

Drilling Process Creates Data Issues Requiring Innovative Data-Gathering and Interpretation Techniques*

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Abstract

The Lower Pennsylvanian Morrow sands and the Lower Pennsylvanian/Upper Mississippian Springer Group are the primary objectives of the recent directional drilling in the Cement Field of Caddo and Grady counties of southern Oklahoma. These marine sands were deposited in the Anadarko Basin and then were subsequently deformed by multiple stages of Pennsylvanian wrench and compressional tectonics. The resulting formations are often found to be steeply dipping to overturned and highly faulted. These reservoirs are deep and generally not extensive in nature. High energy deposition has created discontinuous flow paths, causing compartmentalization ([Figure 1](#)) and inconsistent productive capacities. The compartmentalization creates the need to target relatively small reservoir targets and requires precise bottom-hole locations to accomplish economic production. Directional drilling with down-hole motors, bent subs, stabilizers and diamond bits is the only technique that could consistently achieve these precise bottom-hole locations.

In addition, there is another complication created by the almost vertical nature of the reservoir. [Figure 2](#) is a surface outcrop that allows some visualization of the reservoir down hole. The drilling process, in many situations, was required to drill almost directly down these horizontal striations that have become vertical through subsequent earth movement.

Operational Challenge

The complex nature of the reservoir and subsequent deformation required directional drilling. In general, these bottom-hole assemblies required a rotary motor at the end of the drill string with a configuration similar to that exhibited in [Figure 3](#). This assembly has a stationary reference stabilizer with hardware between the stabilizer and bit to minimize the range of movement of the bit. Even in the best conditions, this range of movement provides an area of movement that always drills a well bore larger than the bit size. This drilling process also created

a rough well bore, many times creating spiral grooves in the well bore. [Figure 4](#) is an image that shows a spiral groove. The image on the left is the well bore definition by depth, the center image is looking down into the well from the top of the image and the image on the right is oriented in the direction of the actual drilling.

As this discrepancy between bit size and bore hole size becomes larger, accurate reservoir evaluation by electric logs becomes more difficult. Hence modifications had to be made to this bottom-hole assembly to minimize the flex issues in the directional drilling process. Oil-based mud was used to keep the wellbore surface as smooth as possible.

Reservoir Evaluation Challenge

One of the most critical issues in the development was how to define the reservoir placement and distribution in three dimensions. A precise understanding of this was necessary to continue the development of this field. Dipmeters were a part of the logging program and, when the shift to oil-based mud occurred, oil-based dipmeters were run. Interpretations of these dipmeters were done using computer correlations (Goetz, 1988). These interpretations were intensely scrutinized, but increasingly it became evident that this data was not providing needed bedding description. There was a poor relationship between the general expected bed directions and angles as defined by the seismic and that presented by the dipmeter. The high angle of the beds combined with the irregular well bore made the computer correlations of the bed definition suspect. Image logs were added to the drilling program to provide a better answer.

These image logs confirmed several important well characteristics. The bottom-hole assembly had created an intermittent spiral groove in the sand face of the well. This groove could confuse any automatic bed picking program and create spurious results. [Figure 5a](#), and [Figure 5b](#) are examples of this image data. This data has been processed to show results similar to automatic dip pick programs (Shin-Ju Ye, 1997).

[Figure 5a](#) is an example of dip magnitude error of as much as 30 degrees along with orientation errors of 15 to 25 degrees. [Figure 5b](#) is an example where the direction of dips is the same from both interpretation techniques, but the magnitude of the computer picks is half that of geologist picks. These errors in the computed products used for geological interpretation cause misunderstanding of the placement and orientation of the reservoirs. Dipmeters were dropped from the logging program to overcome these issues. Only image logs interpreted with geological oversight were able to accomplish the required precision in this difficult environment.

Another major interpretation issue that was created by this non-uniform hole diameter was that the porosity tools would not accurately record their measurements. The density particularly was subject to erratic results since the pad could not stay in contact with the wellbore face. The neutron could also be affected if the well configuration caused the tool to oscillate and not remain vertical in the well while logging.

