

Integrated Reservoir Characterization and Depositional Model of Zubair Formation in Exploration Phase, in Bahrah Area, Kuwait*

Prabir K. Nath¹, Sunil Singh¹, Afrah Saleh Al-Ajmi¹, Subrata K. Bhukta¹, and Eman Saleh Al-Shehri¹

Search and Discovery Article #51106 (2015)

Posted June 30, 2015

*Adapted from extended abstract prepared in conjunction with oral presentation at AAPG Annual Convention & Exhibition 2015, Denver, Colorado, May 31-June 3, 2015. AAPG © 2015

¹Exploration Group, Kuwait Oil Company, Ahmadi, Kuwait (PNATH@kocwk.com)

Abstract

The Barremian to Early Aptian Zubair Formation in Northern Kuwait constitutes the significant oil reserve in Sabriyah, Raudhatain, Abdali and Ratqa areas. In Bahrah area, which is situated to the south of Sabriyah field, Zubair Formation has not yet been explored in a systematic way. Five deep wells, which were drilled to explore Jurassic section, have shown strong hydrocarbon presence during drilling. The open hole log evaluation (16" hole size) has also substantiated the hydrocarbon presence from Zubair section. The challenge of this work has been the evaluation of hydrocarbon potential based on robust depositional model to characterize and to define the geometry of Zubair reservoir.

Integrated core and petrographic analysis indicates the Zubair Formation was deposited under tidal influenced deltaic settings that episodically displayed an estuarine character. This indicates that the architecture and reservoir quality of Zubair reservoir sand bodies are representing the deltaic, estuarine channel fill, mouth bar and sandsheet facies association. The gross sequence stratigraphy of the Zubair Formation in Bahrah can be described in terms of low frequency sequence sets, which contain superimposed higher frequency system tracts. The lower Zubair TST is characterized by back stepping or retro-gradational character suggesting limited lateral extension of sand bodies. The middle Zubair HST shows isolated and stacked channel with very good reservoir potential. The upper Zubair LST is bounded by the sequence boundary at the base and flooding surface at the top that mark the distinct change of depositional style. These channel sand bodies show NW-SE orientation with widespread lateral extent with very good to excellent reservoir quality. Horizon based geo-body extraction of RMS amplitude from PSDM seismic data established the geometry of delta, channel fill and sandsheet facies association. A band pass inversion of seismic guided integrated reservoir model shows very good to excellent reservoir quality with wide spatial distribution of upper Zubair LST sand and comparatively fair to good reservoir quality with limited extent in Lower Zubair TST sand.

Integration of above information, analog of nearby producing fields and seismic attributes indicates Zubair Formation has a significant untapped oil production potential in Bahrah. This work will be highly beneficial for efficient selection of locations to prove hydrocarbon potential of Zubair Formation in Bahrah area.

Introduction

Prospect evaluation of Bahrah field will take us more than 75 years back, when the first exploratory well was drilled in Bahrah area in Kuwait. In 1933, APOC and Gulf Oil worked together and registered a joint venture, the Kuwait Oil Company, in London, and offered a new deal to the Emir of Kuwait. A team of geologists started working in Kuwait in the summer of 1935. They recommended drilling at Bahrah; but a 2,423m well into the Cretaceous sediments drilled during 1936-37 yielded minor oil shows only. Meanwhile, gravity, magnetic and seismic surveys were conducted in the Burgan area, and on October 16, 1936, Burgan No. 1 was spudded at a seepage. The reservoir was the Middle-Cretaceous Wara Sandstone from which 32° API gravity oil flew at the rate of over 4,000 bopd before the well was controlled with great difficulty and was completed on May 14 at a depth of 1,126m (only 6m into the pay zone because of logistic constraints). After that, no significant exploration plan was made to explore Lower Cretaceous section in Bahrah area (Figure 1). Among the drilled wells, only five wells penetrated through total Lower Cretaceous section. These wells were drilled for Jurassic target, wire line log quality is fair to poor due to hostile well condition and no testing was carried out against the Lower Cretaceous section.

Incorporating available mud log information, wire line logs, analog of nearby producing fields, Raudhatain and Sabiriyah, available 2D and 3D seismic and general geological understanding, a robust exploration study was carried out leading to a farm footing for exploration of Lower Cretaceous in Bahrah area.

The Zubair Formation of Hauterivian to Barremian age of Lower Cretaceous age has been a prolific oil producer in Ratqa, Abdali, Raudhatain and Sabiriyah fields in North Kuwait and adjoining south Iraq areas. The Zubair Formation is overlain by Shuaiba and underlain by Ratawi Formations. It predominantly consists of Clastic sandstone inter-bedded with shale. There are minor amount of limestone present towards the base of the formation in some places. The average thickness of the Formation varies from 1400 to 1500 ft in the area. Based on lithostratigraphy, Zubair Formation was divided into Lower, Middle and Upper Zubair Units (Figure 2).

Facies and Internal Geometry

The regional geological correlation and litho-facies analysis indicate that Zubair Formation was deposited on a fluvial to coastal plain environment with more marine (deeper) influence further eastward. Details of depositional environment from core and log analysis data from nearby producing fields are given below which were used in the present area of study, Bahrah Field (Figure 3). The channel dominated delta/estuary GDE dominantly comprises channel fill and flood plain/abandonment facies association. Their geometry, dimension, heterogeneities and reservoir quality are discussed below and given in the (Figure 4) with comparable cartoon of Raudhatain field and modeled one of Bahrah field.

Channel-fill facies. The majority of the sand bodies of this facies association are considered to display concave-up channel type geometries. Individual channel fills are typically several feet thick (3 to 12 feet). More importantly, these channels commonly stack to form amalgamated multilateral and multi-storied sand bodies that appear to range in width from at least several hundreds to a few thousand meters with thickness in the order of several tens of feet. Even larger dimensions are associated with amalgamated estuarine channels in Middle Zubair.

The channel fill sand bodies are largely dominated by clean rock type covered by argillaceous content (shale) and show the best reservoir qualities within the succession. Locally they contain argillaceous laminas, which are likely to restrict the vertical connectivity within sand bodies. Flood Plain / Abandonment facies association- This mud prone deposit represent localized “in-channel features” in which they are expected to have a channel like geometry. They also form more laterally extensive out-of-channel floodplain deposits with sheet-like geometries extending around hundred meters. Both channel abandonment and floodplain are prone to scour by channel sand bodies and hence their preservation is partial. These are rich in detrital clay and are considered non-to-negligible reservoir. However, they form baffles within commonly multi-storied/multilateral sandy channel-fill successions and they have the potential to significantly reduce the vertical connectivity (top of Middle Zubair, ZU04).

Sequence Stratigraphy and Implication on Reservoir Modeling

A sequence stratigraphic understanding of the Zubair Formation was described in terms of four low frequency sequence steps, which contain superimposed higher frequency systems tracts ([Figure 5](#)).

