MudToc Consortium

Fall 2020 Sponsor Meeting

Meeting: Thursday, November 19th, 2020 – Via ZOOM Invite

Website: (With access to Archival Consortia Information: Bakken, Niobrara & Vaca Muerta)

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Evaluating Production Performance of Permian Basin Wells to Improve Hydrocarbon Recovery

Ozan Uzun, Ph.D. Candidate, Department of Petroleum Engineering, CSM

Abstract

The Permian Basin is one of the most prolific oil and gas producing geologic basins in the United States. Permian Basin spans West Texas and Southeastern New Mexico. It has supplied more than 33.4 billion barrels of oil and 118 Tcf of natural gas during a 100-year period (EIA 2018). The ever-increasing water production and usage in the Permian Basin requires produced water management by the operators. Classical waterflooding in unconventional reservoirs is not plausible because of the small pore size and low permeability of shale matrix. Therefore, creative approaches are needed to increase the oil production without relying on large quantities of water injection to displace oil favorably. The practical alternative is cyclic or continuous gas injection which is one objective of my research to increase oil production.

As a preliminary study, I reviewed and organized the production data for the wells that have been drilled into the Wolfcamp Formation of the Delaware Basin in the last eight years. In addition, I performed production decline analysis and Rate Transient Analysis (RTA) on several wells from the Delaware Basin to determine the stimulated formation permeability to determine stimulation effectiveness. This portion of the work will continue as a routine matter.

Unconventional reservoirs are heterogeneous and show strong velocity anisotropy (Vernik and Milovac 2011). Quantifying velocity anisotropy and geomechanical properties are important for reservoir characterization. Thus, I conducted experiments on selected cores from two wells in Delaware basin to determine permeability, porosity, and pore compressibility. Experimental results showed that the pore compressibility decreases with increasing quartz content.

Furthermore, using the data from the MUDTOC existing reports from four different wells, static and dynamic elastic properties, Young's Modulus (E), Bulk Modulus (K), and Poisson's Ratio (v), were compared. The core data and log data were used to obtain a static/dynamic relationship between static and dynamic stiffness coefficients. The results were used as the foundation for a future geomechanics-based reservoir modeling effort.

As for the future, I will conduct **reservoir engineering assessment** and **core flooding experiments** to arrive at a method to improve oil production. For example, the experiments will include injecting low-sanity brine at reservoir conditions with and without a non-ionic surfactant. Other experiments will include the use of Beckman high-speed centrifuge (ACES200) with a 3-rotor system to determine capillary pressure magnitudes for different displacement methods, and saturation endpoints for oil, gas and free gas for each displacement method. I will also

conduct core flooding experiments using Formation Response Tester 6100 (FRT-6100) at reservoir pressure, temperature and confining stress.

In conjunction with the experiments, I built a conceptual compositional dual-porosity reservoir model using CMG-GEM commercial reservoir modeling software. Next, I will use the production data from several wells to characterize the reservoir behavior for Permian Basin during production and I will perform sensitivity analysis to identify the parameters which impact the reservoir performance most. The ultimate goal is to combine geology, fluid flow theory, experimental observations, and reservoir simulation to evaluate production performance and to improve hydrocarbon recovery in the Permian.

Finally, I will evaluate the current machine learning models using data from hydraulic fracture treatments and the associated production data to arrive at an optimal hydraulic fracture design. To accomplish this, I will be collaborating with GOHFER commercial software team. We will build a workflow to be used in GOHFER to arrive at more accurate model interpretations using statistically quantified inputs from many treatments. The first step in this effort (the petrophysics analysis) is to create synthetic logs for the wells when they are not available. I will start with the wells in Ward County, TX.

Reservoir Characterization of the Wolfcamp Formation in Reeves County, Delaware Basin, West Texas

Vicky Yeap, M.S. Student, Department of Geology and Geological Engineering, CSM

Abstract

The Pennsylvanian-Permian Wolfcamp Formation of the Permian Basin in West Texas and New Mexico is one of the most important and actively pursued unconventional plays in the world. In most areas, the Wolfcamp is over 2000 ft thick and contains multiple, stacked pay intervals. A 2018 United States Geological Survey assessment evaluated the potential of technically recoverable and undiscovered resources of the Wolfcamp Formation in the Delaware Basin to contain 29,476 MMbbl of oil, 220,824 Bscf of gas and 14,907 MMbbl of NGLs. The vast opportunities available have sparked interest in understanding the complexity and heterogeneity of the Wolfcamp strata and their impacts on reservoir performance.

The Wolfcamp Formation records deepwater deposition of organic-rich mudstones interbedded with calcareous mudstones, siltstones and carbonates that were deposited in a mixed siliciclastic-carbonate fan system. This fan system resided in a semi-restricted basin with sediment originating from multiple sources. Wolfcamp strata comprises mass movement and sediment gravity flow deposits separated by background hemipelagic settling. The Wolfcamp Formation is subdivided into four benches, from youngest to oldest as Wolfcamp A, B, C and D. Each bench differs in lithology, fossil content, porosity, total organic carbon (TOC), thermal maturity and log signatures. Understanding the geological processes and characteristics that comprise of each member of the Wolfcamp Formation is key for future exploration and help in selecting the best landing zones.

