A Re-Evaluation of Production, Geological and Petrophysical Data of a Mature Clastic Middle East Reservoir Provides a Surprising Outcome*

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Abstract

The Nahr Umr is a regionally extensive, lithological and stratigraphically complex, marine deltaic, cretaceous reservoir. It comprises a highly bioturbated sandstone, clay and ironstone sequence designated the “C” producing reservoir of the Awali Field.

Long considered a key producing horizon in the Bahrain Field the lower sequence, designated Cd, forms the basal member of the Nahr Umr and comprises interbedded sand and shale sequence of two hundred to three hundred and fifty feet in height. Historically there have been ninety-two producing wells, with thirty nine million barrels of oil in place. Currently thirteen Cd wells are active and collectively produce approximately seven hundred and fifty barrels of oil per day, usually as comingled production together with the shallower reservoir designated Cc. Conventional logs indicated that most sand intervals are wet which led to the conclusion that the reservoir was a classic, low resistive pay. This view persisted, despite that fact that the lithologically similar shallower sands which had the same electrical and fluid properties indicated hydrocarbons on the logs.

A recent external review proposed a significant increase to the estimated oil in place and suggested many additional development opportunities for the Cd reservoir. This outcome prompted an in-house re-evaluation of the production data, geology and petrophysics of the reservoir. The findings proved surprising and resulted in a complete re-think of the potential of the Cd.

This “back to basics” review raised key issues that have now impacted the continued development of the reservoir. It is thought that the review process that was undertaken would be very relevant to the assessment of both immature and mature assets generally. The lessons learnt highlighted the need to accurately quality control historical production data, to verify and understand the significance. Petrophysical and geological data and has resulted in a completely new development strategy for the Nahr Umr.

The Challenge

Successive depletion plans had identified the lower Nahr Umr reservoir sand identified as Cd, as a key target for future development. With a target of seven wells to be drilled and an external reservoir study that increased the size of the prize to 500 MMBbl. A major component of the increase in the oil in place was the inclusion of the sideritic (ironstone) zones as pay. These issues became the motivation for the geoscience team to re-visit this opportunity. Geological, petrophysical and production data was reviewed in depth.

Overview of the Bahrain Field

The Bahrain Field is a doubly plunging anticline underlying the central and southern parts of the island of Bahrain (Figure 1). The field has about 20 stacked reservoirs ranging from the shallow Aruma Formation (approx. 800 ftss. Subsea) to nearly the Khuff and Unayzah formations (9,000 to 11,000 ftss.). Most of the reservoirs are carbonate; however the Wara and Nahr Umr consist mainly of clastic sediments. The structure is heavily faulted.

Oil production began in 1933, and peaked at 76 MBOPD in 1970. Recent production strategies have included the implementation of several EOR projects as well as an ongoing infill drilling program.

The Nahr Umr Reservoir

The Nahr Umr reservoir is a shallow marine, clastic, deltaic, estuarine, reservoir, comprising clean sands inter-bedded with variable composition shale's including clays and silts. It is the basal unit of the Wasia Group located immediately below the major Bahrain producing zone, Mauddud, and comprises four reservoir units, Ca, Cb, Cc, and Cd with a total thickness is 350-400 feet. Porosities in the sands are good, usually 30-35% with the Cc and Cd being the best quality sands. Permeabilities are also good, in the range of 100-300 mD.

The lower Cc and Cd Sands are clean high porosity, high permeability. The Cc is the main reservoir sand, about 50-70 feet thick with a high porosity and a high net-to-gross ratio. The lower section of Nahr Umr, the Cd, is similar lithology, thicker varying from 250 ft. at the crest to 300 ft. at the flanks, but has a lower net to gross at about 25%. The major sand bodies are correlatable across the field. The Cc and Cd sand packages are wet towards the flanks. Cd frequently exhibits higher water saturations than Cc and when oil is present, they exhibit a very distinct OWC (Figure 2).

Oil Production

The Cd formation reservoirs have been on production since 1935. A total of 99 wells have been completed in Nahr Umr Cd. As of today there are 13 active completions in Cd Nahr Umr contributing 584 BOPD, with a cumulative production of 38 MMbbl. Well production has been achieved through several completion designs throughout the life of the field. These designs have ranged from dedicated production strings for individual reservoirs to commingled production from Cab, Cc and Cd. The latter were prominent in the early years of the field's life. In some cases the Mauddud reservoir has also been commingled with Cab, Cc and Cd. Neither gas nor water has been injected into Cd reservoir (Figure 3).

Nahr Umr Cd Petrophysics

Several wells have been cored in Nahr Umr. Although the sand grain size variability ranges from very fine, silt to courser with a matrix of mostly pure quartz. Analysis of the shale's identified clays illite, kaolinite glauconitic sands, ironstones (usually siderite) and siltstone. Recent wells drilled since 1986 have used the photo electric (Pe) curve to ensure accurate identification of the ironstone zones. The ironstone is predominantly found in the shale, but occasionally is found in the sands.

The Cc and Cd reservoir sands are often clean with very good permeability, up to 600 mD. Although Cd has not been cored, cuttings analysis indicates a very similar mineralogy. Core analysis results from Cc show a very good agreement for porosity and oil saturation with log derived values (Figure 4). Very little effective porosity has been identified in the core outside of the clean sand bodies. Formation water is fresh throughout both reservoirs with salinities of the order of 8,000 ppm Na Cl. equivalent, in keeping with those of the adjacent reservoirs.

Log interpretation has been undertaken on all wells having logs since 1985 using a consistent mineral model. A single formation water resistivity (Rw) of 0.79 @75 deg. F has been used with water saturations generally calculating high, ranging from 25% to 100%. An additional log evaluation process included the computation of a capillary pressure based water saturation "SW original" (Figure 5). This was used to estimate the water saturation prior to discovery and initial production.

As the presence of oil in the Cd reservoir has been confirmed from production, it had become the practice to use this new, lower "SW original", water saturation when selecting the sand to complete. The apparent disagreement between log based oil saturations and oil production had been ignored until fairly recently. An examination of log and core data of Nahr Umr suggested one of two possibilities for this apparent low resistive pay. Either there was conductive mineral dispersed throughout the reservoir sections, or there had been an error in the water salinity.

Core analysis, predominantly in Cc had only identified potential mineralogical contenders for low resistive pay in glauconite and siderite. The highest amount of glauconite seen in core was 3% but quite large amounts of siderite had been seen in the Photo Electric (Pe) curve. With hundreds of logs reviewed, it was seen that the siderite was usually found in the nonproductive shale zones. Only occasionally did it encroach into the cleaner sands. The attached plot A-XX18 (Figure 6) clearly shows the elevated Pe curve associated with shale and the accompanying elevated resistivity. Siderite was discounted as the cause of the suppressed resistivity.