Transgressive System Tract (TST). A clear sequence boundary separates the Basinal mudstone of Ratawi Formation from the overlying deltaic influenced Lower Zubair formation. The presence of calcareousness within the layer suggests a phase of reduced clastic influx and raises the possibility of more distal marine setting. The presence of key flooding surface at the top of TST is considered as a low order maximum flooding surface. Each layer within this lower part of Zubair is characterized by wide spread mud prone delta top facies. They seem to vertically separate relatively high quality multi-storied /multilateral deltaic channel sand bodies resulting in compartmentalized reservoir architecture. The back stepping reservoir character suggests that these sand bodies are less extensive laterally. Lower portion of Zubair Formation is the product of open marine shore face to offshore deposits and common occurrence of mouth bar sand bodies, which locally stacked and amalgamated. These associations may be due to tidal influences and could be function of episodic sediment supply. Upper Zubair sands have been subjected to intense deltaic influence. Gross depositional environment of Zubair Formation is given in [Figure 6](#).

Highstand Systems Tract (HST). This section is bounded by MFS at the base and a sequence boundary at the top defining a low order highstand system tract. The base of this stratigraphic section is characterized by mud-prone open marine deposits while remaining part mainly comprises a mixture of sand and mud-prone delta-top and channelized sand bodies. Several distinct multilateral/multistoried channel successions may locally be connected vertically because of incision and subsequent removal of interbedded mud-prone deposits. The non-reservoir muddy open marine deposits at the base form a field-wide seal. The remaining portion of the Middle Zubair interval is highly heterogeneous but commonly contains laterally extensive mud-prone deltaic deposits, particularly at the base of ZU-03 and ZU-04 that have the potential to act as baffles. These are characterized by isolated and thicker multi-storied sand bodies, which show excellent reservoir potential with some permeability variations due to change in grain sizes. The major control with respect to the emplacement of these multi-storied channel sand bodies (allocyclic) has implications not only for their precise depositional origin but also for reservoir modeling. In more detail, the acceptance of an allocyclic model (above ZU-02 sand bodies) indicate these incised estuarine channel sand bodies are laterally restricted with overlying flooding surface.

Lowstand Systems Tract (LST). This stratigraphic section considered the thickest reservoir, is bounded at the base by a sequence boundary and at the top by a flooding surface that marks a distinct change in depositional style of the Zubair Formation. The entire succession is characterized by stacked multilateral/multi-storied estuarine channel sand bodies and interbedded mud-prone abandonment deposits. These abandonment deposits, which may show some poorly, constrained marine character, probably formed in response to flooding events defining the reservoir zonation within this interval and three high frequency TSTs could be marked.

- Reservoir quality within channel fill is generally very good to excellent and seems to be mostly controlled by grain size.
- In channel origin for the majority of the interbedded mud-prone abandonment, deposits and their relatively poor preservation potential within this sandstone dominated layers; these represent typically localized extent of baffles.
- Because of base level /sea level rise towards the top, the degree of heterogeneity is expected to increase.
- This is evidenced by the amalgamated channel sand bodies at the top in ZU-06 that are widespread and thinner compared to the underlying layers. However, they may be connected through typically more argillaceous/poorer reservoir quality non-channelized deposits.

Transgressive Systems Tract (TST). This is bounded at the base by flooding surface and is expected to contain a maximum flooding surface at the top, forming the Shuaiba Formation. The interpretation is based on overall facies stacking patterns and general upward change from sand to mud prone deltaic deposits (inter distributary bays/lagoons) interbedded with minor distributary sand bodies. The emplacements of two/three possible deltaic channel sand bodies are incised into underlying open marine mud-prone facies imply that repeated higher frequency base level falls occur in this section. The best reservoir qualities in this stratigraphic level are commonly associated with the deltaic channel-fills that most commonly form isolated, single-storey distributive networks. Mud prone delta top/front deposits occur at the base, are laterally extensive, and may form a significant baffle, which is supported by pressure data from nearby Raudhatain field. Reservoir potential within the marine dominated section at the top of Zubair is considered limited and mainly restricted to the more sand-prone shore face parasequences.

Gross Depositional Environment

Gross Depositional Environment has been introduced in Bahrah area from sedimentological studies of Raudhatain field by Badley-Ashton, 2010 based on log correlation of similar log motif (Figure 6). The facies associations of these studies were modified and grouped into four GDE facies based on their gross depositional make-up and variation in sand content. To establish the geometry and sediments influx direction, isopach, seismic geobodies and RMS amplitude of horizon slices were created and validated the deltaic depositional environment. Semi-regional scale isopach maps indicate the flow direction is from North and NNW direction (Figure 7). PSDM seismic data was used for geobody extraction and RMS amplitude extraction along the Horizons. Strong amplitude burst were calibrated with the major change of lithology from shale to sand using GR, NPHI, Density, resistivity and sonic logs (Figure 8).

For geobody extractions of 100*100*50, cell size was used and repeated iteration and state of the art technology judicially applied to get the pragmatic scenario of deltaic depositional environment (Figure 9). RMS amplitude extractions were made along the horizons with 25 feet window below the respective horizons (Figure 10). A relative P-impedance log is generated using a bandpass (8-65Hz) filter that shows a good

match between the log and inverted section ([Figure 11](#)) with the negative side of the bandpass P-impedance log. The bandpass data is analyzed in each slice for visualizing the facies distribution, using proper cutoff in both log and inverted data, to capture the sand bodies. Stratal slice is analyzed to establish the Upper Zubair sand distribution ([Figure 12](#)); the depositional pattern indicates that it was a product of stacking channel in a deltaic environment.

Reservoir Properties

The properties of Zubair reservoir are controlled substantially by depositional environment. Both porosity and permeability have wide range (15-30% and 200 to 3000 mD). In Bahrah area, porosity is about 10-30 % (from log data). The matrix pore network is often best developed in channel fill facies and permeability goes up to 3000mD ([Figure 13](#)).

Conclusion

Integrated analysis of analog of sedimentological studies, log motif, geo-body, average positive amplitude of seismic PSDM and bandpass inversion could build a robust depositional environment for Zubair Formation in Bahrah area. Zubair sands were deposited in a tidally influenced deltaic environment and are characterized by mouth bar, sand flat/sandsheet reservoir and deltaic channel sandbodies that can be targets in mud prone Lower and Middle Zubair. The multi-stacked channel sand of Upper Zubair are thick, regionally widespread and extend beyond the area of study, have excellent reservoir quality and the possibility of good storage and producibility.

