20-23 May, 2018 • Salt Lake City, Utah
AAPG ACE 2018 ANNUAL CONVENTION & EXHIBITION

Control ID Number: 2833118
Automation Provides Unique Insights of The Rock Record and Subsurface Through the Delivery of a Robotic Sample Collection and Analysis Device

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Summary
Objectives/Scope: From the very early days of oil and gas exploration, appraisal and development drilling, samples have been collected at the rig by mud logging personnel to conduct a preliminary geological analysis of the rock being drilled. This collection typically involves a sample collection recipient, board or bucket to collect a sample of rock over the desired interval. The sample is then sieved and cleaned in the appropriate way depending on the type of drilling fluid being used. As penetration rates have increased in some instances to more than 400 ft. / hr. the sample resolution has deteriorated exponentially. From an ergonomics perspective, the highest frequency to which a person onsite can collect a sample is once every 20 minutes. At 300 ft. / hr. this translates to 100 ft. of drilled rock. A new device has been developed and deployed which automates this manual process and thus ensures faster and more accurate collection of geological samples of the drilled rock interval. Sample resolutions of 5ft rock intervals have been attained at 400 ft./ hr. This technology has provided an important technological breakthrough and enables reduction of personnel at the rig site with a subsequent reduction in cost and HSE risk, particularly in areas of H2S. It further has provided for the potential integration with Measurement while drilling personnel. For both conventional and unconventional play development, this has provided oil and gas operators with an important and cost and risk reducing modus operandi compared to conventional drilling and evaluation techniques. The tool was deployed for an operator in West Texas where both manually collected traditional mudlog samples and automatically collected samples were taken. The samples were analyzed and compared for rock content. In addition, comparisons were made between point sampling with the automated system versus samples collected over a defined interval manually. Results of these comparisons will be presented. Results, Observations, Conclusions: A new method of automated drill cuttings sample collection has been successfully deployed. The new method provides a step change improvement in accuracy and resolution for sampling the rock record during drilling. Novel/Additive Information: Additional data of the rock record provides potential insights to optimize wellbore placement and provide increased geo-mechanical data to optimize completions.

Introduction

Geoscientists over the years have employed various methods to characterize the subsurface to prospect for hydrocarbons, identify potential new basins and drilling targets. From far scale to near scale, seismic, gravity anomalies, geochemical surveys, outcrop mapping, cores, sidewall cores, petrophysical and mudlogs. Cores are referred to as ground truth and provide a continuous solid cylinder of rock providing a direct insight into the rock composition and properties. Coring can be time consuming and costly and hence is used typically in new areas or in zones of high geological uncertainty and or risk. A wide range of petrophysical logs are also run in exploration wells on either wireline or LWD and could include Gamma Ray, Resistivity, Neutron density, sonic, image logs, fluid sampling and NMR. Logs are calibrated to the core and integrated to provide insights into the subsurface. Logs will provide data typically at the sub 1ft scale of depth resolution. Drill cuttings, a natural byproduct of the drilling process are transported to the surface via the drilling mud. Samples are collected at surface for both onsite and laboratory analysis. From Core to wireline to LWD to mudlogs the depth of resolution deteriorates. As rate of penetrations have increased with the advent of rotary steerable technologies, high performance mud motors, improved drilling fluids, fluids and automation it is not unusual to see ROP's in excess of 200-300 ft. / hr.

Theory & Method
The ROP Challenge

As ROP's have increased the ability of humans to keep up with the sample collection process has decreased. Ergonomically it is feasible that samples can be collected and processed once every 20 minutes. Theoretically at ROP's of 240 ft. / hr. allows for a sample to be collected every 80 ft. see Fig 1. At the same ROP the ARM Automated Remote mudlogging system can potentially collect a sample every 120 seconds providing a sample depth resolution of 8 ft. versus 80 ft. utilizing conventional sampling techniques.