Well Production Analysis

The decision was taken to review the individual well production data. Tatweer has well production data going back as far as 1969, and captured by each individual producing zone. A major feature has been the rate of testing on individual wells that has been undertaken over the years. In all some 30 wells that had production from Cc and Cd. These were analyzed in detail. Four wells are shown here, however most wells exhibited similar themes.

Well A-XX38

The logs show good oil in Cc at about 70% saturation, with a small gas cap seen in the upper Cc sand. The Cd sands are thin and exhibit oil saturation below 40%, no gas is evident (Figure 7). This well was completed in 1982 with Cd and Cc set to produce separately through a dual completion. Recorded cumulative oil production was reported as 24 MBbl for Cc and 156 MBbl barrels for Cd. When the production charts were examined, there appeared to be an anomaly. The initial production, from Cc showed high gas of more than 1 MMcuft/D with oil at 100 BOPD. The well was soon changed to Cd production, which continued until 2002 with high gas rates that varied between 0.5 and 1 MMcuft/D. As the GOR increased the well was again switched to Cc production for a further two years before being returned to cyclical Cd production. Although the Cc production had been short lived, the two zones had exhibited almost the same rates of gas throughout the well's production life. Either the logs had completely missed the presence of gas in Cd and under-estimated oil saturations or there had obviously been an allocation or well integrity issue with this well. Certainly the similarity of gas and oil production rates from both Cc and Cd was very suspicious.

Well A-XX62

Drilled in 1990, the logs indicated much of Cc at 60% oil saturation with the upper sands if Cd at 40% or lower. The lower Cc sand showed a low gas saturation, Cd showed no gas (Figure 8). Two sands, one in each zone were perforated and produced through a dual string completion.

The cumulative oil production for Cc and Cd were similar at 566 and 678 MBbl respectively.
The well production chart for Cc showed oil and water at expected rates but the gas rate jumped between 1mmcuft/d and 10 MMcuft/D until 2001. The production chart for Cd showed the same oil production, but had more gas allocated. This remained quite constant at around 1MMcuft/D. Combining the production data for both zones showed very little difference in rates despite the quite different petrophysical characteristics of the reservoirs. The results suggested a misallocation and possibly a casing integrity issue.

Well A-XX54D

This well was drilled in 2012 and completed as a single string producer from Cd initially and then Cc. Logs indicated a very good oil saturation in the Cc sands complete with gas and oil, and a water leg with a water saturation of around 80% (Figure 9).The Cd had a smaller single productive sand with about 40% oil saturation.

The Cd was produced first and had flush production of 100 BOPD with very low gas and very high water rates of 2000 BWPD. The Cd soon watered out and the well was recompleted in Cc. The Cc production was representative of the logs with high water, high gas and associated oil. It was considered that the production of both zones was close to that predicted by the logs. The total cumulative Cd production for this well was 16 MBbl compared to 126 MBbl for Cc. This well is representative of several recent wells completed as single producers for each zone that exhibited very similar productivity for Cd and Cc.

Cumulative Oil Production

An examination of cumulative oil production maps for the two reservoirs also indicated an anomaly. (Figure 10).The Cc reservoir appeared to have a low cumulative production in the crest of the field, exactly where the Cd indicated a high cumulative oil production. The obvious conclusion, was once again, that the allocation between the reservoirs had been inconsistent.

Testing the Ironstone Intervals

A well was selected as a candidate for testing the low resistive pay ironstone intervals (Figure 11). The well was recompleted in a poor Nahr Umr interval that showed water saturation in the Cd sands of greater than 70%. The lower sand was perforated and produced only water.
In order to examine the production potential of the "ironstone" intervals, which consisted predominantly of clay and siderite, these intervals were perforated and the resulting production was monitored. No oil was produced with a water rate slightly higher than previous at 1400 Bbl/D. It was assumed that water production was from the adjacent wet sand interval due to well integrity issues, with production from the sands via the casing annulus.

Conclusions

Production data, both historical and recent, had been subject to incorrect allocation in many producing wells. Much of the production allocated to Cd was in fact, Cc production. The potential of Cd reservoir has been re-assessed and now considered to be less than previously thought. The ironstone intervals which had little effective porosity and showed little evidence of suppressed resistivity and were, in fact, non-productive.

The initial petrophysical model was accurate. The formation water salinity used was correct. Resistivity based water saturations were good.

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Selected References

Al Janahi, Ahmed, Yusuf Buali, Nadia Nemmawi, and Nahr Umr, 2017, Nahr Umr classical waterflood: From pattern pilot to peripheral waterflood, Bahrain: SPE 183683-MS.

Banoco, 1980, A comprehensive review of the Bahrain Field, unpublished.

International Reservoir Technologies, 2014, Bahrain synthesis study, introduction and history, unpublished.

Kollun, S.R., S.R. Ali, and W.K. Ziltan, 1982, Cd lower productive sand, a review for its development: BAPCO Internal Report.

