Characterization of Thinly Bedded Units and 3D Static Model Open Reserves in Sabiriyah Field Middle Burgan Reservoir, North Kuwait*

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Abstract

The Sabiriyah Middle Burgan Reservoir is a part of the North Kuwait Resource which is under-developed. It has a high degree of reservoir rock and fluid heterogeneity, and until recently the establishment of mobile oil was given low priority. In the presence of giant reservoirs, the Middle Burgan Formation is one of the „Minor Reservoirs" thought to have limited opportunity for production upgrade. Improved reservoir characterization and subsequent high definition 3D Static model enhanced the possibility of testing the Middle Burgan. The successful testing results from the first exclusively drilled well and idle well bore penetrating the reservoir showed the reservoir to have potential for dry oil production. These results also helped to prepare a development plan for the reservoir and to identify follow-up actions that will aid increased oil production and reserve accretion.

The Middle Burgan Formation is a stacked shoreface deposit forming prograding parasequence sets made up of upward-cleaning and shallowing parasequences. The parasequence sets reflect the overall transition in depositional environment from muddy offshore deposits, through heterolithic offshore transition zone deposits, to lower shoreface sandstones. The Middle Burgan Reservoir was subdivided into 4 major layers and 17 sub-layers based on sequence stratigraphy and rock quality index. These geological layers combined with 3D seismic data provided the framework for the structural model. The high-resolution geocellular model was built while integrating all the components, which included the deterministic structure maps and petrophysical results. The model and visualization proved valuable for interpreting the primary depositional and secondary digenetic processes that left their influence on Middle Burgan rocks.

The study helped in understanding the reservoir heterogeneity and reduced the uncertainty in the identification of sand. With this more accurate estimation of water saturation, resources previously qualified as "wet" in normal clastic reservoirs can now be exploited as producible reserves. In addition, the study helped to develop the Middle Burgan Reservoir leading to new drilling and workover opportunities. This led to more than

a 600% increase in oil production, and estimated 100% increase in recoverable reserves. Ultimately this study supported a long-term development plan and reserves growth for North Kuwait.

Introduction

The Sabiriyah Middle Burgan Reservoir is of Lower Cretaceous (Albian) age and belongs to the category of "Minor Reservoir" in the Sabiriyah Field, North Kuwait (Figure 1). The Middle Burgan Reservoir is a part of North Kuwait resources and attempts were made to fully understand and develop the reservoir. The Middle Burgan and other minors reservoirs are expected to contribute significantly to the North Kuwait production target.

The Middle Burgan is an extremely challenging reservoir composed of heterolithics and mud-prone sandstones and the reservoir potential is strongly controlled by mud content with bioturbation playing a role in the redistribution of argillaceous material. It is interpreted as stacked shoreface deposited in progradational parasequence sets as sea level started to rise. SAMB reservoir (170 feet thickness) is classified into 4 major units: MB-1A, MB-2A, MB-3A, and MB-4A (from top to bottom) with a little variation between these units. All four units are dominated by marine mudrocks coarsening upward into shoreface sandstones with uniform distribution. It has been penetrated by more than 400 wells but was tested in only three wells so far with significant current production.

A comprehensive study was conducted and a 3D static model was built incorporating geophysical, geological and engineering data available to improve understanding of the potential of the reservoir. The study helped to identify the sweet spots for short term potential locations and maximizing the production target, as well as lowering the uncertainty of input parameters contributing in STOOIP calculations and to be used to build production profile forecasting.

The 5 main sections of the study presented in this article are:

- Seismic Data
- Petrophysical Analysis
- Geology
- Integrated Reservoir Model
- Development Strategy

Seismic Data

The structure of Middle Burgan (MB) reservoir is interpreted as a highly faulted north-south doubly plunging anticline. The MB surface map was created using the interpreted seismic data which covers Ahamdi down to the Zubair formations (Figure 2). Seismic data at MB level is below seismic resolution and appears as a very week reflector. Top and base reservoir structure depth grids (MB-1A and LBLSID1) were generated based on Upper Burgan and MA seismic interpreted horizons.

The footprint of the OOWC at reservoir top is determined for structural delineation. It varies across the field due to structural tilting which implies that the stratigraphy and faulting plays a role in compartmentalization of reservoirs. The unknown vertical separation across the faults is due to the limitation of seismic data, and makes fault potential for sealing and juxtaposition hard to determine. In the absence of pressure and longer-term production data, it is hard to measures the actual fault seal capacity at present. A total of 80 faults were interpreted from the wells and seismic data. Most of the faults are trending northwest-southeast with very steep dip and applied as vertical in the model, except the faults encountered in wells. Seismic attributes could not be used as an aid when mapping the properties due to the limitation of seismic data.

A velocity model was created using all the Sabiriyah Field wells penetrating the MB-1A surface, which is utilized for time depth conversion. Centerline faults were used in generating the top reservoir depth structure map that was used as input to the geologic static model (Figure 3).

Petrophysical Analysis

Petrophysical study of the logs was conducted to provide consistent description of reservoir properties from wells encountering the Middle Burgan. The wireline log datasets are of varying vintage, which limit the accuracy of calibrations. Also, the caliper logs indicate that borehole breakout has occurred in most of wells and this may reduce the reliability of log responses.

The petrophysical models used in estimating porosity, water saturation, lithology, and permeability (Figure 4) have been thoroughly calibrated with available core data. Only one electrical SCAL (a, m, and n) and capillary pressure (saturation vs. height) measurement has been done so far. The model is a deterministic one, utilizing step by step with sequential computations. Various core lithofacies were grouped into 5 facies in 8 wells which have core data and calibrated with logs. These facies were applied across all un-cored wells using a variety of petrophysical properties including effective porosity, PHZ and RQI (Figure 5). The results of this study were used to populate the static reservoir model, including effective porosity, permeability, water saturation and lithofacies.

Geology

Depositional Model

Depositional setting of the Middle Burgan is viewed in terms of the entire Burgan Formation, as Burgan is divided into Lower, Middle and Upper Burgan, as follows:

1) The fluvial dominated delta of the basal part of the Lower Burgan represented either a late highstand or falling stage systems tract.

2) As relative sea-level continued to fall, the overlying stacked braided fluvial channel sandstones made up a lowstand systems tract, the base of which is a sequence boundary.

3) The marine influenced channels at the top of the Lower Burgan indicate that relative sea level was rising and was a transgressive systems tract.

4) The Middle Burgan was deposited in the subsequent highstand systems tract, which continued upward into the Upper Burgan and was subsequently followed by a transgressive systems tract towards the end of the Burgan.

Based on available wells with core data, the Middle Burgan represents a phased progradational shoreface succession, which has been exposed to fair-weather and storm conditions (Figure 6).Three main facies have been identified: offshore, offshore transition zone, and lower shoreface. The wave/storm-influenced lower shoreface deposits generally show the highest degree of variability as the lower shoreface setting is strongly exposed to both fair-weather and storm conditions (with fair-weather deposits only being preserved if storm intensity/frequency is not too high). Offshore transition zone and offshore deposits are less variable as these settings are dominated by fair-weather conditions with commonly variable, but less intensive storm activity. These facies associations are typically organized within upward cleaning/ shallowing successions (parasequences) reflecting the upward change from basal offshore mudrock (Figure 7) to offshore transition zone heterolithics/mud-prone sandstones (Figure 8) and, at the top, slightly cleaner lower shoreface sandstones (Figure 9). Each of these upward-cleaning successions/ parasequences is bound at the base and top by high-frequency flooding surfaces; these flooding surfaces record the episodic backstepping/landward retreat of the depositional system. The paleo-coastline for the Middle Burgan is thought to have a general northwesterly orientation.

Reservoir Stratigraphy and Layering

Sequence stratigraphy based on the integration of core and well logs was applied and identified flooding surfaces as the key correlatable marker. A correlation framework was built and resulted in 4 major layers (MB-4A, MB-3A, MB-2A, and MB1A) from bottom to top with a total of 28 geological surfaces extended over the field (Figure 10). Isopach maps for each layer have been generated and edited by hand to reflect the stratigraphic setting and then incorporated into the model. In gross terms the sequence stratigraphic evolution of the Middle Burgan Formation can be described in terms of four low-frequency parasequence sets, each of which is bound by major flooding surfaces (Figure 11). These parasequence sets form part of an early highstand systems tract and are described below in ascending stratigraphic order.

Layer MB-4A

This is the lowermost layer of the Middle Burgan Formation and is bound at the base and the top by field-wide correlatable flooding surfaces LBLSID1 (Lower Burgan) and MB-4A, respectively (Figure 12). The MB-4A layer comprises two well defined, smaller scale shoreface parasequences that are stacked within an overall, but pulsed progradational parasequence set accounting for the gross upward cleaning motif and upward-shallowing from offshore transition zone heterolithics to lower shoreface sandstones. The top part of this layer, with an offshore transition zone facies affinity, contains locally ductile-rich deposits, including probable glauconitic and siderite replacement of detrital clay. These could reflect the initial stages of flooding prior to the main flooding event at the top of the layer.

The gross upward-cleaning/shallowing trend of the MB-4A layer is also apparent from openhole log signatures with mostly negligible reservoir quality, with marginally better (poor) potential within the thin, slightly cleaner lower shoreface sandstones close to the top with poorly connected macropore-networks. The identification of individual parasequences from openhole logs alone is not straightforward. This suggests lateral facies variations on a smaller (sub-layer) scale and probably locally restricted in their lateral extent.

Layer MB-3A

The MB-3A layer is bound at the base and top by correlatable flooding surfaces MB-4A and MB-3A respectively (Figure 12). The MB-3A layer is composed of progradational/outbuilding shoreface deposits showing a progressive upward change from offshore mudrocks at the base to offshore transition zone heterolithics and lower shoreface sandstones at the top. The sandstones represent the thickest accumulation of stratified lower shoreface, suggesting relatively high rates of sedimentation from possibly low-intensity but comparatively frequent storm events that suppressed any significant biogenic activity; stratified lower shoreface reflects the most proximal/shallowest sediments of the entire Middle Burgan. The very top of the MB-3A layer comprises a sharp-based, oolitic ironstone-bearing, upward-fining sandstone unit that could mark the onset of transgression and the termination of shoreface progradation that eventually resulted in the main flooding and backstepping of the depositional system at the top of the layer.

Correlation confirms the overall upward-cleaning/progradational trend and the sheet-like reservoir architecture of this layer with the vertically amalgamated sandstones toward the top of the layer forming laterally extensive sand sheets of “relatively better” reservoir potential**.** However, the MB-3A layer appears to be of generally negligible to rarely poor reservoir quality. It contains very fine-grained and argillaceous lower shoreface sandstones and can be linked to very limited flow through minor, cleaner laminae and sand-filled burrows observed in thin-section.

Openhole log motifs notably suggest that the MB-3A layer can be genetically subdivided into two higher frequency upward-cleaning parasequences, at least in the southern and middle part of the Field . Only one distinct upward-cleaning parasequence is obvious in the northern (more distal) area implying the possible presence of clinoforms.

Layer MB-2A

The MB-2A layer is bound at the base and top by flooding surface MB-3A and MB-2A respectively (Figure 12). It comprises several feet-thick, stacked upward-cleaning shoreface parasequences, which near the base of the layer are characterized by the upward change from offshore mudrocks to overlying argillaceous offshore transition zone sandstones/siltstones. Earlier there was a suspected limestone bed in the lower part of this layer, but it has in fact been found to be a ferroan dolomite-cemented, originally argillaceous siltstone. It is noteworthy that increased levels of dolomitization have occurred at the base of the layer containing replacive siderite and ferroan dolomite, which represents a field-wide correlatable diagenetic modification. These appear to be linked to higher frequency flooding surfaces within a relatively distal depositional setting following the deepening of the depositional system associated with the major MB-3A flooding surface.

The upward decrease in the frequency of offshore mudrocks and the more common occurrence of stratified, storm-generated (proximal) offshore transition zone and lower shoreface sandstones toward the top of the layer defines an overall upward-cleaning/progradational trend. The lower shoreface interval and the upper part of the underlying (proximal) offshore transition zone deposits at the top of the layer contain thin stratified sandstone beds that are vertically separated by commonly intensely bioturbated sandstones and heterolithics. This suggests deposition from infrequent storm events, which could have been of slightly higher intensity compared to the underlying MB-3A layer as indicated by their overall cleaner composition and coarser character. However, their relative thinness and overall stacking pattern suggests a slightly more distal depositional setting compared to the thicker MB-3A lower shoreface sandstones with the interbedded bioturbated and more argillaceous deposits representing preservation of background/post-storm sedimentation.

The gross upward-cleaning/shallowing motif supports a sheet-like architecture of the entire interval with only minor thinning noted towards the north of the Sabiriyah Field **.**The MB-2A layer displays a marked gross upward-cleaning profile which is reflected in the reservoir quality distribution. The above-mentioned stratified storm deposits at the top of the layer have shown by far the cleanest composition and thus have by far the best reservoir quality, however their thin and vertically isolated occurrence suggests that they form laterally restricted sandsheets/lenses and makes it difficult to predict their exact distribution other than that they preferentially occur towards the top of the layer.

The highly argillaceous, bioturbated offshore transition zone sandstones/siltstones in the lower half of the layer is considered to be non-reservoir. The offshore mudrocks and ductile-rich offshore transition zone deposits at the base of the layer have the potential to act as significant barriers to fluid flow. The seal potential of these deposits may have been further enhanced by the locally intense siderite and (laterally continuous or nodular) ferroan dolomite cementation.

