

Masila 2: Tide-influenced sedimentation in a rift basin – Cretaceous Qishn Formation, Masila, Yemen – a billion barrel oil field

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ABSTRACT

The Lower Cretaceous Qishn Clastics Member in Masila Block 14, Republic of Yemen, are a primary drilling objective, with estimated reserves of 1.1 billion barrels recoverable oil. Masila has produced approximately 656 million barrels of oil to date. Sedimentation took place in an elongate paleo-gulf of the Say'un – al Masila Basin, open to marine carbonates to the east. The Qishn Clastics Member unconformably overlies mixed carbonates and clastics of the Sa'af Member. Lower Qishn onlap resulted in deposition of brackish and tidal (likely macrotidal) estuarine to open bay or gulf deposits. The middle portion of the lower Qishn Clastics Member shows evidence of arid nonmarine sedimentation, including debris flow deposits, red beds and shale-clast conglomerates, in turn, overlain by interfingering coastal and nonmarine deposits. The lower Qishn Clastics Member is truncated by a sequence boundary overlain by an extensive sandstone deposited within a low-accommodation braidplain close to the shoreline. A flooding surface is present at the top of the sandstone, over which progradational, tide-influenced deltaic strata were deposited. Delta progradation culminated in shallow-water clastic dolomitic deposits on the coastal plain. With subsequent transgression, rising water table caused a nonmarine flooding surface with lakes and lacustrine deltas, overlain by tidal-flat deposits. Ongoing transgression resulted in wave-ravinement overlain by shallow shelf clastics and then deposition of slightly deeper shelf carbonates. The uppermost unit comprises bioturbated, clastic shelf deposits related to a drop in relative sea level. Throughout much of the Qishn Clastics interval, accommodation was moderate, except for low accommodation associated with regional sheet sandstone at the base of the upper Qishn Clastics Member. Virtually all marine and brackish deposits show evidence of tidal sedimentation. Climate was arid and seasonally wet. Presented core will show aspects of the above features.

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Introduction

Hydrocarbons produced from Nexen's Masila Block 14 in Yemen (*Fig. 1*) were discovered in 1991 and by November 2002, 656 million barrels of oil had been produced, with estimated reserves of at least 1.1 billion barrels of oil. Daily production is currently 232,000 barrels per day from all zones. The Masila Block 14 is an irregular-shaped concession falling within a rectangle that is 36 by 51 km in size, covering 1250 km². By comparison, the city of Calgary covers an area of 722 km². This core display summarizes of the reservoir characteristics of producing horizons of the Lower Cretaceous Qishn Formation.

The points we emphasize in the core presentation are the sedimentology, sequence stratigraphic framework and depositional environments of prolific clastic reservoirs comprising the Qishn Clastics Member. The interval provides an example of sedimentation of predominantly post-rift clastics in a basin that was strongly influenced by tides in an arid to semi-arid climate.

Details of the geology of Qishn Formation at Masila are described in Leckie and Rumpel (2003). The reader is referred to Leckie and Rumpel (2003) for pertinent references. Other aspects of the geology and history of Masila are described in King et al. (2003) and Putnam et al. (1997). Wilkinson (this volume) describes description of reservoirs of the underlying Saar Formation in a companion paper.

