[PS]Evaporite Facies: A Key to the Mid Mesozoic Sedimentary Stratigraphy of North Kuwait*

Nilotpaul Neog[1], Narahari S. Rao[2], Rawan Al-Mayyas[2], Thomas De Keyser[2], Christian Perrin2, and Christopher Kendall[2]

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Abstract

A sequence stratigraphic frame built from 30 wells used 10,000 ft of core to interpret lithofacies and depositional systems. Authigenic evaporites in North Kuwait Mid Mesozoic are indicators of arid climate and sea level, and occur in three carbonate-evaporite facies:
1. Supratidal sabkha with nearshore enterolithic anhydrite in a matrix of thin, interbedded, laminated carbonates and distal shore chicken wire fabric anhydrites;
2. Evaporite lagoons at or just above sea level, filled by dense beds of anhydrite with thin laminations and ghosts of vertical and inclined palmate gypsum, interbedded with carbonate layers after cyanobacterial mats.
3. Restricted shallow basin fill records drops in sea level with massive to bedded bodies of anhydrite with partings of dolomite, carbonate and/or shale interbedded with layers of massive halite.

The Jurassic of Kuwait overlies Triassic clastic and evaporitic Minjur Formation fill of the rifted Arabian Plate Tethyan margin. It is unconformably overlain by the transgressive 2000 ft (610 m) Jurassic Marrat.

The lower Marrat thickens southeast as thin aggrading, shoaling-upward cycles of evaporite with massive anhydrites of evaporative lagoons and thin, nodular sabkha anhydrites. The overall tabular, but stratigraphically complex middle Marrat thickens to the southeast. The basal portion aggraded as the lower Marrat platform was flooded and rapidly deepened as the carbonate shelf retreated. The depositional profile evolved into platform and basin divided by a high-energy barrier, while the margin prograded into a deepening basin, later filled by debris flows and argillaceous limestone. Massive anhydrites collected in lagoons behind the barrier as the margin prograded, and lagoonal sediments were replaced by tidal flat and sabkha facies.

The upper portion of the middle Marrat changed to carbonate and argillaceous limestone, reducing shelf-to-basin relief, filling the basin. This argillaceous signal continued into the upper Marrat, with thin aggradational cycles of evaporites in shallow evaporative lagoons and adjacent sabkhas.

The upper Marrat became more open marine carbonate deepening into the shale-dominated Dhruma Formation. This argillaceous character and that of the Marrat is from reactivated Hercynian structures of the Arabian Shield to the west and northwest. Though no unconformities were recognized, they may be represented by condensed intervals.

Clay content decreased as the Sargelu Formation aggraded as a drowning platform into the starved, isolated Najmah basin with its shallow marine margin. Sea level drops caused Gotnia Formation basinal anhydrite and halite precipitation. A Tithonian transgression and its shallow evaporitic waters extended over much of the eastern Arabian shield forming the Hith Anhydrite as the final Jurassic fill of North Kuwait. A Valanginian sea level drop accompanied the Cretaceous Sulaiy Formation.

Evaporite Facies: a Key to the Mid Mesozoic Sedimentary Stratigraphy of North Kuwait

ICE Convention, Calgary, 2010

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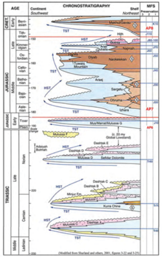

Arabian Plate Sequence Stratigraphy

STRATIGRAPHIC FRAMEWORK AND DEPOSITIONAL SETTING

Knowledge of the stratigraphy and sequence framework of the Jurassic in North Kuwait (location map, below) have changed significantly since the publication of the type log from the Minagish 27 well by Yousif and Nouman (1997) (below, right). An expanded version of the Minagish-0027 log is reproduced at the right, between two halves of a composite log of the Jurassic section from the basal Gotnia to the uppermost lower Marrat as now known in North Kuwait. The composite graphic core description for this section has been inserted into the center track, showing the extent to which the section has been seen in core. Note that, in the type log, there are approximately 1,750 ft (533 m) of Gotnia and Hith. Less than 50 ft (15 m) of the lower Gotnia have been seen in core described for this study. The Marrat Fm. is subdivided into informal lower, middle, and upper divisions in North Kuwait. The lower Marrat reaches over 700 ft (213 m) in North Kuwait but only slightly over 100 ft (30 m) have been seen in core. The middle Marrat has been extensively cored and all but about 100 ft (30 m) have been seen in core. The upper Marrat reaches a maximum of approximately 550 ft (168 m) and approximately the lower half has been seen in core. All of the Middle and Upper Jurassic (Dhruma, Sargelu, and Najmah Fms.) has been seen in core.