The objective of this study involves using core, core associated data and logs sourced from the Wolfcamp play to investigate the vertical variability seen in the different Wolfcamp benches. The key dataset used in this study is the Cimarex Thunder C20-13 #2H well located in Reeves County, Texas. This study utilizes a 739.5 ft cored section that make up portions of Wolfcamp A, B, C and top of D. An integration of detailed core description, X-ray Diffraction (XRD), X-ray Florescence (XRF), Routine Core Analysis (RCA), Source Rock Analysis (SRA), Field Emission Scanning Electron Microscopy (FE-SEM) imaging, geomechanical analysis and petrophysical well logs was utilized in this study to identify types of facies, facies characteristics and associated reservoir properties. Nine lithofacies were identified with considerations including mineral composition, grain size, grain shape, sorting, color, fabric and sedimentary features. The reservoir properties of each lithofacies was evaluated and identified were one primary reservoir facies, three secondary reservoir facies and five nonreservoir facies. Analyses of the facies distribution and stacking patterns aims at providing insights to changes in depositional setting and climatic fluctuations at the time of deposition. In order to extrapolate beyond the cored section, methods to reliably translate observations from core to

petrophysical log responses will be investigated. Establishing a core to log model is aimed at allowing lateral correlation of facies with the end goal of predicting higher quality reservoir units and noting of potential baffles and barriers.

Modeling Geologic Controls on Hydrocarbon Generation in the Wolfcamp: Integrated Analysis of the Delaware Basin, West Texas

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Abstract

The Permian Basin has become a critical source of oil and gas in the United States. Developments in unconventional resource extraction have driven the United States to reach milestones in the energy industry, including becoming a net energy exporter for the first time in decades, as well as becoming the largest oil producer in world exceeding 13 million barrels of oil per day in 2019, with nearly 5 million bpd coming from the Permian. Natural gas produced from the Permian also exceeded 20 billion cubic feet per day in 2019, propping up Texas to produce more natural gas than any other state. The unconventional nature of the Delaware Basin's stacked, heterolithic reservoirs require integrated geological and engineering solutions to continue to lead America's oil and gas production.

The stratigraphy of the Delaware Basin contains multiple intervals of organic-rich source rocks with varying degrees of thermal maturity. Multiple publications have identified a trend in the gas-oil ratio in the Delaware Basin, characterizing the western side of the basin with a significantly higher gas production on the shallower, gently dipping flank of the basin. Varying levels of uplift and erosion, as well as variable spatial and temporal geothermal gradient are both leading explanations for the anomalous spatial change in gas-oil-ratios.

In order to increase understanding of the geologic controls on hydrocarbon generation in the basin, examination and modeling the geologic history identified critical moments in formation of the petroleum system and illuminated areas that require further investigation. The burial history integrates thermal and structural history of the basin, eustatic sea level change, and tectonic subsidence to interrogate timing and magnitude of hydrocarbon generation from the organic-rich intervals. Measured thermal, geochemical, and mechanical well data were used as constraints to calibrate 1D basin models across the basin. Vitrinite reflectance, Rock-Eval pyrolysis, and bottom hole temperatures (BHT's) are all sources for calibration of models by fitting calculated curves to measured well data. Burial history analysis and sensitivity analysis were used to characterize geologic variability across the basin, followed by uncertainty analysis of the results with respect to hydrocarbon generation with emphasis on the Wolfcamp.

Results from the models identify that Wolfcamp peak oil and gas generation occurred in the late Triassic. The Wolfcamp experienced compaction by the end of the Permian due to rapid tectonic subsidence, resulting in maximum porosity and permeability reduction prior to the onset of hydrocarbon generation. Testing the models' sensitivity with respect to the key geologic and geochemical uncertainties identified paleo heat flow and mechanical compaction of the Wolfcamp as influential parameters in calculating both timing and magnitude of

hydrocarbon generation. Results from the thermal models show present day heat flow is not capable creating the thermal and geochemical signatures preserved in the sediments in the western edge of the basin. The western edge experienced a higher paleo geothermal gradient following the Permian basin phase that contributed to higher thermal maturity of the Wolfcamp, converting in-situ hydrocarbons to a more gaseous phase.

Reservoir Characteristics and Production Analyses for the Niobrara A Interval at Redtail Field, Weld County, Colorado

Scott Manwaring, MS Student, Department of Geology and Geological Engineering, CSM

Abstract

The Cretaceous Niobrara Formation of the Denver Basin in northeast Colorado and southeast Wyoming received renewed interest since the success of EOG Resources' horizontal Niobrara 02-1H Jake well in Hereford Field, Weld County, Colorado, in 2009. The coupling of horizontal drilling with multi-stage hydraulic fracturing have caused the Niobrara Formation in the Denver Basin to become a heavily drilled target with nearly 5,000 horizontal wells drilled during the period from 2009 to end of year 2019. These wells targeted the Niobrara (A, B, C, and Fort Hays) Formation and the Codell member of the Carlile Formation. Production during this time is approximately 540 million barrels of oil and 2.7 trillion cubic feet of gas. The majority of development has occurred in Wattenberg Field, Weld County, Colorado, and lesser development in: Silo Field, Laramie County, Wyoming; Fairway Field, Laramie County, Wyoming; Hereford Field, Weld County, Colorado; and Redtail/East Pony Fields, Weld County, Colorado.