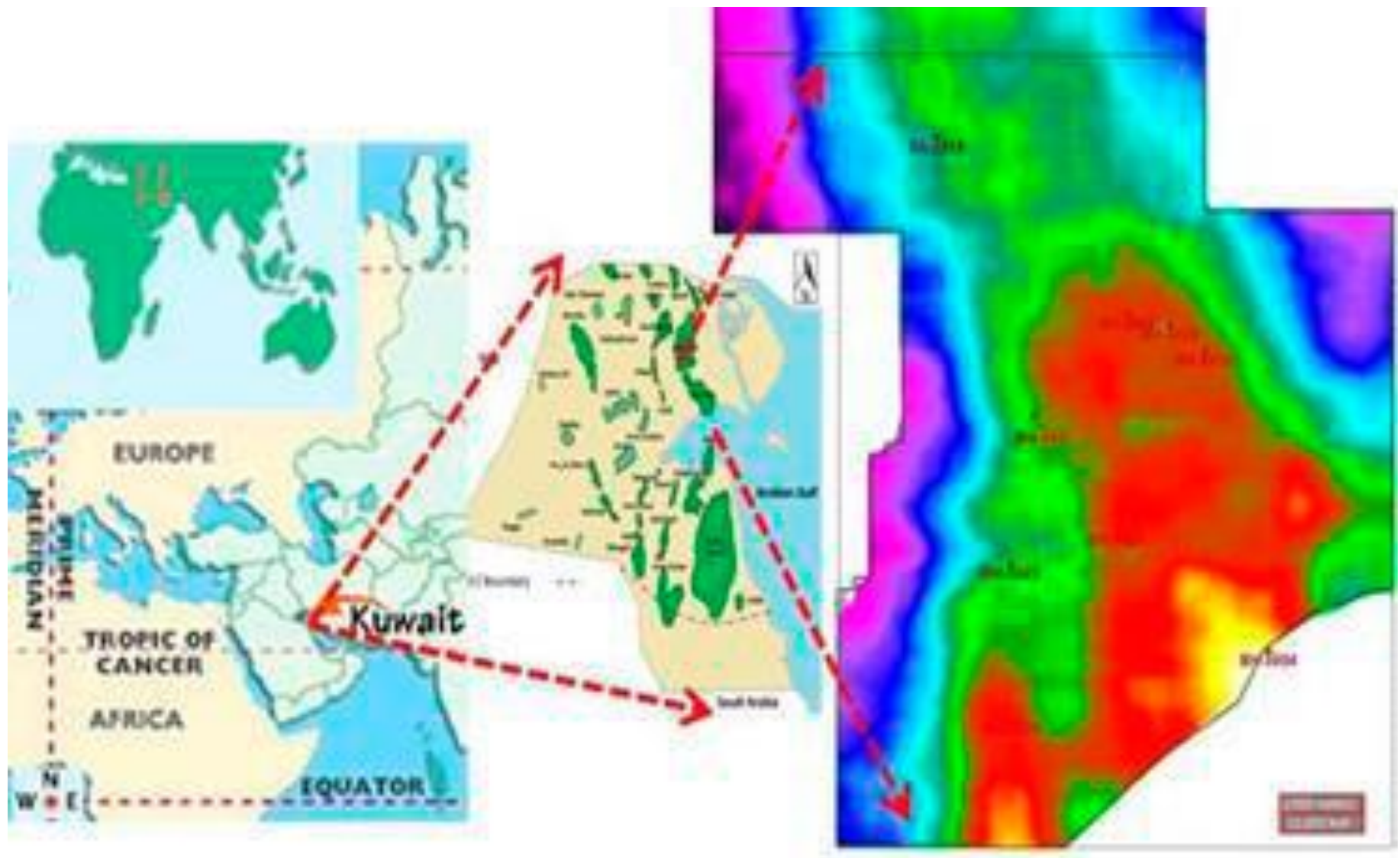


Figure 1. Location map showing area of study.

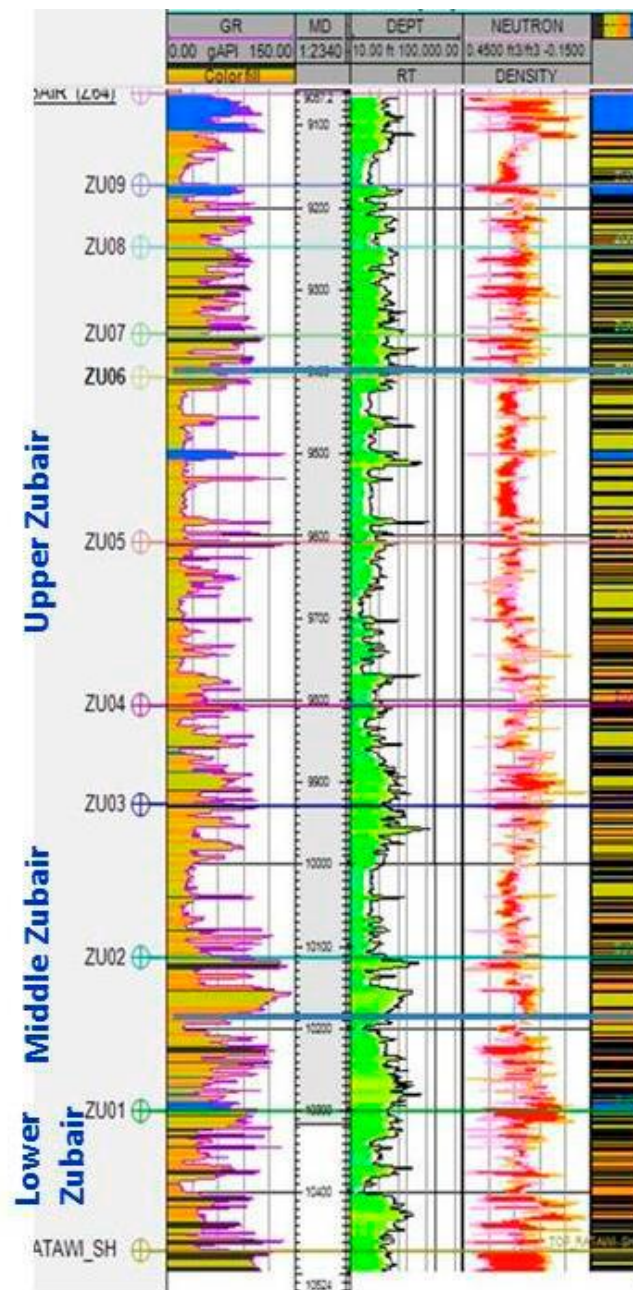


Figure 2. Three division of Zubair Formation.

