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An Innovative New System for Obtaining Open Hole Logs in Difficult Wells

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Abstract

Open hole logging of wells with adverse hole conditions and high deviations is now becoming more commonplace due to newly developed conveyance and acquisition systems. In many cases it can be impractical to obtain logs due to the cost and downside risk of doing so. On the flip side though, having this information can often significantly impact future drilling and completion decisions and possibly the ultimate success of a field.

There is now a system available that features an innovative hollow bit design. This design allows for mutiple methods of deployment of a specially designed slim logging string through the drill pipe and bit into open hole. Basic log information can be obtained in real time on wireline below the bit, in memory while tripping out with pipe, or a combination between the two depending on conditions. The specific method chosen depends on the well design and hole conditions. Added flexibility to ream, circulate, and even drill just prior to logging is also possible. The rig time to run logs, along with the associated cost and risk, can be minimized using this system when compared to other methods that are currently available. An overview of this system's conveyance methods and equipment components will be presented along with some examples that illustrate its use in a variety of situations and wellbores, including horizontal wells.

Introduction

The successful acquisition of open hole log data is important for locating and quantifying potential producing horizons in newly drilled wells. Logs are needed to decide if the final completion of a well is justifed, and how to best proceed with optimizing the ultimate recovery of hydrocarbon reserves. A large percentage of the total cost of the well is attributable to the completion, especially when hydraulic stimulation is involved. Logging data has a significant impact on stimulation design.

There are often times when traditional wireline logs are difficult to obtain due to challenging hole conditions, including sloughing or swelling shales, ledges associated with washouts and high deviations. Horizontal wells present the ultimate challenge. Depending on the circumstances, other log acquisition methods including LWD and pipe conveyed logging are possible alternatives. The associated costs and risks of these other methods can often be substantial.

The concept of logging through the bit [1,2] has been around for some time. It is a method by which small logging tools can be passed into open hole through the protected environment of the drill string after a hollow bit has been positioned past problematic intervals or around highly deviated sections. Logs can then be run beyond the bit in memory or in real time to get the needed information. In the span of time since the original concept of through bore logging was tested, it was conceived that smaller diamater logging tools with enhanced ratings and other complementary devices not previously available could address a wider range of tubular sizes and well conditions. A new set of smaller diameter logging tools was designed to have exceptional ratings compared to other comparably sized tools and allow for increased capability in more difficult settings. Hardware configurations and logging procedures have evolved to complement these new tools and achieve the end goal of obtaining logs in the most difficult scenarios, including horizontal wells, while minimizing the associated costs and risks. This paper is an overview of the equipment and deployment methods that make this data gathering possible. Data sets obtained with this system will demonstrate its quality and usefullness.

Logging Tools and Equipment

Slim Logging Tools

Logging tools with a small enough diameter to pass through the majority of drillstring components and inner diameters of the drill pipe, collars, bit and jars were needed for successful deployment of the tools into open hole. The logging sensors also had to be designed to work in an extended array of hole sizes and environmental conditions. A study was conducted to determine the optimum diameter for the new tool string that would accomodate these prevailing conditions for the majority of anticipated needs. The optimum diameter for the tools was determined to be 2-1/8". Initially the measurements provided were a multi-array induction resistivity with five median depths of investigation ranging from 10 inches to 90 inches, bulk density with photoelectric factor, thermal neutron porosity, powered caliper and gamma ray. Other available auxiliary measurements are SP, casing collar locator, mud resistivity, temperature and tool orientation. Figure 1 is a typical schematic showing these tools and their ratings for a conventional real time open hole logging job on wireline. A monopole sonic tool with a six receiver array and the same ratings as the other 2-1/8" tools was later designed and built. The sonic is combinable with the tools shown in Figure 1.