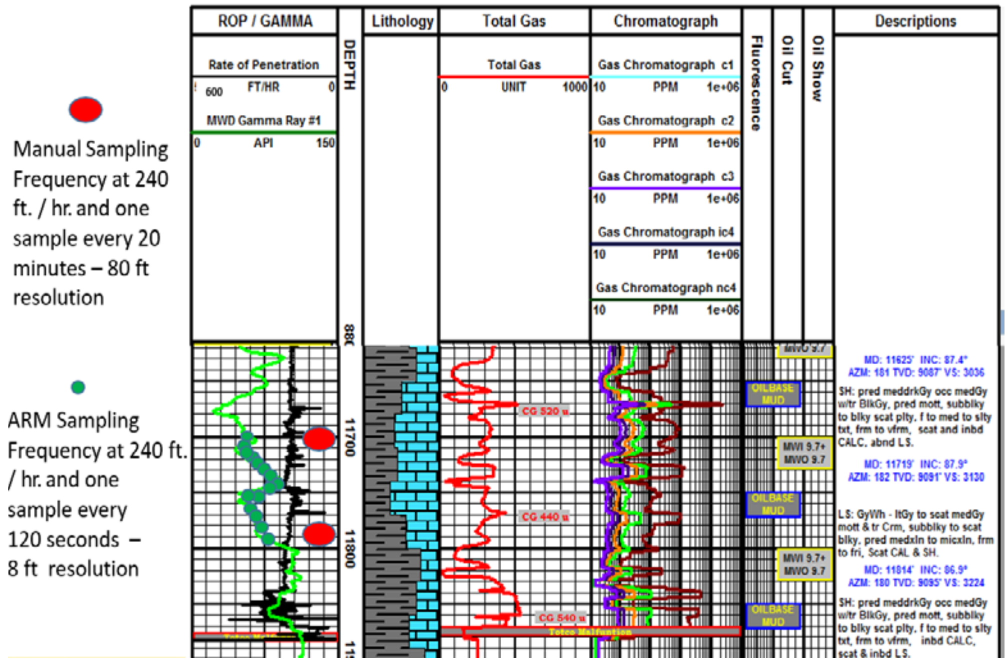

Fig 1.

Fig 1.a

Conventional sampling Techniques

The mudlogger or roustabout collects a sample from the outflow of cuttings as the drilling fluid passes over the shakers separating drilling fluids from solids. The advised method to collect a representative sample over the interval is to place a cuttings collection board or tray at the foot of the shaker and before the solids drop into the waste pit. R.G Swanson AAPG and Shell sample examination manual stated that good quality, clean samples were the exception as oppose to the rule. If a 10-ft. sample is required, the mudlogger calculates the lag time for the cuttings to come to surface and then ensures that they collect a sample over the given depth interval. Once the cuttings have been collected they must be washed and sieved. For water based muds water is used as the cleaning agent and for oil based muds. diesel is used. See Fig 1.a.

The cuttings are sieved with various mesh sizes. The samples are then taken to the mudlogging unit for further preparation and visual analysis. Both wet and dried samples are often required to be processed and then sent to the project stakeholders. Samples are then analyzed under a microscope and the mudlogging geologist will make a visual estimation of the composition of the samples. This will include both a percentage lithology and an interpretation of the rock composition, grain size, shape, sorting, oil fluorescence etc. over a given interval.

Fig 1.b

Once the mudlogger has completed the visual estimation of the rock composition the analysis is transferred to a mudlog and incorporated with Rate of Penetration. Mud gas measurements (C1-C5) & often Gamma Ray from downhole tools. The MudLogger notes the percentage lithological changes and makes a written sample description. See Fig 2. Inset example mudlog.

The conventional sampling process leads to a considerable health and safety risk in the guise of slips, trips & falls. Mudloggers rarely afford the luxury of three points of contact both ascending and descending stairs. The fast rates of pentation mentioned above lead to greater risk of injury due to increased requirement for sample collection frequency.