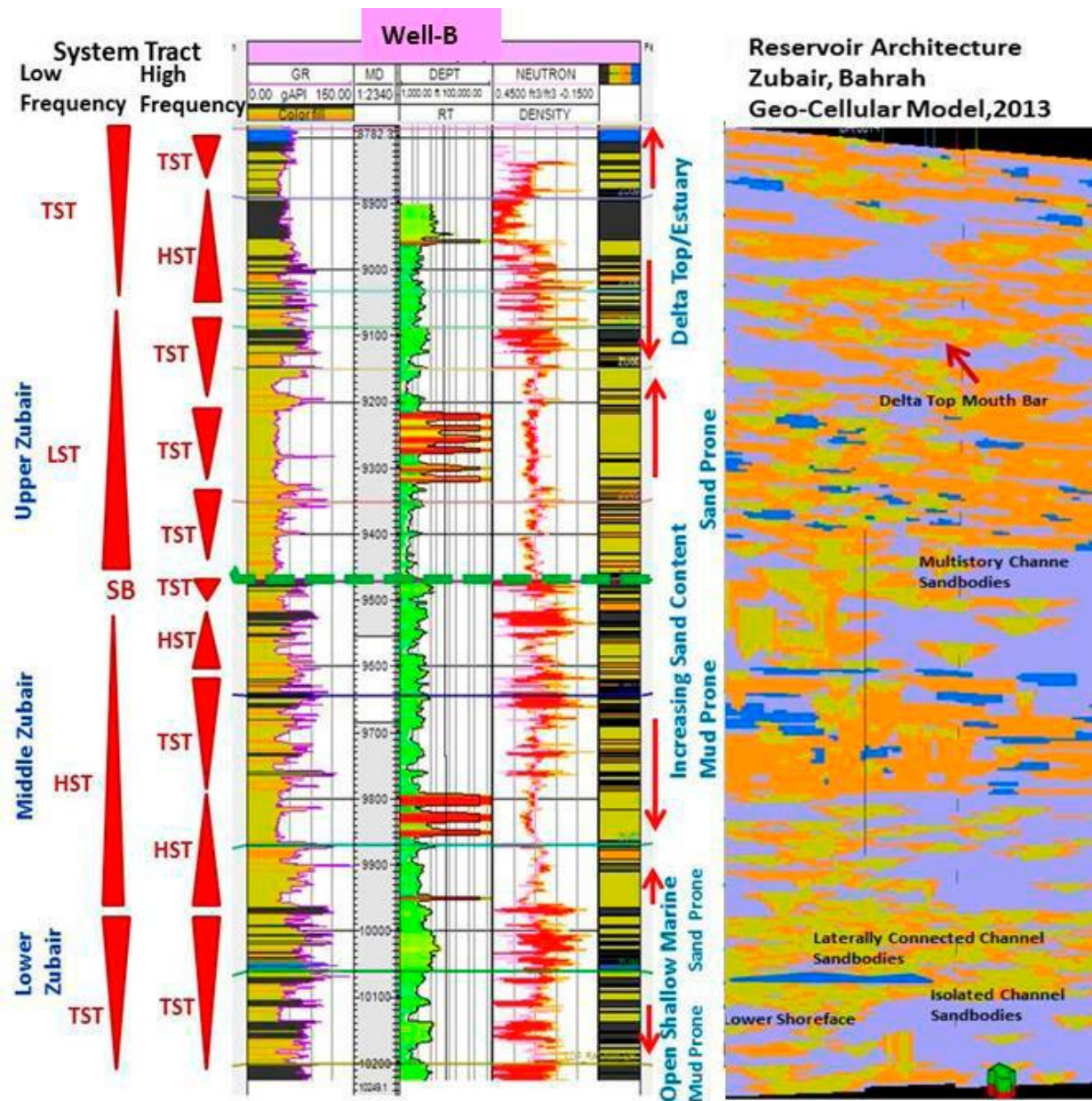


Figure 5. Sequence Stratigraphy of Zubair Formation with four low frequency sets superimposed by ten high frequency sets.

Gross Depositional Environment

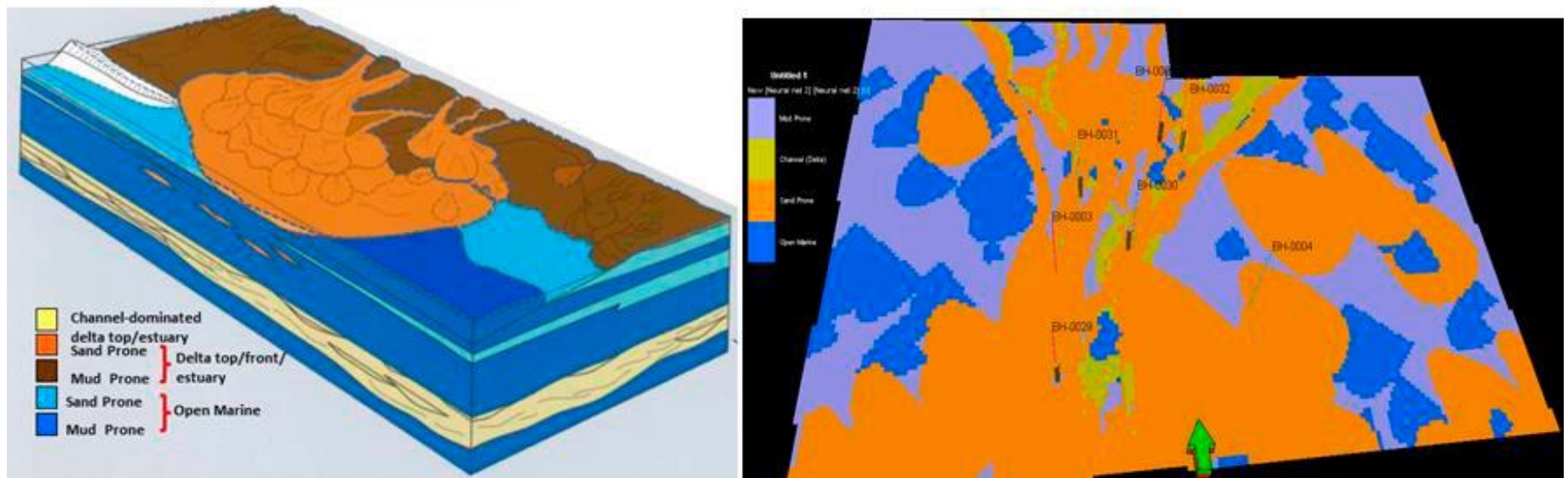


Figure 6. Cartoon of deltaic depositional model (Left) and deltaic depositional model from Geo-cellular model (right).