Figure 2 is a log comparison run with the prototype version of the new 2-1/8' tools (red curves) run in a vertical well in South Texas that was drilled with a six inch bit using oil base mud. The well was first logged with another established logging company (blue curves) immediately followed by the 2-1/8" tools. The maximum outer diameter of the other company's tools was 3-1/2". No well conditioning was done in between the log runs. The most pertinent measurements, deep resistivity and porosity, are compared and show good agreement where there are no tool pulls. Fewer tool pulls were observed with the 2-1/8" tools due to their smaller diameter.

Hollow Through- Bore Bit

Passage of the slim logging string through the drilling tubulars requires a hollow bit design with a large enough through bore diameter to allow the 2-1/8' tools to pass. A modified PDC bit has always been chosen for this design. Figure 3 is a photo of a PDC bit with the through-bore design. Since its initial introduction, the latest generation of these bits has benefited from the following modifications:

- Bits manufactured from new materials
- Improved internal hydraulics – allowing for longer bit runs
- Multiple bit suppliers
- Increased range of bit sizes and configurations. The hollow bits are currently available in sizes ranging from 6 inches to 12-1/4 inches

Specific bits can be designed for the necessary operating environment. This ensures that bit parameters including blade count, cutter size and type, bit hydraulics, etc. are optimized to give equivalent drilling performance compared to standard offset drillbits.

Pressure Control

Standard pressure control equipment utilized for pipe recovery operations can be used during tool deployments described below. This allows the operator to circulate and rotate with the drillstring at all times. A standard rig-up consists of a drill pipe swivel, pump-in sub and wireline pack-off . If drillpipe reciprocation is required, then a pipe recovery style side entry sub can be installed.

A flapper style float valve is available for the BHA and provides an added measure of control in underbalanced situations. This flapper valve allows the passage of the 2-1/8" logging tools, and all ancilliary equipment, to pass through the valve in both directions. A separate sub in the BHA houses this valve. The flapper valve can also be used as a float valve during drilling and conditioning runs.

Methods of Deployment for Specific Well Conditions

Various methods of deploying logging tools have been previously documented in other papers[2,3]. With the further refinement of the hollow bit design, deployment and retrieval equipment designs and the introduction of the new 2 1/8" tools, the methods below have been put into practice. Common attributes of this deployment system that make it unique compared to the other methods are:

- Some configuration of the through-bore bit is always involved with the ability to ream and condition the hole for logging.
- The slim tools are not inserted into the drill string until the well is in satisfactory condition and the bit is at the desired depth based on the logging interval required.
- The 2-1/8" tools are lowered into position with a wireline that is protected inside the drill pipe. The wireline connection enables a downlog and the verification of the tool's full functionality from the time they leave the surface until they either pass into open hole to log in real time, or are switched to memory mode. The resulting downlog of gamma ray, neutron and CCL can be used for depth control. The system reliability is enhanced due to the fact that the tools can be monitored right up until the main log is recorded. Most of the other alternative pipe conveyed wireline methods do not permit this continuous monitoring.
- The 2-1/8" tools and nuclear sources can be retrieved at any time during the operation without tripping pipe.

Due to their slim design and the components described above, the 2-1/8" tools can be deployed in a number of ways depending on the circumstances. Savings in rig time and completion costs associated with logging through the bit have been published.[4] Some of the more common deployment situations are described below.

Level 1 – Conventional Wireline in Real time with the 2- 1/8" tools:

A conventional wireline attempt might be appropriate when combinations of small hole diameters or difficult conditions could prevent larger wireline logging tools to either make it down to the total depth of the well and/or acquire log data of sufficient quality to make a proper evaluation. Smaller profile toolstrings sometimes have a greater chance of reaching TD in these settings and can be used to make a first attempt to get logs when the operator desires them in real time. In sticky hole conditions, tool pulls degrade the quality and validity of log data. Smaller diameter tools have less cross-sectional area in contact with the borehole and therefore create less drag or differential sticking than larger diameter tools. The example shown in Figure 2 is a Level 1 acquisition with the 2 1/8" tools that obtained logs with fewer tool pulls than the larger diameter slim tools. All of the equipment and other types of deployment described below are avaliable onsite in the event that the initial conventional wireline attempt is not successful.

