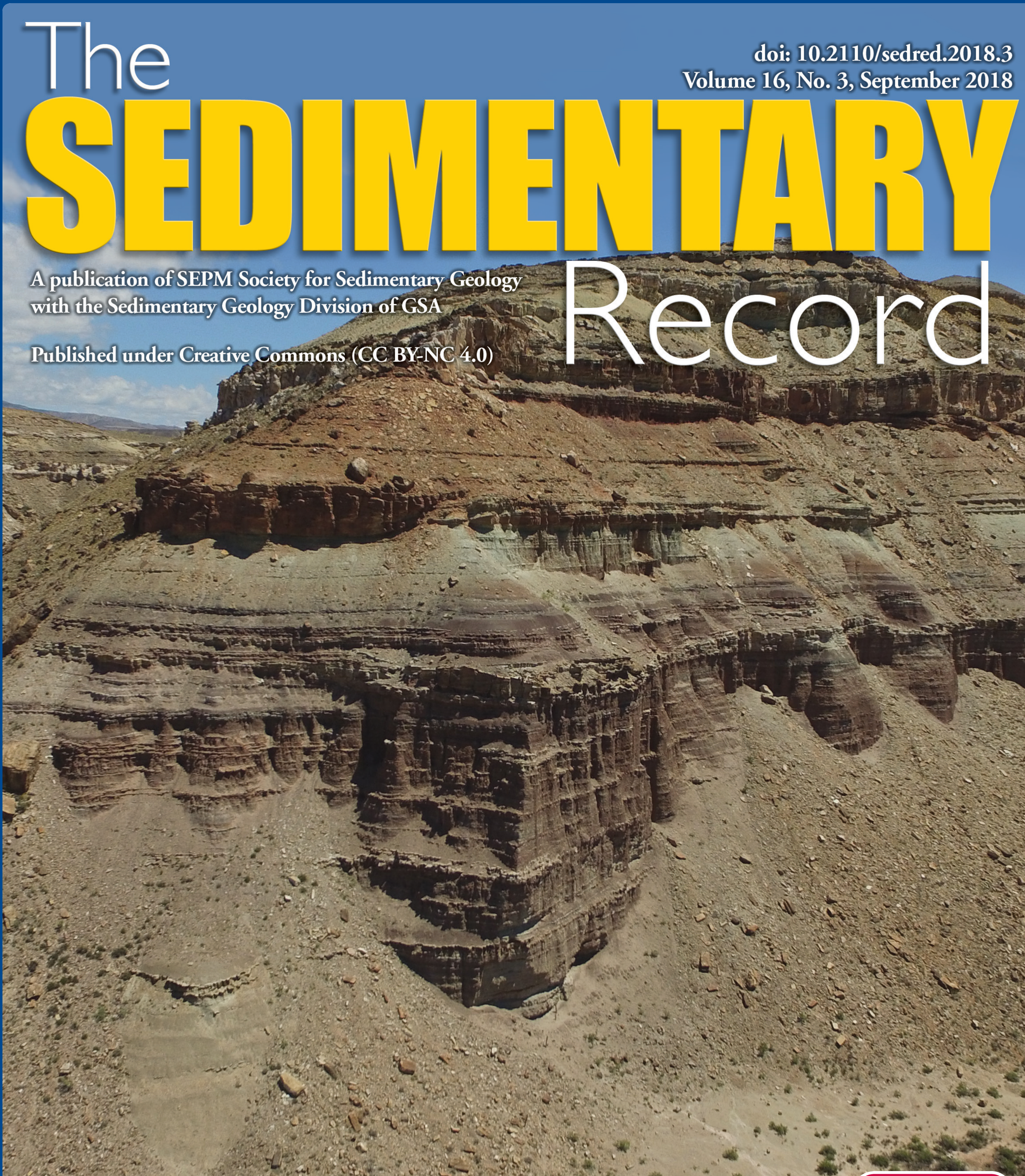

INSIDE: FLUVIAL ARCHITECTURE OF THE BURRO CANYON FORMATION USING UAV-BASED PHOTOGRAMMETRY AND OUTCROP-BASED MODELING: IMPLICATIONS FOR RESERVOIR PERFORMANCE, RATTLESNAKE CANYON, SOUTHWESTERN PICEANCE BASIN, COLORADO
PLUS: PRESIDENT'S COMMENTS, SGD NEWS, UPCOMING CONFERENCES

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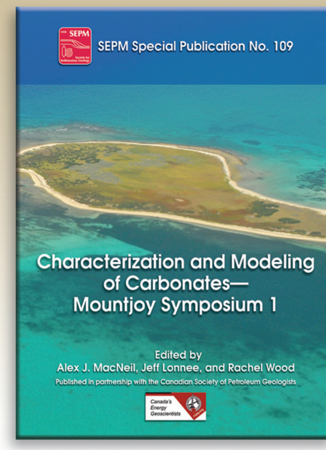
Special Publication #109

Characterization and Modeling of Carbonates—Mountjoy Symposium 1

Edited by: Alex J. MacNeil, Jeff Lonnee, and Rachel Wood



In August of 2015 the first Mountjoy Carbonate Conference, co-hosted by the Society for Sedimentary Geology (SEPM) and Canadian Society of Petroleum Geologists (CSPG), took place in Banff, Alberta. As the approaches to characterization and modeling of carbonate reservoirs are undergoing rapid changes, this was the theme of the meeting. This Special Publication, following the inaugural meeting, contains nine state-of-the art papers relating to the (1) characterization of carbonates and advances in analytical methods, (2) controls on carbonate reservoir quality and recovery factors, and (3) reservoir distribution, the modeling of dolostone geobodies, and reservoir prediction. The Introduction includes an overview of Eric Mountjoy's career and his many contributions to the science. The contents of this Special Publication should be useful to those engaged in the characterization and modeling of carbonate reservoirs, including unconventional carbonate reservoirs, and is highly recommended as one of the most impactful recent publications for those working in this area of sedimentary science.

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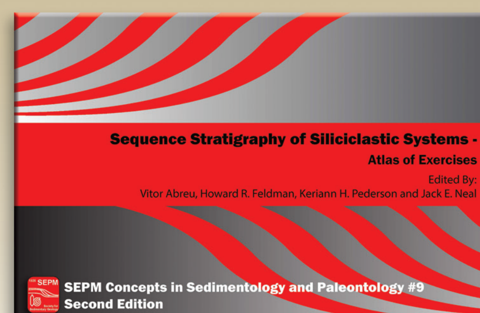
Concepts in Sedimentology and Paleontology 9 (2nd edition)

Sequence Stratigraphy of Siliciclastic Systems

Edited by: Vitor Abreu, Howard R. Feldman, Keriann H. Pederson, and Jack E. Neal



This publication is the result of more than 3 decades of sequence stratigraphy research and application. The objective is to emphasize the most important aspects of Sequence Stratigraphy—a method to guide geologic interpretation of stratigraphic data (seismic profiles, well-logs, cores and outcrops) across scales (from local to regional and global) and depositional environments (from continental to deep marine).The stratigraphic concept of a depositional sequence was introduced to the scientific literature by Peter Vail and his colleagues in the late 70s, building on the shoulders of giants like Chamberlain, Sloss and Wheeler. Since then, several papers compared and contrasted the original sequence-stratigraphic school published in the AAPG Memoir 26 in 1977 with other approaches to subdivide the geologic record, as well as, debating the model validity and impact on the community. At its core, the "model" is really a stratigraphic interpretation method, which was never explicitly documented in the literature. The objective of this book is to present the sequence stratigraphic method in its current form in an attempt to clarify its usage and application in diverse geologic data and depositional environments. This publication is the result of more than 3 decades of sequence stratigraphy research and application. The objective is to emphasize the most important aspects of Sequence Stratigraphy—a method to guide geologic interpretation of stratigraphic data (seismic profiles, well-logs, cores and outcrops) across scales (from local to regional and global) and depositional environments (from continental to deep marine). This book in an 11 x 17 format is designed to be easily used for teaching or self-learning experiences. In the second edition of the "Atlas", the book was divided in 2 separately bound volumes—Exercises and Solutions—to make it easier to use the publication as text book for sequence stratigraphy courses in universities. Also, a new exercise was added and several of the existing exercises went through major updating and editing.

