[PS]Depositional Facies and Environments of the Devonian Jauf Formation in the Shedgum Area, Northeast Ghawar, Saudi Arabia*

Raed Alsalhi[1] and John Melvin[1]

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[1]Reservoir Characterization, Saudi Aramco, Dhahran, Saudi Arabia (raed.salehi@aramco.com)

Abstract

The subsurface Jauf Formation (Early Devonian: Emsian) of Saudi Arabia is a significant gas reservoir along the northeastern flanks of the giant Ghawar structure. It is informally subdivided into lower, middle and upper Jauf intervals, based on extensive core studies. The lower Jauf interval is characterized by aggradational cycles of middle to upper shoreface deposits dominated by the following facies types: variably bioturbated flat to low angle laminated sandstone, bioturbated and locally dewatered argillaceous sandstone, and ripple-laminated sandstone. The overlying middle Jauf interval is mostly characterized by vertically stacked upward-fining packages of tidal inlet to lagoonal bay deposits dominated by the following facies: cross bedded sandstone with argillaceous and carbonaceous laminations, clay-draped tangentially cross bedded sandstone, poorly sorted laminated sandstone with mudclasts, and flat laminated sandstone and siltstone bundles, and rarely occurring sandstones and mudstones showing inclined heterolithic stratification (IHS). These facies represent tidal inlet, tidal channel and bar complex, lagoon, and washover fan deposits. The uppermost part of the middle Jauf interval contains a variably thick (5-13 ft) palynologically defined carbonaceous mudstone unit overlying sediments of interbedded sandstone and mudstone, and highly deformed sandstone and siltstone. Based on the presence of a very low diversity (monospecific?) assemblage of Leiosphaerid palynomorphs, this mudstone unit is interpreted as representing deposition within restricted bays. The overlying upper Jauf interval records a major shift in depositional style, characterized by the vertically stacked successions of upward-fining sandstone dominated fluvial deposits, including cross-bedded sandstone with common mudclasts, ripple laminated sandstone, and rare silty mudstones.

Tentative sequence stratigraphic interpretations suggest that the marine shoreline deposits of the lower Jauf interval represent aggradational transgressive to early highstand deposits of a composite sequence upon which have prograded the tidal dominated late highstand deposits of the middle Jauf interval. The middle Jauf interval contains a laterally extensive restricted bay mudstone unit, previously considered to represent a

maximum flooding event. The upper Jauf interval forms the basal unit of the overlying composite sequence that is dominated by fluvial sandstones.

Reference

Rahmani, R.A., R.J. Steel, and A.A. Al-Duaiji, 2002, High resolution sequence stratigraphy of the Devonian Jauf gas reservoir: a shoreface and estuarine embayment succession, Greater Ghawar area, eastern Saudi Arabia: GeoArabia, v. 7/2, p. 288.

Depositional Facies and Environments of the Devonian Jauf Formation in the Shedgum Area, Northeast Ghawar, Saudi Arabia

Raed Alsalhi & John Melvin, Saudi Aramco

GEO 2012

Introduction:

The subsurface Jauf Formation (Early Devonian: Emsian) of Saudi Arabia is a significant gas reservoir along the northeastern flanks of the giant Ghawar structure. It is informally subdivided into lower, middle and upper Jauf intervals, based on extensive core studies. The lower Jauf interval is characterized by aggradational cycles of middle to upper shoreface deposits. The overlying middle Jauf interval is mostly characterized by vertically stacked upward-fining packages of tidal inlet to lagoonal bay deposits. The overlying upper Jauf interval records a major shift in depositional style, characterized by the vertically stacked successions of upward-fining tidally influenced fluvial deposits.

Tentative sequence stratigraphic interpretations suggest that the marine shoreline deposits of the lower Jauf interval represent aggradational transgressive to early highstand deposits of a composite sequence upon which prograded the tidal-dominated late highstand deposits of the middle Jauf interval.

