# Sedimentological and micropalaeontological evidence to elucidate post-evaporitic carbonate palaeoenvironments of the Saudi Arabian latest Jurassic

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**Key-words:** Saudi Arabia, Tithonian, Hith Firmation, Manifa Reservoir, micropalaeontology, evaporates, carbonates.

**ABSTRACT:** The Hith Formation forms the youngest lithostratigraphic unit of the Jurassic Shaqra Group. It represents the culmination of a succession of hypersaline and euryhaline cycles that characterise the Late Jurassic of Saudi Arabia. The Formation is poorly exposed in central Saudi Arabia, but it has been studied in detail in subsurface eastern Saudi Arabia where the upper carbonate member hosts an important hydrocarbon reservoir called the Manifa Reservoir. Chronostratigraphic control is absent from the formation itself, and the Tithonian age is suggested for the Hith Formation based on its stratigraphic position between the underlying Arab Formation of Late Kimmeridgian age, and the overlying Sulaiy Formation, of Late Tithonian to Berriasian age.

The Hith Formation needs redefining in the light of new lithological evidence, and a tripartite member scheme is suggested. This includes the lower anhydrite-dominated member here termed the "anhydrite" member, and considered to represent hypersaline subaqueous deposition within a restricted deep lagoon during the lowstand systems tract of the Manifa sequence. A "transitional" member consists of interbedded anhydrites and carbonates and approximates with the transgressive zone. The overlying "carbonate" member represents the results of a prograding shallow, normal salinity marine succession related to the highstand systems tract. Interbedded carbonates within the evaporites are interpreted to represent superimposition of a higher frequency, possibly 4$^{th}$ order eustatic cyclicity.

The "carbonate" member hosts the Manifa Reservoir, and here proposed as the Manifa Member, consist of five parasequences, each of which represents a shoaling-upwards cycle with a succession of up to five repeated lithofacies and biofacies that commences with a stromatolitic, microfaunally-barren unit followed by fine-grained grainstones with a monospecific but abundant ostracod biofacies. A succession of coarse pelloidal grainstones with rare foraminifera, including *Redmondoides lugeoni, Trocholina alpina* with a variety of unidifferentiated valvulinids and miliolids then follows, that passes vertically into coarse ooid grainstones, with rare *Redmondoides lugeoni*, forming the uppermost part of each parasequence.

## INTRODUCTION

The Hith Formation of Saudi Arabia, of Late Jurassic age, is characterized by its predominantly anhydritic composition. Within its upper part, however, is a succession of shallowing upwards carbonates with well-preserved primary porosity that hosts hydrocarbons within the Manifa Reservoir of various Saudi Arabian oil fields. The Formation is the youngest lithostratigraphic unit of the Jurassic Shaqra Group of the Kingdom (Powers *et al*. 1966; Powers 1968; Sharland *et al*. 2001). The evaporitic character commences within the Arab Formation, of Kimmeridgian age, and persists into the middle part of the Hith, as currently defined. The evaporite-carbonate association has considerable economic importance, and attempts have been made to interpret such lithological couplets within a sequence stratigraphic framework (Sarj 2001). The objective of this paper is to document the lithology and micropalaeontology of the upper carbonates of the Hith Formation and to discuss their origin.

The Hith Formation is difficult to date with certainty, but a Tithonian age is concluded based on the presence of Kimmeridgian foraminifera within the underlying Arab Formation, and of Tithonian to Berriasian coccoliths in the overlying Sulaiy Formation (Osman Varol, written communication 2006).

The depositional environment of the anhydrite-dominated lower Hith Formation is considered to have been subaqueous, and to represent a prolonged hypersaline event similar to those that preceded it on three main occasions within the Arab Formation (Alsharhan and Kendall 2003; Al-Husseini 1997; Sharland *et al*. 2001; Hughes 2004). The upper part of the Hith Formation consists predominantly of grainstones, although muddier carbonates are also present. The contact between the lower "anhydrite" and the upper "carbonate" members is characterized by a succession of interbedded anhydrites and limestones that are proposed as the "transitional" member.

The study, upon which these new findings are based, focused on subsurface samples from wells drilled on Manifa Field, offshore Saudi Arabia (Fig. 1) contributing to pre-development hydrocarbon reservoir characterization for Saudi Aramco.

## LITHOSTRATIGRAPHY

The Hith Formation was initially described from a single exposure east of Riyadh, where the predominantly anhydritic lithology caused it to be termed the Hith Anhydrite (Powers *et al*. 1966; Powers 1968). The type locality is at the foot of the escarpment known as Dahl Hith, where the succession is 90.3 m (296 ft) thick (Figs 2-3). It is considered to be conformably underlain by the Arab Formation, and overlain by the Sulaiy Formation with possible disconformity. The anhydrite is known to be replaced to the east and south by halite. The Hith Anhydrite is partly equivalent to the Gotnia Anhydrite of Iraq (Dunnington 1967; Al-Husseini 1997) and to part of the Asab Oolite in Abu Dhabi (Ayoub and En Nadi 2000; Sharland *et al*. 2001). Possible equivalence of the Hith carbonate with the Makhul Formation of Kuwait, and the Rayda Member of the Habshan Formation in Abu Dhabi has yet to be confirmed. The Hith covers much of the Arabian Plate and has been mapped in Kuwait, Saudi Arabia, the United Arab Emirates, Oman and Yemen (Ziegler 2001, fig. 11).

Although not formally subdivided, the formation can be conveniently considered to consist of three members, based on subsurface evidence, and include the lower "anhydrite" member, the middle "transitional" anhydrite-carbonate member and the upper "carbonate" member (Fig. 4).

