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WELLBORE POSITIONING USING CONTINUOUS INCLINATION AND AZIMUTHAL GAMMA RAY IMAGES

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ABSTRACT

La formación Manning en Oklahoma se ha revitalizado con la perforación de pozos horizontales. Manning es un depósito costero de carbonatos que cuenta con la presencia de arcillas intercaladas. Se utilizó una herramienta azimutal de rayos gamma equipada con un inclinómetro que proporcionó inclinación de manera continuada. La herramienta permitió la adquisición de imágenes en tiempo real tanto rotando como deslizando. Las imágenes fueron analizadas y los buzamientos clasificados según la magnitud para ayudar en la correlación estratigráfica.En la correlación se usan los buzamientos inferiores a 15 grados para entender el movimiento estratigráfico a la vez que los rayos gamma del cuadrante superior y inferior de la herramienta. Se estudian las inclinaciones y se comparan con las provenientes de la herramienta direccional, dando una idea de la tortuosidad del pozo lateral.

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INTRODUCCIÓN

Exploration and development of the East Hennessy unit (EHU) in central Oklahoma originally began early 1959 from the Meramec formation (Mogharabi 1962). First production from the Manning formation using a dual completion in the Meramec commenced mid-1960. The field was originally developed with vertical wells having 80-acre spacing using dual and triple completions because other producing formations (Oswego, Cleveland, Red Fork, and Skinner) in the field were already developed. The field is currently undergoing redevelopment as part of the current Stack play in Oklahoma using horizontal wells. This paper describes a lateral well thatwas drilled and geosteered using an azimuthal gamma-ray (AGR) and continuous inclination tool in the Manning formation and analyzes the benefits provided by using the AGR and continuous inclination in realtime.

Manning formation

AGR and continuous inclination have been applied in several lateral wells drilled in the EHU field located in the Sooner Trend on the Northwest Oklahoma Shelf (Fig.1).

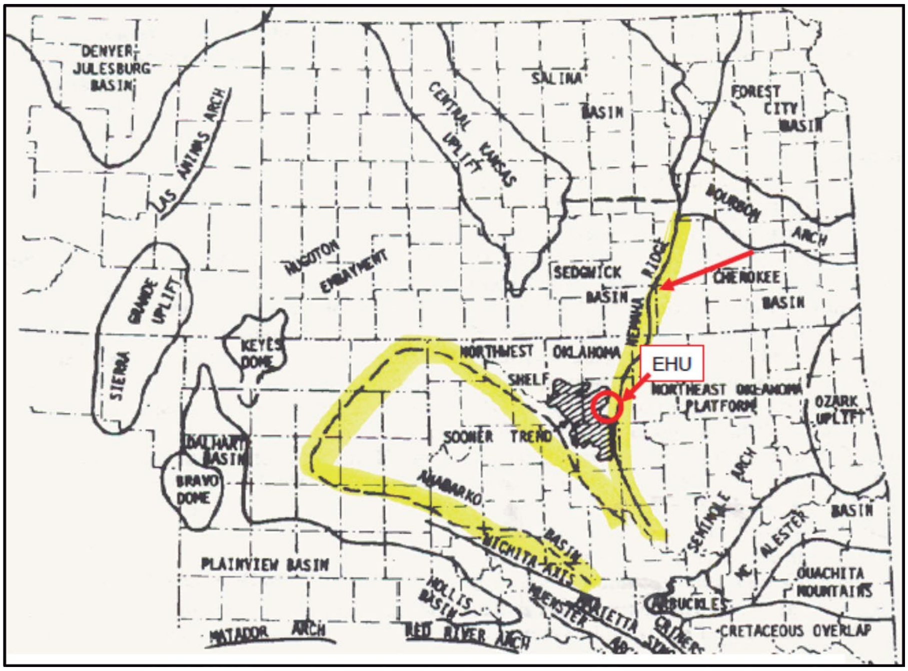

Figure 1. Tectonic features of the central mid-continent as related to the Sooner Trend (after Harris1975).

The well discussedin this paper targets the Manning formation in the EHU field. The stratigraphic column (Fig. 2) shows the Manning formation to be Upper Mississippian in age.

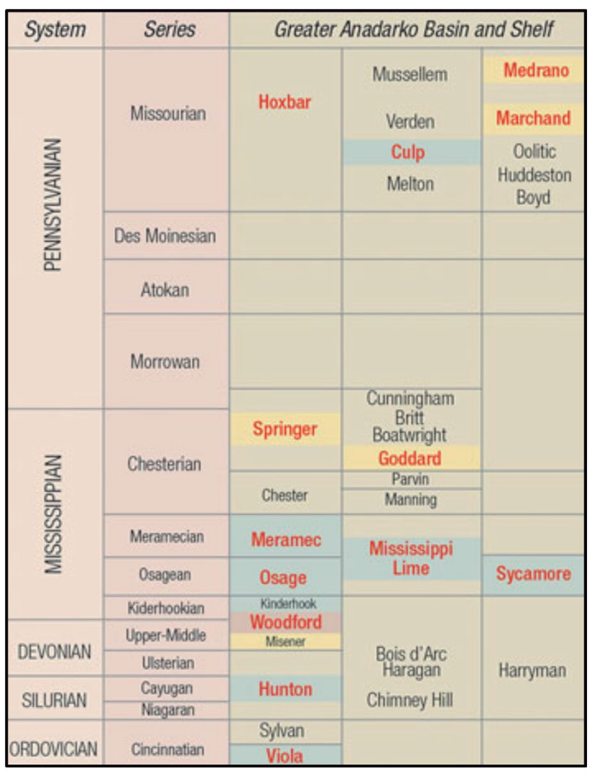

Figure 2. Stratigraphic column of the greater Anadarko basin and shelf (after Boyd 2008).

Widespread erosion occurred post-Mississippian shortly after deposition of the Manning formation. Erosion also occurred with the formation of the Nemaha ridge to the east during Pennsylvanian time. This resulted in a complex series of widespread unconformities on the northwest shelf that merge updip toward the Nemaha ridge. In the EHU area, the updip Mississippian unconformity is located along the eastern limit of the field, causing the Manning formation to thin in this direction.

The depositional environment during the Manning time was a shallow carbonate shoreline and adjacent shelf. The formation is characterized by shoaling upward,indicatingthat it was deposited during a regressive cycle.

Fig. 3 shows a schematic depiction of the Manning depositional environment.

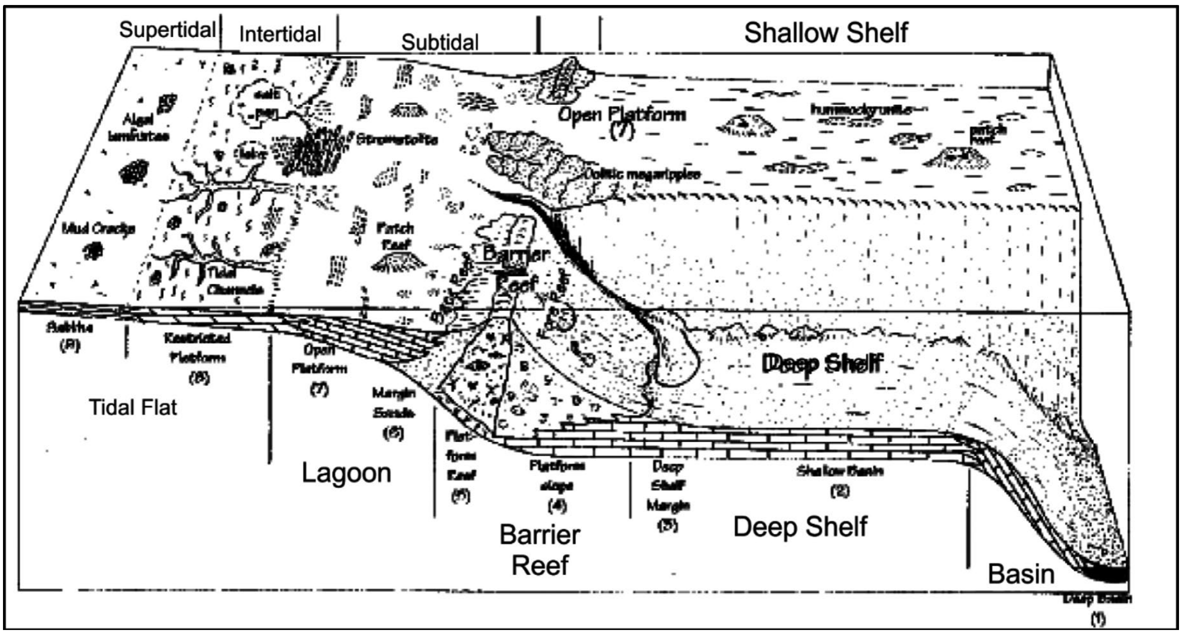

Figure 3. Carbonate depositional environment (afterCSOM 2000).