Base D3B Mudstone Structure Map

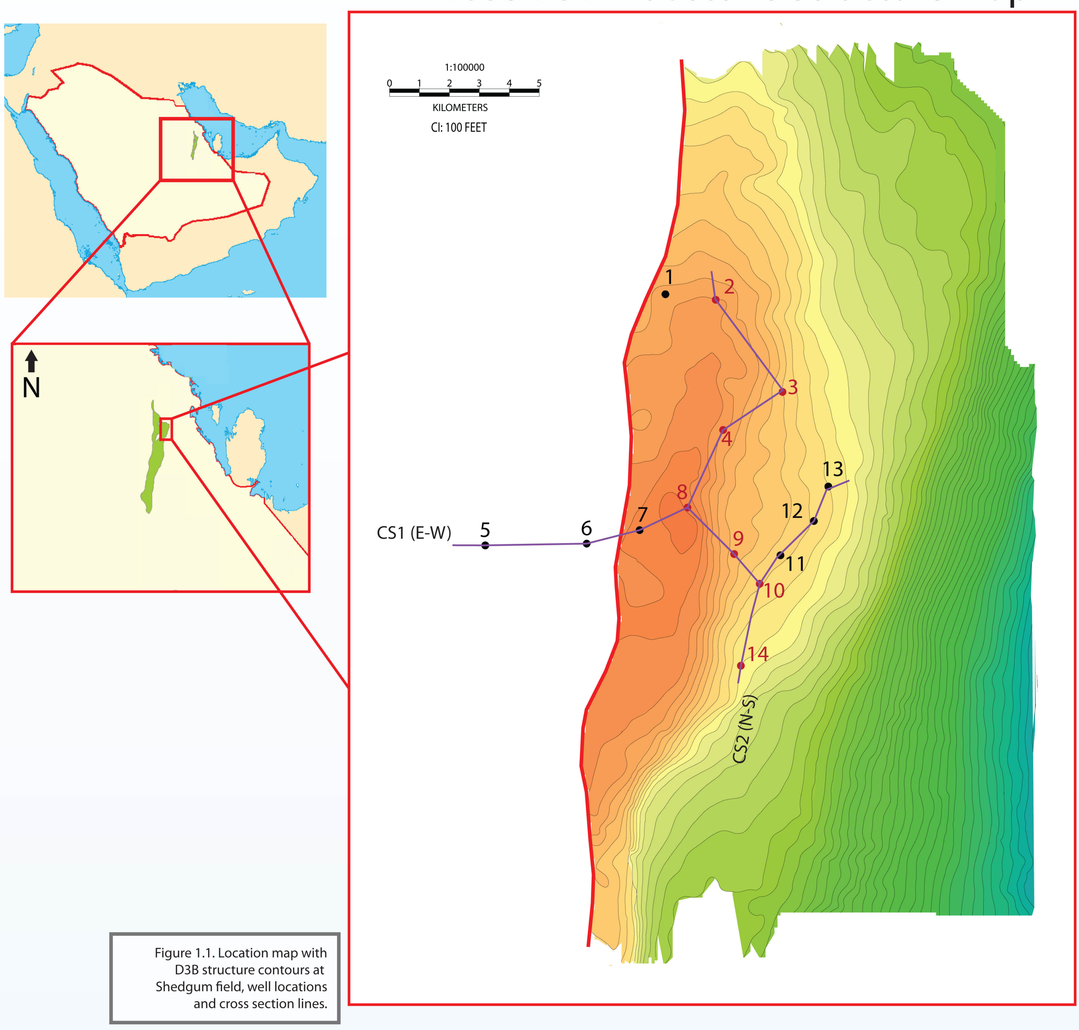

Figure 1.1. Location map with D3B structure contours at Shedgum field, well locations and cross section lines.

Stratigraphy of the Fm at Shedgum Area

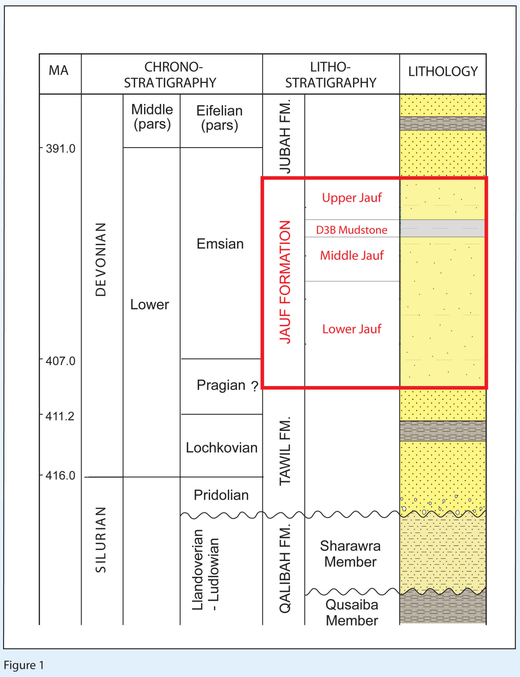

Figure 1.2. Stratigraphic chart of the Jauf Formation showing the three informal units: lower, middle, and upper Jauf.