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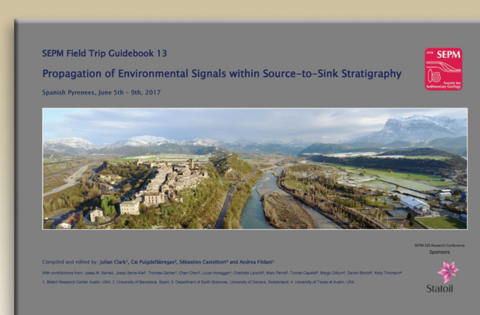
SEPM Field Trip Guidebook #13

Propagation of Environmental Signals within Source-to-Sink Stratigraphy

By: Julian Clark, Cai Puigdefàbregas, Sébastien Castelltort and Andrea Fildani



This guidebook was compiled for the field trip excursions of the SEPM Research Conference on the *Propagation of Environmental Signals within Source-to-Sink Stratigraphy*, (June 4th-10th, 2017). The world-class outcrop exposures and localities visited enabled the investigation of correlative stratigraphy from alluvial, fluvial, shallow marine, slope and deep marine environments with the direct observations of different segments of sediment routing systems. Decades of research in the region have contributed to our understanding of the basin-filling stratigraphic response to orogenic evolution and climatic events. These geologic insights and the well-preserved exposures have made the region a classic locality for both academic and industry-related geologic training, and a natural laboratory for continued research.

This SEPM Field Trip Guidebook presents key outcrops visited during the conference within a source-to-sink framework. The geologic map published herein is a cornerstone of this contribution, enabling and revising stratigraphic correlations required for this approach. An overview of source-to-sink concepts, methods and tools that can be applied to the stratigraphic record is provided, together with new data and analysis demonstrating environmental signals at different scales within the basin.

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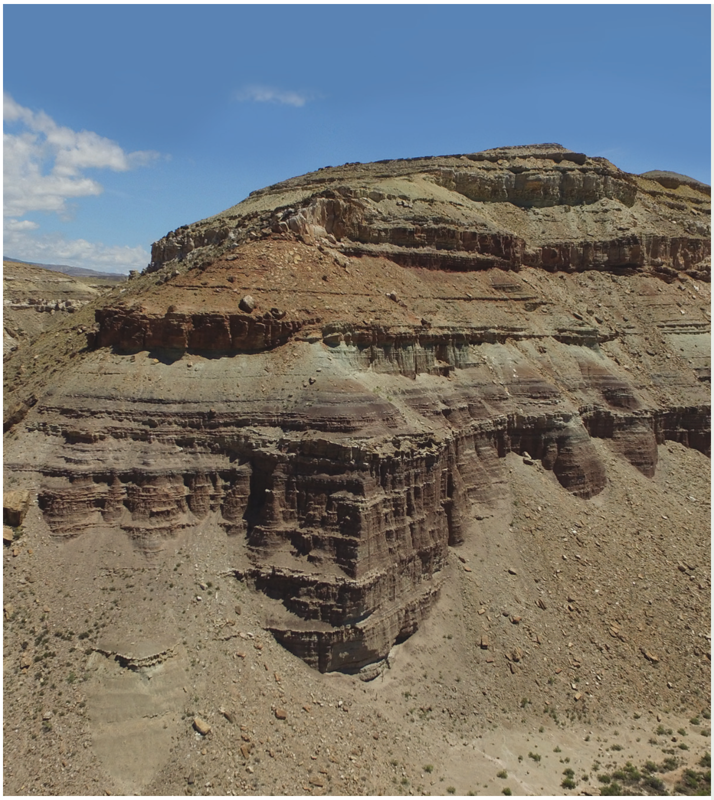

Cover image: Braided fluvial channels of the lower Cretaceous Burro Canyon and Upper Jurassic Morrison formations from Rattlesnake Canyon, Piceance Basin, Colorado. Image taken using UAV-based photogrammetry from a DJI-Phantom 3 drone.

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Fluvial architecture of the Burro Canyon Formation using UAV-based photogrammetry and outcrop-based modeling: implications for reservoir performance, Rattlesnake Canyon, southwestern Piceance Basin, Colorado

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ABSTRACT

The stratigraphic variability of fluvial architectural elements and their internal lithological and petrophysical heterogeneity influence static connectivity and fluid flow. Analysis of the fluvial architecture and facies heterogeneity of the Lower Cretaceous Burro Canyon Formation provides insight regarding their impact on reservoir performance. The Burro Canyon Formation as exposed in Rattlesnake Canyon, Colorado, forms stacked amalgamated and semi-amalgamated channel complexes that consist of amalgamated and isolated fluvial-bar channel deposits and floodplain fines, and represents a perennial, braided-fluvial system. Detailed two- (2-D) and three-dimensional (3-D) static and dynamic reservoir models are constrained using stratigraphic measured sections, outcrop gamma-ray measurements, and Unmanned Aerial Vehicle (UAV)-based photogrammetry. Resulting breakthrough time and sweep efficiency suggest subsurface reservoir performance is most effective perpendicular to paleoflow direction in amalgamated channels. Perpendicular to paleoflow, breakthrough time is 9% shorter than parallel to the paleoflow and sweep efficiency is, on average, 16% greater due to greater sandstone connectivity in this orientation. Variability of preserved channels and lateral pitchouts results in lower recovery efficiency. Facies heterogeneity can account for 50% variation in breakthrough time and slightly lower recovery efficiency (5%). Cemented conglomerates that form channel lags above basal scour surfaces can also create fluid-flow barriers that increase breakthrough time and decrease sweep efficiency (25%) and recovery efficiency (22%).

INTRODUCTION

The stratigraphic variability of fluvial deposits and their internal lithofacies and petrophysical heterogeneity influence sandstone-body connectivity and reservoir performance. At the reservoir scale, architectural elements and their stacking patterns create large-scale heterogeneity that influences reservoir productivity (e.g., Pranter et al., 2007, 2009; Villamizar et al., 2015). Lithofacies associations and their associated reservoir properties create internal heterogeneity within fluvial deposits that also impact fluid-flow (e.g., Pranter et al., 2007; Massart et al., 2016). Understanding the impact of different scales of fluvial heterogeneity on reservoir performance (e.g., sweep efficiency, recovery efficiency, breakthrough time of injected fluids at producing wells) is useful when characterizing and developing these types of reservoirs. To further explore how these types of sedimentological heterogeneities impact reservoir performance, well-exposed fluvial outcrop analogs of the Lower Cretaceous Burro Canyon Formation in Colorado are used as an example.

The Piceance Basin resides in an area once occupied by a much larger Rocky Mountain Foreland Basin formed by the Sevier Orogeny (c. 140-50 Ma) (Johnson and Flores, 2003). Early Cretaceous clastic sediments deposited in the Rocky Mountain Foreland Basin were transported from the Sevier fold-thrust belt eastward and northeast and deposited in the distal portion of the basin (Johnson, 1989; DeCelles, 2004). Deposition of the clastic sediments took place in a series of pulses due to orogenic movements from Aptian to Albian times. In the Late Cretaceous, the Laramide Orogeny caused structural deformation and formation of the modern day Piceance Basin (DeCelles, 2004).

The Lower Cretaceous Burro Canyon Formation is exposed in numerous canyons along the Gunnison River in the southwestern Piceance Basin, northwestern Colorado (Figure 1), and forms minor sandstone reservoirs within the basin (Young, 1975). The Burro Canyon Formation represents braided to meandering river deposits that formed in a coastal-plain setting (Stokes, 1952; Kirkland et al.,

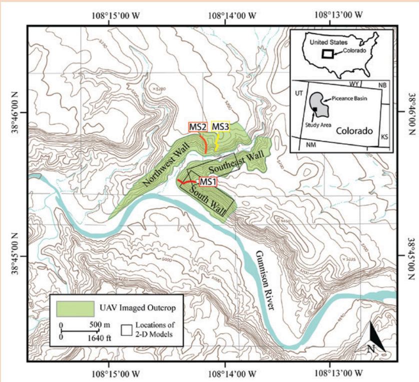

Figure 1: Rattlesnake Canyon study area. MS=measured section.