Layer MB-1A

The uppermost Middle Burgan layer is bound by flooding surfaces at the base and top MB-2A and MB-1A, respectively (Figure 12). The pervasive bioturbation of the argillaceous offshore transition zone sandstones and heterolithics, which dominate this layer, generally hampers the confident recognition of bed contacts and trends in places. Openhole log motifs are ambiguous for this layer and do not help constrain depositional trends. Nevertheless, the layer can be viewed as an overall trendless and, toward the top, subtle upward-fining interval/retrogradational parasequence set interrupted by higher frequency transgressive surfaces, which appear to be locally associated with the development of slightly coarser grained/cleaner transgressive sandstones. The apparent retrogradational organization of this layer, which seems to be supported by openhole log motifs in the south area, whereas openhole log observations in central and northern areas clearly display an overall but phased upward-cleaning/progradational profile consisting of at least two smaller scale upward-cleaning parasequences. This inconsistency requires further investigation with a focus on the southern part of the Sabiriyah Field in order to clarify the exact depositional organization as it is likely to have reservoir implications.

While the lower and upper contacts of this layer are well constrained with correlation suggesting a sheet-like architecture, uncertainties exist with regard to the precise internal make-up of the layer (overall progradational vs. retrogradational). A progradational model implies a generally upward-increasing reservoir quality trend, while a retrogradational model implies a gross upward-decreasing trend in reservoir quality. The MB-1A layer has an overall negligible to poor reservoir potential and very rare higher permeabilities appear to be linked to cleaner sand-filled burrows within moderately argillaceous, bioturbated sandstones within the interval.

Reservoir Quality

The principal control on reservoir quality is the relative abundance and pore-scale distribution of detrital clay (Figure 13), and localized carbonate cementation. The pore-scale fabric scheme which captures these parameters and can be linked to reservoir quality is difficult to definitively relate to the descriptive sedimentological schemes. It is possible to relate the better quality fabrics (i.e. 2A and 3A) to specific sedimentary descriptors. Pore-scale fabric 2A is typically found within the clean bioturbated and massive sandstones, while 3A is typically found within the stratified sandstones. The best reservoir quality occurs within the clean stratified and bioturbated sandstones. The relative lack of detrital clay and authigenic carbonate result in these deposits possessing reasonable macroporosity with good connectivity.

Original Oil Water Contact (OOWC)

The purpose of determining a best field-wide original oil water contact (OOWC) is to establish the limit of the oil saturation and structure delineation of MB reservoir. The limit helps to define the volume of the original oil in place just prior the start of production from the reservoir.

The OOWC is very challenging due to the nature of the shoreface sandstone reservoir. The reservoir is highly shaly, bioturbated and has conductive minerals which are all lowering the resistivity log response and negatively effecting the SW calculation (Figure 14). The OWC could not be picked based on petrophysical calculation SW logs.

From the early studies the data indicates that the structure began filling during Early Late Cretaceous and may still be charging today. Renewed uplift of the structure since Pliocene caused tilting and oil to be spilled southwards to the Bahrah and Burgan fields and redistributed within the RA and SA fields. Observed OOWC from MDT sample, TVDSS vs. SW plot, and spill point with taking in consideration the structure tilting effect. OOWC was picked between -7900, -8000, and -8100 in the Centre, East and North-South sides of Sabiriyah Field.

It is important to recognize that OOWC picks lies within a range of uncertainty. This variation might be due to changes in rock properties, real changes in fluid characteristics, and/or faults acting as lateral barriers that might suggest separate initial oil water contacts. Connecting faults of similar orientation (N-S faults) might be dividing the eastern portion from the central and western portions. Where the faults are more extensive it is possible that more compartments exist

Fluid Properties

Sabiriyah Field Middle Burgan has PVT analysis for a few wells showing a significant vertical and horizontal variation in oil quality of the reservoir. It ranges between 24-33.8 API. The variation was shown in the following fluid properties FVF, Solution GOR, and bubble point pressure, and oil viscosity (Table 1).

Integrated Reservoir Model

An independent static model was built and it would be suitable for reservoir management and development planning. The model incorporated the latest reservoir descriptions, petrophysics, fluid properties, and dynamic production data to support in developing optimum strategic reservoir development, drilling, and facilities plans. The main purpose of the model is to achieve enough vertical resolution and lateral distribution within the stratigraphic layers to capture the reservoir heterogeneity and performance. The model has 61 layers with an average vertical thickness of 2-4 feet (Figure 15).

Geological Model Grid

The geological grid was constructed using the structure of the top Upper Burgan as conforming grid to derive top Middle Burgan top depth as it is a week seismic reflector. The other sub-layers structure grids were constructed using 18 isopach grids, and generated faults from seismic and well data has been integrated and modeled. Faults encountered in wells were modeled as dipping faults (Figure 16). The structure grids, isopach grids and fault segments were incorporated to build the structural frame work .The layer thickness is sufficient to capture the vertical heterogeneity. The lateral resolution of 50 m x 50 m was chosen to provide some flexibility in the specification of the flow simulation grid. This resulted in an easy multiple of 50 m and maintains the optimum grid for upscaling.

Facies Log

The first step in property modeling was to distribute the various facies within the reservoir. Core lithofacies were defined and grouped into five facies. Lithofacies logs were created in cored wells and extended to all Sabiriyah Field wells which covered the reservoir interval for static model input.

Upscale of Well Data

Before the facies and petrophysical modeling could be performed, the well data was upscaled and averaged in one value per each cell at the well location. The arithmetic average has been used to upscale well data from log scale to geocelluar scale for PHIE. Geometric averaging has been used for permeability and the "Most of Common" method has been used for facies. These different algorithms were used to select a representative value for each cell.

Facies Modeling

Core lithofacies were distributed in the static model by using a technique called Sequential Indicator Simulation (SIS) modeling algorithm. This method is the most appropriate where either the shape of particular facies bodies is uncertain or where you have a number of trends which control the facies type. Geometric parameter as length, width and orientation were defined for each zone, based on depositional setting and the type of the dominant facies (Figure 17).

Petrophysical Modeling

Stochastic as well as a deterministic technique (interpolation) was applied to distribute the porosity and permeability within facies template provided by the facies modeling. Other parameters are used to create best fit properties (Phi, Perm) through all of the input data and distributed horizontally and vertically in the model.

Porosity

Data were interpolated by facies for each zone. The properties were distributed deterministically using the moving average algorithm. Geostatistical analysis and variograms were applied and geometric parameters were defined for each zone (Figure 18).

Permeability
The permeability model was transformed from the porosity model. The porosity attribute was used to interpolate the permeability in the 3D grid, which keeps the porosity and permeability distributed simultaneously and the correlation is properly maintained (Figure 19).

Water Saturation
Water saturation was generated directly from log data in addition to SW height function which was created by applying the new technology named GEO2FLOW which determines FWL from TVDSS and SW transform. The different FWL was determined based on the data display for each zone/compartment. Both SW from log and J function from GEO2FLOW were interpolated between the wells in 3D (Figure 20).

Volumetrics
In hydrocarbon reserve estimations, we are concerned with parameters like area (A), pay thickness (H), porosity (Φ), oil saturation (So) and formation volume factor (FVF). All of these appropriate inputs have been calculated into the 3D model. The volume was calculated with results 100% higher than what was originally documented.

Development Strategy

Improved reservoir characterization and building the comprehensive 3D static model (Figure 21) helped to accelerate the development strategy of the Middle Burgan Reservoir. The aim of the development strategy is to expedite and maximize dry oil production by determining the "sweet spot" for the short and long term development plan to meet the production targets.

1) Data Acquisition - Static Data

Obtain and continue to obtain enough good data distribution to help in making decisions and minimize the development risks and lowering the uncertainties (Figure 22). The necessary data required to be obtained from upcoming new wells penetrating the reservoir is:

a) Geological:
Cutting new cores in gap areas of the field, core description, Routine and special core analysis.

b) Engineering Data:
RFT, MDT, PBU, PLT, PVT, relative permeability, formation damage.

2) Reserve Growth

Continue drilling vertical/NCW (Non-Conventional Wells) wells and test the reservoir in new areas (Figure 23). This will help in measuring the reservoir potential and understanding the uncertainty parameters contributing to STOOIP calculations. This understanding will lead to increasing recovery and adding reserves.

3) Drilling Activity

a) Vertical and HAW Wells:
The calculated STOOIP and the performance of the first exclusively drilled producing well indicated that MB was a potential reservoir for enhancement of dry oil production. This detailed study helped in proper placement of the well within the „Sweet Spots" with low risks. The new in-fill locations were selected on optimum locations (better reservoir quality, high API gravity, high structure position and high pressure areas).

Drill and plan HAW wells in thin sand layers to increase productivity and improve recovery as the long wellbore allowing longer completed intervals and therefore increased production rates. In addition, the information obtained will justify drilling more NCW wells and allow development with fewer wells. This will help to increase the recovery and avoid the surface constraint due to the other reservoirs wells.

b) Recompletion of CP/abandoned wells:
Continue reviewing the shut-in wells which have no more production potential left in major reservoirs and to be tested in MB; this will maximize the dry oil production and save drilling new MB development wells.

4) Water Flood (Pressure Support)

The Middle Burgan is a depletion reservoir and the limited production history suggests no evidence of pressure support. The interpreted RFT data before production was started from the reservoir indicates pressure decline due to fault juxtaposition of Upper Burgan producers against Middle Burgan sands. In addition, sink pressure areas around the existing producing MB wells indicates reservoir depletion (Figure 24). Water flood implementation will be essential in the absence of aquifer support to fully deplete the reserves and the plan is to accelerate the water flood pressure support. Especially the wells in MB require artificial lift from the beginning and all producing wells are in ESP/PCP.

Conclusions

The reservoir characterization study and 3D geological model built allowed better understanding of the heterogeneity and variability of the geology as well as the hydrocarbon distribution in the Middle Burgan Reservoir of the Sabiriyah Field. The integration of defined core-based rock-types combined with multidisciplinary approaches of geological, geophysical and reservoir engineering techniques allowed reproducing the depositional settings and characterizing the major reservoir heterogeneities. This study resulted in a robust model suitable for reservoir simulation and well planning which led to new drilling and workover opportunities that will now support short and long term development plans and reserves growth for North Kuwait.

Acknowledgments

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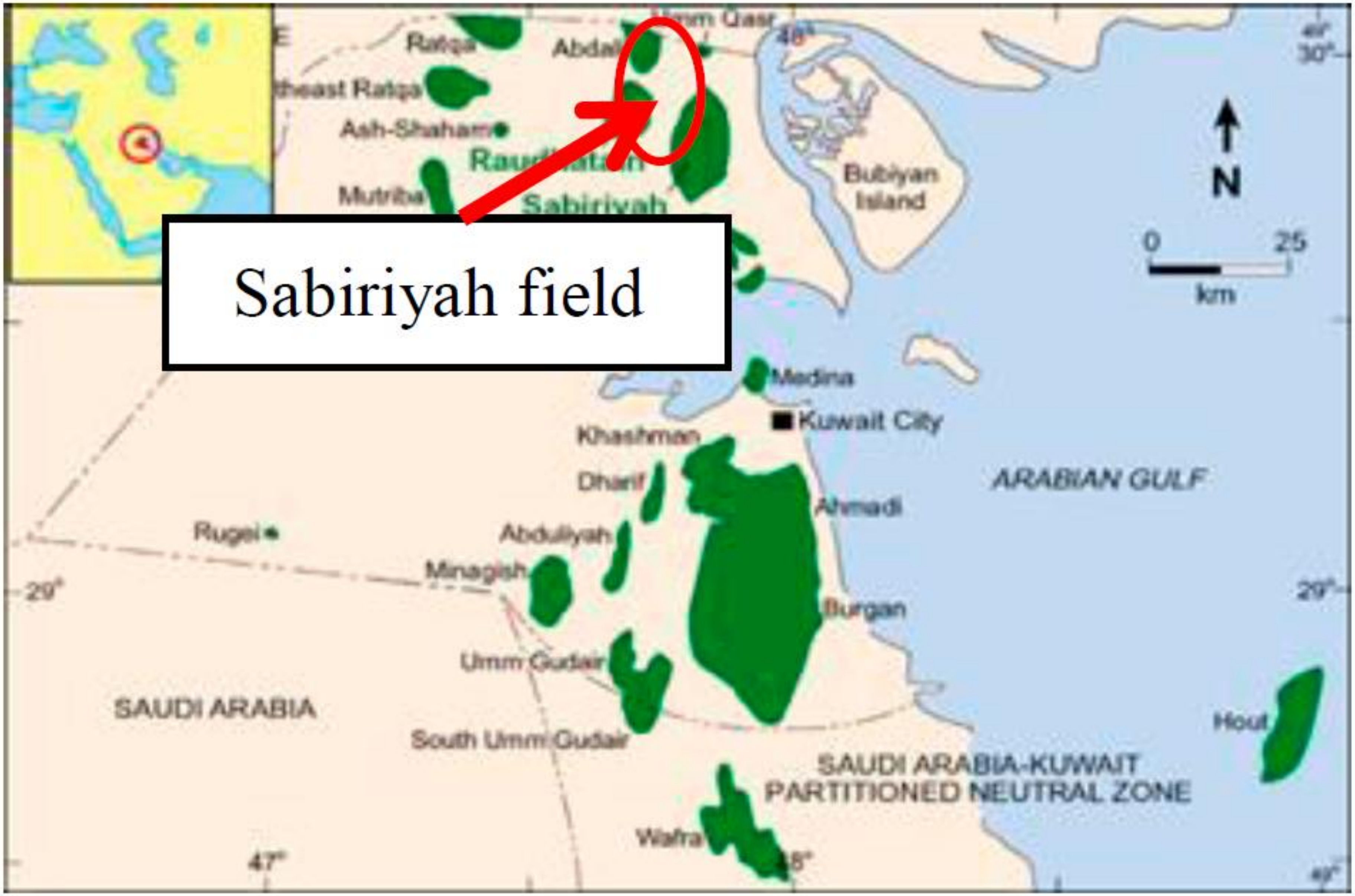


Figure 1. Location map of Sabiriyah Field in Kuwait.