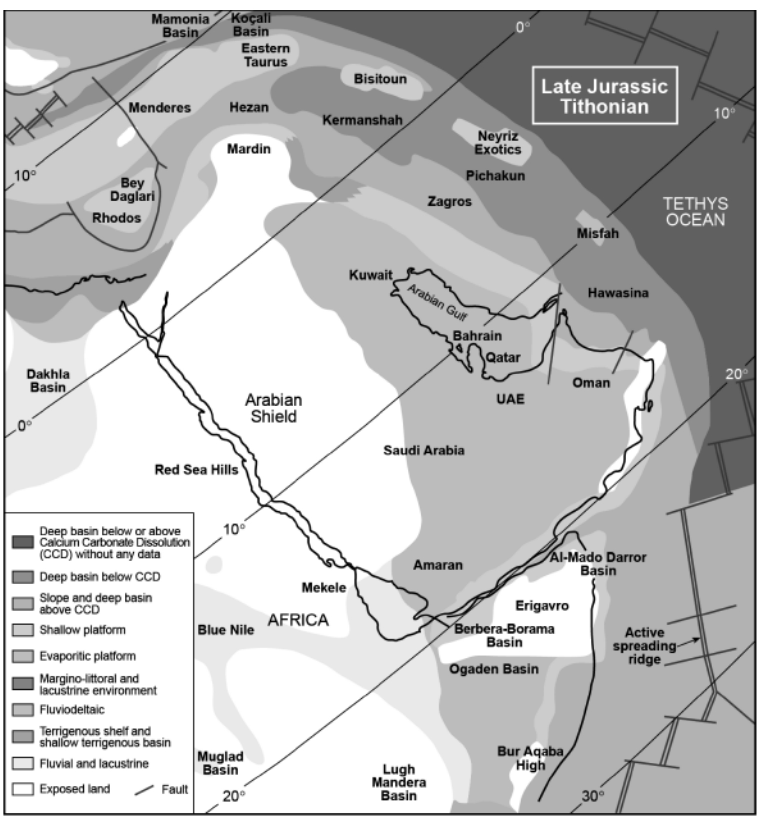



Fig. 1. Palaeoenvironment and tectonic reconstruction of the Late Jurassic, Late Tithonian (146-144 Ma, after Le Nindre *et al.* 1987; Fourcade *et al.* 1993). Figure from Al-Husseini (1997, fig. 11).

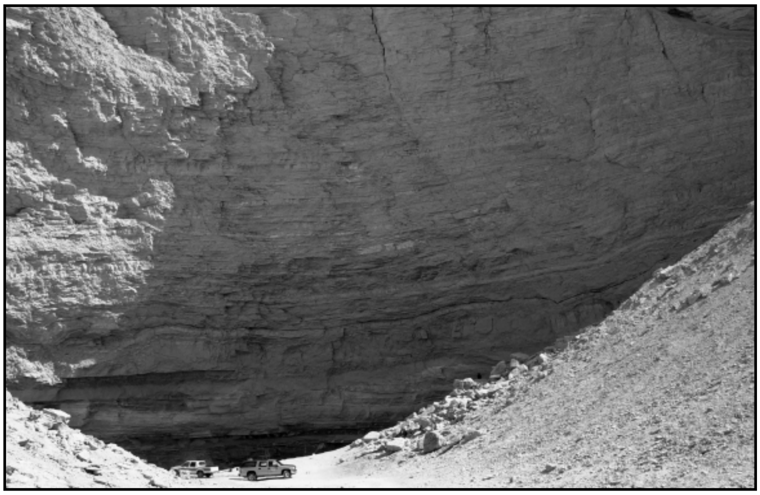


Fig. 2. Dahl Hith, central Saudi Arabia (N 24°29.033; E 46°59.818) where the upper evaporites (lower, darker beds beneath undulating contact) of the Hith Formation are overlain by the Sulaiy Formation. This is the type location for the Hith Formation (note vehicles for scale). See Fig. 3 for detail of contact.

The upper part of the carbonate member hosts the Manifa Reservoir, and it is here suggested that this unit should be named the Manifa Member, as first used by Wilson (1985). Lack of information on the overlying Sulaiy Formation currently precludes inclusion of the Manifa Member as a basal, early transgressive component of the Sulaiy Formation, although such a consideration may be more allostratigraphically correct. The lower evaporate member has not been studied, but is composed of up to 92 m (300 feet) of anhydrite. The middle transitional unit, in Manifa Field, consists of up to 21 m (66 feet) of interbedded anhydrite and carbonate units, each of approximately 3-4.5 m (10 to 15 feet) thick. The upper carbonate unit is up to 31 m (100 feet) thick and consists of a succession of five depositional cycles that are terminated by the transgressive beds of the basal Sulaiy Formation.

## BIOSTRATIGRAPHY

Limestones interbedded with evaporites of the upper Hanifa Formation, together with the limestones not associated with evaporites of the Manifa Member have been analysed extensively for micropalaeontology, but biocomponents of biostratigraphic significance are rare. Using the stratigraphic ranges of Whittaker *et al.* (1998), the presence of the benthonic foraminifera *Trocholina palastiniensis* would indicate an age not younger than the Scruposus Zone of the Upper Tithonian. The foraminiferal species *Redmondoides lugeoni* is well-represented, and must be considered to range younger than the Late Oxfordian age assigned by Whittaker *et al.* (1998). Typical Jurassic benthonic foraminiferal genera, such as *Kurnubia* and *Nautiloculina*, are absent, but considered to be excluded by adverse, probably hypersaline, environmental conditions. Tithonian coccoliths, including the Tithonian species *Conusphaera mexicana minor*, have been recovered from the lower Sulaiy Formation, in the absence of Cretaceous species (Osman Varol, personal communication). Vaslet *et al.* (1991) submitted a sample of anhydrite from Dahl Hith for oxygen ($^{18}O = +13.3$) and sulphur ($^{34}S = +13.3$), and state that these values fitted well within a Late Jurassic portion of the curve of Claypool *et al.* (1980).