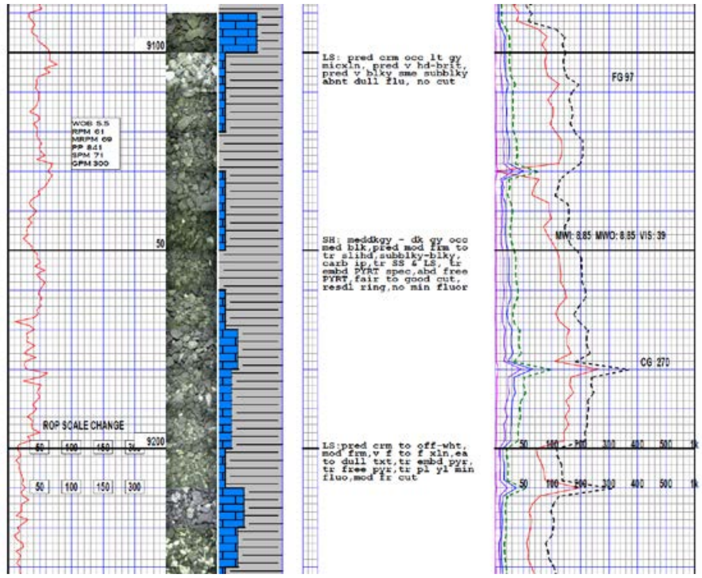

Fig 2

Georgi et al SPWLA 1993 described some potential improvements to sample collection through the deployment of another system. The automated cuttings collection system consists of a mud pump, mini-shaker elutriator and collection vessels. This system, placed downstream of the bell nipple, was designed to minimize contamination of cuttings due to mud solids, cavings and recirculated drill solids. Drill cuttings were collected in clear plastic tubes and are available for analysis at the wellsite or in the laboratory. To the knowledge of the authors this system has not seen any significant adoptions since its introduction in 1993.

Operational Details

For this paper we will analyze the operational details and results from wells where the ARM System was deployed in the Permian basin. The Automated Remote Mudlogger can be installed relatively simply in a couple of hours and with minimal rig Intervention. The footprint is approximately 4ft x 3ft x 3ft and weighs less than 450lbs. It involves the installation of a hydraulic collection device which can be submerged in the possum belly or flow line. Alternatively, a cuttings collection board can be placed at the foot of the active shaker. The samples are drawn into the machine via specialized pumps and valves and deposited in the machine in a proprietary designed collection chamber. Solids and liquids are separated by 635-micron mesh. The mesh is pre-stamped with serial bar codes which are correlated to lag depth via a Wellsite Information Transfer Standard (WITS) connected to the Electronic Drilling Recorder or other data acquisition system of record. Samples are collected onto a rotating drum and held in place by a proprietary designed sealing system. Up to 350 - 20gm samples, can be collected on each reel. At 10ft intervals this corresponds to 3,500 ft. of rock. The reels are 18 inches in diameter weigh less than 20lbs when full and take approximately 5 minutes to change. Between 10-30 gr of sample are collected at each depth. The machine has a high powered digital microscope for high quality photo images of the drill cuttings.

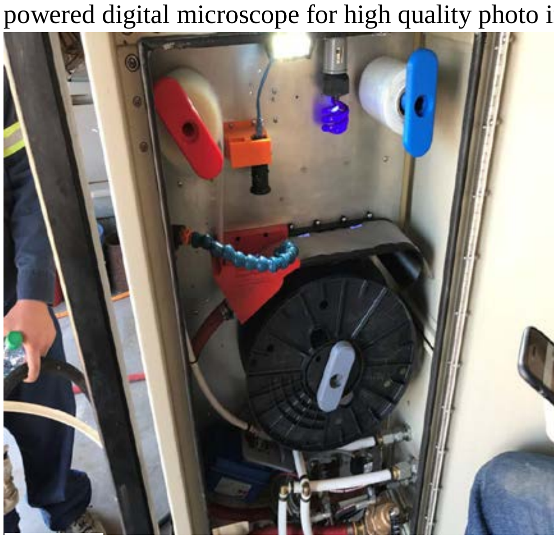

Fig. 3

See Fig 3. of inside of the Automated Remote Mudlogger

The ARM System was recently deployed (Aug. 2017) on a core drilling program. First section was from intermediate casing shoe to core point with 3 coring sections followed by a final fifth section to pilot-hole TD. Fluids program was water based and did not include the addition of Lost Circulation Material (LCM). Gel sweeps were conducted at the end of each section for clean-out and wellbore conditioning.