Core analysis in the Manning formation showed seven different facies: deepwater shales, middle shelf grainstones with crinoid and shell fragments, fine-grained ooidgrainstones, medium-grained ooidgrainstones, fine-grained limy sandstones and burrowed lagoonal sandy limestones, and mudstones. Porosity and permeability development occur almost exclusively in the thin limy sandstone facies of the lower shoreface.

Laterolog imaging analysis of the Manning formation in the area where the studied well was drilledconfirmed the presence of the following facies:

- Tight cross-bedded carbonates of lower shoreface environment (i.e., outer-shelf carbonates)
- Interbedded limestone and mudstone of most likely lagoonal environment
- Calcareous sandstone facies of inner-shelf depositional setting

Additionally, from the laterolog images, it was observedthat the tight carbonate facies is brittle and normally highly fractured. The fracturing in the Chester unit is believed to be associated with movement of the Nemaha Ridge and also movement of the Anadarko basin downward (Mogharabi 1962). High dip angles along some intervals of this facies are interpreted as cross laminations in this grainstone facies.

AGRand continuous inclination tool

The AGR tool used in this geosteering case study featured four near-bit scintillation detectors spaced 90° apart (Fig.4). An AGR tool is used to distinguish two formation beds with different radioactivity values (measured in API units) when the tool approaches or crossesthe bed boundary. One simple and commonly used metric to measure how well the tool can distinguish the two beds is the front-to-back (F:B) ratio. However, various methodsare used to measure or derive the F:B ratio, which canresult in significantly different numerical values for the same tool.

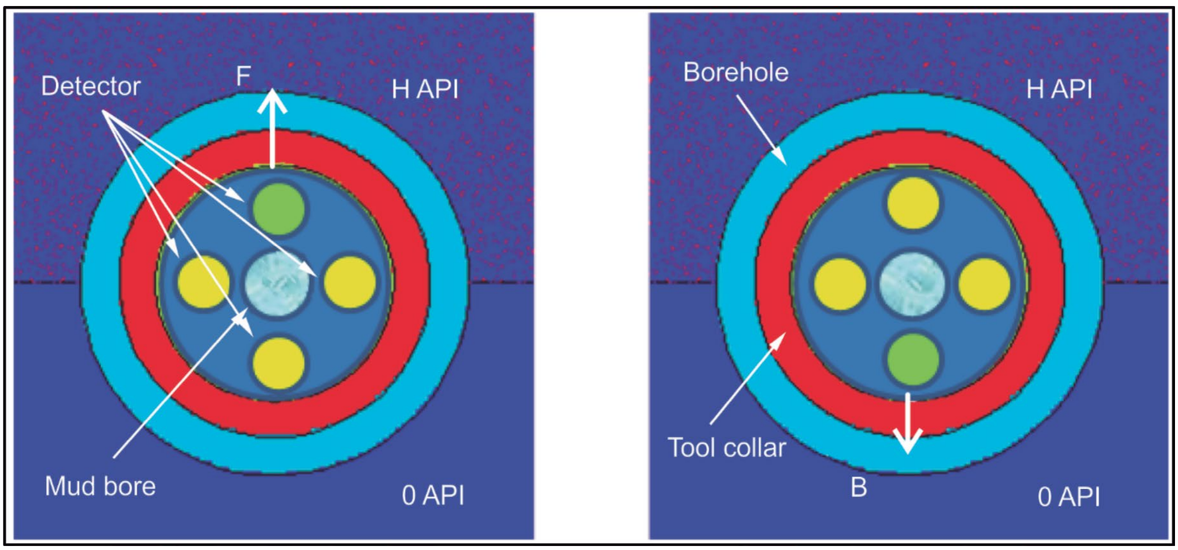

Figure 4. Schematic plot of F:B position of a tool sittingdirectly on the bed boundary in an infinite two-bed formation: one bed with some natural radioactivity (H API, red dotted) and the other bedhavingzeroradioactivity (0 API).

Fig. 4 shows thepreferred methodto define the F:B ratio of an AGR tool. The tool is centered in a borehole and sits directly on the bed boundary in an infinite two-bed formation, with one bed havinguniformly distributed natural radioactivity of an arbitrary amount (H API) while the other has zeroradioactivity (0 API). The front position is wherethe tool's most-sensitive axis of one detector faces the bed having radioactivity and is perpendicular to the bed boundary plane. The back position is where the tool rotates 180° in the borehole. The F:B ratio is the detector's reading in the front position divided by the reading in the back position. The primaryadvantage of this is that the F:B ratio only depends on the tool design and is independent of the API contrast between the two beds. It also includes the backscattering effect of the formation, similar to the actual downhole scenario. The tool reading can also be estimated from this ratio in any given bed API contrast.

The larger the F:B ratio, the better the tool can distinguish two formation beds. When the F:B back ratio equals 1, the tool has no azimuthal sensitivity and thus cannot be used to distinguish beds. The AGR tool used here has an F:B ratio of approximately6, which means that86% of the recorded gammarays come from the front portion. This is among the best AGR tools in the current market.It should be noted that a much higher value could be achieved using other F:B ratio definitions, but this does not necessarily providebetter measurement quality.

Moreover, the number of gammarays recorded in the detectors directly determines the measurement precision, as with other nuclear measurements. The relative precision can be estimated as $\sigma_R = \frac{1}{\sqrt{counts}}$. Generally, the larger the detector and the closer it is positioned to the formation, the more counts it can detect. Forthis AGR tool, the bulk (also called average) gamma measurement is the total of four fairly large scintillation detectors, which are positioned as close to the formation as possible to reduce the attenuation of the formation gamma ray. The resultanthigh counting rate of bulk gamma offers an ultra-high precision measurement (±1 API or 1% at 100 API formation) to detect the small stratigraphic features that are unobservedby a conventional gamma-ray tool (usually having a precision of ±5 API or 5% at 100 API formation).

Because ofthis design, a high-quality gamma image canbe acquired while rotating or sliding. In realtime, the gamma image has fourquadrants, while 16 sector images are recorded downhole for more in-depth post-run analysis. This image can be used to interpret the formation dip angle to allowimproved geosteering and optimized wellbore positioning. In addition, locating the sensors close to the bit makes it possible to detect adjacent bed boundaries before exiting the pay zone, helping avoid unnecessary time spent drilling nonproductive footage.Overall, this is a powerful tool for drilling long horizontal sections and remainingin the pay zone and isparticularlybeneficial as an economic geosteering solution for lower-cost drilling markets.

The AGR tool was also equipped with an inclinometer that sampled the continuous inclination real-time, with the inclination calculated using an accelerometer oriented parallel to the tool axis.

METHODOLOGY

Offset logs

Two offset lateral wells were used to perform a correlation. Offset Well 2 was closer to the lateral case-study well than Offset Well 1 (Fig. 5).

