

PS Carbonate Facies and Depositional Environments of the Marrat Formation (Lower Jurassic), North Kuwait*

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Abstract

Unlike the Gulf of Mexico region and most of the Atlantic continental margins, where stratigraphic successions of Lower Jurassic age are thin or absent, the presence of the Lower Jurassic Marrat Formation in the outcrop region of western Saudi Arabia and in the subsurface of the Arabian Gulf has been known for many years. These strata were thought to be non-prospective until quite recently with limited well penetrations in the northern part of Kuwait. Recent discovery of six independent gas and oil condensate fields in deeper Jurassic reservoirs in this area stimulated an active exploratory drilling and coring program covering an area of about 2000 sq km in North Kuwait. Thirty deep, high-temperature and high-pressure wells have been drilled in the North Kuwait area to date with production mainly from the middle portion of the Marrat. Typical production rates per well is in the range of 2500 to 5,500 BOPD/BCPD and 7 to 15 MMSCFPD. Detailed study of approximately 3,500 feet of core from 22 wells has allowed identification of lithofacies and depositional environments in the middle and upper Marrat Formation. No reefs or large carbonate buildups have been found in these cores, although there is a wide variety of algal and cryptalgal features and thin biostromal algal accumulations. Oolites and mixed high-energy grainstone facies accumulated in aggrading and prograding shoreface/shoal environments, separating a lagoon, tidal flats and sabkha from an open shelf. The shelf can be divided into inner and outer shelf. Limited penetrations of probable slope and basinal strata have also been seen in cores. Reservoir-quality rocks have been found in high-energy shoreface and island/shoal facies but are most often developed in burrowed mudstones, dolomitized by seepage refluxion. The dolomites that have been seen in association with the sabkha environment were syngenetic and mimic original depositional texture. They are very fine-grained and not of reservoir quality. The Marrat, which has a total thickness of approximately 2,000 feet, has been informally divided into lower,

middle and upper units, separated by maximum flooding surfaces (MFS). These flooding surfaces have been correlated to the sequence stratigraphic framework for the Arabian Plate.

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ABSTRACT

Unlike the Gulf of Mexico region and most of the Atlantic continental margins, where stratigraphic successions of Lower Jurassic age are thin or absent, the presence of the Lower Jurassic Marrat Fm. in the outcrop region of western Saudi Arabia and in the subsurface of the Arabian Gulf has been known for many years. These strata were thought to be non-prospective until quite recently with limited well penetrations in the northern part of Kuwait. Recent discovery of six independent gas and oil/condensate fields in deeper Jurassic reservoirs in this area stimulated an active exploratory drilling and coring program covering an area of about 2000 sq km. Thirty deep, high-temperature, and high-pressure wells have been drilled in the North Kuwait area to date, mainly from the middle portion of the Marrat. Typical production per well is approximately 5,500 BOPD and 15 MMSCFPD. Detailed study of approximately 4,400 feet (1,440 M) of core from 25 wells has allowed identification of lithofacies and depositional environments in the middle and upper Marrat Fm. No reefs or large carbonate buildups have been found in these cores, although there is a wide variety of algal and cryptalgal features and thin biostromal algal accumulations. Oolites and mixed high-energy grainstone facies accumulated in aggrading and prograding shoreface/shoal environments, separating a lagoon, tidal flats, and sabkha from an open shelf. The shelf can be divided into inner and outer shelf. Limited penetrations of probable slope and basinal strata have also been seen in core. Reservoir-quality rocks have been found in high-energy shoreface and backshoal/shoal facies but are most often developed in burrowed mudstones, dolomitized by seepage refluxion. The dolomites that have been seen in association with the sabkha environment were syngenetic and mimic original depositional texture. They are very fine-grained and not of reservoir quality. The Marrat, which has a total thickness of approximately 2,000 feet, has been informally divided into lower, middle, and upper units. The maximum flooding surfaces J10 and J20 have been correlated to the sequence stratigraphic framework for the Arabian Plate.