Fig 4

Pre-conditioned mud was used, and sodium hydroxide added to increase gel strength and improve cuttings lift. Fluid temperature rose to +140`f in the last section of the well. The rig utilized was a top – drive retrofit SCR design with 3 shakers ending in a "slide and trough" solids control system. Solids and residual fluid were washed from the trough to a reserve pit system. Pason was the electronic data recorder, contracted by the rig, for monitoring drilling dynamics and rig systems.

ARM Operations:

ARM system was rigged-up at the intermediate shoe and active throughout the pilot well to TD see Fig 2. 10' sampling intervals were collected throughout the drilling program, until switching to 20' intervals (11355') near the end of the well, per on-site geologist request. 5' intervals were attempted twice, per client, in the second coring section but cuttings quantity collected were insufficient to maintain 5' intervals. The system achieved an overall collection rate of 94%. Infrequent samples of less than 12g were observed. Operations issues were encountered with a cuttings jam located at the collections box inside the ARM unit. A second jam was later observed within the transport line at the pump.

On-site, real time, ARM tech support was provided by a separate field engineer. Trips to the shakers during every section were made to adjust the ARM extraction device, to check for adequate flow to the selected shaker, and to troubleshoot cuttings jams to ensure continuity of operations. Trips to clean the camera lens increased as mud temperatures rose in the last section drilled. Frequent real-time adjustments to the ARM duty cycle program were made in every section, to ensure continuity of sample quality/quantity.

Fig 5

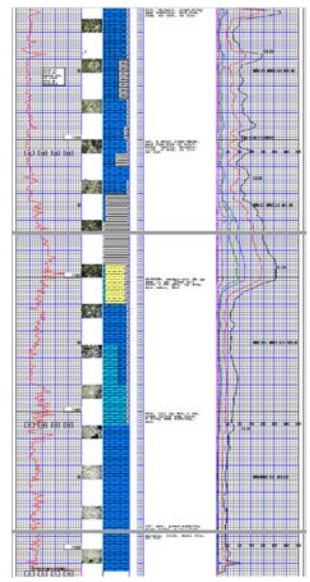

Fig 7

Fig 5. Sample photograph of collected drill cuttings in the ARM, Automated Remote Mudlogger

Results: Total interval to collect was 4718' and included 1150' during coring operations. The ARM System collected 508 samples with 479 samples 15gms or greater. 94% success rate. ARM system collected at 10' intervals vs. 30' from mudloggers. Average ROP of 100'/hr. gave the ARM 10 collections per hour, vs. 3 collections per hour from mudloggers. 5' intervals were attempted on several occasions, but insufficient cuttings load was observed after a few successful collections.

See Fig 6. of a reel returned post well for review and further analysis.

See Fig 7 for mudlog.

Fig 6

On a second well operation for another operator the results were as follows. Total depth to collect was 11,850' at 30'intervals vs. mudloggers with variable rates depending on ROP speeds 250' were logged with collection intervals of 10' vs. mudloggers at 30'. The ARM system collected 447 samples with 349 samples of 10gms or greater. A 78% success rate. ROP -25/hr. in the final 2000' created a low available cuttings environment, and reduced success rate. The Compositional data of the rocks collected by the ARM and the mudloggers manually showed a general broad agreement. Differences observed can be attributed to spot sample (ARM) versus wider intervals collected manually.