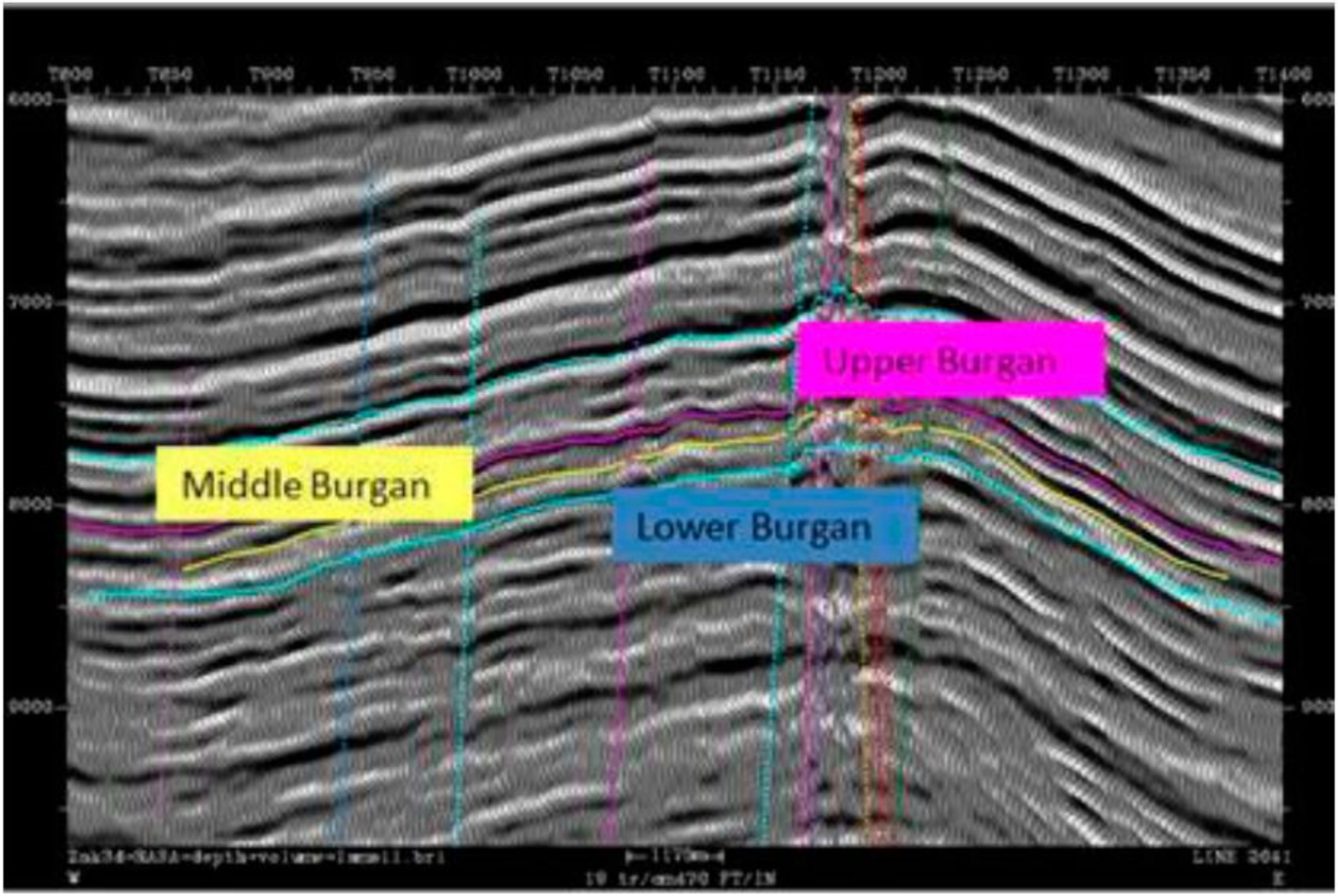


Figure 2. Example seismic section through the Burgan Formation.

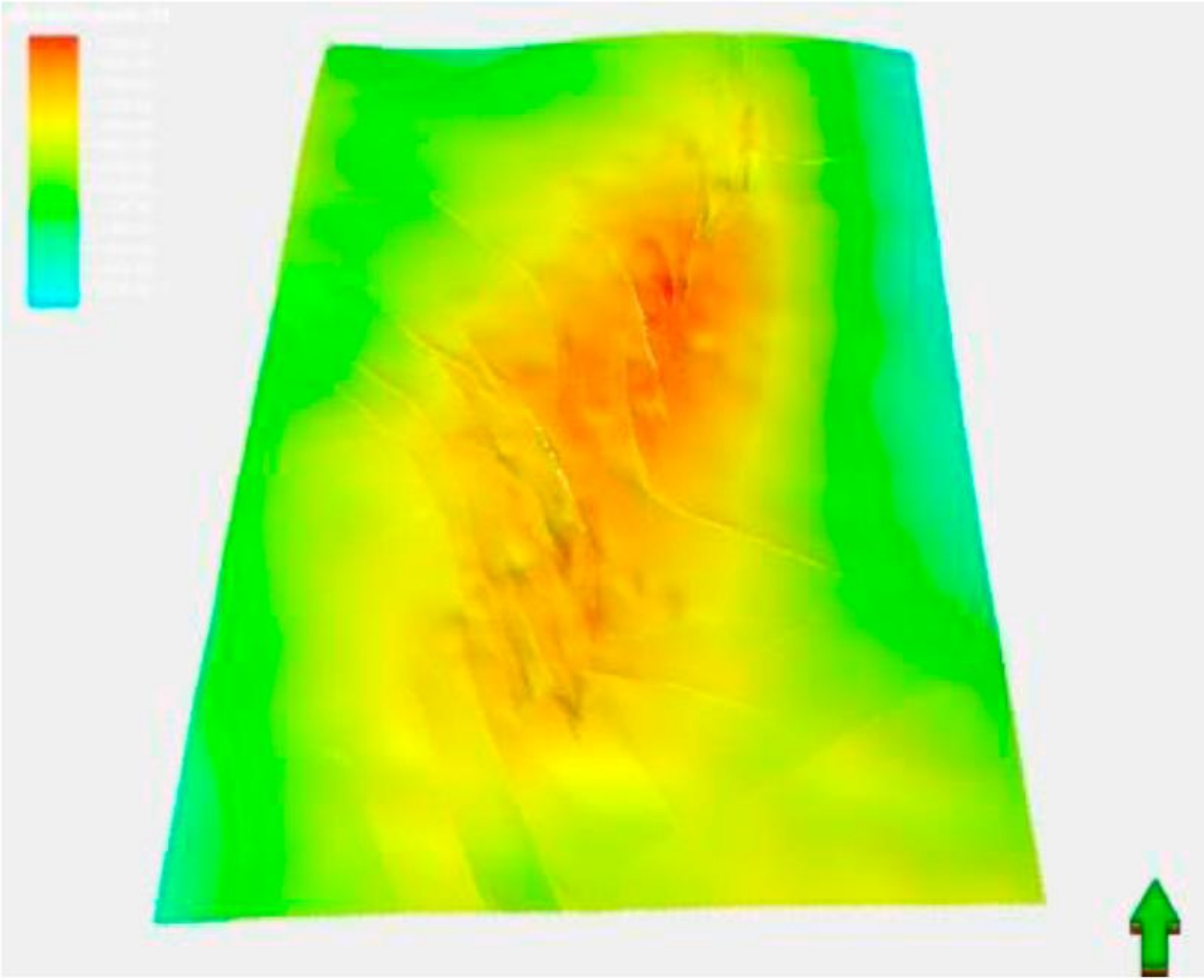


Figure 3. Middle Burgan 1A (MB-1A) structure map.

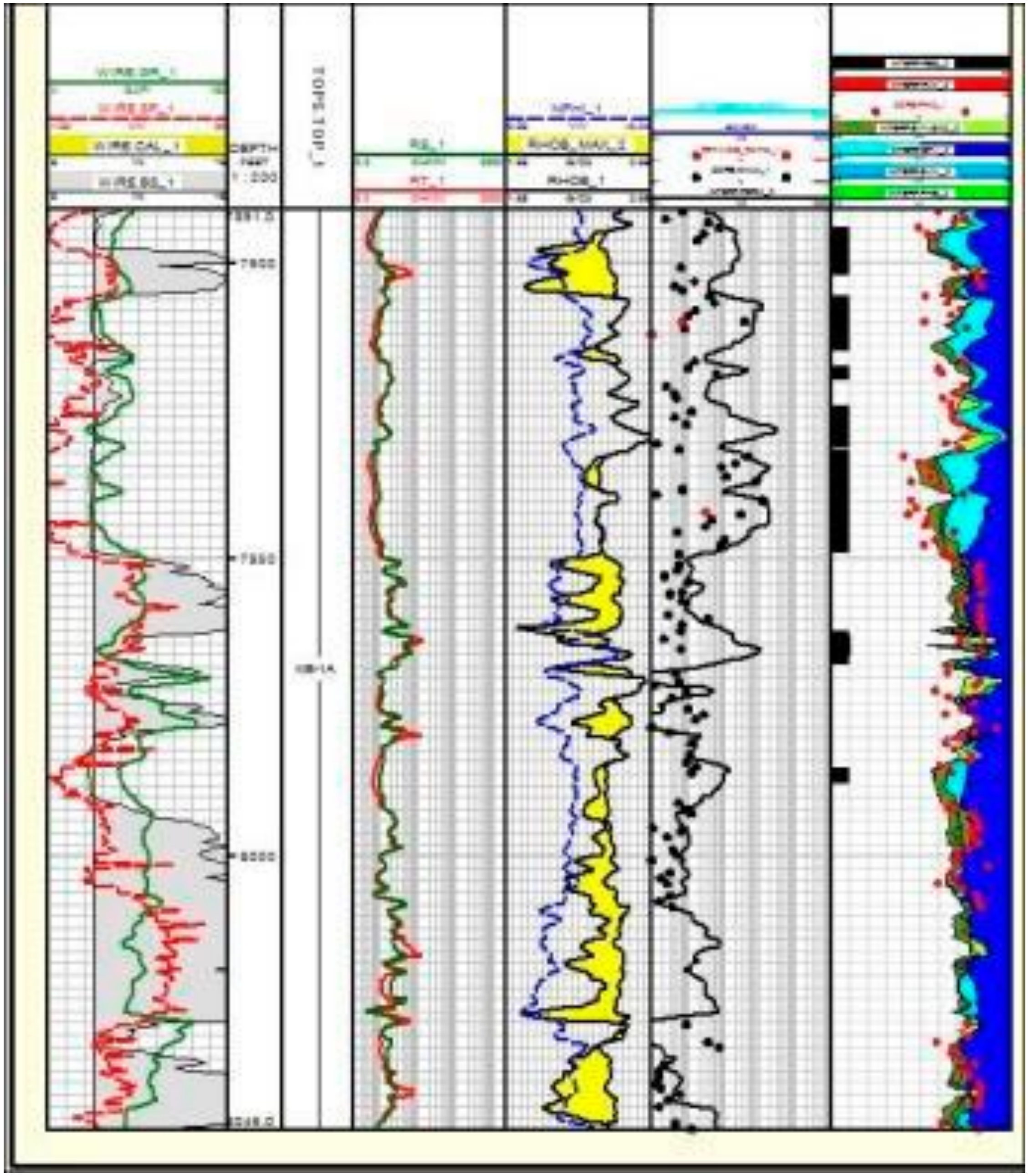


Figure 4. Middle Burgan petrophysical model.