Similarly, understanding of the sequence framework of the Jurassic in North Kuwait has markedly improved. Nowhere is this more true than in the middle Marrat. As these data continue to be studied and integrated, it is certain that the sequence diagram of Sharland and others (2001) (upper right) will be extensively modified. The preliminary sequence framework for the middle Marrat is shown at the lower far right. The most important relation shown in this diagram is the existence of a shelf-like area in the northwest, separated by a high-energy barrier system from a deep, sometimes starved basin to the southeast. The lower and upper Marrat (upper far right) are far more uniform and ramp-like in geometry.

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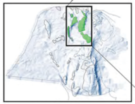
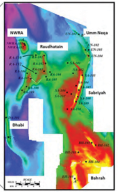
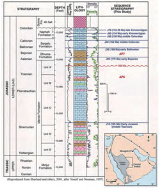


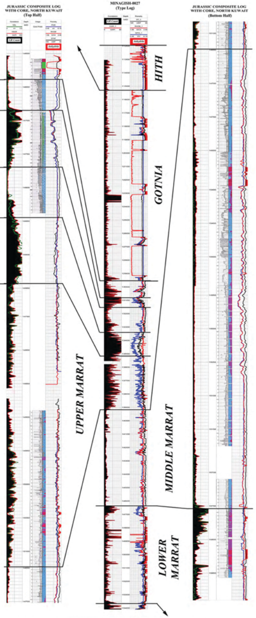
Kuwait

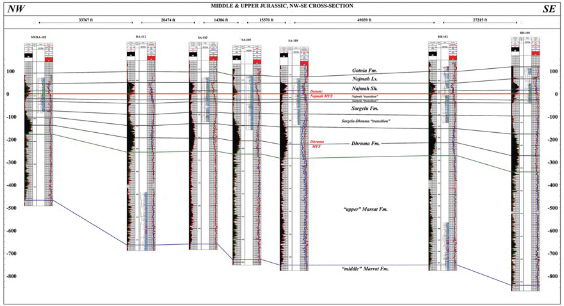


North Kuwait

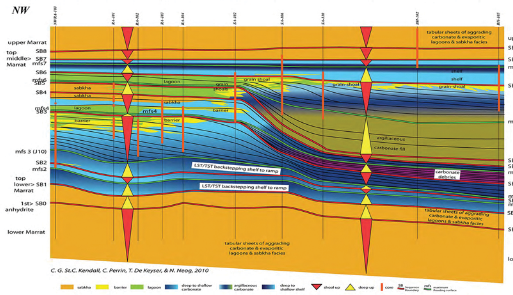


Jurasic, Minagish 27, Kuwait





PRELIMINARY SEQUENCE STRATIGRAPHIC FRAMEWORK FOR MIDDLE MARRAT



EVAPORITE DEPOSITIONAL SETTINGS IN NORTH KUWAIT

Coastal Sabkha

Lithologic Description

Nodular anhydrite was originally deposited as gypsum under evaporative conditions in the supratidal, sabkha environment. Lower on the sabkha surface, at or below the water table, it may occur in thin beds that are commonly deformed into tight folds that have an “enterolithic” character. Under some conditions, it may occur as pseudomorphs after lenticular gypsum crystals, as in the so-called “gypsum mush” facies, just above the intertidal zone. It is most commonly precipitated withinin massive or cm-laminated dolomudstone as continuous or discontinuous beds but may constitute the bulk of the rock, in the well-known “chicken wire” fabric.

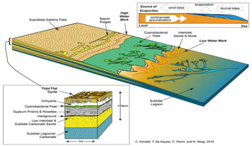
The anhydrite is nearly always bright white, with a mottled or speckled appearance. The nodules consist of very small “laths” of anhydrite that are intergrown in a pattern referred to as “felted.” The dolomudstones, because of being deposited in an oxidizing environment, are commonly shades of reddish brown. Although burrowing is generally sparse or absent in this supratidal environment, burrowing does occur beneath flooding surfaces.

