ORAL PRESENTATION ABSTRACTS

(Listed alphabetically by corresponding author, designated with an asterisk (*)

Oyeleye O. Adeboye*, Natascha Riedinger and Tracy M. Quan -- On Organic Matter Enrichment in the Mississippian Limestone of the Anadarko Shelf of Oklahoma

It has been suggested that the Mississippian Limestone interval is a hydrocarbon source rock, producing self-sourced hydrocarbons in addition to hydrocarbons sourced from the underlying Woodford Shale. To date, over 900 million barrels of oil and 6.4 tcf of gas have been produced from the Anadarko Shelf of Oklahoma. With renewed interest in applying modern completion techniques to organic rich rock intervals, including heterogeneous lithologies such as the Mississippian Limestone within the Anadarko Shelf in central Oklahoma, an investigation of factors responsible for organic matter enrichment and deposition of potential source rock segments in the Anadarko Shelf is warranted. We have previously reported geochemical results from studies conducted on the Mississippian Limestone interval which indicate that depositional redox conditions in our study site within the Anadarko Shelf were oxic to suboxic. Consequently, an investigation of other factors, including paleoproductivity and detrital input, responsible for organic matter enrichment and deposition of potential source rock segments in the Mississippian Limestone interval is warranted.

Utilizing samples from a cored petroleum exploration well drilled in Kingfisher County, Oklahoma, we investigated paleoproductivity and detrital input and their effects on organic matter enrichment in the Anadarko Shelf using various inorganic geochemical proxies. Preliminary results from the current study suggest that organic richness in this area of the Anadarko Shelf is influenced by paleoproductivity and detrital input as well as the interplay between these two processes. Our results corroborate those of previous investigations that utilized organic geochemical techniques to arrive at the conclusion that certain zones of the Mississippian Limestone interval within the STACK resource play of the Anadarko Shelf are enriched in organic matter and are capable of sourcing hydrocarbons.

Studies such as the one presented here could ultimately aid in delineating areas of organic matter enrichments which could be potential completion and production candidates especially in light of recent exploration and multi-zone exploitation efforts focused on resource plays, such as the STACK in the Anadarko Shelf of Oklahoma.

H.M.D. Agbogun*, S.A. Opeloye, Saeed Mohammed -- Organic Geochemical Evaluation of Hydrocarbon Generation-Potentials and Paleo-Depositional Environments: Example from the Chad Basin

The search for hydrocarbons in commercial quantities within large sedimentary basins are often complex. Hydrocarbon occurrences can vary widely in geography and depth within oil bearing formations in basin. For example, the Nigeria sector of the Chad Basin has proven unsuccessfully after more than 30 years of exploration. However, prolific hydrocarbon reserves have been discovered and produced in parts of the Central Africa Rift system to which the Chad Basin belongs. This work aims to improve the understanding of the petroleum system complexity within this non-producing sector of the Chad Basin. Samples from seven exploratory wells from the Nigeria section of the Chad Basin have been analysed using bulk and molecular geochemical chemistry. Hydrocarbon generation-potential, thermal maturity, and paleo-environments of deposition were assessed for two formations in the basin.

The average total organic carbon content was determined to be 0.83 % and 0.93 % for the Fika-Shales and Gongila Formation, respectively, suggesting fair and similar organic richness for both formations. Pyrolysis data show the Fika-Shales to have a fair generative potential as against the poor potential of the Gongila Formation. Hydrogen index values

indicate Type-III kerogen for the Fika-Shale and Type-IV for the Gongila Formation. Analysis of oleanane, gammacerane, and hopane/sterane ratio suggest deltaic environment of deposition for the Gongila Formation. The Fika-Shales is inferred to be deposited under stratified water column conditions with inputs varying from land to marine. Biomarker maturity parameters show both formations to be within the oil window with the Gongila Formation showing narrow range in maturity, while the Fika-Shales show wide maturity range.

The disparity in the hydrocarbon generation-potential, difference in kerogen typing, and variations in the paleo-depositional environment of both formations suggest two different petroleum system. These findings highlight the significance of detailed geochemical studies in planning future exploration works within the basin.

Esmail Ansari*, Eugene Holubnyak, Franek Hasiuk, Jennifer Hollenbach -- Estimates of Permeability and Storage Capacity for the CO_2 Storage Hub Complex at Patterson Field, Western Kansas, USA

Saline aquifers, such as the Arbuckle Group in the US Mid-Continent, are important resources shared among many stakeholders, such as oil and gas companies, the chemical industry, municipalities, landfills, and others. The deep saline aquifers underlying the Patterson site, located in Western Kansas, consist of three formations which are separated by barriers to vertical fluid migration and have structural closures to trap injected CO_2 plume over storage-relevant time-scales.

We used Petrel software to create a geological model of the Patterson site using twenty modern well logs, for which neutron, density porosity, and gamma ray logs were available. The compositional flow simulator GEM was then used to study CO_2 injectivity and capacity for the developed geological model. To account for the limitation that well logs often underestimate carbonate rock permeability by ignoring fractures and vugs, we studied three scenarios: a base geological model, a model where transmissibility of the base case was multiplied by five, and a model where the permeability of the base case was multiplied by five. We found that 19 Mt, 33 Mt and 65 Mt CO_2 could be injected after 25 years for each case respectively, using assumed relative permeability curves. Under these conditions, the CO_2 plume extended less than 15 km from the wellbore and CO_2 saturation was up to 70% in the uppermost layers of the formations.

We also compared our modeling results with permeability analysis based on fall-off test data from UIC underground injection control (UIC) Class V City of Lakin well near the Patterson site. Analysis of fall-off test data from this well and the nearby wells showed that the reservoir-scale permeability of the Arbuckle aquifer at the Patterson site is <500 mD. Injection data for this well suggested that the Arbuckle saline aquifer at the Patterson site meets the needed injectivity (0.17 Mt per year per well). These injection data also suggested that it is advantageous to inject CO_2 in Western Kansas, because it has low historical (<4.5 Mt total) and low current injection volumes (<0.1 Mt/year at the Patterson site). Finally, we present the CO_2 storage capacity of the Patterson site based on available data and discuss its sensitivity to the governing parameters. The presented work will help ongoing site characterization efforts and will guide data collection for future carbon capture, utilization and storage studies.

S.M. Ausbrooks -- Developing Criteria to Characterize and Classify Discrete Clusters of Earthquakes from 2012-2016 in North-Central Arkansas as Natural or Induced.

North-central Arkansas has seen a significant increase in both unconventional resource development and seismicity within the Fayetteville Shale Play since 2009. The study area is historically seismically active, but it has seen a significant increase in seismic activity since 2009 that is likely a combination of both natural and human-induced clusters and even swarms of earthquakes. We reviewed earthquake regional earthquake catalogs to obtain key characteristics including location, magnitude, and depth of the earthquakes within each discrete cluster. We then determined if a spatial and temporal correlation existed between discrete individual clusters of regionally-detected earthquakes that had occurred within 5-km of active Class II saltwater disposal wells, or within 5-km of production wells undergoing hydraulic fracturing (using the hydraulic fracturing notifications - HFNs) during the time of the seismic activity. We used template matching

to produce a catalog of potentially induced earthquakes for each cluster of earthquakes. We are developing criteria to rate and assign a probabilistic classification to these clusters of earthquakes as to their likelihood of being natural or induced. The information from this technique of discriminating natural from induced earthquakes can be used to help determine which earthquakes should be included in future USGS Short-term Induced Seismicity Models and the National Seismic Hazard Maps.

Tandis S. Bidgoli* and Wei Wang -- Detrital Zircon Geochronology of Upper Mississippian Sandstones in the Midcontinent and Implications for Provenance and Sediment Transport

The Late Mississippian was a critical time interval in Laurentia's history. It marks the transition from dominantly carbonate deposition on a stable shelf in the Early-Middle Mississippian, to widespread clastic deposition associated with the Ancestral Rocky Mountains and Alleghanian-Ouachita-Marathon orogens in the Pennsylvanian to Permian. Upper Mississippian (Chesterian) sandstones preserve the earliest record of this dynamic setting. In Kansas, these sandstones fill N-S valleys that are incised into the Meramecian and older carbonates. Here we investigate the provenance of these incised valley fill (IVF) systems using detrital zircon U-Pb geochronology. We obtained 1037 new concordant detrital zircon ages from nine samples of Upper Mississippian sandstone, seven of which were obtained from core from the Mary Jones #2, MLP Black, and Hitch Unit 8-3 boreholes, positioned in the axis of an IVF complex in southwestern Kansas. Two additional samples were collected from outcrops of the Chesterian Batesville and Wedington sandstones in northwestern Arkansas. Detrital zircon U-Pb age distributions are similar and characterized by pronounced clusters of Grenville (900-1300 Ma) and Taconic-Acadian (350-500 Ma) ages, consistent with a primary source in the Appalachian region. Comparison of the age data with published detrital zircon ages from early to middle Paleozoic sandstones (e.g., St. Peter Sandstone), suggest age distributions are distinct and unlikely to have been recycled. Statistical evaluation of U-Pb data and ages from equivalent units indicates relatively uniform provenance across Laurentia. The similarity in provenance across Laurentia is in line with the establishment of a major east-to-west transcontinental sediment delivery system in the Late Mississippian, the development of which was likely triggered by orogenesis on the eastern Laurentian margin. However, inland-to-offshore sediment transport and local variability in the age distributions appear to be controlled by N-S drainage networks, influenced by glacioeustatic fluctuations.

Tiraz Birdie*, Eugene Holubnyak, Lynn Watney, Jennifer Hollenbach, Tandis S. Bidgoli, and Franek Hasiuk -- Carbon Capture Utilization and Storage: A New Field for Petroleum Geologists

In order to restrict the rise of global temperatures to under 2^{o}C, the cumulative emissions of anthropogenic Carbon-Dioxide (CO_2) since the start of the industrial era needs to remain under 800 billion tons (BT). Of this, approximately 500 BT has already been emitted. As per the U.S. Department of Energy (DOE) estimates, the remaining 300 BT will be emitted by early as 2035 even with the rapid adoption of renewables. The DOE has also determined that limiting cumulative emissions to under 800 BT can only be achieved by capturing CO_2 from stationary sources (power plants and industrial facilities such as ethanol, cement, and fertilizer plants) and storing (sequestering) the greenhouse gas deep in the ground until renewables have gained sufficient capacity by mid to late 21st century. This is resulting in the emergence of a new line of technical service for petroleum geologists.

The mid-continent is one of few regions in the United States where suitable hydrogeologic conditions exist for sequestration. The DOE estimates Kansas's CO_2 storage capacity to be 60 BT, which is approximately 10 times the annual U.S. CO_2 emission of 5 BT. In order to evaluate the feasibility of Kansas acting as a region wide CO_2 repository, the DOE sponsored a 7-year $ 11 million study at Wellington, 20 miles south of Wichita. The goals of the study were to store 26,000 tons of CO_2 in the 5,000 feet deep Arbuckle saline aquifer, and inject 26,000 tons of CO_2 in the overlying Mississippian oil reservoir for enhanced oil recovery purposes. The technical challenges and outcome of the project will be shared with an

emphasis on issues of interest to petroleum geologists' especially subsurface characterization to ensure adequacy of the medium to permanently retain the injected CO_2.