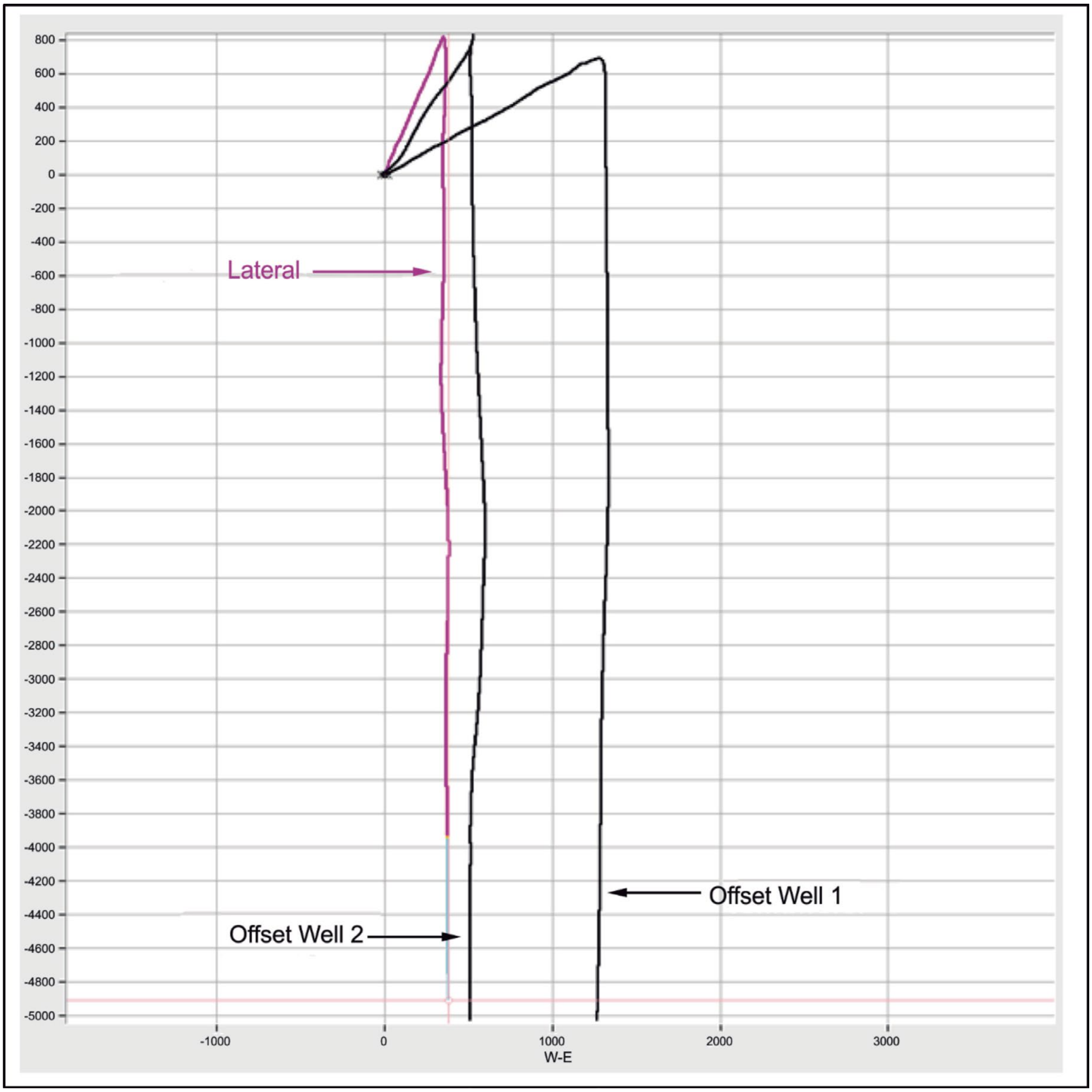

Figure 5. Position of offset wells relative to the lateral case-study well.

It was necessary to consider the proximity of the wells because the software used to conductthe correlation couldperformkriging with the two offset wells if both were to be used. Kriging is a methodology that appliesmore importanceto the well closer to the lateral. Therefore, in this case, if usingthe two offset wells, Offset Well 2 wouldhave more importance.

Offset Wells 1 and 2 have a close gamma signature, with Offset Well 1 reading lower gamma-ray values than Offset Well 2 (Fig. 6).

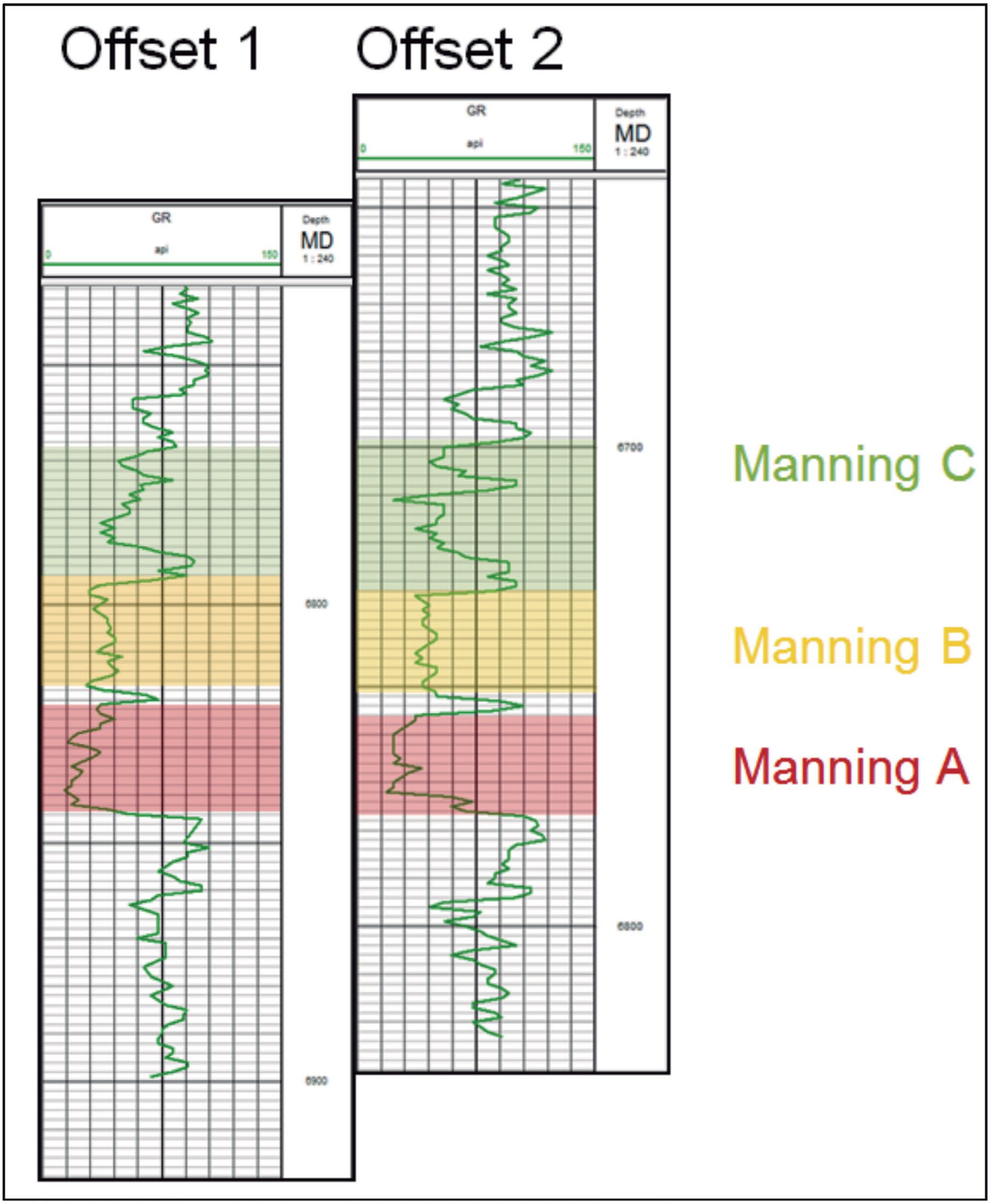

Figure 6. Gamma-ray signature from the two offset wells.

The Manning formation containsthreemembers, and the target zone of the lateral well drilled was Manning A. Manning A has a 20-ft true vertical depth (TVD) thickness in both offset wells (Fig. 7).