SEQUENCE STRATIGRAPHY

The first plate-wide sequence stratigraphic framework for the Arabian Plate was published by GeoArabia (Sp. Pub. 2, Sharland and others, 2001). That sequence framework used genetic stratigraphic sequences (GSSs), as defined by Galloway (1989), separated by maximum flooding surfaces (MFSs). The figure above right, combined and modified from Figures 3-22 and 3-25 of Sharland and others (2001), shows the sequence framework for the Late Triassic to Early Cretaceous for the Arabian Plate. Yousif and Nouman (1997) had proposed a type section for the Jurassic of Kuwait, based on Minagish-27, dividing the Marrat Fm. into five informal units (A to E). Sharland and others (2001) extended their sequence framework to the Minagish-27 well (reproduced below, right), placing their J10 MFS in the lower portion of the Marrat and their J20 MFS in the overlying Dhurma Fm. Core work has shown that the J10 MFS of Sharland and others is actually in argillaceous lagoonal facies and the proper location of this boundary is approximately 200 feet (66 m) higher, in the middle Marrat (right). That surface has been penetrated by four of the cores studied for this report. The section below the J10 MFS, seen in two of those cores, deepens upward for nearly 100 feet (33 m), from grainstones to deep outer shelf or basinal environments. Because of the paucity of argillaceous sediment in most of the middle Marrat, the J10 MFS and most of the higher-order flooding surfaces cannot be identified without the aid of core. For this reason, development of a sequence stratigraphic framework for the Marrat is an ongoing project.

