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ABSTRACTS OF PUBLISHED PAPERS & MEETINGS (1985 – 2014)

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ALSHARHAN, A.S. (2008). Water Resources in the Emirate of Abu Dhabi. Chapter 4, p.114-163. In Terrestrial Environment of Abu Dhabi Emirate, published by Environmental Agency, Abu Dhabi, United Arab Emirates.

The Emirate of Abu Dhabi has a total area of 67,350 km^2, lies in the southeastern part of the Arabian Peninsula. Geomorphic features have a major role in controlling the movement of both surface and groundwater. Geology controls the patterns of aquifers and confining units, stratigraphic sequences, and structural zones. These greatly influence runoff volumes, infiltration rates, and the quality of surface and groundwater.

Topographic maps and satellite images, in addition to the records of stream gauges and meteorological stations, are used to estimate surface runoff, and to assess the flood potential of the major drainage basins in Al-Ain and Liwa areas. This chapter presents a summary on the conventional water resources in the Emirate of Abu Dhabi.

ALSHARHAN, A.S. (2008). Geology of Abu Dhabi Emirate. Chapter 1, P. 19-69. In Terrestrial Environment of Abu Dhabi Emirate, published by Environmental Agency, Abu Dhabi, United Arab Emirates.

The Emirate of Abu Dhabi is located on the eastern side of the Arabian Peninsula, between latitudes 22° 40′ and 25° 00′, and longitudes 51° 00′ and 56° 00′ where the interior platform of the Arabian shelf occurs in the subsurface. It is bounded on the northwest by the Qatar - South Fars Arch, and on the northeast and east by the foreland basin of the Arabian shelf, and adjacent foreland folds and thrust belt of Oman.

Desert sands and coastal sediments characterize the surface geology of the western and central part of the country, while to northeast a mountain range extends from Ras Al Khaimah to Al Fujairah and extend southward to Al-Ain region (the eastern provinces of Abu Dhabi Emirate). A classic carbonate-evaporite complex characterizes the coastal areas adjacent to the Arabian Gulf, whereas siliciclastics, minor carbonate sands, and local sabkhas characterize the coastal areas of the Gulf of Oman. Near the mountainous areas large areas of fluviatile gravel form a plain onto which aeolian sand have been transported by the prevailing wind. Much of the area is covered by sand dunes of varying morphology. The aeolian sand dunes include transverse, barchan and seif dunes complexes, and cover large areas and highly varied in type and orientation. This chapter deals with the geology of Abu Dhabi Emirate supported by field study and Landsat imagery.

ALSHARHAN, A.S. and E.A. Abd El-Gawad (2008). Geochemical characterization of potential Jurassic/Cretaceous source rocks in the Sushan Basin, northern western desert, Egypt. Journal of Petroleum Geology, v. 31(2), p. 191-212.

A close examination of the oil and gas potential of the Egyptian Western Desert confirms the existence of substantial remaining reserves which have yet to be exploited. In the Western Desert, the source rocks are typically shale sequences associated with the transgressive front of the Upper Jurassic and Upper Cretaceous periods. The organic facies and the thermal maturity of these Mesozoic source rocks still need clarification.

Integrating geochemical data, obtained from kerogen and bitumen analyses, is the most effective combination used for evaluating and detecting new horizons as potential petroleum source rocks. This intends to promote and facilitate more exploration and development activities in the study area and its environs.

The thermal maturity of the studied Mesozoic source rocks in the Shushan basin was greatly affected by the burial depth within this basin where the source rocks in the central parts (troughs) of attain higher maturity levels than those encountered in the western (crestal) parts.

In the central parts of the basin, all extracts appear to have terrestrial input in different proportions except Khatatba extract at 4437– 4440 m in the Jb 26-1 well. Moreover, except for the Kharita extracts, all the studied extracts have reached thermal maturities sufficient to generate and expel mature crude oils. Correlation of source rock extracts with the studied oils revealed that the Jb 26-1 Khatatba and Alam El-Bueib source beds show a good correlation with the crude oil sample from the Ja 27-2 well.

Khataba Sandstones represents the main resevoir unit in the Shushan Basin and could be classified into three horizones based on electric logs behavior.

In the western parts of the basin, four distinct organic facies are recognized through a section penetrating the Jurassic-Cretaceous sequence. These are Organic Facies I consists of sandy shale sequences of the Bahariya, Kharita and Alam El-Bueib formations; Facies II Alamein Dolomite and Facies III Masajid Formation are organically lean; and Facies IV comprises the organically rich interval of the Khatatba Formation at the base of the section penetrated.

Rizk, Z.S., A.S. ALSHARHAN and W.W. Wood (2007). Sources of Dissolved Solids and Water in Wadi Al Bih Aquifer, Ras Al Khaimah Emirate, United Arab Emirates. Hydrogeology Journal v. 15, p. 1553-1563.

Regional brines that underlie the potable groundwater appear to be responsible for the increase in dissolved solids in the Wadi Al Bih aquifer in the Ras Al Khaimah Emirate, United Arab Emirates. In this karstic carbonate aquifer, groundwater extraction exceeds recharge and the reduced heads can induce transport of underlying brines into the potable water aquifer. Increasing dissolved solids with time threatens the continued use of groundwater for agricultural and domestic uses. The potential of intrusion of seawater, dissolution of minerals, or intrusion of regional brines as a source of these solutes were evaluated based on groundwater samples collected in April and September 1996 from the Wadi Al Bih well field and isotope data from previously collected samples. Hydrogeologic conditions and solute modeling suggest the dominant source of solutes in the Wadi Al Bih aquifer is most likely underlying regional brine. The pervasive presence of tritium is consistent with recent (since 1960s) recharge in the drainage basin, thus, the solutes and water appear to be from different sources. The chemical and isotopic data are also consistent with enhanced ground water recharge associated with dams constructed to reduce flooding.

ALSHARHAN, A.S. (2006). Sedimentological Character and Hydrocarbon Parameters of the Late Permian Carbonates (Khuff Formation) of the United Arab Emirates. GeoArabia, v. 11(3), p. 121-158.

The Middle Permian to Early Triassic Khuff Formation occurs in the subsurface of the United Arab Emirates at depths that range from 3,688-6,188 m (12,097-20,297 ft) in Abu Dhabi and Dubai, and as outcrops in mountainous areas of the northern United Arab Emirates. The formation consists of a shallow-water carbonates that include limestones, dolomitic limestones with subordinate anhydrite and dolomites. It reaches a thickness of as much as 625-970 m (2,050-3,182 ft) in the subsurface and 125-960 m (410-3,149 ft) in outcrops. The Khuff Formation is interpreted as a second-order composite sequence represented by the KS1 through KS7 third-order sequences. The Khuff transgressive systems set starts with the KS7 event and ends at the maximum flooding surface of KS4. The highstand systems set starts in the upper portion of the Khuff with a second-order maximum flooding surface (MFS-4) and ends with a sequence boundary at the top of KS1 that characterizes the top of the Khuff Formation. The formation is subdivided into ten facies units distinguished on the basis of their depositional textures that represent an overall regressive carbonate-evaporite sequence. Based on the paleoecology, sedimentary structures and lithology, four distinct depositional settings can be recognized: (1) supratidal (sabkha), (2) lagoon, (3) shoal and (4) shallow shelf. The formation can be broadly subdivided into two major carbonate units deposited in two different hydraulic regimes, which are separated by an anhydrite bed (the Middle Anhydrite marker).