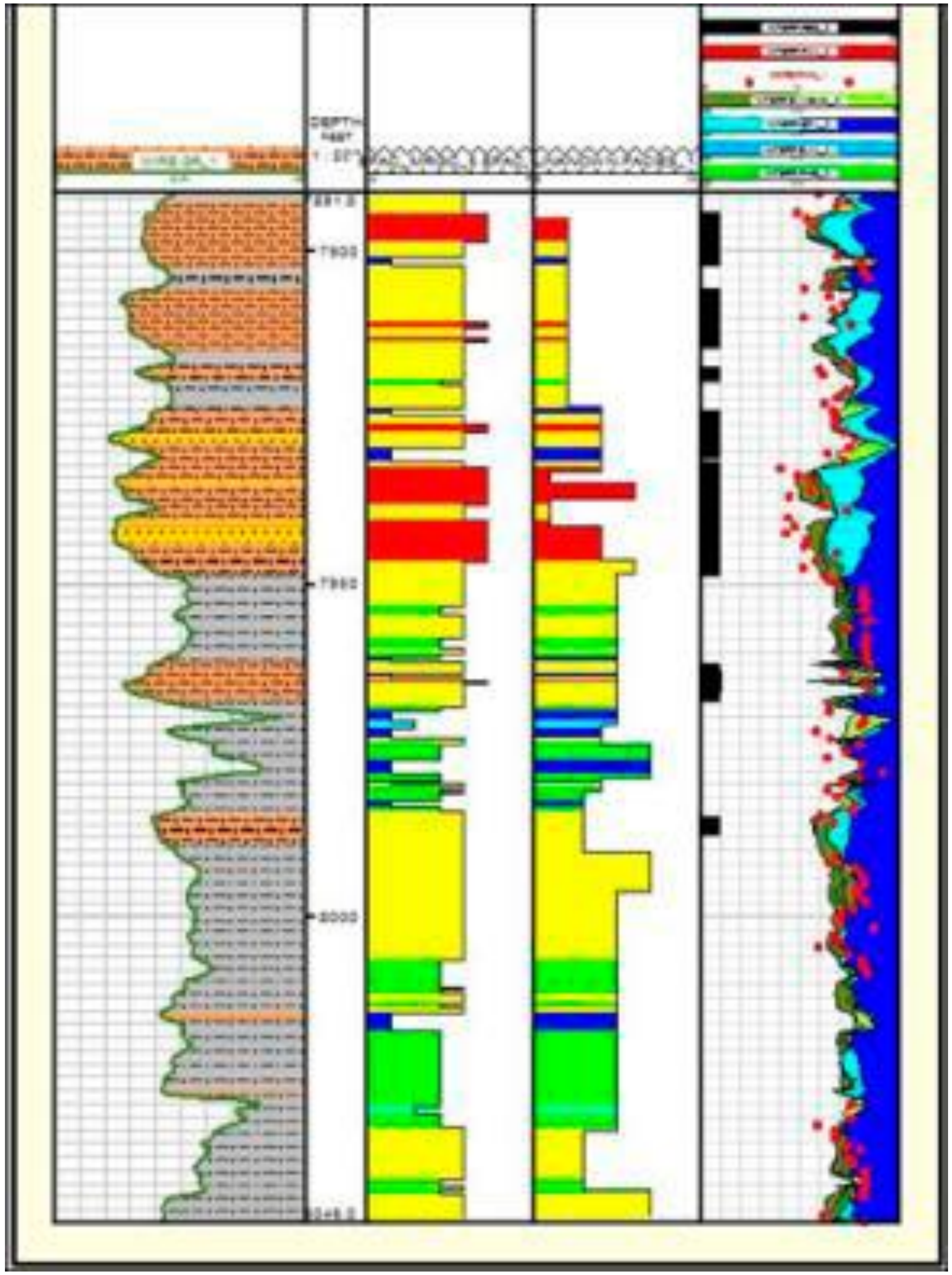


Figure 5. Middle Burgan facies model.

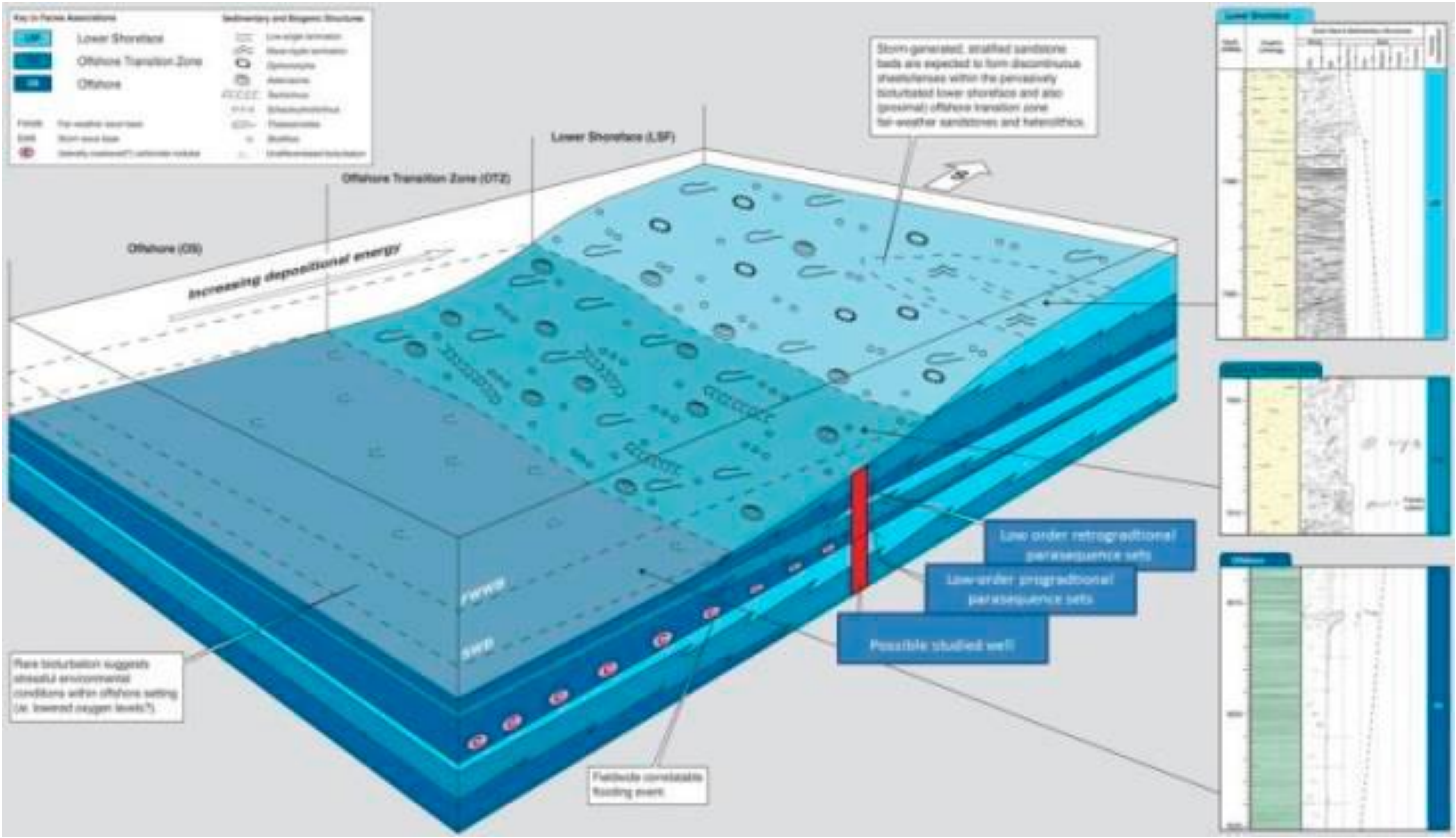
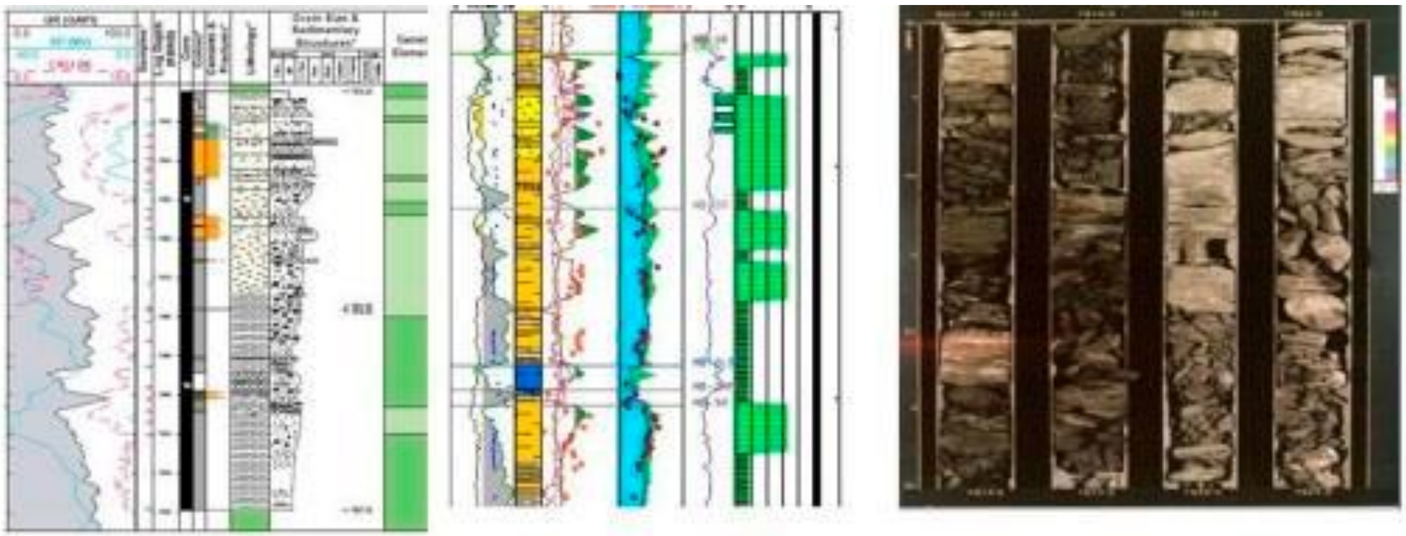


Figure 6. Middle Burgan depositional model.



General Characteristics

•Mud rock-dominated with rare , thinly –bedded siltstone and very fine grained sandstone , typically non calcareous.

•Contain wide Varity of burrows and fully marine bioclasts.

Geometries/ heterogenties

•Can be correlated across the entire field.

•Transmissibility barrier up to 40 feet thick.

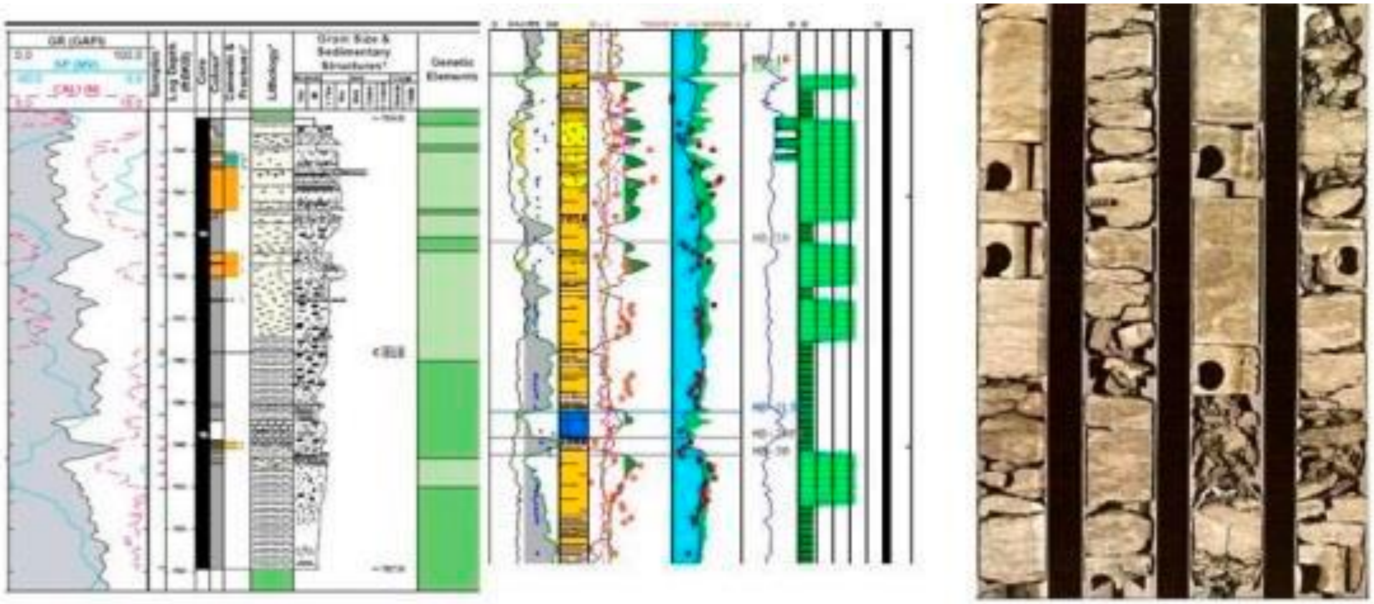
Wire line Log Characteristic

•High gamma ray response

•High and uniform resistivity trends.

•Slow sonic response with rare fast spikes that represented cemented intervals

Figure 7. Offshore facies.



General Characteristics

- Mud prone to bioturbated argillaceous sandstone
- Contain wide varity of burrows and form the middle to upper part of upward cleaning Parasequences underlain by offshore marine mud

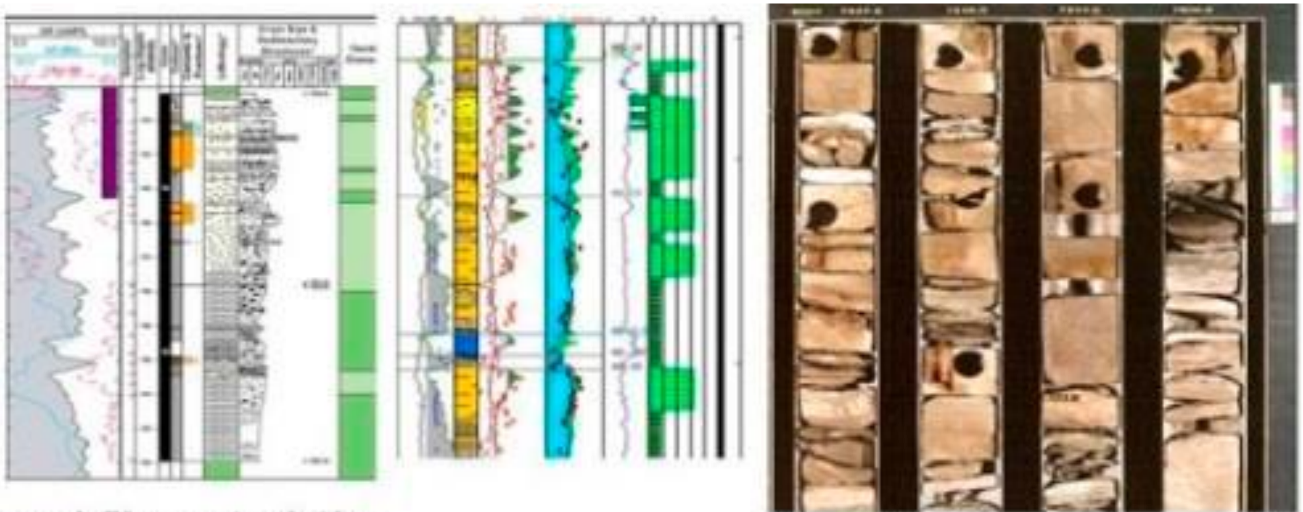
Geometries/heterogenties

- Can be correlated across the entire field.

