Chapter 15

Carbonate Platform Models of Arabian Cretaceous Reservoirs

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SUMMARY

Name: Arabian carbonate shelf
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Location: From 22° to 28° north latitude and 51° to 57° west longitude
Geologic time interval: Early–Late Cretaceous, Barremian–Maastrichtian
Tectonic–sedimentary setting: Passive margin changing to back arc basin
Basin type: Epeiric shelf changing to foreland basin
Paleoclimate: Generally tropical
Platform type: Rimmed shelf changing to distally steepened ramp
Platform geometry: At least 1700 m thick; more than 750 km wide and more than 1500 km long
Facies and fossils: Fine- to coarse-grained carbonates, thin intervals of shale and sandstone; pelagic and benthic foraminifera, algae, molluscs, sponges, and corals
Systems tracts: Transgressive and progradational highstand
Stacking patterns: Buildups

INTRODUCTION

Cretaceous stratigraphy in the Arabian basin can be logically divided into three major cycles separated by unconformities (Harris et al., 1984; Alsharhan and Nairn, 1986; Scott, 1990). In the shallow water phase of each of these cycles, an interval of rudist buildups can be identified. These buildups occurred in areas where the slope changed, particularly at the border of intracratonic basins, their location presumably related to the ecology of the bivalves. A brief outline of the stratigraphy based on the reviews of Murris (1980), Harris et al. (1984), Alsharhan and Nairn (1986, 1988, 1990), and Scott (1990) emphasizes the stratigraphy of the rudist-bearing formations.

The geologic history and locations of the rudist-bearing formations in the Arabian Gulf are relevant to hydrocarbon occurrences because they have high primary porosity. They also occur at the top of coarsening upward sequences and their deposition was often followed by a brief period of emersion. Leaching during emersion has greatly enhance porosities, and such accumulations are consequently prime oil exploration targets (Harris et al., 1984). Their value is limited by the paleogeographic conditions necessary for their development, as well as by the critical balance between sediment accumulation rates and subsidence rates in which water depth permitted extensive thick bodies to accumulate.

The rudist limestones in the Shuaiba, Mishrif, and Simsima formations contain giant oil reservoirs (Figure 1) that have been greatly enhanced by leaching during subaerial exposure. The exposure of these shallow water bioherms apparently resulted from relatively minor sea level fall. The partially aragonitic rudist shells were readily dissolved by meteoric water during leaching. The combination of high sediment production by rudists and leaching during exposure following a relative fall in sea level affected the reservoirs. The basinal source rocks formed during the early part of the next succeeding transgressive cycle sealed the reservoirs.

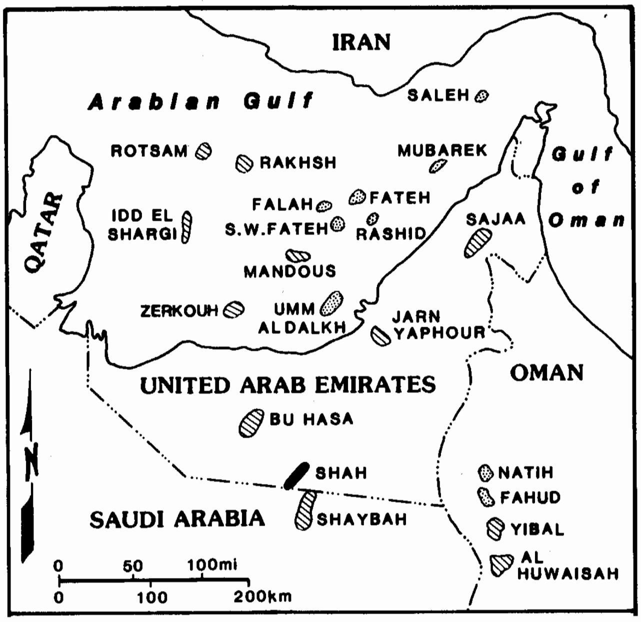


Figure 1. Location map of the fields producing from Cretaceous rudist buildups and associated sedimentary rocks in the southern part of the Arabian Gulf. Key: hatchured, Shuaiba oil (Lower Cretaceous); stippled, Mishrif oil (middle Cretaceous); black, Simsima oil (Upper Cretaceous).

CRETACEOUS STRATIGRAPHY

In the Arabian Gulf region, three major Cretaceous sedimentologic cycles are separated by regional unconformities (Harris et al., 1984; Alsharhan and Nairn, 1986) (Figure 2):

1. Lower Cretaceous Thamama Group, which includes Berriasian to middle–late Aptian age rocks,
2. middle Cretaceous Wasia Group formed during the late Aptian–latest Cenomanian or earliest Turonian, and
3. Upper Cretaceous Aruma Group, which includes beds of Coniacian–Maastrichtian age.

Each cycle can be divided into subcycles, although these are not always clearly defined in every area.

The Lower Cretaceous Thamama Group accumulated over a time span of about 30 m.y. during a cycle of extensive flooding of the Arabian Peninsula. The middle Cretaceous Wasia Group was deposited over a span of 20 m.y. Deposition of the Upper Cretaceous Aruma Group occurred over a period of about 25 m.y. following a period of emergence and erosion during the Turonian, which may have lasted as long as 5 m.y. in the northern United Arab Emirates (Harris et al., 1984; Alsharhan and Nairn, 1990). The most complex lithofacies and thickness variations are found in the deposits of this latter cycle.

The sedimentary succession was influenced by sea level fluctuations and tectonics. Shallow marine platform carbonates accumulated by marine flooding over the platform during the initial period of sea level rise. The depositional environments and lithofacies changed during the cycle of relative sea level. These Arabian platform carbonates demonstrate two models: a mixed carbonate–siliciclastic ramp that developed during regression and relative low sea level, and a differentiated carbonate shelf that formed during transgression and relative highstands of sea level (Ahr, 1973; Bay, 1977; Murris, 1980; Read, 1985).

The Cretaceous carbonate ramp phase was characterized by peloidal–bioclastic wackestones and packstones with local ooidal grainstones and associated marls and shales. The stratigraphic units can be correlated over long distances and change little or only gradually in both thickness and lithology. The differentiated carbonate shelf consists of fossiliferous wackestones and packstones and ooidal–peloidal packstones and grainstones, which formed on the shallower parts of the shelf, and common euxinic lime mudstones and marls, which formed in deeper waters. Time transgressive hardgrounds separate individual cycles and formed by the lithification of the slope in front of the shelf margin over which muds accumulated during the succeeding transgressive cycle. Simultaneously, the shallower part of the shelf was subjected to erosion and lithification as marine conditions receded.