Biostratigraphic investigation of the Hith Formation in adjacent countries is also limited, but strontium isotope studies on samples from the Arab-A and Hith anhydrite in Abu Dhabi (Azer and Peebles 1998) provided Late Kimmeridgian and Early Tithonian ages, respectively. The Rayda Formation of Oman yields small ammonites belonging to Perisphictidae of uppermost Tithonian age (Rousseau *et al.* 2005) and would support a Tithonian age for the equivalent Hith carbonates in Saudi Arabia. It is of interest to note that these forms are present 5 m (16.4 ft) above the basal Rayda unconformity, and 15 m (49.2 ft) below the presence of lowermost Berriasian calpionellids. In Kuwait, the Makhul Formation is considered

Fig. 3. Dahl Hith, central Saudi Arabia, showing bedded grey anhydrite overlain by pale-brown carbonates of the Sulaiy Formation. At this location, the Hith carbonates are not developed.

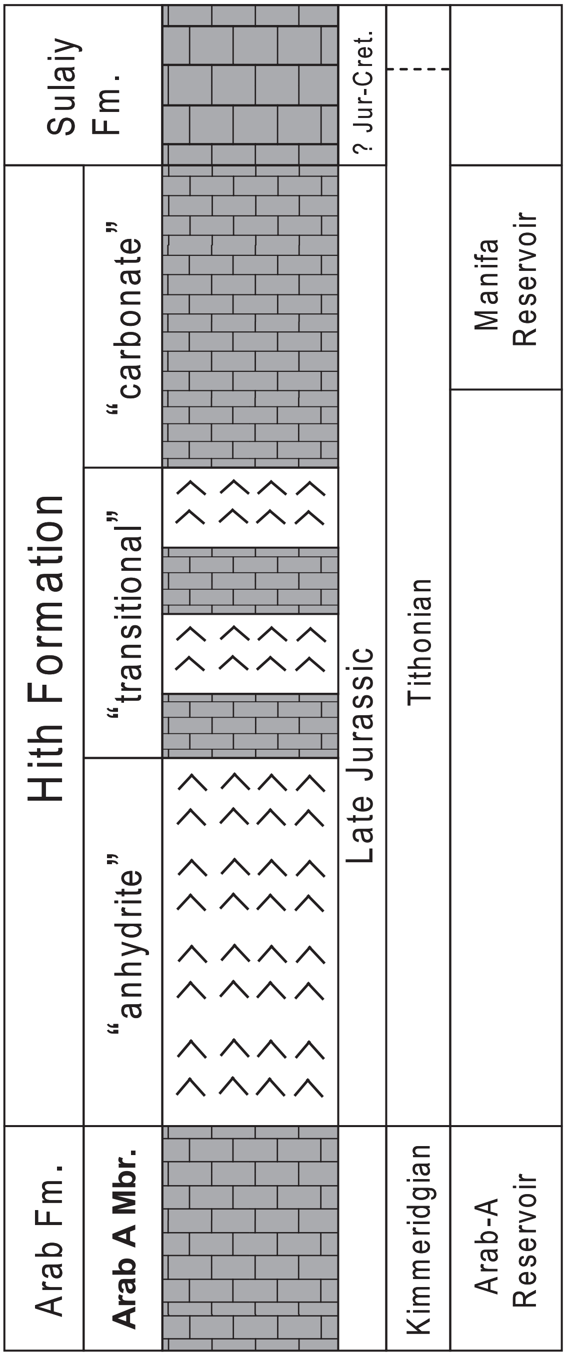



Fig. 4. Lithostratigraphical subdivision of Hith Formation (not to scale).

by Yousif and Nouman (1997) to equate with the lower Sulaiy Formation of Saudi Arabia. It yields the Tithonian coccolith species *Conusphaera mexicana minor*, and the overlying Minagish Formation yields the coccolith *Polycostella senaria* proving a Berriasian age (Al-Fares *et al.* 1998). This suggests that the Jurassic-Cretaceous boundary in Saudi Arabia may not, as expected and reported by Ziegler (2001), conveniently coincide with the Hith-Sulaiy sequence boundary but may lie within the lower Sulaiy Formation, and further work is required to resolve this problem. The Hith Formation lies within the Arabian Plate megasequence AP8 of Sharland *et al.* (2001), of which the maximum flooding surface J110 is considered to be located within the "... stromatolitic Manifa carbonates above the Hith..." and to equate with a basal shaley limestone of the Makhul Formation.

## SEQUENCE STRATIGRAPHY

Integrated sedimentology and micropalaeontology of an oilfield in Saudi Arabia has yielded a succession of shoaling upwards depositional cycles, considered to be 3rd order sequences, that naturally divide the reservoir into lower and upper sequences. The lower sequence has been subdivided into three higher frequency, probably 4th order sequences, labeled 1A, 1B and 1C. The upper sequence has been subdivided into three higher frequency, probably 4th order sequences, labeled 2A, 2B, 2C and 2D (Fig. 5). A suggested origin for the various lithologies and relationships in which the carbonates are associated with elevated sea levels and the evaporites to episodes of reduced sea level.

## BIOFACIES, LITHOFACIES AND PALAEOENVIRONMENT

Semi-quantitative micropalaeontological analysis of thin sections taken from core samples, at one foot spacing has provided considerable insight into the biocomponent composition as well as providing evidence for defining various biofacies. This study has led to the recognition of environmentally significant biofacies, of which their vertical tiering provides significant contributions towards ongoing hydrocarbon reservoir characterisation studies.

### Carbonates interbedded with Hith "transitional" evaporites

Carbonates from the Hith inter-evaporitic "transitional" succession typically consist of grainstones. Micropalaeontological components that indicate a lower transgressive-linked biofacies that includes *Redmondoides*, pelloids and minor ostracods and stromatolite and an upper, regression-associated ooid-dominated succession.

**The Manifa Carbonates**

With reference to Fig. 6, a series of five biofacies and four local sub-biofacies are recognised, each of which displays a relationship with the underlying biofacies. It should be noted, however, that not all biofacies are present at each location. Each of the following biofacies has been interpreted in terms of the palaeoenvironmental significance.

**Biofacies 1 (Stromatolites/Microbialites)**(Pl. 1: 1-6).
LITHOLOGY: Thinly laminated packstone-to-grainstone boundstone that exhibits well preserved fenestral porosity. Stromatolites are found mostly in the lower section of the Manifa Reservoir.
MICROPALAEONTOLOGICAL COMPONENTS: none except for microbialite laminae.
PALAEOENVIRONMENTAL INTERPRETATION: very shallow marine, very hypersaline, low energy, possibly intertidal or within shallow sub-tidal inter-bank depressions.