Level 2 – Conventional Wireline in Real Time conveying the 2-1/8" tools through drill pipe and bit:

For situations when there is only one perspective interval near TD that needs evaluation and the shallower hole conditions would not permit easy passage of the tools, the Level 2 method may be applicable. In Level 2 deployment, the hollow bit is substituted for the normal bit prior to the conditioning trip. The driller can then condition the hole for logging using this bit. Once the well is ready, the bit is positioned at a depth just above the target zone. The 2-1/8" logging string attached to a wireline is then inserted into the drill string at the surface. Pressure gear can then be installed and the tools are logged down as they are lowered through the remainder of the drillstring and bit into open hole. The pressure equipment and swivel allow for circulation and rotation of the pipe throughout this operation. The capability to circulate can also enable the well temperature to be lowered and more controlled in areas where the BHT is near the tool's rating. Once the tools reach TD, the open hole interval is logged on wireline in real time. The logging string and wireline are then pulled back through the bit and drill string to surface. Any further wellbore conditioning needed prior to running casing can then be completed without tripping the drillstring out of the hole, resulting in rig time savings. In certain situations with well control problems, it is possible to rig up a full lubricator allowing the operator to obtain open hole log data in an underbalanced environment.

An operator in East Texas recently drilled an S-shape well and encountered problems when trying to pass another company's large diameter logging tools around the kick-off point and drop sections. The Level 2 conveyance method was utilized, positioning the through bore bit and drill string past these curves. This enabled the 2-1/8" slim logging tools to easily pass through these areas to log the lower interval of the wellbore.

Another operator drilled a vertical well in which the casing shoe was damaged. This situation discouraged the use of conventional wireline logging due to the added risk of sticking the tools or wireline in the damaged casing. The Level 2 method was used to position the through bore bit past the split casing shoe and enabled successful log acquisition of the interval below.

In both of these cases, logs were successfully obtained at lower risk while eliminating the added rig time associated with making multiple logging attempts or more expensive alternative logging methods.

Levels 3 & 4 – Memory Logging with the 2-1/8" tools being deployed through the drill pipe and bit:

When there are multiple zones to be evaluated or the deviation is too high to allow gravity to take the tools to the farthest desired depth, then the Level 3 or Level 4 method is used. These techniques eliminate the risk of exposing the wireline to open hole and the logs will therefore be recorded in memory. The surface rig up and initial deployment are the same as in Level 2. The through-bore bit is placed near TD with just enough room between the end of the drilling assembly and TD to allow the toolstring to extend beyond the bit. As before, the logging tools are logged down to the desired depth through the drill pipe and bit on a wireline. In horizontal wells the tools are pumped around the curve and to the desired measured depth using the rig's mud pumps. Pumping the tools down is the only difference between Level 3 and Level 4, so Level 4 is the mode of choice for all horizontal wells. Level 3 is appropriate in vertical, S shaped and slightly deviated wells with sticky or unstable conditions.

Figure 4 is a typical tool string schematic for a Level 3 or 4 logging operation. The wireline, Wired Drop-off and Retrieval tool and Hang-Off tool remain inside the drill string. When the tools reach the bit, the tool string is extended through the bit just far enough to extend the logging sensors into open hole. The tools are then hung off using the Hang-off sub and Hang-off tool. The Hang-off sub is a modified bit sub located above the bit that contains a landing ring. The Hang-Off tool contacts the landing ring and prevents the tools from traveling any further beyond the bit. This arrangement also allows independent rotation of the pipe and logging tool during acquisition. The Hang-off sub and tool are designed to allow for circulation of both drilling fluids and lost circulation material (total flow area of assembly with tools deployed is 2.3 sq.in.).