The Niobrara Formation consists of two members, from oldest to youngest: the Fort Hays Limestone, and the Smoky Hill Member. Within the Smoky Hill Member, the Niobrara is divided into four benches, from oldest to youngest: the Niobrara D, C, B, and A. These benches are demarcated by series of alternating chalks and marls. Additionally, each bench differs in fossil assemblages, porosity, permeability, total organic carbon, thermal maturity, and log signatures. The majority of production has come from wells that target the Niobrara B interval, rather than the underlying Niobrara C and D intervals, or the overlying and sometimes missing Niobrara A interval. However, in the vicinity of Redtail Field, sufficient thickness of the Niobrara A interval allows the development of this bench. At present, 108 wells have targeted the Niobrara A interval at Redtail Field, where a total of 331 wells have been drilled. These wells represent the only extensive commercial development of the Niobrara A interval in the Denver Basin.

The objective of this study is to explain how and why development of the Niobrara A interval is possible in the vicinity of Redtail Field and not in other areas of the Denver Basin. This question will be answered using the following data: core and core associated data and logs from the Redtail Field area; total organic carbon and pyrogram analyses; examination of production data to determine economic viability at Redtail; extrapolation of production analyses and core-to-log models to the larger Denver Basin.

Reservoir Characteristics for the B Interval of the Niobrara Formation in the Redtail Area, Weld County, Colorado

Adam Simonsen: MS Student, Department of Geology and Geological Engineering, CSM

Abstract

Adam is a second semester Master's student in the MUDTOC Consortium. His research will focus on the Niobrara B1 and B interval of the Niobrara Formation in Redtail Field of the Denver Julesburg Basin in Weld County, Colorado. The scope of the research will include: subsurface mapping, mineralogy, core descriptions, X-ray Fluorescence (XRF), X-ray Diffraction (XRD), Field Emission Scanning Electron Microscope (FE-SEM), source rock analysis, petrophysical analysis, and geochemical analysis. There are three well cores that fully include the B1 and B intervals and two well cores that partially include them. These cores were provided by Whiting Petroleum Company.

He has acquired XRF data though the B1 and B interval for the Razer 25-2514H well operated by Whiting Oil and Gas. This is the type well for Redtail Field and has core that samples the entire Niobrara Formation and Codell Sandstone.

The Late Cretaceous Niobrara Formation is a prominent source rock as well as an oil and gas reservoir in the Denver Basin. It was deposited during a marine transgressive cycle known as the Niobrara Cyclothem. In the Late Cretaceous, the Western Interior Seaway covered the DJ Basin and deposited chalks and marls. The Niobrara Formation is an unconventional chalk play that consists of alternating chalk and marl beds. Due to low porosity and low permeability the reservoirs require fracture stimulation in order to produce hydrocarbons. The marls have a higher total organic carbon (TOC) and act as the seal and source rock, while the chalks are more brittle and act as the reservoir. The Niobrara is subdivided from oldest to youngest: Fort Hays Limestone, D Interval, C Interval, B Interval, B1 Interval, and A Interval. Within the Niobrara the B1 and B chalks are one of the main producers and are often targeted for completions. The Niobrara is a key play in the DJ Basin. Better understanding of the reservoir characteristics in this field will help in future development and production of hydrocarbons.

CCUS in Redtail Area, Weld County, Colorado

Chris Beliveau, MS Candidate, Department of Geology and GE

Abstract

Carbon capture, utilization, and storage (CCUS) is the process to capture CO_2 from the atmosphere, utilize that carbon in some way (such as facilitation of oil and gas production) and find a safe, permanent storage option. It's becoming increasingly common in the oil and gas industry as both a means to enhance production as well as decrease what some see as "negative externalities" associated with production. While carbon capture and storage (CCS) has sometime garnered more attention, carbon capture utilization and storage is more attractive as it offers additional economic incentives. Primary and secondary means of oil and gas recovery can still leave up to ~80% of oil in the reservoir and in some cases CCUS can be a more effective means of production than primary and secondary recovery. CCUS is continuing to expand and has the potential to capture ~6GtCO_2 per year by 2050.

The Niobrara System was deposited in the Western Interior Seaway (WIS) during a series of transgressions and regressions. The geologic environment of cooler, oxygen-rich water from the north, mixing with warmer, oxygen-poor water from the south facilitated carbonate development. The Niobrara has been explored and produced from extensively with recent production focused on the Niobrara A and B. Our core data from the Redtail field of the Niobrara offers a unique opportunity to explore CCUS technology running tests over the Niobrara A, B, C, and Codell. Using lab tests, I'll look at porosity and permeability at different confining stresses with the CMS 300, CO_2 miscibility with oil saturated core plugs using the ACES-200 centrifuge, and production flow and injection treatments with CO_2 acting on a core plugs. This data will be tied back into petrophysical logs to correlate favorable characteristics observed in lab. The objective of this study is to discern favorable characteristics and properties for CCUS from core as well as petrophysical data.