Ibukun Bode -- NMR Characterization of Pore Syetems within Diagenetically Complex Reservoirs: Mississippian-Aged Carbonates (Reno County, Kansas)

Several studies have associated the presence and relative amounts of microporosity in reservoirs with underestimated recoverable hydrocarbon assessments, low-resistivity pay, and poor sweep efficiency. Hence in the majority of carbonate reservoirs, there is a need for accurate reservoir characterization that relates pore architecture, rock fabric, and loggable properties such as nuclear magnetic resonance (NMR). This study investigates the relationships between multiple scales of pore architecture and laboratory-derived NMR parameters in the dominant Mississippian-aged reservoir facies of Kansas. NMR transverse relaxation times (T2) provide direct information on porosity, pore sizes, and pore size distribution, and by implication, the rock fabric. Empirically-derived T2-cutoff values partitions bound fluids associated with microporosity from movable fluids related to larger pores; thus by comparing T2-cutoff to microporosity estimated from DIA, additional insights into the contribution of microporosity in different facies can be observed.
Facies examined in this study include skeletal peloidal packstones and grainstones, spiculitic chert, dolomitized grainstones, and skeletal wackestones to mudstones – all from a core in the diagenetically complex "Mississippian Lime" reservoir. Porosity ranges from 3.6% to 46%, with associated permeability values between 0.02mD and 56mD in these rocks. Micropore types identified from ion-milled surfaces have varying contributions to effective porosity. Image analysis-measured pore sizes range from 84nm to 3.08mm, over four orders of magnitude. T2 cutoff values vary from 24ms in dolomitic grainstones to 115ms in the spiculitic cherts, and bound volume estimations increase with percentage micro- to nanoporosity. Additionally, results from multiple linear regression models show specific relationships between micropore size, amount, and complexity with permeability, fluid saturation, and T2 cutoff. This study helps to extend the application of NMR measurements and the effects of micropore geometry and heterogeneity of reservoir rocks, particularly for diagenetically complex carbonate rocks.

Marvin P. Carlson -- Midcontinent Rift and the Nemaha Uplift – Prospecting "Tectonic" Reservoirs

The Midcontinent Rift System (MCR) and the Nemaha Uplift (NU) are prominent tectonic features of the Midcontinent. Although much different in age and genesis, they are often discussed as similar features in affecting structure, stratigraphy and environments of deposition. The 1.1 billion-year-old MCR represents a rift that has a subcontinental extent, is up to 50 miles wide and contains about 50,000 feet of basalt and sediments. The basins bounding the rift contain up to 30,000 feet of Precambrian clastic sediments that have been suggested as a gas reservoir. Exploration of these sediments is encouraged by the presence of free oil in a mine at the northern end of the MCR. The NU is characterized as a granite ridge bounded on the east by the Humboldt Fault Zone with over 3,000 feet of movement. A common misconception is that the NU represents a reactivation of the MCR. There is however an important interrelationship as to the influence of the MCR on the location and development of the NU as well as the resulting patterns in the Paleozoic. During Early and Middle Pennsylvanian time, major orogenic and epeirogenic activity occurred along the southern margin of the continent. The Ouachita, Arbuckle, and Wichita orogenys had tens of thousands of feet of vertical and horizontal movement. It was suggested that as much as 50 miles of northward horizontal movement occurred. This strong force encountered the major rift block that was highly resistant to this stress. Thus, the NU was created by at least 3,000 feet of vertical uplift adjacent to the MCR. Studies of the NU have noted a variety of fault types throughout its extent. It is suggested that, particularly in the Nebraska portion, significant reverse faulting created under thrusting of portions of the Paleozoic sediments below the granite ridge. This would have created structural traps and a thermal regime that would have enhanced the generation of petroleum to fill these traps. In addition, several important Devonian and Ordovician oil fields are located deep within the Forest City Basin. It has been suggested that

most of these fields are flower structures created by wrench faults in the basement, again the result of the northernly directed stress fields. At least three Midcontinent tectonic patterns suggest new and expanded targets for exploration.

Brett M. Carpenter*, Max Firkins, & Folarin Kolawole -- Critically Oriented Faults and Fluid Pathways: Ingredients for Induced Seismicity in North-Central Oklahoma

The dramatic increase of widespread seismicity in Oklahoma, from 2009-2016, has been attributed to the reactivation of pre-existing, critically-stressed, and seismically unstable faults due to decades of wastewater injection. The vast majority of the noted earthquakes occurred in the Precambrian igneous terranes that underlie much of Oklahoma, whereas the majority of injection, during that time period, occurred in the Arbuckle Group. Two conditions required for pore-fluid pressure driven fault reactivation are the nature, distribution, & geometry of basement-hosted faults, and pathways for downward fluid pressure migration. In this study, we explore basement deformation and structures in north-central Oklahoma. We analyze structures in seven post-stack time-migrated 3-D seismic reflection volumes (cumulative 639 km^2 area) around Kay and Osage counties, utilizing structure-oriented seismic attributes to better resolve structures. Overall, our results reveal 115 fault lineaments at the top of the Precambrian basement with dominant trends along north-south, northeast-southwest, and east-west. Some mapped faults at the top-basement surface extend downwards and offset pervasive sub-horizontal (10-20˚) intra-basement reflectors (diabase sills). Further, we find that that some of these steeply-dipping basement-rooted faults penetrate the overlying sedimentary sequences, representing pathways for wastewater migration. Our analyses show: 1) Oklahoma's igneous basement is riddled with pre-existing faults, many of which are critically oriented in the current stress field, and 2) basement-hosted faults penetrate into the overlying sedimentary sequences, including the Arbuckle and Simpson groups. These analyses demonstrate that the geometry and structure of faults found in Oklahoma's basement make them critically susceptible to reactivation.

Chris J. Carson – Coming off the Bench: Geoscience in Unconventional Times

Over the last fifteen years, the role of an oil and gas geoscientist has covered a spectrum of responsibilities from primary idea and value generation, to ancillary role player that only spends money on pointless science. When the belief became pervasive that any tight reservoir in a basin (including the source rock) could be made economic with a longer lateral and larger completion, geoscience was largely moved to the sideline. The realm of engineering and finance in the form of efficient operations, cost savings, and accurate reserve and cashflow forecasting became paramount. I believe that imbalance contributed greatly to the conditions that have eroded the trust of the investment community in the energy sector. The geoscientist will be critical in reviving that trust by providing realistic expectations based on data driven analysis and deeper understating of reservoirs and rock.

Bill Coffey – Energy is Now a New Concept

This talk is focused on current macro-economic trends, growing renewable initiatives, and how the role of traditional E & P efforts still play a role in our future as geoscientists in the next 20 years.

Energy in the geoscience field as we know it today has radically changed since 2015. Traditional roles in energy for geoscience graduates led them to a variety of opportunities, typically focused on asset drilling and development activities or frontier exploration, employing mainly conventional tools and techniques, even in "unconventional" drilling projects.

Today, energy related to geoscience roles includes a host of previously unknown terminology and descriptions. Job skills and requirements now include: PostgreSQL, Redis, MongoDB, JAVA, UI (User Interface) Python/Ruby/Matlab

programming, broad GIS applications, MV Stat, and Spotfire. These all require specialized coursework and internships to be competitive in today's job market.

Further, major oil companies are embracing this new energy concept as they are "decarbonizing" in response to environmentally astute investors, and increasing funding in renewable initiatives.

All these trends point to the redefinition of geoscience roles in our industry. This progression toward renewables includes increased consumption of raw materials, expanding the search for strategic minerals and Rare Earth Elements (REE's), and changing conventional geology/geophysical academic coursework to incorporate data and analytics into a given degree track.

However, the role of hydrocarbons still fit in this new energy concept, with oil and gas exploration, drilling and production soundly contributing to our total energy solution.

Nicholas Counts* and Hendratta Ali -- Biostratigraphic Characterization of a Mississippian Core: Canton SWD#1, Bitikofer field McPherson, Kansas

The Canton SWD #1 core was obtained from the Bitikofer field in Mcpherson country Kansas and analyzed for fossil evidence. The goal of the project is to examine and describe the fossil content in the cores from the Mississippian interval in central Kansas. The objective was to investigate the fossil content in order to characterize, identify and classify the type of fossils into body and trace fossils and infer their depositional environment. Rock samples were obtained from a core interval between 886m and 898m (Canton SWD 1-36 well) in McPherson KS. Core slabs were described to identify lithology. Thin sections were produced from specific depths of the core and studied for fossil evidence. Samples that were found to have fossils were described and information regarding size, morphology, and position was recorded. The interval is composed of three major lithologies which were determined from core slabs: limestone, dolostone, and chert. Alternating limestone and dolostone lithologies constitute the upper interval, and the lower interval is predominantly chert with sparse dolostone incursions. Thin section observations show the presence of marine fossils, within the rock cores. The specimens were too fragmented for detailed identification. The components that were identifiable were carbonate shell fragments and disarticulated crinoid ossicles. These fossils are characteristic of benthic invertebrates. Crinoids were more abundant than other identifiable fossils. The amount of crinoids has implications for the depositional environment of the rock cores. The fragmented state of the carbonate shells could be due to high energy processes, and the abundance of crinoid ossicles suggests a turbulent shelf environment. Their small size is consistent with an offshore variety.

Andrew Cullen*, Cody Totten, Matthew Pranter -- Regional Correlation of Caney-Meramec-Sycamore Formations: Implications for Sediment Delivery and Source-Rock Development

Correlation of Early to Middle Mississippian strata from the Anadarko basin into the Ardmore-Marietta basins is difficult owing to facies changes and imprecise biostratigraphic zonation crossing major structural features, as well as mixed use of North American and International Age designations. These strata are of considerable interest as they are prolific coupled source rock-tight reservoir systems. These systems are also important from a paleoclimate standpoint as they record the onset of an influx of voluminous silt-sized quartz into the basin. Using more than 8,000 wells we built a regional stratigraphic framework that ties the "Osage" shelf and Meramec ramp to deposition of the laterally equivalent Sycamore and Caney formations on the basin floor of what is now the Ardmore basin. This framework suggests the following:

1. The upper and middle Caney is correlative to Chesterian shales on the slope and shelf.
2. The lower Caney (Alhoso member) represents distal, basin- floor deposition, beyond the upper toe sets of the Meramec ramp shown by prior studies to consist of multiple parasequences of strike-elongate shallowing-upward clinoforms.
3. The Sycamore Formation is dominated by calcareous siltstone and is time equivalent to upper units of the Osagean shelf inboard of the Meramec ramp. No direct linkage of these systems can be established. The Sycamore Formation can be divided into a least 5 intervals that tend be sharp-based and have serrated internal log motifs. This is consistent with core and outcrop observations that indicate deposition was dominated by mass- flow deposits. Isopach maps show these Sycamore deposits have lobate geometries with offset stacking, a feature suggestive of small submarine fans. Although no distinct feeder systems are identified, regional geological constraints largely preclude southern or western sources.

Regional V-shale maps using gamma- ray cutoffs and core-calibrated regional petrophysical maps of Total Organic Carbon in the Caney and Sycamore formations using the log R techniques show a progressive southward increase in shale and organic enrichment towards the Fort Worth basin which suggests tectonic influences on the development of dysoxic conditions as the Rheic Sea narrowed in the Early to Middle Mississippian.