1999; Kirkland and Madsen, 2007; Currie et al., 2008; Cole and Moore, 2012). The Burro Canyon Formation unconformably overlies the Upper Jurassic Morrison Formation and is unconformably overlain by the Cretaceous Dakota Formation (Young, 1975) (Figure 2). Burro Canyon Formation lithofacies primarily consists of: 1) fine- to coarse-grained sandstone and conglomerate, 2) sandy granule-pebble conglomerate, and 3) green calcareous mudrock.

This study further establishes the depositional environment and stratigraphic architecture of the Burro Canyon Formation. The significance of the stratigraphic architecture and the different scales of fluvial sedimentological heterogeneity on reservoir performance is explored using the well-exposed outcrops of the Burro Canyon Formation in Rattlesnake Canyon, Colorado. Additional details are explained in Lewis (2018).

METHODOLOGY

The Burro Canyon Formation is well exposed on three sides of Rattlesnake Canyon. Outcrop orientations provide perspectives that are both sub-perpendicular and parallel to the paleoflow direction. Outcrops were analyzed through three measured sections (MS-1 to MS-3; total length ~360 ft, ~110 m) for lithology, grain-size, sedimentary structures, bounding surfaces, and deposit width, thickness, and orientation. Outcrop samples for petrographic analysis of thin sections were obtained at significant lithological changes along the traverses. Paleocurrent measurements (N=124, M=58°) based on the dip and azimuth of cross-stratification were acquired for multiple stratigraphic levels. Using a DJI Phantom 3 drone, high-resolution images were systematically acquired at three different distances from the outcrop (10-100 ft; 3-30 m). This was done to capture large-scale features such as channel geometries and architectural elements and small-scale features such as sedimentary structures. The georeferenced images were used to create a digital 3-D point-cloud model of Rattlesnake Canyon. Vertical lithofacies logs for 127 pseudo sections were created along the outcrops using a 30-ft (10-m) lateral spacing and 0.33 ft (0.1 m) vertical sample increment. The pseudo wells capture the bounding surfaces and lithofacies as exposed in Rattlesnake Canyon. The lithofacies logs and surfaces were used to create stratigraphic zones for geologic (static) models and to constrain lithofacies models.

Two 2-D model grids are oriented parallel to paleoflow, and two 2-D model grids are oriented perpendicular to paleoflow (Figure 3). One 3-D model grid was created. Both 2-D and 3-D grids have cell dimensions that are 3 ft x 3 ft x 0.3ft (1 m x 1 m x 0.1 m). The 2-D and 3-D models include the stratigraphic interval from the base of the uppermost channel in the Morrison Formation to the base of the Dakota Formation; thus, incorporating the entire Burro Canyon interval For each paleoflow orientation, the stratigraphic zones associated with the two 2-D grids reflect different levels of stratigraphic detail. The first grid has zones defined for each isolated-sandstone body (e.g., fluvial channel fill; Patterson et al., 2012) and amalgamated-sandstone body encompassed in floodplain mudstone (herein referred to as the sandstone-body model); note that smaller scale zones are not defined within the amalgamated-sandstone bodies. The second grid includes more stratigraphic detail and zones are defined for each channel fill (herein referred to as the channel-fill model; Figure 3). The 3-D model grid includes the same stratigraphic details and zones as defined for the 2-D channel-fill model. For the 3-D model, zones (channel fills) were mapped in three dimensions by using projected stratigraphic surfaces

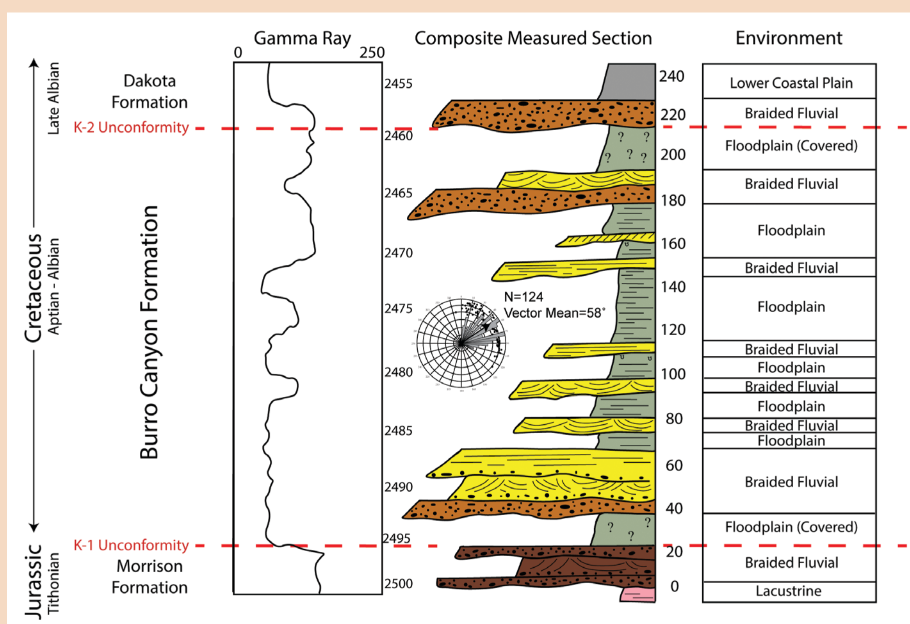

Figure 2: Composite measured section from Rattlesnake Canyon of the uppermost Morrison Formation Burro Canyon Formation, and lower Dakota Formation. Gamma-ray log from Mitchell Energy 8-1 Federal well (approximately 30 miles away). Includes rose diagram of Burro Canyon Formation paleocurrent measurements (N=124, vector mean=58 degrees).