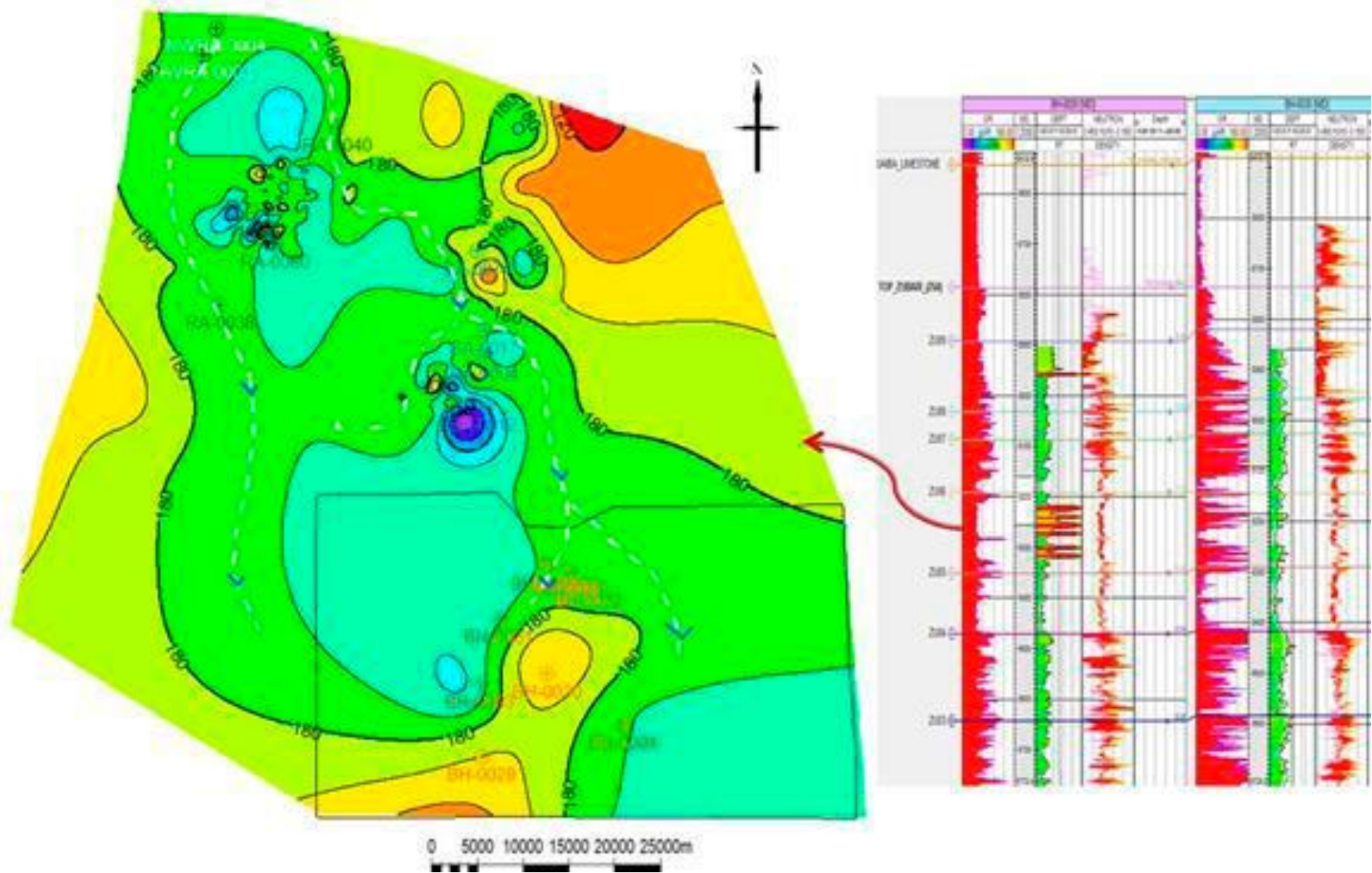


Figure 7. Isopach map of ZU06-ZU05 unit showing sediment input from north and NNW.

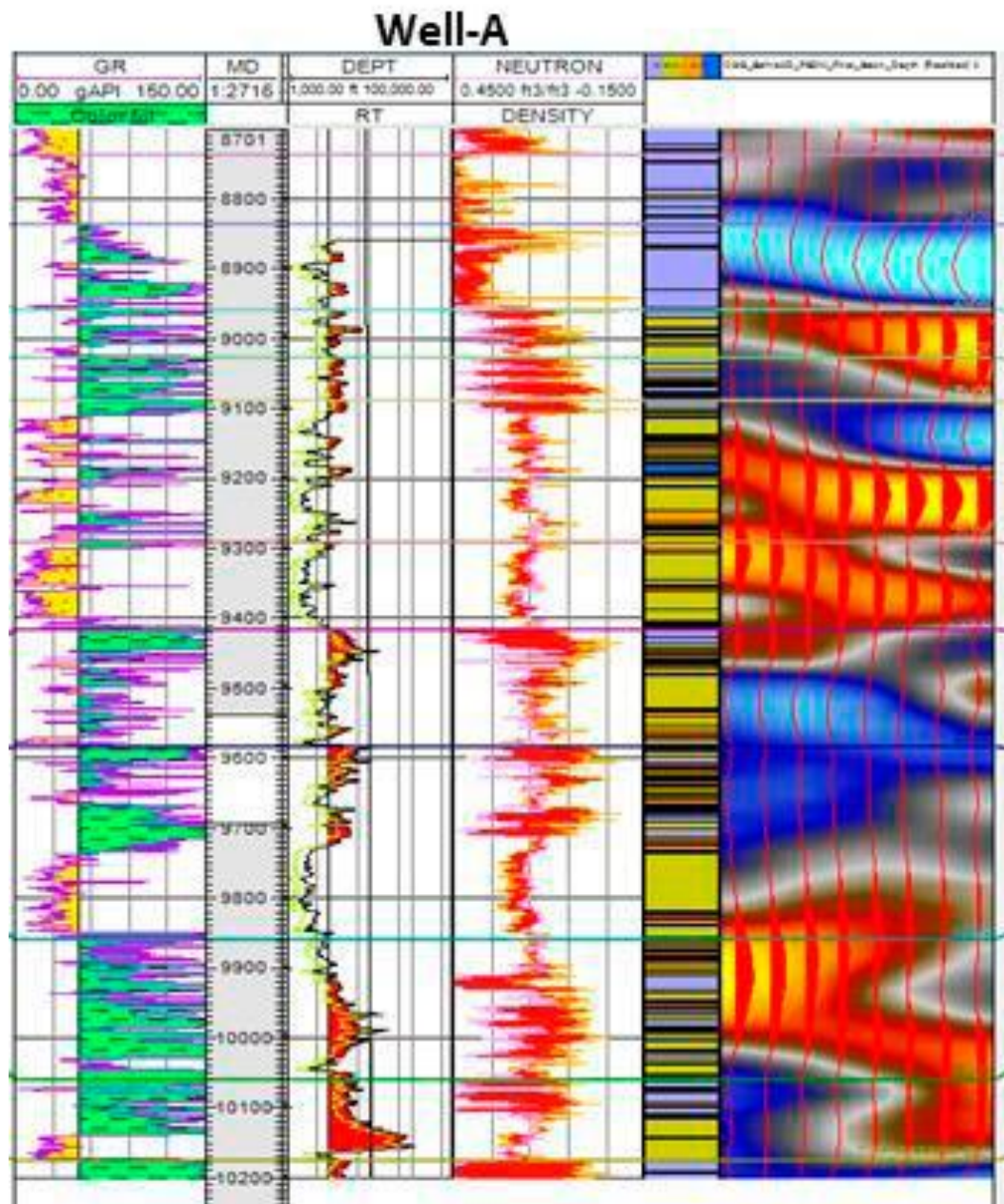


Figure 8. Good calibration with seismic amplitude and change of lithology at well point.