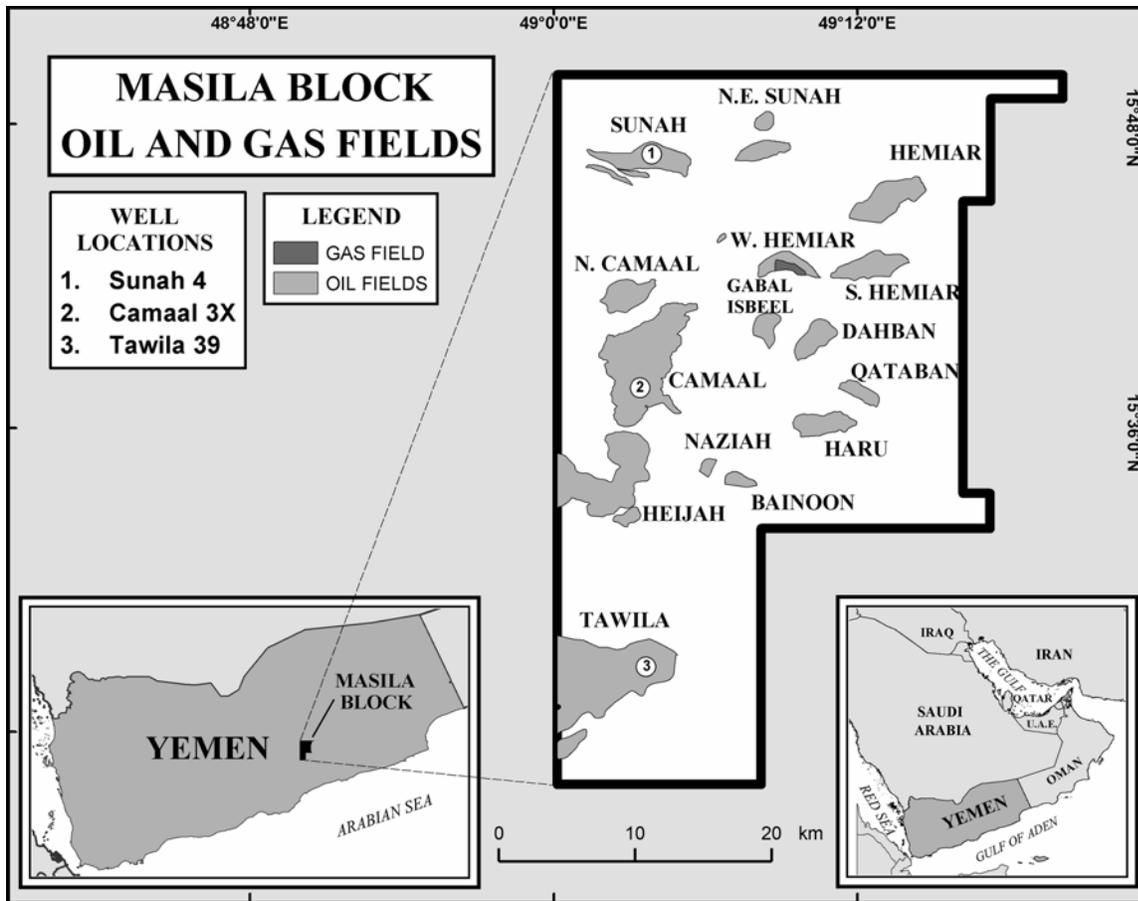


Fig. 1. Location map showing oil and gas fields of Masila Block 14 in the Republic of Yemen. Locations of 3 core presented at core conference and illustrated in Figure 5 are numbered. The three cores - Sunah 4, Camaal 3X and Tawila 39 provide a near complete composite core profile of the Qishn Clastics Member.

Stratigraphic Setting

In east-central Yemen, the Qishn Formation is the lowermost clastic unit of the Tawila Group in the west and the lowermost carbonate unit of the Mahra Group in the east (*Fig. 2*). The Qishn Formation is divided into the Qishn Carbonate and the Qishn Clastic members. In Masila Block 14, the ~198 m (650 ft) thick Qishn Clastics Member is further subdivided (*Fig. 3*) (King et al., 2003). The 128 m (419 ft) thick lower Qishn Clastics is the interval from top of the Sa'af Member to the base of the S3. The 70 m (231 ft) thick upper Qishn Clastics are informally subdivided into, from bottom to top, S3, S2, S1C, S1B, and S1A.

The lower Qishn Clastics Member was deposited during the Middle to Late Barremian (G. Norris, 2001, personal communication) over a duration of 7 to 10 My. The S3, S2 and S1C of the upper Qishn Clastics Member were deposited in the Late Barremian to

Early Aptian. The S1B was deposited in the Early Aptian, and the S1A in the Early to Middle Aptian.

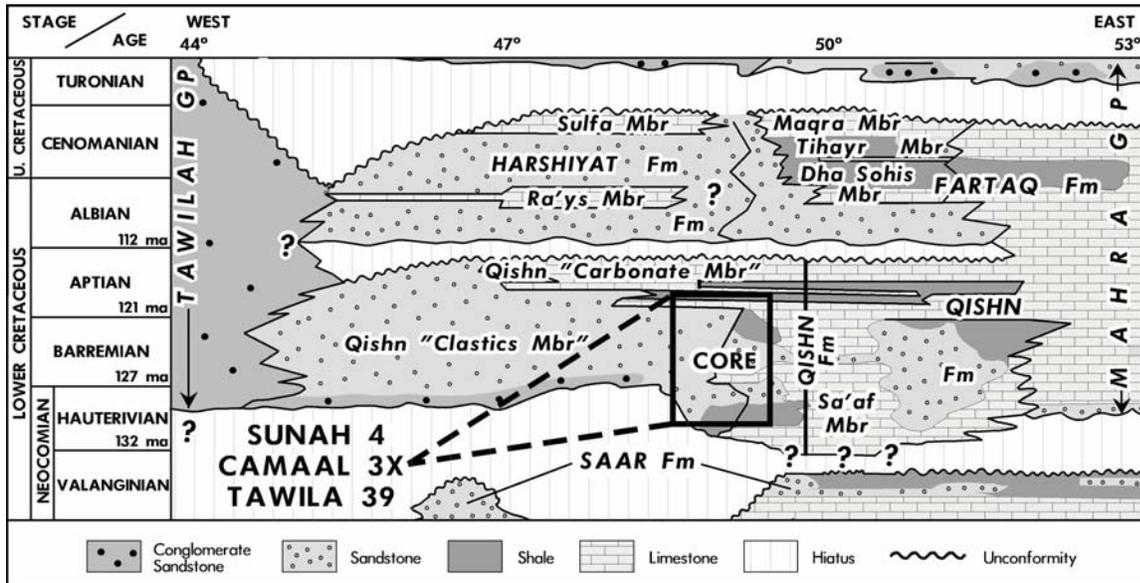


Fig. 2. Regional Lower Cretaceous stratigraphy in east-central Republic of Yemen (modified from Beydoun, 1997; Beydoun et al., 1998) showing the approximate stratigraphic position of the three cores described in this core display.