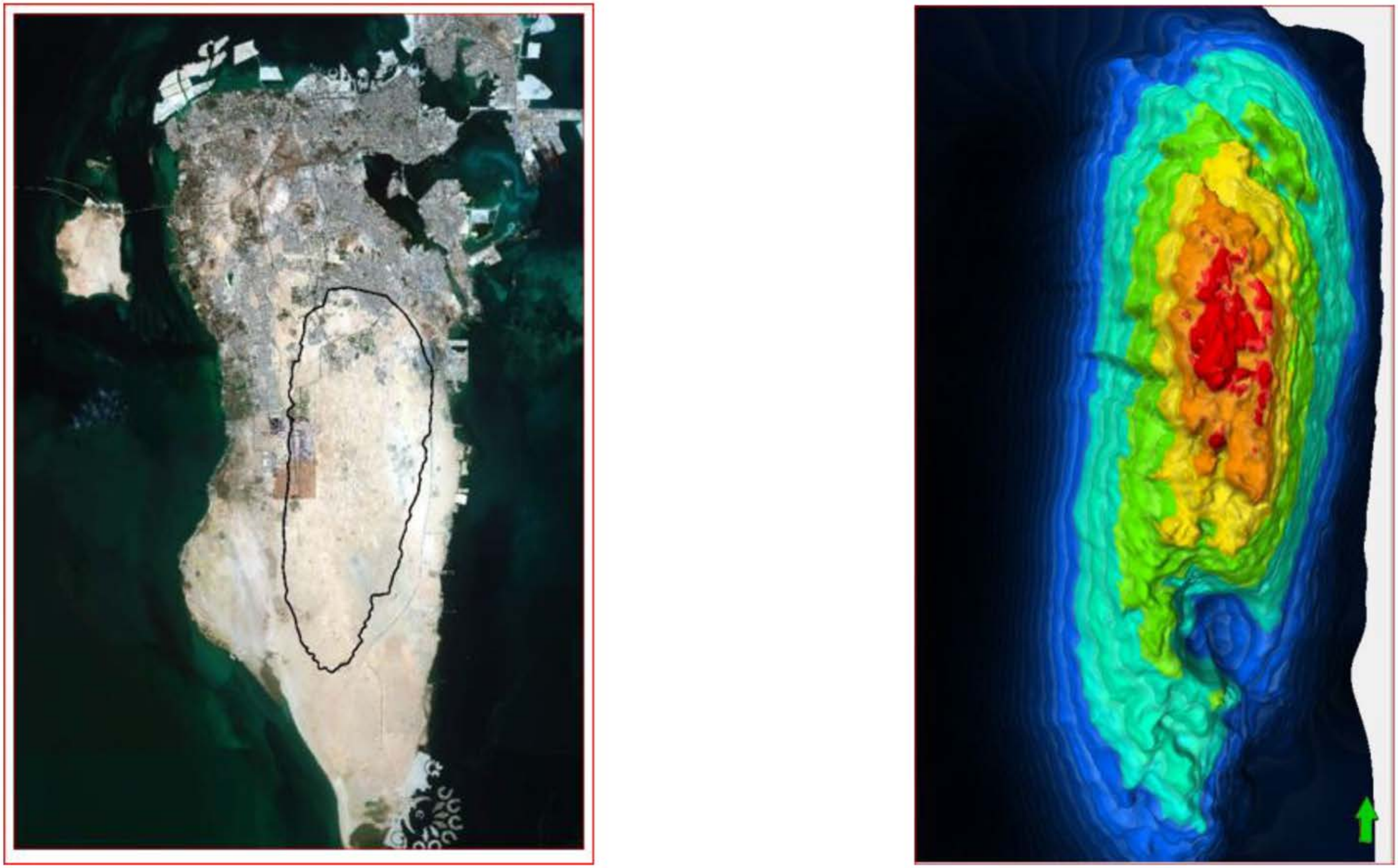

Figure 1. The location of the Bahrain Field and a recent structure map.

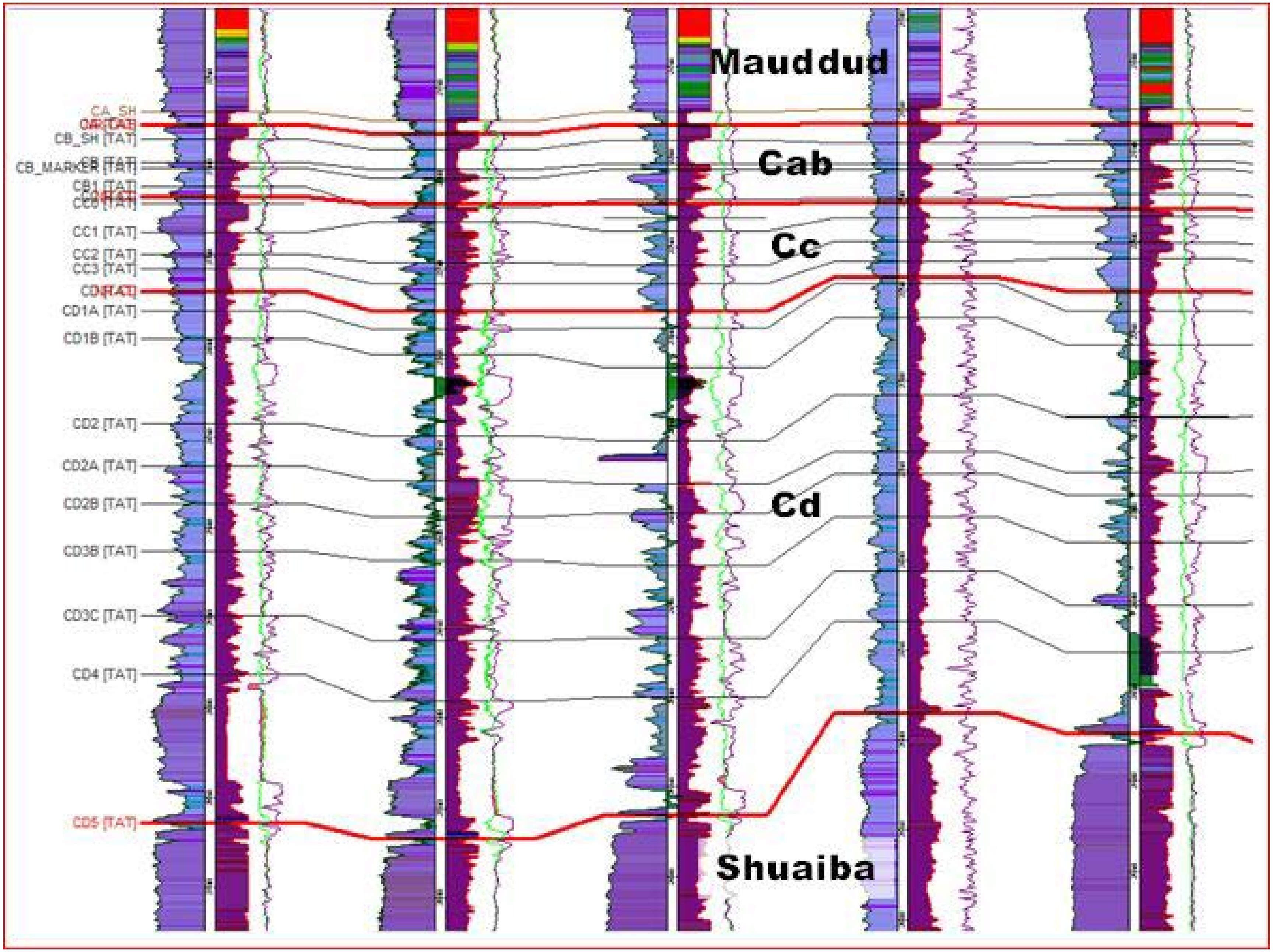

Figure 2. The various zones of the Nahr Umr Formation showing cross field correlation.