A detailed petrographic study of the Khuff carbonates reveals a complicated diagenetic history. Four diagenetic settings have been identified: (1) marine phreatic, (2) mixed phreatic, (3) meteoric phreatic, and (4) burial. The Khuff Formation has both primary and secondary porosity. Most open pores are a result of interparticle, intercrystalline, dissolution vug or enlarged mouldic porosity. The diagenetic features in these sediments are mainly partial cementation, dolomitization and the development of secondary anhydrite. Porosity ranges from 6-20% and permeability from less than 1.0 to more than 500 md. Horizontal permeability is greatly enhanced by subvertical partings of the open pores, common in microcrystalline dolomites. Stylolites are common, but unimportant as vertical barriers. Extensive fracturing of the reservoir has produced a dense network of intersecting vertical and subvertical fractures. These fractures have a significant impact on the enhancement of the effective porosity and permeability.

The Khuff Formation has large volumes of proven gas reserves in Bahrain, Iran, Qatar, Saudi Arabia and the United Arab Emirates and minor oil in an. While the Khuff Formation forms prolific gas and condensate reservoirs in the offshore United Arab Emirates, no hydrocarbons have been found in the onshore area. Locally here the reservoir is capped by the shales and dolomites of the overlying Sudair Formation (Early Triassic). The formation is sourced from Silurian Qusaiba shales.

I.A. Al-Jallal and A.S. ALSHARHAN (2005). Arabia and the Gulf. In: Encyclopedia of Geology, R. Selley, R. Cocks and I. Plimer (eds.), Elsevier, p. 140-152.

Arabia consists of two main geological features: the Arabian shield and the Arabian shelf. Charles Doughty, who in 1888 produced the first geological map of Arabia, wrote "the Geology of the Peninsula of the Arabs consists of a stack of plutonic rock, whereupon lie sandstones, and upon the sand-rocks limestones. There are besides great land-breadths of lava and spent volcanoes". These two sentences encapsulate the geology of Arabia, and indeed of the whole of the southern shoreline of Palaeo-Tethys, from the modern Atlantic Ocean to the Arabian Gulf.

The Arabian shield is a Precambrian complex of igneous and metamorphic rocks that occupies roughly one-third of the western part of the Arabian Peninsula. The Arabian shield is a continuation of the adjacent African shield from which it is separated by the Red

Sea rift (see Africa: Rift Valley). The rocks in West Arabia, Yemen, Aden, and Oman are dated as Precam-brian by radioisotopic dating and by the presence of Cambrian fossils in sediments above. Radiometric dates show that the Arabian shield was involved in the Pan-African Orogeny (see Africa: Pan-African Orogeny). The shield crops out along the east coast of the Red Sea rift, south to Yemen, and extend eastward into central Arabia with varied degrees of exposures.

ALSHARHAN, A.S. and A.A. El-Sammak (2004). Grain-size analysis and characterization of sedimentary environments of the United Arab Emirates coastal area. Journal of Coastal Research, v. 20(1), p. 464-477.

There are no previously published granulometric studies of the sediments from the coastal areas of the UAE. In this study one hundred and forty-four beach sediment samples were collected from coastal districts of seven emirates (Abu Dhabi, Dubai, Sharjah, Ajman, Umm Al-Quwain, Ras Al-Khaimah and Fujairah) for the purposes of grain size analysis and province delineation. A range of grain size data analysis methods, such as bivariate scatter plots and discrimination functions, were employed in the interpretation of the environments and mechanisms of sediment deposition. Multivariate statistical analysis was also used to discriminate between different coastal zones.

The Arabian Gulf coast can be divided into the following three provinces: a) Abu Dhabi/Dubai province, b) Sharjah/ Ajman/Umm Al-Quwain province and c) Ras Al-Khaimah province. The Gulf of Oman coast can be divided into the following four provinces: a) Rol Diba Province, b) Dadnah/Aqqa province, c) Khor Fakkan province and d) Fujairah province. The results from this study suggest that the variations between different sites may be due to either the diversity of the sources of the sediments, or to the geomorphology of the coastal area. The second factor has controlled the details of transport of sediments along the coastal areas. Another important variable is the geology of the coastal strip that affects the types and distributions of coastal sediments.

F.N. Sadooni and A.S. ALSHARHAN (2004). Stratigraphy, lithofaceis distribution and petroleum potential of the Triassic strata of the Northern Arabian plate. American Association of Petroleum Geologists Bulletin, v. 88(4), p. 515-538.

Triassic strata of the northern part of the Arabian plate mark the establishment of the Neo-Tethys passive margin. This ocean first opened in the western part of the Mediterranean region directly after the Hercynian orogeny. The strata were deposited on a shallow carbonate platform surrounded by clastic-evaporitic lagoons and continental fluvial and eolian settings. The rocks are divided between continental clastics (such as the Budra and the Ga'ara formations), continental-marine clastics and evaporites (such as the Mohilla, Abu Ruweis, Beduh, and Baluti formations) and epicontinental marine facies (such as the Saharonim, Salit, and Kurra Chine formations). These settings are comparable to those of the German Triassic and have matching lithofacies and eustatic sea level changes. The succession has been divided into four "high-frequency" sequences dominated by highstand systems tract carbonates and highstand systems tract-lowstand systems tract evaporites and clastics: the Mu-lussa Formation, the Kurra Chine dolomite and oolitic limestones, the clastics in the Euphrates-Anah graben in Syria and Iraq, and the Triassic buildups in the northern parts of the

Levant form attractive hydrocarbon reservoirs when they are overlain by the Triassic -Jurassic evaporite sequence and are in communication with Silurian source rocks. In Syria, the Kurrachine Formation contains both source and reservoir rocks. On the Aleppo plateau, this formation is believed to lie at the beginning of the thermal maturation window, whereas in the areas of Jebbissa, Soukhne, and Souedie, it is in the mature or overmature windows. The Triassic strata produced fair amounts of light oil, gas, and condensates from some fields in Syria and Iraq with a high potential of gas and condensate accumulations in the Levant region.

C.G.ST.C. Kendall, V. Lakshmi, J. Althausen and A.S. ALSHARHAN (2003). Changes in Microclimate Tracked by the Evolving Vegetation Cover of the Holocene Beach Ridges of the United Arab Emirates. In: Desertification in the Third Millennium. Edited by A.S. Alsharhan, W.W. Wood, A.S. Goudie, A. Fowler and E.M. Abdellatif. 2Swets & Zeitlinger Publishers, Lisse, The Netherlands, p.91-98.

At 24° N, the U.A.E. has an arid, subtropical climate, with an annual temperature range 50 to 0 °C. This causes a widespread occurrence of carbonates and evaporites, and the restricted character of the vegetation, though diurnal dews, associated with onshore late afternoon and evening winds, support vegetation on dunes at the shoreline and near shore hillsides. In the eastern U.A.E., barrier islands are positioned on a narrow shelf with little protection from heavy seas. They have steep beach faces landward of which are subaerial dunes that are greater than 5 m in height. In contrast in the western U.A.E. landward of the Khor al Bazam and west of Abu Al Abyad, parallel sets of small subaerial dunes 1 to 2 m in height are common along the landward edge of a broad intertidal platform.

These local dunes closer to the sea and areas of higher topography are colonized and stabilized by the halophyte, *Salicornia* sp. The occurrence of these halophytes appears to be directly related to the occurrence of diurnal dews. The wetting effect of the dews dies out landward across the dune belt, and is matched by a corresponding loss of vegetation and the deflation of the dunes. The inner lagoons of the Holocene shallow-water carbonate and supratidal evaporite tract that lines the U.A.E. are rimmed by a series of stranded and deflated beach ridges that now lack dune ridges, formed at the end of the last major sea level change some 3000 to 4000 years BP. Supratidal flats are now encroaching on these lagoons through the development of cyanobacterial flats in the place of the beach ridges. It is predicted that all the coastal lagoons of the U.A.E. will fill naturally or by man driven reclamation. A concurrent change in microclimate will cause the demise of the current halophyte cover of the coastal dunes.