Minerals & Elements

XRF and XRD analysis were carried out on the samples collected by the ARM and provided important insights into the nature of the elemental and mineralogical composition of the Rock. Elements and minerals have been measured using XRD and XRF for many years and advancements over the last decade have led to a widening of the application uses and adoption. Tonner et al SPWLA 2012 described how the XRF was utilized to characterize a vertical pilot well in the Eagleford to select an optimal landing target for the lateral and then take that signature and utilize it to validate wellbore placement(Geosteering) and optimize completion design. It is expected that high Resolution ARM sampling will see increased use of these data sets with improved depth resolution. Other significant papers in these areas Mainali et al AAPG 2016, Dix et al AAPG 2006, El-Gezeery et al. 2007 AAPG-I, Rowe et al. 2008 Chem Geo. Future development of the ARM contemplate the inclusion of real time element and mineral analysis. From Tonner et al SPWLA Cartagena see Fig 8; It is well-established that the most effective preservation of organic matter in mudstones (i.e., high-TOC "black shales") is most often related to anoxic/euxinic conditions at the seafloor during deposition (see papers in Harris 2005). It is also well known that certain trace elements (particularly V, Ni, Mo, and U) are concentrated in the sediments and the organic matter because of these conditions (e.g., Tribovilliard et al. 2006). The trace metal enrichments can be quickly measured in cuttings samples by the XRF. Wright et al SPE 2010 explained how Paleo redox plays an important role in determining TOC values. Consideration of redox-sensitive elements, such as V, Ni, Th, U and Mo provides a means to determine the degree of anoxia during deposition.

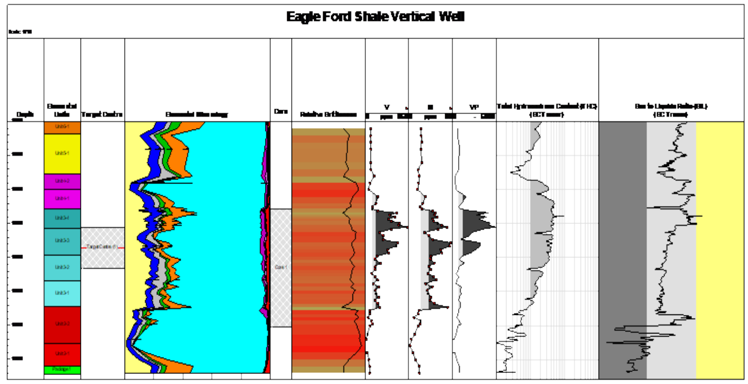

Fig 8.

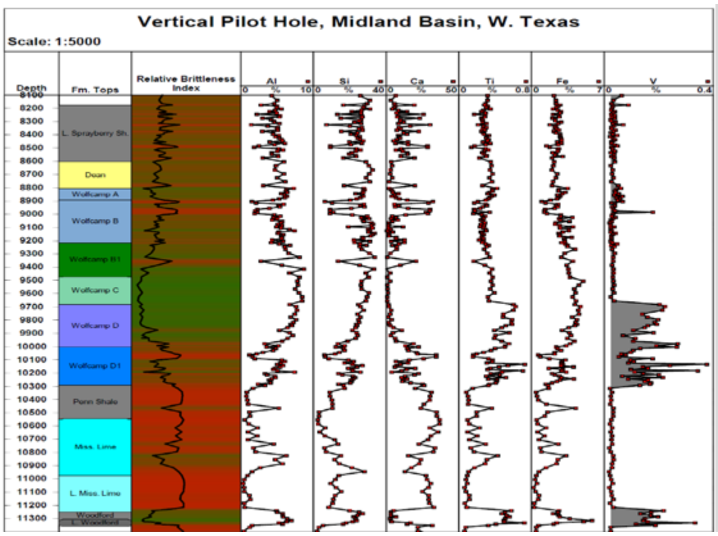

Fig 9

XRF Data from the ARM collected High Resolution Samples

XRF analysis was carried out on the samples collected by the ARM at high resolution sampling rates. Several observations can be drawn from the data. The Redox element vanadium commonly a proxy for TOC (Total Organic Carbon) can be seen at its highest levels in the Woodford, Wolfcamp D and Wolfcamp D1. The most ductile rock can be seen from the green shading on the relative brittleness index in Wolfcamp C & D. Silica and Calcium trend in opposite directions as sequences change from predominantly silici-clastic to carbonates. See Fig 9.