**Biofacies 2 (Ostracod)**(Pl. 2: 1-8).
**Biofacies 2a (Abundant thin-walled ostracods).**
LITHOLOGY: very fine-grained grainstones that are locally associated with thin beds of oolitic grainstones.
MICROPALAEONTOLOGICAL COMPONENTS: abundant thin shelled, monospecific ostracods.
PALAEOENVIRONMENTAL INTERPRETATION: very shallow marine, moderately low energy, probably elevated salinity conditions that exclude foraminifera.

**Biofacies 2b (Abundant very thin-walled ostracods).**
LITHOLOGY: very fine-grained grainstones that are locally associated with thin beds of oolitic grainstones.
MICROPALAEONTOLOGICAL COMPONENTS: abundant very thin-walled ostracods.
PALAEOENVIRONMENTAL INTERPRETATION: very shallow marine, moderately low energy, probably elevated salinity conditions that exclude foraminifera.

**Biofacies 2c (Abundant thin and very thin-walled ostracods).**
LITHOLOGY: very fine-grained grainstones that are locally associated with thin beds of oolitic grainstones.
MICROPALAEONTOLOGICAL COMPONENTS: abundant thin-walled and very thin-walled ostracods.
PALAEOENVIRONMENTAL INTERPRETATION: very shallow marine, moderately low energy, probably elevated salinity conditions that exclude foraminifera.

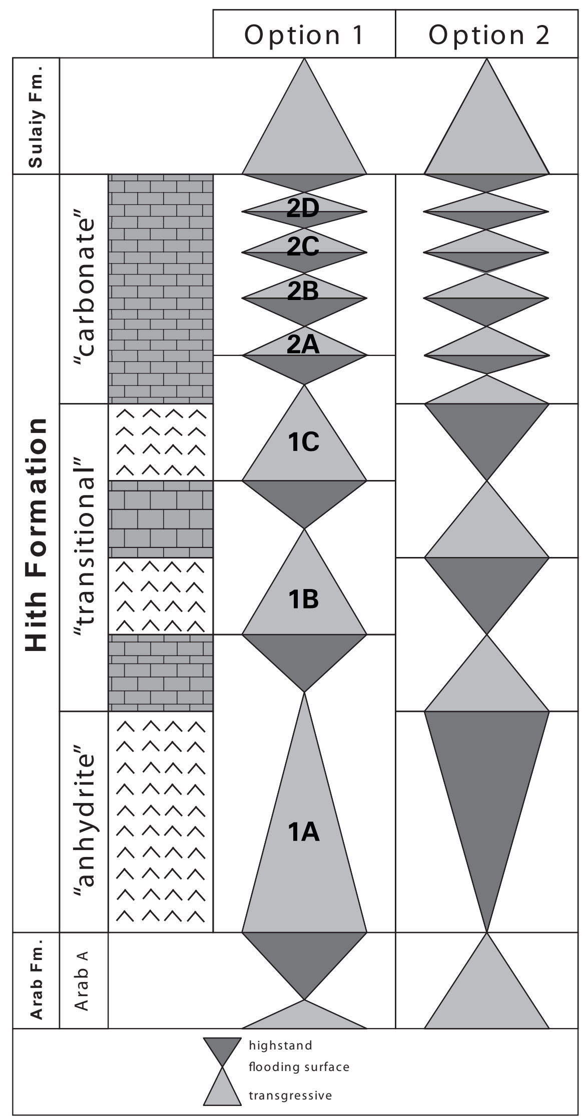



Fig. 5. Diagrammatic representation of the suggested influence of 3rd and 4th order of eustatic sea level variation on the type of lithology deposited.

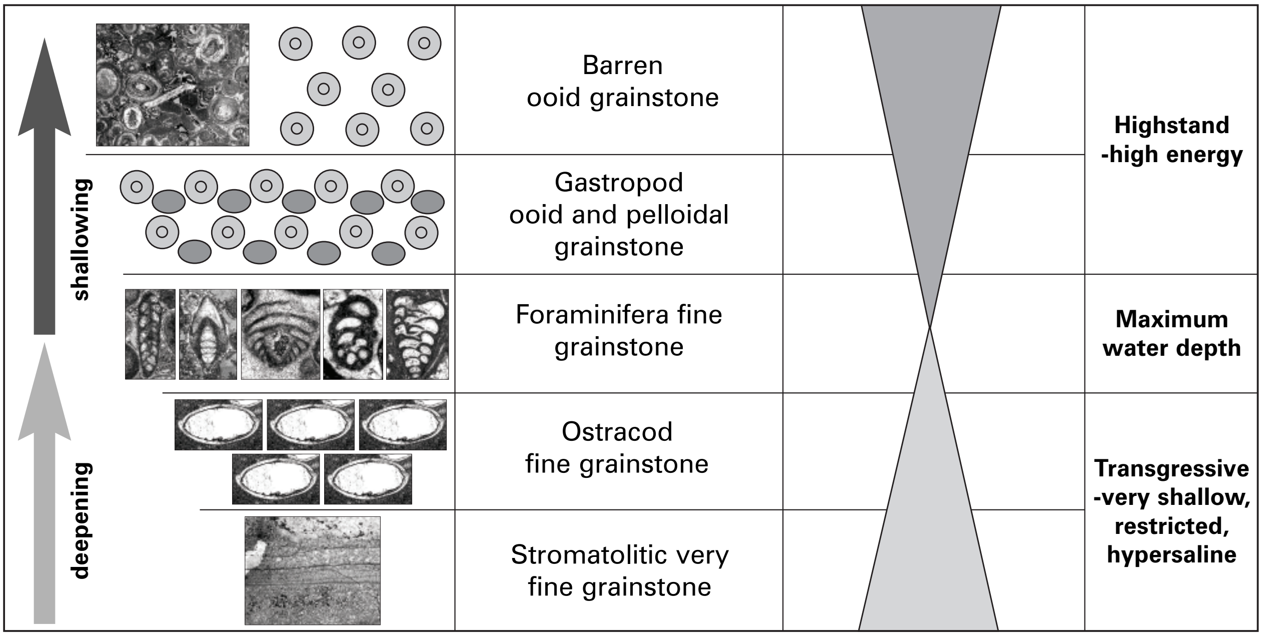



Fig. 6. Biofacies and their stratigraphic tiering within a single depositional cycle of the Manifa carbonate, i.e. the uppermost member of the Hith Formation.