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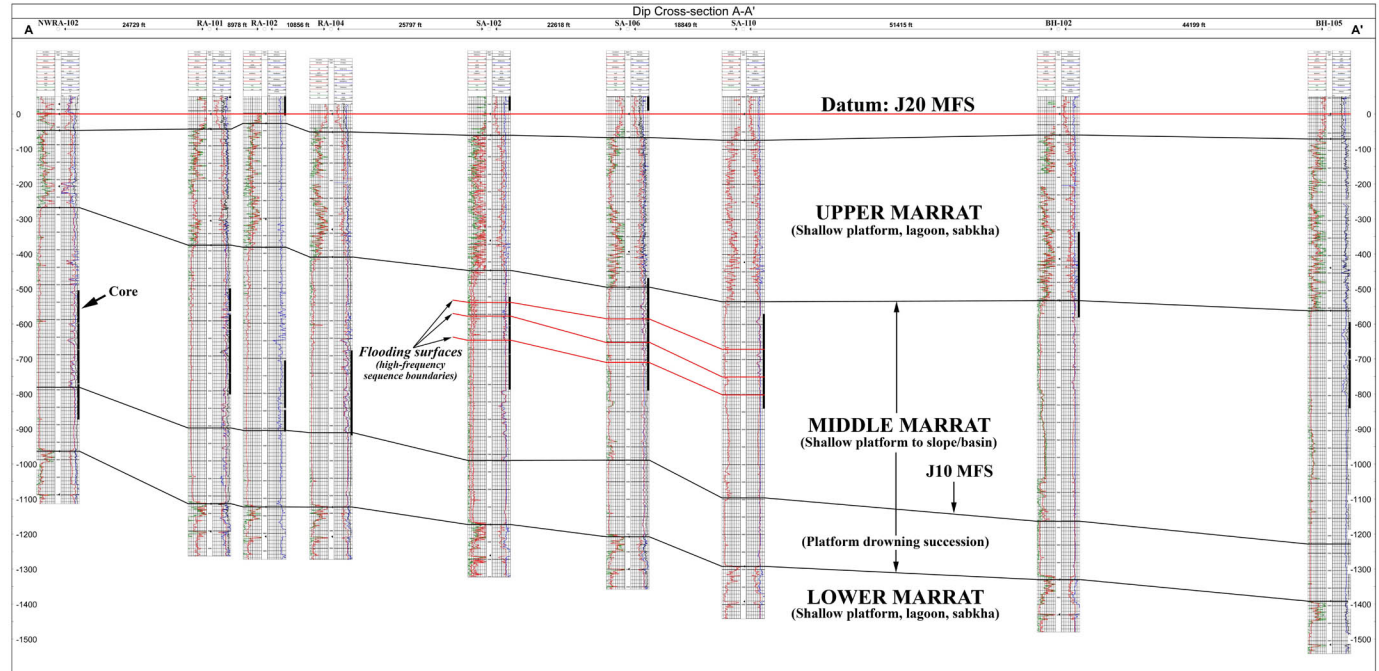
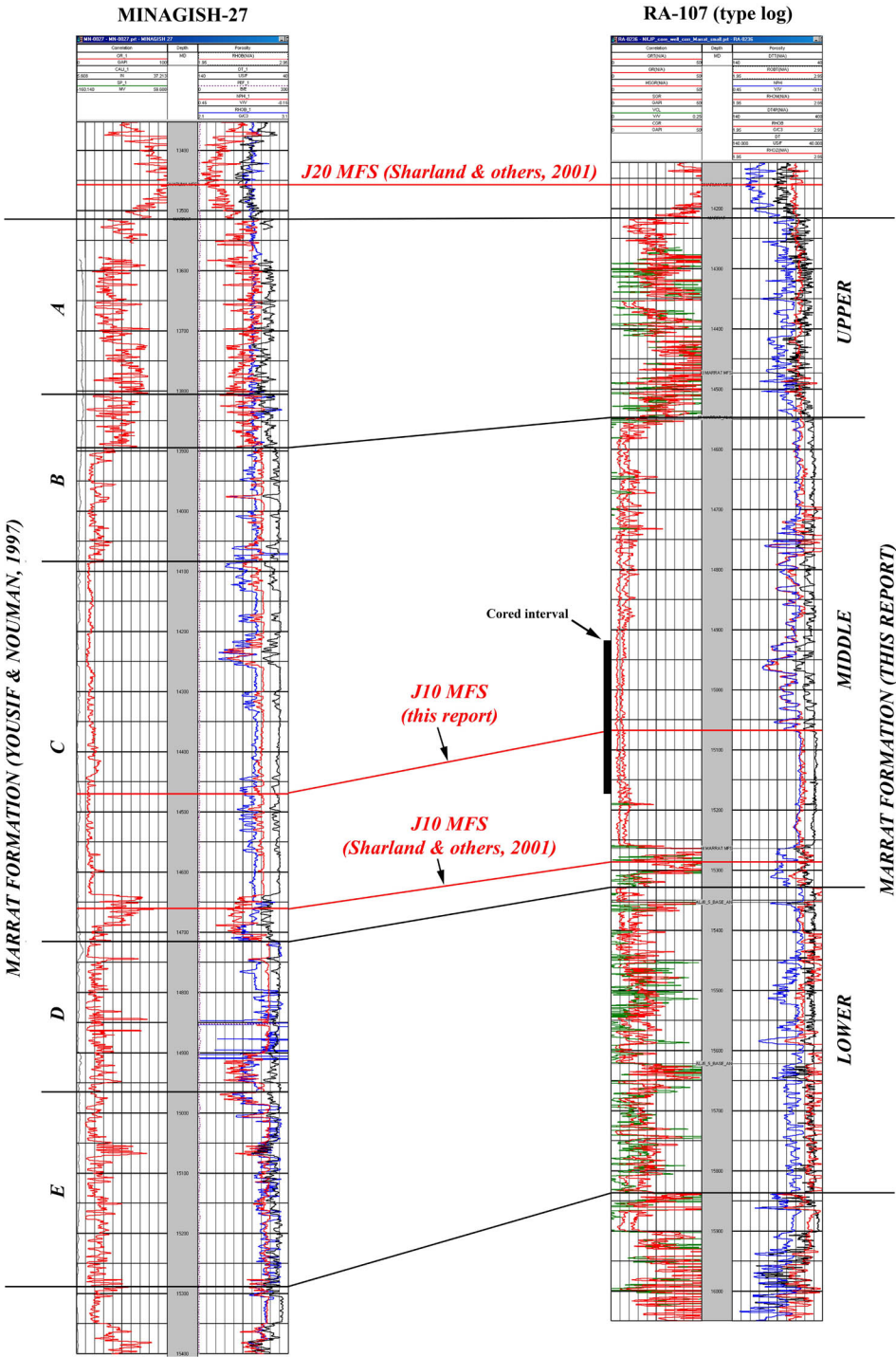
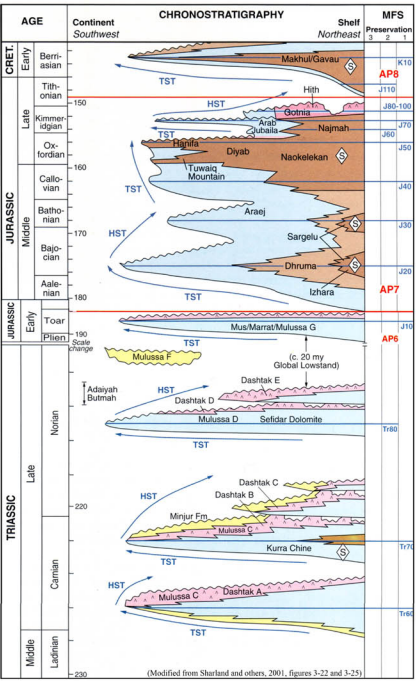
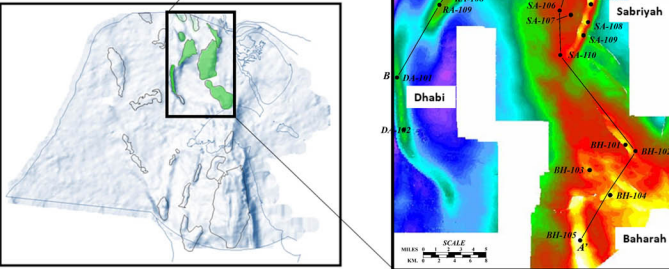
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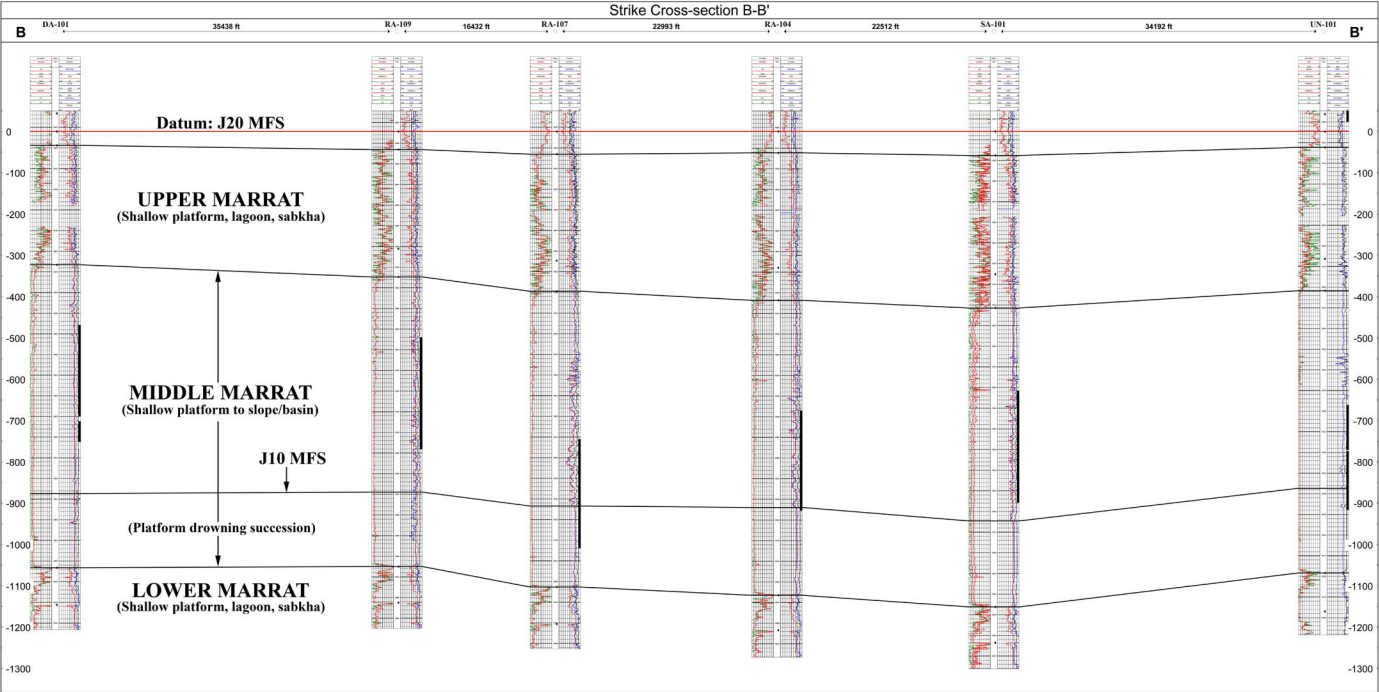
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These two cross-sections, one in the dip direction (A-A', above), and one in the strike direction (B-B', below) illustrate the geometry of the Marrat carbonate platform. The available data suggest that a platform was formed during the lower Marrat, with its margin to the east of the North Kuwait area. It is overlain by a platform drowning succession in the lower portion of the middle Marrat, up to the J10 MFS. That flooding surface became a downlap surface for the upper portion of the middle Marrat as the depositional system aggraded, then prograded basinward, to a final position east of the North Kuwait area of interest. The boundaries between the lower and middle Marrat and between the middle and upper Marrat are lithostratigraphic. On the dip section, above, flooding surfaces, defining high-frequency sequences, have been identified between three of the wells, illustrating the dipping geometry of the high-frequency sequences that define the reservoir units.