Fig 10 inset, shows excellent correlation from the mud gas measurements of C1, C2 & C3 together with the elemental compositions from the XRF. Highest methane, ethane & propane peaks correspond to highest levels of Vanadium both in the Wolfcamp D, D1 and Woodford formations.

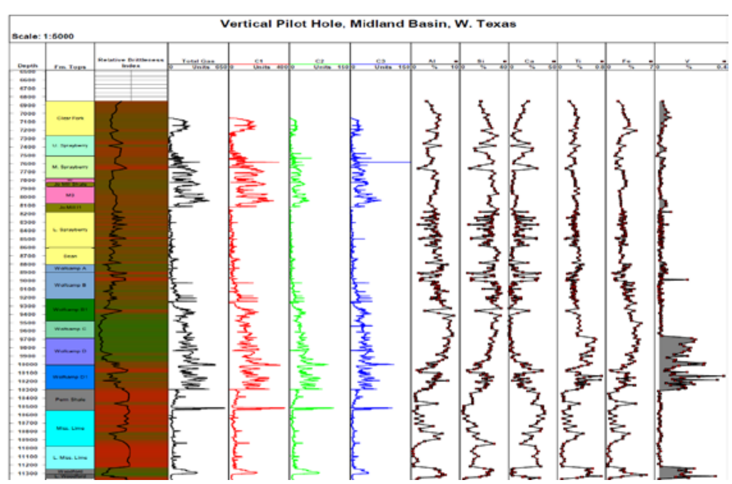

Fig 10

Fig 11 shows a comparison of ARM collected samples (red squares & black curves) vs a whole core (green curves). Both sets of rock were analyzed with XRF. The cuttings samples were also analyzed with a LECO TOC and compared to the trace metal Nickel. The below results show a very favorable comparison and correlation between the ARM collected samples and core. Nickel on the core correlates well with Nickel from ARM collected samples. Nickel compares well to LECO TOC from the cuttings. Vanadium and LECO TOC does not demosnstrate a favorable correlation in this section.