During the Early Cretaceous cycle, ramp-type conditions were established and clastic influx was low, reflecting the paleogeographic conditions of the continental region. Later in the Early Cretaceous, an advancing sea pushed clastic sources westward toward western Arabia, and a differentiated carbonate shelf

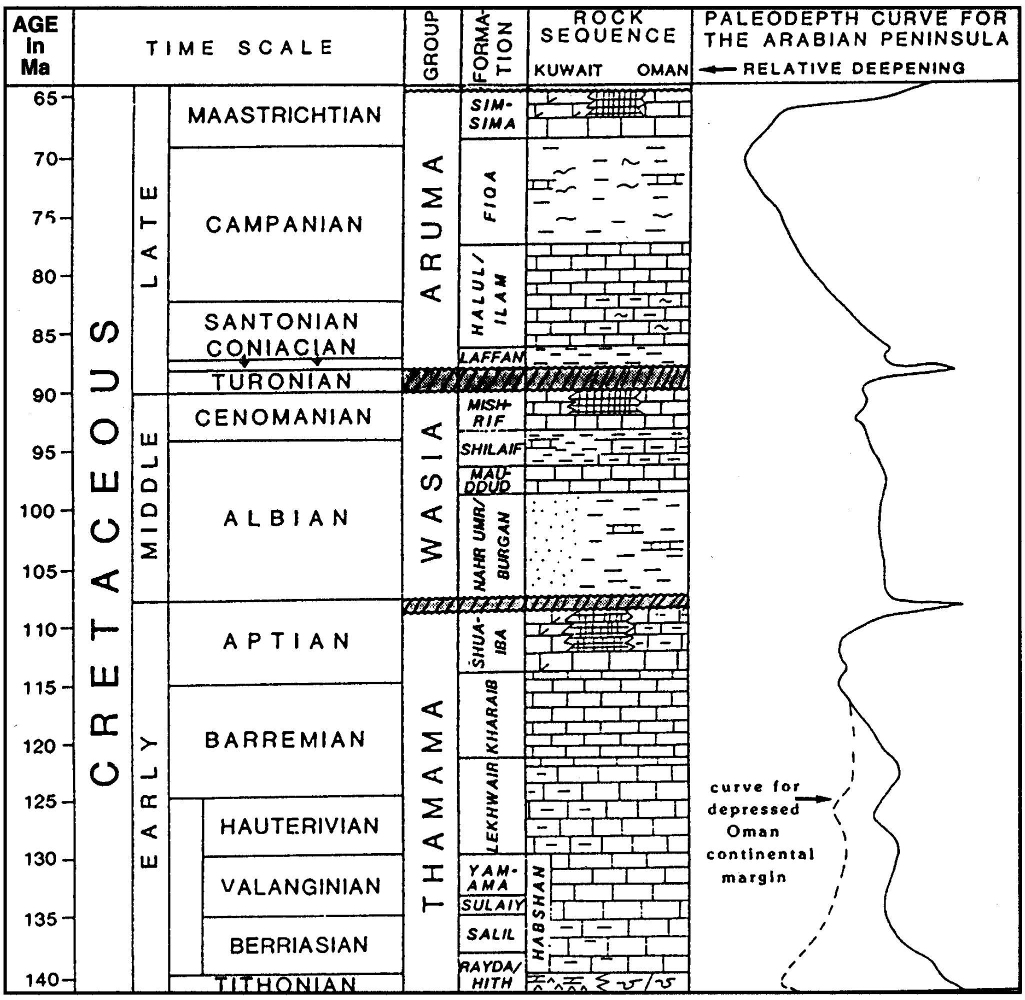


Figure 2. Cretaceous stratigraphy and sea level fluctuations in the Arabian Gulf region. Reef buildup during the Cretaceous is shown by cross-hatchures. The relationship between the Rayda and Hith formations is hypothetical and not proven by well logs or biostratigraphy. (From Harris et al., 1984; Alsharhan and Nairn, 1990.)

replaced the ramp. In extreme eastern Arabia during the Early Cretaceous, the Oman foredeep trough was a deep shelf carbonate environment (Harris et al., 1984). In the southern part of the Arabian Gulf, an intrashelf basin developed on the differentiated carbonate shelf during middle Aptian time (Figure 3a). Around the margins of this basin, rudist reefs developed (the subsequent Shuaiba reservoir facies) (Figure 3a). During the Albian regression, a siliciclastic regime advanced across almost the entire Arabian platform only to be replaced in latest Albian by shallow shelf carbonates as carbonate shelf conditions were reestablished.

During the middle Cretaceous cycle in late Albian–Cenomanian time, the Shilaif–Khatiyah intrashelf basin formed in the southern part of the Arabian Gulf (Figure 3b). It was filled by deeper water sediments, but along the margins of the basin, the carbonates show substantial lateral facies variation with rudist buildups occurring in some areas. It has been proposed that the rudist bioherms, and the subsequent development of secondary porosity, was controlled by the same salt structures over which the present day Mishrif reservoirs are found (such as Fateh Field, offshore Dubai) (Jordan et al., 1985).

At the end of the Albian–Cenomanian–Turonian cycle, a major unconformity developed that marked the first phase of orogenic events (Robertson and Searle, 1990; Scott, 1990). At this time, the initial thrust sheets were emplaced in the eastern and northeastern United Arab Emirates. Erosion of these structures supplied the sheet of synorogenic deposits that spread across the platform. Shelf deposits beyond this fringe are lithologically more variable. The clastic influx mixed with shelf carbonates, which included some rudist buildups formed during the late Maastrichtian (Simsima Formation).