John H. Doveton -- Think Deep: The Science of Petrophysics

The term “petrophysics” was first proposed by Archie in 1950 as the study of physical and chemical rock properties and their interactions with fluids. However, the downhole application of this concept was constrained by subsurface measurements available at that time which were dominated by electrical logs. Since then, downhole measurements of natural and induced radioactivity have radically expanded capabilities to resolve rock compositions, while pore-size distributions are now characterized by nuclear resonance. However, it is borehole imaging that changed geologists’ perceptions of logs to be considered as geological tools rather than simply a medium for stratigraphic correlation. In some ways, the progressive integration of petrophysics within geology parallels the advances of astrophysics beyond traditional optical astronomy. In addition, because petrophysical data are both numerical and numerous, petrophysics is a post-Newtonian science when contrasted with the descriptive geological observations of earlier times. In recent years, the application of petrophysics to the textural complexities of carbonates and the dark opacity of mudrocks has provided exciting new geological insights which have both significant academic relevance and important commercial value.

Misagh Esmaeilpour* and Behzad Ghanbarian -- Effect of scale on porosity and permeability in homogeneous porous media: A pore-network modeling study

The effect of scale on flow and transport in porous media has been known for decades in various research disciplines such as petroleum engineering and geology. The main reason for the scale dependence of transport modes in disordered rocks is the presence of heterogeneity at various scales. The main objective of this study is providing insights into the scale-dependent petrophysical properties in ordered and homogeneous media. For this purpose, we simulate permeability in cubic networks constructed of cylindrical pore throats of the same radius via the OpenPNM package and networks of various sizes (e.g., 3, 10, 30, 40, 60, and 80 m). Results show that porosity increases, while permeability decreases with the network size increase. Although evidence in the literature indicate that porosity and permeability should be directly proportional, we find the contrary due to the scale dependence of tortuosity. More particularly, we find that tortuosity increases as the network size increases, and its effect on permeability is more profound than porosity.

Bill Fairhurst*, Robin Dommisse, Scott Hamlin, Dave Carr, Amin Gherabati, Frank Male, Svetlana Ikonnokova and Inessa Yurchenko -- Geologic - Reservoir 3D Characterization Modeling used to develop Analytic and Economic Outlook Models of Unconventional Resources, onshore continental United States

Geologic/Reservoir three-dimensional (3D) characterization and full basin 3D models are developed to reconstruct four major unconventional gas resource plays (Marcellus, Barnett, Fayetteville, and Haynesville-Bossier) and four major unconventional oil resource plays (Midland, Delaware, Eagle Ford, and Bakken). The project goals are to define: original oil in-place (OOIP), technically recoverable and economically recoverable hydrocarbon resources for each of these unconventional, resource plays / basins. These 3D Reservoir/Geocellular models incorporate a framework based on new sequence stratigraphic correlations, multiple subsurface horizons, and isochore maps. Technical (drilling and completion) data and interpretations from the Bureau of Economic Geology's core and cuttings, petrophysical models, previously published research, geochemistry, reservoir pressures, decline curve analyses and numerical modeling simulations are tied into this framework.

Geologic/Reservoir characterization 3D models are compared statistically to economic outcomes using technology inputs (well landing zones, lateral lengths, completion designs) and to predict future production results. The machine learning, analytical models define the weight of input parameters used and to predict individual well and play-wide production. Results include modeling currently drilling and completing wells, future investment opportunities and economic outlooks using various price and cost scenarios. Models include the basin water-balance, infrastructure, other capital expenditure and capital structure cost sensitivities.

Outlook models predict the incremental locations and drilling density for future activity based on price and cost sensitivities. These models indicate that production and recoverable reserves, future drilling locations and drilling density are not limited by geologic, reservoir, technical factors (drilling and completions), production rates, Estimated Ultimate Recoveries (EURs) nor current economic parameters but the limitation or constraint of capital deployed.

Bill Fairhurst*, Frank Male -- The Perfect Unconventional Resource Portfolio

This investigation is made to determine whether Bureau of Economic Geology research and Oil & Gas Industry results within each of the Unconventional Resource Plays can be used to construct an ideal unconventional resource portfolio representing the optimum Drilling and Completion and economic results by basin/play choices in time = zero (T_o).

Most economic optimization models, developed for Oil & Gas Industry project selection during the 1970s – 1990s, focused on the optimum level or percentage for each individual project or investment choice. Portfolio optimization modeling determines the level or percentage of the Portfolio that should be invested in each project, investment option, or similar class of multiple projects or choices.

Using the Bureau of Economic Geology previous evaluations and research the distributions by standard deviation quantile and log-probability plot for five gas resource basins / plays (Barnett, Fayetteville, Haynesville, Marcellus, and Utica) and five oil resource basins / plays (Bakken, Eagle Ford, Midland, Delaware, and Niobrara) are presented.

An Optimal Portfolio is constructed on a single economic metric. Several other metrics may be used as screening criteria. The model develop uses Investment Efficiency (IE), Discounted Return on Investment (D(ROI)).

Individual firm (microeconomic scale) solution will fall within the Industry (macroeconomic) scale. The current reserve estimation includes all current technologies, economic, and financial advancements. However, an individual firm may

have reason to use a different distribution of outcomes vs the Industry Total outcomes (timing, technology, opportunity differences). Examples are provided.

This research demonstrates construction of Perfect Unconventional Resource Portfolio representing the optimum D&C, production, and economic results by basin/play/project choices in time = zero (To).

Curtis J. Faulkner -- The Distribution of Marine Phosphate Nodules from Oklahoma's Pennsylvanian Cyclothems with Implications on the Black Shale Problem and the Phosphate Corridor

An unexpected discovery in the occurrence of phosphate nodules from Pennsylvanian cyclothems in the Cherokee Platform/Tulsa Basin of Eastern Oklahoma was a surprise. One expects to find PO_4 nodules within most anoxic black shales of typical Pennsylvanian cyclothems in the Mid-Continent; this is not the case for parts of Eastern Oklahoma. Phosphate nodules (PO_4) generally occur within the heart of the cyclothem's black and dark gray "core shale"; with the occasional PO_4 nodules forming lags deposits along erosional contacts. However, within the Cherokee Platform/Tulsa Basin, the phosphate nodules are restricted to an area ranging just south of the Tulsa, Oklahoma area near the town of Glenpool, and are distributed northward into Kansas.

The discovery of the PO_4 distribution started as part of an experiment in mapping the marine shales and limestones from eastern Oklahoma's cyclothems. PO_4 nodules are an important aspect of this study because they occur regionally in black shale marker beds; they are resistant to erosion; they contain stratigraphic important fossils; they can be distinguished from other shale's nodules, and they are environmental/depositional indicators. Originally the PO_4 occurrence pattern was thought as an artifact of collecting and research bias, but as mapping continued the pattern stayed restricted to the northern part of the basin. As mapping continued, a pattern of "core shale" stacking and carbonate buildups also began to emerge. Limestones in Tulsa County develop a strong east-west linear ridge of stacked carbonate buildups develops with black shales bearing PO_4 nodules separating these limestone units. This same east-west pattern develops again north of Bartlesville.

Currently the mapping study illustrates multiple carbonate ridge buildups in which limestone accumulations reestablishes time and time again with the waxing and waning of cyclothymic events. The anoxic black shales with PO_4 nodules are accumulating, thickening and stacking around the edges of the carbonate ridge deposits. The black shales are thinning or eroded through the carbonate ridges with PO_4 nodules found in the shales or incorporated within the limestones as lag deposits. These black shales possessing abundant PO_4 nodules with distinctive characteristics are well developed within a phosphatic corridor between the carbonate buildups.

K. Goldberg*, C. Adam, S. Brower -- Automatic interpretation of the depositional conditions in black shales: application to the Chattanooga Formation in Kansas

Despite the importance of black shales as source rocks and unconventional reservoirs, the complex controls on the accumulation of organic shales are still poorly understood. The debate about whether anoxia or primary productivity are critical to the burial of organic matter is overly simplistic, as anoxia may result from high productivity, or from stagnation. Likewise, the delivery of nutrients in highly productive settings can result from upwelling or riverine input, the latter of which would also favor the development of stratification and stagnation. The intricate inter-relationship between these factors render the interpretation of the depositional controls difficult. A number of chemical proxies have been devised to infer parameters such as degree of oxygenation and stagnation of bottom waters, and primary productivity. However, the integrated interpretation of chemical proxies in large datasets may be complicated and laborious. Therefore we developed a Matlab code to automatically interpret the depositional conditions (primary

productivity and anoxia) from chemical indices (Fe_T/Al, and enrichment factors in Mo, U, Cu, Ni). For this, we designed a conceptual model to represent the control of these two factors in the deposition of either organic-rich or organic-poor sediments, using published values for the chemical indices. The code was tested in a dataset from the Irati oil shales, Permian of the Paraná Basin in Brazil. The ability to differentiate between the different depositional scenarios suggests that this program is a promising tool for the automatic evaluation of the controls in the accumulation of organic matter. The application of sedimentological and chemostratigraphic analysis to the Chattanooga Formation in KS allowed the identification of three depositional sequences in the Middle Member (from bottom to top, sequences 1 trough 3). Sequences 1 and 3 are characterized by a dominance of phytoclasts over amorphous organic matter (AOM) and *Tasmanites*, highly variable chemical indices and high detrital input, interpreted as deposited in settings with frequent, short-lived aeration events. Sequence 2 is dominated by mostly AOM and *Tasmanites*, with constant chemostratigraphic indices and low detrital input, having been deposited under stable oxygen conditions.

Franciszek Hasiuk -- Insights into Meteoric Diagenesis in Microporous Limestones from Stable Carbon Isotopes

Subsurface carbonate reservoirs are common throughout the world and provide substantial economic benefit to private organizations, public entities and individual landowners by hosting deposits of petroleum, water, and/or non-hydrocarbon gasses (e.g., helium). In addition, carbonate reservoirs are used for wastewater disposal from industrial and municipal activities in many places. Unlike many clastic reservoirs where most pores occurs between sedimentary particles, carbonate reservoirs commonly have a variety of pore sizes and shapes beyond only interparticle pores (e.g., vugs, micropores, and nanopores).

Microporous limestone is common throughout the Phanerozoic record and has been reported in all carbonate platform types, depositional environments, facies, grain types. It is most often associated with micron-size crystals of calcite between approximately 1 and 9 microns. These microcrystals display many crystal habits that can be used to predict rock properties (e.g., porosity, permeability, pore throat sizes). Geochemistry suggests they are an inorganic cement that forms during shallow burial.

Many workers, however, have proposed that microporous limestone can be produced through through meteoric diagenesis. In this method, meteoric water undersaturated with respect to calcite dissolves micrite (i.e., microcrystalline calcite), rounding the edges of the crystals and producing highly porous (>20%), but relatively low permeability (<10 mD) reservoir rock. A commonly invoked geochemical proxy for meteoric diagenesis is highly negative d13C, the normalized ratio of carbon stable isotopes. Few published d13C data from microporous limestones show strongly negative d13C. Remaining published data showing negative deviations from a contemporaneous burial trend on a d18O-d13C plot snow only minor deviation (2-4 per mil) and many of these samples were collected from outcrops.