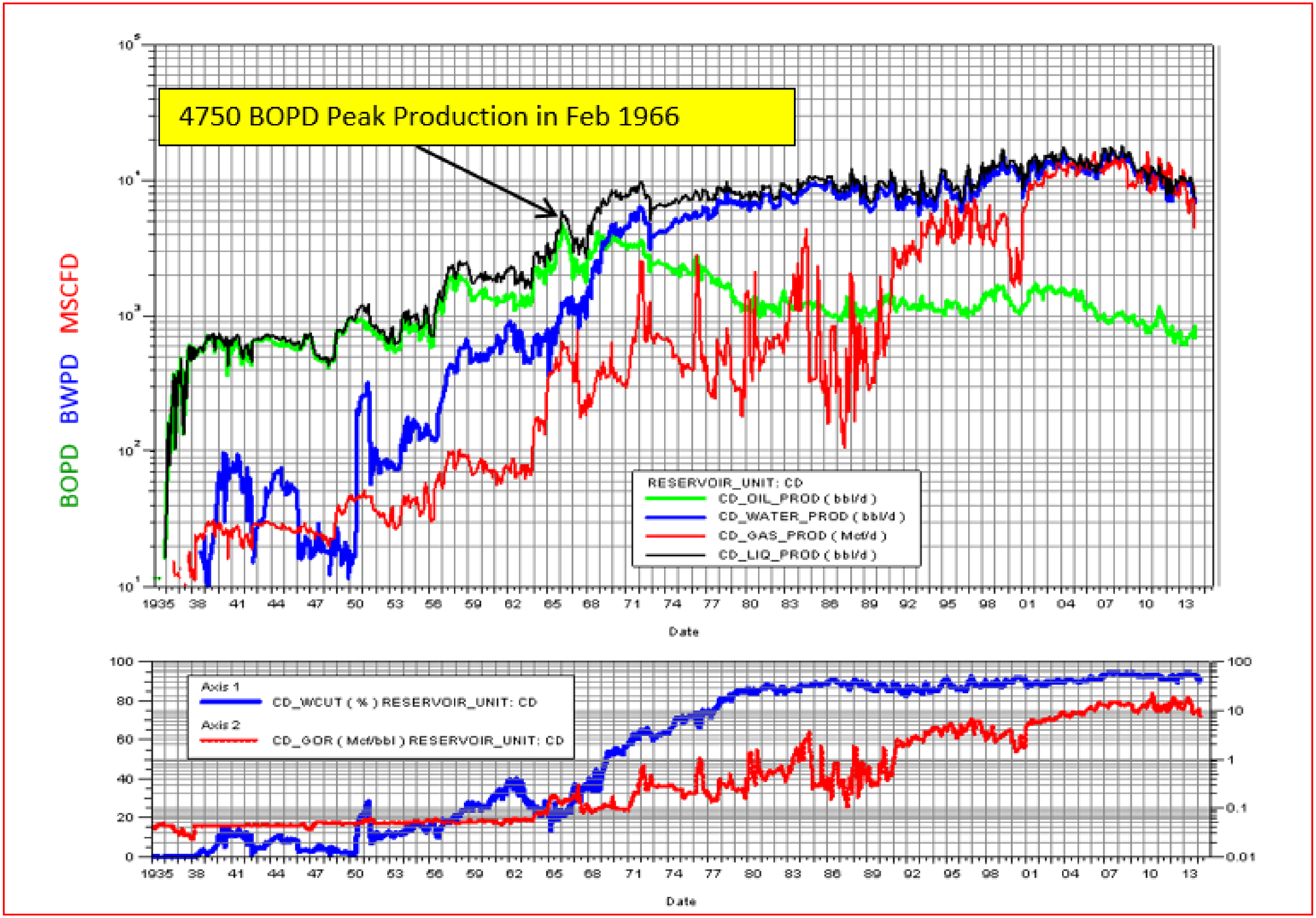

Figure 3. Cd production began in 1935 from the discovery well.

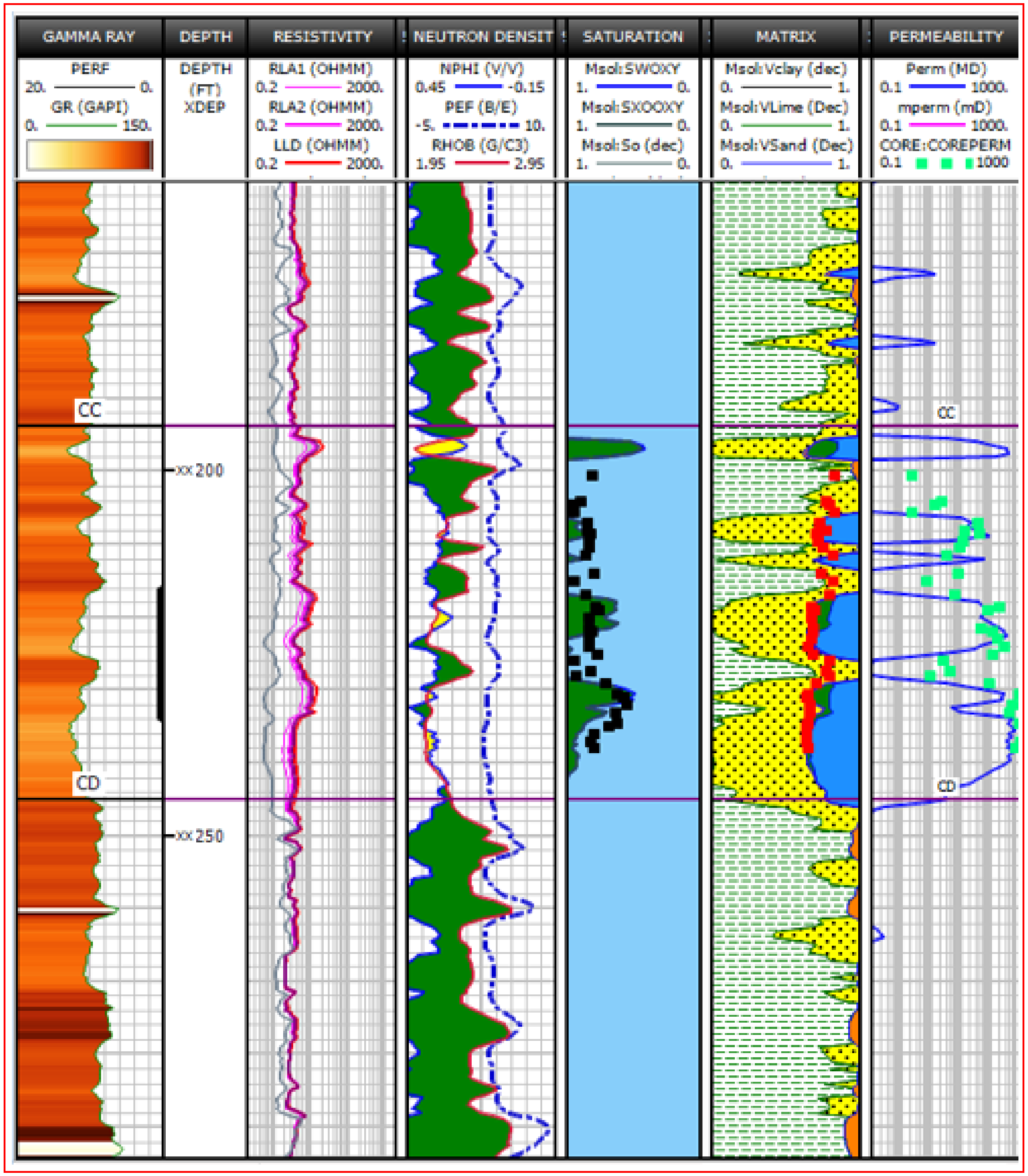

Figure 4. Well A-XX18, showing good agreement between log and core porosity and oil saturation.