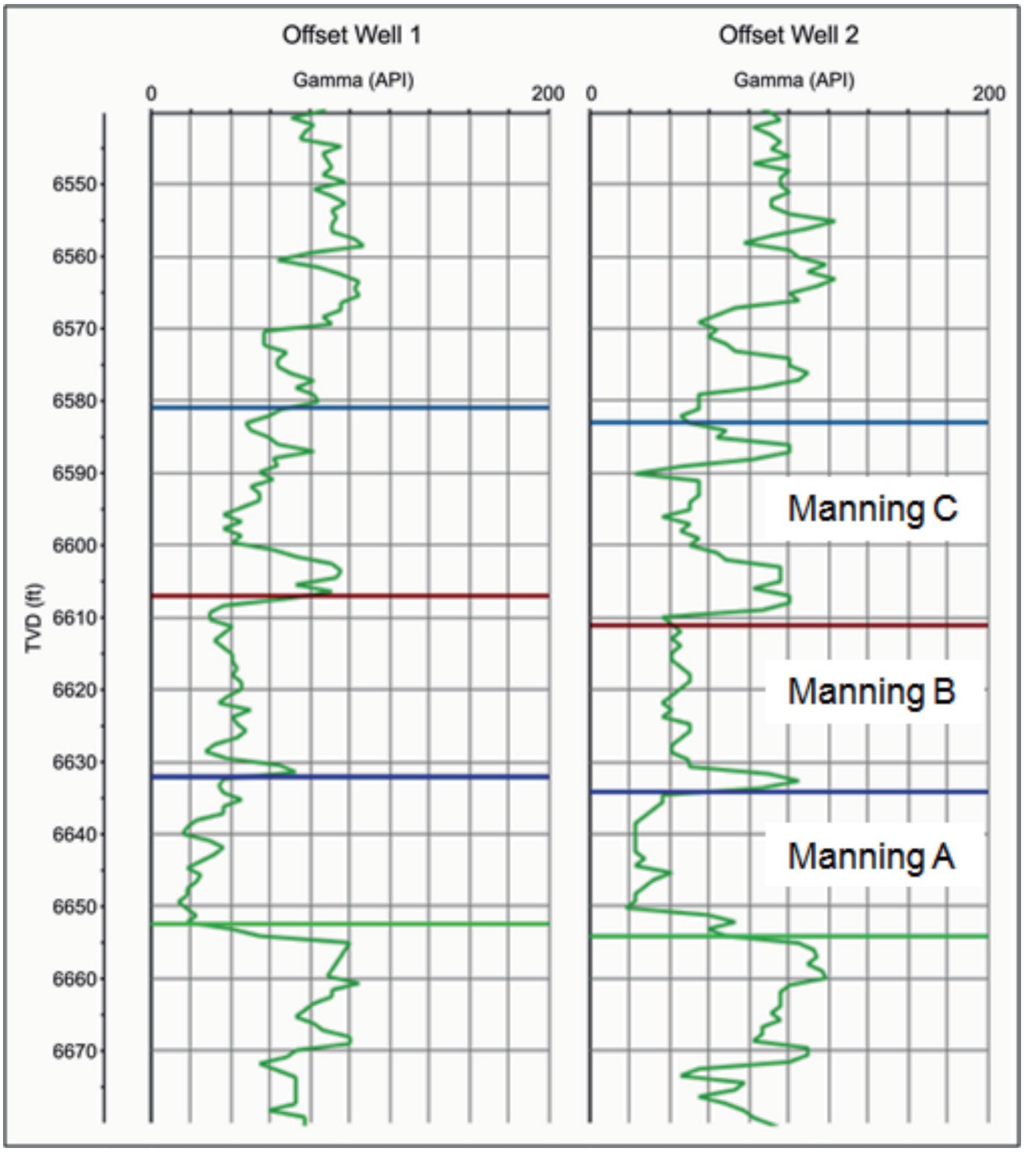

Figure 7. The two offset wells in TVD scale, with the tops for Manning C, Manning B, Manning A, and the base of the Manning formation.

Real-time azimuthal gamma images

The real-time azimuthal gamma images were interpreted using dip picking software that included a dynamic gamma image to allow better visualization of the gamma-ray contrast. The dips picked were classified according to magnitude (Fig. 8).

The dip magnitude classification was used in the stratigraphic correlation to differentiate between cross-bedding and structural dipping. Only the structural dipping (dips less than 15° in magnitude) was used for stratigraphic movement.

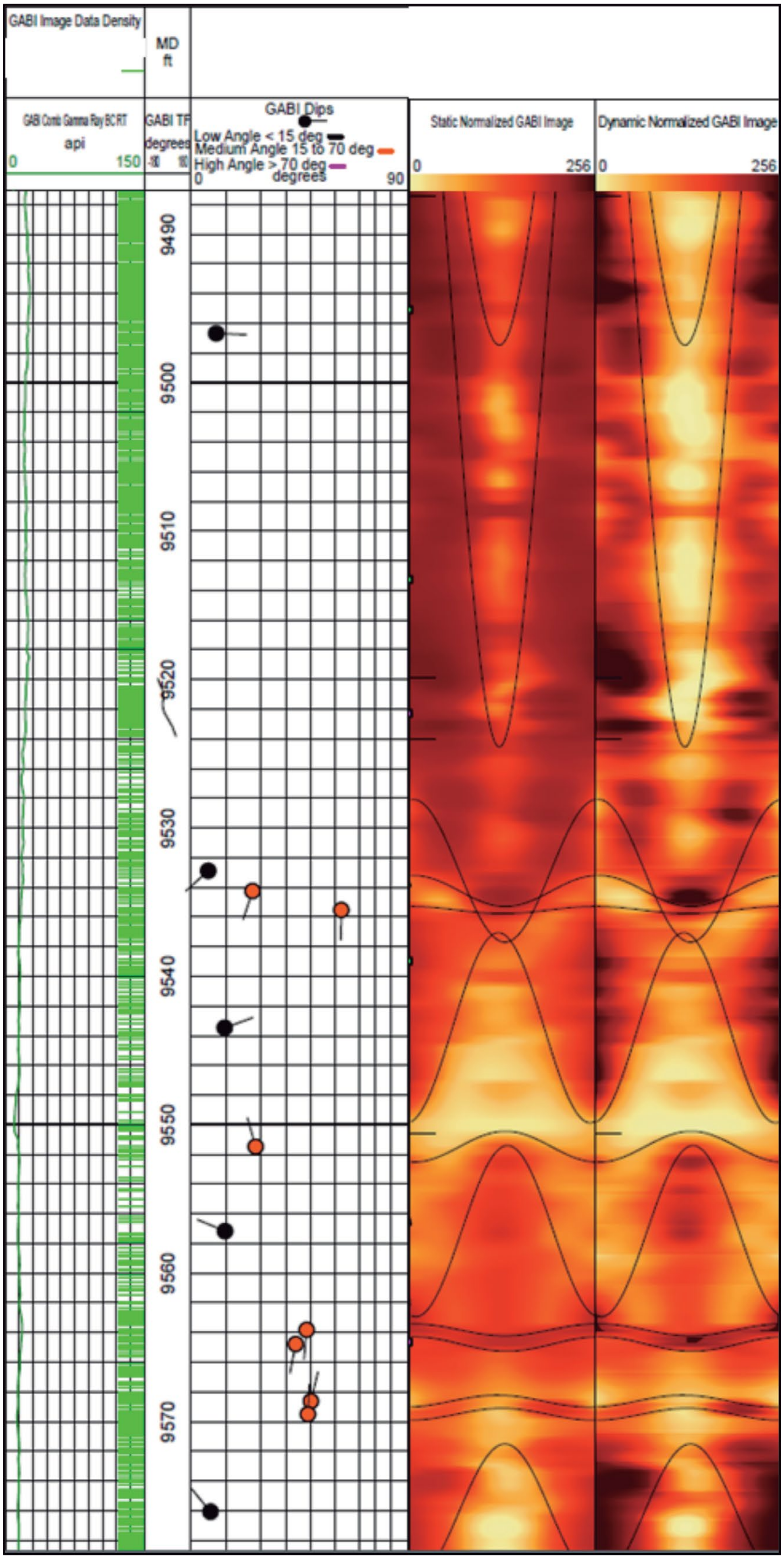

Figure 8. Example dip interpretation for the lateral well.

Landing correlation

OffsetWells 1 and 2 and surface grids for the top and base of Manning A were used for the correlation. Fig. 9 shows the landing; the bottom left shows the well trajectory in pink, the top and base of Manning A are shown in light green, and the palette used is based on the expected gamma-ray values (lower gamma-ray in yellow and higher gamma-ray in brown). Because of the proximity of Offset Well 2, the expected gamma-ray values are higher thanfor Offset Well 1, which can be observedon the right side of Fig. 9, where the pseudo-log (result of kriging between Offset Wells 1 and 2) shows the maximum value in green (Offset Well 2), the minimum value in pink (Offset Well 1), and the gamma-ray value used for a particular measured depth (MD), in this case, 7,053 ft MD.