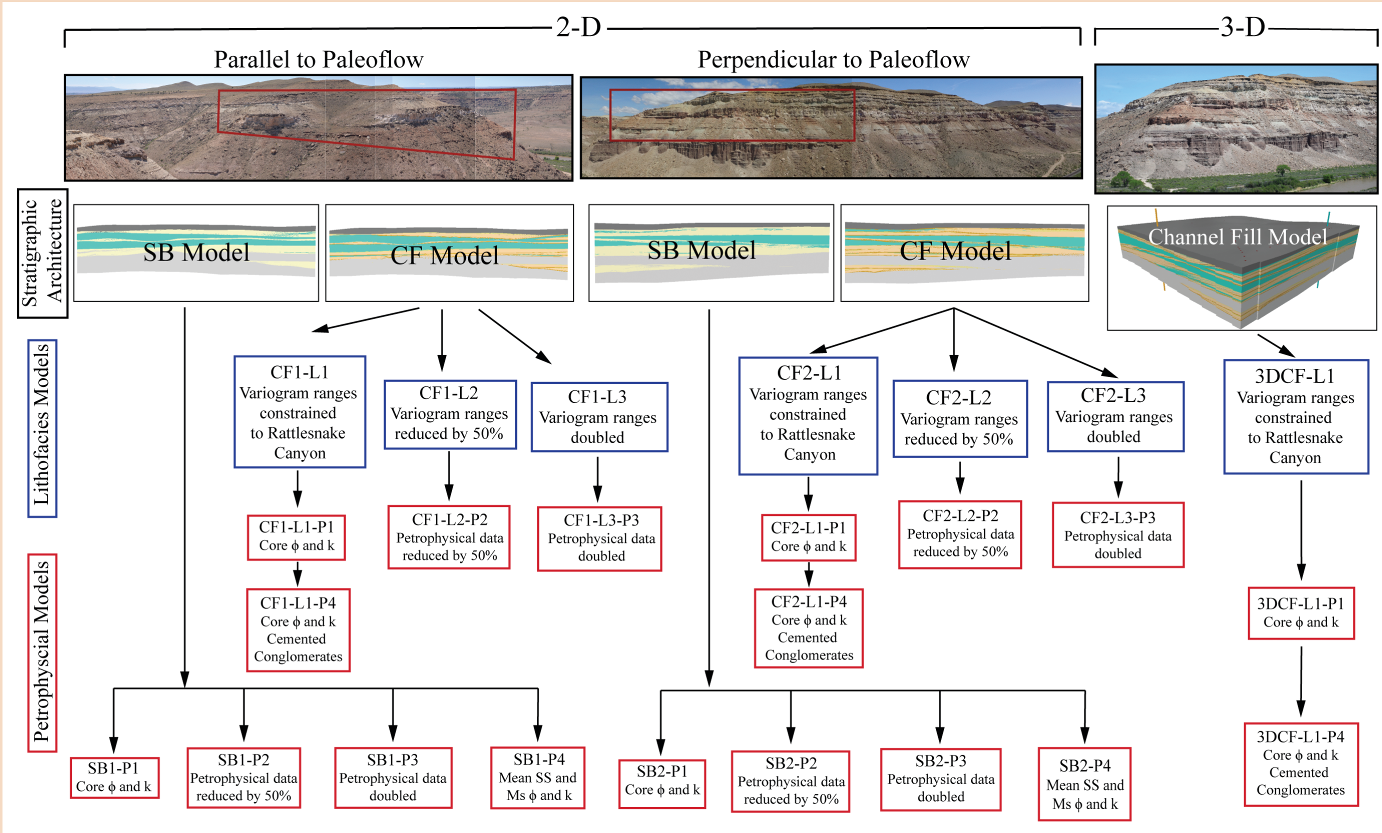

Figure 3: Diagram depicting model scenarios created using Burro Canyon Formation data from Rattlesnake canyon. Two-dimensional models have been oriented parallel and perpendicular to paleoflow directions. Within each 2-D orientation is a Sandstone Body (SB) model and a Channel-Fill (CF) model. SB models contain sandstone bodies along the outcrop and grouped together, individual channel fills and scour surfaces are not defined within this model. Within the SB model, four petrophysical scenarios are defined in each direction. CF models contain individually defined channel-fill deposits and incorporates zones of mudstone that may be present in between these channel fills. CF models are broken into three lithofacies models with associated petrophysical models. The 3-D model is classified as a CF model as it contains individually defined channel fill deposits; variogram ranges for lateral extent of lithofacies found in outcrop observations. The 3-D lithofacies model is used in two petrophysical models.

defined from the 3-D digital outcrop model and 151 pseudo wells. As with the 2-D channel-fill model, the channel fills that form each zone exist as both isolated sandstone bodies and more complex amalgamated sandstone bodies composed of stacked channel fills. Additional details are provided in Lewis (2018).

For each paleoflow orientation, eight different outcrop-based lithofacies were modeled within individual sandstone bodies of the channel-fill models using sequential-indicator simulation with the following data and constraints: (1) channel-fill models (lithofacies were modeled within each channel fill); (2) lithofacies logs for pseudo wells (N=38); and (3) variogram parameters. Variogram inputs were estimated from outcrop measurements of lateral and vertical lithofacies continuity derived from measured sections, pseudo well lithofacies logs, and the 3-D digital outcrop models. Three different lithofacies model scenarios were produced by using different horizontal variogram ranges to explore the impact of lateral lithofacies continuity on various reservoir performance metrics. A high-resolution 3-D lithofacies model was also constructed using sequential-indicator simulation.

For both paleoflow orientations, porosity and permeability models were generated using the sandstone-body models and channel-fill lithofacies models as constraints (Figure 3). High-resolution porosity and permeability models were created by either assigning mean values or mapped using sequential-Gaussian simulation (SGS) with the following data and constraints: (1) sandstone-body models or channel-fill lithofacies models; (2) triangular porosity and permeability distributions for sandstone and mudstone, or average values of porosity and permeability, or triangular porosity and permeability distributions for each lithofacies (core data from the Mitchell Energy Federal 8-1 well), and (3) variogram parameters.

For each sandstone-body model (for both orientations), four porosity and permeability model scenarios were generated (Figure 3). For the first model scenarios, triangular porosity and permeability distributions were used with SGS to map these properties within sandstone and mudstone model lithologies. For the second and third model scenarios, the porosity and permeability values were reduced by 50% and doubled, respectively, to test the impact on reservoir performance.

For the fourth model scenario a, more simplistic model was produced as mean values for sandstone and mudstone porosity and permeability were assigned to the corresponding model lithologies.

For each of the six channel-fill lithofacies models, a corresponding porosity and permeability model was generated (Figure 3). For the first porosity and permeability models, triangular porosity and permeability distributions for each lithofacies were used with SGS to map the properties. Second and third model scenarios, porosity and permeability values were reduced by 50% and doubled, respectively. Two additional porosity and permeability models were generated in each orientation that were conditioned to the first channel-fill lithofacies models. However, the final two models assume that the conglomerates are significantly cemented; therefore, the corresponding porosity and permeability values were reduced to a range of 0–8% (mean = 4%) and 0.001–0.5 mD (mean = 0.02), respectively, similar to previously documented cemented braided-fluvial deposits (Clarke, 1979; Cant and Eth, 1984).

Two 3-D porosity and permeability model scenarios were generated with sequential-Gaussian simulation using the 3-D lithofacies model as a constraint (Figure 3). The first model uses the same porosity and permeability histogram and variograms as with the first 2-D channel-fill porosity and permeability models. Like the 2-D cemented conglomerate scenario, a second set of porosity and permeability models were generated that assume the conglomerates are significantly cemented.

Two-phase oil-water fluid-flow simulations are performed using single injector and production wells with commercial reservoir simulation software. Models were constructed at reservoir conditions. Simulations for 2-D and 3-D models are each run for 100 and 120 years, respectively, to ensure water breakthrough. Simulations are evaluated in terms of 1) breakthrough time (BTT), 2) volumetric sweep efficiency (SE) at BTT, 3) recovery efficiency (RE) at BTT and at 100 years, and 4) cumulative production of oil, gas, and water at 100 years. For the swept volume calculation, cells were considered with water saturation greater than connate water saturation. The sum of the volume of these detected cells divided by the total cell volume of the model cells determines the SE.

RESULTS

The Burro Canyon Formation consists of alternating lenticular beds of fine- to medium-grained sandstones and conglomerates interbedded with gray-green mudstones. In Rattlesnake Canyon, the Burro Canyon Formation consists of eight lithofacies: (1) granule-pebble conglomerate; (2) trough cross-bedded sandstone; (3) chert-rich sandstone; (4) planar-laminated sandstone; (5) structureless sandstone; (6) low-angle planar-laminated sandstone; (7) fissile gray-black mudstone; and (8) gray-green mudstone. The Burro Canyon Formation contains isolated to amalgamated sandstone bodies that range from 3.7–33.8 ft (1.1–10.3 m) in thickness and often exhibit an upward-fining grain-size profile. The sandstones are generally conglomeratic at the base and beds thin upward into a fine- to medium-grained sandstone. Sandstone bodies are bounded at the base by sharp scour surfaces and are commonly amalgamated.