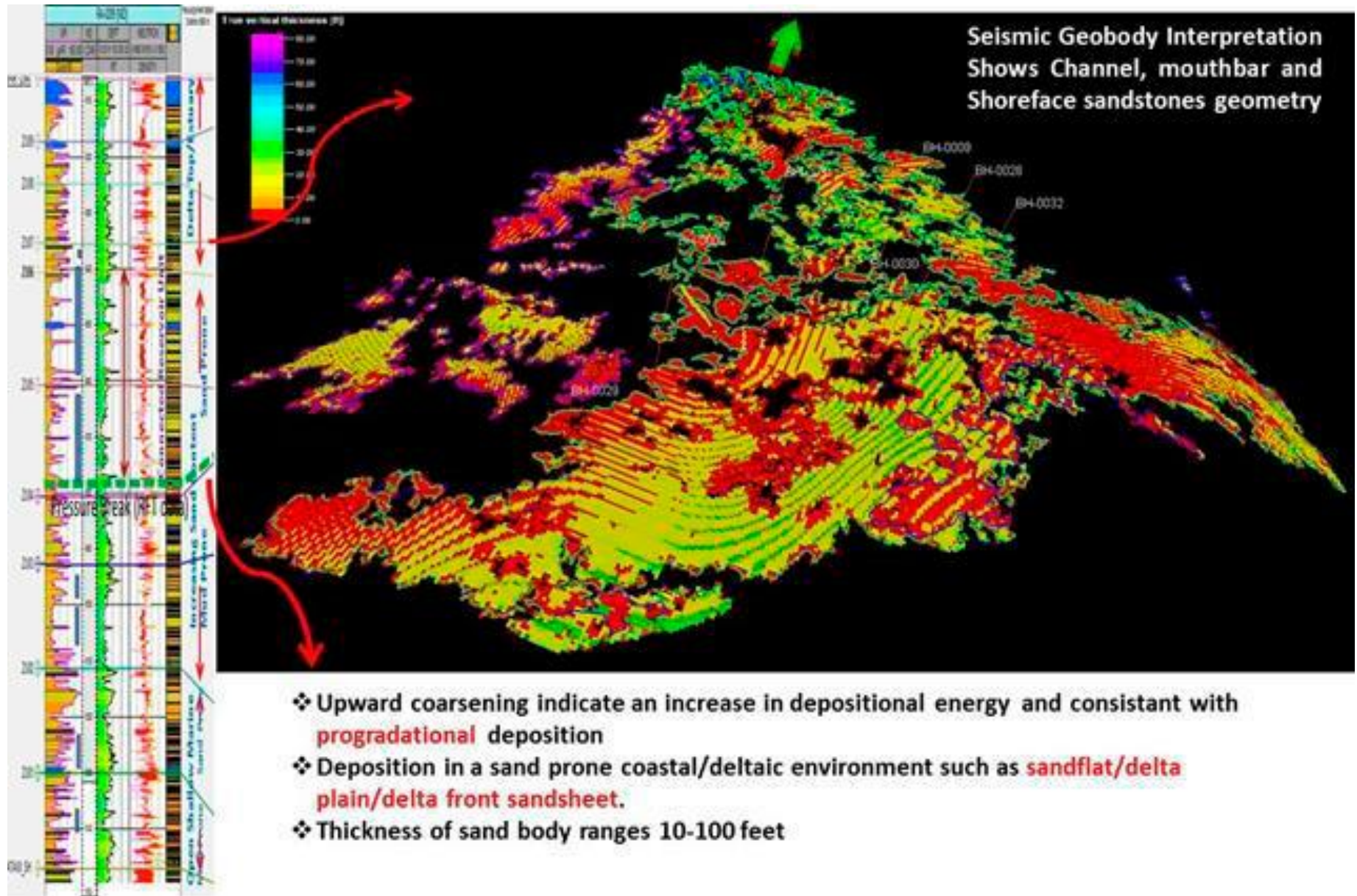


Figure 9. Geo-bodies show channel geometry, lobes at the end of the channel and amalgamation of lobes.