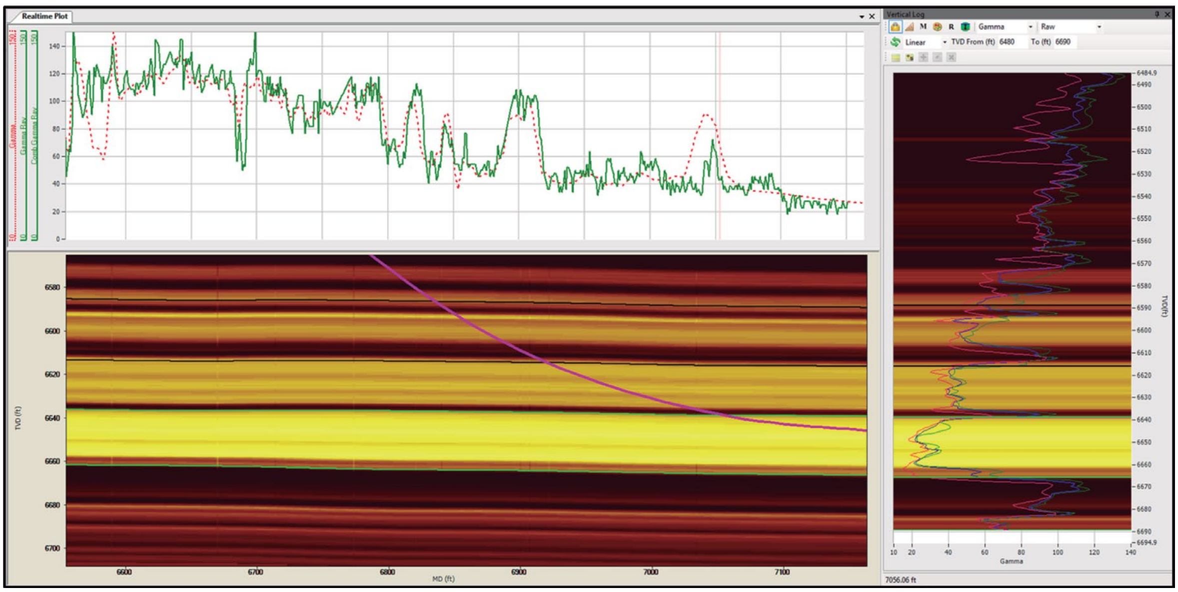

Figure 9. Stratigraphic correlation software showing landing in Manning A.

Landing was achieved using only a standard average gamma-ray tool. Surface control was excellent, and no correlation points were needed because,as can be observed in the top of Fig. 9, the predicted gamma-ray values (red dotted line)closely follow the actual gamma-ray values encountered (solid green line).

Lateral correlation

To help visualize the lateral correlation, AGR dynamic and static images are displayed in the correlation software (Fig.10). The dynamic image shows all dips picked with the imaging software, while the static image only shows the dips with less than a 15° dip magnitude, whichare used to infer stratigraphic movement.The third track from the top displays the top (in blue) and bottom (in brown) gammaray.The fourth track from the top displays the average gammaray from the AGR tool vs. the pseudo-log.At the bottom of Fig. 10, modified grids are shown in solid green and the original grids are shown in dashed green. It can be noted that the surfaces are 5ft TVD shallower.

At 400ft MD of the lateral well, downward stratigraphic movement is observed clearly in the top and bottom gammaray; the bottom gamma ray (brown), from 7,400ftMD,begins reading higher than the top gammaray (blue), but the blue never reads higher, indicating that a higher

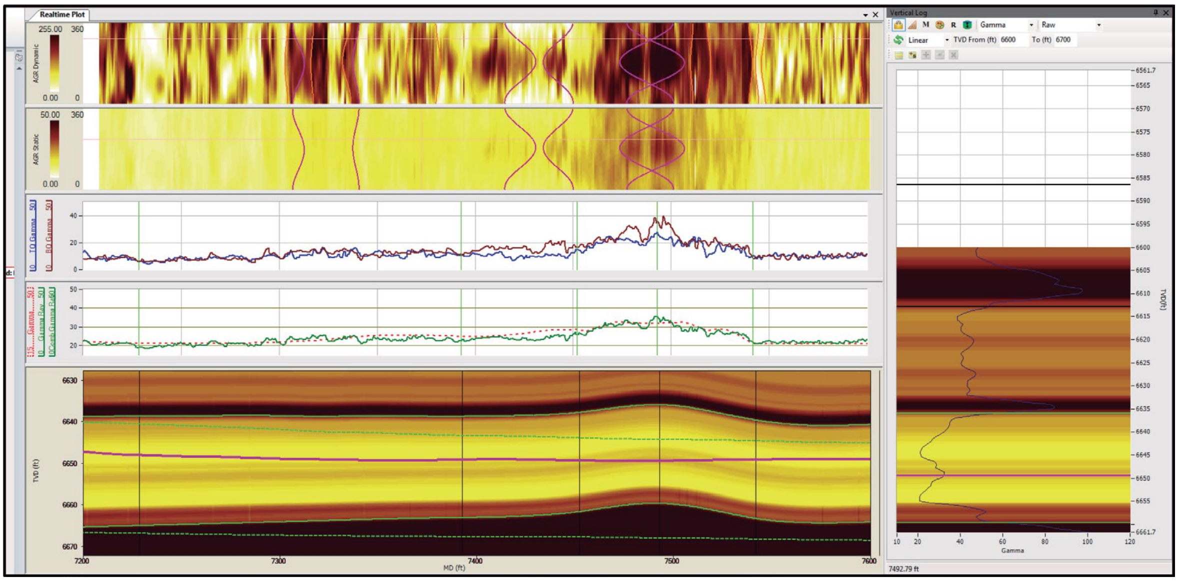

Figure 10. Stratigraphic correlation software showing initial 400ft of the lateral.

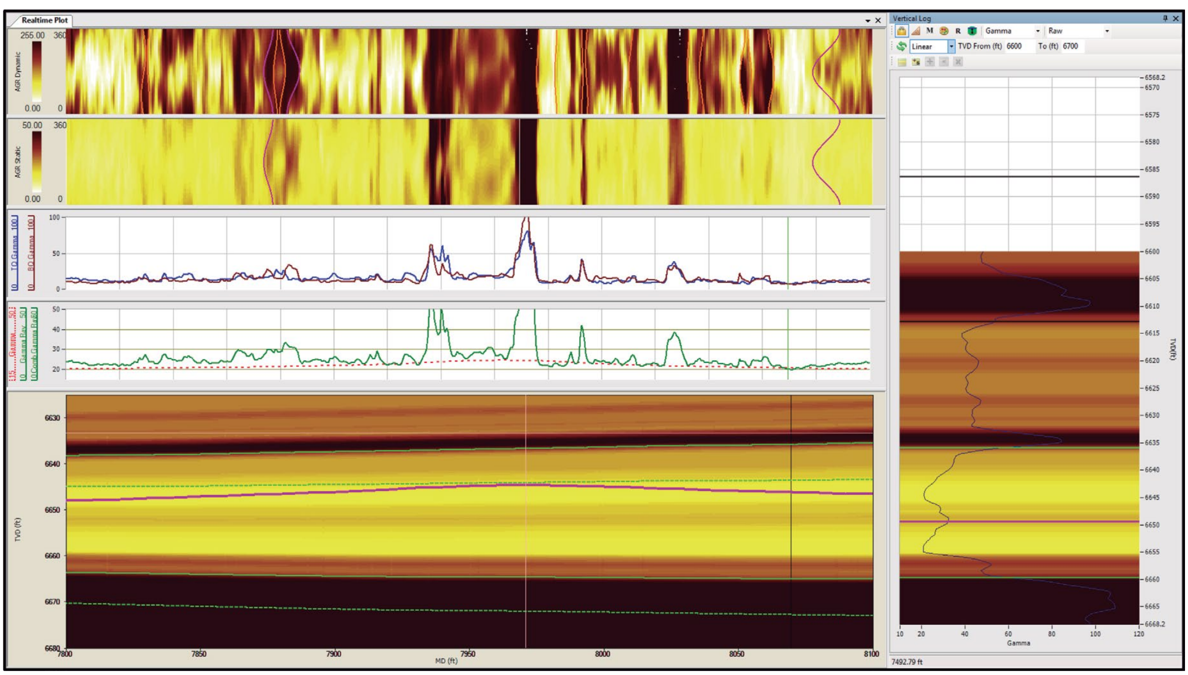

Figure 11. Correlation software showing an area with interbedded mudstones.