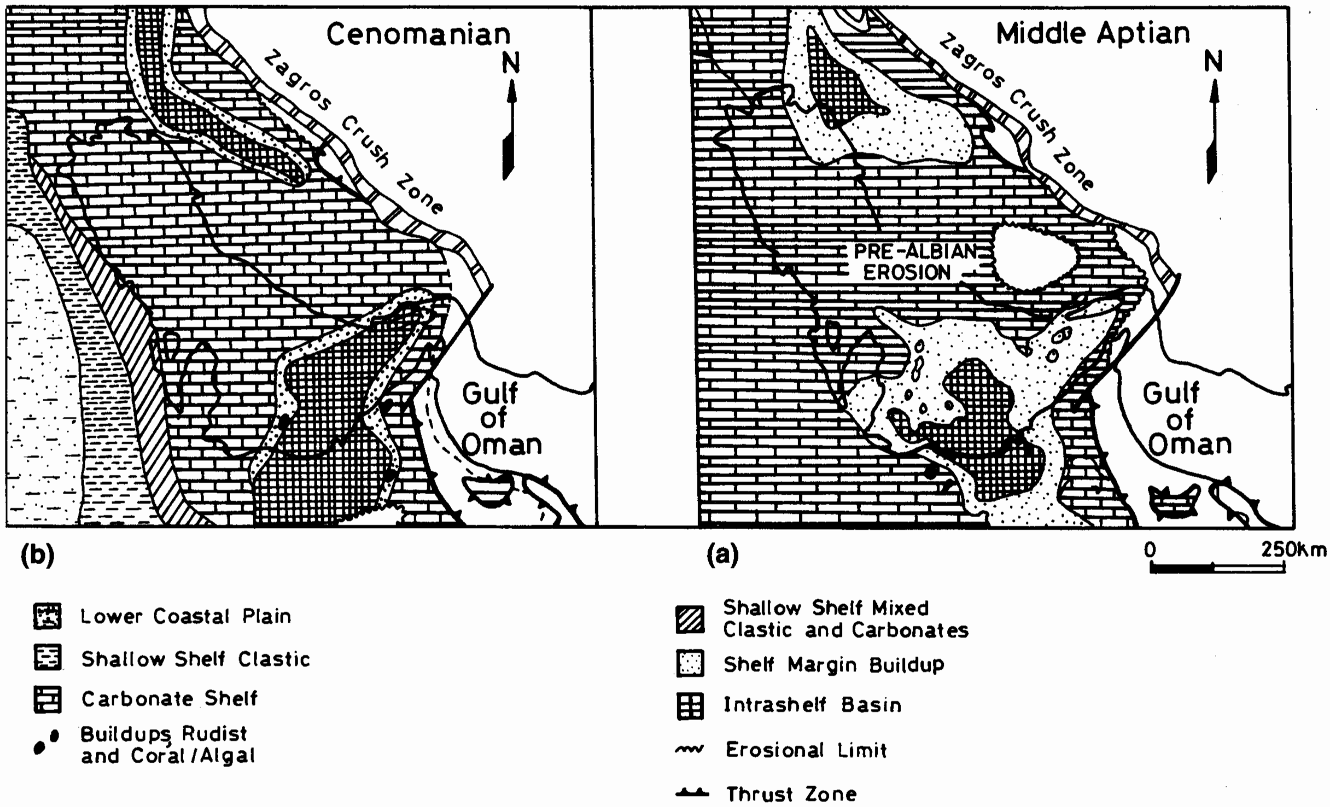


Figure 3. Paleogeographic maps of the Arabian Gulf region (a) during Aptian time and (b) during Cenomanian time. (From Murris, 1980; Harris et al., 1984; Frost et al., 1983; Alsharhan and Nairn, 1986, 1988.)

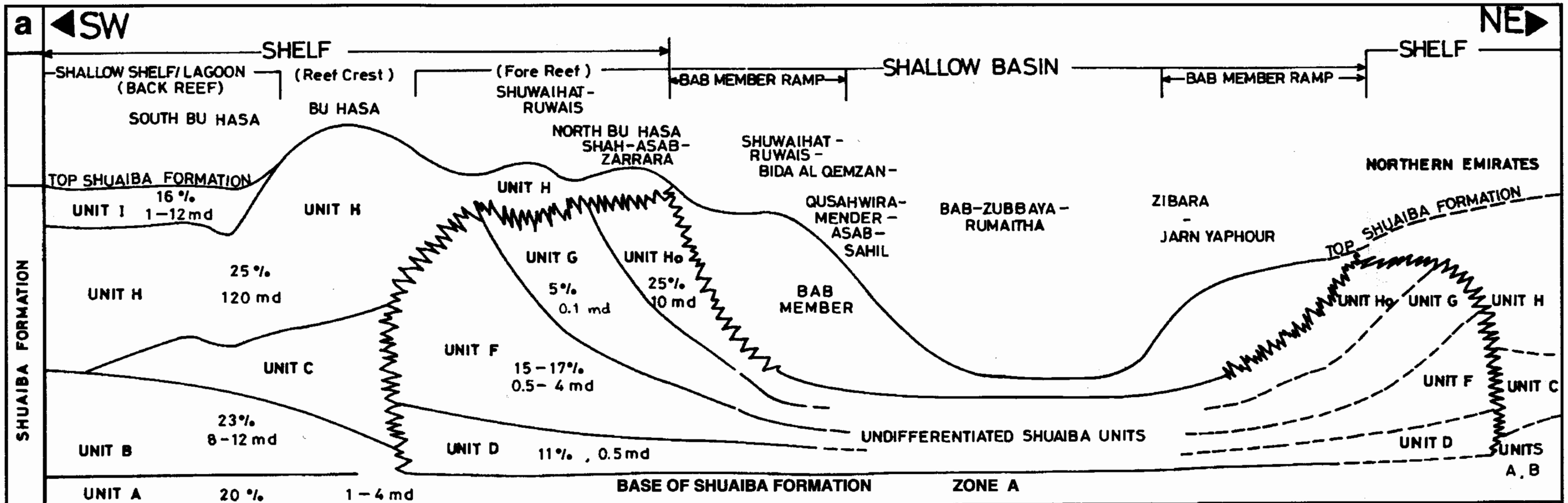
In summary, the rudist reefs–bioherms are concentrated in three formations: the Aptian Shuaiba, the Cenomanian Mishrif, and the Maastrichtian Simsima formations. In each of these formations, the rudist reefs–bioherms contain significant hydrocarbon reservoirs. In the following sections, the petrography and sedimentology of each formation is followed by data from fields lying within them.

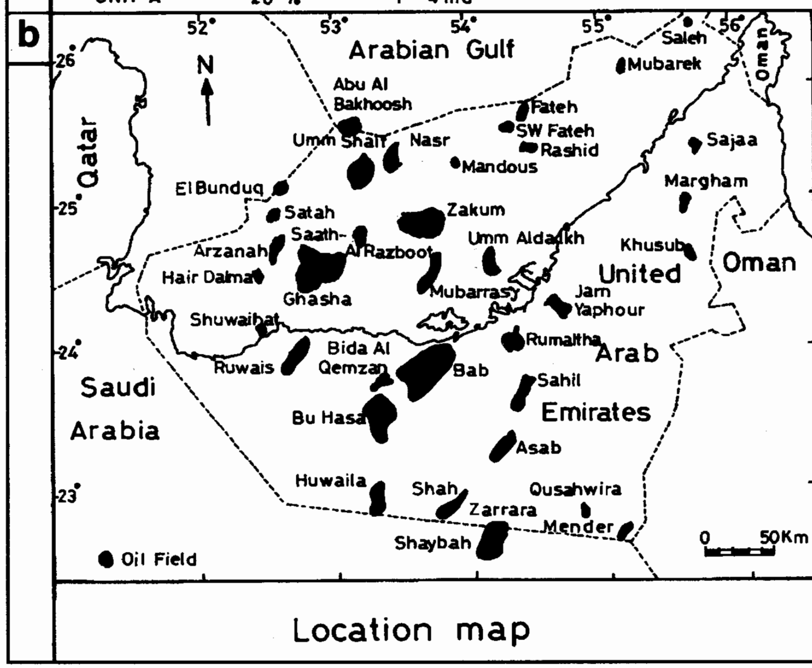
SHUAIBA FORMATION (APTIAN)