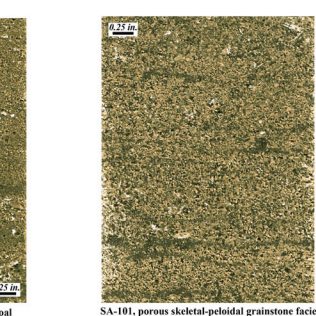
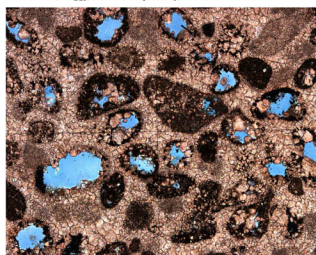
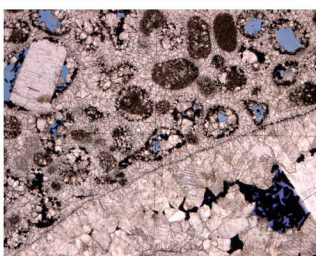
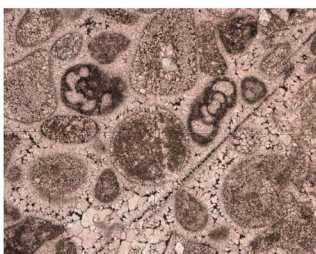
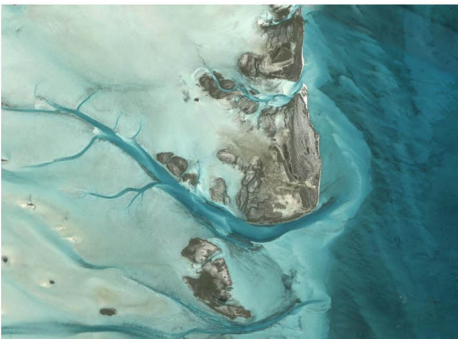
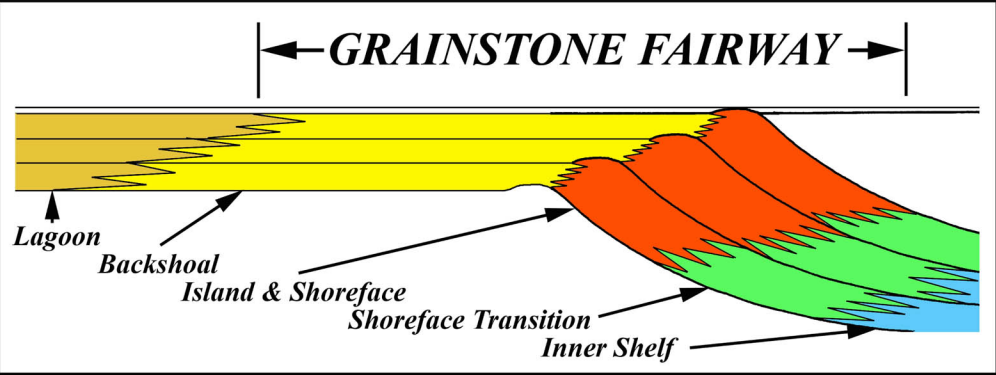
RESERVOIR GEOLOGY OF THE MARRAT FM.