The Burro Canyon Formation represents a single depositional sequence that is composed of a lower amalgamated channel complex and overlying semi-amalgamated channel complex and consist of four key architectural elements (facies associations) that stack to form a depositional sequence: (1) channel complex (amalgamated, semi-amalgamated), (2) amalgamated fluvial-bar channel-fill deposits, (3) isolated fluvial-bar channel-fill deposits, and (4) floodplain fines (Figure 4). The largest architectural element, amalgamated channel complexes, consist of channel-fill elements that are vertically stacked and overlain by a mudstone-dominated interval of semi-amalgamated channel complex

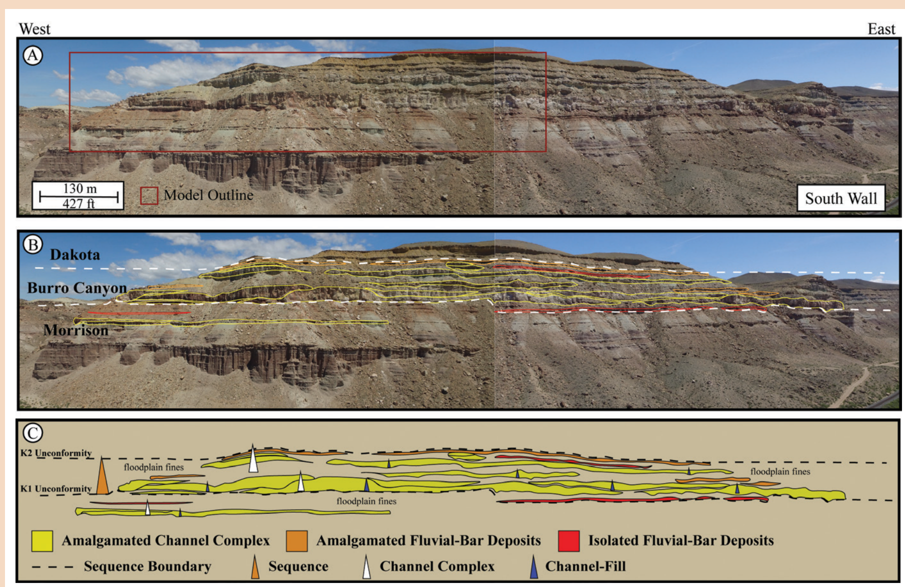

Figure 4: Photomosaic of architectural elements and hierarchical elements along the South Wall of Rattlesnake Canyon associated with those defined by Patterson et al., 2012 and Sprague et al., 2002. Facies associations are outlined in yellow, orange and red. Unfilled areas represent floodplain fines architectural element. A single sequence represents the entire deposition of the Burro Canyon and contains two channel complexes. The first being an amalgamated channel complex towards the base of the sequence, topped by a semi-amalgamated channel complex near the top of the sequence.

elements. The amalgamated channel complex is sandstone-prone and possesses an erosional base interpreted as a sequence boundary. Amalgamated fluvial-bar channel-fill deposits form sandstone beds with an upward-fining nature and are horizontal-planar laminated to low-angle planar-laminated lithofacies. Amalgamated fluvial-bar channel-fill deposits are encased in floodplain mudstones and are less extensive than amalgamated channel complexes. Amalgamated fluvial bars range from 4 to 35 ft (1.2 to 10.5 m) in thickness with width-to-thickness ratios range from 5:1 – 155:1. Isolated fluvial-bar channel-fill deposits are fining-upward sandstone successions encased in floodplain mudstones that together form a semi-amalgamated channel complex. Low-angle planar laminations and minor horizontal-planar laminations are common in these architectural elements and mudstone rip-up clasts occur irregularly throughout the deposits. Isolated fluvial-bar deposits are relatively thin and laterally continuous, averaging 2 ft (0.6 m) in thickness. The gray-green mudstones are interpreted as alluvial floodplain (floodplain fines) and are indicative of the Burro Canyon Formation throughout the Piceance Basin (Currie et al., 2008; McPherson et al., 2008). Floodplain deposits encase channel deposits, have no discrete boundaries, and are considered as non-reservoir rocks in this study (Figure 5).

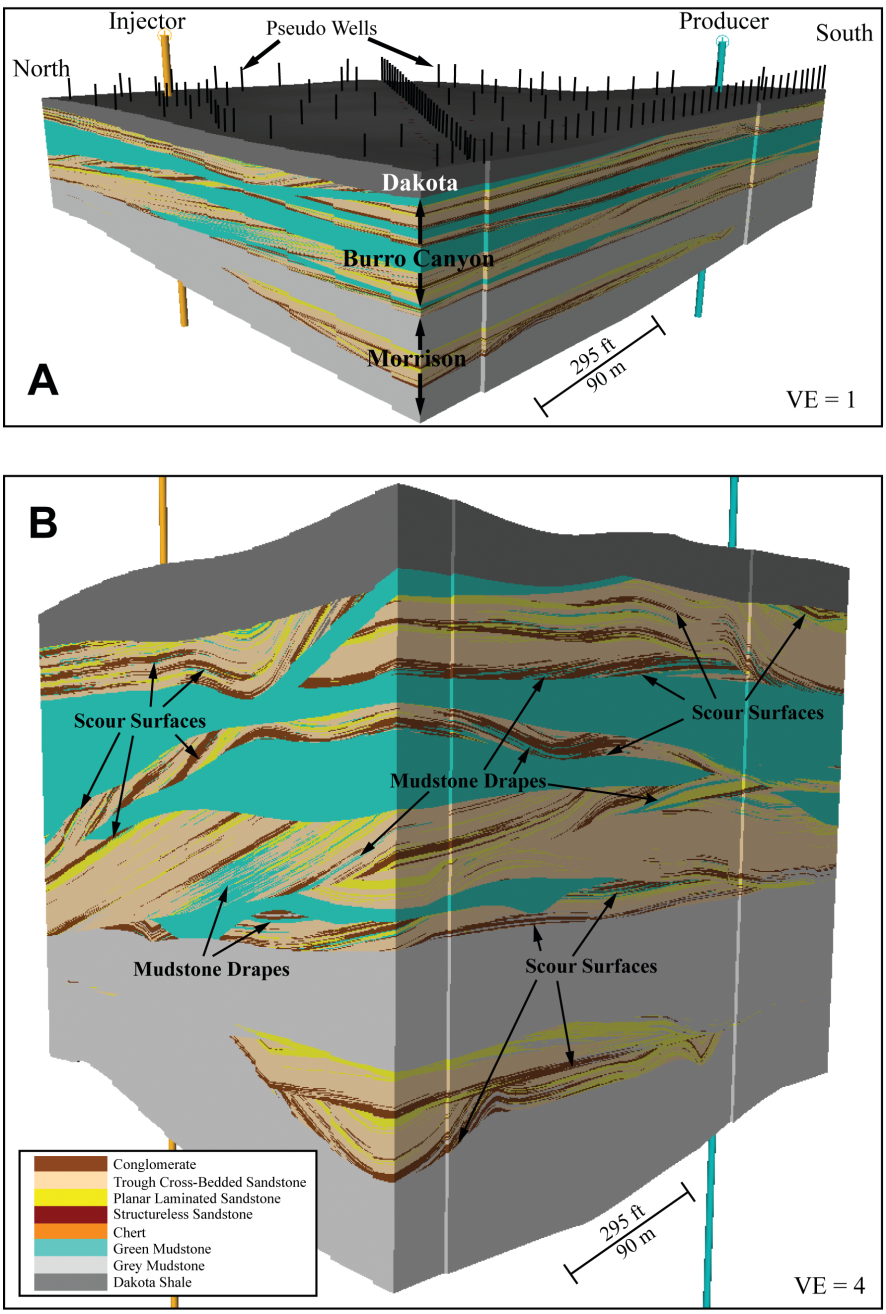

Figure 5: A) Three-dimensional static geologic model of Rattlesnake Canyon with no vertical exaggeration (VE=1). Black lines indicate position of 151 pseudo wells created to constrain geologic model. B) Vertically exaggerated (VE=4) three-dimensional static geologic model of Rattlesnake Canyon. Vertical exaggeration reveals scour surfaces and internal mud drapes within individual channel complexes of the Burro Canyon Formation. Basal conglomerates can be seen dividing up individual scour surfaces within channel complexes showing locations of individual channels.