Structural Cross Section; Khuff-Tawil Fm

(Cross Section #1)

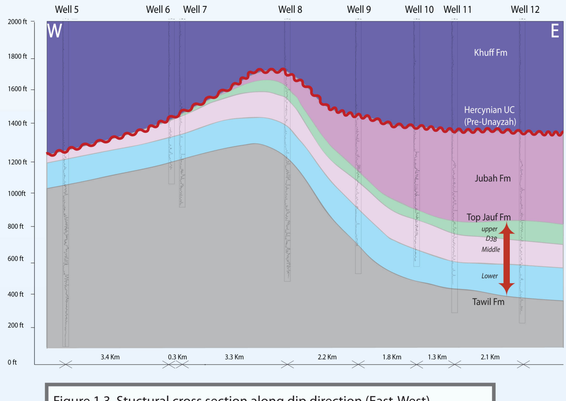

Figure 1.3. Stuctural cross section along dip direction (East-West). Note the eastward thickening of the Jauf Fm and the westward erosion of the upper and middle Jauf by the Hercynian unconformity.

Figure 1

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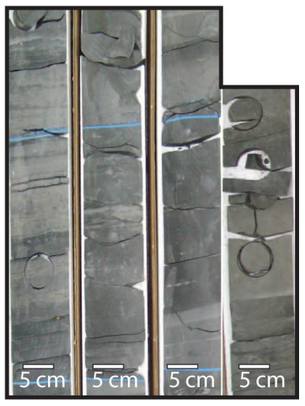
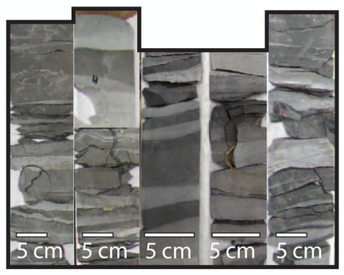
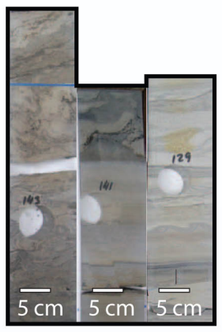
Facies:



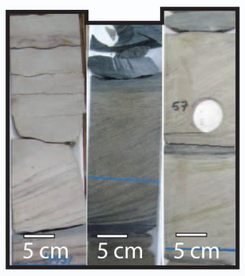
1) Carbonaceous Mudstone (D3B Mud):
This facies is extensively developed in the Jauf Formation among all the wells across the study area. Its thickness ranges from 3' to 13' (0.9-3.9 m). It consists of blocky to poorly fissile, dark gray to black, carbonaceous siltstones and mudstones. These are generally massive (i.e., lacking any well-developed lamination) and non-bioturbated. They commonly display subtle sharp-based, graded mudstone units. In all wells where it has been cored, these D3B mudstones are underlain by interbedded sandstones and siltstones of Facies IBSS (see below). They are most commonly terminated above by erosion at the base of the superseding sandstone. The D3B mudstone facies are considered to be very fine-grained gravity flows (mud turbidites) laid down in a lagoonal setting (see Panel 4).



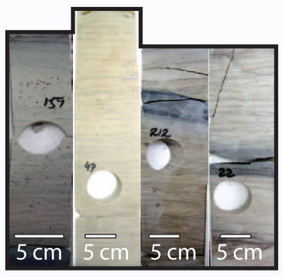
2) Interbedded Sandstone and Siltstone (IBSS):
This facies is restricted in its occurrence everywhere to immediately underlying the distinctive D3B carbonaceous mudstones. It consists of thin (cm- to dm-scale) interbedded sandstones and siltstones and generally occurs with an overall thickness of 1 ft to several feet. The sandstones are gray, and very fine-grained, displaying sharp lower contacts and common graded bedding. The siltstones are muddy, dark gray to black in color and locally display similar normal grading. In this sense they are very similar to the D3B mudstones (*sensu stricto*) described above. This facies represents accumulations of gravity flow deposits that were laid down on the floor of an extensive coastal lagoon (see Panel 4).