At this point, only the logging tools are in open hole and the wireline is still attached. The logging tools are again checked for proper operation and the caliper is opened. Deviation sensors inside the tool can be checked to verify that the density skid is facing to the low side of the hole in horizontal wells. The toolstring is then switched over to battery power. The wireline and upper part of the Wired Drop-off and Release tool are subsequently released and removed from the drillpipe. The Wired Drop-off and Retrieval tool consists of an electro-mechanical release mechanism which allows for a soft release of the wireline from the logging string. An electrical signal from the uphole wireline unit is required for the release to occur. Once the wireline and upper part of this mechanism is separated from the logging string, an industry standard fishing neck is left exposed to allow easy retrieval of the system. The upper part of the Wired Drop-off and Retrieval tool that was previously brought to surface can be reset to later be utilized in the retrieval of the tool string by latching onto the exposed fishing neck. The logs are recorded in tool memory as pipe is tripped to the top of the logging interval or the surface. The speed of the pipe is typically much less than the 1800 feet per hour required to make the nuclear measurements valid.

Once the logging is completed, or at any time desired, the upper part of the Wired Drop-off and Retrieval mechanism described above can be lowered through the drill pipe on wireline to retrieve the toolstring. This step allows the data to be accessed sooner and verified prior to tripping the pipe to surface. The retrieval process is not mandatory since the tools can simply be tripped all the way to surface with the pipe. Depending on circumstances, it is the operator's decision whether to stop the pipe and retrieve the tools, or wait until the end of the trip to download the data.

During memory logging the downhole sensors store data in tool memory and the data is recorded in the time domain. A second dataset containing bit depth versus time is required to produce a conventional log in the depth domain. Surface systems similar to those used for LWD/MWD, consisting of a drawworks encoder and a hookload sensor, are utilized to obtain the bit depth and time data required for the final memory data processing. The surface data file can also be obtained from using the rig sensors and recording data from the WITSML (Wellsite Information Transfer Standard Markup language)[5]. The time indexed log data from the tool is merged with the depth-time data recorded by the rig to produce the final log.

An Oklahoma operator had plans to drill a deviated pilot hole through their target formation prior to drilling horizontally. The original well plan specified a maximum inclination of 50 degrees to allow logging the with larger diameter logging tools. The

Level 3 option was used to enable the pilot well to be drilled at a higher inclination (approximately 70 degrees). Logs were successfully obtained in memory. Additional operational efficiency was gained due to the fact that the operator was able to come out laying down pipe as the well was being logged.

Figure 5 is a partial section of log obtained using Level 4 in a horizontal well drilled through the Granite Wash formation in the Mid-Continent. The Granite Wash is known to be very sporadic in its deposition. The log shows that borehole traverses intervals of better reservoir rock, shown as the yellow cross-over between the neutron and density porosity. The cleaner zones with cross-over also have higher resistivity on the induction as one would expect and there is variation in the porosity. Note that there is no clear correlation of the gamma ray with the cleaner rock versus the shaly intervals in between. This is due to the complex minerology of the Granite Wash and the presence of radioactive feldspars and clays. For that reason, a gamma ray by itself is of limited use for correlation and geo-steering. The laterally discontinuous nature of this formation is even more obvious in Figure 6 which is another measured depth section in the same well. Clay bearing intervals are the ones with positive separation where the neutron porosity (blue dashed curve) reads higher than the density porosity (black solid curve). The significance of having this log for planning the completion is obvious from the standpoint of selecting which intervals to complete and the staging of the fracs.

Level 5 – Drilling and logging with the 2-1/8" tools through the hollow bit with a center insert:

This method allows the operator to drill new hole with a special adaptation of the through-bore bit, deploy the logging sensors, obtain logs and remove the drillstring from the wellbore all in one trip. The modified bit includes a center insert mechanism that enables it to drill like any other PDC bit just prior to logging. During deployment of the slim tools, the insert containing a latching mechanism is removed by the downward movement of a mechanical running tool attached to the bottom of the logging string. After being unlatched, the insert stays firmly attached to the bottom of the logging string. Photos of this bit with the center insert attached and removed to be extended beyond the bit are shown in Figure 7. Logs are then acquired in either real time or memory as in Levels 2 or 3. After the logging is complete, the entire tool string including the running tool and insert are pulled back into the drilling assembly and the bit insert is re-attached with the upward movement of the tool. Like in the other methods, the logging sensors and nuclear sources can be removed through the middle of the drillstring at any time.