Stratigraphy and Source Rock Characterization of the Early Cretaceous Skull Creek Formation, Denver Basin, CO

Patrick Sullivan, M.S. Student, Department of Geology and Geological Engineering, CSM

Abstract

The Skull Creek Formation of the Lower Cretaceous Dakota Group is a relatively thin (10-60 m thick) package of shallow marine mudstone that extends from southwestern Montana to southeast Colorado. The Skull Creek Fm. outcrops along the Front Range and thickens to the north into Wyoming and east into the Denver Basin, where it is present in the subsurface. The Skull Creek Fm. represents the earliest period of marine deposition within the Cretaceous in the Rocky Mountain Region. Thus, understanding its distribution, sedimentology, and sequence stratigraphic correlations can offer insights into the depositional timing and early paleogeographic evolution of the Western Interior Cretaceous Seaway. The Skull Creek Fm. also likely plays a significant and previously undocumented role in charging both conventional and unconventional reservoirs in the Wattenberg Field in the northern Denver Basin including the overlying Muddy (J), and Codell Sandstone. This study introduces four new cores from the central Denver Basin, correlated in a north-south cross section using both well-logs and key outcrops along the Front Range. X-Ray Fluorescence and pyrolysis data was obtained to generate mineral models to identify facies trends and study organic richness. These data will lead to a better understanding of the depositional environments, paleogeographic evolution, and source rock quality of the Skull Creek Fm. in the Denver Basin.

Reservoir Characterization of the Codell Sandstone, Redtail Field Area, Weld County, Colorado

Nick Damon, M.S. Student, Department of Geology and Geological Engineering, CSM

Abstract

Nick is a second semester master's student in MUDTOC Consortium. His research will examine the Codell Sandstone member of the Carlile Formation at Redtail Field. The Codell is an Upper Cretaceous unconventional play comprised of a very fine- to fine-grained sandstone and represents one of the more prolific formations targeted within the Denver Basin. The Codell is typically divided into three different facies: the lower bioturbated facies, middle low-angle cross stratified facies to heterolithic facies, and upper bioturbated facies. The Codell requires fracture stimulation to produce due to its low porosity and permeability reservoir characteristics. Oil source beds for the Codell include local organic-rich carbonates and shales. These formations are the Sharon Springs member of the Pierre Shale, Niobrara, Greenhorn Limestone, Graneros Shale, and Mowry Shale. The Codell is bounded unconformably above and below by the Fort Hays Limestone and Carlile Shale, respectively. The Codell was deposited during a major regressive period at the end of the Greenhorn cycle in the Western Interior Seaway and is interpreted to be a shallow marine sediment between the Greenhorn and Niobrara formations.

Nick's research on the Codell will entail a multiscale analysis of the controls on reservoir quality within the Redtail Field area of Weld County. This analysis will include (but not be limited to) thin section analysis, core description, x-ray diffraction analysis (XRD), field emission scanning electron microscope analysis (FESEM), source rock analysis (SRA), and x-ray fluorescence analysis (XRF), and subsurface mapping with Petra. Cores and associated core data were provided courtesy of Whiting Petroleum Corporation. Through examination of these data suites, he aims to gain an improved understanding of the distribution and depositional controls on reservoir quality in the Codell Sandstone in this area.

Reservoir Characterization and Assessment of the Controls on Reservoir Performance for Unconventional Niobrara and Codell Reservoir Targets within the Hereford Field Area, Weld County, Colorado

Chad Taylor, M.S. Student, Department of Geology and Geological Engineering, CSM

Abstract

With the completion of the Jake 2-01H well outside of Hereford Colorado in 2009 for an impressive 90-day IP of 555 BOPD, EOG Resources proved the Niobrara Formation's viability as a significant unconventional resource play in the Denver Basin. The Hereford Field is located in the north-central part of the Denver Basin. The Niobrara consists of chalks and organic-rich marls deposited in the Western Interior Cretaceous Seaway. The Niobrara unconformably overlies the Codell Sandstone. Both the Niobrara and Codell are being developed in the Hereford area. Reservoir producibility within the Hereford Field appears to be influenced by the fracturing driven by the area's proximity to the NE trending paleo structure, the Morrill County High. Fracturing may create reservoir heterogeneity and complexity in field wells.

As of October 2020, all wells located within the Hereford Field study area cumulatively produced more than 13.3 MMBO, 18.6 BCF, and 12.7 MMBW. The Niobrara B chalk and the Codell Formation are the established main reservoir targets within the Hereford area; however, additional reservoir potential exists in the B1 chalk and C marl facies. Drilling and completion methodologies employed in the field have evolved since the completion of the Jake well in 2009. Modern operations incorporate pad drilled - cemented laterals (XRL and SRL), plug and perf completion designs similar to Niobrara wells of the Wattenberg Field. Many of the newer horizontal wells in the area exhibit increases in production associated with modern completion design deployment, while some wells do not. Understanding the geological controls driving well performance has led High Point Resources to design and acquire high-resolution geochemistry, petrophysical, and geophysical data covering two extended reach drilling and spacing units, called the Chalk Bluff Project. The Chalk Bluff DSU's are strategically located in the center of the field and less than 3 miles from the Jake 2-01H well.