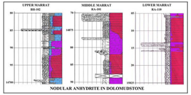
Lithofacies Associations and Depositional Environment

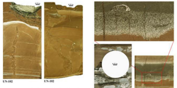
The nodular anhydrite lithofacies has been observed in association with a large number of lithofacies but the most common are the cm-laminated and mm-laminated dolomudstones. They are also associated with cryptmicrobial boundstones, mm-laminated calcareous shale, wavy-laminated mudstones, wavy-laminated skeletal mudstones and dolomudstones, and wavy-laminated argillaceous dolomudstones. All of these lithofacies appear to be nearshore, shallow subtidal, intertidal, or supratidal and may be evaporative. All of these characteristics are consistent with an interpretation of a supratidal sabkha environment of deposition for the nodular anhydrite in dolomudstone lithofacies.

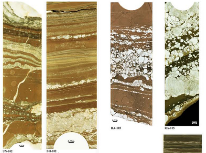
Petrophysical Characteristics and Reservoir Potential

The anhydrite is essentially non-porous and non-permeable because of its intergrown, finely crystalline nature. Thick beds of nodular anhydrite may function as seals and not uncommonly are associated with oil staining. Likewise, the dolomudstones are microcrystalline and subhedral to anhedral. These interlocking crystalline fabrics characteristically have very low porosity and permeability.
On logs, nodular anhydrite beds, if thick enough to be resolved by the logging tools, are easily recognized by their high density (3.94) and typically low gamma ray count. The low gamma ray count may be obscured if the nodules are enclosed by argillaceous sediment.



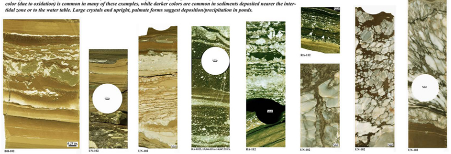






The coastal sabkha environment may be areally extensive and is divisible into a number of subenvironments. Because of the very low relief, slight changes in relative sea level may result in large lateral shifts in the depositional profile, so that sabkha deposits may be interbedded with tidal channels, cryptmicrobial laminae, beach lag deposits, wind deflation surfaces, tidal flat laminites, and rippled and burrowed lagoonal deposits.

The scanned images of core slabs shown here document some of the wide range of lithologies, sedimentary textures, sedimentary structures, and anhydrite morphologies commonly seen in the coastal sabkha. The red color (due to oxidation) is common in many of these examples, while darker colors are common in sediments deposited nearer the intertidal zone or to the water table. Large crystals and upright, palmate forms suggest deposition/precipitation in ponds.



Evaporative Lagoon

Lithologic Description

The massive anhydrite lithofacies is distinctly different from the nodular anhydrite lithofacies. Although both are easily identified on logs due to their high density and typically low gamma ray count, they were deposited in different settings and under somewhat different environmental conditions. Their lithofacies associations are distinctly different.

The occurrences of massive anhydrite recognized in core can be divided into two groups. In the first group are occurrences of anhydrite that have a distinctly vertical or palmate character, reminiscent of swallowtail gypsum crystals. They are generally thin and may occur between nodular anhydrite layers or other lithofacies or within thicker, massive anhydrite units.

The second type of massive anhydrite typically occurs in massive beds, whose thickness is measured in feet. A number of these occurrences have units that appear to have been cryptmicrobial boundstones that have been entirely replaced by anhydrite, preserving rather delicate depositional structures. They may be associated with more granular bedded anhydrite units that resemble grain-rich carbonate beds that have been replaced by anhydrite. In other instances, the anhydrite may have a vaguely layered or mounded appearance and may approach a nodular character. However, these massive anhydrites rarely include the reddish-brown cm-laminated dolomudstones of the nodular anhydrite lithofacies. Rather, they may include gray or black dolomite and wisps of shale and argillaceous material. Any of the massive anhydrite depositional fabrics may be broken and collapsed into brecciated masses by dissolution during intervals of exposure.