Significant improvements in the inner workings of the modified through-bore bit and detachable insert mechanism have been made since its original design and the final version is nearing full commercialization. Level 5 deployment is a single trip system for drilling just prior to logging, thus eliminating the additional time and risk required for a trip out of the hole for logging and well conditioning prior to running casing.

Conclusions

The unique combination of a recently developed set of 2-1/8" logging tools, a refined through-bore bit design and customizable deployment techniques permit a wider range of capability than was previously available for obtaining open hole log data in difficult hole conditions and horizontal wells. Deployment levels two through five allow the advantage of having a bit in place and the confidence of knowing that a well is in the desired condition for logging or running casing prior to positioning of the slim logging tools at depth. Rig time savings can be realized since the logs can be run during the conditioning trip without the need to trip out of the hole. By virtue of the fact that these tools are connected to a wireline that is protected inside the drill pipe prior to positioning in the survey interval, logging sensors can be continuously monitored for proper operation until either memory or real time acquisition takes place after a downlog is recorded. This aspect adds to the overall reliability of the job and is a cross-reference on depth control of the final log. The risk of logging is further minimized since the 2-1/8" tools are retrievable at any time during the logging operation. To date over 450 jobs have been completed using this system. Lower lost in hole risk, greater reliability and cost savings can be realized as a result of these features when compared to other pipe conveyed and LWD systems that are currently available.

Log data from the 2-1/8" tools compared favorably to other logs in a South Texas well and were found to be of exceptional quality by the operating company. The 2-1/8" tools experienced fewer tool pulls because of their smaller diameter. Logs obtained from this new toolstring in a horizontal well showed considerable variability in reservoir properties and demonstrated the need for log information to optimize the selection of completion intervals in horizontal wells. Significant savings in stimulation costs are possible as a result of unproductive intervals being eliminated from the overall completion.

Acknowledgments

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Nomenclature

BHA = *Bottomhole assembly*
BHT =*Bottomhole temperature*
LWD =*Logging while drilling*
MWD =*Measurements while drilling*
SP =*Spontaneous Potential*
CCL =*Casing Collar Locator*