Wire line Log Characteristic

- Moderate gamma ray response
- Low to moderate resistivity trends with tightly spaced curves

Figure 8. Offshore transition.



General Characteristics

- Coarsening upward , dominated by bioturbated sandstone litho type and wide Varity of burrows type.
- Sandstone are very fine to fine ,rarely medium grained with Laminated sandstone (Sl) are minor, Contain siderite cemented.
- Dominated in upper most part of each reservoir unit.

Geometries/ heterogenties

- Sand stone are less mud prone and increase the argillaceous to basin ward.
- Lateral continuous sandstone which could become target for HAW in-fill drilling
- Thickness rang from 10 to 15 feet and correlated across the entire field.

Wire line Log Characteristics

- Gamma ray display well developed cleaning upward trends which reflect grain size trend.
- Positive neutron log cross-over in sand prone intervals.
- Cemented intervals commonly capping upward-coarsening packages show fast sonic responses

Figure 9. Lower shoreface facies.

FM	Layer	Sub-Layer	Facies
Middle	MB-1A	MB-1A	Distal SF
		MB-1B	Proximal SF
		MB-1C	Distal SF
		MB-1D	Proximal SF
		MB-1E	Marin
	MB-2A	MB-2A	Proximal SF
		MB-2B	Distal SF
		MB-2C	Proximal SF
		MB-2D	Transition
		MB-2LST	Dolomitizatio siltstone
		MB-2MFS	Marin Mud
	MB-3A	MB-3A	Proximal SF
		MB-3B	Distal SF
		MB-3C	Transition
		MB-3D	Marin Mud
	MB-4A	MB-4A	Proximal SF
		MB-4B	Transition
Lower Burgan			

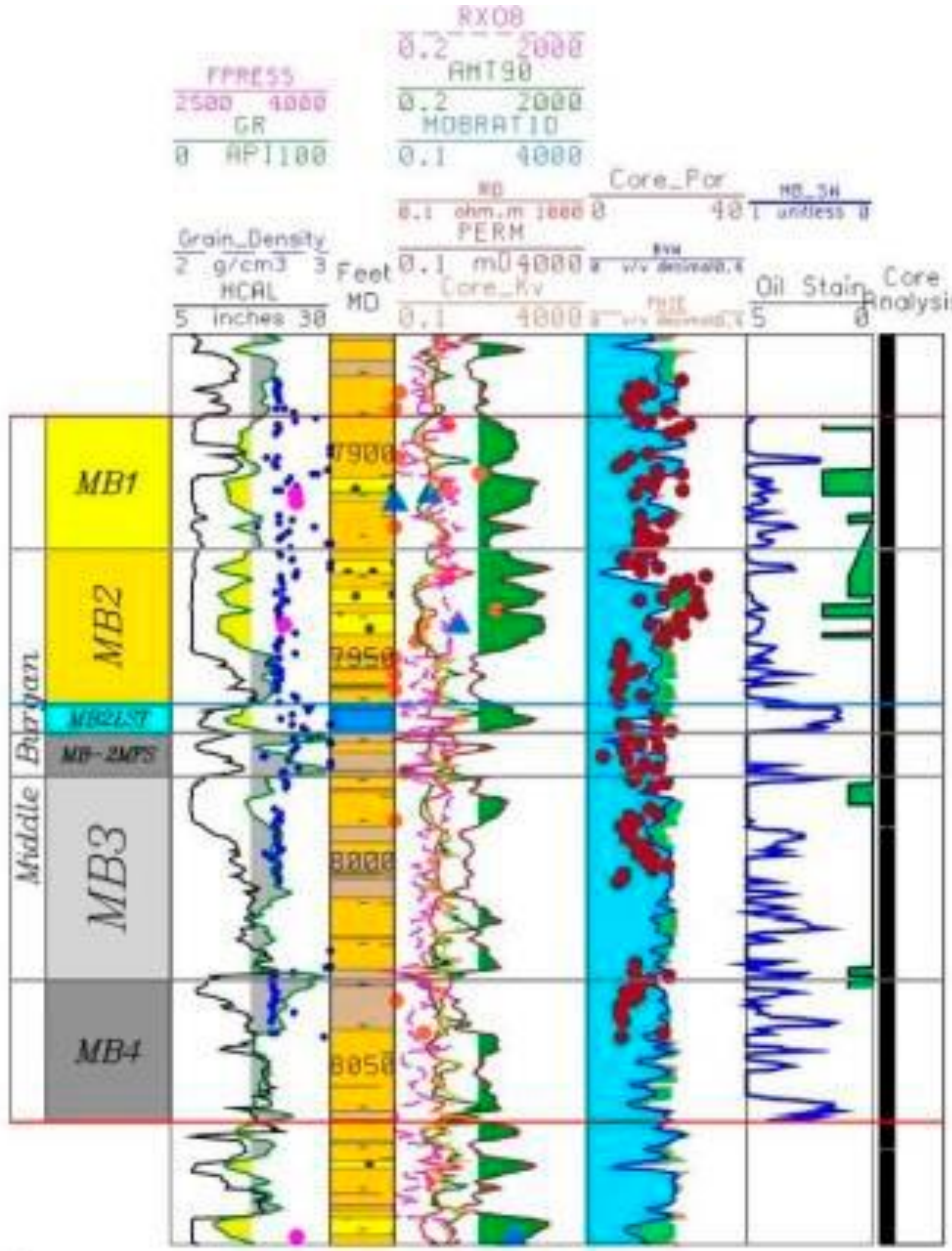


Figure 10. Detailed stratigraphic column.

Figure 11. Stratigraphic characteristics.

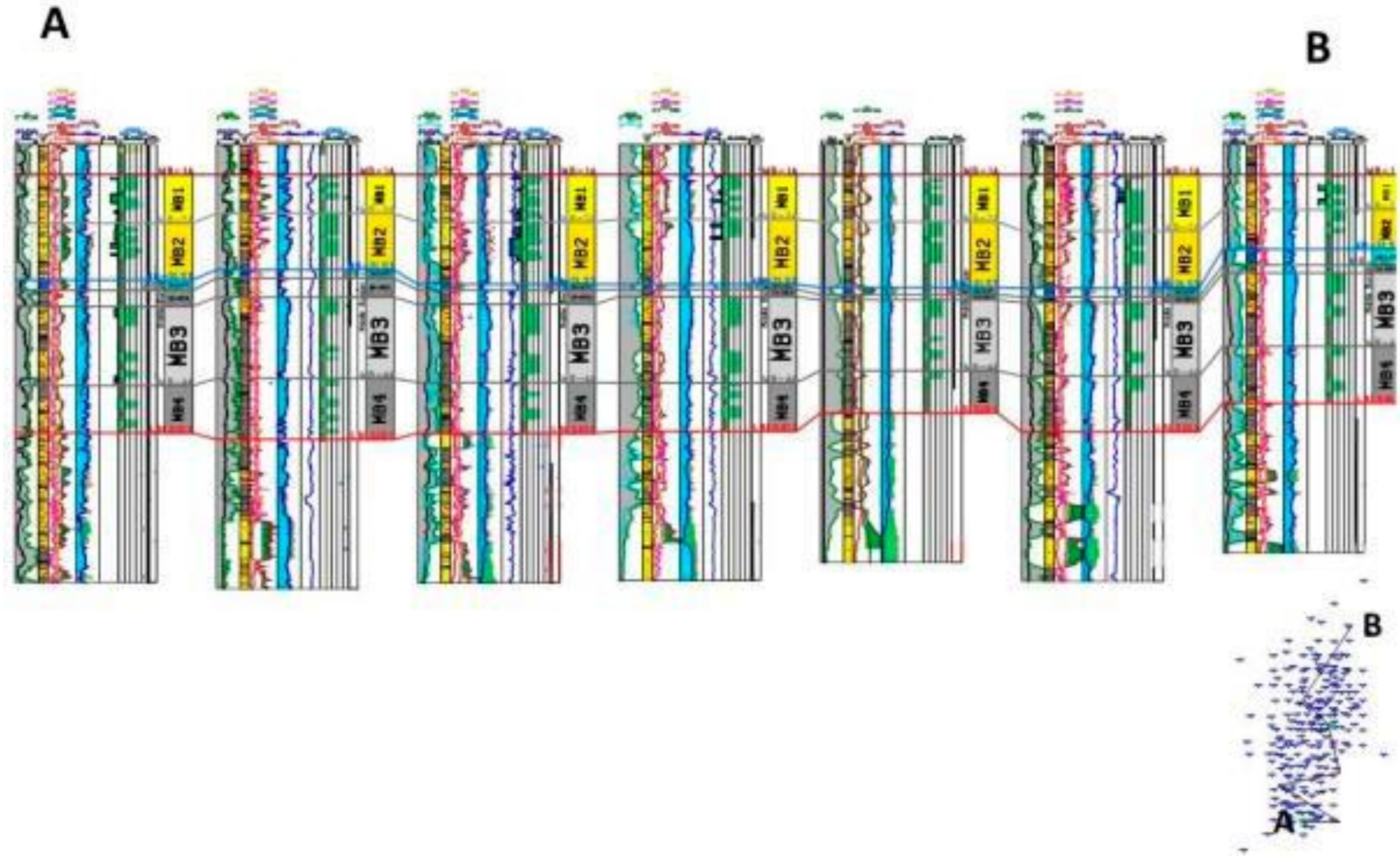


Figure 12. Cored wells cross section.

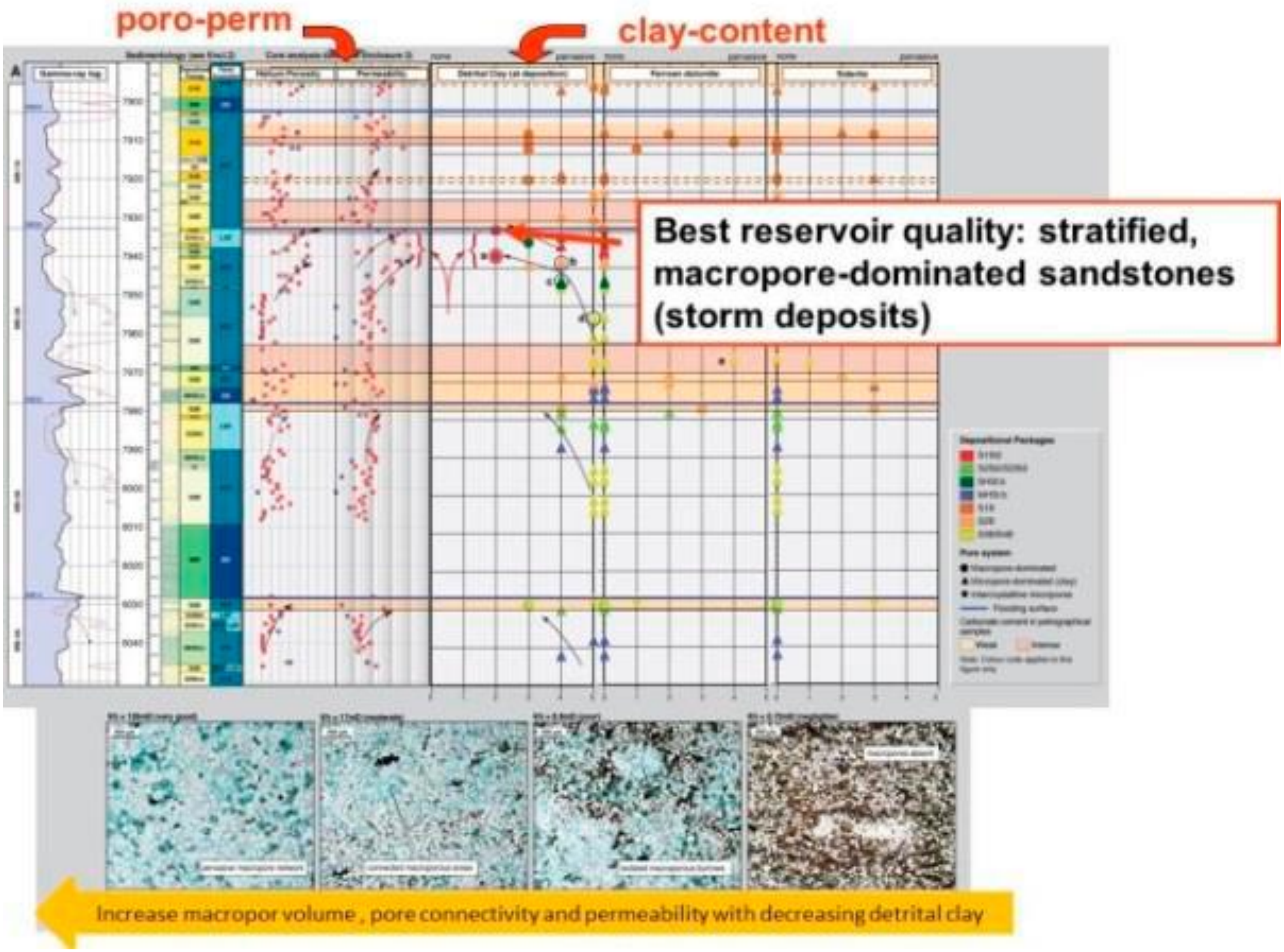


Figure 13. Controls on reservoir quality.