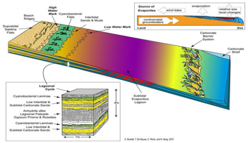
Lithofacies Associations and Depositional Environment

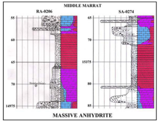
The two types of massive anhydrite discussed above may occur together, interbedded, or transitional with nodular anhydrite. For that reason, there is considerable overlap in the sets of lithofacies that they are associated with. Nevertheless, when considered separately, those suites of lithofacies can be viewed as overlapping sets. Both types of massive anhydrite deposit are associated with cryptmicrobial boundstone that may exhibit desiccation cracks. The thin, palmate massive beds are associated with cm-laminated dolomudstone, peloidal mudstone, peloidal-oncoidal wackestone/mud-dominated packstone, intraclastic mudstone, and ripple-laminated dolomudstone with scoured surfaces.

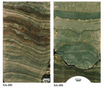
The thick, massive anhydrite beds are associated with skeletal peloidal grainstones and grain-dominated packstones, wavy and planar-laminated dolomudstones, intraclastic dolomud/wackestones, and burrowed, wavy-laminated peloidal skeletal mud-dominated packstone.

Petrophysical Characteristics and Reservoir Potential

Massive anhydrite is essentially non-porous and non-permeable because of its intergrown crystalline nature, although the crystals may be larger than in the nodular anhydrite. Thick beds of massive anhydrite may function as seals and not uncommonly are associated with oil staining. Unlike the nodular anhydrites, the massive anhydrites are more commonly associated with grain-supported fabrics that may have significant porosity and permeability. When these lithofacies are beneath the massive anhydrites, they may form stratigraphic traps for hydrocarbons.
On logs, the massive anhydrite beds, because they tend to be much thicker, are easily recognized by their high density (3.94) and typically low gamma ray count. Because they are deposited in lagoons, during periods of restricted circulation, the massive anhydrites form synchronously deposited packages that are easily correlated.

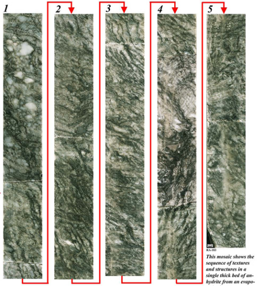






Anhydrites deposited in the evaporative lagoon display a variety of textures and structures. They commonly occur in thick beds that lack silty dolomudstone matrix and are associated with peritidal and subtidal lithofacies typical of tidal flat, lagoon and backbarrier environments. The images above and below show cryptmicrobial (stromatolitic layering, enterolithic deformation, and large subaqueous crystals.

Top
Interior (mosaic)
Base



This mosaic shows the sequence of textures and structures in a single thick bed of anhydrite from an evaporative lagoon.

Restricted Shallow Basin

Lithologic Description

Because it is dominated by the occurrence of anhydrite and halite, it is appropriate to discuss the Gotnia Formation here. Although commonly referred to as the “Gotnia salt,” this unit contains several different lithofacies and should more properly be referred to as the Gotnia Formation.

To date (May, 2010), six Upper Jurassic cored intervals have been described which contain varying thicknesses of the Gotnia, measuring from 0.25 to 38.0 feet in thickness. Excluding the two wells in which less than one foot of Gotnia was preserved in core, the remaining four cored intervals contained 113.75 ft of Gotnia, of which approximately 60% was evaporites. Of the 68.5 ft of evaporites described, 10 ft were halite or approximately 17%.

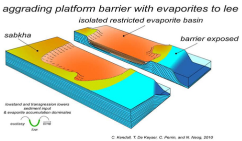
The non-evaporite portion of the Gotnia Fm. that was described consisted predominantly of argillaceous limestone, dolomitic limestone, and calcareous shale. These sediments are generally dark, reddish brown to nearly black in color. They are typically mm- or cm-laminated mud/wackestones and are often cryptmicrobial in character, varying between a clotted peloidal or thrombolitic appearance to distinct cryptmicrobial “clumps,” to cryptmicrobial boundstone laminae. Skeletal fragments (especially gastropods and ostracods), ooids, and intraclasts are common in the basal beds above the sub-Gotnia unconformity. One distinctive bed, consisting of what appears to be graded peloidal mudstone, varies in position from less than one foot to several feet above the basal unconformity, suggesting that there was significant relief on the unconformity surface.