Sean Hussey* and Todd Halihan -- Initial piezometric conditions of the Arbuckle Group

The Arbuckle Group of the Midcontinent U.S. is generally described as an underpressured thick carbonate formation used currently as a disposal zone for produced water from hydrocarbon production. In 2009, increases of induced seismicity events caused scrutiny of the hydrogeology of this formation. Little is understood of the initial conditions and hydraulic boundaries of the Arbuckle Group. Initial potentiometric data for formations are critical for analyzing and interpreting pressure changes that may result from long term, high volume injection of fluids. Reconstruction of pre-development pressure conditions was achieved by compiling pressure data from drill-stem-tests (DSTs) performed within the Arbuckle Group or equivalent lithology (Texas-Ellenburger Group) in Oklahoma, Kansas, and Texas. These tests indicate an underpressured formation with 86% of the107 petroleum well tests measuring below hydrostatic conditions with an average deviation of -2.5 MPa below hydrostatic conditions. Vertical hydraulic gradient data gathered

using single-well vertical succession DSTs indicate a downward vertical hydraulic gradient existing in the Arbuckle Group adjacent to near vertical crystalline basement faults. Potentiometric lows and downward vertical gradient may be associated with downward leakage into the granitic basement. The understanding of pre-development pressure conditions can provide insight into current in situ pressure conditions, which can be input into models for evaluating disposal effects or seismicity.

B. Lacroix*, R. Keast, T.S. Bidgoli, A. Raef, C. Adam, H. Leclere, D. Guillaume -- Assessing Fault Reactivation Potential Related to Increased Fluid Pressures within Wellington and Anson-Bates Fields, Sumner County, Kansas

Since 2013, south-central Kansas has experienced an important increase in seismic activity of its Proterozoic basement, with more than 3986 earthquakes recorded by the United States Geological Survey (USGS) seismograph stations. Fluid pressure increases associated with current high-rate wastewater injection into the dolomitic Arbuckle disposal zone is the hypothesized cause of fault reactivation within the study region's Proterozoic basement. Although the magnitude of the pressure change required for reactivation of these faults is likely low given failure equilibrium conditions in the midcontinent, heterogeneities in the basement could allow for a range of fluid pressure changes associated with injection. This research aims to quantify the fluid pressure required for fault reactivation of the Proterozoic basement. To address this issue, we use 103 focal mechanisms and 3,414 seismic events, from the USGS catalog, within an area encompassing ~ 4,000 km^2. Three major fault populations have been identified using the dense seismicity and focal mechanism datasets. One fault population strikes parallel to the Nemaha Ridge basement structure (~030˚). Another reoccurring fault population is oriented ~310˚, closely paralleling the Central Kansas Uplift, a subtle anticlinal structure subjected to repeated movement during the Paleozoic. The third population of faults is parallel to the regional maximum compressive stress oriented 265˚ as determined by previous researchers using borehole image logs and shear wave anisotropy. Effective stress ratios, $R = (\sigma'_1/\sigma'_3)$, and stress tensors required to reactivate any fault plane for twelve 22 km by 17 km grid squares covering the study area for twelve 22 km by 17 km grid squares covering the study area have been computed. Effective stress ratios, $R = (\sigma'_1/\sigma'_3)$, demonstrate that 80% of the basement fault planes are favorably oriented for reactivation, requiring low fluid pressure in the range 1.3-9.8 MPa. In addition, the orientations of these normal and strike-slip fault populations suggest the presence of a transtensional basin, not yet identified.

Mike Kuykendall – Back to the Future of Petroleum Geology: Uniformitarianism vs Catastrophism

Uniformitarianism is a foundational geologic theory developed by some of the early founding fathers of geology in the late 18th century and utilized in petroleum exploration. It assumes that slow and uniform present-day geologic processes are the key to understanding and reconstructing geologic history—"the present is key to the past". Catastrophism, on the other hand, is the theory that abrupt and periodic violent events shaped the earth. The reality is that both theories have played a critical role in our understanding of the earth's cyclic history and it's subsequent future. The past, present, and future of petroleum geology, and energy in general, has similar elements associated with these fundamental geologic theories, in that forces that create "boom or bust cycles" in the oil and gas industry usually follow some type of uniform fundamentals, but are punctuated with the occasional, sudden, short-lived events who timing is unpredictable. Oil & gas supply / demand fundamentals and associated economics, along with technological advances, shifting geopolitical and regulatory landscapes, among many other factors, makes predicting the future of petroleum geology very uncertain. However, one thing is certain…..geologists will continued to be valued resources far into our energy future.

G.A. Ludvigson*, **R.M. Joeckel**, **A.L. Layzell**, **A. Möller**, **J. Doveton**, **R.D. Mandel** -- **Record of the Middle Cenomanian Event from the Cretaceous Western Interior Seaway (WIS) in Kansas**

The Middle Cenomanian Event (MCE; ~ 97 Ma) is the first positive C*arbon Isotope Excursion* (CIE) that occurs stratigraphically below the rising limb of the positive CIE of the OAE2 Cenomanian-Turonian boundary event (~ 94.5 Ma). In Kansas, the record of the MCE is preserved in the marine Graneros Shale, just below the geographically-widespread X-bentonite (95.53 ± 0.36 Ma). The MCE is penetrated by three long drillcores in Kansas, the KGS Gaydusek #1 (Washington Co.), KGS Kenyon #1 (Republic Co.) and KGS Jones #1 (Lincoln Co.). Organic carbon $\delta^{13}C$ profiles of the MCE from these cores are characterized by abrupt transitions from baseline $\delta^{13}C$ values ranging from -26‰ to -25‰ VPDB below the MCE, to baseline $\delta^{13}C$ values ranging from -28‰ to -27‰ VPDB above the MCE. The positive CIE of the MCE in the Gaydusek #1 core rises to a peak $\delta^{13}C$ value of -22‰ VPDB. The abrupt shift in baseline $\delta^{13}C$ values from below to above the MCE is a unique feature on the cratonic margin of the WIS, related to an abrupt landward shift on the gently westward-sloping seafloor during a eustatic sea-level rise. Rock Eval pyrolysis data show that the $\delta^{13}C$ shift coincides with an abrupt increase in Hydrogen Indices of sedimentary organic matter in the Graneros Shale. The shift in $\delta^{13}C$ values is interpreted to reflect changes in the balance of organic matter burial in the Graneros Shale from terrestrially-dominated below, to marine-dominated above. The abrupt MCE flooding event is also associated with unusual paleohydrologic phenomena. The MCE horizon is characterized by cone-in-cone limestones with associated benthic molluscan fauna—in both core and outcrop. We interpret the fibrous calcites of the cone-in-cone limestones to be products of cold fresh-water seeps on the sea floor, based on stable isotope compositions. These calcites have $\delta^{13}C$ values that range from -22 to 0‰ VPDB, and $\delta^{18}O$ values that range from -8 to -4‰ VPDB. Data from these calcites are arrayed in discrete *meteoric calcite line* (MCL) patterns that are suggestive of successive increments of fibrous calcite growth resulting from unique groundwater $\delta^{18}O$ compositions. The MCL $\delta^{18}O$ values reported here are probably related to regional Cretaceous meteoric groundwater flow systems that were recharged on the terrestrial seaway margin, and discharged to the seafloor through a subterranean estuary.

S. J. Mazzullo – Porosity Evolution in Lower to Middle Mississippian Petroleum Reservoirs, Kansas and Northern Oklahoma

Petroleum reservoirs in Mississippian (Kinderhookian to lower Meramecian) limestones and cherty limestones in central to southern Kansas and northern Oklahoma were deposited in shelf and basin-margin settings. Reservoir paragenesis (diagenetic evolution) was evaluated by thin section petrography and stable oxygen-carbon isotope geochemistry of 63 cores. Marine cementation by presumed high-Mg calcite cements is indicated in some basin-margin reefs. In muddy slope deposits, incipient replacive chert nodules and layers formed syndepositionally in the shallow sub-seafloor environment, and chert and adjoining limestones were mechanically compacted attending further burial. Based on petrographic relationships, the relatively minor amount of dolomite in slope deposits formed over a long period of time (either continuously or sporadically) as it pre-dated, was concurrent with, and post-dated early silicification. In sum, marine cementation, silicification, and dolomitization resulted in early porosity reduction in the rocks. In contrast, regardless of specific reservoir age most porosity in the Mississippian rocks is of post-depositional, meteoric dissolution origin related to recurrent episodes of subaerial exposure. A range of mesoscale to microscale pores are present, the dominant types being vugs, biomolds, interparticle pores from dissolution of mud matrix, intercrystalline pores in limestone and tripolite, and spicule molds in cherts. Residual chert breccias from wholescale limestone dissolution are common in shelf rocks. Reservoir-grade porosity is heterogeneously distributed in the section, and later tectonic fractures, some of which are dissolution-enlarged, enhanced permeability in many reservoirs. There is only local minor evidence of later (i.e., post-Meramecian) deep-burial diagenesis and the flow of hot fluids through the reservoirs examined.

Jenny Meng*, Yevhen Holubnyak, Jennifer Hollenbach, Francsizek Hasiuk -- Evaluating Seal Integrity for CO_2 Storage Complex at Patterson Field, Southwest Kansas

There are multiple geologic complexes in Southwest Kansas that could serve as potential commercial-scale carbon storage sites that are in close proximity to coal power plants and ethanol producers that emit more than 2M tonnes of CO_2 per year. Previous studies estimate that up to 4 billion tonnes of CO_2 could be stored in the Arbuckle saline aquifer in South-Central and South-Western Kansas as well as other nearby saline aquifers with adequate reservoir characteristics. This research is part of an effort to understand the geological setting for future commercial CCUS projects and is funded through DOE CarbonSAFE program. The evaluation of seal integrity at the Patterson site in Southwest Kansas is part of the focus of the present study.

In a preliminary analysis of the Patterson site, we identified more than 50 million tonnes of CO_2 storage potential in a set of stacked saline aquifer reservoirs, including the Mississippian Osage, Ordovician Viola, and Cambrian-Ordovician. Three reservoir candidates are sealed by continuous shale or tight limestone of the Cherokee-Meramec, Kinderhook, and Simpson units, respectively.

In this study, we analyzed the quality of the primary top seal from the Morrow to the Meramec formation. Stratigraphic correlations, mapping, and modeling were performed by using existing geophysical well log data. Results show that the Morrow to Meramec interval contains laterally continuous shale and tight limestone and would provide adequate primary seal integrity for the reservoir candidates. The Morrow sandstone in the Patterson Field is comprised of isolated sand bodies that act as both reservoir and caprock, depending on a location. Ongoing research is focused on the geomechanical analysis of the reservoir and caprock. Rock mechanic properties are studied by integrating laboratory results and numerical analyses to establish seal integrity and maximum CO_2 injection pressures. This research will provide insight on safe and long-term CCUS assessment in the Patterson Field.

Benmadi Milad*, Ifunanya Ekwunife, and Roger Slatt -- Applications of Machine Learning Techniques in Geology: Facies Classification and Clustering Methods. The Sycamore/Meramec, Woodford Shale, and Hunton Group examples

An effective facies classification is critical for the reservoir characterization to reduce the risk of facies interpretation for an exploration and development programs. Identifying the number of facies/ clusters from well logs and/or x-ray fluorescence (XRF) data are required prior to applying Self organizing map (SOM) and K-means clustering techniques. An arbitrary number of clustering can lead to redundant number of clustering of facies. Too many or too few clusters lead to misclassification of facies. Using a uniform statistical methodology of classifying facies resulted in a consistency within the outputs of optimal number of clustering and facies (Chemo and electro facies) outputs.