GRAINSTONES

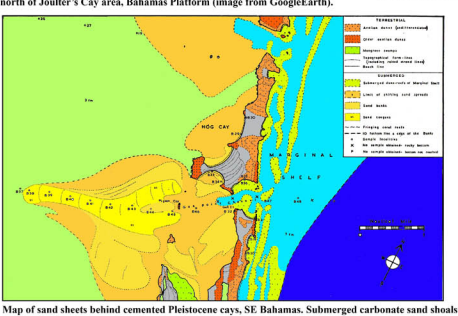
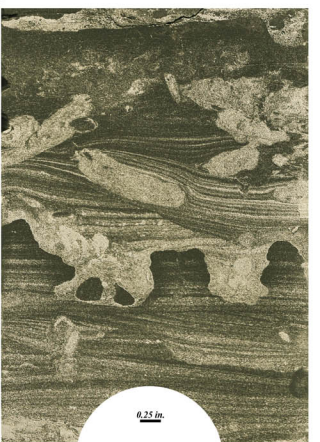
Grainstones are one of two important classes of reservoir in the Marrat Fm. They occur as two types, ooid and skeletal-peloidal, and in two geometries, sheets (backshoal) and clinoforms (shoreface). These two geometries occur in each high-frequency sequence and, when stacked, define a broad exploitation fairway. They also occur at more than one general level within the middle Marrat, thereby defining larger, composite sequences.

Grainstone sheets a few m thick may occur in a belt several km in width and tens of km long, along depositional strike, landward of the shoreface in each high-frequency sequence. They display little vertical aggradation and exhibit a strong dial influence. They may also be agally bound and/or subjected to meteoric diagenesis, due to frequent exposure.

Grainstone clinoforms deposited in a shoreface environment occur in narrow belts, generally less than a kilometer in width but tens of km in length, along depositional strike. They are usually wave-dominated but may exhibit tidal influence and algal binding in their upper portions. They tend to be more oolitic in their upper and middle portions and skeletal-peloidal in their lower portions. They exhibit a clear transition zone with the inner shelf, including hummocky cross-stratification (HCS), storm beds, and burrowing. The thickest example contains two stacked aggradational packages totaling more than 20 m. These clinoform packages are also subject to early cementation from both marine and meteoric diagenesis.