During the Barremian–early Aptian, Thamama Group deposition was differentiated into shallow shelf carbonates and an intrashelf basin within the stable cratonic shelf. The hemipelagic carbonates within the intrashelf basin were thicker than the surrounding shallow shelf carbonates. The basin is presumed to have formed as a result of differential subsidence (Alsharhan and Nairn, 1986). The dip of the ramp margins of the basin did not exceed 2° and was possibly less than 1° (Aldabal and Alsharhan, 1989), but depth changes were sufficient to be reflected in the lithofacies.

The basinal lime mudstones facies of the Shuaiba Formation is commonly referred to as the Bab Member. This member becomes progressively more argillaceous and denser toward the center of the basin. In Abu Dhabi, these beds are well-bedded, gray to dark gray, marly and burrowed lime mudstones that contain *Orbitolina* spp. and planktonic foraminifera and ammonites (Alsharhan, 1985a). Toward the basin margin, they grade into orbitolinid-bearing limestones and rudist skeletal debris in a wackestone and muddy packstone matrix. In the Rashid and West Fateh fields (offshore Dubai), the Shuaiba wackestone and packstone are locally dolomitized. Dolomite crystals commonly contain a micritic core enclosed within clear overgrowths or are found as isolated rhombs in the matrix.

Locally in the United Arab Emirates, carbonate buildups are found on the slopes of the intrashelf basin. Their magnitude decreases progressively as the basin shallows, and as they become broader, they are less differentiated from the surrounding carbonate facies. In the deeper parts of the basin near Jarn Yaphour, Zibara, Zerkouh, and Mandous in Abu Dhabi (Figure 4b), the buildups have the form of pinnacle-like mounds of algae and corals. The sparse rudist debris here probably represents material carried in from the adjacent shelf margin. It has been suggested that these mounds developed over slowly rising evaporite diapirs triggered by deep-seated fault movement (Alsharhan,





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RESERVOIR UNITS

Unit I : 3 to 40 m thick. Packstones that grade into Poorly-Sorted grainstones containing Skeletal grains.

Unit H: 3 to 78 m thick. Medium to coarse-grained Packstone and grainstones with abundant rudist build-ups.

Unit Ho: 9 to 37 m thick. Orbitolina Packstones to grainstones and rare Wackestones.

Unit G: 8 to 60 m thick. Dense lime mudstones with scattered fine bioclastics, grading to wackestones.

Unit F: 20 to 50 m thick. Microporous, dense lime mudstones, burrowed and argillaceous.

Unit D: 3 to 35 m thick. Microporous lime mudstones that are bioturbated, slightly argillaceous, and burrowed.

Unit C: 20 to 55 m thick. Wackestones containing abundant and frequently large algal colonies and thick biostrome of corals.

Unit B: 4 to 37 m thick. Wackestones and boundstones with abundant codiacian algae.

Unit A: 14 to 17 m thick. Wackestones and packstones with colonies of codiacian algae, graded upwards to microporous lime mudstones.

Bab Member : 30 to 85 m thick. Microporous argillaceous lime mudstons and wackestones with calcareous shales and deep water fauna.

Figure 4. (a) Cross section of the Shuaiba Formation from the Bu Hasa in the United Arab Emirates. Depositional phases show the transition from shallow to deep water sedimentation. (Modfied from Harris et al., 1968; Alsharhan, 1987; Abou-Choucha and Ennadi, 1990.) (b) Location map of the major oil fields in the United Arab Emirates. (c) Description of the reservoir units in the Shuaiba Formation. (From Alsharhan, 1987.)

1985a; Frost et al., 1983). The deepest water conditions appear to be indicated by microporous argillaceous limestones seen in the Lakhwair Field in Oman. Here the limestones contain a sparse *Hedbergella* sp. and *Globigerinelloides* sp. fauna. However, these grade up into limestones containing large benthonic foraminifera, including *Orbitolina* spp., indicating the reestablishment of shallow water conditions.

The middle Aptian sea level fall exposed the Shuaiba Formation to subaerial leaching for about 1.5 m.y. (Frost et al., 1983). The leaching of the rudists and other skeletal fragments created moldic porosity in the mounds, which made them a prime exploration target. The seal of these reservoirs is formed by the shales of the Albian Nahr Umr Formation at the base of the succeeding middle Cretaceous cycle. The diagenetic history of the Shuaiba is complex and has been described by Alsharhan (1985b, 1987), Budd (1989), Moshier (1989), and Wagner (1990).

Around the margins of the Abu Dhabi intrashelf basin, the main part of the carbonate buildup consists of rudist mounds with fore reef skeletal rudist debris and algal grainstones with excellent moldic and interparticle porosity. The back reef lagoonal muddy facies provides a lateral as well as vertical seal for the biohermal reservoirs. The usual reef crest facies of *Lithocodium–Bacinella* algal encrustations has excellent porosity, but also contains multiple stage cementation (Frost et al., 1983; Alsharhan, 1985b). These rudist buildups typically have low relief, but are broader and have greater lateral extent than the basinal mounds (Figure 4a). The various lithofacies comprise nine reservoir units based on petrophysical and lithologic characteristics (Figure 4c) (Alsharhan, 1987). The rudist buildups form the reservoirs of Shaybah Field in Saudi Arabia, Bu Hasa and Sajaa fields in the United Arab Emirates, Al Huwaisah Field in Oman, and Idd El Shargi Field in Oatar (Figure 1) (Baumann, 1983, Alsharhan, 1985a,b, 1987; Alsharhan and Williams, 1987; Moshier et al., 1988; Moshier, 1989).

Typical rudist buildups in the Shuaiba Formation consist of coarse-grained bioclastic packstones and grainstones with whole rudists or large fragments in a lime mud matrix (Frost et al., 1983; Hamdan and Alsharhan, 1991). The caprinids and caprotinids are more abundant than monopleurids and requienids (Alsharhan, 1987). The rudists grew under low energy conditions below wave base or were protected from storm surge. Algae and stromatoporoids did not bind these into a resistant framework. Typical rudist facies crop out at Wadi Mi'Aidin in Oman.