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FIGURES

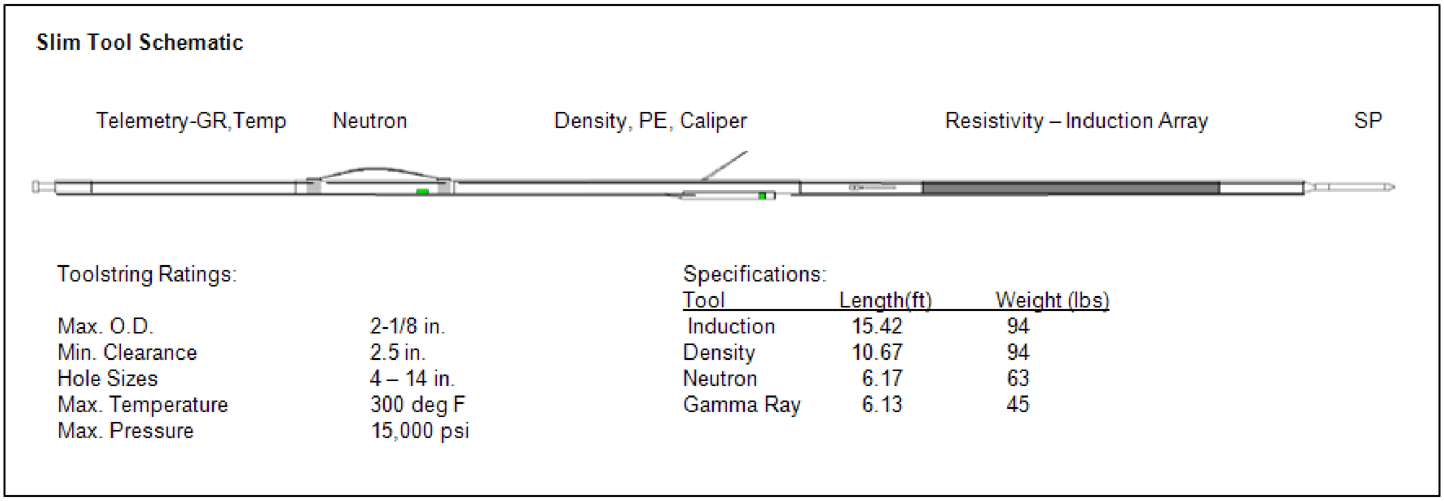

Figure 1 – 2-1/8' tool schematic showing ratings and other specifications. This diagram is the configuration that these tools would be run in for a normal real time wireline job.