A combination of multivariate statistical analyses, such as principal component analysis (PCA), the Elbow method, and K-means clustering or Self organizing map (SOM) were used to identify facies types. PCA finds the variables (log and/or XRF data) that best account for the variability in the data set to be used as an input for clustering. The elbow method was used to determine the optimal number of clusters based on the variances between and within clusters. SOM and K-means used the dataset identified from the PCA analysis to classify the data set traces over a geologic interval into groups identified as ‘facies codes.’ These facies codes were corroborated to hard rock data from outcrop/quarry descriptions, petrographic analyses, x-ray diffraction (XRD) mineralogical data, core porosity, core permeability, and borehole images when it is available, to provide geologically meaningful rock and reservoir descriptions.

Three, five and seven are the optimal number of clusters (facies) obtained from the elbow method for the Hunton Carbonate (well logs), Mississippian Sycamore (outcrop and well logs), and McAlister Quarry Woodford Shale (XRF data). This work provides a workflow to classify facies in a consistent and fast method to produce accurate and realistic outputs that have geological meaning, instead of running an arbitrary number of clustering and interpreting the facies results based on trial and error. An application to Hunton Carbonate (well logs), Mississippian Sycamore (outcrop and well logs), and McAlister Quarry Woodford Shale (XRF data) demonstrates the effectiveness of the proposed workflow.

Keith A. Nolte* and George P. Tsoflias -- Monitoring Seismicity near a CO_2 Enhanced Oil Recovery and Sequestration Site

The Kansas Geological Survey completed a CO_2 Enhanced Oil Recovery project at the Wellington oil field in Sumner County in 2016. Approximately 22,000 tons of CO_2 were injected into the Mississippian Reservoir. The county area was monitored to observe if the injection caused local seismicity. No earthquakes observed here were caused by the CO_2 injection. Prior to the start of the monitoring period in 2015, the US midcontinent saw a dramatic increase in seismicity, caused by the increase in wastewater injection into the Arbuckle carbonate saline aquifer, directly above the granitic basement. Although there are no large volume injection wells near Wellington field, the Wellington array of seismometers has identified over 3,000 local earthquakes ranging in magnitude from 0.4 to 3.6, and depths of 1 to 12 km. These earthquakes are delineating previously unknown faults, with the seismicity being the first data on faults in the upper basement. This Seismicity has progressively occurred further north, indicating a changing regional pore fluid pressure.

Michael Olaniran* and Mian Liu -- A Systmatic Analysis of Possible Causes of Earthquakes in Central Eastern United States (Ceus): Evidence from Seismicity Rate, Strain Rate, Elastic Strain Budget and Frequency-Magnitude Relationship

Earthquakes have a history of predominantly occurring along plate boundaries, however dozens of large as well as thousands of moderate to low magnitude earthquakes have been known to occur in supposedly ‘stable continental region’ like Central-Eastern United States. The inability of plate tectonic theory to explain this phenomenon has left the scientific community with no unifying model that explains how and why stress and strain accumulate in SCR and the mechanism behind the spatiotemporal pattern of seismicity in this region.

The goal of this research is to not only understand why earthquakes occur in certain locations in the Central-Eastern United States (CEUS), but also to decipher what these seismic events are and what they mean in terms of seismic hazard assessment.

In order to address these questions, a thorough systematic study of these intraplate seismic events was carried out using insights derived from their b-value, correlation with strain rate, reconciliation of accumulated strain with released seismic energy, as well as their relationship with indicators of active fault movement.

From this work, it was inferred that a significant number of earthquakes in CEUS cluster around reactivated faults that were created from the rifting of the supercontinent Pangea over 200 million years ago. The result from this study showed that most of these seismic events are likely aftershocks of historic earthquakes that were triggered by transient stress perturbation along fault lines at failure equilibrium in a prestressed lithosphere. This was corroborated by b-value estimates that were consistently in excess of 1.0 in all the seismic zones analyzed. The remainder of earthquakes (non-aftershocks) in Central -Eastern United States are likely to be attributed to anthropogenic activities -top amongst them: wastewater injection and mining activities.

I conclude that seismic hazard assessment of Central - Eastern United States based solely on geodetic strain rate measurement and the location of occurrence of past (historic) earthquakes is spatially limited and could be misleading. This is because where strain release occurred (as past earthquakes) does not necessarily have to be the exact location where strain accrual for future earthquakes take place, as evidenced by the inability of the GPS strain rate to resolve seismic moment release in all of the seismic zones in CEUS. Strain release in the future might occur on a distant unidentified fault through transient stress perturbation -one that might have been erroneously classified as 'safe' based on near-zero strain rate picked up by today`s GPS measurements.

Pablo Javier Díaz Pérez*, Ernesto Adrián Juárez Portillo, Francisco del Carmen Solano González, José del Carmen Jiménez Osorio, Octavio Reyes Domínguez -- New Synthetic Acid Technology Used to Successfully Removing Scale Damage by Laboratory Custom-Designed Systems in HPHT Wells in Mexico´s Offshore.

Stoichiometric evaluation performed in laboratory is presented comparing conventional hydrochloric acid and Synthetic Acid based stimulation systems in static and dynamic conditions to verify the speed and reaction performance applied in real tubing segments with severe Carbonate Scale at different times verifying efficiencies. With these tests, it was determined that Synthetic Acid system showed a higher dissolution efficiency, and it was applied in the stimulation of a well located in Mexico´s Offshore, achieving successful results.

Conventionally, carbonate scale complications in tubing production, downstream pipes, wellhead choke pipes, gas lift mandrels valves and surface pipes are corrected mostly with hydrochloric acid and occasionally with organic acids; in the quest of a solution to reduce the corrosion rate in pipes, increase in reaction efficiency and stability at critical pressure and temperature conditions, a synthetic acid system was developed which meets the established objectives compared to conventional systems.

Tubing production pipe with carbonate scales was recovered during minor repair and cut into segments with equal dimensions, which were measured and weighed to quantify the stoichiometry of the two types of acid. The evaluation developed to dynamic and static conditions verified the impact that the turbulence has on the efficiency and speed of reaction in different observation times.

Based on the results obtained from the laboratory tests, a stimulation Treatment with Synthetic Acid was carried out in the oil producing well in the BKS formation, achieving immediate increases in their operating conditions (temperature, pressure in the downstream pipe, pressure in wellhead); subsequently the well maintained an incremental trend of its flow conditions over time.

The use of synthetic acid to stimulate and remove the damage by precipitation of carbonate scale present in the formation water, allows it to do so without practically causing any corrosive damage, is highly efficient in dissolution and friendly to the environment.

Shelby L. Peterie*, K. David Newell, Geoffrey C. Bohling, Richard D. Miller, John Intfen, Carl Gonzales, Julia Gonzales, Rolfe D. Mandel -- Regional trends in seismicity, formation pressure, and fluid levels in Kansas

A dramatic increase in earthquakes in southern Kansas is largely believed to be the result of pore pressure increases from unprecedented saltwater disposal volumes (particularly in the Arbuckle Group) injected near the Kansas–Oklahoma border. In response to the increased seismicity, the Kansas Geological Survey (KGS) began deployment of a statewide seismic monitoring network in 2015. With enhanced network sensitivity in south-central Kansas, the KGS network is

capable of locating microearthquakes with magnitudes less than 1 in some places. Earthquakes initially occurred in dense swarms primarily in proximity to high-volume disposal wells in Harper and Sumner counties. In subsequent years, epicenters migrated into adjacent counties where minimal fluid injection was being reported. By 2017, epicenters advanced into neighboring counties, where earthquakes continue today. Detection and location of microearthquakes was crucial for evaluating the progression of seismic activity.

Estimates of formation pressure and static fluid level were obtained from wells that terminate in the Arbuckle Group. Key to analyzing and interpreting these data are proper preconditioning and geospatial sampling. The preconditioned data reveal a pattern of regionally-elevated fluid pressure that correlates with the temporal progression of seismicity. Pressure trends in south-central Kansas suggest that pressure diffusion from cumulative disposal to the south likely induced earthquakes much farther than previously documented for individual injection wells. Along with elevated formation pressures, static fluid levels are also rising in south-central Kansas, consistent with the hydrostatic equation whereby these two properties are directly related. In some areas where the elevation of the land surface is locally reduced (such as river valleys), the hydrostatic surface of the Arbuckle Group is beginning to approach the land surface and may impact the ability of wells in these areas to inject using gravity feed alone.

Gary J. Rowell -- Injection Wells and Earthquakes: Volume and Pressure or Rate and Geochemistry?

Induced earthquake research is generally based on injection fluid increasing pore pressure and reducing the coefficient of friction of earth materials, or existing fault systems. This requires that injection pressures survive fluid dispersion and time. In Kansas and Oklahoma, it must also work in an Arbuckle-Basement system that is usually under-pressured.

Can the coefficient of friction within a fault zone be changed by something other than pore pressure? Researchers have noted faults tend to slip at much lower shear stress than the stresses inferred from rock mechanic experiments. Society of Petroleum Engineers studies regarding hydraulic fracturing and research associated at the Rocky Mountain Arsenal shows that injection reduced the subsurface temperatures in the injected intervals for months or years.

Temperature effects all chemical activity. Chemical reactions from injection operations frequently result in the formation of precipitates and scales that plug the storability and can damage the injection zone. The damage can create flow restrictions that cause fluids to find a path of least resistance and move greater distances, including towards earthquake hypocenters.

The hypocenter pathways were likely created by reoccurring structural adjustments to the sealed Arbuckle-Basement system during regional orogenic activities (Acadian/Wichitan?/Arbuckle??). These tectonic adjustments created additional fracturing in the Arbuckle-Basement system which provided additional storage, allowed dispersion of fluids and dissipation of pressure. Instead of the “injection-seismicity lag” being related to the time it takes for a pressure pulse to reach the hypocenter, the lag is associated with cooling and geochemical alterations along fault zones or asperities by direct exposure to the high volume of injected fluids.

The oil and gas industry has a long history of identifying and dealing with fluid compatibility problems with disposal wells and water-flood projects. Consideration of these issues to induced seismicity could allow preservation of storage capacity which will contain the disposal volume within the intended formation, preventing fluids from migrating to susceptible earthquake nucleation sites.

Thomas Schafer*, Hendratta Ali, Richard Lisichenko -- Black Oil, Red Victory: The Impact of Petroleum on the Eastern Front in World War Two

Prior to the invention of the internal combustion engine, gasoline – the most notable petroleum product – was little more than a waste product. However, by the dawn of the 20th century, the value of many petroleum products had skyrocketed and the global world wars later heightened their value. With modern technology in society the role of petroleum in the conflicts of the world as a strategic tool is well documented and ubiquitous. Historically however, its central role in international conflicts is also closely related to the location and distributions of major field discoveries, access and production potential at the time of the conflicts. The Eastern Front was the largest and most merciless area of combat in the biggest war in human history, but the role played by petroleum resources on the course of the conflict remains relatively unexamined from a geoscience perspective, despite their outsized impact. This paper examines the role that petroleum resources played in the launching of the war on the Eastern Front, the impact that they had on the strategy of the two totalitarian opponents, and how the oil industry of the USSR, often slighted or ignored in Communist ideology, became one of the guarantors of victory for the Red Army in the conflict. Utilizing spatial modeling we propose to analyze the variety of scenarios based upon historical and current locations and related geographic factors e.g. terrain, distances, oil resources and modalities of delivery to assess the impact and counter factuals and their impact on the strategy and decisions on the war during the mid-20th century. A surprising conclusion is that the "mad dictators" Hitler and Stalin often displayed a greater appreciation of the importance of "War Oil" than did their generals and economists.