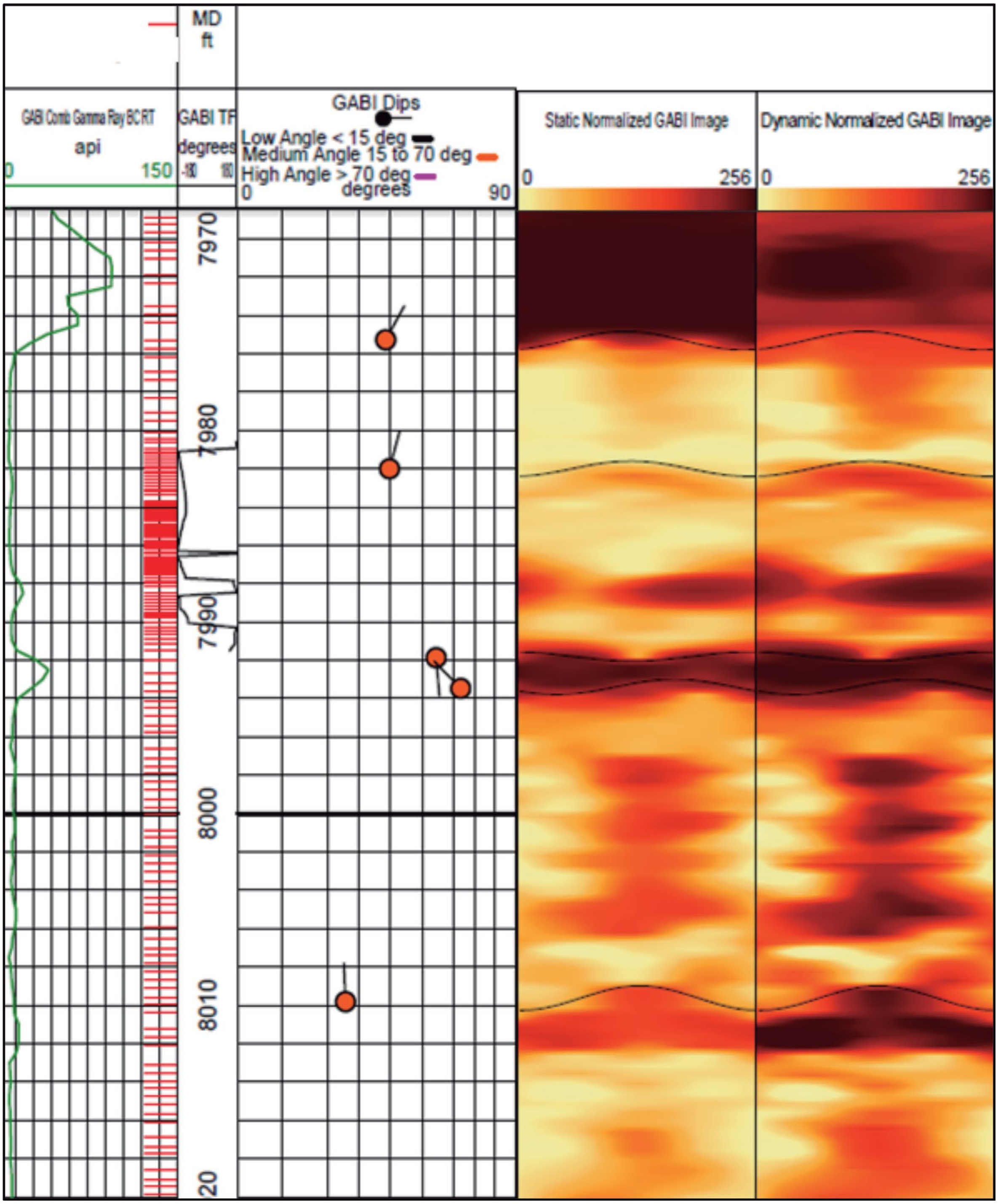

Figure 12. Imaging software showing high-angle feature dip picks.

gamma-ray area was approached from the bottom but the tool did not traverse it.Additionally, with the dips picked just before 7,500ftMD, there is a downturn followed by anupturn, with symmetryon both sides.

High-angle features were encountered while drilling the lateral, possibly interbedded mudstones of lagoonal origin. The high-angle features were ignored for wellbore placement because they could not be correlated and did not indicate any stratigraphic positioning. Fig. 11 shows an example.

The high-angle features were identified with the dip picking software (Fig. 12) and displayed in the AGR dynamic track in orange (Fig. 11).

By considering only dips that show stratigraphic movement and top and bottom gammaray, a final correlation was achieved, whichshowed a maximum difference in TVD compared to the original surface of 25ft TVD (Fig. 13). In the top track, AGR is modeled based on the offset log, showing similarity with the AGR static image.

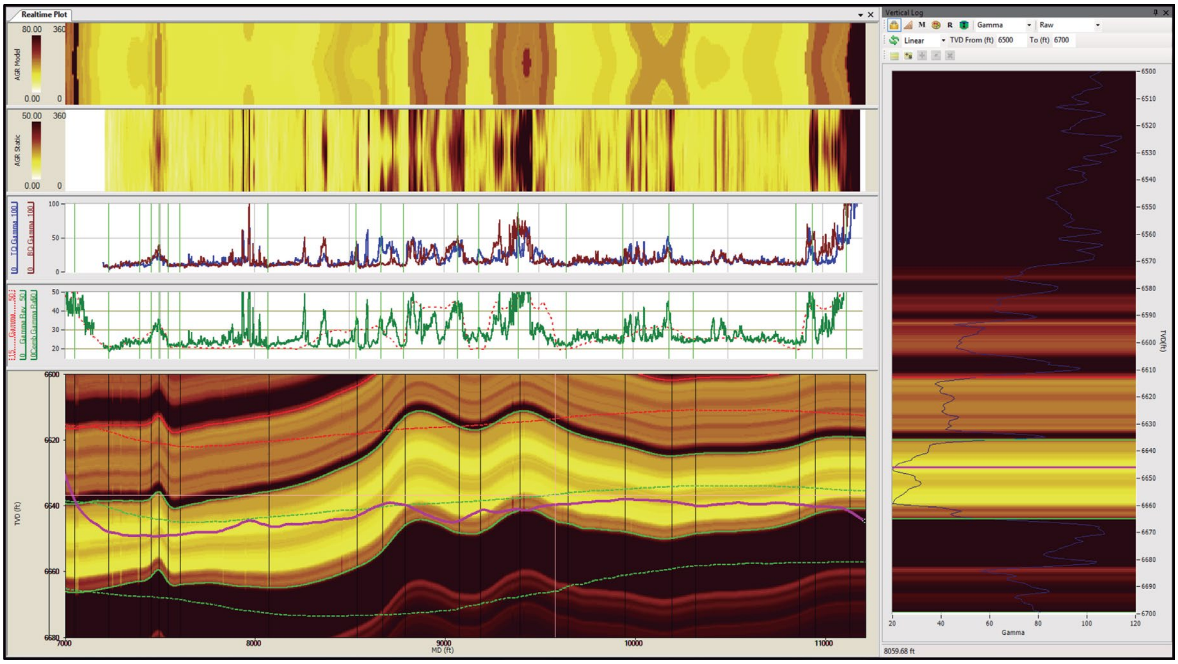

Figure 13. Final correlation of the lateral well.

Continuous inclination

The AGR tool was equipped with an inclinometer to provide continuous inclination while drilling. The data acquired by the survey tool werecompared to thosefromthe AGR. Adefinite inclination offset can be observed between the survey tool and AGR and continuous inclination data.Closely observing a section between depths 9,500 and 10,500 ft shows this inclination offset more clearly (Fig. 14).