This study aims to identify meaningful combinations of rock and reservoir properties for each reservoir unit to help guide future exploitation projects to maximize ultimate recovery of oil and gas. Additionally, this study will evaluate the upside production potential and overall viability of the secondary reservoir targets from High Point's operation footprint. The study will integrate the area's widespread legacy well and production data with the high-resolution Chalk Bluff Project data set to build a multilayer reservoir characterization/performance model. This model will be fully calibrated by the extensive petrophysical analysis, fluid and sample geochemistry, laterally acquired-formation image logs, full mechanical core evaluation, and

reservoir produced fluid and pressure analysis that is available throughout the Chalk Bluff Project and greater Hereford Field area.

Reservoir Characterization and Petroleum Potential of the Mowry Formation: Powder River Basin, Converse and Campbell Counties, Wyoming

Brian Hankins, M.S. Student, Department of Geology and Geological Engineering, CSM

Abstract

The Lower Cretaceous Mowry Shale has long been considered an important source rock in the Powder River Basin. It is an organic-rich mudstone that was deposited in the Western Interior Seaway during the early stages of the Greenhorn transgression. At the time of the Mowry deposition, the northern arm of the seaway transgressed southward from the Arctic Ocean and terminated in central Colorado. The Mowry in the Powder River Basin accumulated in a distal marine environment and is characterized as a finely laminated siliceous mudstone with abundant radiolarian and fish debris, sparse bioturbation, and numerous altered volcanic ash beds.

Since the advancements of horizontal drilling and hydraulic fracturing technologies, the Mowry has received little exploration. The production results from the early wells were poor and the wells proved to be uneconomic. However, the most recent wells drilled in 2018 and 2019 have production results that are encouraging for the play.

The aim of this study is to evaluate the reservoir properties of the Mowry Formation in the Powder River Basin in Converse and Campbell counties. This will be accomplished primarily through core analysis. Existing core data will be used to identify lithofacies and changes in the reservoir properties. FE-SEM will be used to identify the nature of the silica diagenesis while NMR will be used to characterize the microporosity. This analysis will lead to a better understanding of how the microcrystalline quartz is affecting the reservoir properties and potentially identify the best facies to target. Additionally, programmed pyrolysis data from wells across the basin will be used to calculate total hydrocarbons generated. This will identify maturity trends and the location of the highest amounts of available and retained hydrocarbons.

Influence of Rock Type and Maturity on Core-Scale Reservoir Characteristics of the Mowry Shale, Powder River Basin, WY

Alexa Socianu, Ph.D. Candidate, Department of Geology and Geological Engineering, CSM

Abstract

Using a dataset from a suite of seven Mowry Shale cores in the Powder River Basin (PRB), this study examines variation in source rock, mineralogic, and petrophysical properties as a function of rock type (facies) as well as maturity. The mid-Cretaceous Mowry Shale has an average 2-3wt% TOC of a mixed Type II/III source. Average porosity is ~7% and permeability averages 200-300nD in the core samples available. The overall lithology of the Mowry Shale consists of organic-rich, siliceous mudrocks interlaminated with silty and bentonitic laminae. There are subtle yet perceptible changes in silt content and lamination style that differentiate the various facies encountered in the PRB where the most distal, fine-grained mudrock deposition occurred. Coarser facies generally exhibit an elevated proportion of detrital silica, have lower hydrocarbon saturations, lower TOC, slightly higher porosity, and increased permeability relative to the more biosiliceous facies.

Thermal maturity appears to have a major influence on the reservoir quality of the Mowry Shale, a result with critical importance for defining the boundaries of this burgeoning unconventional shale play. Elevated thermal maturity core samples are associated with decreased illite/smectite content, significantly lower water saturations, and higher median permeabilities. A strong positive correlation between permeability and thermal maturity in the early oil window, up to approximately Ro=1.0%, are consistent with modelled increases in kerogen porosity and transformation ratio. Observed covariation in permeability and Rock-Eval data suggest that TOC and/or clay content play an important role in pore development as function of thermal maturity. This is a topic of ongoing research and will be further discussed in subsequent MUDTOC meetings.

Petroleum Geology of the Turner Sandstone in the Porcupine and Tuit Draw Fields, Southern Powder River Basin, Wyoming

Corey Milar, MS Candidate Department of Geology and Geological Engineering

Abstract

The Late Turonian Turner Sandstone (Turner) is a low porosity, low permeability reservoir and one of the fastest growing unconventional plays in Wyoming's Powder River Basin (PRB). In the study area, production is from a cryptically bioturbated medium-grained sandstone (Reservoir Facies 1) and a heavily burrowed and bioturbated very fine to fine-grained sandstone (Reservoir Facies 2). Bioturbation is one of the most important processes in the Turner, where burrow intensity and burrow connectivity are the two principle factors that control reservoir quality. Although many operators are targeting bioturbated intervals within the Turner, no publications exist that petrophysically characterize biogenic sedimentary structures and trace fossils with respect to their influence on hydrocarbon recovery and overall reservoir performance prediction.