C.G.ST.C. Kndall, P. Lake, H.D. Weathers III, V. Lakshmi, J. Althausen and A.S. ALSHARHAN (2003). Evidence of Rain Shadow in the Geologic Record: Repeated Evaporite Accumulation at Extensional and Compressional Plate Margins. In: Desertification in the Third Millennium. Edited by A.S. Alsharhan, W.W. Wood, A.S. Goudie, A. Fowler and E.M. Abdellatif. 2Swets & Zeitlinger Publishers, Lisse, The Netherlands, p.45-52.

Arid climates have been common and effected water resources throughout Earth history. This climatic history provide a key to understanding current causes for desertification and a means to devise realistic strategies for coping with its effects. Desert climates are often indicated in the geologic record by thick sections of evaporites (anhydrite, gypsum and halite) that have accumulated in both lacustrian and marine settings either adjacent to margins of recently pulled apart continental plates, in compressional terrains of colliding margins, or in areas of local tectonic uplift or sediment accumulation that have isolated standing bodies of water from the sea. These linear belts of evaporitic rocks can be directly related to rain shadow caused by:

1) The aerial extent of adjacent enveloping continental plates
2) The occurrence of uplifted crust marginal to linear belts of depressed crust
3) The occurrence of linear belts of depressed crust, with surfaces that are often below sea level
4) The occurrence of internal drainage and/or limited access to open ocean waters
5) The location within a climatic belt already characterized by low rainfall

Examples of evaporite generation in depressed extensional basins belong to the Mesozoic sedimentary section of the North and South Atlantic margins: the Mesozoic of the northern Gulf of Mexico; the Mesozoic of the Yemen rift belt; the Mesozoic and Tertiary of Eritrea; the East African Rift; the Dead Sea, and so on.

In contrast the current Arabian Gulf and its underlying Mesozoic to Tertiary rock section is a prime example of a linear intercontinental compressional zone that has a history punctuated by limited access to the sea and repeated desert climates. Other comparable examples include sections of the Silurian of the Michigan Basin and western New York State; the Devonian of western Canada and the Northwest USA; the Pennsylvanian of the Paradox Basin; the Permian of New Mexico and west Texas; the Permian of the Zechstein Basin; the Jurassic of the Neuquen Basin of Argentina; the Tertiary of the Mediterranean; and the Mesozoic and Tertiary of the final phases of the Tethys Sea (e.g., the Caspian and Aral Seas, etc.).

Examples of evaporite accumulation behind barriers developed by structure and sediment buildup include the Permian Khuff Formation and the upper Tuwaiq Mountain Group, both of which accumulated on the eastern margin of the Arabian Shield and were isolated from the Tethys Ocean.

The recognition of the strong tie between plate setting and climate can be used to predict the evolution of the climatic conditions within present day desert settings. The water resources in these areas of rain shadow and their proximity to the continental margins of lakes and narrow marine bodies match those of the past. These resources are often finite and need to be husbanded. Though some effects of deserts associated with rain shadow can be circumvented through river diversion and creation of artificially dammed water reservoirs, reverse osmosis etc., many other desert areas are subject to depletion of fossil water resources no matter the care taken to avoid this effect.

The geologic record of the earth has a strong message for us all, particularly hydrologists, suggesting that despite human intervention, the effects of desertification are difficult to contend with and often almost impossible to avoid. The overwhelming signal from Nature suggests that the solution to water resource problems is often a mix of better engineering of the current resources and thoughtful political decisions.

V. Lakshmi, C.G.St.C. Kendall, J. Althausen and A.S. ALSHARHAN (2003). Studies of Local Climate Change in United Arab Emirates Using Satellite Data. In: Desertification in the Third Millennium. Edited by A.S. Alsharhan, W.W. Wood, A.S. Goudie, A. Fowler and E.M. Abdellatif. 2Swets & Zeitlinger Publishers, Lisse, The Netherlands, p.61-66.

This paper presents a case study of 10-years of satellite data relating the atmospheric and land surface variables to the desertification in the United Arab Emirates. These studies demonstrate the usefulness of long-term, spatially continuous data sets for studies in the field of global warming. The analysis of the data between 1989 to 1999 shows that the anomalies exhibit a greater degree of variability in the second five year period, 1994-1998 as compared to the 1989-1993 periods. Increase in variability is an indicator of global change. These results should be interpreted as a precursor to a longer and more definitive study.

J.D. Althausen Jr. C.G.ST.C. Kendall and V. Lakshmi, A.S. ALSHARHAN and G.L. Whittle (2003). Using Satellite Imagery and GIS in the Mapping of Coastal Landscapes in an Arid Environment: Khor Al Bazam, Western Abu Dhabi, United Arab Emirates. In: Desertification in the Third Millennium. Edited by A.S. Alsharhan, W.W. Wood, A.S. Goudie, A. Fowler and E.M. Abdellatif. 2Swets & Zeitlinger Publishers, Lisse, The Netherlands, p.443-449.

A geographic information system (GIS) has been developed to map assess the coastline to the west of Abu Dhabi, United Arab Emirates. The study area, Khor Al

Bazam, is an embayment prone to environmental hazards natural changes. The eastern portion of the bay has been classified and mapped for its bathymetric geologic features using digital image processing techniques. Past beach ridges, sabkha flats, algal mats, black mangroves, associated with the Khor Al Bazam, were identified on Landsat Thematic Mapper (TM) scenes of the region. The images were evaluated using a hybrid combination of band ratioing, iterative-statistical clustering, and principal components analysis to produce classification maps. The findings of this research reveal that seven land cover features, in the uplands, four bathymetric features, in the coastal waters, can be identified in the Landsat data sets.

Using digital image processing algorithms and techniques it was possible to enhance the imagery in such a way that features nearly undetectable in visual examination were discernible after classification, i.e. oolitic ridges and black mangroves. The functionality of combining raw TM bands with principal components and band ratios in a hybrid spectral analysis is demonstrated by this research. Also, the arid climate of the study area makes it ideal to use in this case because of the low levels of atmospheric constituents and water vapor, associated with the region. Atmospheric 'noise' usually limits the usage of principal components analysis and band ratioing because the degradation of the signal associated with the noise is usually enhanced by the two statistical analyses.

This project has revealed some interesting findings that must be explored by further research in this study area and other regions of the Arabian Gulf. Some improved digital image processing techniques have been tested and can be potentially useful in additional analysis of the region, especially in helping to identify areas that are sensitive to environmental stresses, i.e. algal mats, corals, and black mangroves. Certain upland and bathymetric features 'fell-out' nicely in feature space analysis and could easily be classified, while others had to be rigorously identified using advanced statistical image processing techniques.

ALSHARHAN, A.S. and C.G.St.C. Kendall (2003). Holocene coastal carbonates and evaporites of the southern Arabian Gulf and their ancient analogues. Earth-Science Reviews, v. 61, p. 191-243.

The Holocene sediments of the coast of the United Arab Emirates in the southeastern Arabian Gulf are frequently cited in the literature as type examples for analogous assemblages of carbonates, evaporites and siliciclastics throughout the geologic record. This paper is intended as a convenient single source for the description of sediments of this region, providing information on how to reach the classic localities and some of the analogs.