Valerie Smith*, R.M. Joeckel -- Carbon Storage and the Characterization of the Lansing-Kansas City Group through Cores and Logs.

The porosity of carbonate units and their relationships with interstratified, confining mudrock units of the Lansing–Kansas City groups (LKC) must be understood prior to the development of a CO_2 storage strategy for the Integrated Midcontinent Stacked Carbon Storage (IMSCS) Hub Project. A refined static earth model (SEM) for Sleepy Hollow Field in Red Willow County, southwest Nebraska, necessitates a comprehensive stratigraphic framework for the LKC in support of the IMSCS-Hub.

Original assessments of stratigraphy for the project utilized existing core data and petrophysical analysis of wireline logs from 205 wells. Petrographic observations from LKC zones B, C, and F and, core data, and petrophysical logs have since been integrated. These efforts validate the lithologic composition of repetitive log motifs seen within the LKC. The most favorable LKC lithology for CO_2 storage is oolitic grainstone, which offers superior effective porosity and permeability, 12-17% and 4.4-67 mD respectively. Intermediate quality rock is peloidal and skeletal grainstones, ϕ: 6.9-12%, K: 0.017-3.9mD. The poorest reservoir quality rocks are, not surprisingly, siliciclastic mudrocks, which include claystones and mudstones that exhibit possible pedogenic features (12 to 18% porosity due to clay-bound water and negligible permeability). Extant models of deposition driven by sea-level fluctuations crystalize the key lithofacies associations observed here, setting an interpretive framework necessary for SEM development. This LKC stratigraphic framework is applicable to future commercial stacked carbon storage sites along the Cambridge Arch and the Central Kansas Uplift.

Ray Sorenson – Shales That Burn

The exploitation of shale oil and gas resources has expanded exponentially in recent years with the benefit of technological advances in drilling and completion practices, converting non-commercial low-permeability rocks into major producing reservoirs. The hydrocarbon-bearing character and source-rock potential of many of these shales has been known for decades, as millions of historical wells have drilled through them in the search for conventional reservoirs in stratigraphic proximity.

Long before the drilling industry provided access to these shales under subsurface pressurized conditions, the outcrop versions of many of them had been studied and occasionally utilized along the basin margins, in some cases for a century or more. Reference to bituminous shale was common in geological studies from the 19th century. Although organic content was rarely analyzed in the pre-Drake era, shales with a high bituminous level were recognized from physical characteristics such as color and texture, and occasionally an associated oil or gas seep.

The richest of the bituminous shales were identified by a unique property, the ability to burn and maintain a flame without any other fuel source. Geological and exploratory parties that encountered burning shales would commonly mention them in their reports because of their unusual properties, plus the hope that they could be indicative of proximity to coal deposits, a common objective for governmental surveys.

By the time the 1859 Drake Well was drilled, inflammable shales ranging in age from Pennsylvanian to Ordovician had been documented in North America, with locations in at least 12 U. S. States and 4 Canadian Provinces. Based on this available information, if the modern shale plays had been described to a 19th century geologist, the choice of target formations such as the Marcellus and Utica would not have been a surprise.

Carl Symcox* and R. Paul Philp -- Geochemistry of STACK/SCOOP Production in the Anadarko Basin, Oklahoma

The Devonian-Mississippian STACK/SCOOP Play of the Oklahoma Anadarko Basin is a complex assemblage of tight carbonate and siliciclastic strata and an important Midcontinent oil and gas province. The Mississippian group is a pervasive-tight unconventional reservoir that is widely believed to be charged by the over-pressuring and expulsion from the underlying Woodford, however in the last decade, prolific drilling has demonstrated significant heterogeneity in the composition of oils produced from STACK/SCOOP reservoirs. This study discusses possible geoscientific explanations for the heterogeneity observed in produced oils and describes how source, maturation, and migration affect their composition.

Geochemical and production data from 156 produced oils across 12 counties from 4 producing reservoirs is reviewed with data from 11 Woodford and Mississippian cores. Calculated thermal maturity (Rc%) from alkylated polyaromatic compounds shows excellent agreement with oil thermal maturity increasing with increased depth. Oils produced from overpressured reservoirs exhibit a strong relationship between Rc% and Gas-Oil Ratio (GOR), while normal- to underpressured reservoirs exhibit GORs up to an order of magnitude higher at similar Rc%. In some areas, elevated diamantanes in low maturity fluids suggest a complex process of migration and mixing in the subsurface. Light hydrocarbon analysis show that paraffinicity varies starkly with producing reservoir, suggesting compositional fractionation from diffusive migration through tight and argillaceous strata. Conversely, aromaticity and organosulfur compounds varies geographically by Play Region, indicative of changing depositional environments and organic input across the basin. Isoprenoid and sesquiterpane biomarkers indicate all oils are generated by Type II or Type II/III mixed organic matter, but Springer Group reservoirs are charged by a highly argillaceous, non-Woodford source. Numerous biomarker ratios are mapped and confirm a broadly changing depositional environment spanning the STACK/SCOOP play with implications drilling, exploration, and understanding the petroleum system.

Steven A. Tedesco -- Comparison of the Wrench Fault Trap Systems of the Livengood and Kizler North Fields, Kansas and the Runamuck Field, Missouri, Forest City Basin

The Forest City Basin is an asymmetrical depression that was formed in Late Devonian to Mississippian time. The western side of the basin is defined by the Nemaha Ridge whose eastern flank contains numerous Paleozoic reservoirs of predominantly Ordovician and Devonian in age. These reservoirs are related to complex localized wrench faults systems that are difficult to define without 3D or 2D seismic surveys and ultimately drilling. Oil within these reservoirs

are derived locally from Lower to Middle Ordovician carbonaceous mudstones that have been thermally altered by upward migration of low temperature hydrothermal fluids. The main productive reservoirs are the Hunton (Devonian-Silurian) and Viola (Middle Ordovician) limestones with minor production from the Simpson and Pennsylvanian sandstones and carbonates. These reservoirs can recover between 30,000 to over 400,000+ BO per well from ten acres. The Livengood Field discovered in 1944, has produced over 246 MBO from the Viola and Hunton reservoirs at less than 3,300 feet. A 3D survey did help define additional locations but some of the subsequent drilling based on seismic has not always led to production. The Kizler North Field lies on the southern edge of the Forest City, discovered in 1972, has produced from the Hunton, Simpson and Arbuckle reservoirs at less than 3,000 feet. The reservoirs in the Livengood and Kizler North fields are less than 10 feet thick. The Runamuck Field discovered in 1987 has produced over 200 MBO from the Viola and Hunton reservoirs are greater than 10 feet thick from less than 2,800 feet. The Runamuck Field wrench fault system is far more complex with abrupt changes in stratigraphy and structure when compared to the Livengood and Kizler North fields. Aeromagnetics interpretation indicates all three fields lie at junctures of multiple deep and shallow basement faults. The wrench fault complexes for each field had different timing of structural events based on interpretation of well bore imaging tools. No one tectonic event(s) can define all three of structures formation. Both fields will be discussed and an integrated exploration model presented as a tool to help find more of these prolific and unique traps in the Forest City Basin.

Steven A. Tedesco -- The Arikaree Creek Field, Southern Denver Basin, Colorado – Anomaly or Typical Target in the Area?

The Arikaree Creek Field discovered in 2012 and is located in the Southern Denver Basin in Lincoln County, Colorado. Its discovery was the result of leasing for and shooting of a 3D seismic survey by Running Foxes Petroleum Inc., that original targeted organically rich (10% to 11% average TOC) Cherokee and Atokan age carbonaceous mudstones that are in the oil window. The 3D seismic survey of the Arikaree Creek Field indicates it is composed of three structural horsts bounded by major wrench faults in a northeast direction. The upper horst contains 60% of the recoverable oil, two of the wells pumped at 400+ BOPD, with over 100 feet of closure. A third well was a marginal producer as it was further down dip on the horst and a fourth was dry as it was significantly structurally lower and at the edge of the horst. Water production from the two main producing wells did not occur for several months. The middle horst reservoir has similar reservoir thickness and quality but the oil productive leg is less than 20 feet thick. The lower horst is to date wet. The Arikaree Creek main productive reservoir is the Mississippian Spergen Dolomite, with up to 50 plus feet of productive pay in the upper horst. The reservoir is found in the Spergen carbonates that have been replaced by secondary low temperature hydrothermal dolomite across the structural feature. Low temperature hydrothermal dolomitic reservoirs in other basins throughout the world can be a highly productive reservoirs and an example is the Albion-Scipio Field (200+ MMBO), Michigan Basin. The source of the oil based on source rock analysis is of Atokan age from thin carbonaceous mudstones. At least three additional structures have been defined by seismic and drilling along the northeast-southwest structural trend that Arikaree Creek Field defines but to date the Spergen is generally nonproductive. The Arikaree Creek also has had limited production from the Pennsylvanian Cherokee age carbonates but presently many of these opportunities remains behind pipe in several wells. The Arikaree Creek Field is presently unique, no similar feature has been found like it, and maybe an anomaly in this part of the basin. This presentation will discuss the timing of the tectonic events and reservoir that makes Arikaree Creek unique and as model for further exploration in the southern part of the Denver Basin.

Steven A. Tedesco -- Application of Surface Geochemical Survey with Aeromagnetic, Subsurface Geology and Seismic Data in Exploration for Conventional Reservoirs

Surface geochemistry can be an integral part in finding conjunction with petroleum reservoirs when used in conjunction with subsurface and seismic data. One of the pressing questions for an explorationist is whether a target defined by subsurface geology, 3D or 2D seismic contains hydrocarbons. Surface geochemical methods presented here are micro-magnetics, iodine and soil gas results that detailed regional and specific areas for further exploration and delineation by subsurface and seismic tools. The use of surface geochemical methods is based on the concept that vertically migrating hydrocarbons migrate from a reservoir to the surface along micro-pores, micro-fractures and micro-unconformities. Macroseeps are the visual form of microseeps. The presence of macroseeps did not always lead to the discovery of productive petroleum accumulations but they have led to the discovery of many of the major fields worldwide. Macro and microseeps are derived from petroleum fluids migrate as the result of simple physics whereby they move toward an area of ever decreasing pressure. The petroleum compounds eventually enter the soil substrate and react with existing oxides, carbonates, metals, plants, bacteria, water and clays. They can cause changes in Eh, pH, deposition of or removal of radioactive, halogen and carbonate minerals. The presence or absence of a surface geochemical anomaly can determine if exploration or development should stop or move forward. The lack of a surface geochemical anomaly, as defined by actual drilling case histories, indicate it is likely 95% plus of the time will result in a dry hole, marginal or uneconomic well. The presence of a surface geochemical anomaly, strong or weak, definitive or chaotic in shape, does not predict a productive discovery. Based on actual case histories that have been published over the past 90 years, the use of surface geochemistry can increase drilling success, depending upon the area, from 10% to 60%. Surface geochemistry has proven to be a successful exploration tool when integrated with subsurface and seismic methods. Presented here will be onshore case histories utilizing surface geochemistry with seismic and subsurface geology from the Denver, Williston, Cherokee and Forest City basins, USA; Michigan basin, Canada and the Zuunbayan and Unegt basins, China.