Reservoir Facies 1 is cryptically bioturbated and displays 100% bioturbation (BI 6). Reservoir Facies 2 contains traces of Asterosoma, Macronichnus, Ophiomorpha, Paleophycus, Phycosiphon, Planolites, Skolithos, and Thalassinoides and displays 100% bioturbation (BI 6). The lateral variability of the identified reservoirs will be characterized across the study area in order to better understand the relationship between burrow intensity, burrow connectivity and the net impact of directional permeability. The anisotropic porosity and permeability associated with heavily bioturbated intervals can have dramatic effects on reserve estimates and the ability to predict fluid flow to the wellbore. In the Turner, conventional plug analysis cannot adequately capture the degree of heterogeneity and does not represent the effective permeability associated with intense bioturbation. If porosity and permeability are enhanced due to bioturbation but the effects are not recognized, reserve calculations will be underestimated. Alternatively, if porosity and permeability are reduced due to bioturbation but the effects are not recognized then reserve calculations will be overestimated. The ability to recognize this variability has direct implications on developmental strategies pertaining to reservoir simulation models and will result in higher recoveries with fewer wells, at minimum cost through optimization.

Reservoir Characterization of the Shannon Sandstone near Pine Tree Field, SW Powder River Basin, Wyoming

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Abstract

The Shannon Sandstone near Pine Tree Field is an Early Campanian aged unconventional stratigraphic play in the southwestern part of the Powder River Basin in Wyoming. There are varying interpretations of the depositional environment for the Shannon. These include a shelf sand ridge complex, prograding shoreface, or incised valley fill. In the southwestern part of the Powder River Basin, the Shannon and Sussex are productive reservoirs in Hartzog Draw, Jepson Holler Draw, and Pine Tree Field. The Shannon Sandstone near Pine Tree Field has not been studied as extensively as in the Hartzog Draw and Jepson Holler Draw fields. This study will include detailed analysis of up to 9 cores in Johnson and Campbell Counties and field outcrop work in Natrona County in addition to other data analyses across the area. Examining the core as well as the outcrop will allow for increased understanding of lateral changes within the Shannon. The goal of this study is to better understand the stratigraphy and reservoir characteristics of the Shannon in order to maximize efficient development and production.

Characterizing Diagenetic Silica in the Upper and Lower Shales of the Bakken Formation, Williston Basin, North Dakota

Ryan Rogers, MS Candidate, Department of Geology and GE

Abstract

The Bakken Formation has been a major producer of oil and gas in North Dakota and Montana since the advent of horizontal drilling. It is Upper Devonian and Lower Mississippian in age and consists of four members; in ascending order: (1) the Pronghorn Member, (2) the Lower Bakken Shale, (3) the Middle Bakken Member, and (4) the Upper Bakken Shale. These members have been interpreted as depositional sequences of transgression and regression related to eustatic sea level variations. The Lower and Upper Bakken Members were deposited in euxinic bottom-water conditions linked to transgressive systems and contain a significant portion of biogenic silica.

To date, the characteristics of silica diagenesis in numerous geological settings has been studied by different authors. The diagenesis occurs in multiple stages, beginning with amorphous silica (opal-A) and followed by a sequence of metastable intermediates known as opal-CT, then chalcedony, and finally microcrystalline quartz. The transition from amorphous silica to progressively more orderly crystallographic stages in this sequence is largely controlled by an increase in temperature and a decrease in silica saturation. Various stages in the sequence of silica diagenesis have been studied in settings such as the Monterrey Formation and more recently the Mowry Shale. However, silica diagenesis remains understudied in the setting of the Bakken Formation's silica-rich lower and upper shale members.

The purpose of this study is to observe and characterize different phases of silica in the Lower and Upper Bakken Shales in order to estimate the extent to which diagenesis affected the development of pore networks within the shales. Data has been collected via XRF analysis of four different cores stored at Colorado School of Mines. Multiple chemostratigraphic facies have been defined by using a mineral model that stoichiometrically calculates and normalizes quartz, calcite, and illite content from the XRF data. These models will guide XRD and FESEM analysis that is anticipated to be conducted in the near future. An increased understanding of the process of silica diagenesis in the Lower and Upper Bakken Shales may result in a more complete comprehension of the nature of porosity formation within those shales.

Distribution of anoxia and water mass circulation during the Cretaceous Ocean Anoxic Event 2 (Cenomanian-Turonian); a global carbon cycle perturbation in the Western Interior Seaway

Chris Matson, PhD Candidate, Department of Geology and Geological Engineering, CSM

Abstract

The distribution and nature of ocean anoxia and water mass circulation during the Cretaceous Western Interior Seaway (WIS) of North America remains disputed. The vast catalog of Western Interior Basin (WIB) studies amassed over the last 125 years advantages a new multi-proxy approach to clarify and detail the oxygenation state of the water column, bottom water, and sediment-water interface within the WIS during discrete, time-correlative intervals. Moreover, the contemporaneous emplacement of submarine Large Igneous Provenances (LIP's) before, during, and after the positive C isotope excursion that marks Ocean Anoxic Event 2 (OAE 2; Cenomanian-Turonian Boundary) in the WIB may also provide a unique isotopic water provenance signature. Using existing and unpublished core locations across the WIB, this study seeks to characterize these relationships between multiple redox proxies (isotopic, bulk elemental, iron speciation, and biomarker analyses) and isotopic signatures characteristic of submarine weathering of LIP's. The first investigation phase will involve core data from well penetrations within the Redtail Field (Denver Basin, NE Colorado) representing a more distal hinge-zone of the WIB during the deposition of the Bridge Creek Limestone (Cenomanian-Turonian Greenhorn Formation). Future investigations will seek to elucidate how these same redox sensitive and water provenance proxies vary geographically during OAE 2 between the deeper-water Mancos Shale of central Colorado (sometimes referred to as Mancobrara) along the basin axis and the neritic Tropic Shale of Southern Utah. Variability may also be assessed within time-correlative sediments to distinguish the contribution of ocean water provenance to anoxia, the nature of water mass circulation and mixing in the WIS, and the degree of continental weathering to nutrient cycling during OAE 2. If successful, the approach may be applied to other times of global carbon cycle perturbations such as OAE 1 (Aptian-Albian) and the less discretely resolved OAE 3 (Coniacian-Santonian).