Three typical stages of rudist reef growth are seen in Bu Hasa Field in Abu Dhabi (Figure 4a):

1. Deposition of microporous lime mudstone and wackestone and an early *Bacinella* algal biostrome
2. Development of a layer of *Lithocodium* algae that prograded into the basin where *Orbitolina* limestones grade into lime mudstones
3. Rudist reef growth over the algal platform that shed fore reef debris into the deeper water basin. A detrital shoal phase capped the reef, and lagoonal deposits accumulated behind it.

Subaerial exposure to meteoric waters at the end of Shuaiba time resulted in the development of extensive moldic porosity (Alsharhan, 1987).

MISHRIF FORMATION (CENOMANIAN)

In the early Albian–middle Cenomanian, radiolitid rudist reefs accumulated over local bathymetric highs that were the result of extensional block faulting (Figure 5). These carbonate sands form reservoirs in western Oman and in offshore United Arab Emirates. The geologically younger fields appear to have developed over rising salt domes near the margins of the Shilaif–Khatiyah intrashelf basin.

Radiolitid rudist debris contributed to the carbonate buildups in the Dubai oil fields such as the Fateh Field. These small, cup-shaped shells lived in a shallow subtidal environment below the depth of wave agitation. Even in such relatively calm water conditions, the skeletal wall structures broke down relatively rapidly into tabular, sand-sized and silt-sized particles, a process no doubt aided by bioerosion. Tethyan (middle Cretaceous) radiolitid rudists are typically associated with large quantities of skeletal sand (Bein, 1976). The reef core in the Fateh Field is formed by radiolitid rudists in apparent growth position (Jordan et al., 1985). Only a small fraction of the buildup is composed of cemented and intergrown adjoining shells. In Oman Mountain outcrops, radiolitid rudists form loosely packed communities, where no more than one or two generations of shells are superposed. Unlike the assemblages in Fateh Field, these do not have frameworks and probably occurred at different positions on the shelf.

The gradual coarsening upward transition from basinal limestones (Shilaif–Khatiyah) to shallow marine reef limestones (Mishrif) suggests a very low gradient, ramp-like platform margin. This prograding, shoaling upward sequence may represent deposition during a sea level highstand, but its timing cannot be correlated precisely with the chart of Haq et al. (1987) (Alsharhan and Kendall, 1991).

The Shilaif–Khatiyah intrashelf basin developed in the southern part of the Arabian Gulf during late Albian–Cenomanian time. It was apparently large and deep enough to have sustained significant water circulation in its upper part and yet have an oxygen minimum zone in the deeper part of the basin. In this deeper part, a potential source rock of dark kerogen-

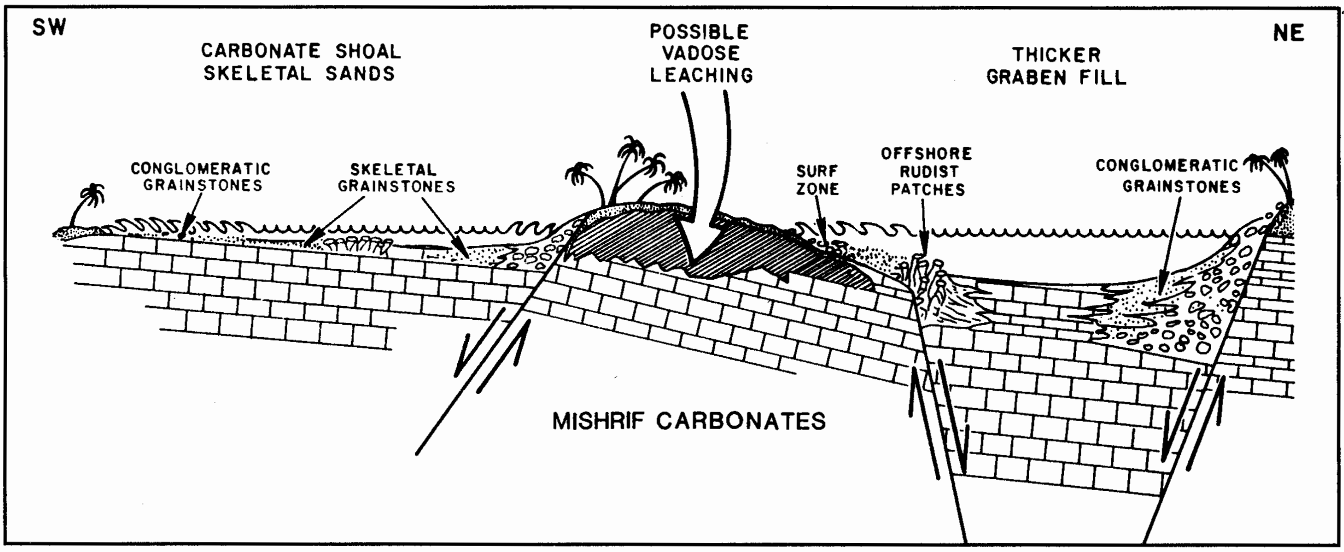


Figure 5. Depositional model of the Mishrif Formation carbonates in Oman. The complex pattern of lithofacies variation resulted from sedimentation on sea floor topography formed around uplifted fault blocks. (After Harris and Frost, 1984.)