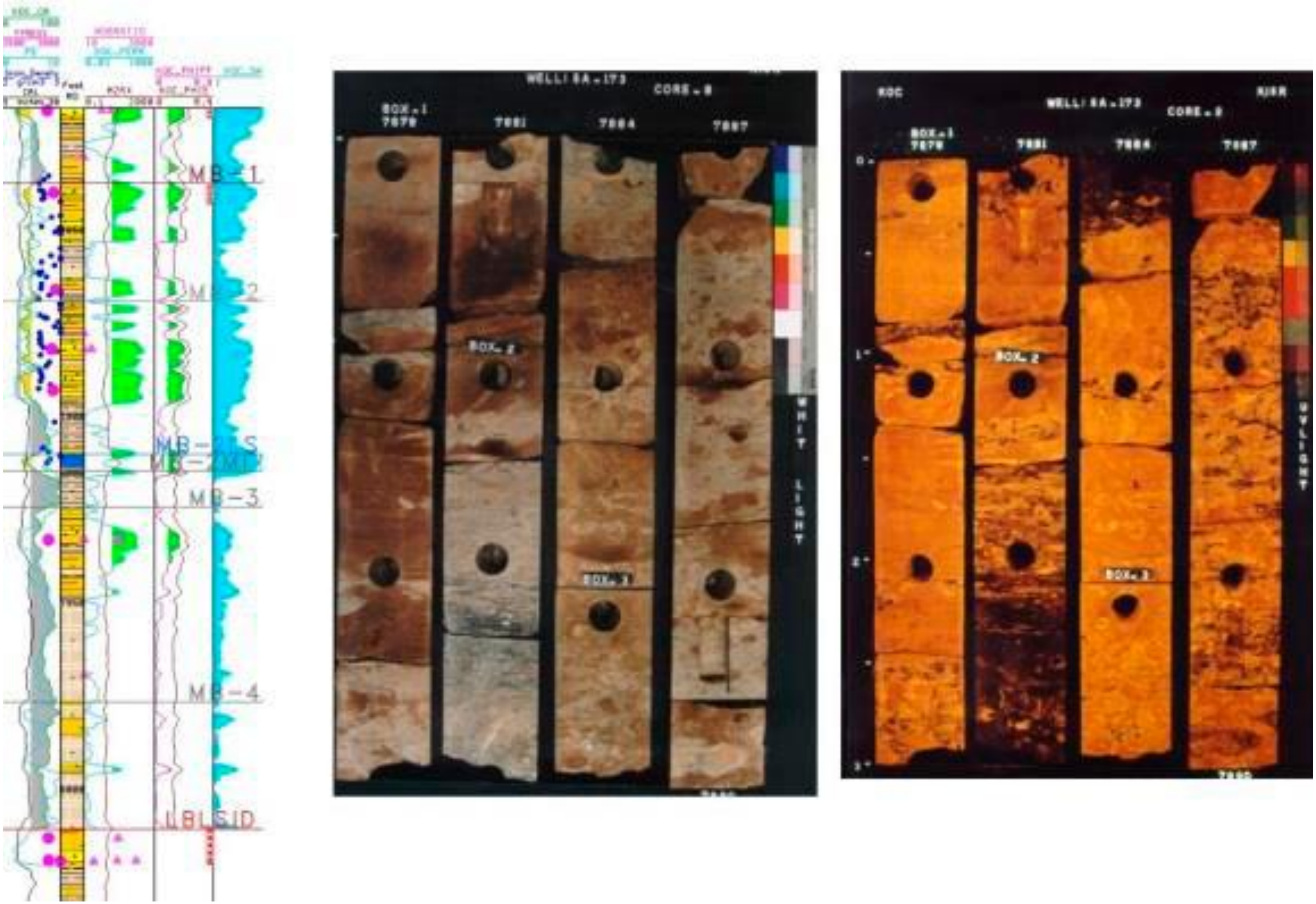


Figure 14. Core/log set showing oil stain with high salt water saturation.

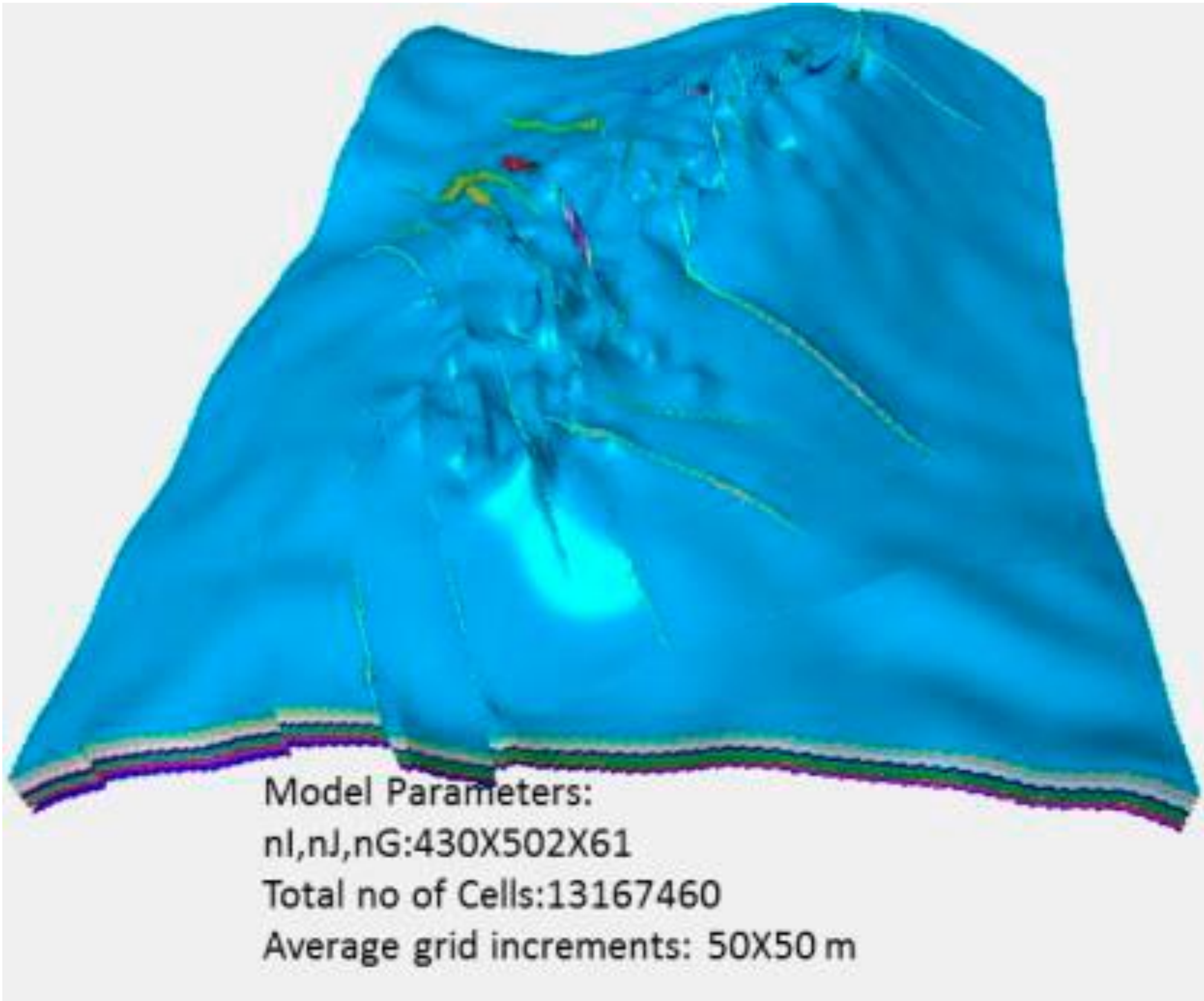


Figure 15. 3D grid identification model.

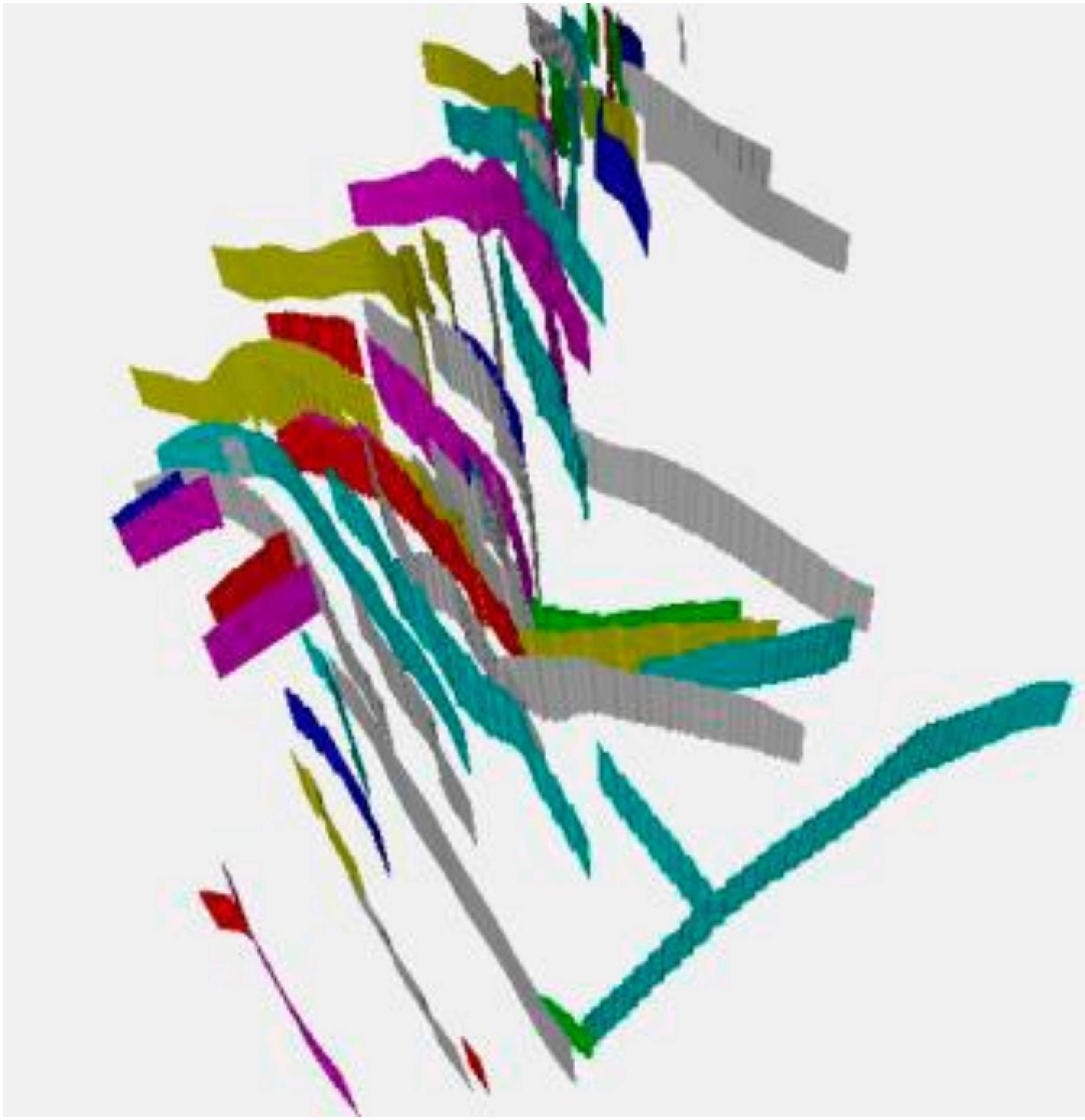


Figure 16. Fault map.

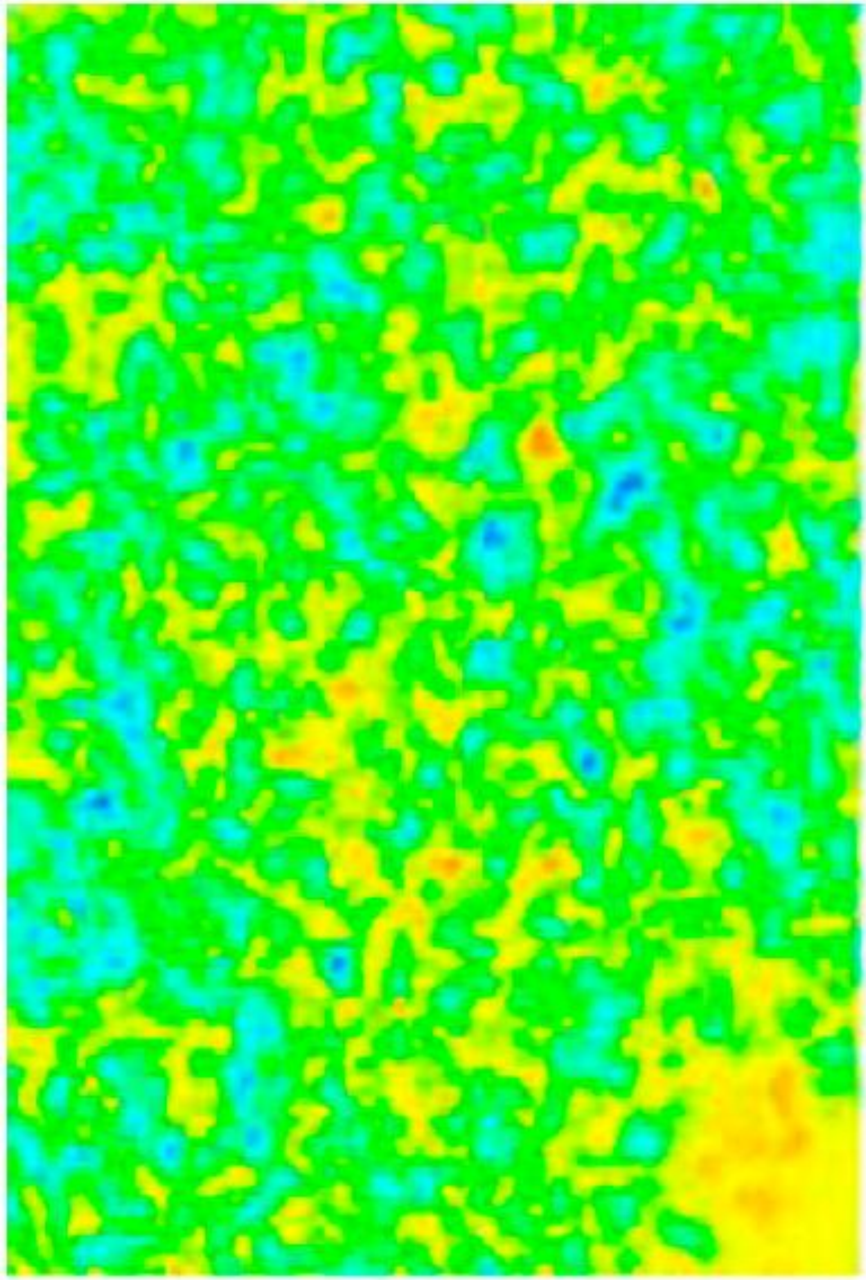


Figure 17. Rock type map.