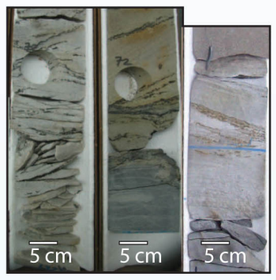
3) Highly Deformed Sandstone and Siltstone (HDSS):
This facies is observed in most of the described wells in the Jauf Formation. It occurs within a few feet (meters) of the lower contact of Facies IBSS at the base of the D3B mudstone package (see Panel 4). It varies in thickness from 0.5 ft to 3 ft (0.15-0.90 m), and comprises variable colored, very fine- to fine-grained sandstones and siltstones. The rocks are characterized by the high degree of soft sediment deformation including pervasive dewatering, contorted and overturned bedding, and small scale synsedimentary faulting. The sediments represented by this facies were clearly subjected to (varying) degrees of post depositional disruption.



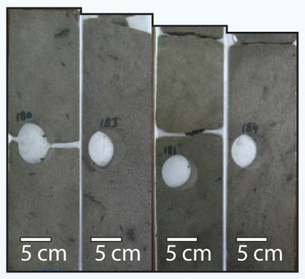
4) Clay-Draped Tangential Cross-bedded Sandstone (CDCB):
This facies consists of variable colored, very fine- to fine-grained, well sorted sandstone that occurs in sets about 1 ft (0.30 m) thick. These sets can occur singly or in multiply stacked bedsets. Each set displays cross-bedding that characteristically has well-developed topsets, tangential foresets, and argillaceous toesets. The foresets are characteristically draped with a thin lamina (or double laminae) of mudstone that commonly thickens down into the toesets. In some cases the foresets display abundant carbonaceous mudclasts. These sandstones show strong evidence of having been deposited as sandbars in a tidal setting.



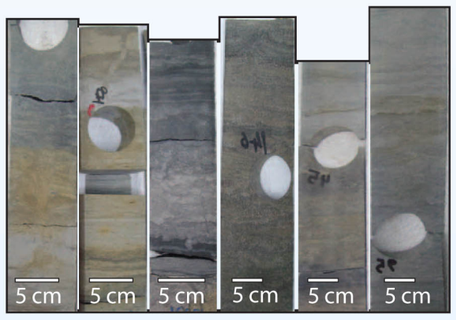
5) Ripple Laminated Sandstone (RLS):
This facies consists of multi-colored, very fine- to fine-grained, moderately well to well sorted sandstone with thicknesses from a few feet and up to 25 ft. It displays multiple laminasets of small-scale ripple cross-lamination. Facies associations suggest this facies was deposited in tidal sand flats on sheltered areas of estuarine tidal sand bars.



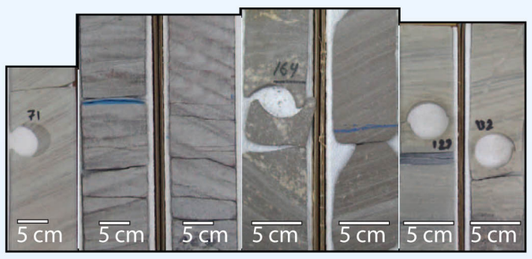
6) Cross-bedded Sandstone with Argillaceous and Carbonaceous Laminations (CBSAC):
This facies is relatively uncommon within the Jauf Formation. It displays variable thickness, from 1ft to 3 ft (0.30-0.9 m) and consists of off-white and tan, very fine- to fine-grained, moderately to well sorted sandstone. It is characterized by discontinuous, high angle argillaceous and carbonaceous laminations. The rocks are also characterized by abundant angular mudclasts especially near the base of the sandstones where the lower contact is sharp and erosional. This facies represents deposition in the lower parts of channels that were subjected to tidal influences.



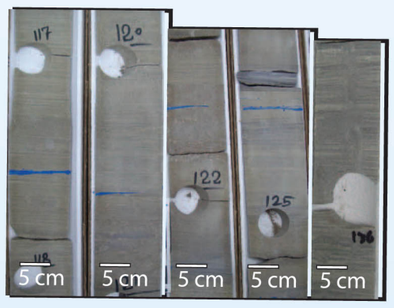
7) Slumped and Dewatered Sandstone With Mudclasts (SDSM):
This facies is relatively uncommon in the Jauf Formation, thickness ranging from 1ft to 4ft (0.3-1.2 m). It consists of tan, brown, or off-white, poorly sorted sandstone with mudclasts, and oversteepened and contorted bedding suggestive of slumping and/or dewatering structures. It is normally associated with an erosional scoured basal surface.



8) Bioturbated and/or Dewatered Sandstone (BDW):
This facies is very common in the Jauf Formation, in places extending up to tens of feet (several meters) in thickness. It consists of grey-green, variably argillaceous, fine-grained, poorly sorted sandstone. It is characterized by an irregular and mottled texture indicative of varying degrees of bioturbation and/or dewatering. Facies associations suggest that these sandstones were deposited in the distal reaches of washover fans in a lagoonal environment.