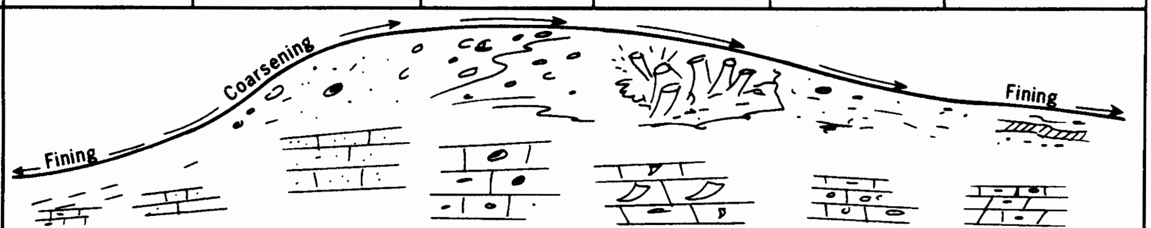
FORMATION	*SHILAIF*	*M I S H R I F*				
LITHOFACIES	Intrashelf basin	Platform margin slope	Shoal	Rudist biostrome	Back shoal	Platform lagoon
MODEL OF LOW-GRADIENT CARBONATE PLATFORM MARGIN						
LITHOLOGY	Dark brown-dark tan, silt-grade bioclastic packstone,wacke-stone and mudstone.	Coarsens upwards from well-bedded, bioturbated silt-grade bioclastic pack-stones to poorly bedded medium-grained pack-stones.	Unbedded medium to very coarse-grained bioclastic packstones and grainstones	Unbedded extremely coarse cream colored shelly bioclastic packstones and wackestones.	Fine to very coarse-grained, fawn bio-clastic packstones, wackestones and grainstones	Greenish-grey, light brown, indistinctly bedded benthonic foraminiferal and peloidal mudstones and wackestones.
FOSSILS	Oligostegina; pelagic foraminifera, rare placunopis and Exogyra; uncommon burrowing organisms.	Bivalves: *Lima semiomata, Lithophaga sp., Plagio-stoma sp., Agerostrea sp., burrowers*	Rudists: *Praeradiolites sp.*, *Radiolites sp., Sauvagesia sp.* , uncommon caprinids and monopleurids. Other molluscs: *Chrondro-donta, Tylostoma.* Corals: *Cladophyllia* Uncommon benthonic foraminifera and echinoids		Abundant chrondro-donta, common ophiomorpha, scattered radiolitid rudists, burrowing organisms	Benthonic foraminifera: *Dicyclina, Orbitolina, Avalveolina, Praeal-veolina, Valvulammina picardi, Nezzazta conica, Pseudochrys-alidina, Ostracodes,* uncommon molluscs.
SEDIMENTARY STRUCTURES	Well-bedded intensely compacted, locally with nodular fabric, discrete low amplitude and wispy microstyolites	Grading up from moderately well-bedded to poorly bed-ded. Styolites and biotur-bation common.	Bioturbation	Coarsening upwards succession, minor bioturbation	Styolites and biotur-bation common, rare ripple-cross lamination	Burrows, styolites, and nodular fabric common; lamination rare
POROSITY (%)	0.3-13	0.1-29	6.5-36	4.8-30	4.7-20	0.1-21
PERMEABILITY (md)	0.01-110	0.1-90	0.01-700	0.01-950	0.02-950	0.01-80
DEPOSITIONAL ENVIRONMENTS	Open marine basinal, low turbulance and poor oxygenation	Progradation of a carbonate platform slope into the basinal environment.	Moderate energy shoals and banks at the platform margin.	Biostromal buildup near prograding shelf margin	Transition zone from platform to margin shoals and platform interior lagoon. The sediment is shoal-derived carbonate sand sheets and washovers	Broad quiet water lagoon sheltered by platform-margin shoals

Figure 6. Lithofacies analysis of the Mishrif and Shilaif formations in eastern offshore Abu Dhabi. (Compiled and modified from Burchette and Britton, 1985.)

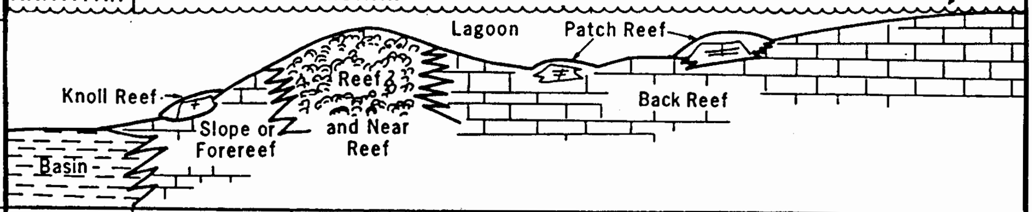
West				East
FORMATION	KHATIYAH	MISHRIF		Shoreline
REEF CLASSIFICATION				
LITHOLOGY	Mudstones & gray calcareous shale.	Rudist grainstones to packstones. Pelletal grainstones to packstones.	Rudist grainstones to packstones and rudist grainstones with whole rudists. Pelletal grainstones to packstones.	Algal foraminiferal wackestones to mudstones (mainly platy green algae and miliolids). Rudist boundstones to packstones and pelletal packstones to wackestones.
FOSSILS	Thin-walled pelecypods Oligostegina planktonics and ostracods	Radiolitid Rudist and pelecypod fragments are very abundant; with some miliolids and echinoids.	Chondrodonta, Radiolitids, Caprinids, Monopleurids, Tylostoma, miliolids, echinoids, cladophyllia, and coral.	Caprinids and Monopleurids occur in patch reefs, miliolids, Praealveolina small benthonics, agglutinated foraminifera, Bacinella and dasyclad algae and echinoids.
SEDIMENTARY STRUCTURES	Burrowing, fractures stylolites.	Burrowing, fractures, geopetals, argillaceous wisps fractures.	Burrowing, fractures, geopetals.	Burrowing, brecciation, fractures, geopetals, stylolites, internal fracture filled with pyrite.
POROSITY TYPES	———	Interparticle, vuggy, moldic, shelter and Intraparticle	Interparticle, Intraparticle, shelter moldic, and vuggy.	Interparticle and moldic.
POROSITY(%)	———	10 – 25	20-25	1 – 25
PERMEABILITY (md)	———	5 – 30	50	5 – 10
AVERAGE THICKNESS (ft)	200	75 – 150	100	30 – 50
RESERVOIR QUALITY	Source	Excellent	Good to excellent	Poor to zero
PROFILE POSITION	Basin	Slope	Outer shelf	Middle shelf

Figure 7. Sedimentologic analysis and reef facies distribution in the Mishrif facies, Fateh Field, Dubai. (Compiled and modified from Jordan et al., 1985.)

rich limestones accumulated (Jordan et al., 1985). The oligosteginid limestones of the Shilaif and Khatiyah formations are densely compacted, cemented by calcite, and contain many stylolites and microstylolites.

The middle Cretaceous Mishrif Formation is a major reservoir in offshore Dubai and Abu Dhabi. It has been divided into a number of lithofacies units described in detail by Schlumberger (1981), Burchette and Britton (1985), and Jordan et al. (1985) and presented here in cross sections (Figures 6 and 7). Typical stages of rudist reef growth are observed in Umm Al Dalkh Field in Abu Dhabi (Figure 8).

The back reef facies consists of medium- to coarse-grained grainstones, breccia–conglomeratic limestones, rudist fragments, and bituminous lime mudstones with local coal seams. Variations in the petrophysical properties of this facies are controlled mainly by the nature and distribution of fracturing. Open fractures impart medium to high porosity and permeability and good reservoir characteristics. However, where closed, bitumen-filled, or cemented fractures occur, permeability is reduced and poor reservoir characteristics result.