The solution to this was the utilization of a mandrel-based Nuclear Magnetic Resonance device. Since the response is measured at fixed diameters, this allowed measurement of formation porosity without the complicating factors of the spiral groove. The tool also provided an

excellent confirmation of reservoir quality through the evaluation of the T2 relaxation times. The Bray-Smith permeability (Smith, 2008) derived from T2 bin distribution provided an important additional piece of data:

$$BPERM = \left[MPHI^n * \left(\sum_{T2\ Bphi4ms}^{T2\ Bphi2048ms} wf * T_2^{Bphi / BVI} \right) \right]^m$$

Where:

BPERM = Bin calculated Permeability

MPHI = NMR effective porosity

wf = Bin weighting factor

Bphi = Bin porosity

BVI = Irreducible porosity fraction

Factors n and m are empirically derived constants

Conclusions

- Oil-based image logs are capable of making precise bed descriptions, even in very adverse conditions.
- Geologist oversight of the image log results is imperative for precise conclusions.
- Mandrel-based NMR is capable of determining correct porosity in rugose hole conditions.
- Bin-based permeability description can be applied to provide a very valuable description of reservoir quality.

References

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Ye, S., P. Rabiller, and N. Keskes, 1997, Automatic high resolution sedimentary dip detection on borehole imagery, *in* Transactions of the SPWLA Thirty-eighth Annual Logging Symposium, Houston, Texas, USA, 15-18 June 1997: internet resource, Paper O.



Figure 1. Outcrop exhibiting discontinuous flow paths.