Comparison of breakthrough time (BTT), sweep efficiency (SE) at BTT and 100 years, recovery efficiency (RE), and cumulative production of oil and water illustrates the effects of reservoir heterogeneity on fluid flow. Reservoir heterogeneity has a significant impact upon BTT. As a reference case, in general sandstone-body models with assigned mean values for porosity and permeability have the longest BTT as they exhibit more "piston-like" displacement. In contrast, petrophyscially heterogeneous sandstone-body and channel-fill models that are constrained by outcrop-based spatial statistics (variogram ranges) produce, on average, 43% and 46% shorter BTT, respectively, as compared to petrophysically homogeneous sandstone-body models. On average, due to greater sandstone connectivity, models oriented perpendicular to paleoflow experience a 9% shorter BTT than models oriented parallel to paleoflow. For both orientations, the homogenous sandstone-body models produce the longest BTT. In general, BTT is less sensitive to changes in variogram range (only 1% difference). Incorporating cemented conglomerates, which account for 21% of lithofacies, has a more significant impact on BTT causing, on average, 9% shorter BTT for 2-D models (both orientations) and

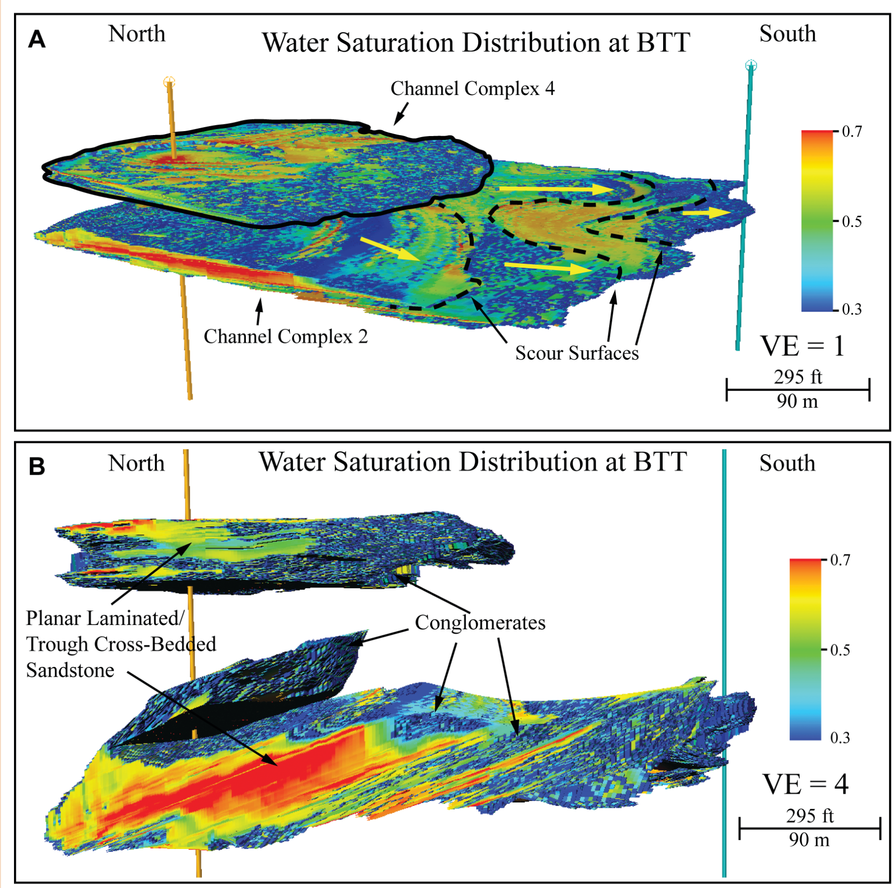

Figure 6: Three-dimensional dynamic reservoir model for 3DCF-L1-P1 model. This three-dimensional reservoir model was simulated through breakthrough time. Resulting water saturation model is shown depicting reservoir saturation at breakthrough time. A) Amalgamated channel complex shows the most efficient fluid flow pathways for production.. Individual channel scours and flow pathways can be observed in this channel complex. B) When the water saturation distribution is magnified (VE=4) fluid-flow pathways can be observed. Water saturation is largely confined to the main channels of the reservoir in the trough cross-bedded and planar laminated sandstones. Low water saturation is observed in the conglomeratic intervals of the formation.

32% short BTT for 3-D models.

Two-dimensional models orientated perpendicular to paleoflow exhibit 16% higher SE than those oriented parallel to paleoflow. For 2-D models with cemented conglomerates, SE is 26% lower perpendicular to paleoflow and 23% lower parallel to paleoflow. The base-case 3-D model exhibits an average SE of 32% (Figure 6). Cemented conglomerates in 3-D produced 28% higher SE than in the base-case 3-D model.

RE for oil is the ratio of cumulative oil volume produced for a specified time period divided by the oil volume initially in place. RE is calculated at BTT and also at the end of the 100-year simulation period to insure full BTT of 3-D models. RE is sensitive to similar parameters as SE. Perpendicular to paleoflow, 2-D models on average, result in 14% higher RE than parallel to paleoflow. RE for cemented channel-fill models, perpendicular and parallel to paleoflow, are 15% and 13% lower, respectively, than channel-fill models that incorporate outcrop-derived spatial statistics. RE is less sensitive to changes in variogram range. For 3D models, RE is 22% lower with the cemented conglomerates as compared to the 3-D base-case model. On average, models perpendicular to paleoflow produced 23% more oil than those parallel to paleoflow. Variations in variogram range produced limited change in the cumulative oil produced at 100 years. For models with short ranges, a 4% increase in cumulative oil volume produced is observed as compared to models with outcrop-based ranges. For models with long ranges, a 6% decrease in cumulative oil volume produced is observed as compared to the models with outcrop-based ranges. Shorter variogram ranges show an increase in cumulative oil volume produced; however additional simulations are needed to confirm the magnitude of the increase.

Petrophysically homogeneous sandstone-body models exhibit SE and RE at BTT that are 37% and 27% greater, respectively, than heterogeneous channel-fill models that are constrained by petrophysical properties based on outcrop spatial statistics. Incorporating and honoring the petrophysical properties of each facies rather than having a wide distribution across facies decreases both SE and RE. Heterogeneous channel-fill models exhibit, on average, 21% lower SE at BTT and 5% lower RE at BTT than relatively homogeneous sandstone-body models. For the different heterogeneous channel-fill models, changes in the variogram range had limited effect on SE (1%) or RE (1%). Incorporating cemented conglomerates reduced cumulative oil production by 49% as compared to channel-fill models with non-cemented conglomerates. Intuitively, cement forms barriers that create tortuous fluid-flow pathways in the reservoir.

DISCUSSION

Characterization and modeling of fluvial reservoirs are challenging because fluvial reservoirs are heterogeneous at different scales as related to the stratigraphic framework, architectural elements, and lithofacies (Jackson, 1977; Miall, 1988; Willis, 1989; Sharp et al., 2003). Fluvial reservoir connectivity varies at the field scale owing to the stratigraphic variability in sandstone-body stacking patterns (e.g., Robinson and McCabe, 1997; Willis, 2007; Pranter et al., 2009; Smith et al., 2009), and lithofacies associations (architectural elements) exhibit internal heterogeneity that impacts fluid flow (e.g., Pranter et al., 2007; Fustic et al. 2011; Hubbard, et al., 2011; Labrecque, et al., 2011).

The results of this outcrop-analog study further illustrate how channel architecture and lithofacies heterogeneity of a fluvial reservoir can act as baffles or barriers to fluid flow within a reservoir and impact the spatial distribution of petrophysical properties, fluid-flow behavior, and reservoir performance in terms of BTT, SE, and RE. The representation of stratigraphic and lithofacies architecture and petrophysical properties within modeled fluvial deposits is important depending on the degree of heterogeneity.

Given the geometries and spatial variability of Burro Canyon Formation architectural elements and the relatively low net-to-gross ratio, a high well density is required to effectively deplete the reservoirs. Channel-fill reservoir bodies contain fine-scale lithologic heterogeneity and directional permeability associated with trough cross-bedded sandstone, planar-laminated sandstone, conglomeratic beds, and other facies that influence fluid movement throughout the reservoir. Given the connectivity ratios of the architectural elements present in Rattlesnake Canyon, sandstone connectivity and channel amalgamation is greatest perpendicular to paleoflow direction, indicating swifter BTT. This result indicates when producing a braided-fluvial reservoir with similar amalgamated and semi-amalgamated channel complexes, it would be favorable to align production-injection well pairs such that displaced fluids flow perpendicular to paleoflow direction to achieve higher SE and RE. Because upward-fining grain-size trends can partially compartmentalize the reservoir vertically and reduce SE, deviated wells might be preferred depending on the magnitude of grain-size variability. However, if lithological variability exists and vertical wells are used, producer-injector well pairs should be aligned perpendicular to the paleoflow direction to maximize SE.