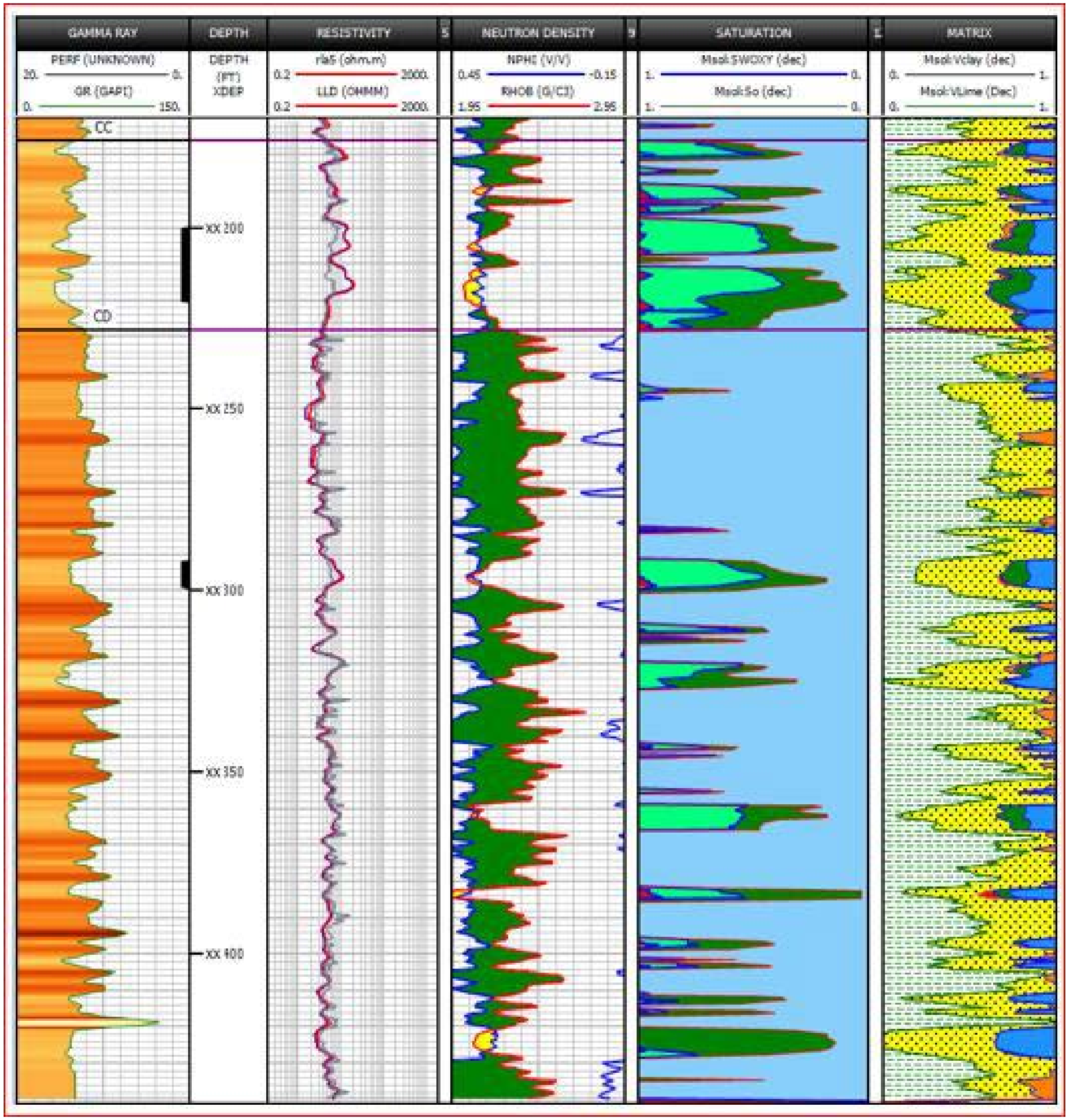

Figure 5. Log interpretation showing the difference in oil saturation between log (light green) and that calculated from capillary pressure (dark green).

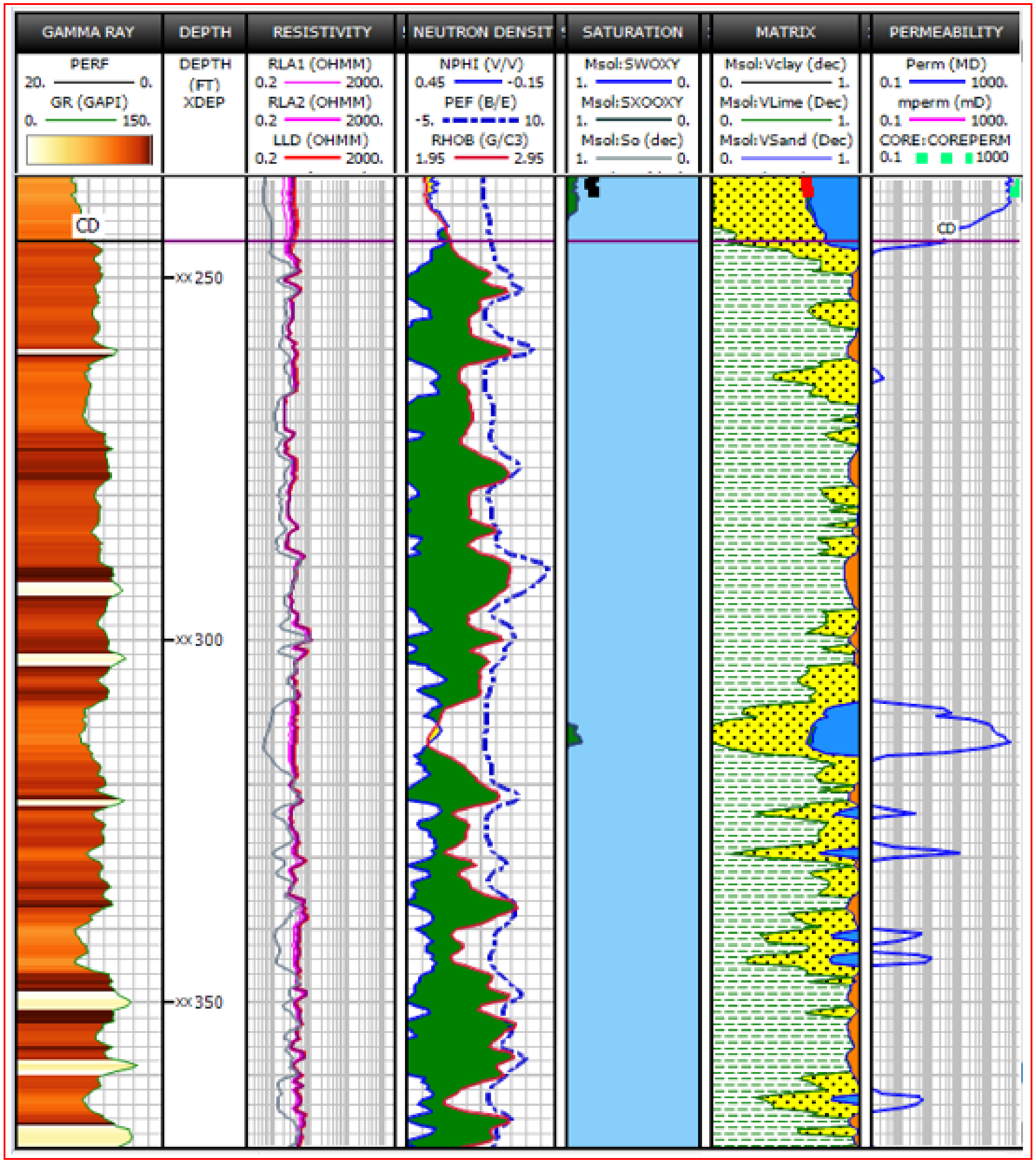

Figure 6. The occurrence of siderite, orange mineral in track 6, is often associated with elevated resistivity and shale zones.