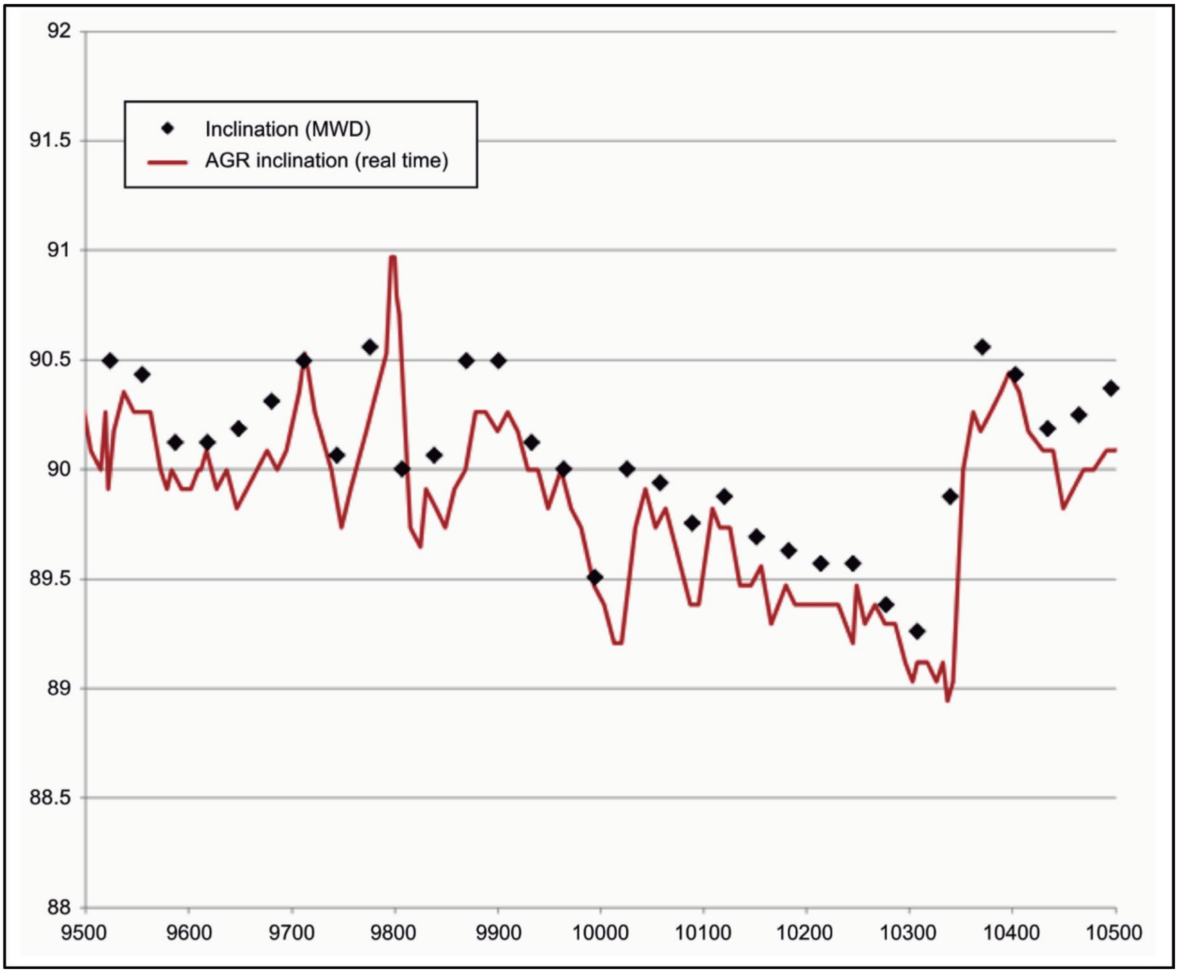

Figure 14. Inclination difference between survey tool (black dots) and continuous inclination (red line).

The TVD difference between thesurvey tool and continuous inclination was calculated as approximately13ft (Fig. 15). However, this was primarilya result of the systematic offset in the inclination and not a consequence of modelling the tortuosity of the well trajectory.

The surveys were SAG corrected to determine whetherit was possible toexplain the offset observed, but no significant difference was identified.The SAG correction value varied from 0.0015 to 0.0007°.

Therefore, an offset existed between the survey tool and continuous inclination.This could be a result of Gz biases in both tools.It is also possible that misalignment issues occurred with the continuous inclination.The survey toolprovidesthe moreaccurate inclination, and an offset was applied (0.175°) to the smoothed continuous inclination. Fig. 16 compares the inclinations after the offset is applied. Fig. 17 shows the TVD difference.

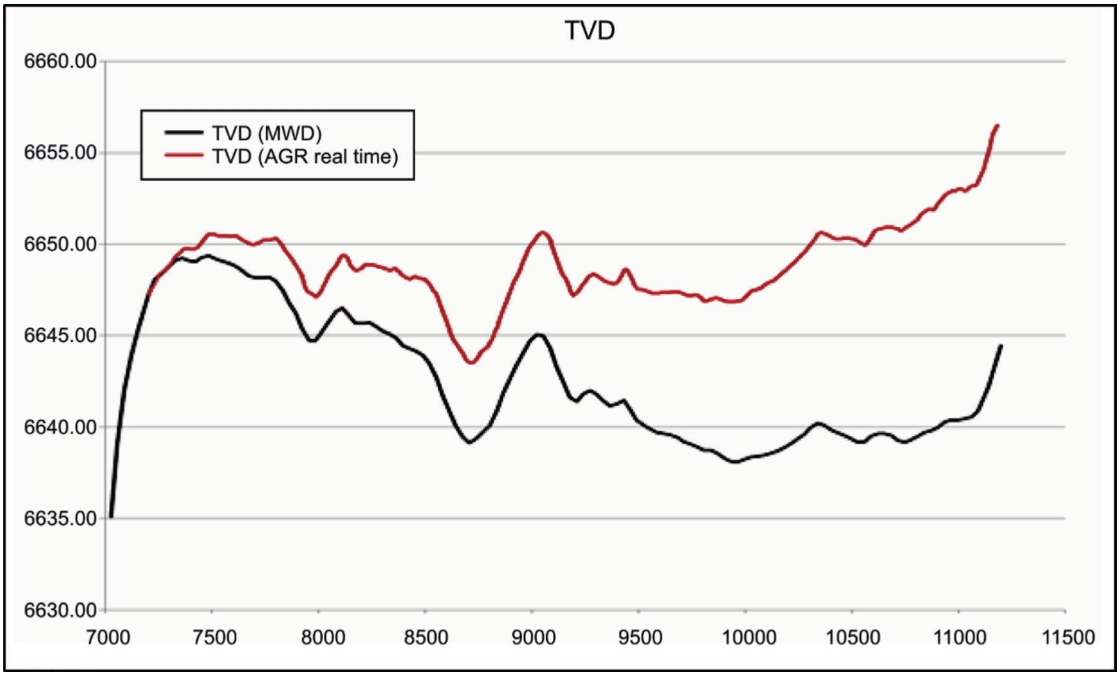

Figure 15. TVD difference between the survey tool and continuous inclination.

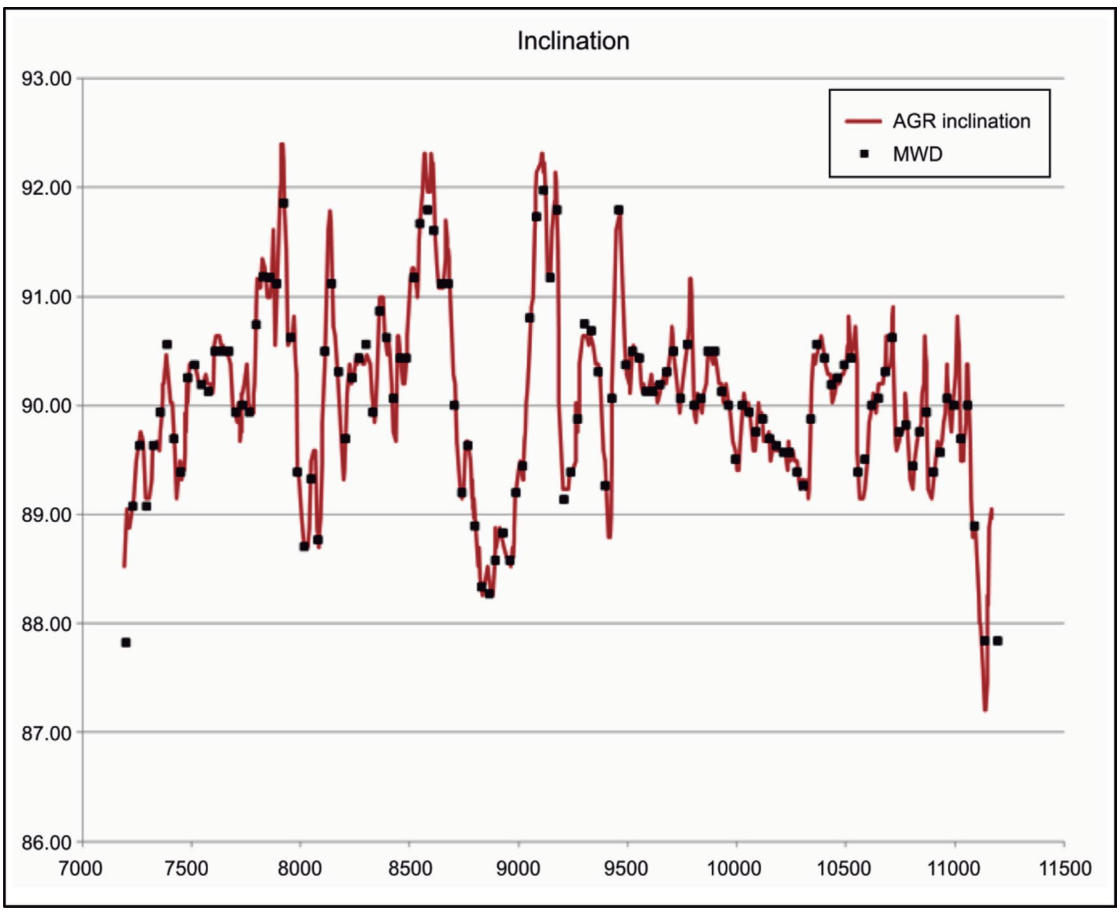

Figure 16. Comparison of continuous inclination betweensurvey tool inclination values.