**Biofacies 3 (Foraminifera)**(Pl. 3: 1-11).

LITHOLOGY: moderate to fine-grained grainstones.

MICROPALAEONTOLOGICAL COMPONENTS: brachiopod fragments, ostracods, gastropods, foraminifera including: *Redmondoides lugeoni*, *Trocholina alpina*, *Reophax* spp., *Pseudocyclammina* spp., *Siphovalvulina* spp., *Quinqueloculina* spp., high conical forms resembling *Coskinolina* spp. and forms resembling *Pfenderina* spp. On the flanks of the Manifa Field, slightly deeper conditions are suggested by the rare presence of *Lenticulina* spp.

PALAEOENVIRONMENTAL INTERPRETATION: shallow marine, normal salinity, moderately low energy.

**Biofacies 4 (Gastropod)**(Pl. 1: 8; 3: 12-15).

LITHOLOGY: Ooid and pelloidal grainstones, occasionally cross-bedded with rare cryptalgal laminations; found mostly in the lower section of Manifa Reservoir.

MICROPALAEONTOLOGICAL COMPONENTS: cerithid gastropods.

PALAEOENVIRONMENTAL INTERPRETATION: shallow marine, normal to possibly elevated salinity, high energy, possibly intertidal or adjacent to ooid-pelloid shoals.

**Biofacies 5 (Barren)**

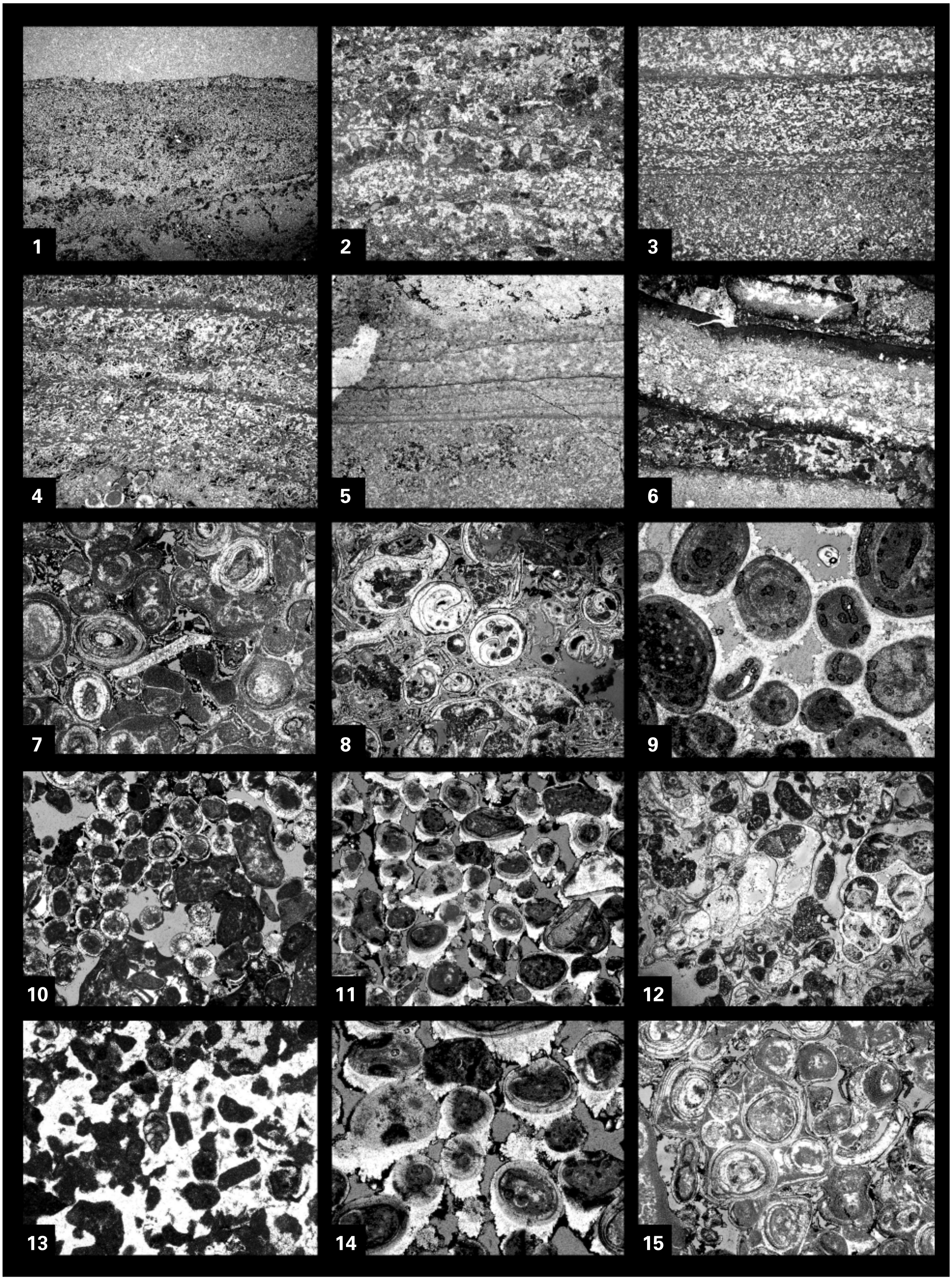
LITHOLOGY: Ooid grainstones, mostly cross-bedded well-sorted high-energy medium-to-coarse grained; found in the upper section of reservoir where it represents the best developed Manifa Reservoir.