The Holocene sediments of the region accumulate over an area that is 500 km long and up to 60 km wide. The sediments collecting offshore are predominantly pelecypod sands mixed with lime and argillaceous mud, with these latter fine sediments increasing as the water deepens. The pelecypod-rich sediments also collect east of Abu Dhabi Island both in the deeper tidal channels between the barrier island lagoons and in deeper portions of the protected lagoons. West of Abu Dhabi Island the shallow water margin is the site of coral reefs and coralgal sands, whereas to the east oolites accumulate on the tidal deltas of channels located between barrier islands. Grapestones accumulate to the lee of the reefs and the oolite shoals where cementation becomes more common. They are particularly common on the less protected shallow water margins of the lagoons west of Abu Dhabi Island. Pelleted lime muds accumulate in the lagoons in the lee of the barrier islands of the eastern Abu Dhabi. Lining the inner shores of the protected lagoons of Abu Dhabi and on other islands to the west are cyano-bacterial mats and mangrove swamps. Landward of these, a prograding north facing shoreline is formed by supratidal salt flats (sabkhas), in which evaporite minerals are accumulating.

This paper describes the localities associated with (1) the mangrove swamps of the west side of the Al Dhabaiya peninsula; (2) the indurated cemented carbonate crusts, cyanobacterial flats and sabkha evaporites on the shore of the Khor al Bazam south of Qanatir Island; (3) the reef and oolitic sand flats on the coast just east of Jebel Dhana; and (4) the marine travertine and aragonite coats associated with the beach sediments in a small bay south of Jebel Dhana; and (5) the Sabkha Mutti between Jebel Barakah and Al Sila.

Similar sedimentological associations of carbonate and evaporites to those of the Holocene of the United Arab Emirates are to be found in the Tertiary and Mesozoic sedimentary rocks of the immediate subsurface in the Arabian Gulf. Other analogs to this setting include the Paleozoic carbonates of the western USA, Europe, and Asia, Mesozoic carbonates of the Gulf of Mexico, Europe, and Middle East and Tertiary sedimentary rocks in the Middle East.

A.S. Rizk and A.S. ALSHARHAN (2003). Geographical Information System Modeling of Groundwater Potentiality in the Northeastern Part of the United Arab Emirates. In: Desertification in the Third Millennium. Edited by A.S. Alsharhan, W.W. Wood, A.S. Goudie, A. Fowler and E.M. Abdellatif. 2Swets & Zeitlinger Publishers, Lisse, The Netherlands, p.423-434.

Digitized grid maps on the hydrogeology, groundwater chemistry and quality, soil classification, geologic structures and drainage lines, were used along with the Arc View GIS 3.2 package to construct an analytical GIS groundwater-potential model for the Al Dhaid area, in the eastern part of al Sharjah Emirate, United Arab Emirates. Cross-correlation of model output zoned maps was performed to identify areas of high groundwater potential for domestic and agricultural purposes.

Results of the GIS model indicate that the eastern strip of the eastern Sharjah Emirate (Al Dhaid region) has the highest groundwater potential. The strip is located close to the recharge area in the Northern Oman Mountains and is dominated by intersections of the Dibba zone, Hatta zone and Wadi Ham structural trends, which seem to control groundwater-flow velocity and recharge rate. The strip is also characterized by fresh (total dissolved solids < 1,500 mg/l), soft (total hardness < 80 mg/l) groundwater suitable for domestic uses. Results also show that the northern and southern central parts of the study area are favorable for agriculture because both areas have cultivable soil types (Calciorthids, Torrifluvents and Torripsaments-2) and shallow groundwater (< 45 m deep) of appropriate quality (total dissolved solids < 3,000 mg/l and sodium adsorption ratio < 10).

Because the eastern strip and channels of major wadis in the study area have several water wells used mainly for domestic and agricultural purposes, it is proposed to minimize or even prohibit urban and industrial activities in the upstream side of these wells and assign it as a groundwater protection zone in order to secure and maintain the present supply of good-quality groundwater.

Rizk, Z.S. and A.S. ALSHARHAN (2003). Hydrogeology, Groundwater Chemistry and Isotope Hydrology of the Quaternary Liwa Aquifer in the Western Region of the United Arab Emirates. Proceeding of the WSTA 6th Gulf Water Conference, Saudi Arabia.p. 155-183.

The present hydrogeological investigation of the Quaternary sands in the Western Region of United Arab Emirates revealed the presence of a local, fresh water aquifer in the Bu Hasa area, and confirmed a similar feature between Liwa and Madinat Zayed. Because of the striking similarity of hydraulic properties, chemistry and natural isotopes of the groundwater at Bu Hasa and Liwa, the aquifer in both areas is dealt with as a single aquifer named the "Quaternary Liwa aquifer".

Two fresh water mounds belonging to the Quaternary Liwa aquifer represent relics of an old, large aquifer originated during past pluvial periods and occupy the northwestern part of study area. A large, elliptical (40 km wide and 120 km long) mound occurs between Madinat Zayed and Liwa Crescent, and a small, oval mound (40 km average diameter) exists between Habshan and Bu Hasa camp. The depth to groundwater varies between a few meters and 50 m at Liwa, and from 24 m to 52 m at Bu Hasa. The aquifer saturated thickness ranges from 75 m at Shah oil field to 175 m at Bu Hasa. The aquifer's hydraulic conductivity (K), derived from grain-size analysis, is 2.3 to 8.5 m/day. The aquifer transmissivity (T) varies between 200 and 650 m^2/day and its specific capacity (SC) is 40 to 90 m^2/day. The specific yield (Sy), 0.1 to 0.3, indicates a free aquifer, and the hydraulic gradients, 0.01-0.001, reflect the effect of pumping and heterogeneity of the aquifer.

The concentrations of major, minor and trace chemical constituents indicate that the groundwater in the Quaternary Liwa aquifer is fresh (< 1,000 mg/1) to saline (> 10,000 mg/1). In most parts, the groundwater is hard (TH > 200 mg/1) and not suitable for drinking or domestic purposes. Except bicarbonate ion (HCO_3"), the concentration of all major ions increases from the center of fresh water mounds outwards in all directions. The contents of nitrate ion (NO3"), Fluoride ion (F-), Boron (B), chromium (Cr) and zinc (Zn) are generally above the WHO limit for drinking water. The values of electrical conductivity (EC) and sodium adsorption ratio (SAR) show that the groundwater is harmful to very harmful for irrigation of traditional crops.

The study of the chemistry and stable isotopes (^{2}H and ^{18}O) of the groundwater in United Arab Emirates indicates the presence of three groundwater-flow systems; local, intermediate and regional groundwater-flow systems (Alsharhan et al., 2001). The flow system encountered in the Bu Hasa and Liwa areas is the regional groundwater-flow system, which is characterized by old water (low ^{14}C activities and low or absence of ^{3}H). These findings support the proposed past pluvial periods indicated by the radiocarbon dating of lacustrine deposits in the Liwa area (Wood and Imes, 1995).

The stable isotopes (^{2}H and ^{l8}O) are highly enriched in the groundwater of the Quaternary Liwa aquifer, suggesting intensive evaporation prior recharge. The ^{2}H and "O values in the groundwater of the Quaternary Liwa aquifer at Liwa and Bu Hasa are identical, suggesting a single common source of the groundwater in both areas. The low ^{14}C activities and lack of ^{3}H in most samples indicate old groundwater age and absence of present-day recharge.

Wood, W.W., Z.S. Rizk and A.S. ALSHARHAN (2003). Timing of recharge, and the origin, evolution, and distribution of solutes in a hyperarid aquifer system. *In*: A.S. Alsharhan, W.W. Wood (eds.), Water Resources Perspectives: Evaluation, Management and Policy, Developments in Water Series #50, Elsevier Publishers, p.295-312.