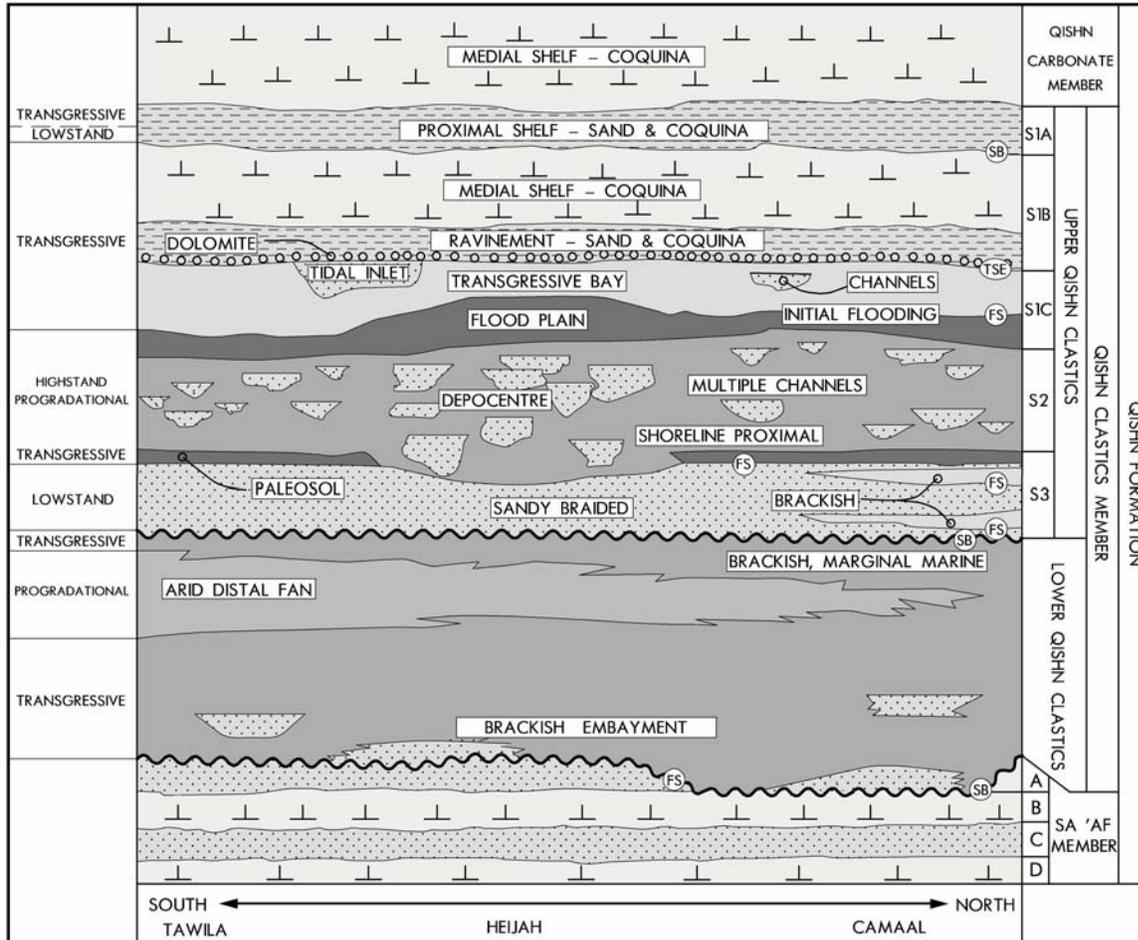


Fig. 3. Stratigraphy, bounding surfaces, facies assignments and interpretation of the Qishn Formation on the Masila Block 14, Republic of Yemen. SB refers to sequence boundary; TSE refers to transgressive surface of erosion; FS refers to flooding surface. No vertical or horizontal scale is implied.