9) Cross Bedded Sandstone with Variable Bioturbation Intensity (CBS):
This facies is very common in the lower Jauf Formation across most of the studied area and with variable thicknesses ranging from few feet to tens of feet (few to several meters). It consists of off-white and tan, fine- to medium-grained, well sorted sandstone. It is characterized by pronounced, flat to low angle cross-laminated sandstone. In places these laminated sandstones are disrupted by (locally intense) bioturbation, characterized in general by Skolithos ichnofacies. This facies is considered to represent a middle to upper shoreface environment.



10) Flat and Low Angle Laminated Sandstone and Siltstone Bundles (FLSS):
This facies occurs in a thickness of up to 20 feet. It consists of tan, fine- to medium-grained, well sorted, sandstone, interlaminated with siltstone. It can be variably bioturbated. This facies represents a relatively protected environment that was exposed to tidal influence, such as tidal sandflats around a lagoon or the protected margins of tidal channels.

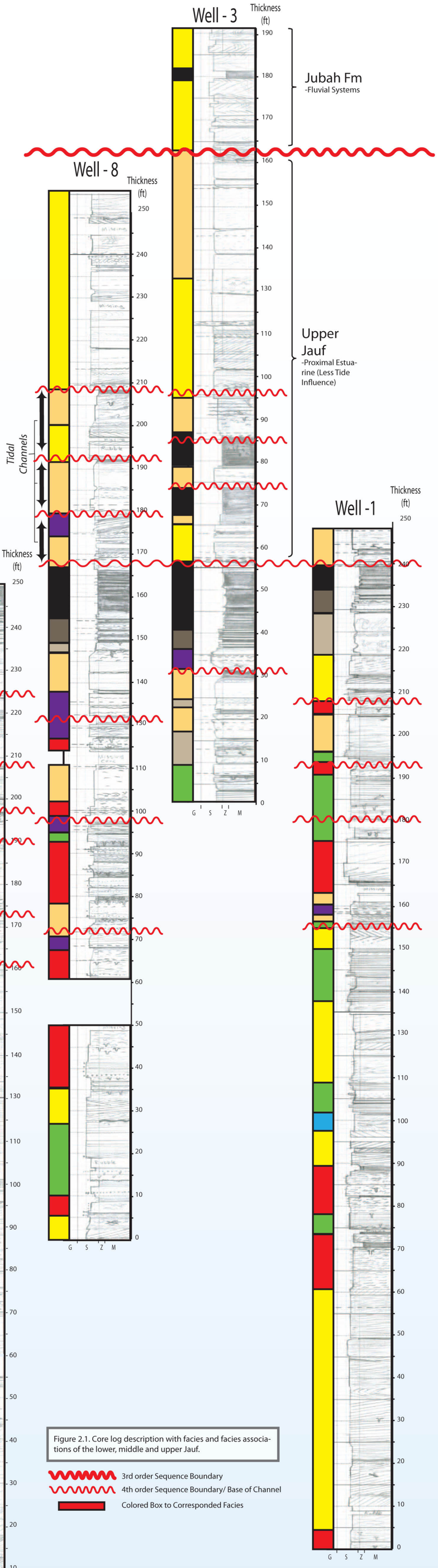


Figure 2.1. Core log description with facies and facies associations of the lower, middle and upper Jauf.