The reef to near reef facies consists of coarse-grained bioclastic grainstones, packstones, and wackestones with abundant broken and intact rudists; *in situ* rudists are locally present. Abraded rudist shells become more abundant in the near reef facies. These are high to moderate energy deposits and form a thick reefal buildup. This facies has low to high porosity and permeability. The reservoir rudist grainstones and packstones are cemented by calcite and have interparticle porosity enhanced by leaching.

The off reef facies of bioclastic grainstones and pack-

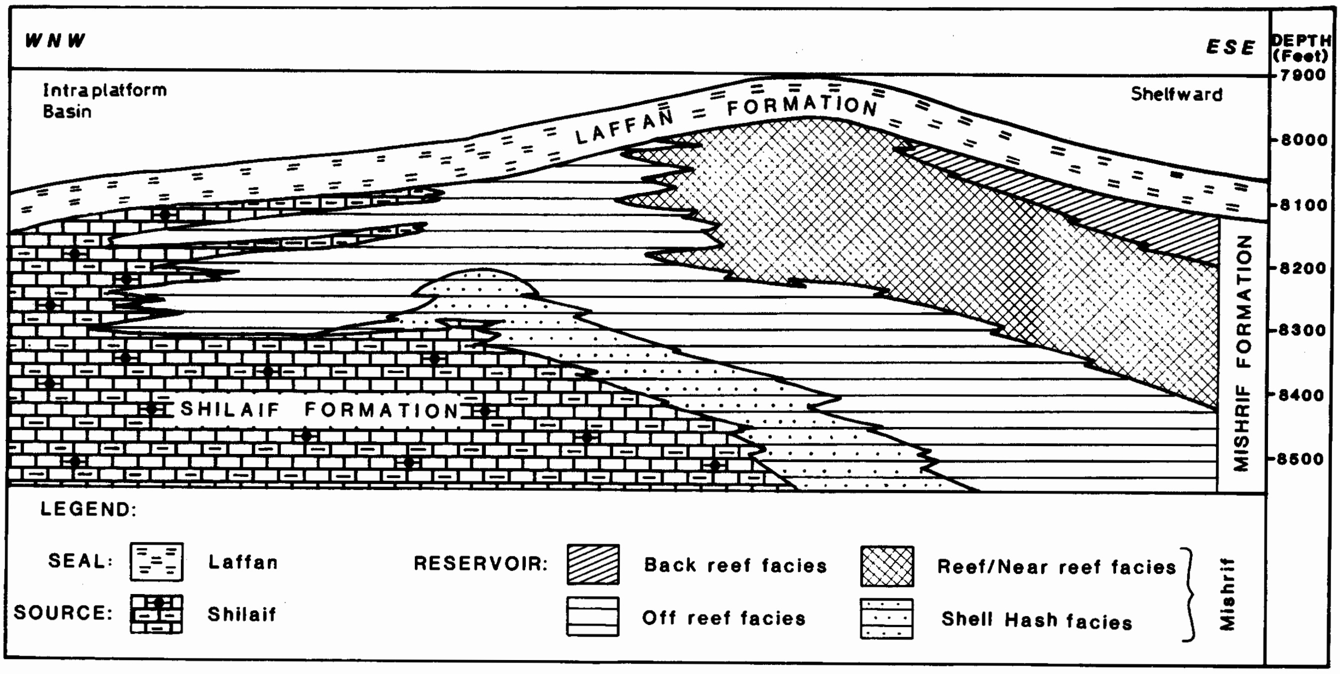


Figure 8. The relation between Mishrif reservoir facies and Shilaif source rock facies, Umm Al Dalkh Field, Abu Dhabi. (Modified from Schlumberger, 1981.)

stones consist mostly of abraded and comminuted skeletal debris, with grain sizes ranging from very coarse to very fine. This facies has medium to high porosity, which is due to original matrix porosity supplemented by leaching.

The shell hash facies consists of silt-sized, bioclastic, bioturbated wackestones and lime mudstones deposited in a low energy environment. This facies has abundant microstylolites and stylolites and is characterized by medium porosity and low permeability. The matrix porosity has been reduced by compaction.

The Mishrif carbonates are underlain by and interfinger with the Shilaif Formation, which was deposited in a low energy environment that existed over large areas in the southern part of the Arabian Gulf. The Shilaif and Khatiyah formations are believed to be the source rock for the oil in the Mishrif reservoir in Oman and the United Arab Emirates (Hughes Clarke, 1988; Alsharhan, 1989).

The Shilaif Formation grades laterally into the Khatiyah Formation, which are transgressive basinal facies overlain by the prograding Mishrif rudist facies. The basinal facies is characterized by bituminous calcareous shales, laminated and locally burrowed, which grade upward to argillaceous lime mudstones containing abundant *Oligostegina* sp., *Hedbergella* sp., and planktonic foraminifera. Erosion during the major post-Mishrif hiatus completely stripped the Mishrif from the crest of the Fateh structure and left a reduced thickness over the flanks. Extensive solution during subaerial exposure resulted in biomoldic porosity. Alsharhan and Kendall (1991) recognize as many as five log cycles in the Shilaif and Khatiyah formations, which appear to match sea level positions on the Haq et al. (1987) chart. These cycles are best developed at the center of the basin and are obscured at the margins by the prograding Mishrif Formation. Organic deposition of the Shilaif and Khatiyah sequence is associated with sea level cycles or climatic cycles during which carbonate sediment flux varied so as to make the sediments periodically organic-rich. As a result, the Shilaif and Khatiyah sequence is a significant source rock.

SIMSIMA FORMATION (MAASTRICHTIAN)

The Simsima Formation represents the regressive phase of the second subcycle in the Upper Cretaceous section and probably correlates with one of the cycles on the Haq et al. (1987) chart (Alsharhan and Kendall, 1991). It is the terminal sedimentary event in the Arabian Cretaceous sequence and is characterized by shallow shelf limestones and deeper water marly limestones. The carbonates of the upper Maastrichtian Simsima Formation formed on a shallow platform that resulted from shoaling of the relatively deep water shelf or slope existing during deposition of the underlying Fiqa Formation. The Simsima Formation overlies in part the truncated margins of the ophiolites and sedimentary rocks of the Hawasina nappe in the western Oman