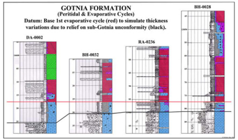
The Gotnia evaporites seen in core resemble both the nodular and massive anhydrites described in greater detail for the Marrat Formation, below, with the exception of the addition of the 10 ft of halite seen in DA-101. The halite consists of clear, coarsely intergrown crystals a few mm to more than 1 cm across. The halite is overlain and underlain by massive anhydrite with sharp contacts, marked by no more than a film of clay. That relationship suggests an evaporative cycle in which the degree of restriction and concentration of brine increased until anhydrite precipitation was replaced by halite precipitation, which was then succeeded by decreasing restriction and replacement by anhydrite precipitation at the top of the cycle. Although such a cycle was only preserved in DA-101, there are probable collapse zones in the massive anhydrites in the other wells, suggesting that the halite may have been removed by dissolution in the thinner cycles.

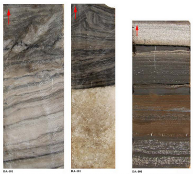
The massive anhydrite in contact with the halite in DA-101 contains laminations and growth forms diagnostic of cryptmicrobial boundstone in a tidal flat or marginal marine depositional environment. Similar forms were seen in the massive anhydrites described in the Marrat Fm. and suggest that these boundstones were actively growing in the restricted waters as the anhydrite was being deposited, binding the minute gypsum crystals to their filaments, just as they would bind aragonite needles in less restricted environments. The tolerance of these microbial communities for elevated salinities is well known and is a factor in the preservation of the stromatolites in Shark Bay, Australia, where the high salinity excludes the algal grazers. Near the base of these evaporative cycles, there is commonly a change from massive, layered, or palmate depositional textures to more nodular or chickenwire fabrics in dolomitic mudstones.

Lithofacies Associations and Depositional Environment

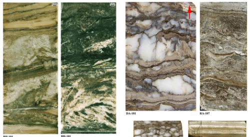
This set of lithofacies, massive anhydrite, nodular anhydrite, cryptmicrobial boundstones, and laminated peloidal mud/wackestones, is highly indicative of an overall peritidal depositional environment, varying from sabkha to tidal flats to subaqueous evaporitic lagoon or pond. There is no evidence of high-energy conditions or active winnowing of sediment by wave action. The lamination of the argillaceous mud/wackestones and the cryptmicrobial boundstones suggests tidal influence throughout. Based on these observations, it is difficult to conceive of maximum water depths greater than about 1 m. The extent of these evaporite deposits, however, greatly exceeds that envisioned for the sabkha and evaporative lagoon models. Instead it is thought to represent a broad, subsiding intrashelf basin in which evaporite deposition kept up with subsidence.



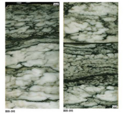


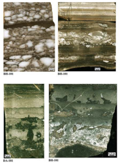


Evaporites deposited in the restricted shallow basin depositional environment (Gotnia and Hith Fms.) combine features of the sabkha and evaporative lagoon. These images show cryptmicrobial laminae composed of anhydrite (left) in contact with crystalline halite (center) and partially dolomitized peritidal peloidal mudstones (right).

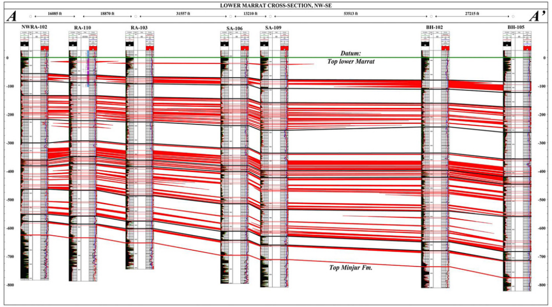


Images of assorted textures and structures (clockwise from upper left): collapse features, nodular and palmate anhydrite in cryptmicrobial dolomudstone, nodular anhydrite in dolomudstone, graded peloidal dolomudstone at base of Gotnia, and enterolithic deformation.