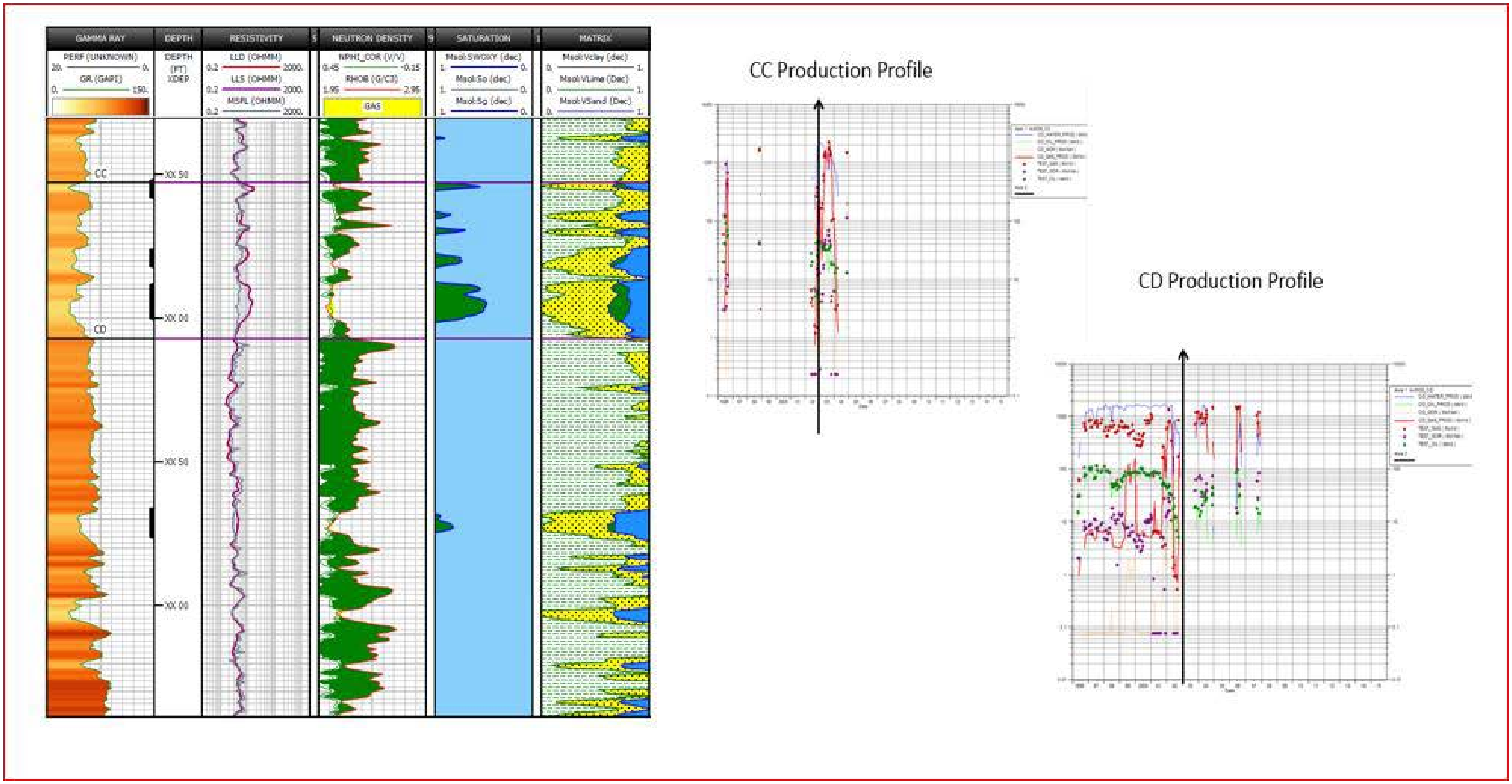

Figure 7. A-XX38 Well log interpretation and associated production profiles.