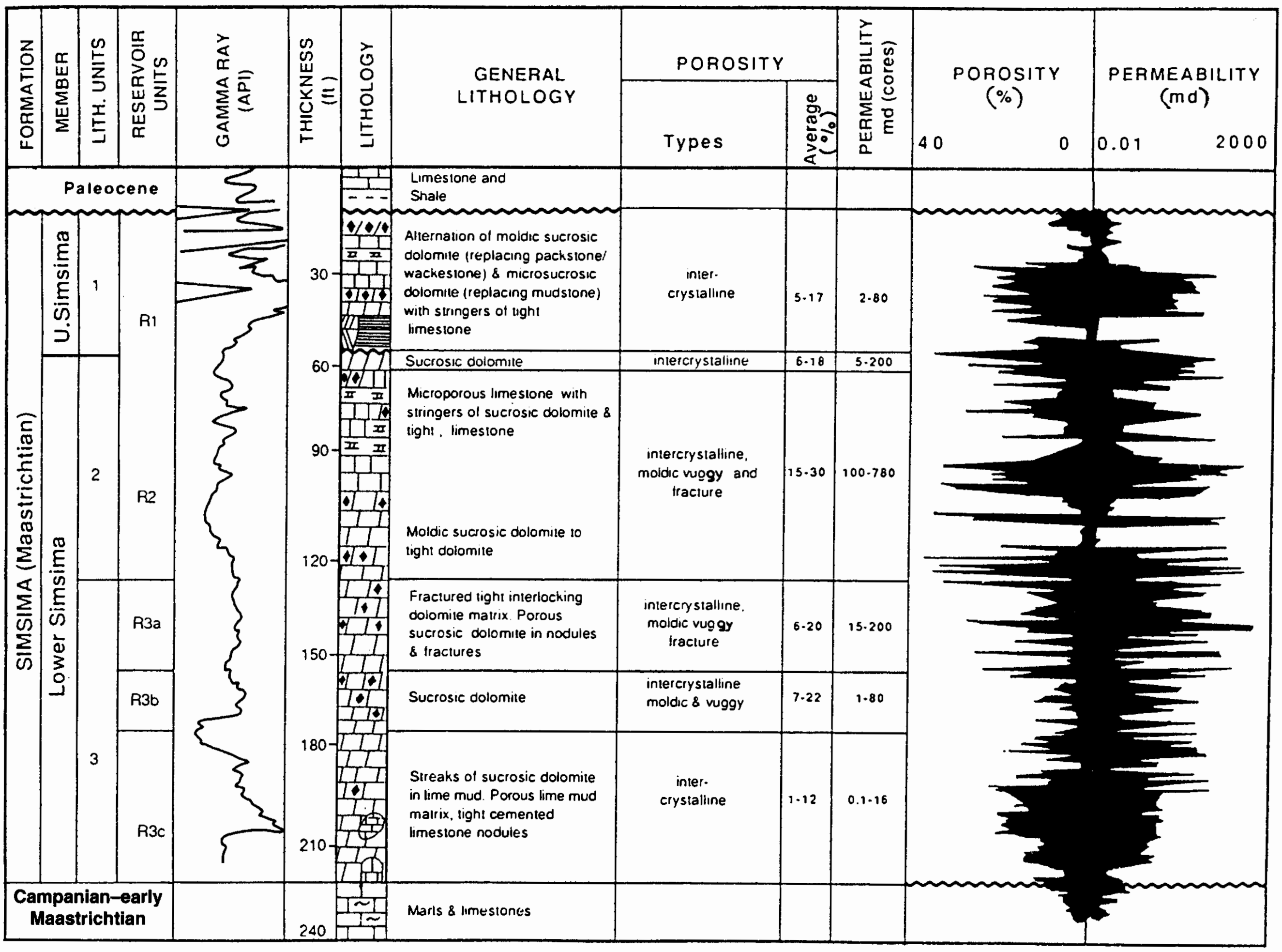


Figure 9. Lithofacies interpretation and petrophysical characteristics of the Simsima Formation, Shah Field, Abu Dhabi. (Based in part on data from Schlumberger, 1981; Badr and Ayoub, 1989; Alsharhan and Nairn, 1990.)

Mountains. It extends northward in a narrow belt from Jebel Hafit (eastern Abu Dhabi) into the northern United Arab Emirates (Skelton et al., 1990). In the subsurface, the Simsima can be traced over much of Abu Dhabi, where it includes the producing horizon of the Shah Field.

The Simsima consists of bioclastic and dolomitized limestones with locally abundant large benthonic foraminifera and large rudists. Coral and rudist buildups flanked the margin of the subsiding Oman foredeep in northeastern Dubai in the northern United Arab Emirates. They possibly extend into the subsurface, where they may be targets for future exploration. They are part of a shoaling upward succession capped by lime mudstones and wackestones deposited under subtidal and tidal flat conditions. Locally within the Simsima, large collapse breccias are found that originated by solution of interbedded evaporites. The evaporites probably formed under supratidal conditions.

At Shah Field in Abu Dhabi, the Simsima Formation is the main reservoir and consists of two large-scale depositional cycles (Figure 9). The lower cycle (Lower Simsima Member) is composed of packstones with *Orbitoides tissoti* deposited in a shallow, open marine environment overlain by packstones and wackestones with *Orbitoides media* and echinoid debris deposited in a warm, shallow marine environment. Above this are thick *Lepidorbitoides* packstones that reflect a semi-restricted shelf environment. This lower cycle is capped by rudist packstones deposited under restricted shallow marine and moderate energy conditions (Alsharhan, 1989; Badr and Ayoub, 1989).

The upper cycle (Upper Simsima Member) begins with black, argillaceous, organic-rich limestones overlain by rudist and bioclastic packstones and grainstones deposited in a shallow marine (semi-restricted) subtidal to low intertidal environment. The next unit in the succession is gray-green lime mudstone deposited in a normal marine subtidal environment. This upper cycle is terminated by yellow to brown algal bioclastic wackestones of semi-restricted marine subtidal origin.

CONCLUSIONS

The Arabian Cretaceous carbonate shelf was deposited on a passive margin beginning in Barremian time; by Maastrichtian time, it had changed to a back arc basin. The dominate facies are fine to coarse carbonates with thin intervals of shales and sandstones; the abundant bioclasts include molluscs, algae, sponges, corals, and pelagic and benthic foraminifera. In the Cretaceous sequence of the Arabian Gulf area, the primary reservoirs are rudist accumulations having enhanced porosity due to subaerial leaching resulted from relatively minor sea level fall. The rudist buildups occurred in three locations: on basin margins (Bu Hasa Field), along fault block margins (Fahud Field), and above active salt domes (Fateh Field). Source rock facies developed in intrashelf basins characterized by laminated argillaceous and shaly lime mudstones–wackestones and kerogen-rich limestones with abundant planktonic foraminifera.

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