Regional Setting

The Qishn Formation was deposited as predominantly post-rift sediments in the east-west oriented Say'un – al Masila rift basin (Fig. 4) that initiated during Late Jurassic to Early Cretaceous as part of the second Mesozoic rift phase. Deposition was related to a regional east to west transgression overlying a regional lower Cretaceous unconformity at the top of the Sa'af Member. Regionally, the Qishn Formation was deposited on an inner neritic to shallow-marine platform setting within the graben. During deposition of the Qishn Formation, the Say'un – al Masila Basin was open to fully-marine waters based on the presence of correlative carbonate strata toward the southeast at Socotra Island in the Gulf of Aden. Carbonates intertongue with fluvial deltaic to littoral deposits, becoming fully siliciclastic westwards (Fig. 2).

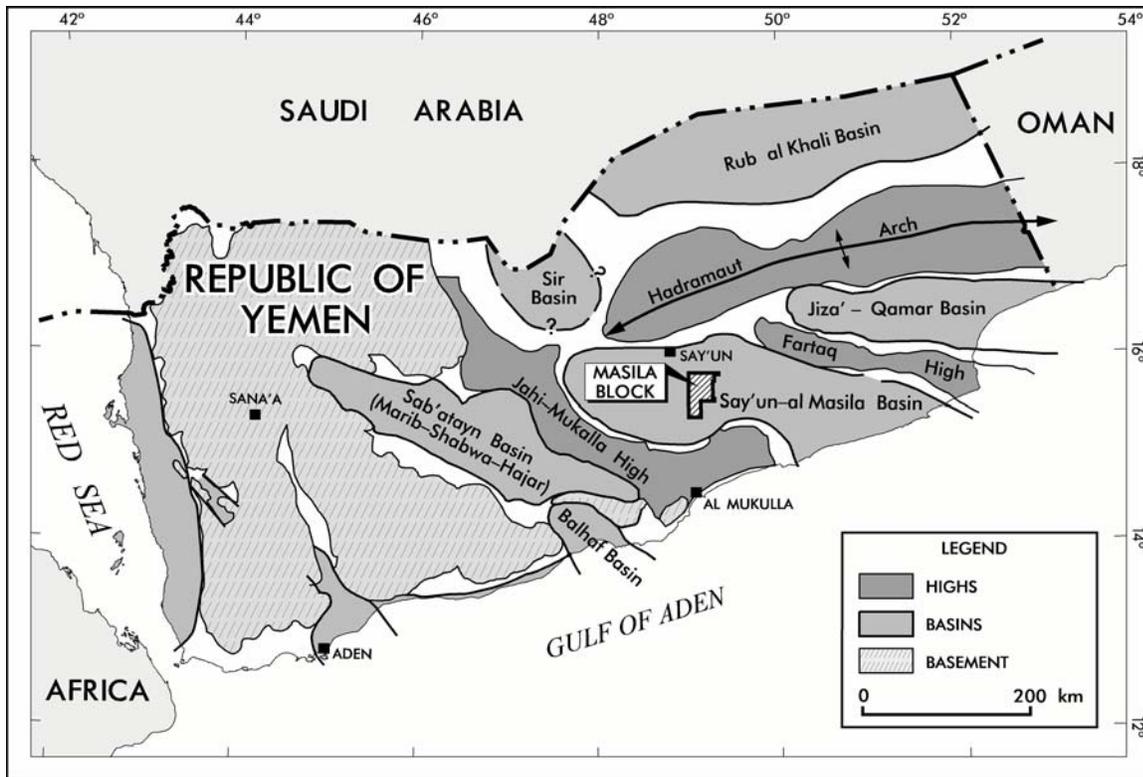


Fig. 4. Yemen Mesozoic rift basins modified from Beydoun et al. (1998) showing location of Nexen's Masila Block.

Core Of The Qishn Clastics Member

Core descriptions of the Qishn Clastics Member are shown in Fig. 5. Three cores are presented to provide a near complete composite section of the interval. The core descriptions (Fig. 5) show grain size, sedimentary structures, burrows, important bounding surfaces, and sedimentological interpretations.

Core from Tawila 39 (Fig. 5A) illustrates reservoir from the Lower Qishn Clastics Member. The Camaal 3X core (Fig. 5B) covers the uppermost Lower Qishn Clastics Member and most of the Upper Qishn Clastics Member. The Sunah 4 core (Fig. 5C) covers the S1A interval at the top of the Upper Qishn Clastics Member.

The lower Qishn Clastic Member (Tawila 39, Fig. 5A) reservoirs are subarkose with good to excellent reservoir quality with core porosity values as high as 28% and permeability values above 1 Darcy. Average porosity and permeability values are 25% and 560 millidarcies. Controls on reservoir porosity and permeability are grain size, sorting, sediment compaction, detrital clays, silica and carbonate cements, and carbonaceous-pyrite laminae.

Upper Qishn sandstones are of excellent quality with no inhibiting authigenic clays or diagenetic problems largely due to their quartz-rich composition and relatively shallow

depth of burial. Primary porosities are 15 to 28%, with an average of about 20%. Permeabilities range up to 10 darcies with an average of about 1.5 darcies. There are very minor quartz overgrowths and minor calcium carbonate cement.