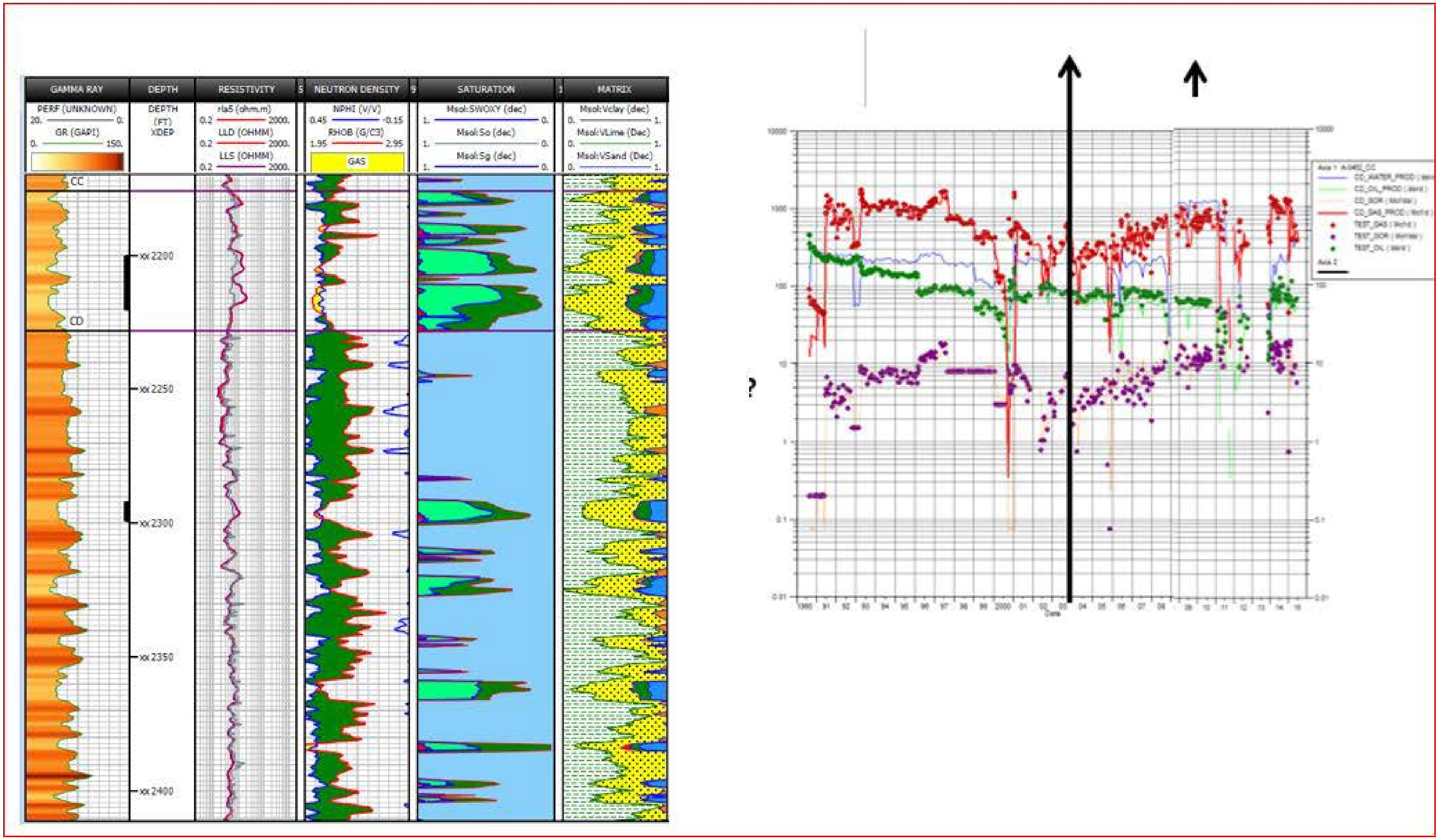

Figure 8. A-XX62 Well log interpretation and associated production profiles.

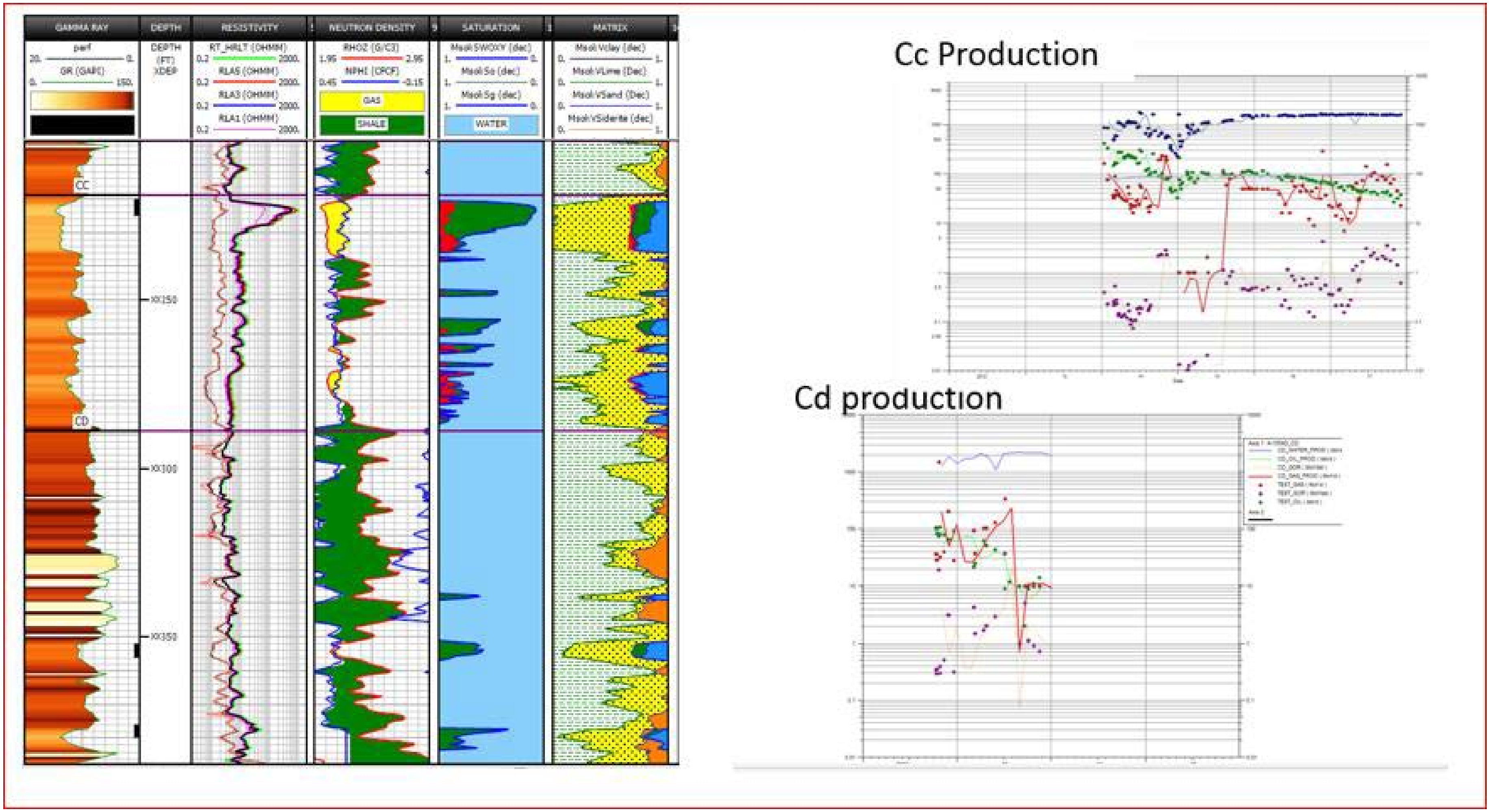

Figure 9. A-XX54 Well log interpretation and associated production profiles.