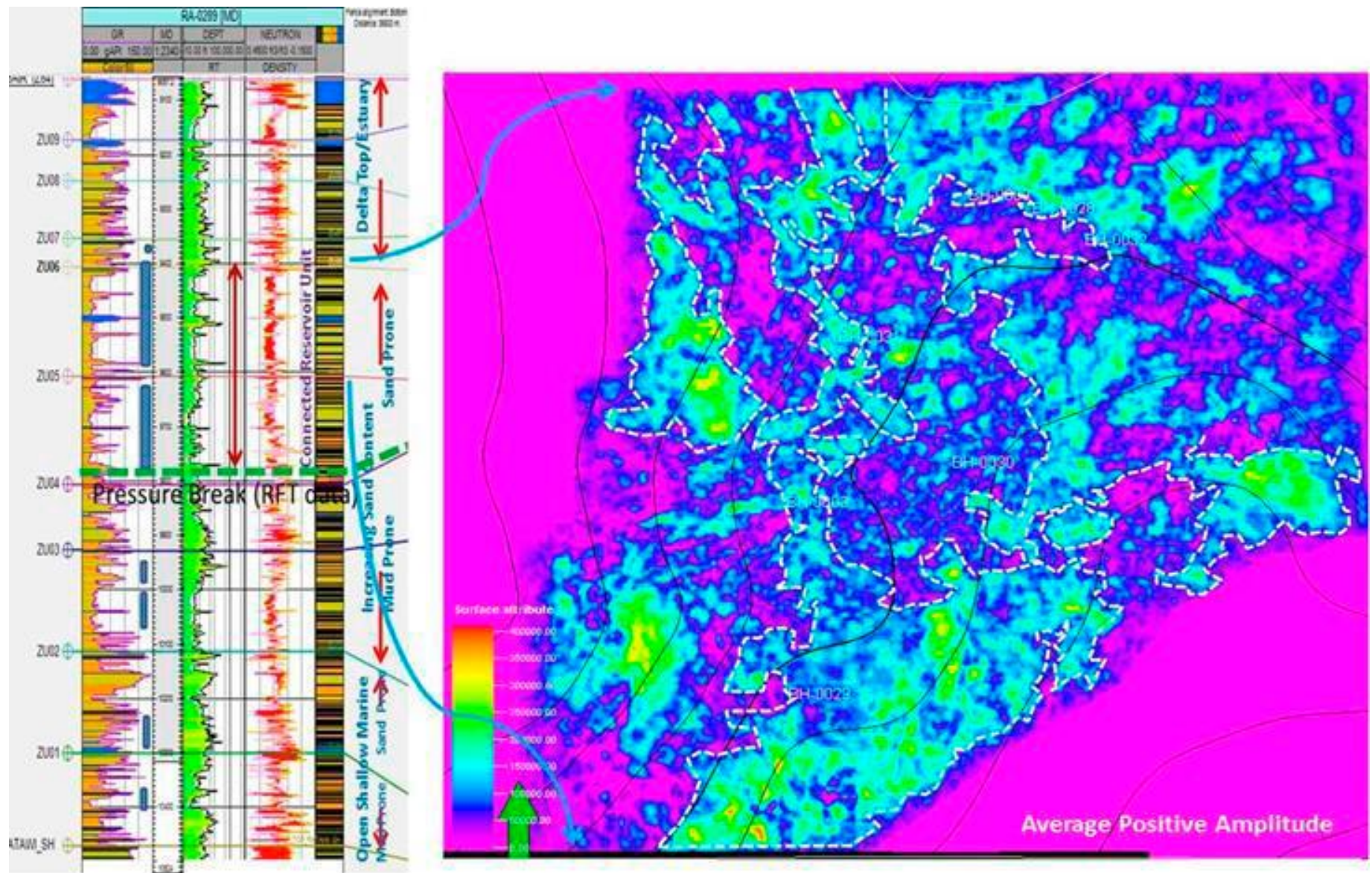


Figure 10. RMS amplitude attribute shows channel geometry, lobes and amalgamated lobes.

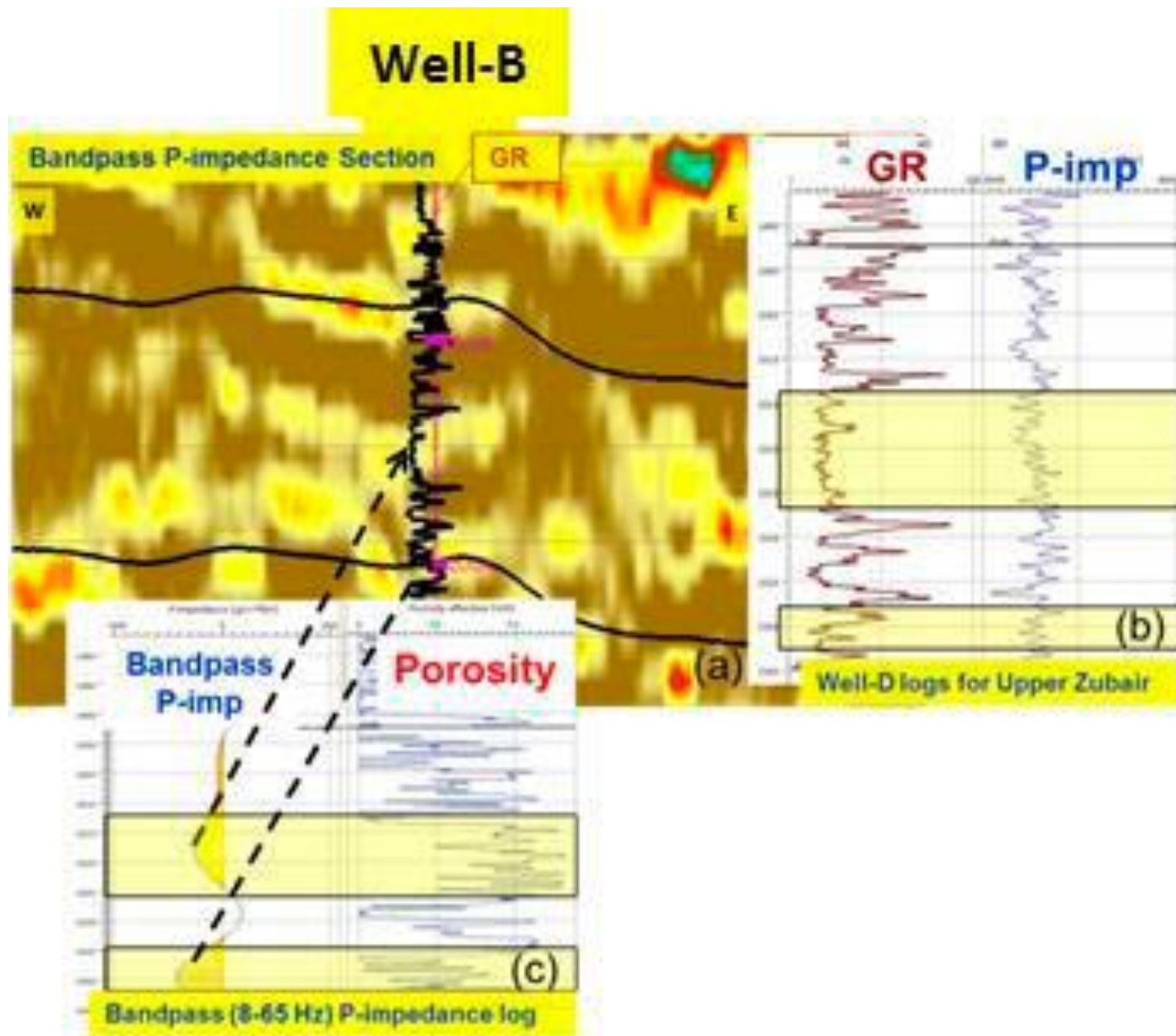


Figure 11. (a) Inverted bandpass P-impedance section by GR log, (b) GR log and P impedance, (c) bandpass (8-66Hz) P-impedance log with porosity.