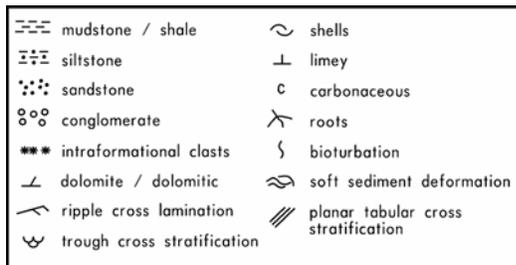
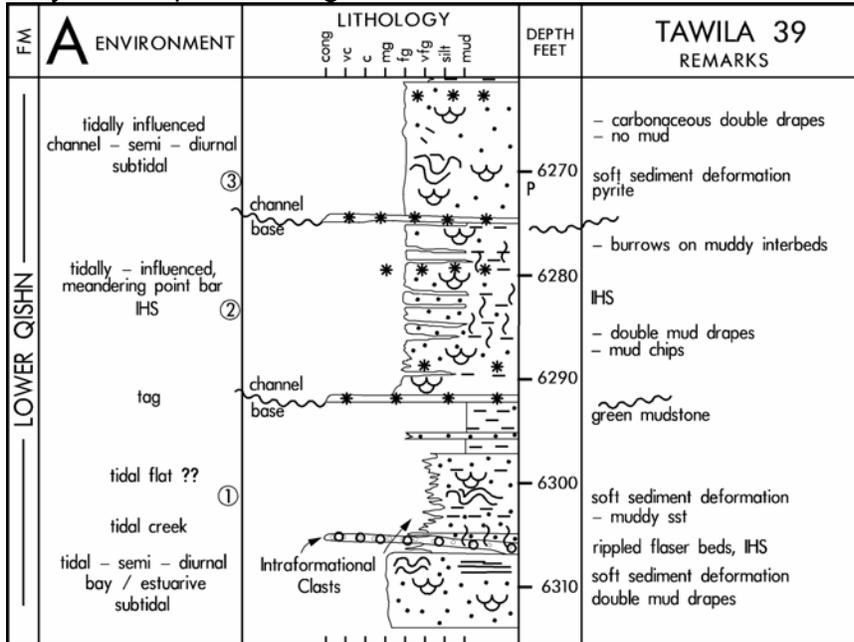


Fig. 5. Measured core sections of the Qishn Formation showing facies, bounding surfaces and interpretations. The three cores provide a near complete composite section of the Qishn Clastics Member. A) The Tawila 39 core shows reservoir rocks from the base of the Lower Qishn Clastics. Locations of cores shown in Fig. 1.

Sequence Stratigraphy

Fig. 6 summarizes the depositional framework of the Qishn Formation and provides a series of paleogeographic reconstructions. Two major sequence boundaries are present within the Qishn Clastics Member. The lowermost sequence boundary is present at the base of the lower Qishn Clastics Member, truncating the Sa'af Member (Fig.3). Evidence for this sequence boundary include indications of lithification with sandstone clasts of the underlying truncated Sa'af Member incorporated into the basal lower Qishn Clastics Member sediments.

The second major sequence boundary occurs at the base of the widespread S3. Strata of the lower Qishn Clastics Member, below the unconformity, consist of finely interdigitating (on a decimetre to meter scale) tidal flat, marginal marine, nonmarine and paleosol sediments. S3 sediments are the deposits of a braided river system deposited close to the shoreline. The facies relationships on either side of the unconformity represent an abrupt basinward shift in facies, one of the criteria to define a sequence boundary. There is also a marked petrographic change across the unconformity. Sandstones of the lower Qishn Clastics Member have feldspar contents of up to 56%. Above the basal S3 contact, feldspar content abruptly reduces to 0 to 7%.

There are several flooding surfaces within the Qishn Clastics Member (*Fig. 3*). The lowermost major flooding surface is that associated with brackish bay or estuarine to marine deposits onlapping the basal sequence boundary at the top of the Sa'af Member (Lower Qishn sandstone of Tawila 39 core - *Fig. 5A*).