Figure 2. Outcrop of near-vertical bedding

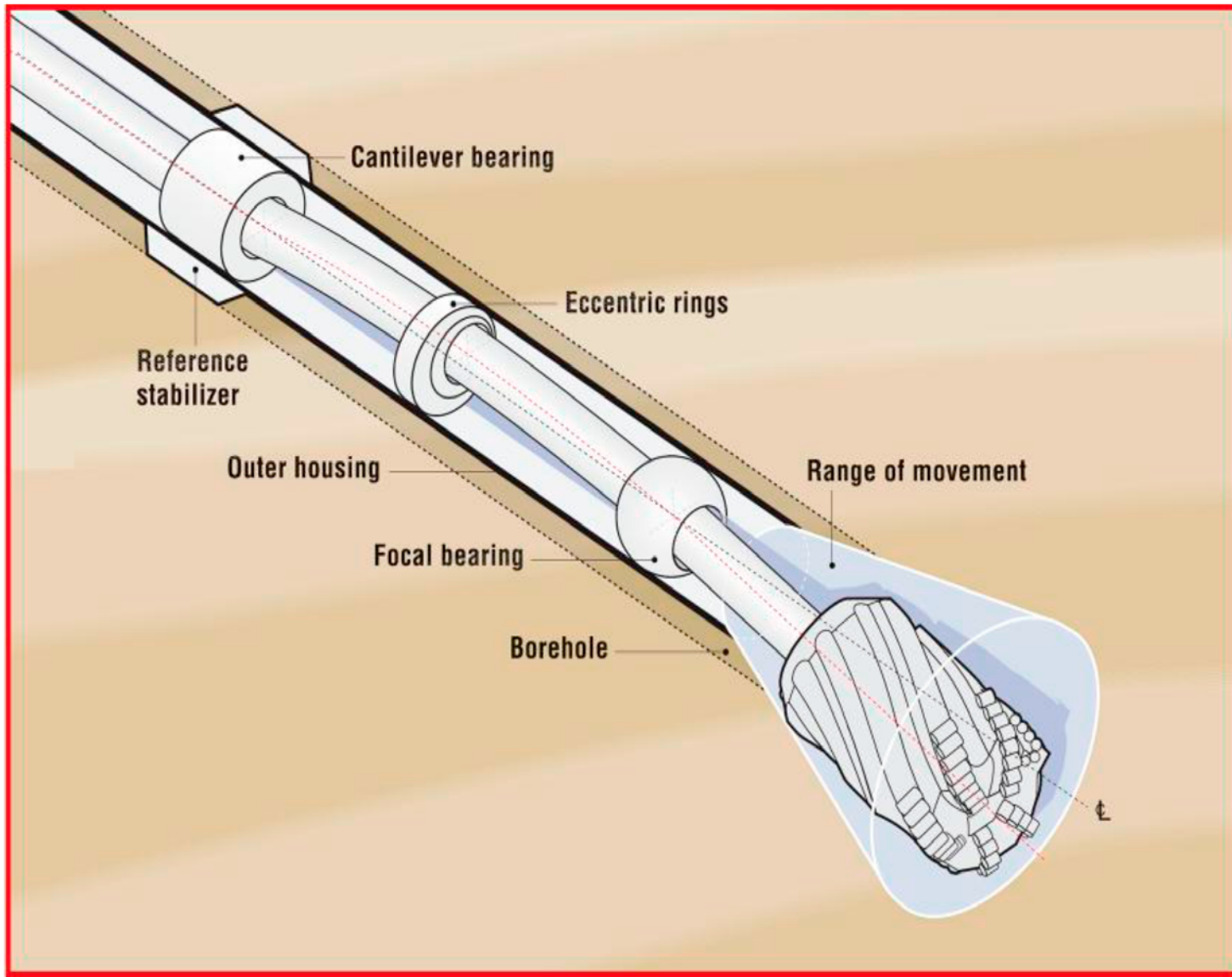


Figure 3. Typical directional bottom-hole assembly.