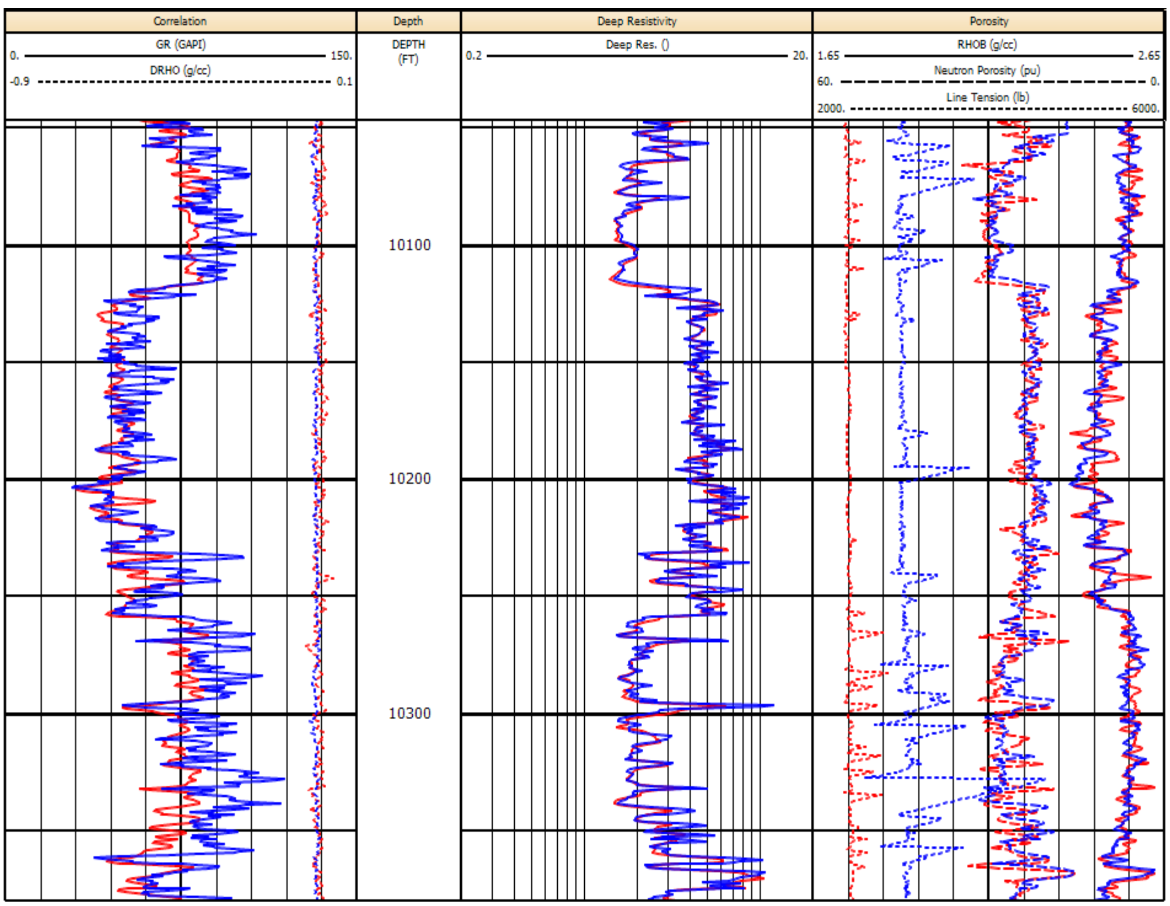

Figure 2 – Log comparison of the new 2-1/8" tools in red with another company's tools (3.5" max OD) in blue in a South Texas well. The log runs were made back to back with no well conditioning in between. The open hole bit size was 6 inches and the well was drilled with oil based mud. Tension cuves shown in the porosity track show fewer and less severe tool pulls with the 2-1/8" tools.

Figure 3 – The PDC through bore bit. The slim 2-1/8” tool string can easily pass though the middle in both directions.

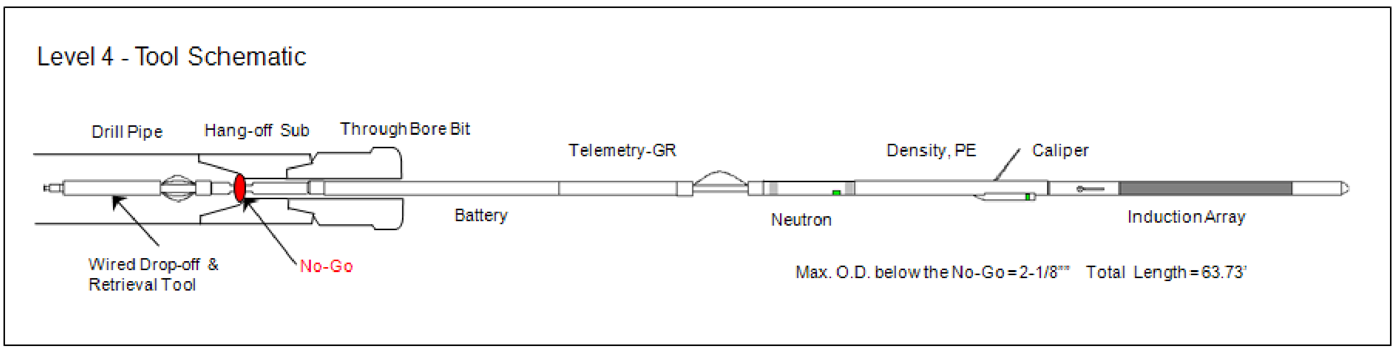

Figure 4 – Tool schematic for a Level 3 or 4 memory job. Additional hardware including the Hang-Off tool, battery, and a Wired Drop-Off and Retrieval tool enable logs to be recorded in memory as pipe is tripped from the well. The tools can be retrieved at any time after the wireline is released.