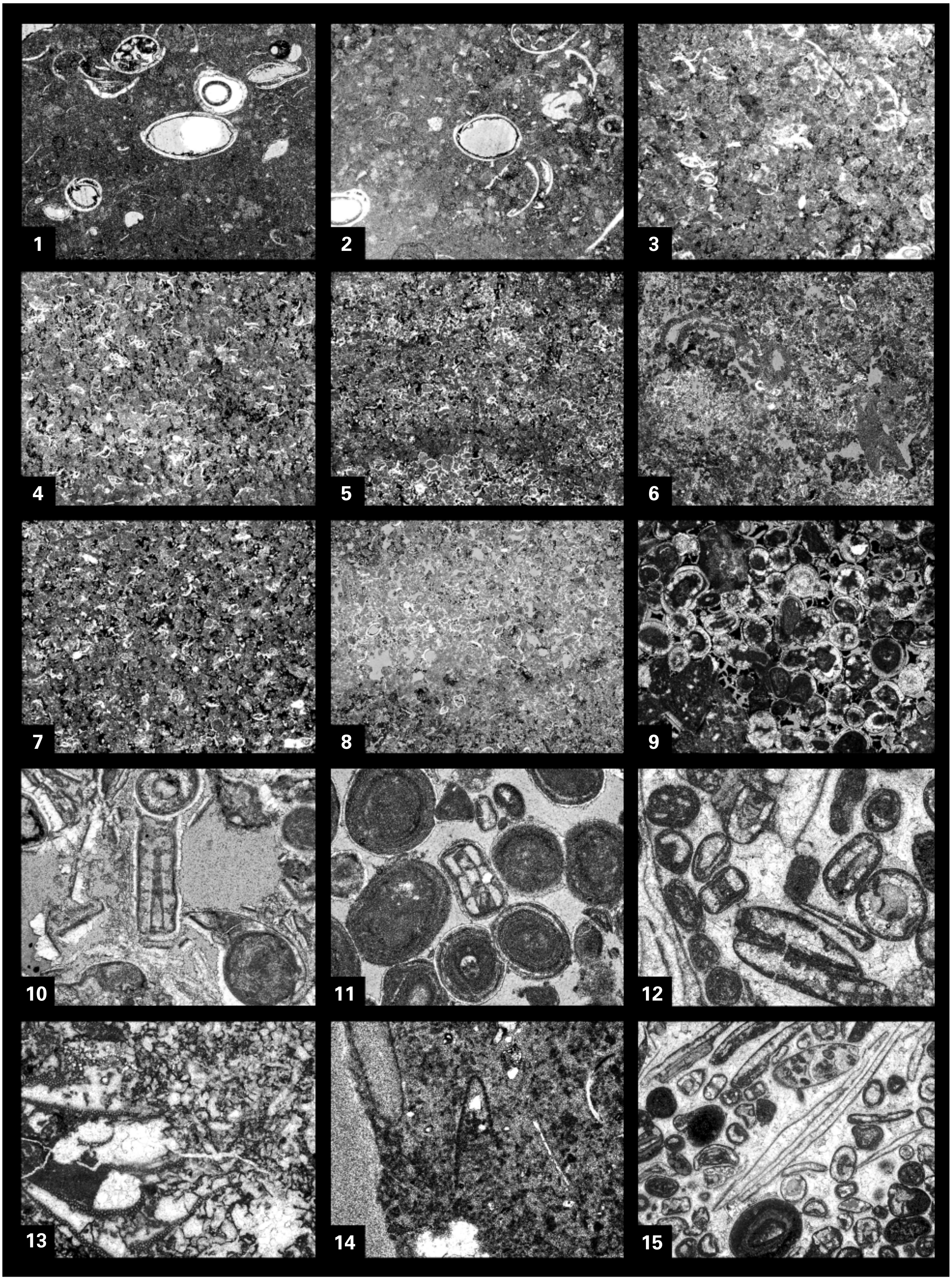
MICROPALAEONTOLOGICAL COMPONENTS: barren.

PALAEOENVIRONMENTAL INTERPRETATION: shallow marine, hypersaline, very high energy, possibly intertidal or within ooid shoals.

Plate 1

Photomicrographs of selected biocomponents from the Manifa reservoir, Manifa Field (width of image given in mm): 1 – stromatolite, MNIF-25, plug #863 (8 mm); 2 – stromatolite, MNIF-59, plug #725, (4 mm); 3 – stromatolite, MNIF-27, plug #645 (8 mm); 4 – stromatolite, MNIF-27, plug #270 (8 mm); 5 – stromatolite, MNIF-23, plug #217 (4 mm); 6 – stromatolite, MNIF-63, plug #214 (8 mm); 7 – ooid grainstone, MNIF-25, plug #928 (4 mm); 8 – ooid and gastropod grainstone, MNIF-11, plug #11 (8 mm); 9 – ooid, pelloid and *Favreina* grainstone, MNIF-2, plug #652 (2 mm); 10 – ooid and peloid grainstone, MNIF-25, plug #932 (4 mm); 11 – ooid and pelloid grainstone with pendant cement, MNIF-26, plug #821 (4 mm); 12 – ooid and gastropod grainstone, MNIF-59, plug #630 (8 mm); 13 – juvenile *Valvulina* sp. in cemented grainstone, MNIF-27, plug #763 (2 mm); 14 – ooid and pelloid grainstone with pendant cement, MNIF-26, plug #821 (2 mm); 15– ooid and intraclast grainstone, MNIF-59 plug #602 (4 mm).