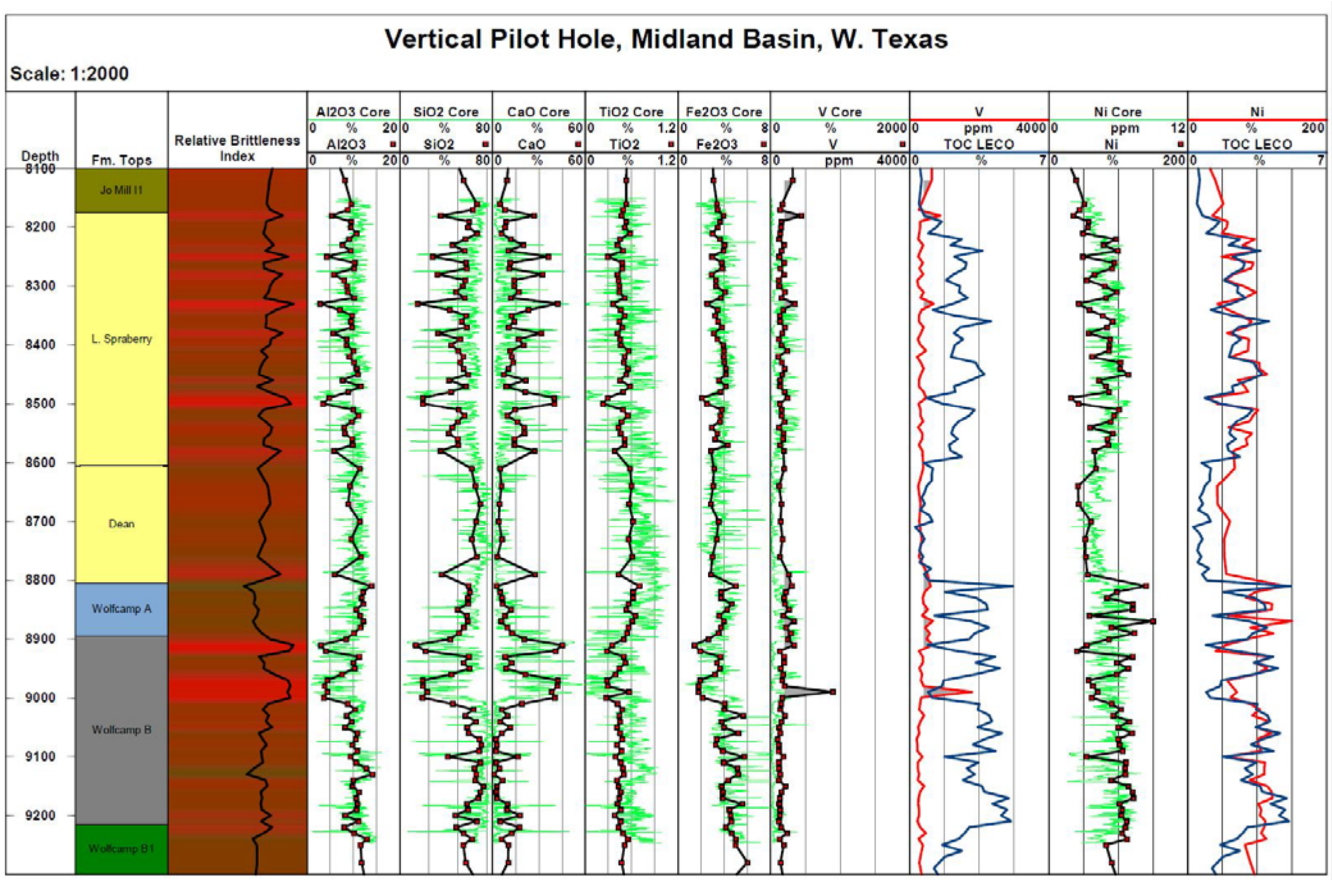

Fig 11.

Observations and recommendations

A new method of automated drill cuttings sample collection has been successfully deployed. The new method provides a step change improvement in accuracy and resolution for sampling the rock record during drilling. Additional data of the rock record provides potential insights to optimize wellbore placement and provide increased geo-mechanical data to optimize completions. The system is easy to set-up and install while still requiring some human intervention. A versatile “shaker board” extraction system will eliminate much of the hands-on adjustments required, but versatility of mounting the system to different rig-designs is ongoing. Observed duty-cycle time averaged +100secs, plus the reel speed of +60secs, makes for sampling time intervals of ~3 mins. High RoP will extend sampling intervals considerably. Loss Circulation Materials like paper and cotton seed can have a negative impact on operations regardless of extraction system. Extraction systems in an air drilling environment have not yet been addressed. The system can consume 2 gallons per minute of diesel and this must be communicated and coordinated with the drilling engineer, company man and drilling fluids engineer. Reels are currently sent to warehouse for storage and or individual bag packaging for storage or transport. The high-resolution ARM collected samples proved very useful for posterior XRF analysis and integration of gas measurements to provide a better overall understanding of the subsurface. Conuducting XRF on the manually collected samples would also provide a more comprehensive comparison going forward. Efforts are ongoing to incorporate real time elemental composition analysis to reduce the lag from collection to result and reduce uncertainty compared to manual collection process and subjective manual estimation of rock composition. The system affords the opportunity to integrate with MWD personnel for overall potential manpower reduction and to greatly assist in picking of landing zones, casing points coring points and geo-steering once real-time elemental composition is incorporated.

Conclusions:

The Automated Remote Mudlogging machine proved to be a viable and reliable method of collecting and storing drill cuttings with minimal human intervention. The machine collected drill cuttings which when compared to human collection of the samples represented a greater than 300% improvement. 10 samples per hour or a sample less than 6 minutes was easily achieved by the machine. This new technique for sample collection provides an important improvement in the areas of collection frequency and sample collection integrity. Using high resolution sampling and applying XRF analysis provides the opportunity to optimize wellbore completion through greater understandoing of geomechanical properties. In addition, the tool provides an important potential step change in HSE improvement through the reduction of potential for slips, trips and falls.