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Jauf Depositional Model

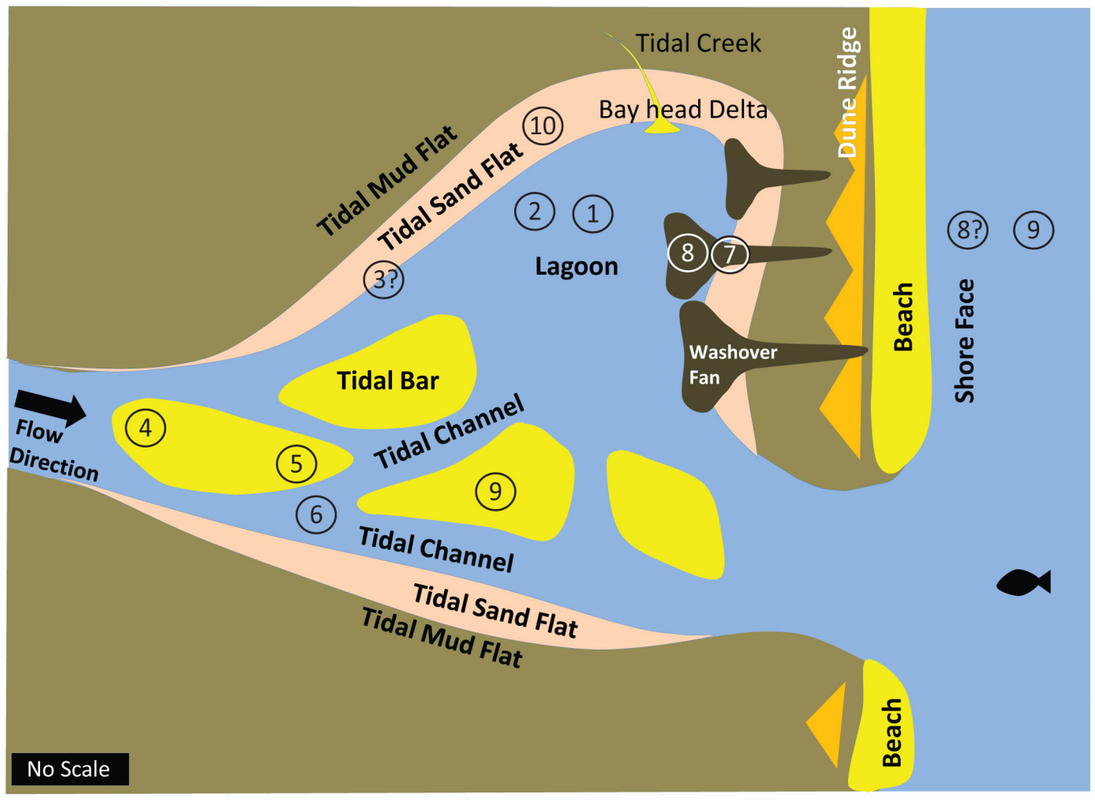

Figure 3.1. Schematic depositional model of the Jauf Formation environments. Numbered circles correspond to facies in previous pannel (e. g. carbonacous mudstone is (1))

Stratigraphic Cross Section Across Jauf Interval

(Cross Section #1)