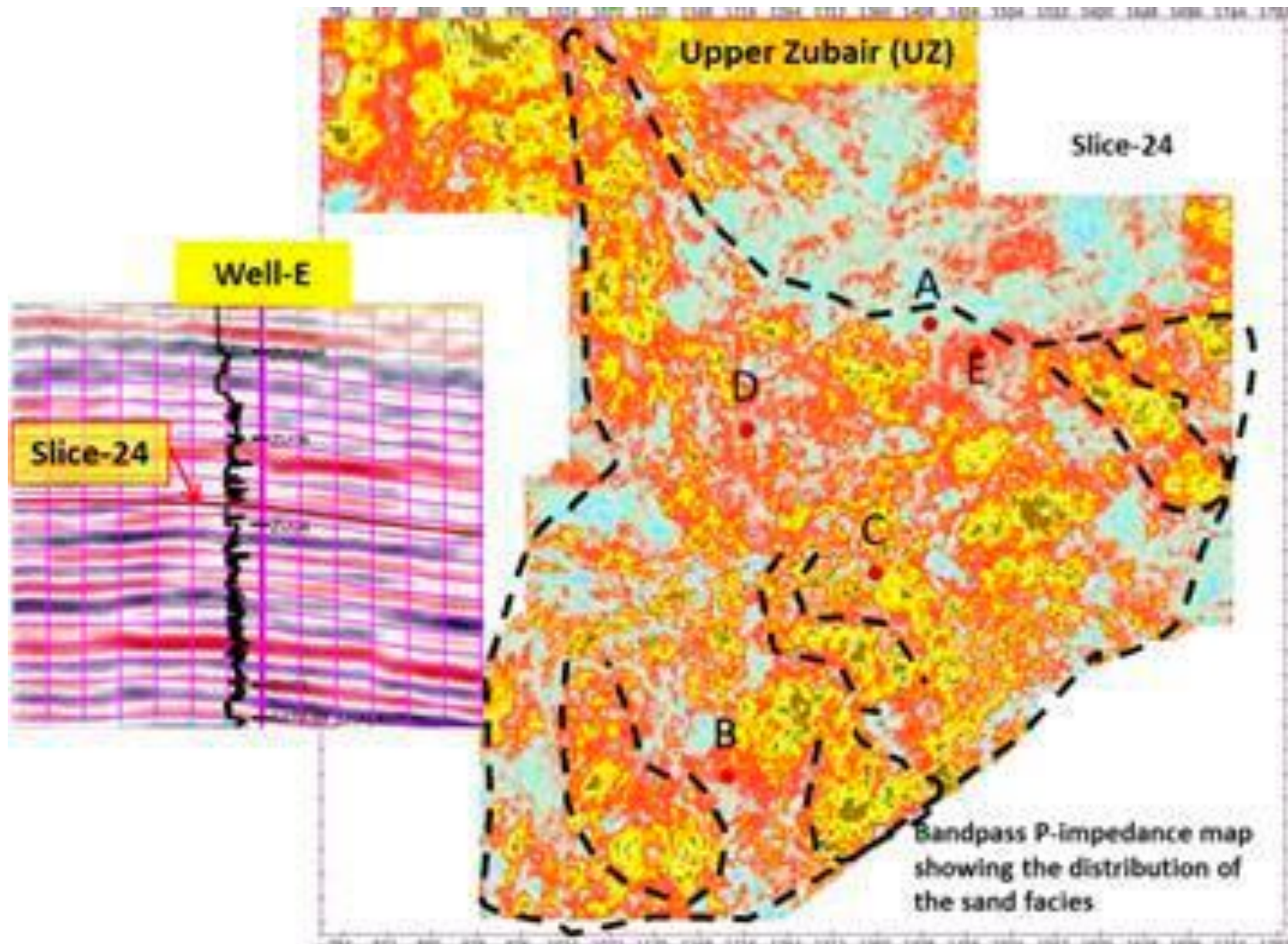


Figure 12. Bandpass P-impedance anomaly distribution map of stratal slice-24 showing the Upper Zubair sand distribution & pattern and the seismic inline section passing through Well-E shows the corresponding slice. The warmer color indicates sands facies, dim color indicates shale facies and brightness indicates the quality of facies.

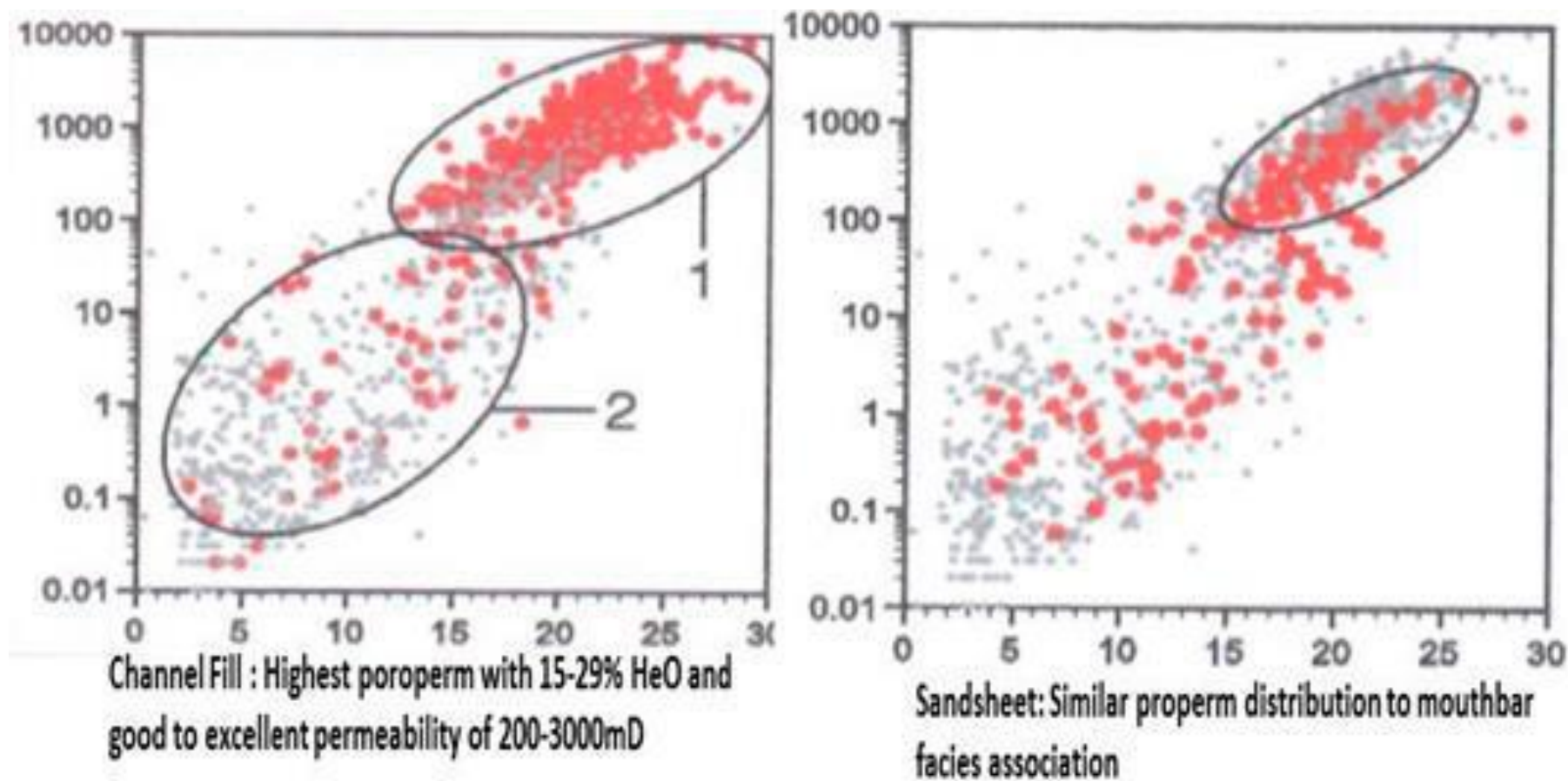


Figure 13. Cross plot of the poro-perm distribution of different reservoir facies.