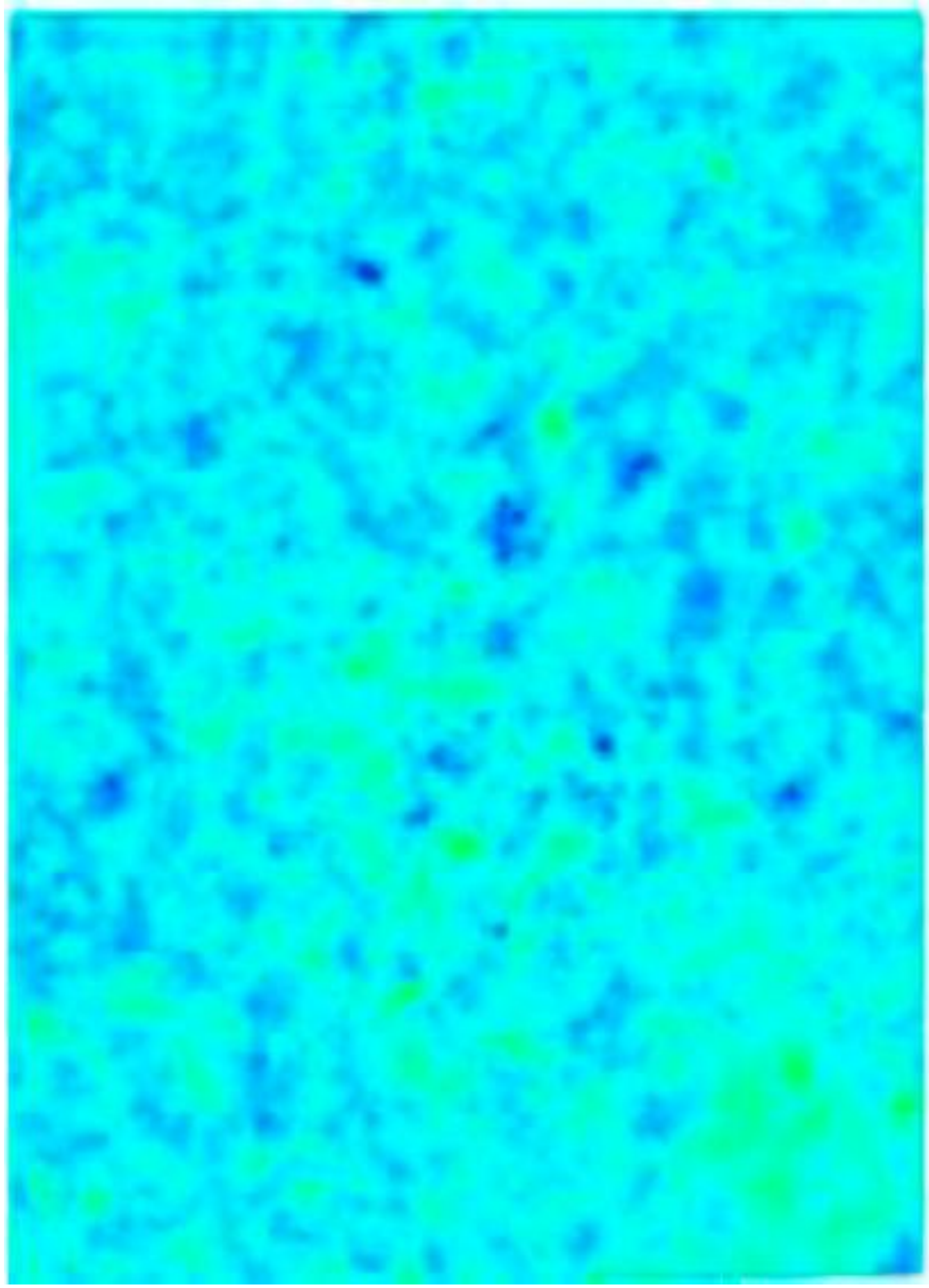


Figure 18. Porosity map.

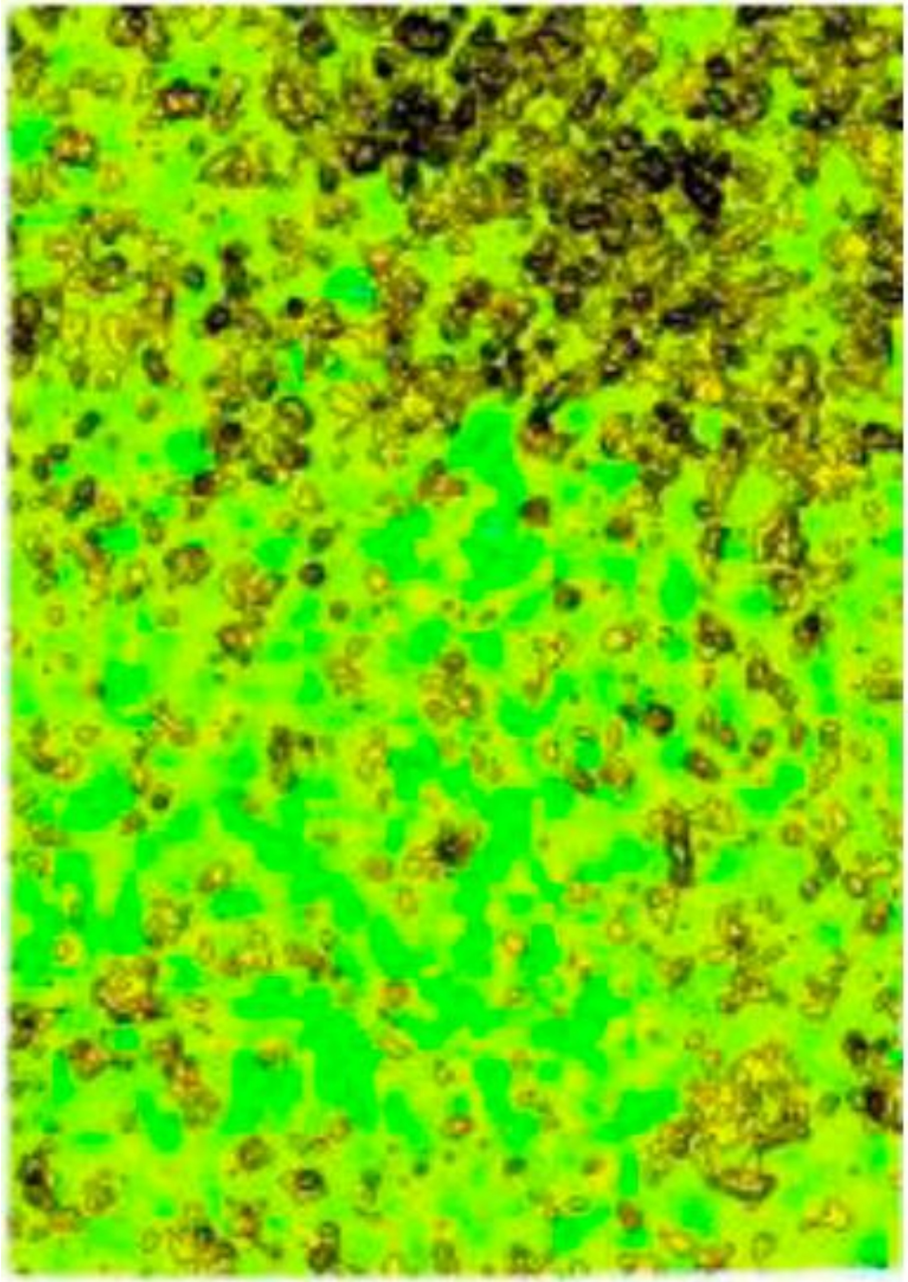


Figure 19. Permeability map.

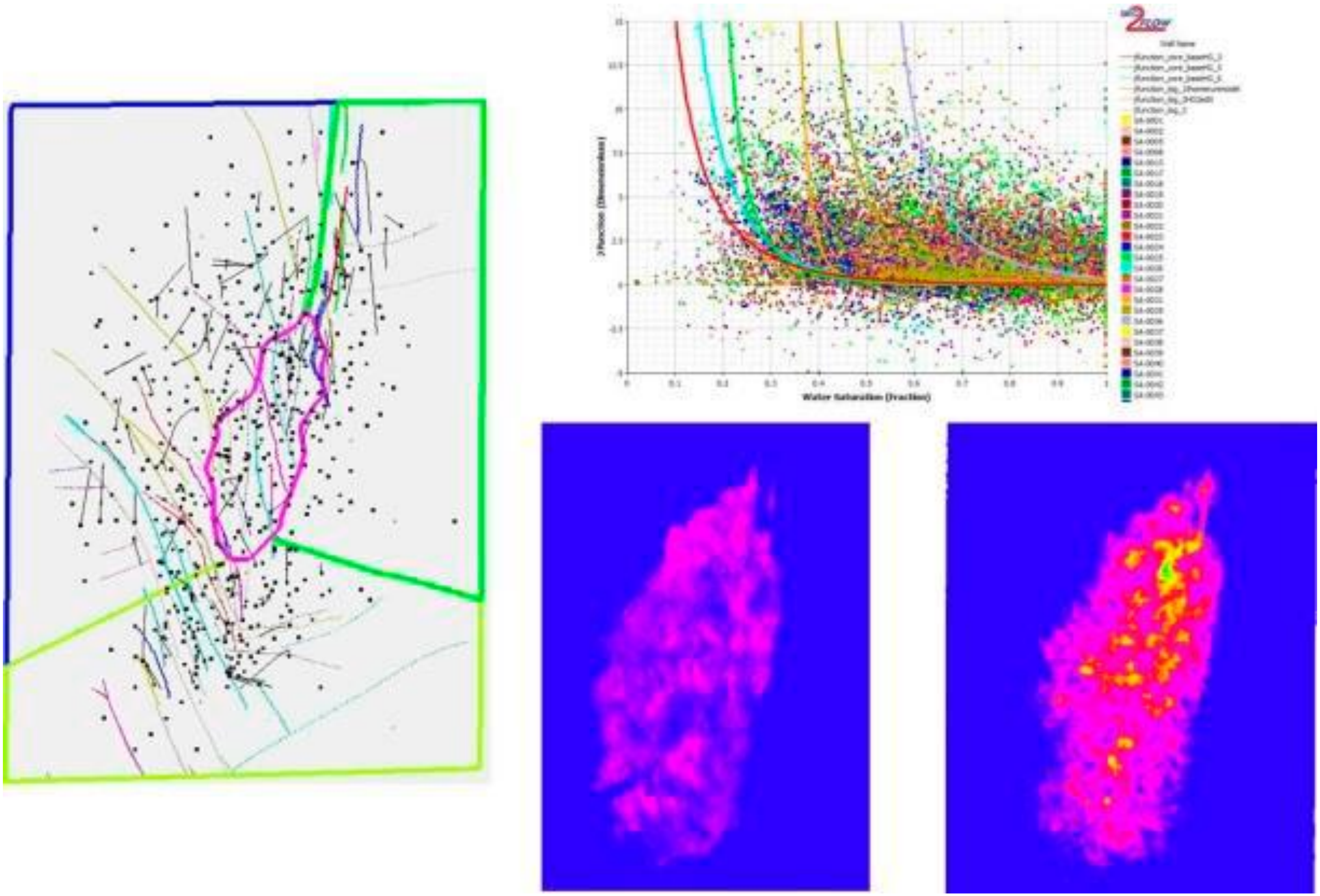


Figure 20. Water saturation field model.