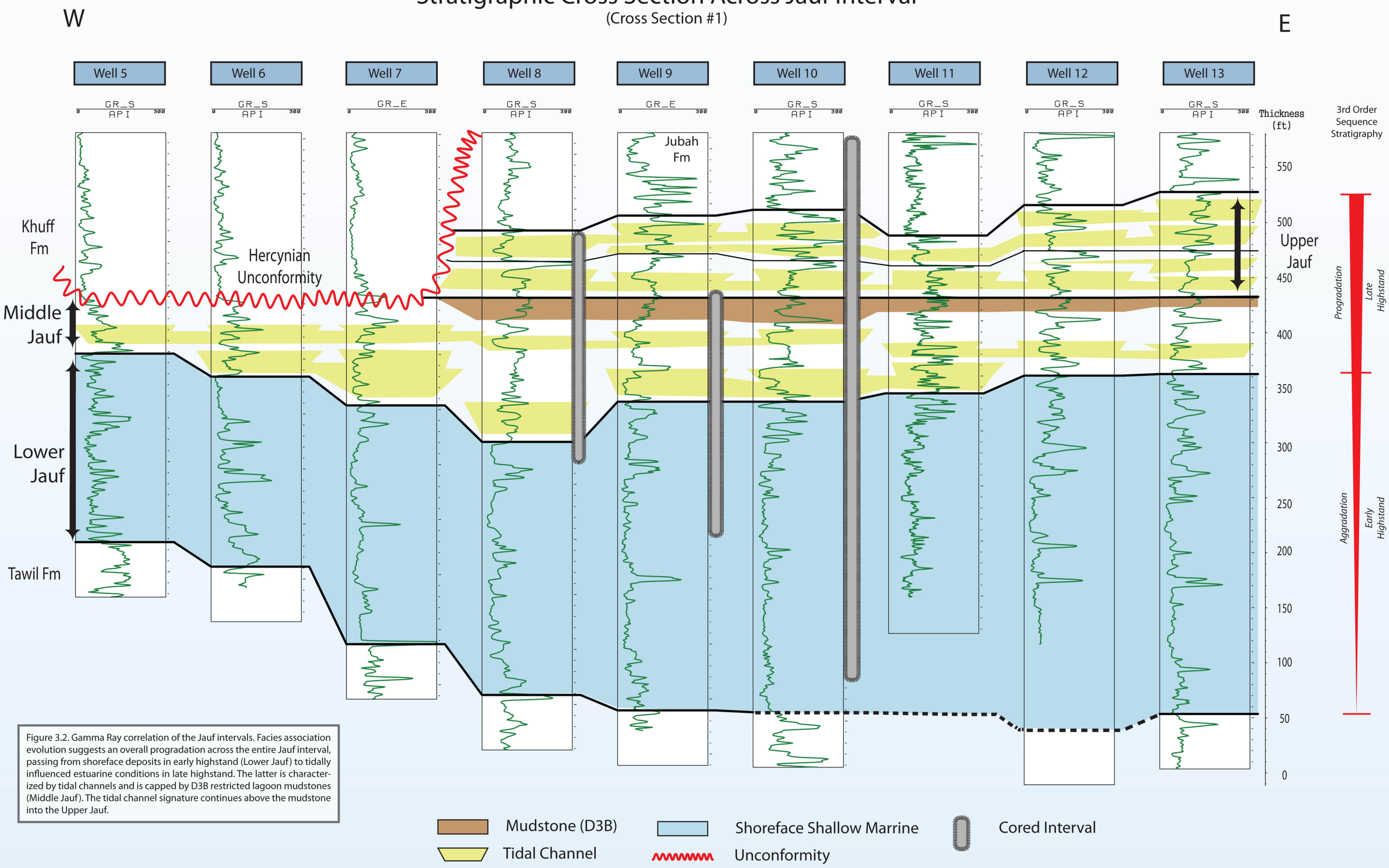

Figure 3.2. Gamma Ray correlation of the Jauf intervals. Facies association evolution suggests an overall progradation across the entire Jauf interval, passing from shoreface deposits in early highstand (Lower Jauf) to tidally influenced estuarine conditions in late highstand. The latter is characterized by tidal channels and is capped by D3B restricted lagoon mudstones (Middle Jauf). The tidal channel signature continues above the mudstone into the Upper Jauf.

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Does the D3B Mudstone Represent a Maximum Flooding Event or Not?

The D3B mudstone is a prominent, laterally extensive lithological and palynological marker that extends across the Shedgum area and beyond, having been identified in the offshore Arabian Gulf as well as in the Devonian outcrop belt in northwest Saudi Arabia. Previous interpretation of this mudstone unit considered it to be a marine maximum flooding interval, marking the end of an underlying transgressive systems tract (Rahmani & Steel, 2002).

Our current studies suggest that this may not be quite as simple and clear cut a case as it might appear. Any marine flood mudstone deposits should display prominent lamination, unless this was destroyed by subsequent bioturbation. Furthermore, paleontological and palynological signatures of such marine flood deposits would be expected to show high faunal and/or floral diversity involving fully marine forms in the respective assemblages.

Contrary to such expectations, the D3B mudstone does not display a strongly laminated character. It comprises an accumulation of massive (specifically, non-laminated) graded mud turbidites (Figure 4.2.a). These mudrocks display no evidence of bioturbation, and in almost all cases overliean interval of interbedded turbidite sandstones and siltstones (Facies IBSS: see Panel 2, and Figure 4.3). No macrofossils are identified in the mudstones, and palynological analysis reveals a very low diversity (almost monospecific) assemblage dominated by *Leiospheridia* (P. Breuer, personal communication) (Figure 4.2.b). Those leiospheres are themselves indicative of a highly restricted or stressed environment (P. Breuer, personal communication). In short there is no sedimentological, ichnological, paleontological or palynological evidence to suggest that this widespread lithology is representative of a marine maximum flood scenario. The evidence presented here suggests instead a widespread, but otherwise much more restricted environment compared to the diversity to be expected from a fully marine setting.

A resolution of the dilemma presented by this evidence may be found in the sedimentology. It is thought significant that the widespread "D3B package" of thin-bedded turbidite sandstones and mudstones overlain by mud turbidites of the D3B mudrock sensu stricto is almost universally heralded within the stratigraphy by the highly deformed sediments of Facies HDSS (Figure 4.4). It seems likely that these widely occurring, deformed sediments convey the signature of some seismic event (such as an earthquake). Such an event could have created a restricted near-coastal depocenter, nonetheless protected from the full effects of the sea. This may then have been subjected more to infill from a landward direction (such as from seasonal riverine floods). More work needs to be done on this issue, and discussion and feedback is welcomed.