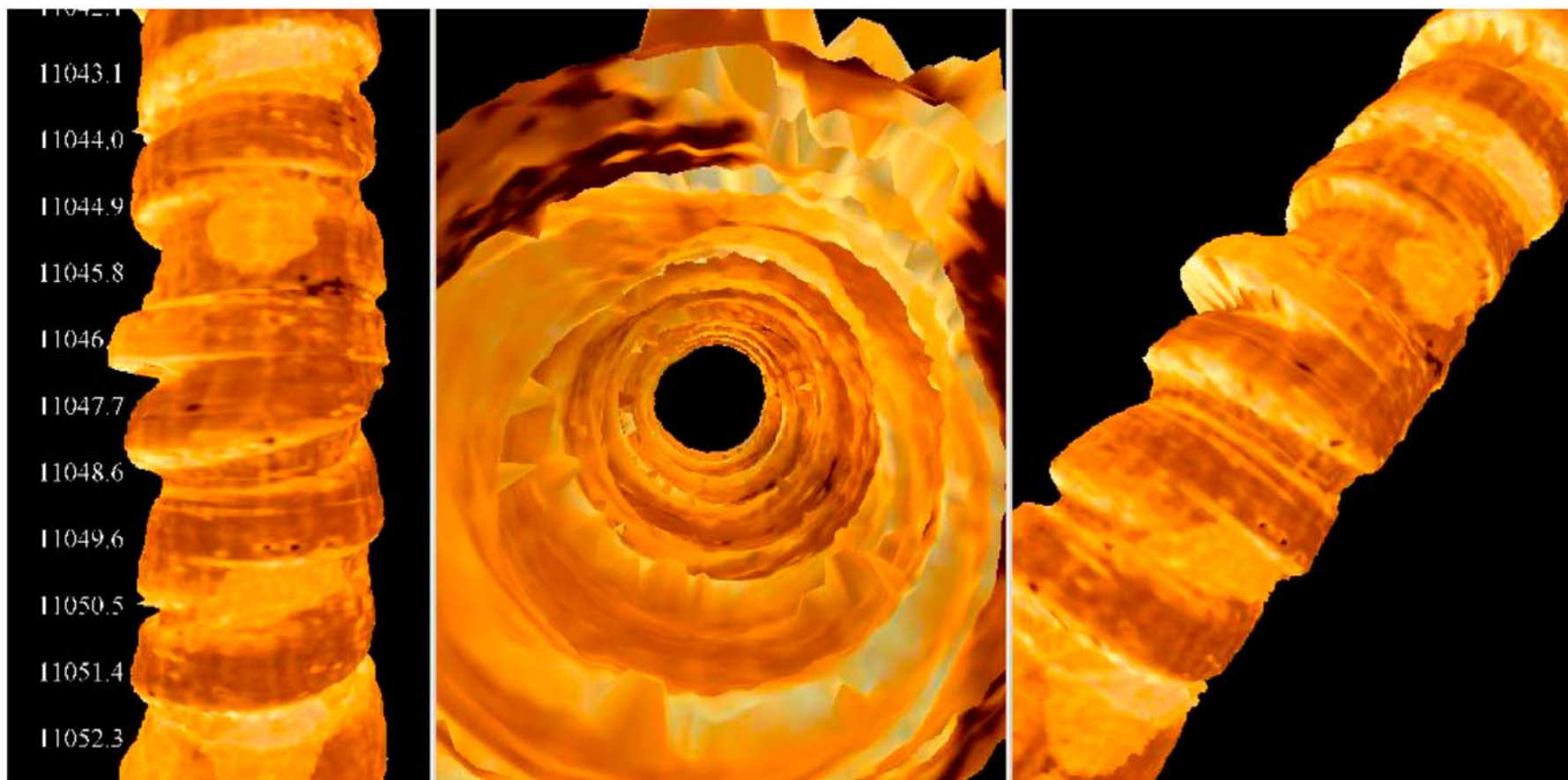


Figure 4. Typical groove created in a well by the motorized down-hole assembly for directional drilling.