S3 deposits are low accommodation fluvial deposits directly above the sequence boundary, likely associated with the lowstand to early transgression. A red, pedogenically-altered mudstone that commonly overlies S3 sandstones represents initial flooding of lowstand deposits. This mudstone occurs across most of the Masila Block, but is not present in the Camaal 3X core (*Fig. 5B*). Continued flooding is associated with bioturbated and green mudstone above the red mudstone below discontinuous S2 sandstone bodies (Camaal 3X, 1648-1649 m - *Fig. 5B*). The S2 sandstones were deposited as aggradational and highstand deposits of a tide-dominated delta with multiple distributaries (Camaal 3X, 1630-1648 m - *Fig. 5B*). Highstand coastal-plain deposits of the lower S1C consist of evaporative dolomitic lacustrine sediments, locally desiccated and rooted, that cap the distributary channels of the S2 (Camaal 3X, 1632-1638 m - *Fig. 5B*). In the inferred arid climate, there was minimal coaly sediment preserved. Evidence of the subsequent transgression occurs in the middle of the S1C. Initial flooding is commonly marked by an erosional surface and lag of coarser sand grains overlain by black, finely laminated lacustrine shale (Camaal 3X, 1628-1629 m - *Fig. 5B*). This surface and facies represents the beginning of relative sea level rise, rising water table and development of a broad shallow lake on the floodplain. Ongoing transgression is represented by tidal flat deposits, tidal inlet deposits with associated tidal-ravinement surface and then the shoreface ravinement surface (TSE Camaal 3X, 1624.5 m - *Fig. 5B*) at the base of the S1B. S1B consists of open-marine, shallow-shelf clastics grading up to deeper shelf, shelly carbonate and lime mudstone.

The overlying S1A consists of shallow shelf, clastic deposits transported by oceanic currents. The abrupt superpositioning of more proximal shelf clastics on medial shelf carbonates necessitates a fall in relative sea level with a sequence boundary at the contact between the lithological change; the sequence boundary is melded with a transgressive surface of erosion. In several cores, the contact was marked by a lag of coarse shell debris representing a transgressive lag overlying the TSE (Camaal 3X, 1612.1 m - *Fig. 5B*; Sunah 4, 1706 m, *Fig. 5C*).