Examination of an aquifer system in the Liwa Crescent/ Bu Hasa area of the Emirate of Abu Dhabi on the southeastern edge of the Rub al Khali, Arabian sub-continent, provide insight into the timing of ground-water recharge and the origin and evolution of solutes in a representative hyperarid area. Ground-water flow in the aquifer system is radially outward from the center of two ground-water mounds, corresponding to two 110 m-thick sand deposits. The isotopic data from ancient ground waters from the Liwa Oasis with its unusual "d" (deuterium excess) of approximately -15 indicate that Holocene moisture derived from previously evaporated water on the surface of the Indian Ocean rather than from the Mediterranean/Arabian Gulf. Such a source is consistent with a summer monsoonal circulation. Hydraulic heads in underlying aquifers are lower than those of the Liwa/ Bu Hasa aquifer; thus, there is no advective water or solute input from these lower units. Solute diffusion from underlying aquifers provides a small solute flux, but it is inadequate to account for the observed solute mass, nor is the ionic ratio consistent with this source. There are no laterally adjacent aquifers; thus, there is no influx of solutes from these sources. Dissolution of the aquifer framework provides for only a minor fraction of most of the observed solutes. Most solutes in this aquifer system are derived from atmospheric precipitation. Salts contained in rain were stored on the surface and in the unsaturated zone during the hyperarid time interval between the ends of the Pleistocene recharge event (26,000 years BP) and the beginning of the Holocene recharge (9000 years BP). During the Holocene recharge era (9000 to 6000 years BP), these stored salts were mobilized and transported to the ground water. The initial solute distribution has been slightly modified as the solutes and water were transported along the flow path. As ground water moves away from the apex of the mound, it encounters a series of interdunal sabkhat. Water is evaporated from the sabkhat leaving soluble chloride and nitrate minerals on the surface and retrograde carbonate and sulfate minerals in the unsaturated zone. When recharge occurs through the interdunal sabkhat, which are the only areas of recharge in the aquifer, soluble salts on the surface, modern ^{14}C, and tritium are added to the aquifer. There is vertical mixing within the aquifer because the density of the recharged water is greater than the density of the ground water in this nearly homogeneous and isotropic aquifer. Relatively insoluble carbonate and sulfate minerals are retained in the unsaturated zone of the interdunal sabkhat, causing a change in the solute ratios downgradient. Only the portion of the aquifer not associated with interdunal sabkhat retains the original solute composition determined by mobilization of stored salts. These findings, although specific to this aquifer, provide a useful model by which to evaluate other aquifer systems in hyperarid environments.

Rizk, Z.S. and A.S. ALSHARHAN (2003). Water resources in the United Arab Emirates. ***In*****: A.S. Alsharhan, W.W. Wood (eds.), Water Resources Perspectives: Evaluation, Management and Policy, Developments in Water Series #50, Elsevier Publishers, p.245-264.**

The United Arab Emirates rely on non-conventional water resources, in addition to conventional resources, to meet the ever-increasing demands for water. Conventional water resources include seasonal floods, springs, falajes and groundwater. Non-conventional resources are the desalinated water and treated-sewage water. The existing conventional water resources in the United Arab Emirates include 125 Mm^3/yr (million cubic meter per year) from seasonal floods, 3 Mm^3/yr from permanent springs, 22 Mm^3/yr from seasonal springs, 20 Mm^3/yr of falaj discharges, 109 Mm^3/yr of aquifer recharge. The existing non-conventional water resources include 475 Mm^3/yr of desalinated water and 150 Mm^3 of reclaimed water. Future developments may increase the discharge of seasonal springs to 40 Mm^3 and falaj discharges to 40 Mm^3. Parallel increases in the volumes of desalinated water and treated wastewater may also be achieved. The most important water-related problems in the United Arab Emirates are the depletion of aquifers in several areas, such as at Al Ain and Al Dhaid; saline-water intrusion, and water quality degradation, such as that associated with the oil industry and agricultural activities.

Improvement of water-resource management in the United Arab Emirates can lead to water conservation, maintenance of better quality water, and restoration of deteriorating aquifer systems in many areas. The use of advanced irrigation technologies, construction of groundwater-recharge dams, and growing salt-tolerant crops are suitable agricultural approaches. Development of human resources is a priority in the United Arab Emirates, to provide trained national experts in water-related fields. Establishment of data banks and the application of advanced groundwater modeling and isotope hydrology techniques are powerful water-resources management tools.

ALSHARHAN, A.S. (2003). Petroleum geology and potential hydrocarbon plays in the Gulf of Suez rift basin, Egypt. American Association of Petroleum Geologists Bulletin, v. 87(1), p. 143-180.

The Gulf of Suez in Egypt has a north-northwest-south-southeast orientation and is located at the junction of the African and Arabian plates where it separates the northeast African continent from the Sinai Peninsula. It has excellent hydrocarbon potential, with the prospective sedimentary basin area measuring approximately 19,000 km^2, and it is considered as the most prolific oil province rift basin in Africa and the Middle East. This basin contains more than 80 oil fields, with reserves ranging from 1350 to less than 1 million bbl, in reservoirs of Precambrian to Quaternary age. The lithostratigraphic units in the Gulf of Suez can be subdivided into three megasequences: a prerift succession (pre-Miocene or Paleozoic-Eocene), a synrift succession (Oligocene-Miocene), and a postrift succession (post-Miocene or Pliocene-Holocene). These units vary in lithology, thickness, areal distribution, depositional environment, and hydrocarbon importance. Geological and geophysical data show that the northern and central Gulf of Suez consist of several narrow, elongated depositional troughs, whereas the southern part is dominated by a tilt-block terrane, containing numerous offset linear highs.

Major prerift and synrift source rocks have potential to yield oil and/or gas and are mature enough in the deep kitchens to generate hydrocarbons. Geochemical parameters, sterane distribution, and biomarker correlations are consistent with oils generated from marine source rocks. Oils in the Gulf of Suez were sourced from potential source rock intervals in the prerift succession that are typically oil prone (type I), and in places oil and gas prone (type

II), or are composites of more than one type (multiple types I, II, or III for oil prone, oil and gas prone, or gas prone, respectively).

The reservoirs can be classified into prerift reservoirs, such as the Precambrian granitic rocks, Paleozoic-Cretaceous Nubian sandstones, Upper Cretaceous Nezzazat sandstones and the fractured Eocene Thebes limestone; and synrift reservoirs, such the Miocene sandstones and carbonates of the Nukhul, Rudeis, Kareem, and Be-layim formations and the sandstones of South Gharib, Zeit, and post-Zeit. The majority of oil fields in the region incorporate multiple productive reservoirs. Miocene evaporites are the ultimate hydrocarbon seals, whereas the shale and dense limestones of the prerift and the synrift stratigraphic units are the primary seals. Structural, stratigraphic, and combination traps are encountered in the study area. The Gulf of Suez is the most prolific and prospective oil province in Egypt, and any open acreage, or relinquished area, will be of great interest to the oil industry.

F.N. Sadooni and A.S. ALSHARHAN (2003). Stratigraphy, microfacies, and petroleum potential of the Mauddud Formation (Albian-Cenomanian) in the Arabian Gulf basin. American Association of Petroleum Geologists Bulletin, v. 87(10), p. 1653-1680.