Cory Terrell – Regional Stratigraphy and Diagenetic Characterization of the Mississippian Meramec, Osage, and Sycamore Formations, Anadarko Basin, Central Oklahoma

The Meramec, Osage, and Sycamore formations in the STACK (Sooner Trend of the Anadarko Basin in Canadian and Kingfisher counties), MERGE, and SCOOP (South Central Oklahoma Oil Province) are poorly understood unconventional targets in the Anadarko Basin that overlie the Devonian to Mississippian Woodford Shale. The principal goals of this study were to characterize the regional stratigraphy, analyze the extent of diagenetic alteration, and determine the factors controlling reservoir quality of these units. The Mississippian Meramec, Osage, and Sycamore formations are composed of low permeability anisotropic siliciclastics and carbonate rocks with limited source potential and storage capacity.

Regional well log correlations, petrographic analysis, core descriptions, anisotropy of magnetic susceptibility, and hand-held X-Ray fluorescence spectroscopy (HHXRF) was used to characterize the spatial and temporal relationships of the regional Mississippian stratigraphy within the study area. From this analysis, it was concluded that the lower portions of the Sycamore (Sycamore Limestone) in the SCOOP are the time equivalent of the Osage in the STACK. This work also showed that the upper portions of the Sycamore (Sycamore Shale) are the time equivalent of the STACK Meramec. These trends also point to a northern Osage source and a southern Sycamore Limestone source, which is supported by clinoforms geometries, facies analysis, and Chemostratigraphy data collected within each formation.

Petrophysical analysis, HHXRF, and petrographic relationships were integrated to determine that reservoir quality is lithology dependent. Marine calcite cements have occluded primary porosity within siltstones in the Meramec, Osage,

and Sycamore Formations that lack detrital clay influx or bioturbation. Increased clay content can preserve primary porosity as well as provide interlayer clay porosity. Porosity within the Osage and Sycamore Limestone Formations are locally enhanced as a result of meteoric diagenesis. Local sea level fluctuations decalcified carbonates and developed secondary porosity. The Sycamore Limestone and Osage both contain mineralized fractures with hydrothermal minerals such as mega quartz and baroque dolomite that developed coeval with hydrocarbon migration.

Geoffrey Thyne -- Does the Salinity of Injection Water Matter?

In this paper we present experimental results for wettability alteration by injected water salinity in sandstone and carbonate reservoirs. The relationship between salinity and wettability can be used to increase recovery for many waterfloods. Injection water salinity is usually a function of produced water chemistry. While fresher water may be preferred to minimize interactions with the other chemicals added and to avoid formation damage, the potential for increased recovery is rarely considered. Knowledge of the impact of salinity on wettability provides the opportunity to steer reservoir wettability towards more oil recovery at low cost.

The methodology used is an extension of the modified flotation technique and produces accurate and rapid wettability measurements. The method can rapidly screen the relationship between salinity and wettability using core or cuttings samples and produced oil samples. The laboratory methodology also offers determination of in-situ wettability as a starting point in design of engineered fluids unlike current methods.

This work has identified temperature, mineralogy, oil acid, base and sulfur content and formation water chemistry (salinity and composition) as the most important variables that control wettability alteration by salinity. This approach will not work in some reservoirs and identifying the potential response in advance of field testing is valuable. The laboratory results for several typical sandstone and carbonate reservoirs show that there is a relatively narrow range of salinity and chemical composition that can significantly alter wettability in the test rocks. Accompanying economic models show the cost is between $1.50-4 per incremental barrel for many reservoirs in the region. The optimum salinity will vary depending on the target reservoir but offers an alternative to surfactants or can be used in conjunction with surfactants to change wettability to increase recovery.

Luke Truman* and Hendratta Ali --Geosteering for Wellsite Beginners: A Review of Fundamentals

Geosteering is a practical skill that allows optimal placement of a wellbore by geoscientists and engineers in real time during drilling. Geosteering involves exploiting a variety of real-time petrophysical data, obtained from Measurement While Drilling (MWD) tools, to determine formation structure in order to navigate an optimal drill path, resulting in the strategic collaborative placement of a lateral wellbore in a pay zone. Unlike vertical wells, lateral drilling increases the extent of wellbore surface area in a producing formation and attempts to curtail a multitude of production problems including, but not limited to: low production rates, drawdown in the oil-water contact, truncated pressure around the wellbore, and un-ideal formation drainage patterns. The geosteering component of a lateral well is an essential tool for refining the probability of success in any well, by guiding directional drilling teams through a pay zone. Despite the almost ubiquitous need for geosteering engineers and experst on modern drilling rigs in the midcontinent area, there is limited comprehensive information on the fundamentals necessary for early well site geoscientists to start as geosteering engineers. With the exception of focused case studies, laborious patented procedures, and advanced technical methods, there is not copious literature on the topic of geosteering as a fundamental stand-alone concentration. This paper attempts to complement the existing literature repertoire by providing a practical guide on the fundamentals of geosteering for well site beginners.

George Tsoflias*, Eugene Holubnyak and Lynn Watney -- Mississippian CO_2 EOR Validates Seismic Prediction of Reservoir Properties

The Mississippian is a prolific oil-producing reservoir in Kansas undergoing secondary recovery. At Wellington field in south-central KS, the Mississippian is a heterogeneous, fractured, below seismic resolution thickness (6 to 20 m) reservoir of limestone, dolostone and chert that exhibits decreasing porosity with depth, from 30% to 4%. Analysis of pre-stack gathers from the Wellington 3D seismic volume in the offset (AVO) and azimuth (AVAZ) domains was used to infer reservoir porosity distribution and fracture orientations. Seismic predictions agreed well with borehole measured porosity and fractures. In Spring 2016 approximately 20,000 metric tons of CO_2 were injected in the Mississippian reservoir over a six-month period for a pilot EOR study and to evaluate the potential for geologic storage. Water chemistry, pressure, production and CO_2 breakthrough were monitored at nearby wells. In this study, the Mississippian reservoir fracture and porosity predictions from 3D seismic are compared to the monitored mobility of the injected CO_2. Movement of the CO_2 plume correlates with mapped fracture zones in the upper Mississippian that directed the plume predominantly in an EW orientation. Seismically inferred fracture orientation and density appears to influence the shape of the CO_2 plume and its overall areal extent, which appears to be limited and within a more intensely fractured zone. Wells in proximity to the injector and within the intensely anisotropic (fractured) zone trending NW-SE produced CO_2 and experienced oil production improvement within weeks from the start of injection. Wells to the south, north and east of the injector experienced delayed CO_2 breakthrough and marginal oil production improvement. We conclude that borehole field monitoring of CO_2 breakthrough during EOR operations at Wellington field, south-central Kansas, is consistent with 3D seismic interpreted fracture patterns and porosity distribution in the Mississippian reservoir. This work validates the utility of pre-stack seismic analysis methods (AVO and AVAZ) for prediction of Mississippian reservoir properties.

Zachery Tunin* and Jim Puckette -- U-Pb Detrital Zircon Geochronology and Provenance Analysis of Middle Pennsylvanian Cherokee Sandstones, Anadarko Basin and Cherokee Platform, Oklahoma

Reconstruction of Early-Late Pennsylvanian paleogeography and sediment dispersal patterns can be extremely valuable in developing an accurate model for deposition of important sandstone reservoirs in the North American Midcontinent. While several potential sources of detrital grains existed for Middle Pennsylvanian sandstones in the Oklahoma Cherokee platform and Anadarko basin, sediment provenance has yet to be sufficiently explored to reconstruct sediment dispersal systems. This study used U-Pb detrital zircon geochronology to establish sedimentary provenance of the Bluejacket (surface name) and Bartlesville (subsurface operational name) sandstones in order to reconstruct Middle Pennsylvanian sediment dispersal patterns for the Midcontinent. Four samples were collected from the Bluejacket Sandstone outcrop in Mayes County along OK Highway 20, west of Pryor, OK on the Cherokee Platform. The samples were processed and analyzed at the University of Arizona LaserChron Lab and the results from 452 concordant analyses were interpreted. U-Pb ages of approximately 72% of the zircons occurred within three dominate age bins with provenances interpreted as the Alleghenian-Taconic (270-490 Ma), Neoproterozoic (530-750 Ma), and Grenville (950-1300 Ma) terranes in the Appalachian region. Subordinate populations of zircons consisted of Yavapai-Mazatzal Terrane (1600-1800 Ma), Midcontinent Granite-Rhyolite (1300-1500 Ma), Trans-Hudson and Reworked Archean Terrane (1800-2300 Ma), and Superior provenance (>2500 Ma). The Appalachian Mountain region is determined to be the primary source of zircons in the Bluejacket/Bartlesville sandstones with sediment likely transported from a north-northeasterly source by a substantial trans-continental fluvial system. This allowed southward movement of sediment across the Midcontinent onto the Cherokee Platform and Arkoma shelf where the Bartlesville sands were deposited mostly in migrating distributary channels and as transgressive valley fills.

Alec Walker -- Best Practices for Unstructured Data Management in Oil and Gas

The talk will provide an overview of unstructured data and its importance to the oil industry followed by two case studies highlighting successful implementation of data management tools. Attendees should expect to gain perspective on the following: What is the difference between structured and unstructured data? What is changing that makes unstructured data management so crucial to the oil and gas industry? What are the inefficiencies in the industry created by mismanagement of unstructured data? How should firms approach the problem of building or buying unstructured data management solutions? What are the implications for the future of geology work in oil and gas?

Jake Walter -- Elevated Potential for Damaging Earthquakes Across the Mid-Continent

The rate of earthquakes across the United States mid-continent has dramatically increased since 2009, concurrent with a surge in activity to extract hydrocarbons from unconventional plays. Oklahoma, over the last decade, experienced a year in 2015 where there were ~900 M3.0+ earthquakes against a prior tectonic background rate of just 2-3 M3.0+ earthquakes per year. During that surge in small earthquakes, 4 of the 5 largest earthquakes occurred, all greater than or equal to M5.0. These earthquakes caused moderate but not widespread damage to the rural communities in which they occurred. The scientific community has since identified wastewater disposal into the Ordovician-age Arbuckle Group as the most plausible cause of the surge in earthquake activity. In recent years, as hydraulic fracturing practices have yielded better returns for investors, several clusters of earthquakes (sometimes exceeding M3.0+) have been triggered by hydraulic fracturing. Though out of greater than 3,000 completions we find only a small percentage (<5 %) of hydraulic fracturing well stimulations produce a regionally-detected earthquake on the state network. I will present our latest findings related to seismologically discriminating between earthquakes directly triggered by hydraulic fracturing and others that may be related to background tectonic activity or wastewater injection. I will discuss the elevated potential for inducing seismicity in areas where active injection and/or hydraulic fracturing are already ongoing. Finally, I will discuss a hopeful roadmap to the future where scientists, industry, and regulators can work quickly to identify induced seismicity and mitigate damage to lives, property, and public opinion. The growing pains that Oklahoma experienced through a few waves of induced seismicity provide important lessons for other areas across the mid-continent.

Anthony W. Walton -- Some Thoughts on the Classification of Shales and Other Mudstones.