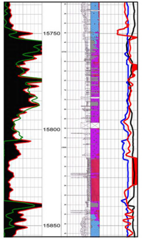


LOWER MARRAT



ANHYDRITE DISTRIBUTION & TEXTURE

RA-110

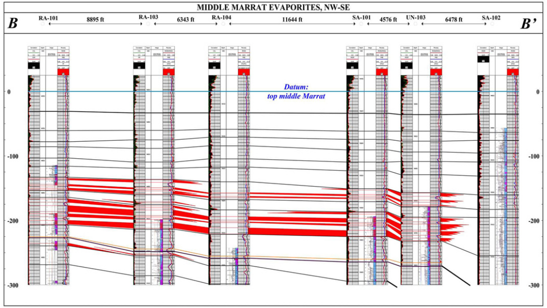


Very little core was available from the lower Marrat Fm. for this study. The well with the longest core (RA-110) is included in the cross-section, above, and the cored portion is shown with the log at the right. The dolomite, anhydrite, and shale portion of the log between approximately 15753 and 15846 ft (4800-4830 m) consists of sabkha, tidal flat, and shallow lagoonal environments. The base of the middle Marrat is at 15753 ft (4800 m). The limestones at top (basal middle Marrat) and bottom are normal marine in character. Based on these observations from core, the lower Marrat is presumed to consist of alternating cycles of highstand (normal marine) and lowstand (restricted marine) sediments.

The cross-section shows a platform succession that thickens slowly and uniformly in a basinward direction, from NW to SE. The cycles delineated by correlating several easily recognized GR markers show a similar cyclicity, with packages of numerous closely spaced anhydrite beds, separated by intervals with little or no anhydrite.

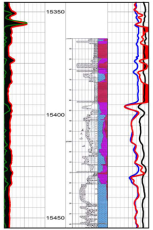
The anhydrite beds (red) have relatively good lateral continuity, overall, but the thin beds may thicken and merge into thick beds toward the SE and some of the thick beds show a tendency to divide into thin beds and terminate to the SE, also. The thin beds, based on cored intervals are probably nodular anhydrites deposited in a sabkha environment. The thick beds contain both nodular and upright, subaqueous textures, suggesting a lateral change to evaporative lagoon environments. This probably reflects the depositional topography on this broad carbonate platform in thin cycles resulting from high-frequency relative sea level changes.

MIDDLE MARRAT



ANHYDRITE DISTRIBUTION & TEXTURE

SA-101



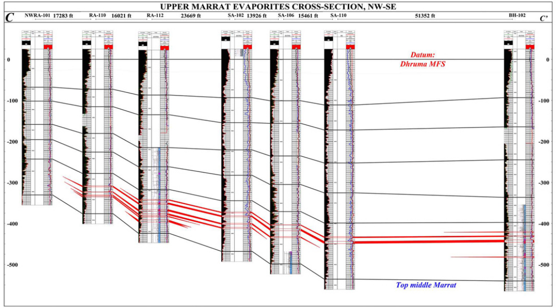
Six cored intervals in the middle Marrat have thick units of massive anhydrite that have been interpreted as evaporative lagoon deposits. Unfortunately, no single well was cored in the entire interval that contains such beds. Eight wells have cored middle Marrat intervals that contain thin nodular anhydrite beds that have been interpreted as having been deposited in a sabkha depositional environment.

The cross-section above is entirely on the platform, behind the barrier system and is oriented approximately normal to the shelf margin. The wells are projected into the line of section. At the base of the section, clinoforms can be seen prograding and dipping downward. the upper portion of the cross-section consists of thin platform units with good lateral continuity.

There are two intervals that contain thick, probable evaporative lagoon anhydrites, separated by a thin package of strata that contains no anhydrite beds. It is presumed to represent a highstand cycle because in SA-102, on the right end of the section, it contains outer shelf mudstones that overlie a skeletal-oncoidal grainstone facies that appears to represent the barrier behind which the evaporative lagoon anhydrite beds were deposited. In the upper anhydrite-bearing cycle, the sediments in SA-102 are meter-scale skeletal-oncoidal packstones and grainstones which are partially dolomitized and contain anhydrite cement. They are interpreted as having been deposited in shoal and backshoal depositional environments.