The Albian-Cenomanian Mauddud Formation extends over most parts of the Arabian basin including north Iraq. The formation consists mainly of Orbitolina-bearing limestone with local basin margin rudist buildups in the offshore North field of Qatar and northeast Iraq. Extensive dolomitization, with wide variations in both extent and texture, has been reported from both outcrops and wells. The Jurassic-Cretaceous pelagic strata are probably the possible source for the Mauddud Formation oil in northern Iraq, whereas indigenous sources in the Mauddud strata and Nahr Umr shales, as well as the Upper Jurassic rocks, are probably the source rocks in the southern parts in the basin. Porosity of 10-35% and permeability of 10-110 md have been reported from different fields of the basin. This porosity is attributed to a combination of dolomitization, fracturing, and dissolution. There are two main oil provinces where the Mauddud Formation is a major oil-producing reservoir. The northern province includes Iraq's oil fields such as Ain Zalah, Bai Hassan, and Jambur. The southern province includes the Ratawi field in southern Iraq, Raudhatain, Sabriya, and Bahra fields in Kuwait, Bahrain (Awali) field in Bahrain, and Fahud and Natih fields in Oman. The formation has high oil potential in the southern and southeastern fields of Iraq and the offshore areas of Qatar and Saudi Arabia.

ALSHARHAN, A.S. and C.G.St.C. Kendall (2002). Holocene carbonate-evaporites of Abu Dhabi, and their Jurassic ancient analogs. In: Hans-Jorg Barth and Benno Boer (Eds.), Sabkha Ecosystems, Volume I: The Arabian Peninsula and Adjacent Countries, Kluwer Academic Publishers, p. 187-202.

The Holocene shallow-water carbonate and supratidal evaporite tract of Abu Dhabi consists of seaward reefs, barrier islands and tidal flats. As with similar sedimentary sequences in the subsurface of the Arabian Gulf, and elsewhere, the sediments of this coastal region pass landward into continental facies and seaward into basinal facies. In eastern Abu Dhabi oolites form on the inter-island tidal deltas and coral reefs are restricted to small patches along channels and just seaward of the center of the islands. To the west, coral reefs grow along the northern edges of most of the offshore banks north of the Khor al Bazam. Eastward, in the protected lagoons, carbonate muds and pellets are accumulating, whereas to the west of Al Dhabaiya Island, carbonate muds only accumulate in a narrow belt south of the offshore bank. Grapestones and skeletal debris are the dominant components. South of this bank, supratidal flats are encroaching on the lagoons through the development of beach ridges and cyano-bacterial flats. The similar relationship of these sedimentary facies to some of the Upper Jurrassic Period found in the subsurface of the Central Arabian Gulf, suggests that Abu Dhabi's coastal area can be used as a comparative model for understanding some ancient carbonate/evaporite depositional and diagenetic processes. In the Late Jurassic facies relationships at the pinch out between the Ilith Anhydrite and the Asab Oolite in Central Abu Dhabi suggest that these sediments accumulated in a nearshore to sabkha setting. Eastward of this margin the Hith changes its character and appears to have accumulated in a standing body of water.

Kendall, C.G.St.C., A.S. ALSHARHAN and A. Cohen (2002). The Holocene tidal flat complex of the Arabian Gulf coast of Abu Dhabi. In: Hans-Jorg Barth and Benno Boer (Eds.), *Sabkha Ecosystems, Volume I: The Arabian Peninsula and Adjacent Countries*, Kluwer Academic Publishers, p. 21-36.

Carbonate sand and mud of the offshore bank Hanking the Khor Al Bazam lagoon, the lagoons of the western Abu Dhabi and the mainland coast are accreting and prograding. Seaward of the Khor Al Bazam lagoon the offshore bank is progressively extending its shoal and channel area, coral banks, tidal deltas, and nearshore coastal terraces. Where wave energy is minimal cyano-bacterial mats colonise protected intertidal sediments, building seaward, binding any sediment washed onto them and raising the sediment surface to the high water mark, here the cyano-bacterial mats are entrapped beneath prograding supratidal carbonate/evaporite coastal sabkhat. Mangroves flourish in tide-dominated areas protected from all but the smallest waves, and aid the entrapment of sediment later colonised by algal mats. Local beach ridges develop from spits that acquire beach faces, berms and dunes. These dunes are deflated as the beach line is stranded by coastal accretion. Landward of the beach ridges windblown and wind tide floodwater sediment has accumulated. Traced landward from the middle intertidal zone of protected coasts the following are found: lime muds and sand flats in association with carbonate cemented hardgrounds passing to cyano-bacterial mat which exhibit a cindery mammillated character, and then polygons and algal crinkles. These latter are associated with a gypsum mush that thickens landward and is replaced by 20 cm thick anhydrite layer. Landward these sediments lie beneath a salt dominated crumpled polygonal surface and near surface interlayers of thin anhydrite and nodules that are flanked by stranded beach ridges of an earlier coastline. The cyano-bacterial materials are preserved as peats beneath the supratidal sabkhat. They have a high potential for being preserved in the geologic record.

Shebl, H.T., and A.S. ALSHARHAN (2000). Microfacies analysis of Berriasian-Hauterivian carbonates, Central Saudi Arabia. In*:* A.S. Alsharhan and R.W. Scott (eds), *Middle East Models of Jurassic/Cretaceous Carbonate Systems*, Special Publication # 69, SEPM (Society for Sedimentary Geology), USA., p. 115-128.

The deposition of the Lower Cretaceous in Saudi Arabia is interpreted within the framework of a model of a simple eastward-dipping carbonate ramp that formed as the result of the extensive flooding of the Arabian Plate during Early Berriasian time. Carbonate deposition was only slightly interrupted by a minor marine regression after the deposition of the Yamama Formation/ and it was succeeding by bioclastic limestones of the Buwaib Formation. It was later terminated by a Barremian regression during which clastic deposition dominated most of Central and Eastern Arabia.

The Early Cretaceous carbonates of the Sulaiy, Yamama, and Buwaib formations crop out in central Saudi Arabia. According to sedimentological and paleontological data these formations consist of twenty-two successive microfacies correlated with the published standard microfacies types and belts. The Sulaiy, Yamama, and Buwaib formations were deposited in open-platform and lagoonal settings interrupted by two breaks in sedimentation: (1) a pre-Buwaib disconformity, which is marked by an abrupt change from the fine-grained lime mudstones of the upper Yamama to the sandy wackestones containing cyclammiiuds of the basal Buwajb, and (2) me more pronounced unconformity between the Buwaib bioclastic wackestone and the overlying Biyadh Sandstone.

Kendall, C.G.St.C., A.S. ALSHARHAN, K. Johnston and S.R. Ryan (2000). Can the sedimentary record be dated from a sea-level chart? Examples from Aptian Depositional Cycles of Abu Dhabi and the National Petroleum Reserve of Alaska: In: A.S. Alsharhan and R.W. Scott (eds), *Middle East Models of Jurassic/Cretaceous Carbonate Systems*, Special Publication # 69, SEPM (Society for Sedimentary Geology), USA., p.65-76.

Ten depositional shoaling-upward cycles have been identified in the Aptian Shuaiba Formation of the United Arab Emirates (U. A.E.). A similar number of cycles have been recognized in the National Petroleum Reserve of Alaska (NPRA). Similarities of these cycles with the onlapping shelf geometries of the Neogene of the Bahamas suggest that the sequence geometries of Aptian strata of the NPRA and the U.A.E. are a response to high-frequency changes in eustatic sea-level position. Because the Aptian cycles of the NPRA match similarly dated, events in the U.A.E., it is suggested that where biostratigraphic data are poor the sedimentary section can be tentatively dated by relating the geometries of the shelf margin to the character of the coastal onlap curve and its coincident sea-level chart. Thus, a sea-level chart might be used at locations for which biostratigraphic data is sparse to determine and constrain preliminary depositional models for specific time intervals.

With this in mind, two biostratigraphic models for dating the Shuaiba Formation and the Bab Member were tested against the sea-level curve of Haq et al. (1987) using a sedimentary simulation. The results were ambiguous because both biostratigraphic models could not be matched. Also in both cases, the simulation suggested that just prior to the deposition of the Bab Member the basin margin was uplifted and then subsided, causing a local relative sea-level fall followed by a rise, an event not found on the sea-level chart of Haq et al. (1987). Additionally, the sedimentary simulation supports the position that the Aptian in the U.A.E. is bounded by erosional unconformity surfaces and contains higher-frequency cycles.