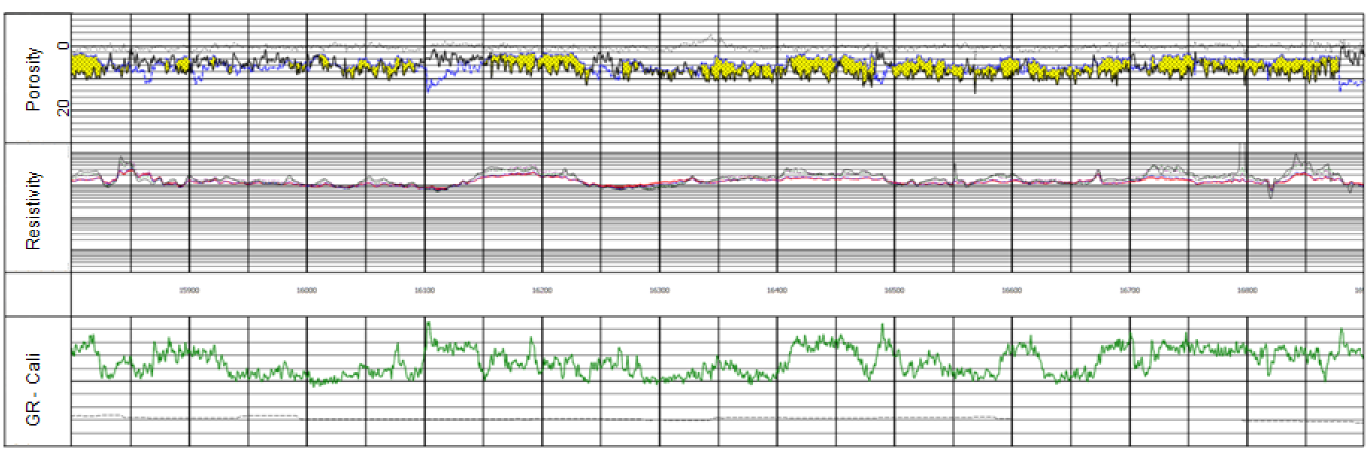

Figure 5 – Portion of horizontal well log from the Granite Wash formation acquired using the Level 4 deployment method. The porosity logs show crossover in yellow which is an indicator of better quality reservoir.

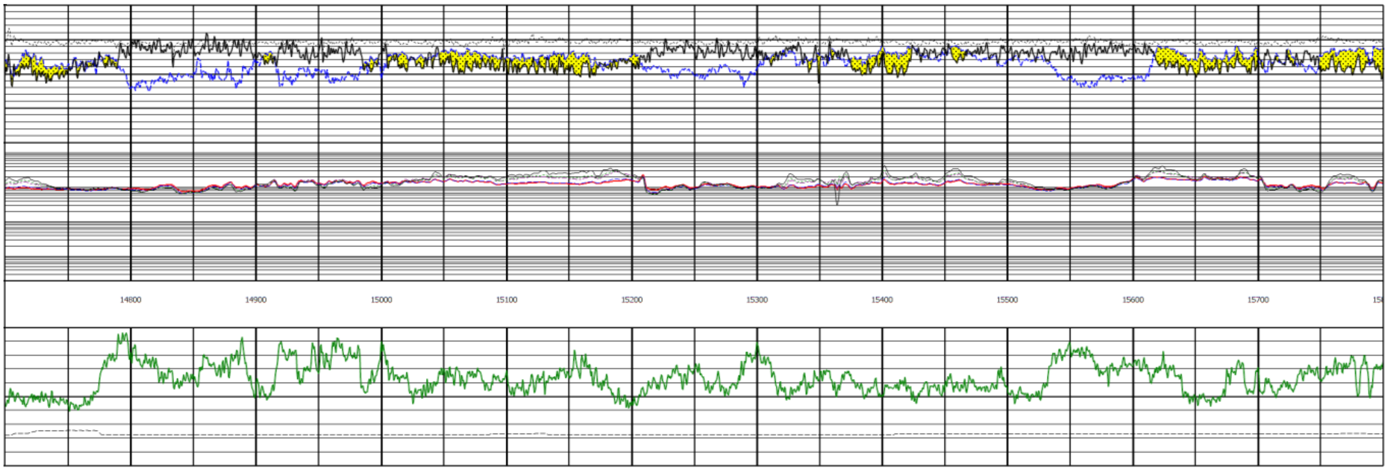

Figure 6 – Shallower measured depth section from same well as in Figure 6. There is less clean reservoir rock in this interval with more shale in between.

Figure 7 – A 7-7/8" through-bore bit with the center insert in place after completing a drilling run (left), and the same bit after the running tool has removed the insert and extended it beyond the bit(right). The 2-1/8" logging string is then exposed to open hole to obtain logs in either real time or in memory. After logging, the tools are retrieved and the center insert is securely relatched into the bit.