Stratigraphic Complexity, Source and Reservoir Potential of the Niobrara Formation in the Rocky Mountain Region: A Regional Synthesis

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Abstract

The Niobrara Total Petroleum System in the Rocky Mountain Region is a productive unconventional petroleum play. The Niobrara Formation was deposited in open marine conditions in the Western Interior Seaway (WIS) during a eustatic sea level rise in the Late Cretaceous. The formation displays a mix of siliciclastic and carbonate deposition within the WIS. In the WIS, siliciclastic sediments are sourced from the Sevier Highlands located on the western thrust belt. The eastern parts of the basin displayed increased carbonate deposition of coccoliths pellets, forams, inoceramid, and oyster shells due to minimal dilution by siliciclastics and favorable geological conditions for carbonate deposition and preservation.

The paleogeographic extent of siliciclastic and carbonate deposition is ambiguous in the literature. In this research, the main goal is to characterize the paleogeographic extent of carbonate and siliciclastic deposits and geological controls on carbonate deposition and preservation in the WIS. Basement topography is also seen to have an influence on the distribution of different rock type in the WIS.

Understanding the paleogeographic distribution of siliciclastic and carbonate deposits will be performed using an integrated approach combining a high-resolution well-log stratigraphy with biostratigraphy, chemostratigraphy, and sequence stratigraphy. Regional mapping of the key surfaces will provide an understanding on the variable distribution of different lithologies as mineralogical and elemental data suggests variable trends in the WIS.

The stratigraphic framework will involve understanding the Late Cretaceous paleogeography, paleoclimatology, and paleoecology which will provide fundamental understanding on geological conditions promoting the deposition of different rock types during the deposition of the Niobrara Formation. The framework will be improved by the addition of radiometric age dating of region-wide bentonites and ash beds to better understand the geochronological relationship of key surfaces in the WIS. Chemostratigraphic approaches in the Niobrara Formation and mudrock sequences have been proven useful for providing a greater detailed understanding on the lithological and chemical variations in elemental scale. Chemostratigraphic approaches will include the use of XRF elemental data, XRD mineralogy, and trends in stable isotopes to better understand the preservation of organic matter, as well as quality of productivity of carbonates and bottom water oxygen conditions, which relate to the depositional conditions in the WIS.

The Niobrara Formation is one of the most productive source-reservoir intervals in the Rocky Mountain Region. The formation is also known to source Frontier, Turner, Codell, Sussex,

Shannon, Terry, Hygiene, and Parkman sandstones. The Niobrara Petroleum System has produced more than 1 BBO and more than 8 TCF of gas to date. The changes in the stratigraphic nature of the Niobrara Formation greatly influenced its reservoir and source potential distribution. Based on literature, reservoir quality of the Niobrara Formation depends on its mineralogy, diagenetic features, storage capacity, and presence of natural fractures. Therefore, understanding the variations in the stratigraphy in the WIS in combination with geomechanical testing will have a direct influence on understanding the reservoir potential. The formation is organic rich as it displays 1-16 wt. % TOC in the WIS. The formation in the eastern parts of the WIS mainly displays Type-II kerogen, whereas, in the western parts additional influence of Type-III kerogen is well documented. Source rock potential of the Niobrara Formation will be determined by studying the quality, quantity, and maturity of the organic matter present. The understanding of the source rock and reservoir potential of the formation will also be supported by the high-resolution stratigraphic framework as well as petrophysical models and lab measurements to further decipher the nature of organic richness, fluid-phase profile, and geomechanics.

Overall, this study aims to generate a high-resolution stratigraphic framework to explain the nature of siliciclastic and carbonate deposition in the Niobrara Formation as well as its source and reservoir potential distribution in the WIS.

Lewis Shale high resolution reservoir characterization, Greater Green River Basin, Wyoming

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Abstract

The Lewis Shale is a turbidite system that encompasses sandstones, siltstones, and organic-rich shales, deposited during the last Cretaceous seaway transgression. It is informally subdivided into three members; lower (characterized by high clay and organic matter content), middle member (a mixture of siltstones, shales, and sandstones), and an upper member or Dad sandstone member (with decreasing amounts of sandstone and greenish-grey shales) that can reach up to 2600 ft.

Each of the members has variable amounts of sands, siltstones, and shales depending upon their depositional location within the platform. It includes channels, sheet sands, mass transport deposits, and flooding surfaces. The sequence stratigraphic framework was developed by Pyles (2001) and Pyles and Slatt (2000). It is characterized by third-order progradational highstand systems tracts, comprised of several fourth-order lowstand-highstand cycles and a shallowing upwards sequence. Its maximum flooding surface is located in the lower member, named the Asquith Marker. It has a maximum thickness of 50 ft within the basin, and it is believed to be a source of hydrocarbons, with TOC values that ranging between 0.68% and 3.15% in core and outcrop.