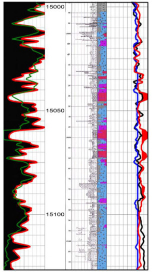
The evaporative lagoon anhydrite beds probably represent high-frequency lowstands, when the barrier system was exposed but the lagoon was still receiving at least intermittent inflow through gaps in the barrier.

UPPER MARRAT



ANHYDRITE DISTRIBUTION & TEXTURE

RA-112



Four wells were cored in the upper Marrat through intervals that contain nodular anhydrites indicative of a sabkha depositional environment. Approximately the upper half of the upper Marrat and the contact with the base of the Dhruma Fm. has not been seen in core in North Kuwait.

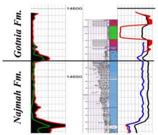
The cross-section above was constructed with a shelf-to-basin orientation, similar to that of the lower and middle Marrat. The section between the top of the middle Marrat and the Dhruma MFS thickens uniformly basinward, from approximately 360 ft (110 m) to 560 ft (170 m), suggesting an absence of tectonic activity. The section has been arbitrarily divided into large-scale cycles (sequences?) along several prominent GR markers, highlighting the tabular nature of the sedimentation seen in core.

All of the anhydrites occur in the lowest of these large-scale cycles, with a total vertical range of occurrence of approximately 200 ft (60 m). Individual beds of anhydrite increase in lateral extent, upward, and prograde basinward. The lowest anhydrite bed has a lateral extent of approximately 4 mi (6000 m), while the longest extends approximately 21 mi (34 km) in a dip direction.

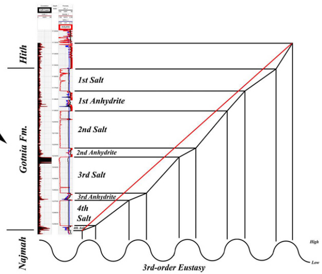
This upward increase in lateral extent appears to reflect basinward progradation and formation of a broad, low relief platform top. However, the textures seen in core show predominantly nodular textures, with no obvious transition to an evaporative lagoon depositional setting. The nodular anhydrites are associated with cm-laminated, reddish brown, occasionally silty dolomudstones, cryptmicrobial laminites, mm-laminated argillaceous dolomudstones, and skeletal-peloidal, wavy bedded mudstones and wackestones, representing sabkha, tidal flat, tidal channel, and shallow lagoon depositional environments.

GOTNIA & HITH FORMATIONS

DA-101



MN-0027



Although only four cored intervals described for this study contained more than a few inches of the Gotnia Fm., several observations are pertinent to their interpretation:

(1) The sub-Gotnia unconformity is always overlain by peritidal sediments;

(2) The sediments are interbedded with anhydrite that may have either a nodular (sabkha) or subaqueous (pond or lagoonal) character;

(3) The halite is interbedded with anhydrite but not directly with the peritidal sediments.

Based on these observations, some assumptions can be made:

(a) The peritidal sediments were deposited in a less restricted environment than the evaporites and represent a relative sea level highstand condition;

(b) The anhydrite and halite were deposited in a restricted, hypersaline depositional environment, representing a relative sea level lowstand.

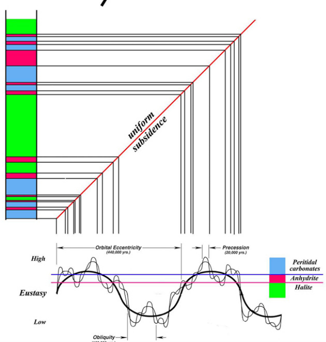
(c) The halite was deposited in a more restricted depositional environment than the anhydrite and, together, they represent a symmetrical cycle of falling, lowstand, and rising relative sea level.

(d) Because the sediments all represent peritidal facies, the evaporative cycles completely filled the available accommodation space in each cycle.

These observations and assumptions can be visualized for the Gotnia and Hith Fms. in a graphic correlation diagram (upper right), using the log from the Minagish 27 well, displayed along the y-axis, labeled with the stratigraphic terminology. In a manner analogous to a Fischer plot, the 3rd-order eustasy is displayed along the x-axis, assuming constant time and constant cycle amplitude. the sloping red line shows the predicted line of intersection if uniform subsidence is assumed. The correlation line, however, shows increasing departure from the uniform subsidence line during deposition of the 4th, 3rd, and 2nd salt depositional cycles, then reconverges with it in the upper cycles.