ALSHARHAN, A.S., and R.W. Scott (2000). Hydrocarbon potential of Mesozoic carbonate platform-basin systems, UAE. In: A.S. Alsharhan and R.W. Scott (eds), *Middle East Models of Jurassic/Cretaceous Carbonate Systems*, Special Publication # 69, SEPM (Society for Sedimentary Geology), USA., p. 335-358.

The United Arab Emirates (U.A.E.) is located on the eastern Arabian shelf, bounded on the northwest by the Qatar-South Fars Arch and on the east and northeast by the foreland basin and the adjacent foreland fold-and-thrust belt of Oman. Two passive-plate-margin basins were developed in the area, the northern Rub Al Khali basin and the Ras Al Khaimah basin. Since the Permian, a variety of sub-basins, separated by depositional and tectonic highs, have formed, filled, and been buried, but the style of sedimentation has been maintained. The Upper Permian to Holocene rocks and sediments of the U.A.E. consist mainly of epeiric shelf carbonates, associated with minor evaporites and elastics, reflecting major cycles of transgression and regression. These sediments were deposited on the eastern margin of the Arabian Shield, which lay along the southern margin of the Tethys Ocean during the Mesozoic and Cenozoic eras. Sedimentation patterns were controlled by prominent regional structural features, epeirogenic movements, and/or sea-level fluctuations. Abundant oil and gas reserves have been proved in the Mesozoic rocks of the U.A.E., and are contained in the shallow-water carbonates of the Jurassic (Araej and Arab formations) and the Cretaceous (Thamama Group, Mishrif, and Simsima formations). Reservoirs are sourced by deep-water bituminous shale and argillaceous limestones and sealed by evaporites, dense limestones, and shales. The distinctive sedimentologic and structural style, together with the development of source-reservoir-seal, has made the U.A.E. one of the world's richest Mesozoic oil habitats. Detailed studies of the occurrences and distributions of the factors controlling hydrocarbon distribution are important in the understanding of local oil fields and future plays.

ALSHARHAN, A.S., A. Ziko, H.T. Shebl and G.L. Whittle (2000). Microfacies and microfabrics of Maastrichtian carbonates, Northwestern Oman Mountains, UAE. In: A.S. Alsharhan and R.W. Scott (eds), *Middle East Models of Jurassic/Cretaceous Carbonate Systems*, Special Publication # 69, SEPM (Society for Sedimentary Geology), USA., p. 129-142.

The Simsima Formation (lower Upper Maastrichtian) is a shallow-water carbonate that crops out in eastern United Arab Emirates along the northwestern border of the Oman Mountains. Its thickness ranges in this region from 30 to 80 m. From detailed sedimentological and petrographical analysis, various microfabric types and eight sedimentary facies are recognized in the Simsima Formation. These microfacies are arranged according to their frequency and collected into three groups as follows: packstone group (orbitoidal packstone, bioclastic packstone, algal packstone, and planktonic f oraminif eral packstone); boundstone group (milleporid, coral, and algae), and dolostone, which consists mainly of dolomitized limestone. The Simsima Formation in this study can be subdivided into two new members, called here the lower member and the upper member, each with a distinct-character and considerable vertical and horizontal distribution.

ALSHARHAN, A.S., and J.L. Sadd (2000). Stylolites in Lower Cretaceous carbonate reservoirs, UAE. In: A.S. Alsharhan and R.W. Scott (eds), *Middle East Models of Jurassic/Cretaceous Carbonate Systems*, Special Publication # 69, SEPM (Society for Sedimentary Geology), USA., p. 179-200.

The major Lower Cretaceous reservoirs of the United Arab Emirates (U.A.E.) are characterized by stylolite-rich zones. Although their distribution and frequency are variable, stylolites tend to be most common and abundant toward the flanks of the fields. Three main types of stylolites are found in these reservoirs, each characterized by variations in amplitude, morphology, lateral continuity, and thickness of the accumulated insoluble residue. The recorded stylolites are classified as rectangular or high amplitude, solution seams or wave-like, and wispy seams or horsetail. The composition of the relatively insoluble seam material is variable, and depends mainly upon the composition of the nearby host rock. Most of the seams are composed of clay minerals, black bitumen, pyrite, and fine- to medium-grained calcite crystals or dolomite rhombs. Stylolites affect the petrophysical characteristics (porosity/permeability) and thickness reduction (compaction). The lower porosity and permeability values are found associated with the well-developed stylolites. Most stylolites observed in cores are parallel to subparallel to bedding (the horizontal type), indicating the predominance of vertical stress imposed by overburden pressure in stylolite formation. This also suggests a relative absence of tectonic or metamorphic activity in the area, which might produce inclined to vertical stylolites, although vertical to subvertical tension fractures are found associated with the well developed stylolites.

M.A. Noweir and A.S. ALSHARHAN (2000). Structural style and stratigraphy of the Huwayyah Anticline: an example of an Al-Ain Tertiary fold, Northern Oman Mountains: GeoArabia, v. 5(3), Bahrain, p. 387-402.

Detailed field mapping and structural studies in the Jebel Auha-Jebel Huwayyah area northeast of Al-Ain indicate that folding of neoautochthonous sedimentary rocks produced the north-northwest-trending Huwayyah Anticline. The anticline at the surface is composed of the Maastrichtian Qahlah and Simsima formations unconformably overlain by shallow-marine carbonate rocks that are correlated on faunal grounds with the Middle Eocene Dammam Formation. The investigation of the Huwayyah Anticline has identified three microfacies of bioclastic packstone, nummulitic packstone, and nummulitic packstone-grainstone in the local Dammam Formation. Diagenesis in the form of silicification, cementation, recrystallization, dissolution, compaction and neomorphism is widespread.

The Huwayyah Anticline is a fault-propagation fold above a thrust ramp. The ramp developed from a pre-existing Late Cretaceous basal thrust within the Semail

Ophiolite on the Oman Mountain Front. The anticline was formed as a result of regional compressive deformation due to rejuvenation of the Late Cretaceous thrust in post-Middle Eocene times. Westward-directed high-angle reverse faults of Jebel Auha trend parallel to the fold axis of the anticline. The Auha faults probably originated as west-dipping thrusts on the western flank of the anticline and were subsequently rotated to their present attitude as the flank of the anticline became steeper due to compression from the east.

Al Suwaidi, A.S., A.K. Taher, A.S. ALSHARHAN and M.G. Salah (2000). Stratigraphy and geochemistry of Upper Jurassic Diyab Formation, Abu Dhabi, UAE. In: A.S. Alsharhan and R.W. Scott (eds), *Middle East Models of Jurassic/Cretaceous Carbonate Systems*, Special Publication # 69, SEPM (Society for Sedimentary Geology), U.S.A., p. 239-263.

The Diyab Formation (Oxfordian to mid-Kimmeridgian) is widely distributed in Abu Dhabi. It consists of argillaceous lime mudstones/wackestones (rich in organic matter) in the west, which change laterally eastward into oolitic packstones and grainstones. Its thickness reaches up to 1300 ft (395 m) towards the southern onshore Abu Dhabi. Geochemical evaluation of the Diyab Formation was carried out using analytical data from five different laboratories. Source rock screening indicated the presence of a rich source-rock interval in the lower part of the formation in western Abu Dhabi, which becomes a lean source-rock in eastern Abu Dhabi. The Diyab source rock contains oil- and gas-prone kerogen, and was deposited in an intrashelf basin that was enclosed by the Diyab shelfal facies sediments, which restricted water circulation, causing anoxic conditions below wave base.