CONCLUSIONS

The Burro Canyon Formation as exposed in Rattlesnake Canyon, Colorado, forms stacked amalgamated and semi-amalgamated channel complexes that consist of amalgamated and isolated fluvial-bar channel deposits and floodplain fines, and represents a low-to-moderate sinuosity, braided-fluvial system. Detailed two- and three-dimensional static and dynamic models of the deposits that are constrained to stratigraphic measured sections, outcrop gamma-ray measurements, and UAV-based (Unmanned Aerial Vehicle-based) photogrammetry illustrate the impact of stratigraphic, facies, and petrophysical heterogeneity on reservoir performance. Resulting BTT and SE suggest subsurface reservoir performance is most effective perpendicular to paleoflow direction in amalgamated channels. Perpendicular to paleoflow, BTT is 9% shorter than parallel to the paleoflow and SE is, on average, 16% greater due to greater sandstone connectivity in this orientation. Variability of preserved channels, scour surfaces, and lateral pitchouts results in lower RE. Facies heterogeneity can account for 50% variation in BTT and lower RE (5%). Cemented conglomerates that form channel lags above basal scour surfaces can also create fluid-flow barriers that increase BTT and decrease SE (25%) and RE (22%).

ACKNOWLEDGEMENTS

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PRESIDENT'S COMMENTS

In this edition of the Sedimentary Record there is a notice about a Tribute to George Pemberton that will appear on the SEPM 'In Memory' page. George passed away in July, so I am thankful that back in June I had been able to inform him that he had been awarded the Twenhofel Medal, the highest award of the Society. He told me he was *'truly overwhelmed by this news as I never considered myself worthy of such an honour'*: anyone who knew George and his work will have no doubt that he was indeed worthy.

Medals and Awards provide an opportunity for our community to recognise scientists who have made a significant contribution to sedimentary geology. In the context of the history of our society over nearly a century as predominantly focussed on North America and the history of our science as having been male-dominated in the past, it comes as no surprise to find that most recipients have been North American men. However, sedimentary geology, like the rest of earth sciences, is changing, becoming more diverse in every sense and it is important that SEPM reflects these changes. We are starting to see some change in the recipients of SEPM awards who have been coming from a wider range of countries and backgrounds in recent years. However, the trend needs to continue and the awards committees need help from the community with suggestions of suitable nominees - there is a nomination form on the SEPM Website.

People join societies because they identify with its purpose and with other members: broadening the range of people who receive awards will help our society appeal to a wider group of people working in sedimentary geology. SEPM Council held a strategy meeting recently and considered other ways in which the society could grow by attracting a more diverse membership. A number of the initiatives discussed will need further development, but there is a common theme of providing more benefits to members and to the community in general. The initiatives include supporting more workshops and meetings both in North America and elsewhere, affiliating with more local sedimentology groups internationally and with societies representing related disciplines, and generally providing more resources to our community (including on-line resources, more of which in the next edition of the Sedimentary Record). There are financial commitments associated with these activities, but they are an investment in our society with the intention of encouraging its growth.

Every member of SEPM can help the society grow, and if you are one of the 36% who is resident outside of N. America your assistance is particularly welcome in the following ways:

- contact an SEPM Ambassador if there is one in your country (www.sepm.org/Ambassadors) and put them or anyone on Council in touch with any local organisations with similar scientific interests;
- are there any meetings or workshops in your country that SEPM could support;
- make students aware of the awards and grants available to them from SEPM;
- encourage colleagues to join;
- and, of course, consider nominating somebody from your local sedimentary geology community for a medal or an award.

Gary Nichols,
SEPM President 2018-19

SEPM Society for Sedimentary Geology
"Bringing the Sedimentary Geology Community Together"
www.sepm.org

SEPM In Memory

SEPM remembers its members that have passed away on its In Memory page (www.sepm.org/In-Memory).
Recent losses in 2018 include: S. George Pemberton, Robert Folk, Joanne Kluessendorf, Robert Dott and Chris Edwards.

THE GEOLOGICAL SOCIETY OF AMERICA®

SEDIMENTARY GEOLOGY DIVISION

SEDIMENTARY GEOLOGY DIVISION

Fall 2018 Newsletter

If dynamic sedimentation piques your interest, 2018 is quite the year! Event sedimentation is as dynamic as it gets, and source to sink interconnections are becoming more clear as they play out in drought-ridden and burned landscapes in the west, and in flooded deluges in the east. Never has our world needed more scientific expertise in understanding, predicting, and mitigating active sedimentation. The Geological Society of America, and specifically the Sedimentary Geology Division in collaboration with our partner societies like SEPM, bring together that expertise, the best new science, in an exciting forum for professionals and students.

GSA 2018

4–7 November

Indianapolis, Indiana, USA

Join us this year at the GSA annual meeting, where the Sedimentary Geology Division has sponsored or co-sponsored 27 Topical Sessions!

And don't forget Seds and Suds!!

Join us Tuesday, 6 November 2018: 6:00 PM - 8:00 PM, Indiana Convention Center, Sagamore Ballroom 3, for a stimulating evening of talk about SEDS while enjoying the requisite SUDS (and appetizers)! We will recognize the winners of the Sloss, Laubach, and Student Research Awards and give away door prizes.

We will also roll out the exciting international collaboration network that the SGD Student Representative(s) have been creating. Catch up with your SGD colleagues and meet new connections!

Check Out the SGD/SEPM Student Poster Session!

Sedimentary Geology Division/ SEPM Student Research Competition: Dynamics of Stratigraphy and Sedimentation (Posters)

Monday, November 5th, Halls J-K Indiana Convention Center

See the rising wave of new sedimentologists and stratigraphers at the 40 poster-rich SEPM/ SGD Poster Session! Thanks to the generosity of SEPM and SGD, student authors of the top four ranked posters will be awarded $500! If you are interested in being a judge, and don't have a student in the session, please e-mail SGD Vice Chair, Dr. Amy Weislogel: Amy.Weislogel@mail.wvu.edu

https://gsa.confex.com/gsa/2018AM/webprogram/Session45293.html

Sedimentary Geology Division Awards

The **Laurence L. Sloss Award** for Sedimentary Geology is given annually to a sedimentary geologist whose lifetime achievements best exemplify those of Larry Sloss—i.e., achievements that contribute widely to the field of sedimentary geology and service to the Geological Society of America.

The Sedimentary Geology Division is pleased to announce **Dr. Kenneth G. Miller** (Rutgers University) as the 2018 Laurence L. Sloss Award 19threcipient.

Kenneth Miller in Green River Utah

Kenneth G. Miller is a Distinguished Professor in the Department of Earth and Planetary Sciences of Rutgers, The State University of New Jersey. He received an A.B. from Rutgers College (1978) and a Ph.D. from the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Oceanography (1982). As author of over 100 peer-reviewed scientific papers, his most significant publications include a widely cited synthesis of Cenozoic oxygen isotopes (Miller et al., 1987) and a synthesis of global sea-level change (Miller et al., 1998, 2005). He has previously been awarded the Rosenstiel Award from the University of Miami (2003) and is a two-time JOI/USSAC (1995, 2006) and AAPG (2014) Distinguished Lecturer.