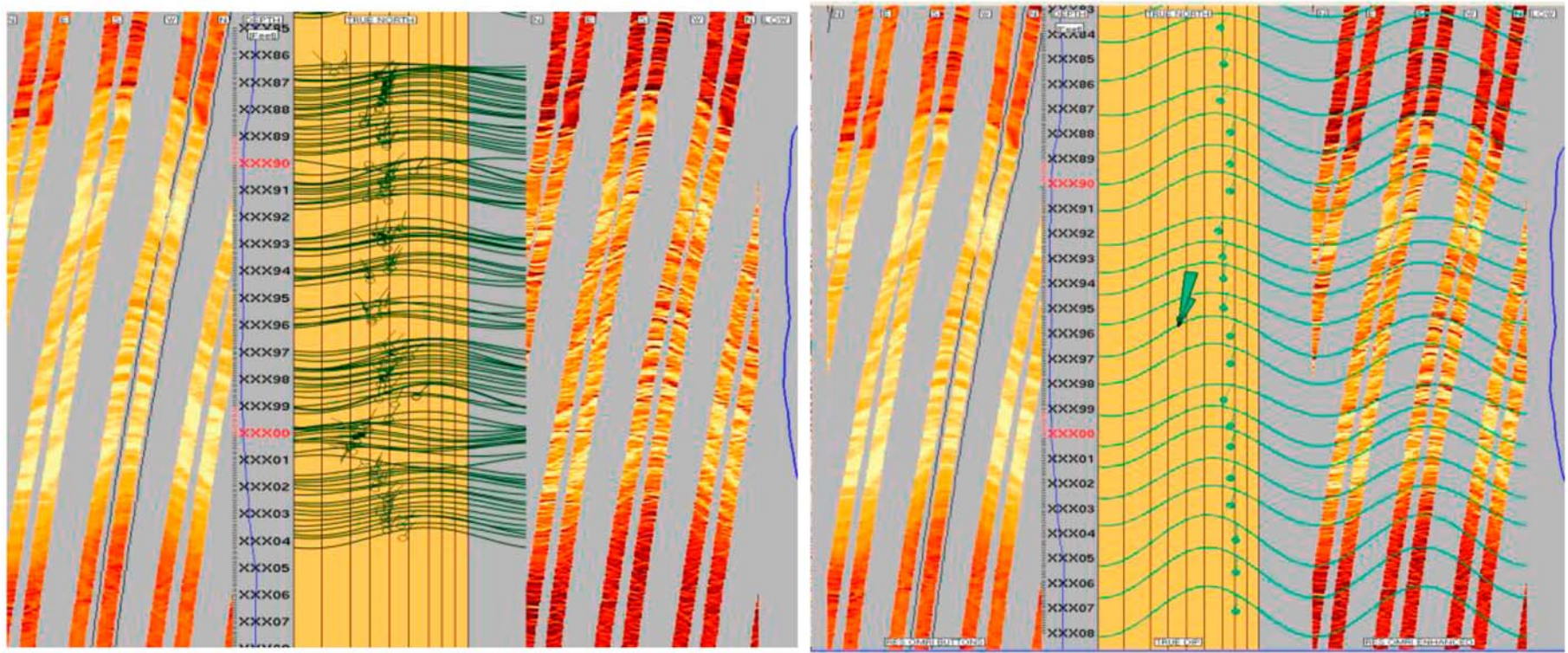


Figure 5a. Autodip indicates 35 degrees NNE, Manual dip indicates 70 degrees NNE.

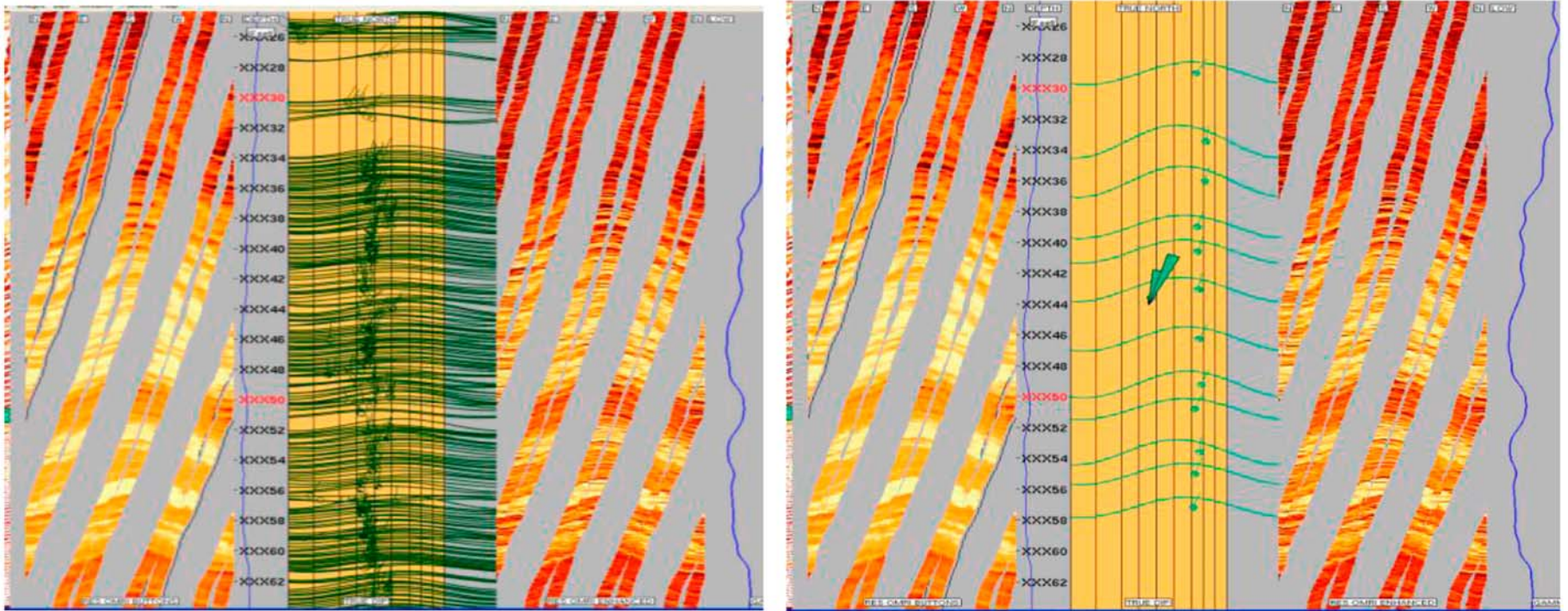


Figure 5b. Autodip indicates 35 degrees NNE, Manual dip picks indicate 65 degrees NNE.