D3B Mudstone Log Correlation

(Cross Section #2)

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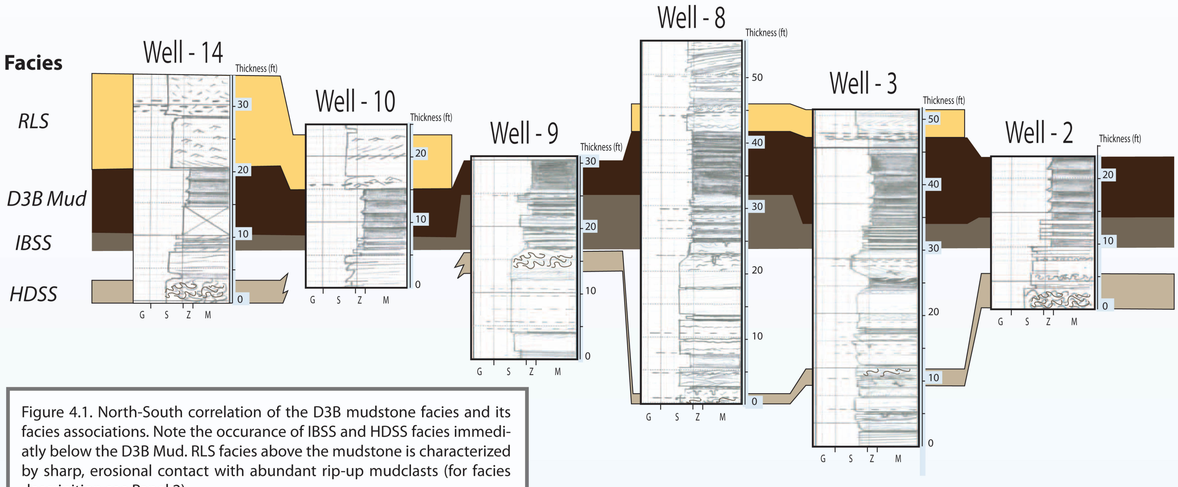


Figure 4.1. North-South correlation of the D3B mudstone facies and its facies associations. Note the occurance of IBSS and HDSS facies immediatly below the D3B Mud. RLS facies above the mudstone is characterized by sharp, erosional contact with abundant rip-up mudclasts (for facies descripition see Panel 2).

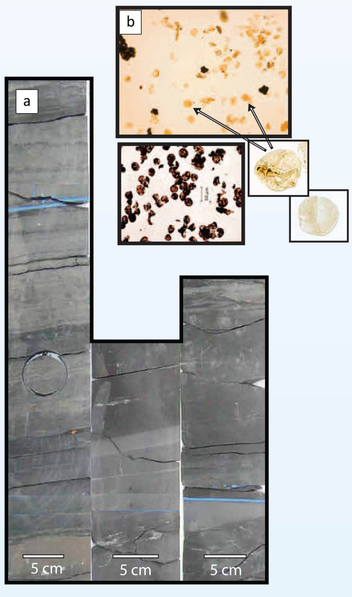


Figure 4.2. (a) D3B core photos, and (b) photomicrographs of the *Leiosphaeridia jaufensis* miospores. Note: abundance and near monospecific nature of the miospore population. See text (above) for discussion. (Photomicrographs courtesy of P. Breuer, Saudi Aramco)

Figure 4.3. IBSS facies core pictures.

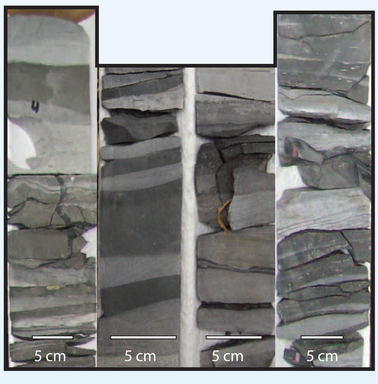
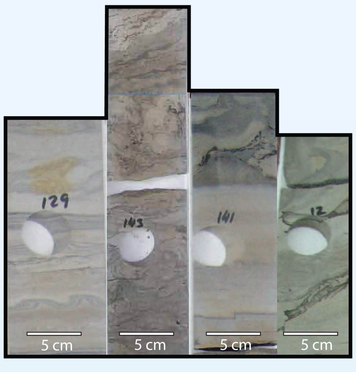


Figure 4.4. HDSS facies core pictures



References:

Rahmani & Steel, 2002, "High-resolution Sequence Stratigraphy of the Devonian Jauf Gas Reservoir: A Shoreface and Estuarine Embayment Succession, Greater Ghawar Area, eastern Saudi Arabia", GEO Abstract #38-O.

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