Ackowledgements
We would like to acknowledge Petrolegacy Energy's Bret McDaniel and Stephen Seacrest for their assistance and contribution.

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Authors:

David Tonner received a Bachelors of Science in geology from the University of Nottingham in the UK. He has over 28 years' experience in the field of surface logging measurements. Dave spent his formative years as a mud logger and pore pressure engineer working with Geoservices in Africa and the Middle East. From there he worked with Datalog Technology in the Western Canadian sedimentary basin including the Mackenzie Delta and then lived and worked in Latin America from 1993 to 2000. Dave moved to Houston in 2000 and became part of Weatherford in 2008 through the acquisition of International Logging/Datalog Technology. Dave was vice president of Weatherford's global surface logging group and oversaw global business development for Mudlogging, Rotary steerable drilling, LWD, MWD and directional drilling. Dave spent a brief period at Nabors as global director for performance drilling prior to joining Diversified Well Logging as Chief Executive Officer in late 2016. Dave has spent his career focusing on the development of improved wellsite measurements including advanced mud gas extraction/detection and techniques to provide quantitative analysis of rock cutting compositions. Dave has been an active member of the HGS Houston Geological Society where he chaired the Northsider's group for over 4 years. He is also a member of SPWLA, AAPG and SPE.

Simon Hughes holds a B.Sc. in Geology from the University of London (UK). After completion of post-graduate studies in Mining Geology and Mineral Exploration at the University of Leicester (UK), he gained four years' experience mud logging and formation pressure evaluation on both oil and gas exploration and development wells in the North Sea, Europe, West and North Africa and the FSU. He was then involved in the development of LIBS (Laser Induced Breakdown Spectroscopy) instrumentation to perform the rapid analysis of inorganic elemental data at the rig site. As Senior Geoscientist and Global Technical Support for Halliburton, Simon was responsible for the deployment of wellsite geochemical services on over 85 wells, in both clastic and carbonate reservoirs in the Middle East, North Sea, Brazil, West and North Africa, Canada and the FSU. This involved the use of elemental data to geosteer highly deviated and horizontal wells, pick core and casing points in exploration wells, together with enhanced formation evaluation such as the identification of heavy oil in carbonate reservoirs.

More recently he has been involved in the introduction of wellsite geochemistry as an aid to drilling lateral wells in unconventional resource plays in North America, such as the Haynesville and Eagle Ford. This includes application of the elemental data to aid in wellbore placement and also formation evaluation such as the assessment of mineralogy, organic richness and geomechanical properties from drilled cuttings, real-time while drilling. Simon brings some 22 years geoscience experience including 18 years wellsite geochemistry. Simon joined Weatherford as Product Line Manager for Wellsite Geochemistry in 2009. His role included development of a global integrated wellsite geochemistry service to aid in drilling more efficient wells chiefly through better wellbore positioning and enhanced formation evaluation. Integration with more conventional LWD and wireline geosteering and formation evaluation techniques provide better petrophysical interpretation and input into "smart" stimulation and completions particularly in unconventional resources and was key to his role there. Simon recently joined Diversified Well Logging as a senior technical advisor. He is an active member of the AAPG, SPE, HGS and SPWLA.

Aaron Swanson is the Chief Operations Officer for Diversified Well Logging LLC. Mr Swanson has held various roles in Energy and Defense over the last 29 years including: quality, regulatory, innovation, project management, software development, marketing, maintenance, training, and field operations. He served in the US Navy aboard the USS Kitty Hawk and taught at the Naval Air Technical Training Center in Pensacola Florida. Mr. Swanson Joined Diversified Well Logging as Chief Operations Officer in 2013. He holds a Master of Project Management degree and a Graduate Certificate in Supply Chain from Penn State, a Bachelor of Science degree in e-business, and an associate's degree in computer networking systems.