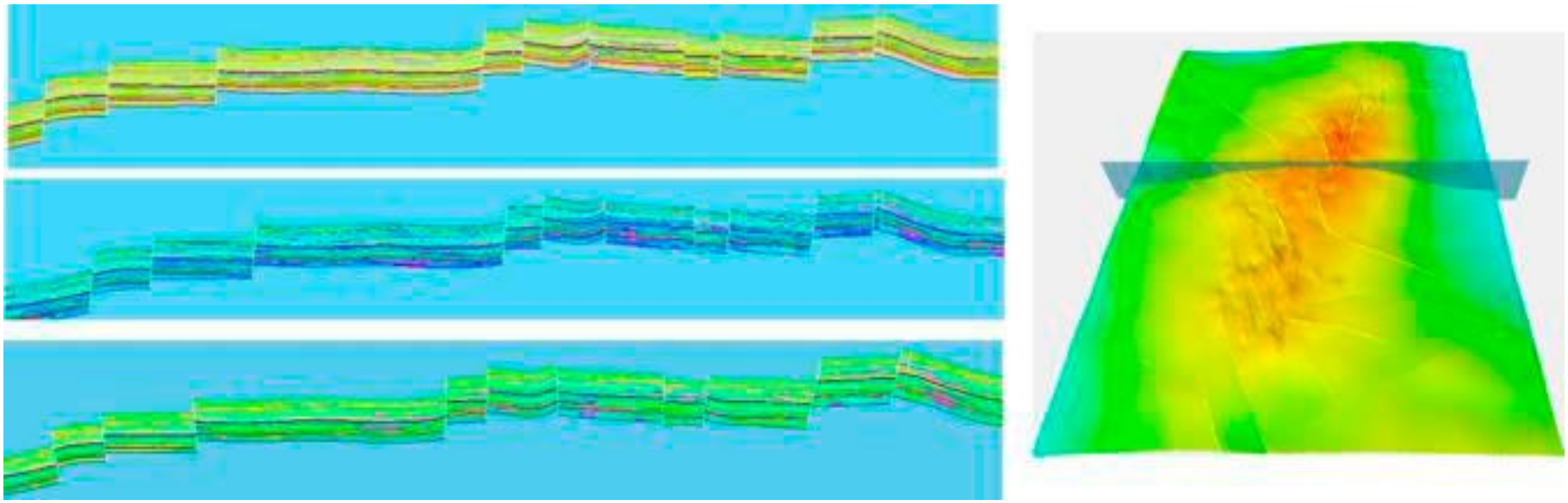


Figure 21.Property distribution map and cross sections.

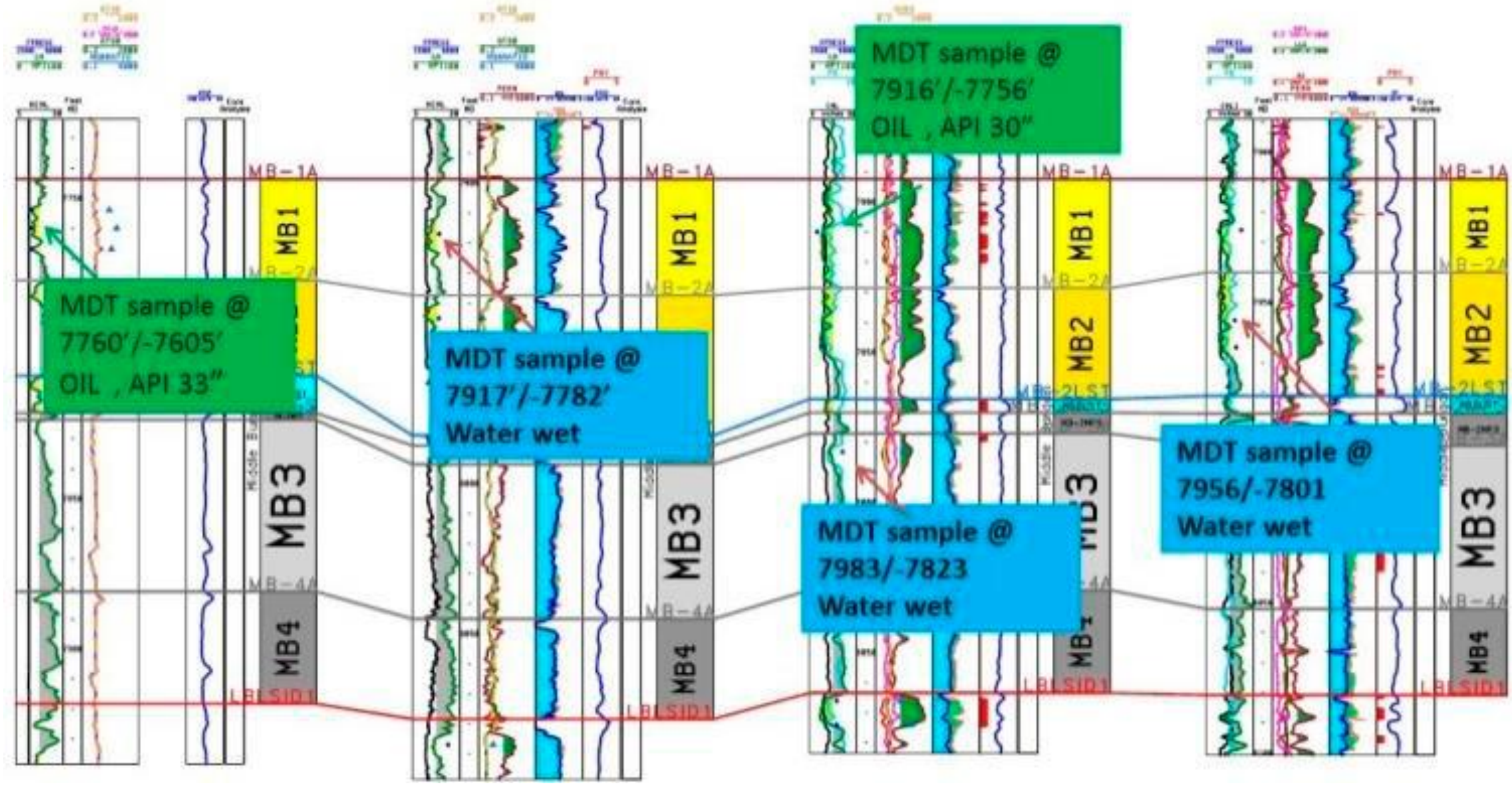


Figure 22. Cross section with MDT log responses.

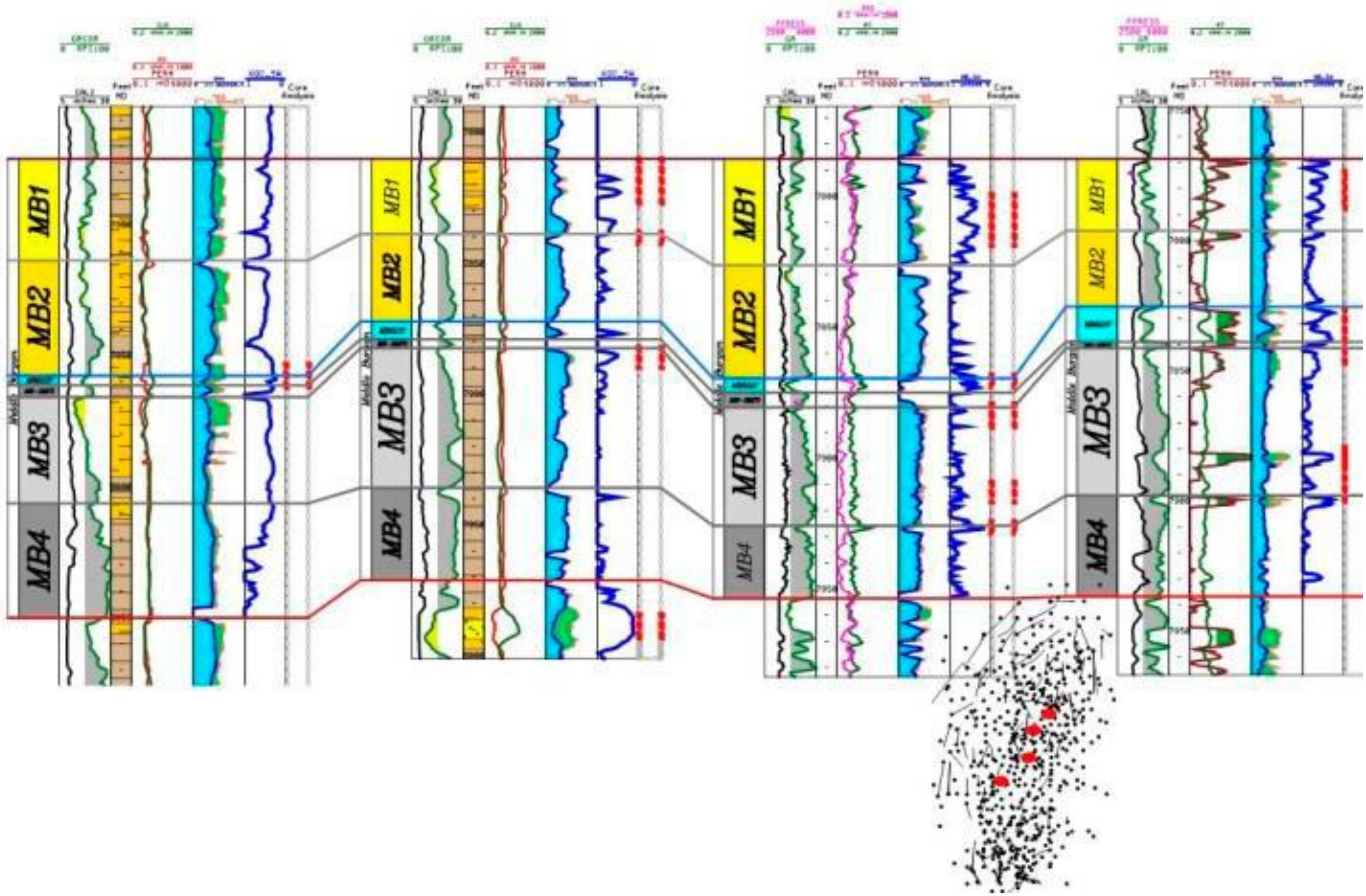


Figure 23. Cross section of Middle Burgan wells tested.

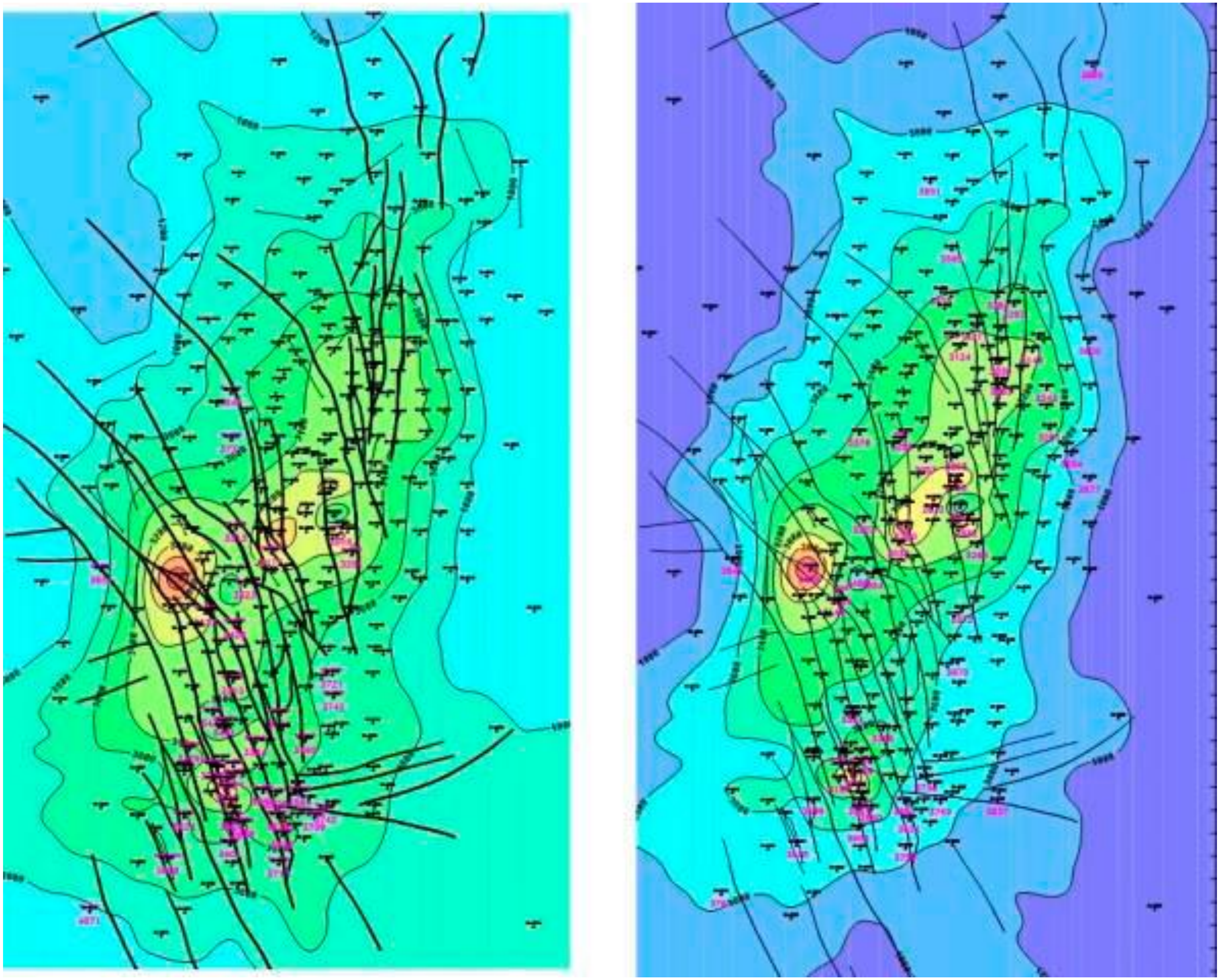


Figure 24. Sabiriyah Field pressure maps.

Datum	Pi	Psat	Bo	µo	Rs	Oil	Gas
[ftSS]	[psi]	[psi]	[v/v]	[cP]	[scf/stb]	API	[v/v air]
7760	3600	2756	1.23 -1.562	0.493	**1009**	24- 33.8	0.762

Table 1. Fluid properties of Sabiriyah Field.