The log and depth-shifted core description for DA-101 is shown at the upper left. Even from this very small portion of the lower Gotnia, it is clear that there is higher-order cyclicity present than can be explained by a simple highstand-lowstand model. The diagram at the right attempts to explain the observed depositional pattern, utilizing the Milankovitch orbital forcing model. In this diagram, the time/eustasy axis includes the convolved curves for orbital eccentricity, obliquity, and precession. The resulting high-frequency relative sea level curve intersects the boundaries separating peritidal sediments, anhydrite, and halite in many cycles of varying length. These cycles are projected up to the uniform subsidence line and over to the modeled lithologic column, resulting in a stacking pattern similar to what is seen on the log from Minagish 27 and in the core from DA-101.

The exact correlation of the Gotnia section seen in the core described from DA-101 is not known. Cross-sections shown by Ali (2006) suggest that portions of the 3rd anhydrite, 2nd salt and/or 2nd anhydrite could be present. Biostratigraphic data may eventually clarify these correlations.



SUMMARY AND CONCLUSIONS

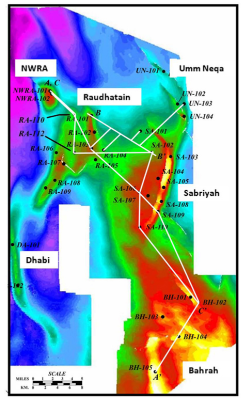
The cross-sections presented here illustrate the depositional geometries for the lower, middle, and upper Marat Fm. in North Kuwait. The log template uses black infill betwen the left margin and the GR curve, to highlight the depositional cycles. The GR scale for each well was adjusted to accommodate the highest values in the shales immediately below the base of the middle Marrat. The density curve (red) was shaded red for values of 2.85 and greater, making it possible to see the anhydrite intervals at a small scale and at a single glance. The evaporite and lithofacies asociations seen in the cores and the geometries and evaporite distributions seen in the cross-sections above lead us to the following conclusions:

The lower Marrat consists of tabular packages of alternating highstand (normal marine) and lowstand (evaporitic/dolomitic) strata, deposited on a broad, shallow platform behind a barrier system along the rim of the Arabian Plate.

The depositional profile for the middle Marrat Fm. in North Kuwait, shown at the right, has been called a calciclastic shelf model, in which a coastal sabhka, tidal flats, and lagoon are separated by a barrier system consisting of backshoal, shoal, and shoreface environments from open marine iner and outer shelf, slope, and intrashelf basin. Middle Marrat evaporites accumulated in a narrow sabkha and associated evaporative lagoon during falling and lowstand relative sea level cyclic deposition.

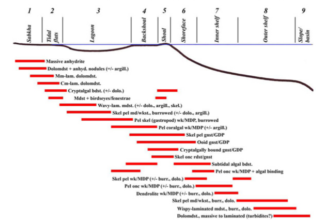
The lagoon and intrashelf basin were infilled during late middle Marrat time. Upper Marrat evaporites were deposited as coastal sabkha and shallow subaqueous pond facies. They are interbedded with tidal flat and shallow lagoon or open marine shelf facies, suggesting that these were lowstand deposits

Although no tectonic subsidence is evident for the Marrat or for the Middle and early Upper Jurassic Dhruma, Sargelu, and Najmah Formations, the great thickness of evaporative cycles in the Gotnia and Hith Formations implies rapid, localized subsidence. Nevertheless, the symmetrical evaporite cycles, punctuated by peritidal sediments, show that rapid deposition filled all the accommodation space and a bathymetric basin never developed. The high-order cyclicity seen in core and reflected in logs allows construction of a predictive facies model in which sediments are deposited during highstands, anhydrite during rising and fall ing stages, and halite during lowestands. This graphic corelation model is analogous to a Fischer plot that incorporates lithofacies prediction. Plots of this type might be utilized to map differential subsidence during Gotnia and Hith deposition.



North Kuwait

MARRAT FM. LITHOFACIES DISTRIBUTION



Middle Marrat Depositional Environments