The Lewis Shale comprises different depositional environments within the deep-water system, including turbidite channels, sheet sands, and mass transport deposits. Deeper depositional areas are located towards the south and transition to shallower areas towards the north.

Upper Cretaceous rocks were deformed in a series of intermontane basins that formed during the Laramide orogeny. During this time, the Sierra Madre uplift, Rawlins uplift, Cherokee uplift, Lost Soldier anticline, and Rock Springs uplift were uplifting and served as a source for the Lewis Shale. McMillen and Winn (1991) and McGookey et al. (1972) identified submarines fan sandstones from several directions matching the placement of the other uplifts of the time.

This formation is considered an unconventional reservoir due to its low porosity and permeability and the need to use hydraulic fracturing to obtain hydrocarbons. Unconventional reservoirs are highly complex reservoirs that are still not completely understood but hold high percentages of hydrocarbons. The increasing importance of these reservoirs has led to a need to understand several aspects, such as their internal characteristics, to correlate them regionally and locally, determine gas migration pathways, and determine well placements.

The present study is located in the Sweetwater and Carbon counties in Wyoming. Data includes four cores located around the basin provided by MorningStar Partners/Southland Royalty.

Cores have various lithologies, including shales, siltstones, and sandstones, representing the Lewis Shale's variety and complexity. A high-resolution reservoir characterization is a crucial tool for understanding this reservoir and decreasing uncertainty when planning new well placements. It is unclear whether or not the Asquith Marker is the source rock for all the hydrocarbon within the Lewis Shale, but it is undoubtedly the source of some of it. Migration pathways and optimal reservoir quality are essential to make this play economical. Thus, high-resolution reservoir characterization from cores and logs will help understand this highly heterogeneous system and even aid during the geosteering process. The high-resolution reservoir characterization includes but is not limited to XRD, XRF, thin section, and porosity and permeability analyses on the cores and maps of the main intervals and correlation that will aid in determining the depositional environment and ultimately will control the reservoir quality.

New Students:

Adrienne Bryant: Introduction

Adrienne is a first year Master's student in the MUDTOC Consortium under Steve Sonnenberg. Her research will be to further characterize the Graneros Shale in the Denver Basin. XRD, core analysis, XRF, and FE-SEM will be utilized in order to better understand what makes the Graneros such a valuable source rock.

Adrienne graduated from the Colorado School of Mines with a B.S. in Geological Engineering, Exploration Track in May of 2020. For her senior design course, Petroleum Exploration Design, she developed an integrated structural/stratigraphic interpretation of the Northern Paradox Basin and the Northern Carnarvon Basin using a combination of sub-surface data (2D & 3D seismic, well logs). This information was used to locate potential conventional oil and gas traps as well as unconventional resources in both basins. Adrienne is eager to advance her knowledge in exploration geology.

Scott Kennedy: Introduction

Scott Kennedy is a first semester master's student in Dr. Steve Sonnenberg's MUDTOC consortium. Scott's research will be focused on the Semilla Sandstone of the San Juan Basin - an age equivalent formation to the Codell Sandstone in the Denver-Julesburg Basin. Through outcrop studies in southwest Colorado and northwest New Mexico, he will look further into the depositional environment of this marine sandstone and characterize the formation for its reservoir potential.

Scott is from Jackson, Mississippi and moved to Colorado in the fall of 2016 to attend the Colorado School of Mines for his undergraduate degree. He graduated in the spring of 2020 with a degree in Geological Engineering through the exploration tract. Having a passion for fly fishing, Scott has worked as a fly shop employee and fly-fishing guide in the summers since 2015, both in Island Park, Idaho and right here in Golden. Having enjoyed the many field exercises offered in undergrad at Mines, he is excited to continue with more field studies in his thesis work on the Semilla Sandstone.

Selena Neale: Introduction

Selena Neale is a third-generation geoscientist/oil and gas scientist. She graduated cum laude and received her BA in Geology from the University of Colorado at Boulder in December 2016. During her last semester at CU Boulder, she completed an undergraduate thesis project that modelled potential paleoclimates during numerous glacial cycles in Rocky Mountain National Park and how these climates could produce glaciers of such magnitude as to shape Front Range mountains. Her undergraduate thesis was chosen as one of the three best undergraduate theses done at CU Boulder during the fall semester of 2016. After graduating from CU Boulder, Selena worked at Fracture ID, a small oil and gas technology company based in Denver, for four years as a GeoTech. While there, she normalized FID data to established geologic parameters, set up and executed workflows for normalized FID data, researched formations and basins for geologic QC development, and correlated FID data to wireline and image log data. Selena started her master's program in geology with a focus in sedimentology at Colorado School of Mines in August, 2020. She is working with Stephen Sonnenberg as part of the MudTOC Consortium on a thesis project studying carbonate gravity flows in the Upper Wolfcamp Midland Basin and the hazards they create when drilling and producing wells. She plans to graduate in 2020 and pursue an oil and gas career.