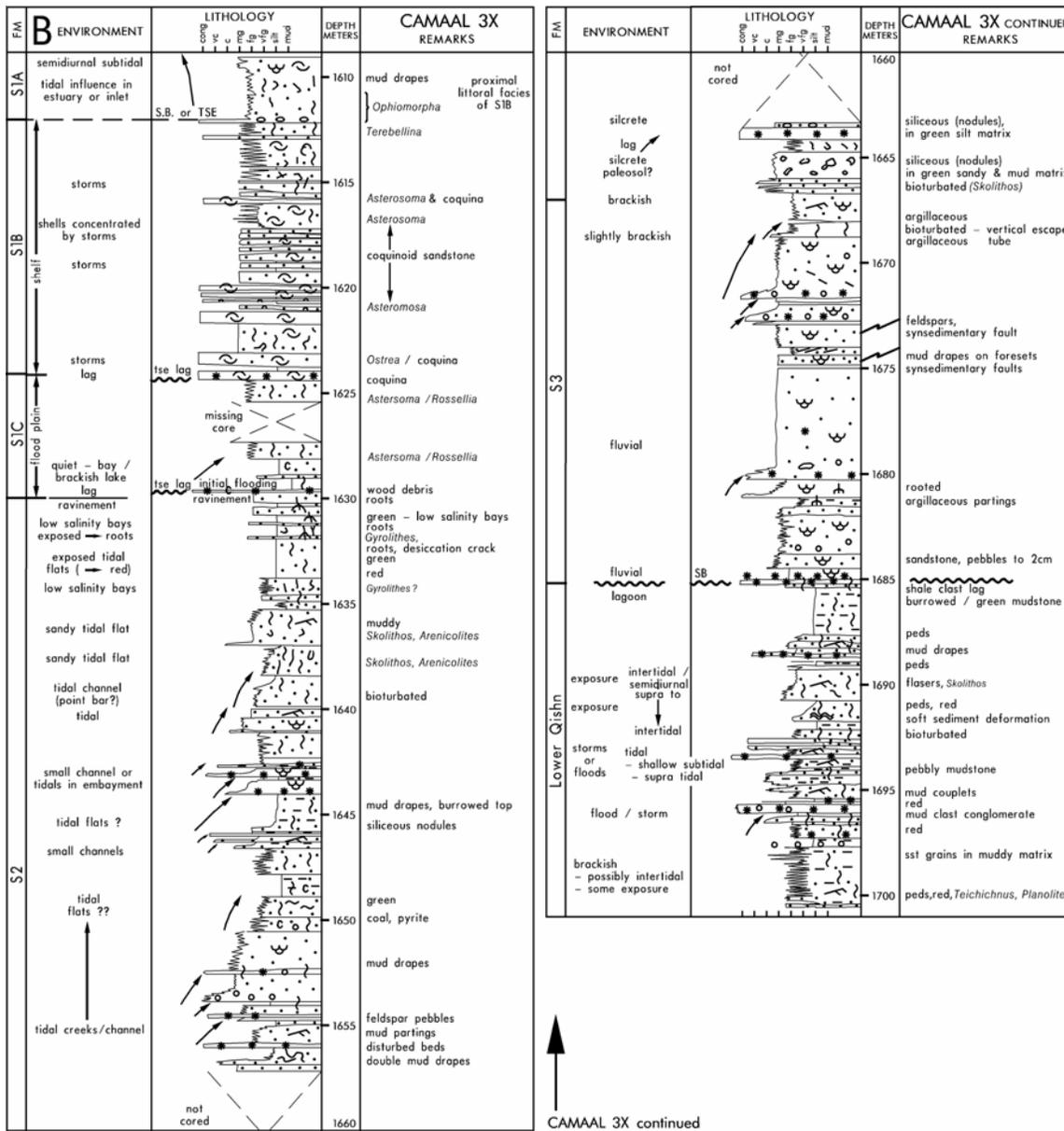


Fig. 5B. Measured core sections of the Qishn Formation showing facies, bounding surfaces and interpretations. Camaal 3X core covers the uppermost Lower Qishn Clastics and most of the Upper Qishn Clastics. Locations of cores shown in Fig. 1.

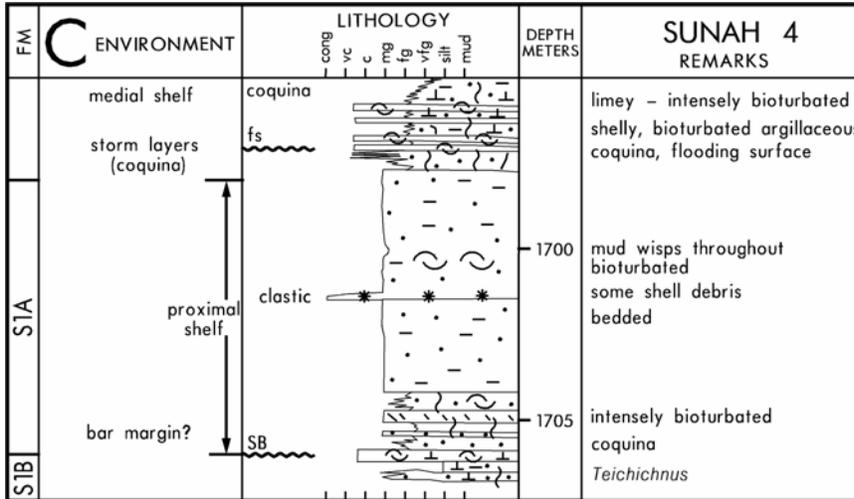


Fig. 5C. Measured core sections of the Qishn Formation showing facies, bounding surfaces and interpretations. Sunah 4 covers the S1A interval at the top of the Upper Qishn Clastics. Locations of cores shown in Fig. 1.

Fig. 6. Note: Fig. 6 on following page. Paleogeographic reconstructions of the Qishn Formation in the Masila Block 14. A. for time of lower Qishn Clastics Member showing transgressive bay/estuary facies; B. for time of S3 showing sandy braided fluvial system proximal to shoreline; C. for time of S2 and lower S1C showing progradational tide-dominated delta; D. for time of transgressive facies of the S1C showing lakes, lagoons, barrier islands and tidal inlets; E. for time S1B showing fully marine shelf carbonates; F. for time of S1A showing fully marine clastic shelf deposition with formation of shelf ridges.