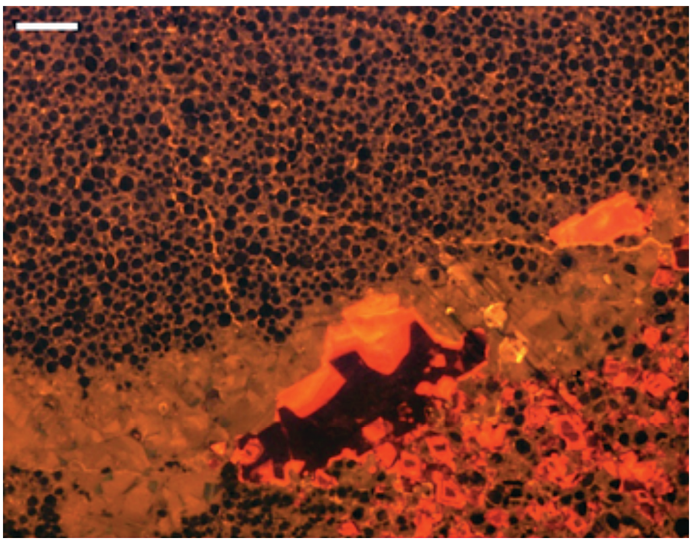
Ken is the consummate sedimentary geologist: Integrating biostratigraphy, sedimentology, seismic stratigraphy, and sequence stratigraphy. His work has established the New Jersey margin as a global laboratory in the study of Cenozoic sea-level change. His passion and commitment has also inspired countless students, colleagues and collaborators. This collaborative and integrative approach have been integral in the advance of our understanding of global controls on the stratigraphic record that he and his team have made over the last three decades.

The **Stephen E. Laubach Structural Diagenesis Research Award** promotes research combining structural geology and diagenesis, and curriculum development in structural diagenesis.

The Sedimentary Geology Division and the Structure and Tectonics Division of GSA is pleased to announce **Dr. William T. Jackson, Jr.** as the recipitent of the 2018 Stephen E. Laubach Structural Diagenesis Research Award. William is an Assistant Professor of Geology at the University of South Alabama. He will use his $2500 award to support his work entitled "Exploring the control of depositional environments on the expression of Laramide soft-sediment deformational structures in the Elk Basin anticline, northern Bighorn Basin, USA". We look forward to hearing more about his research in Indianapolis!

Will Jackson in the field in Wyoming

The **Sedimentary Geology Division Student Research Award** is given to an outstanding student grant proposal in the field of sedimentary geology and stratigraphy. **Augustin Kriscautzky**, has been selected as the **2018 SGD Student Research Grant Award** for his Ph.D. project entitled: "Using Precambrian Molar-tooth structure to test geochemical proxies". This $1000 award will fund his research and travel to GSA. Congratulations!



Augustin Kriscautzky, 2018 Student Research Award winner (top), and a petrographic cathodoluminescence image from his research. Agustin is working to understand distinct diagnetic pathways reflected in complex carbonate fabrics, and to better understand the geochemical signals of diagenesis (scale = 50 microns)

Bylaw Revisions Ballot Fall 2018

The Management Board of SGD requests your support by voting yes to our proposed revisions which update our Bylaws. We feel these will help the division be more effective at helping all our members and more clearly define the roles and responsibilities of division officers.

The Bylaw revisions include elections for the Student Representative position, making the Student Representative a voting member of the SGD Management Board, and outlining their responsibilities. Additional revisions include increasing the term of the Secretary Treasurer from 2 years to 3 years to ensure continuity, defining responsibilities and duties for officers, and creating a new section for procedures for removing chairs who are not active or violate the GSA Code of Ethics. Lastly revisions move the procedures for award nomination and selection into separate documents. To see a copy of the revised bylaws please go to: https://community.geosociety.org/sedimentarygeologydiv/home and look on the "Newsletters and Resources" pulldown tab.

Election for SGD Secretary Treasure

SGD member, Dr. Linda Kah, is stepping down from her position as the Secretary-Treasurer of the Sedimentary Geology Division of the Geological Society of America. We thank her for her dedication to the SGD and the continuity that she has provided over the last decade.

The Secretary-Treasurer position is the only member of the SGD board that can be re-elected for consecutive terms. If bylaw revisions are approved, the new term will be 3 years, with the change in personnel begin immediately following the annual business meeting.

Two candidates have expressed a desire to take on this important work during the next term; Sam Hudson and Brett McLaurin. Please find their biographies and personal statements below.

SGD Secretary-Treasurer Candidates

Sam Hudson has been an Assistant Professor at Brigham Young University since 2014. He received an MS from UNLV studying salt-sediment interaction and fluid migration in La Popa, Mexico, and a PhD from the University of Utah, where he focused on basin analysis and shale geochemistry of the South Caspian Basin. After his PhD, he worked at ConocoPhillips for six years (in the basin modeling, geomodeling, and sed/strat technology groups), and as an exploration geologist in the Gulf of Mexico and offshore Canada for 3 years. His current research is focused on fluvio-deltaic and shale systems, with a focus on understanding depositional processes involved in facies heterogeneity. Though most of his current research is directed towards these systems, he considers all good rocks are fair game. Sam wants to be more involved with GSA

– “GSA was an important society for me as a student and continues to be valuable to me today. Attending the annual meetings and seeing the breadth of research happening globally gets me excited as a scientist, and sharing my work with others makes it better and helps me see connections to other ideas and disciplines. As a graduate student, I received funding from GSA to help with my research, which I have always been grateful for. I'd like to help out with the Sedimentary Geology division by serving as the Secretary-Treasurer so that I can pay it forward. Helping to inspire and support young geologists is one of the primary responsibilities and privileges of the society in my opinion, and if I can help to make that happen through this position I will. The sedimentary geology community, from academics to industry, is an awesome group of people, and if I can help make it even a little bit better by serving, I'm all for it.”

Brett T. McLaurin, is a Professor at Bloomsburg University of Pennsylvania where he has taught since 2007. His research and teaching deal with both sedimentary geology and sedimentology. He received his BS and MS from UNC-Wilmington, and his PhD from the University of Wyoming, joining Bloomsburg University after a postdoctoral stint at UNLV.

Brett has already served as a GSA Representative to the North American Commission on Stratigraphic Nomenclature (2006-2009), and as a GSA Campus Representative (2008-Present). He has also been involved in the EarthCube End-User Workshop for Sedimentary Geology (2013, 2015).

Brett notes that “It is critical to the growth of the Sedimentary Geology Division that we strive to express the importance of sedimentary geology to real-world applications. By demonstrating the value of sedimentary geology research to natural hazard delineation, health risk assessment, and non-fuel resource development, we can position the SGD to expand its interdisciplinary efforts and influence. A key aspect of continued growth of the organization is to recruit and encourage student participation in the SGD at the Annual meeting as well as Section meetings.”

2018 Sedimentary Geology Division Officers:

Chair – **Gary Gianniny**
Vice Chair – **Amy Weislogel**
Secretary Treasurer – **Linda Kah**
Student Representative – **Angela Delaloye**
Webmaster – **Stefania Laronga**

2018 Joint Technical Program Committee:

Piret Plink-Bjorklund (Colorado School of Mines), **Ryan Morgan** (Tarleton University)

@GSA.SGD

CALL FOR TOPICS – SESSIONS, WORKSHOPS, FIELD TRIPS

Submissions open on September 1st, 2018 and closes on November 30th, 2018

To foster continued interaction between the many sub-disciplines of sedimentary geosciences, sessions should be proposed under the umbrella of two broadly designed themes:

Theme 1: Geodynamic and tectonic evolution of the continents and their margins: implications for ancient depositional systems.

Theme 2: Ocean-atmospheric controls on surface processes: evolution of life, landscapes, and the sedimentary record.

Email Session Topic, Short Course/Workshop and Field Trip proposal submissions to: SEPM2020Topics@sepm.org

- Topics should have title, short description and suggested key speakers
- Courses, Workshops and Field Trips should have title, short description, number of days and leaders/instructors.

CALL FOR ABSTRACTS NOW OPEN - SUBMIT TODAY

Deadline for Submissions: 11 October 2018

To begin your submissions follow the instructions at these links.

- SUBMISSSION GUIDELINES https://ace.aapg.org/2019/technical-program/information-for-presenters
- THEMES AND SUBTHEMES https://ace.aapg.org/2019/technical-program/program