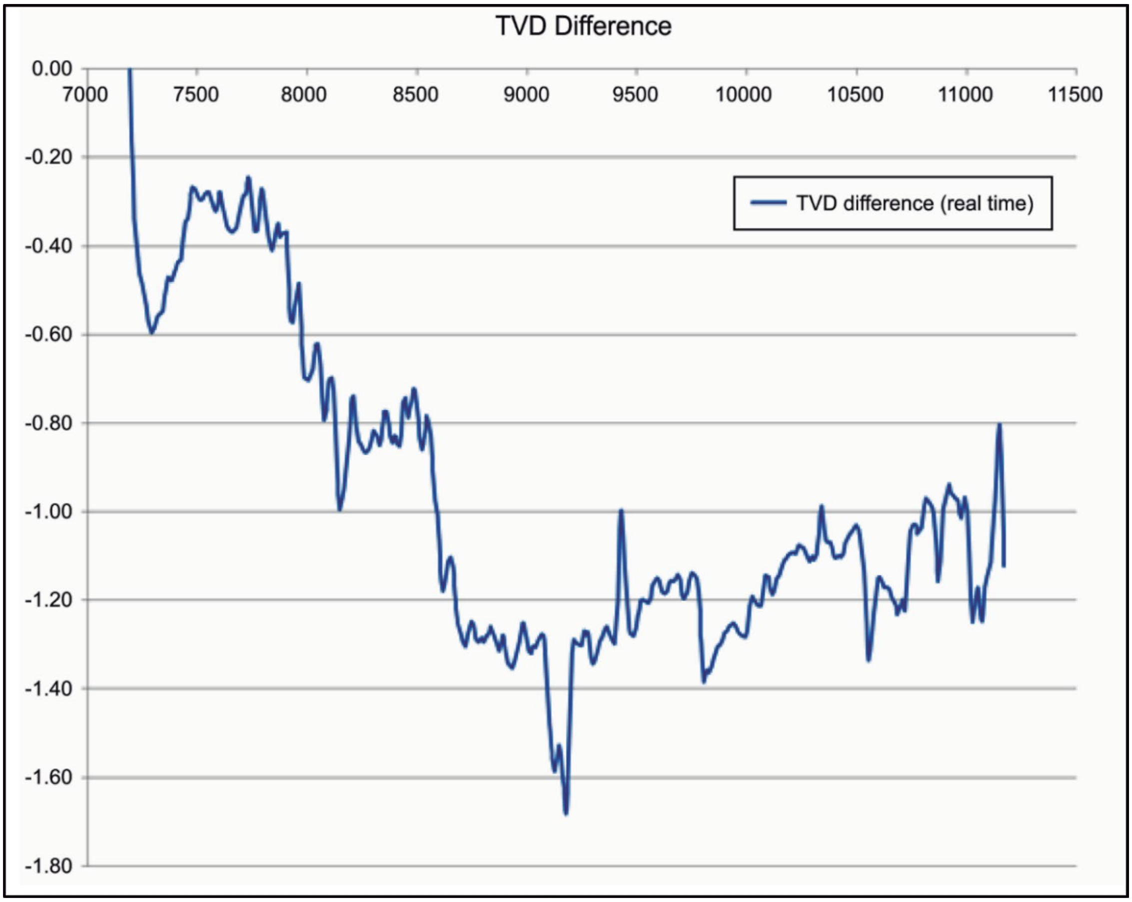

Figure 17. TVD difference between the survey tool and continuous inclination.

Using the AGR continuous inclination does not significantly affect the TVD but does define the microtortuosity of the well.

Continuous inclination was not used with the correlation software but could have been used to enhance the survey file and avoid excessive bending of the original surfaces around 9,400 ft MD (Fig.18). The survey tool recorded an inclination of 89.2° at 9,398 ft MD, but the continuous inclination recorded 88.7° at 9,417 ft MD followed by a survey inclination of 90.1° at 9,430 ft

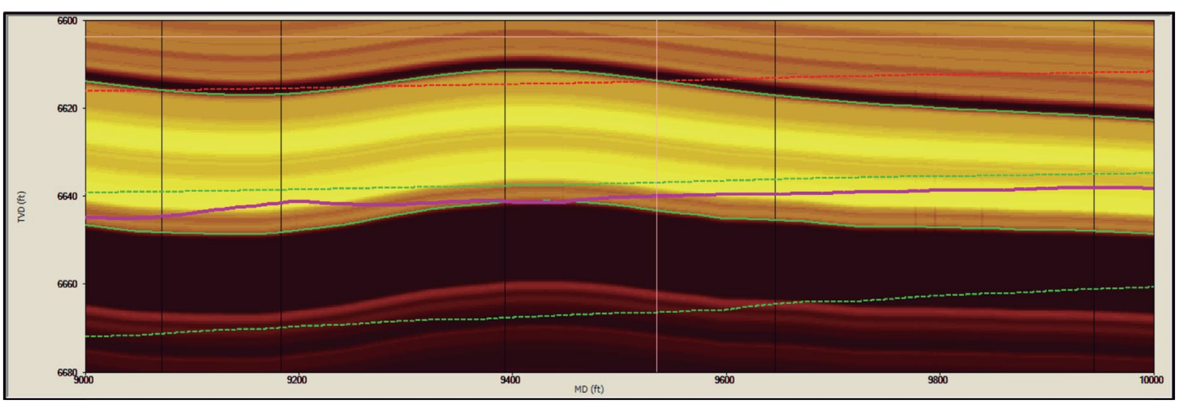

Figure 18. Example of excessive bending of modified surfaces.

MD. Therefore, at least 0.5°were missed, which could have prevented the base grid from coming up. At 9,400 ft MD, an approximate 27-ft TVD discrepancy exists between the original grid and the modified surface, which was the highest in the interval.

RESULTS

The well was drilled inside Manning A until exiting the reservoir through the base, and images confirmed the downward stratigraphic movement at the exit. The base was scratched once, but inclination was quickly increased to return to the center of the target zone. Dip picking was performed and used in a qualitative manner for wellbore positioning. Using continuous inclination helped while drilling the well and explained why excessive bending of the surfaces was necessary to match the correlation.

CONCLUSIONS

The use of AGR allowed for accurate stratigraphic correlation. Values above and below the target zone were similar;using an average gamma-ray tool, it would not have been possible to determine at 9,400ftMD whether the top or the base were scratched. The originalsurface grid for the base of Manning A planned for the operationshowed a maximum 27-ft TVD difference with the actual Manning A base encountered, which was sufficient to exit the target zone if the well would have been drilled to well plan. Continuous inclination while drilling allowed for a quick reaction when the base was approached at 9,400 ft MD.

REFERENCES CITED

Boyd, D.T., 2008, “Stratigraphic Guide to Oklahoma Oil and Gas Reservoirs”, Oklahoma Geological Survey, University of Oklahoma.

COSM, 2000, Website of James Madison University College of Science and Mathematics <http://csmgeo.csm.jmu.edu/geollab/Fichter/SedRx/carbdepoenvir.html> Accessed May 9, 2018.

Harris, S.A., 1975, “Hydrocarbon Accumulation in “Meramec-Osage” (Mississippian) Rocks, Sooner Trend, Northwest-Central Oklahoma”, AAPG,Vol. 59, No.4, p.633-664.

Mogharabi, A., 1962, “Petroleum Geology of T.19N., R.6W., Hennessey Area Kingfisher County, Oklahoma”, The Shale Shaker Digest IV, Vol. XII-XIV, p. 336-349.

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