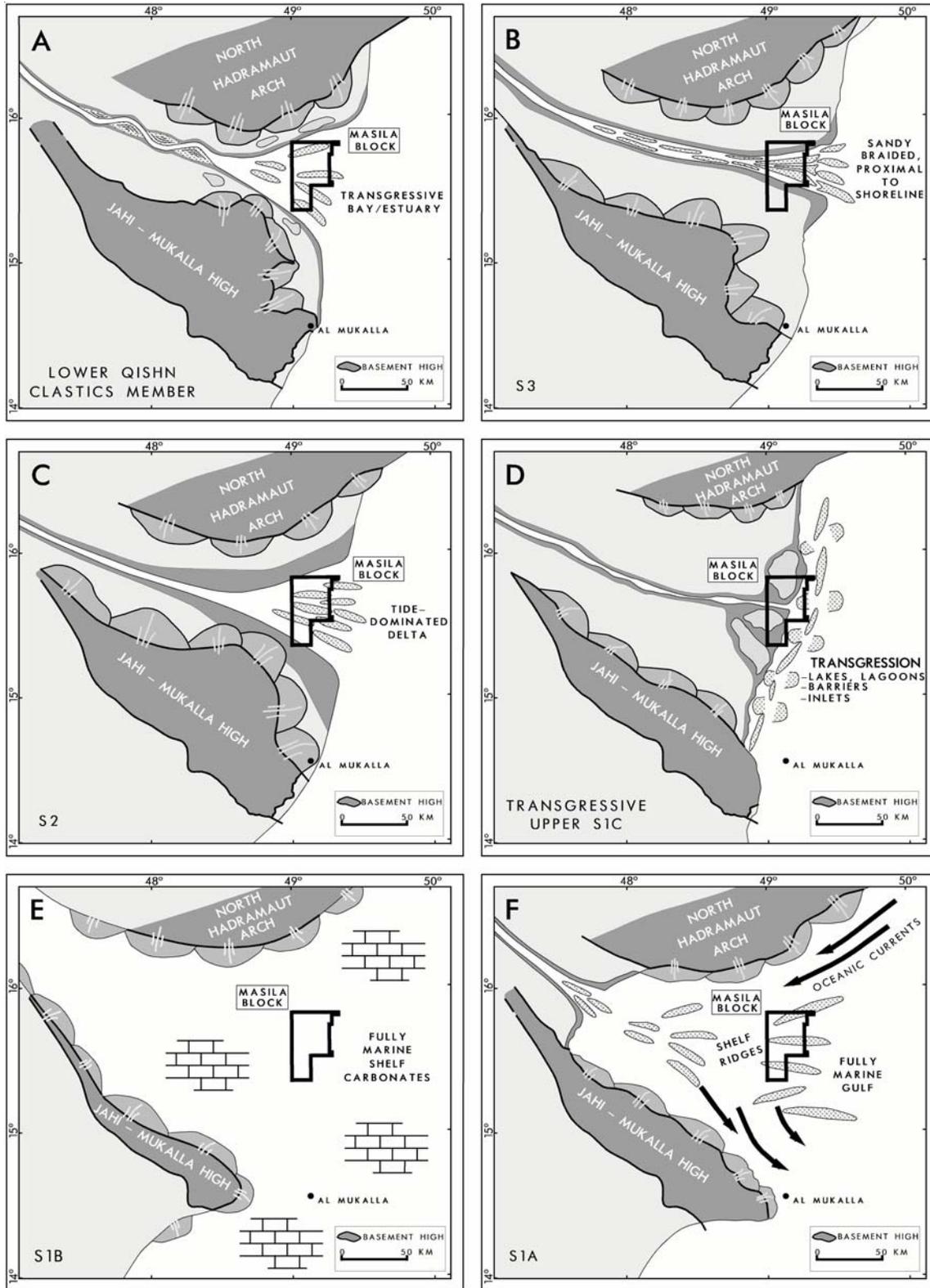


Fig. 6. Paleogeographic reconstructions of the Qishn Formation in the Masila Block 14. Description notes on previous page.

Evidence Of Tides

Fully marine and brackish strata throughout the lower Qishn Clastics Member bear indicators of tides. Double mud and carbonaceous drapes, tidal bundles, evidence of salinity variations, mud flats and tidal inlets (S1C) indicate significant (macrotidal?) and prevailing tides. Evidence of storms is extremely rare in fully marine strata of the S1B and S1A, only being inferred in a few instances from rare hummocky beds and coquina layers in mudstone or sandstone. Marine conditions dominated by carbonates prevailed to the east and nonmarine clastics to the west. The Say'un – al Masila Basin had a funnel shape, tapering westwards from several hundred kilometres wide to approximately 60 km wide (*Fig. 4*). To the east, it was connected to the open Tethys Ocean (paleo-Indian ocean) on the early-rifted Gondwanaland continent. The tapering and constricting configuration of the Say'un – al Masila rift basin facing the paleo-Indian ocean would have been the ideal setting for the development and amplification of tides.

Paleoclimate

There are several indicators of Lower Cretaceous paleoclimate within sediments of the Qishn Formation. Dolomite occurs as diffuse microcrystalline forms and as nodules up to 10 cm (4 inch) diameter at several horizons. The dolomite is associated with green to grey mudstone, which variably contains roots, desiccation cracks and may or may not be bioturbated (Camaal 3X, 1648-1648 m; *Fig. 5B*). The dolomite indicates deposition in shallow coastal water bodies that were saline to hypersaline and characterized by seasonally-variable salinity, similar to that described from the coast of Brazil (Vansconelos et al., 1995). In the Brazilian example, climate is semi-arid with seasonally high evaporation rates. In the Qishn Formation, the lakes periodically dried up resulting in the formation of desiccation cracks formed in the mudstone. This is consistent with the abundance of red mudstones.

Red coloration of sediments requires oxidizing conditions, preferably in a tropical to subtropical climate with a distinct dry season. Palynomorphs in the red mudstones are typically highly oxidized. Pedogenic slickensides and gilgai, most common in red mudstones in the Lower Qishn, base of the S2, and in the S1C, require seasonal wetting and drying to induce alternations of shrinking and swelling. Mudstone clast conglomerate beds that occur in the Lower Qishn are typical of flash floods that occur in an arid climate. These indicators show that the climate in Yemen during the Lower Cretaceous was arid and seasonally wet.

Conclusions

This cores presented in this paper illustrate the detailed sedimentology, sequence stratigraphic setting and paleogeography of a 1.1. billion barrel oil field. Major reservoirs units include the deposits of sand and gravel braided rivers, tidally-influenced distributary channels, sand flats, sand shoals, and tidal ridges.

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