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## PALAEOENVIRONMENTAL DISCUSSION

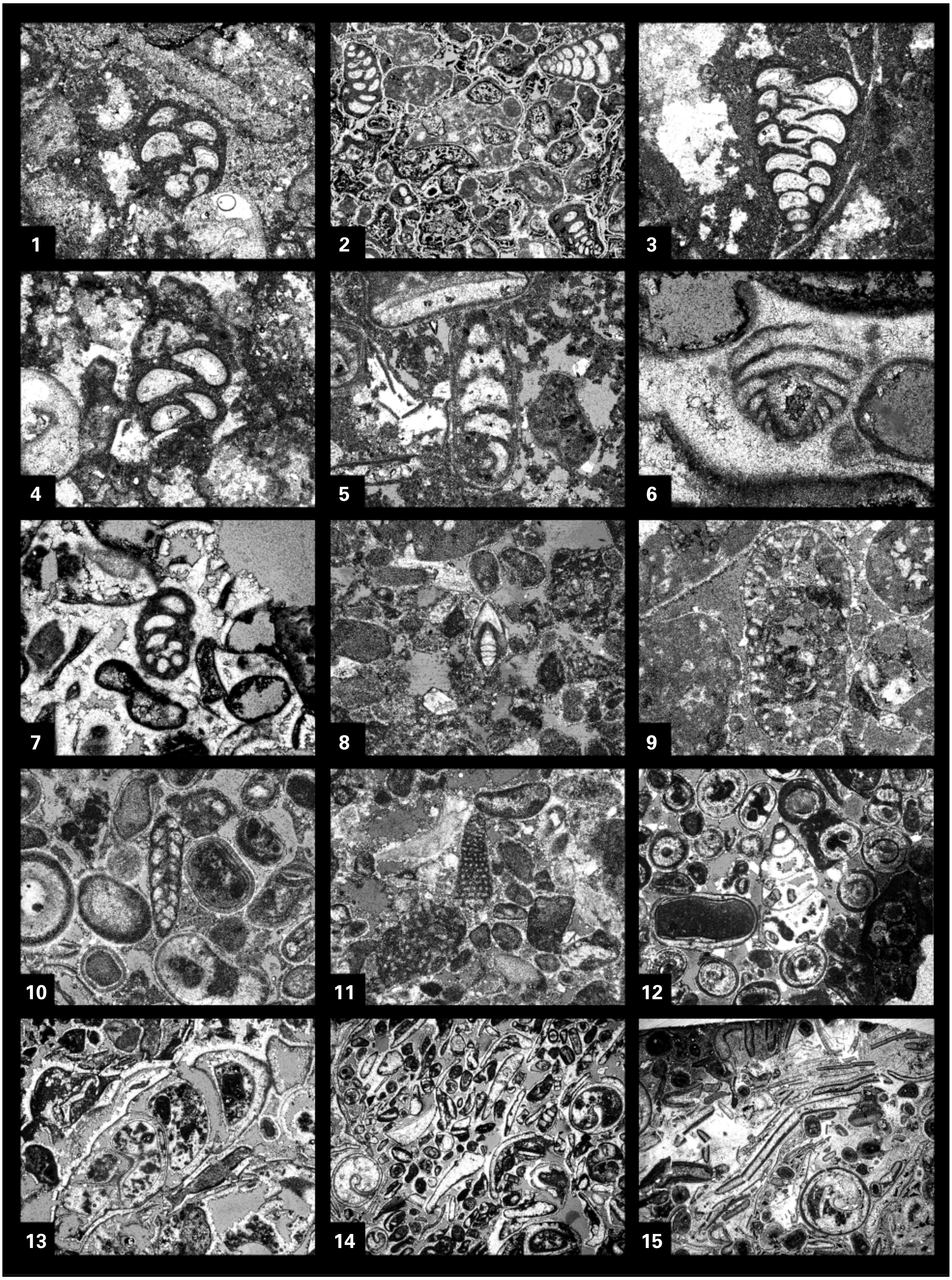
The Hith Formation forms the uppermost lithostratigraphic unit within the Jurassic succession known as the Shaqra Group (see Hughes 2009). This predominantly carbonate unit becomes increasingly evaporitic during the latter part of the Late Jurassic, leading Alsharhan and Scott (2000) to conclude that the Hith represents "...the final regressive, supratidal stage of the last major Jurassic cycle...". There is an ongoing discussion regarding the most accurate interpretation of the Late Jurassic evaporites of Saudi Arabia, for which the fossiliferous carbonates and their sedimentology may contribute some valuable supportive evidence. Before the carbonates are discussed, it is worth expanding on the concepts currently being considered for the origin of the underlying evaporites.

Palaeoenvironments that led to the deposition of evaporates are the focus of much attention, and mechanisms for their origin range from evaporitic pumping within a supratidal sabkha setting to a submarine hypersaline setting. Mixed sabkha and submarine or playa-like, conditions are interpreted for the Hith Formation in the Arabian Gulf region by Warren and Kendall (1985) and Alsharhan and Kendall (1994) in which a carbonate/sabkha barrier existed along the eastern and southern margins of the Arabian Platform. A subaqueous origin associated with restricted conditions during the late highstand is concluded by Le Nindre *et al.* (1990). Al-Husseini (1997, fig. 12) suggests that the Hith evaporites could have formed during the late transgressive systems tract as well as the early highstand, and accumulated landwards of the Arab-A and Asab carbonates. The entire Hith of Abu Dhabi has been subdivided into five depositional cycles by Azer and Peebles (1998), of which the lowermost carbonate component is considered to represent the transgressive episode and followed by highstand-associated evaporites.

It is acknowledged that both settings, *i.e.* supratidal sabkha and submarine hypersaline, may be represented within evaporates that are interbedded with the Arab Formation carbonates (Bob Lindsay, Saudi Aramco, oral communication, 2006). The relatively great thickness of the Hith "anhydrite" can be compared, to a certain degree, with the Middle to Late Miocene evaporites of the Red Sea (Hughes and Johnson 2005), where the Mansiyah Formation displays over 3800 ft of anhydrite with minor halite. Unlike the Red Sea, however, the Arabian platform is considered to have hosted intra-shelf basins during the Late Jurassic, with no evidence for exceptional depths (Al-Husseini 1997). The presence of karst features at the top of the carbonates of the Arab-D Member of the Kimmeridgian Arab Formation in Saudi Arabia (R.F. Lindsay, Saudi Aramco, oral communication, 2006) and of exposure surfaces, karst and channeling below and above the Arab-B carbonates (C. Toland, oral communication, 2007) suggest that the carbonates are disconnected from the overlying evaporites and that they do not pass into them as a depositional continuum.