SA-101, porous skeletal-peloidal grainstone facies, backshoal



SA-101, porous, vuggy grainstone, backshoal

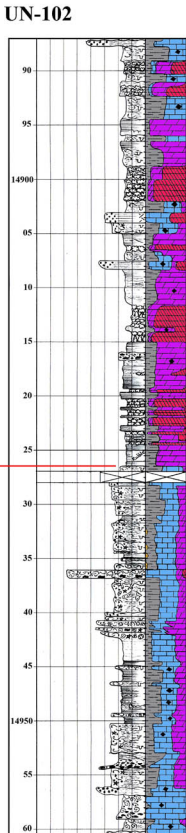
DOLOMITE

There are at least three types of dolomite present in the Marrat Fm., two of which are present in relative abundance. The first is the syndepositional or early post-depositional dolomite associated with subaerial exposure and hypersaline conditions in peritidal environments. These dolomites are most commonly seen in cryptalgal boundstones and associated mudstones and skeletal material from the base of the intertidal zone to the highest limits of the sabkha environment. They are micro-crystalline, hence they tend to mimic original depositional textures but, because of the fine crystal size, these dolomites are most often impermeable.

The second type of dolomite is thought to form as stratiform plumes as the result of seepage refluxion. In this model, dense brines formed in the sabkha and in hypersaline lagoons, sinks into porous and permeable sediments in the near-surface and flows down-dip, parallel to the stratification. As developed in the Marrat Fm., these dolomites are fabric-selective. They first dolomitize sediments whose porosity and permeability have been enhanced by burrowing. Dolomite replacement gradually extends out into the unburrowed matrix and, in extreme cases, dolomitizes the entire rock fabric. The reflux dolomites are coarsely crystalline and gradually destroy the original rock fabric. Partial dolomitization, however, enhances the visibility of ichnofabrics and makes burrows generally more visible and easily identifiable. Reflux dolomite reservoirs are most common in outer shelf environments but may also occur in inner shelf, the base of the shoreface, and in lagoonal sediments.

Saddle or baroque dolomites are present in faulted and fractured strata but are not abundant.

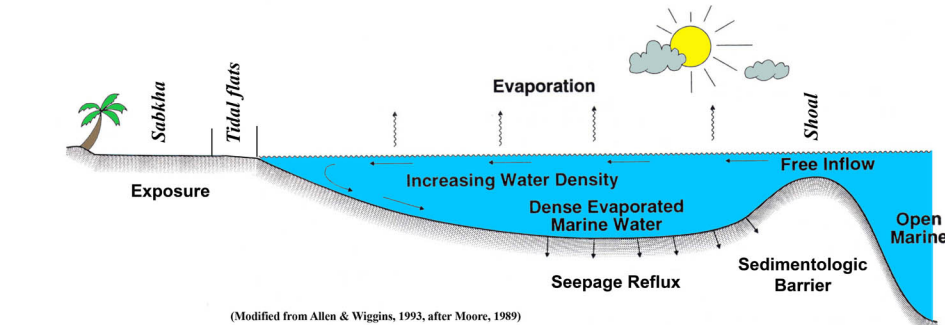
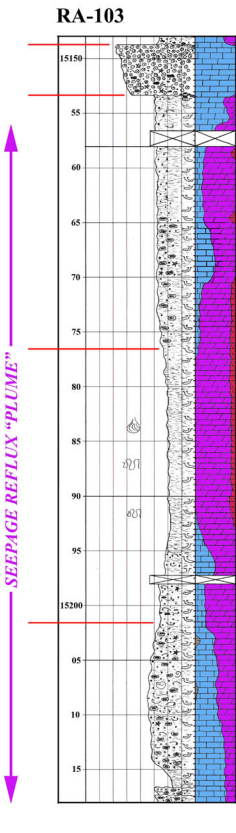
EXPOSURE



Predominantly sabkha, tidal flat, and lagoon lithofacies, characterized by thin cycles and frequent exposure

Predominantly tidal flat, lagoon, and open marine shelf lithofacies, characterized by thin cycles but limited exposure

SEEPAGE REFLUX



In the seepage refluxion model, dense brines are formed and accumulate in the lagoon (above) and infiltrate into porous sediments beneath and down-dip from the lagoon. The pathway followed by the brines is determined by porosity and permeability of the sediments and stacking patterns in the underlying stratigraphic section (below).