Classifications are testable hypotheses about nature and serve two vital purposes: Analysis of available data, for developing a classification draws upon the knowledge of the range of objects to be classified, and communicating some information, either useful or heuristic, about specific objects. Mudstones (including shale), i.e. sedimentary rocks composed of more than 50% by volume of particles less than 0.0625 mm in diameter, have rocketed into prominence over the past two decades, and several classifications have been proposed. Many of these recently proposed classifications are based upon 3 compositional components, so they are conveniently represented by triangles, with a component being 100% at each apex. The interior of the triangle is then divided into a number of fields by arbitrary lines. Rococo versions of such classifications have subsidiary triangles that subdivide each of the components into fractions. Nomenclature is a mixture of coined and conventional terms with such components as “dominated” and “bearing” in the names of the various fields so defined.

Key thoughts about classification of mudstones are 1) That the nature of the rocks is concisely and clearly conveyed by a numerical measure of each defined component. Numerical measures avoid the twin problems of arbitrary lines that separate highly similar rocks and broad fields combining a diverse range of compositions, and such measures have the advantage that they can be plotted as log curves. 2) That one kind of utilitarian classification should convey information

about the stiffness of mudstones—"fracability"—as that is important in developing many unconventional resources. 3) That a heuristic classification of mudstones would guide toward the sources of their particles, e.g. autochthonous vs. allochthonous, or conditions of their deposition: nearshore, shelfal, abyssal, lacustrine, fluvial, etc. or oxic, dysoxic, or anoxic. 4) Classifications based upon field observation, quantitative analysis of logs, and laboratory study should be nested so that further examination provides more information, rather than contradicting previous conclusions.

Wei Wang* and Tandis S. Bidgoli -- Provenance and Thermal History of the Mississippian-Pennsylvanian Arkoma Shelf and Basin, Northwestern Arkansas, through Detrital Zircon U-Pb and (U-Th)/He Double Dating

Double dating of detrital zircons, using the U-Pb and (U-Th)/He systems, is a powerful tool for provenance analysis. With each grain providing a crystallization age and a cooling age, double dating may allow for identification of unique U-Pb-He populations that can lead to refined provenance interpretations. However, the role of post-depositional hydrothermal events is seldom taken into consideration when interpreting results. In this study, we analyzed five samples, collected from outcrops of Upper Mississippian to Middle Pennsylvanian shelf and foreland basin strata, located between the Ouachita orogenic front and world-class Mississippi Valley type (MVT) Pb-Zn districts in the Ozark region. We obtained 534 new concordant detrital zircon U-Pb ages from the samples. Detrital zircon age distributions are characterized by pronounced clusters of Yavapai– Mazatzal (1800-1600 Ma), Grenville (~1300–900 Ma), and Paleozoic (~500–350 Ma) ages and subordinate older age groups (e.g., Midcontinent Granite–Rhyolite, 1550-1300 Ma). A subset of the grains (108 total), from each of the major age groups, was analyzed using the (U-Th)/He method. Zircon (U-Th)/He dates range from 202±16 Ma to 842±67 Ma, with many (31-73%) younger than the depositional ages of samples. To evaluate the cause of these anomalously young dates, we explored relationships between dates and effective [U] and measured grain widths, and none was found, indicating that neither radiation damage nor grain size are major factors. The estimated maximum burial depths (< 3 km) of the sampled formations are also too shallow to explain the He loss and reset ages. However, comparison of the (U-Th)/He dates with MVT ore-formation ages shows good agreement, suggesting that the detrital zircon grains may have been partially to fully reset by regional hydrothermal events after deposition. The results have important implications for the application of double dating in orogenic systems and suggest that the potential effects of the regional hydrothermal systems, like those responsible for the formation of MVT Pb-Zn deposits, must be taken into consideration when interpreting datasets. The results also have implications for the diagenetic evolution of Carboniferous reservoirs in the region and imply that some units experienced fluids and temperatures of up to 200 ℃ despite their shallow maximum burial depths.

Yulun Wang*, Ralf Weger, Gregor Eberli, Runar Nygaard, G. Michael Grammer -- Testing the Value of Rebound Hardness in Estimating Petrophysical and Rock Mechanical Properties From Core and Well Logs: Examples From the "Miss Lime"/STACK Play and Vaca Muerta Formation

Rebound hardness (RHN) has become a widely applied rock mechanical parameter in the petroleum industry, in large part because of the low-cost of the equipment and the easy-to-perform testing procedures. However, the RHN data is often under-utilized because of a lack of a detailed integration with reservoir properties. This study tests the utility of RHN in reservoir characterization and production by correlating RHN with petrophysical and rock mechanical properties from core and well logs of the unconventional "Mississippian Limestone"/STACK play in north-central Oklahoma, USA, and from the Vaca Muerta Formation in Argentina.

Rebound hardness can be a valuable parameter in assisting petrophysical rock typing and sample selection for detailed laboratory analyses of petrophysical and rock mechanical properties which are critical for reservoir characterization and production design throughout a core-based reservoir characterization project. RHN data collected on core slab samples from the "Mississippian Limestone"/STACK play show correlative trends with XRD mineralogy and porosity. This indicates the potential value of RHN in estimating these parameters in a more time- and cost-efficient and sample-conservative way as compared to conventional laboratory tests. For all correlations, different facies groups show data

clusters with variable patterns, implying the impact of mineralogy and the importance of conducting a systematic facies characterization in estimating these data from RHN and designing a comprehensive sampling and testing protocol to capture facies variability. These patterns are also observed in the data from the Vaca Muerta Formation, illustrating the potential value of RHN in characterizing similar types of mixed carbonate-siliciclastic reservoirs worldwide. In contrast, no distinct pattern is observed when RHN is plotted against similar types of data from well logs in three wells from the "Mississippian Limestone"/STACK play, and is likely related to the difference in the scale of data between well log data and rebound hardness. In addition, the aforementioned correlations show a relatively scattered data pattern, indicating that rebound hardness may be less valuable for some aspects of reservoir analysis including direct ties to wireline logs, especially in complex mixed carbonate-siliciclastic rocks.

Nathan D. Webb* and Nathan P. Grigsby -- Screening for and Characterizing Residual Oil Zones for CO_2-EOR and Storage in a Variety of Geologic Settings; Illinois Basin Examples

Residual Oil Zones (ROZs) are volumes of rock of significant scale into which oil accumulated and, later, was naturally displaced, leaving behind a low, largely immobile, remaining oil saturation. ROZs have been proven to be viable targets for carbon dioxide enhanced oil recovery (CO_2-EOR) – for example, thick carbonate ROZs in the Permian Basin of West Texas – and their regional extent provides opportunities for associated CO_2 storage. Research has begun to identify ROZs in other US basins.

In the Illinois Basin, several formations are being screened for potential ROZs. The focus is on oil-producing formations that are conducive to ROZ development (i.e., regionally extensive, porous, and permeable fairways that would facilitate basin-scale groundwater flow necessary for ROZ formation). The approach defined by Trentham and Melzer (2016) to explore for ROZs provides a useful framework for leveraging existing data (e.g., records from drilling, mud logging, drill stem testing, core analysis, well completions) to screen out formations that are unlikely or poor ROZ candidates and identify promising candidates. While this approach is useful for identifying ROZs in a binary sense and defining the preliminary extent of the fairway, geologic setting-specific characterization is required to define the extent, thickness, and oil saturation of ROZ prospects within the fairway.

Three promising ROZ candidates (Cypress Sandstone, Carper Sandstone, Geneva Dolomite) demonstrate the application of the characterization methodology to a range of geologic settings. For each candidate, rock and reservoir fluid samples are being analyzed to identify the unique rock properties (e.g., mineralogy, pore network, wettability) that control residual oil retention and ultimately impact the likelihood that residual oil can be detected and produced using CO_2. For example, clay mineral cements were found to adversely impact the detectability of residual oil in the Cypress Sandstone using well log analysis, despite making up <5% of the rock's bulk mineralogy.

Preliminary results of the coupled screening and characterization methodologies applied to the ROZ candidates will be presented to show how geologic setting-specific characterization is key to identify and quantitatively assess ROZ resources for CO_2-EOR and associated storage.

David Williamson*, Keith Kimme, Charles H. Smith, and Tiffani Kennedy -- Horizontal Reservoir Value Increased by Enhanced Geological Knowledge

Horizontal wells can offer unforeseen reservoir complexity. Although well characterized by surrounding legacy wells, bed dip and thickness may vary in unexpected ways. These variations can yield heterogeneous geomechanical and poro-perm properties in a single well. These may be barriers to fracture propagation or effective rock volume stimulation during completion.

In this project, geosteering services were not routinely employed because a well-defined understanding of the reservoir had already been established. Regional and local dip were well known and the impact on drilling, evaluation, and production had mostly been consistent.

Execution issues became apparent in the drilling of a horizontal well drilled between two legacy vertical fields. Midway through the lateral, the gas and cutting shows diminished abruptly. Mud log data indicated that the pre-drill structural interpretation was in error and that the lateral had drilled up section back into tighter top seal rock. Attempts to change bit inclination were successful but did little to migrate the wellbore into productive portions of the reservoir. Gas and cutting shows were never recovered. Upon completion, over half of the lateral length was ultimately abandoned due to excessive water production and low oil cut.

Fortunately, the operator had collected LWD gamma ray (GR) data while drilling, so post-drill re-steering was applied to the available information. After several iterations, a geologically complex model was derived that matched all the available drilling and mud log information and fit actual production results.

Re-steering added valuable knowledge to reservoir characterization efforts and illustrated the variable nature of localized structure and reservoir quality that could not be resolved sufficiently from offset well data alone. A key insight was the need to have sufficient geological description processes in real-time. Geosteering was added on all subsequent wells as a critical geotechnical assessment component. Real-time geological description of the reservoir assisted in keeping wellbores in the most productive portions of the pay zone. As a result, well performance (initial production rates and estimated ultimate recoveries) improved dramatically, and the company's production has increased by over 400%.

Edith Newton Wilson – Exploring New Energy Frontiers

The energy landscape is evolving from petroleum dominance to include an array of renewable and non-renewable opportunities. Along with wind, hydro, and geothermal, solar has reached an economic threshold that fosters rapid market growth. Storage requirements for electric vehicles and solar-plus-storage are spurring increased demand for critical minerals such as lithium and graphite. Mineral exploration and extraction rely on the same surface and subsurface datasets and models as those used in the petroleum industry. Critical mineral evaluation will benefit from application of drilling technology and advanced geophysical techniques, including 3D seismic. Successful exploitation of geothermal energy depends on defining the heat resource, drilling, fracking, and circulating brines. Structural geology and sedimentology studies remain crucial to proper siting, monitoring, and remediation of hydro-electric projects. Geoscientists can also apply our environmental experience to minimize the footprint of mines and industrial sites. Solar and wind design and construction are fertile ground for the application of geography and GIS skills. In parallel to development of renewable energy, a shift from heavy to light hydrocarbons for transportation and electricity generation requires traditional petroleum skills to define and extract stranded global gas resources. We can also work to optimize returns in the oilfield by introducing solar pumps and vapor recovery units. These opportunities are appropriate to discuss within the Energy Minerals Division, since our members are those in the AAPG who look beyond the conventional horizon. As exploration geologists and EMD members, we can use our strengths in creativity, risk assessment, and environmental stewardship - learned from a century of exploring the subsurface - to ensure access to affordable, reliable, sustainable and modern energy for all.