A saltern is a term applied to "extensive shallow subaqueous evaporite beds, up to 50 m thick, deposited across hundreds of kilometers in the hypersaline portions of an ancient .....seaway" (Warren 2006). The Hith anhydrite has been considered as a saltern by Azer and Peebles (1998) and Warren (2006). Hydrographic separation of the Arabian Platform from the Tethys Ocean must have existed during the Hith saltern development, but were the extreme hypersaline conditions created during a eustatic lowstand or highstand Warren (2006, p. 724) suggests that marine transgressions caused flooding of the shelf and permitted carbonate deposition. During the subsequent regression, shelf-edge shoals were exposed to create a hydrodynamic barrier that caused hypersaline conditions to replace the previous normal salinity conditions, leading to gypsum precipitation. Warren further states (p. 347) that low amplitude low frequency sea level oscillations in greenhouse earth favoured formation of stable, large, highly restricted, at times evaporitic, depre-

Plate 2
Photomicrographs of selected biocomponents from the Manifa reservoir, Manifa Field (width of image given in mm): 1 – ostracod and pelloid packstone, MNIF-26 plug #825 (2 mm); 2 – ostracod and pelloid packstone, MNIF-26 plug #708 (4 mm); 3 – ostracod and pelloid packstone, MNIF-63 plug #279 (2 mm); 4 – ostracod and pelloid packstone, MNIF-27 plug #708 (4 mm); 5 – ostracod and pelloid packstone, MNIF-25 plug #954 (4 mm); 6 – burrows in ostracods and pelloidal grainstone, MNIF-6 plug #517 (4 mm); 7 – ostracod and pelloid packstone, MNIF-25 plug #956 (4 mm); 8 – ostracod and pelloid packstone, MNIF-25 plug #928 (4 mm); 9 – ooid grainstone, MNIF-25 plug #930 (4 mm); 10 – dasyclad and ooid grainstone, MNIF-26 plug #737 (2 mm); 11 – ooid and dasyclad grainstone, MNIF-63 plug #235 (2 mm); 12 – cemented dasyclad grainstone, MNIF-23 plug #123 (2 mm); 13 – *Lithocodium aggregatum* and *Thaumatoporella parvovesiculifera*, MNIF-23 plug #153 (4 mm); 14 – *Aeolisaccus kotori*, MNIF-63 plug #209 (2 mm); 15 – gastropod and replaced dasyclad and bivalve/alga grainstone, MNIF-23 plug #123 (4 mm).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ssions on the inner portions of many marine platforms. Strasser (1994) describes such cycles from the Jurassic-Cretaceous. The effect of slight sea level fall on a rimmed carbonate platform, such as the Arabian Platform during the Kimmeridgian-Tithonian, would tend to isolate large expanses of shallow shelf depressions behind continuously exposed reef or shoal rims. This would lead to hypersaline conditions, with saltern development if there was sufficient seepage replenishment of sea water, during both or either high frequency, low amplitude eustatic fluctuations. Such a situation would explain the interbedded carbonates and anhydrites in the "transitional" facies of the Hith, in which the carbonates would relate to increasingly dominating transgressive events within high frequency eustatic fluctuations. The continuous presence of carbonates in the upper Hith, or Manifa Member, would represent a permanent trend of sea level rise and an end to marine isolation of the platform.

The carbonates display a succession of biofacies and lithofacies that is partly or completely represented in most of the five cycles identified in the inter- and post-evaporitic carbonates. The biofacies and lithofacies tiered succession of basal stromatolitic very fine grainstone, ostracod fine grainstone, foraminiferal fine grainstone, ooid and pelloidal grainstone and ooid grainstone, provide clues towards the palaeoenvironmental controls. The stromatolites are interpreted to represent initial adverse, probably hypersaline conditions that may have existed within a restricted, low energy, intertidal to shallow subtidal environment. The overlying ostracod-bearing grainstones indicate a slight change in conditions that could be tolerated by the monospecific, high abundance but very low diversity foraminiferal assemblages. Near normal marine conditions are suggested by the overlying low abundance and low diversity foraminifera-bearing grainstones. The overlying pelloid-ooid and subsequent ooid grainstone lithofacies that are barren of in-situ biocomponents suggest shallow, high energy conditions. The trend is, therefore, one of low energy hypersaline conditions that gradually reduce salinity conditions to a level that permits shallow marine, typically of normal salinity, to become established within the foraminiferal grainstones. This phase is followed by increasingly adverse conditions related to high energy and possibly elevated salinity. This trend could be readily explained by a gradual rise and subsequent fall of sea level.

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Plate 3

Photomicrographs of selected biocomponents from the Manifa reservoir, Manifa Field (width of image given in mm): 1 – *Redmondoides lugeoni,* MNIF-63 plug #211 (2 mm); 2 – *Redmondoides lugeoni*, MNIF-59 plug #563 (4 mm); 3 – *Redmondoides lugeoni*, MNIF-63 plug #213 (2 mm); 4 – *Redmondoides lugeoni*, MNIF-63 plug #211 (2 mm); 5 – *Ammobaculites* sp., MNIF-63 plug #223 (2 mm); 6 – *Trocholina*/*Anderselina* cf. *alpina*, MNIF-27 plug #665 (1 mm); 7 – *Ammobaculites* sp., MNIF-27 plug #665 (2 mm); 8 – planispiral rotalid, MNIF-2 plug #121 (2 mm); 9 – *Pseudocyclammina lituus*, MNIF-2 plug #120 (2 mm); 10 – *Bolivina* sp., MNIF-2 plug #628 (2 mm); 11 – *Coskinolina* sp., MNIF-2 plug #120 (2 mm); 12 – gastropod and ooid grainstone, MNIF-63 plug #223 (2 mm); 13 – gastropod and pelloid grainstone, MNIF-63 plug #229 (4 mm); 14 – gastropod and dasyclad grainstone, MNIF-82 plug #258 (10 mm); 15 – gastropod and replaced bivalve/algal plate grainstone, MNIF-11 plug #11 (10 mm).

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