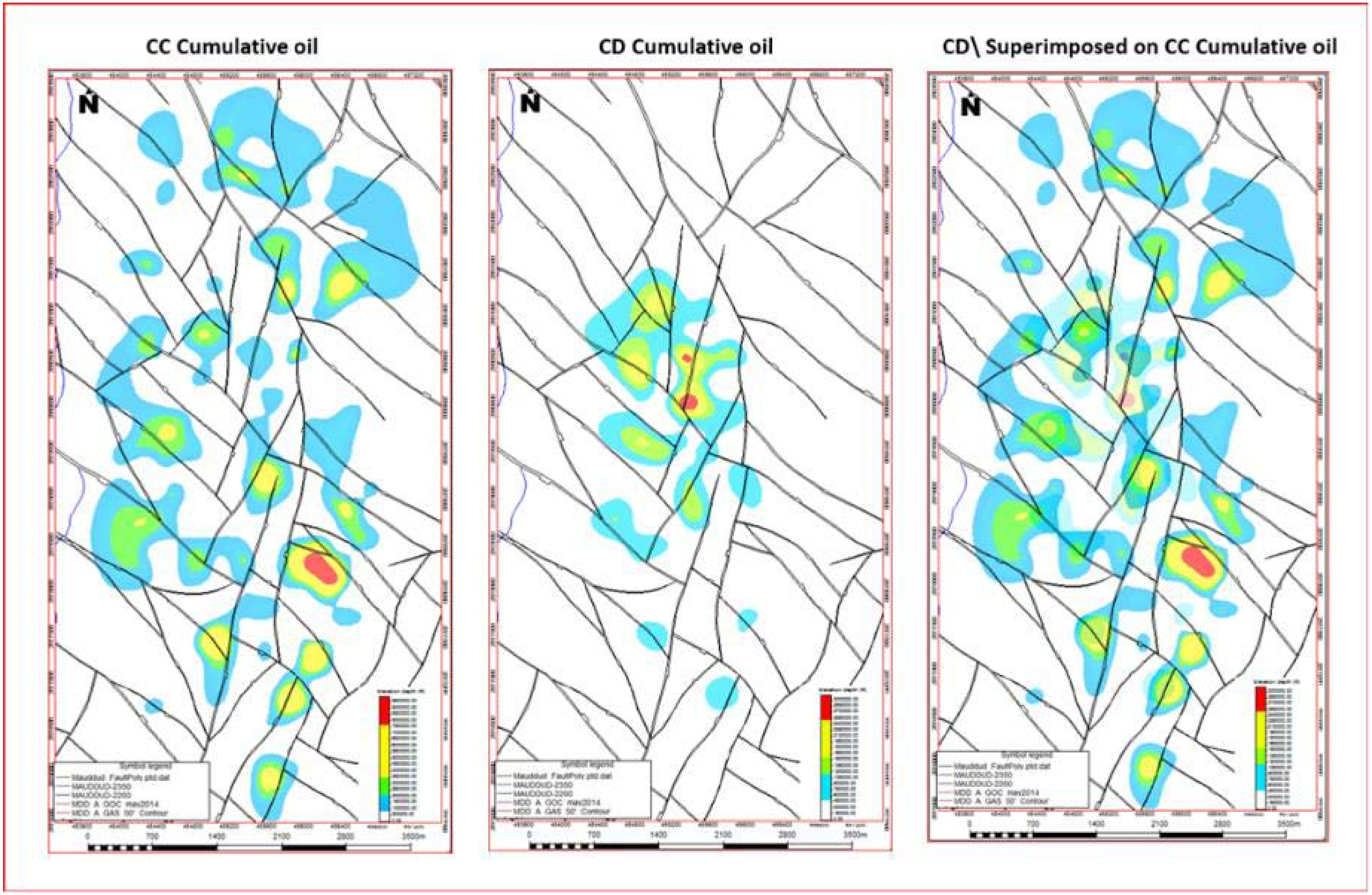

Figure 10. Cumulative oil production maps of Cc, Cd, and a combined Cc Cd reservoirs.

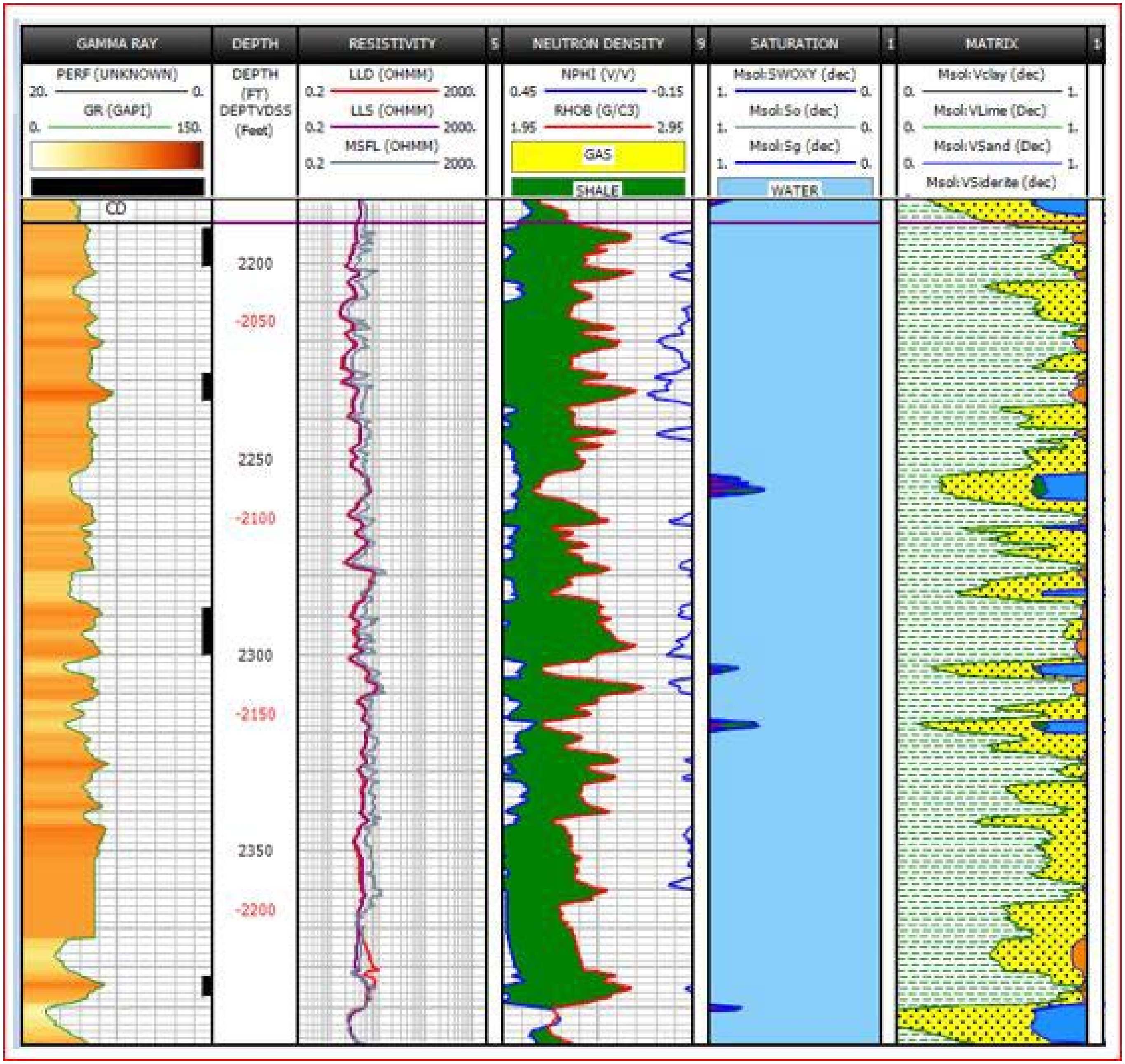

Figure 11. A-XX43 Well log interpretation showing location of the siderite zones and associated perforated intervals.