A combination of geological and geochemical information was used to reconstruct burial and thermal histories of the potentially petroliferous intervals in the Diyab source rock. This source rock was sufficiently mature in the southwestern onshore Abu Dhabi to generate hydrocarbons since Late Cretaceous time. Currently, this formation lies within the gas generation window for most of onshore and southern offshore Abu Dhabi.

Comparative analysis of oil and source-rock characteristics, using both bulk and molecular parameters, carbon-isotope analysis, gas chromatography (GC), and gas chromatography-mass spectrometry (GC-MS), was carried out. The oils from both the Thamama Group and the Arab Formation have the characteristic of oils derived from carbonate source rocks. However, Arab oils are less mature and have lower concentration of saturate, and are isotopically lighter than Thamama oils at equivalent reservoir depth.

The secondary migration scheme was based on a series of structure and paleostructure maps at the top of the Arab-D level. The migration direction of the

Arab Formation was controlled mainly by the presence of western synclinal structures. East of these synclines, oil migration is predominantly northeastward. The early Tertiary (50-40 Ma) was the major expulsion phase, with more than 75% of the total oils being generated from Diyab source rock, approximately 95% of which comes from the Lower Diyab section.

Crude oil and extract analysis resulted in identification of four main oil families. The Simsima-reservoired oil appears to originate from the Shilaif source rock, whereas the Thamama oils are sourced from the Shuaiba Basal Facies (Bab Member) and the Diyab Formation. The Arab oils were sourced mainly from the Diyab Formation, and the Araej oil was sourced mainly from the Diyab Formation and possibly from an unknown pre-Diyab source rock.

ALSHARHAN, A.S., I. Al-Aasam and M.G. Salah (2000). Stratigraphy, stable isotopes and hydrocarbon potential of the Aptian Shuaiba Formation, UAE. In: A.S. Alsharhan and R.W. Scott (eds), *Middle East Models of Jurassic/Cretaceous Carbonate Systems*, Special Publication # 69, SEPM (Society for Sedimentary Geology), U.S.A., p. 291-308.

The Shuaiba Formation of the United Arab Emirates (U.A.E.), forms one of the most important petroleum reservoirs in the Arabian Gulf. Its reservoir quality is controlled by diagenetic processes that were active during early shallow burial to late deep burial. Detailed well log evaluation, petrographic and geochemical studies of carbonate diagenesis, X-ray diffraction, cathodoluminescence microscopy, and oxygen and carbon isotopic determinations from cores and an outcrop section allowed evaluation of the stratigraphic and depositional framework of the Shuaiba Formation, its diagenetic history, and the prediction of its local reservoir potential. The Shuaiba Formation consists of two informal and one formal members: the lower Shuaiba and upper Shuaiba members and the Bab Member, in ascending order. The Shuaiba ranges in thickness from 45 to 145 m, having accumulated in a wide range of depositional settings from shallow to deep shelf. The lithofacies identified within the Shuaiba Formation include peloidal skeletal algal packstone/grainstone; ooidalpeloidal grainstone/packstone; skeletal algal (Lithocodioidea) floatstone; intraclastic and coated packstone/grainstone and skeletal wackestone/ packstone. These facies were deposited during third-order depositional sequences, including two transgression system tracts (TST) separated by a highstand system tracts (HST). Diagenetic alteration of the original carbonate components proceeded through marine, shallow burial, and deeper burial settings related to stabilization of the carbonate matrix, cements, and rudist shells. Oxygen and carbon isotopes of calcitic matrix have the least altered components of these rocks (av. $5^{18}0$ = 5.7%◦ PDB; $8^{13}C$ = +2.5 %° PDB), whereas the calcite cements occluding shell porosity and veins have more depleted isotopic values (av. $5^{18}0$ = 8.8%◦ PDB; $S1^{3}C$ = +0.5% PDB). The variations of oxygen and carbon isotopes reflect changes in the water-rock interactions and increasing burial.

The carbonates of the lower and upper Shuaiba members have porosities between 12% and 32% and permeabilities between 1.0 and 160.0 md. The reservoir quality is highly affected by the diagenetic processes which include stabilization of metastable carbonate phases, cementation, dolomitization, stylolitization, and dissolution. The Bab Member, which was deposited in a basinal setting, is organically rich and forms substantial source rock in the eastern and northeastern parts of central UAE and is mature enough in deep troughs to generate and expel hydrocarbons to the reservoirs.

Rizk, Z.S. and A.S. ALSHARHAN (1999). Application of natural isotopes for hydrogeologic investigations in United Arab Emirates. Proceedings of the 4th Gulf Water Conference, Bahrain, 13-17 February, 1999, v. 1, p. 197-228.

The natural, stable (^{2}H and ^{18}O) and radioactive isotopes (^{3}H and ^{14}C) in rain and groundwater are used to characterize precipitation, determine origin and age of groundwater, identify the source of increasing groundwater salinity and assess groundwater pollution in the Bu Hasa area, UAE.

The meteoric water line for the present-day precipitation in UAE has a mean ^{18}O = -1.99 %o, a mean ^{2}H =-0.4 %o and a deuterium excess () =16, suggesting two sources of precipitation; the Mediterranean Sea in winter and Indian Ocean in summer. The average ^{3}H content in rainfall for the period 1984-1987 was 4.7 Tritium Units (TU).

The depleted stable isotopes in groundwater of Wadi Al Bih Permian limestone aquifer, eastern Quaternary gravel aquifer and easternmost parts of the western gravel aquifer show the effect of recent recharge at high altitudes, Ru'us Al Jibal (1,050-2,090 m) in the north and Oman Mountains (650 m) in the east. The parallel increase of EC and ^{18}O indicates salt-water intrusion in the western Quaternary gravel aquifer, whereas the increase of salinity and constancy of ^{18}O in Wadi Al Bih and Liwa aquifers indicate dissolution of salts from the aquifer matrix. Stable isotopes in groundwater of the western gravel aquifer and Liwa sand aquifer are distinctly different. Enrichment of stable isotopes in the Liwa aquifer indicates evaporation prior infiltration. However, the projection of stable isotopes in both areas on the Local Meteoric Water Line (LMWL) indicates a common, high elevation recharge source (the northern Oman Mountains). Groundwater of the northern and eastern parts of UAE has high ^{3}H and ^{14}C activities, indicating ages from modern to 5,000 years old, while the groundwater in the western and southwestern parts has low ^{3}H and ^{14}C activities, indicating ages of 15,000 years or older.

Interpretation of stable isotope data in light of the geochemical modeling suggests the source of saline water in the Wadi Al Bih aquifer is not from sea water intrusion, but most likely from mixing of a deep circulating component that has undergone water-rock reactions with evaporites or mixing with a unknown brine from lower stratigraphic units. Stable isotopes (^{2}H and ^{18}O) of oil-field brine and Liwa aquifer from the Bu Hasa area are distinctly different and does not suggest mixing of oil-field water injected in the Miocene clastic aquifer with the shallow, fresh Liwa aquifer.

Noweir, M.A., ALSHARHAN, A.S. and Boukhary, M.A. (1998). Structural and Stratigraphical Setting of the Faiyah Range, North Western Oman Mountain Front, UAE: Geo Arabia, Bahrain, v. 3, no. 3, p. 387-398.

The Faiyah Range belongs to a group of regional ridges that formed by post-obduction folding of the Upper Cretaceous-Tertiary sedimentary rocks exposed along the western margin of the Northern Oman Mountains. The Faiyah Anticline, generally trends north-northeast to south-southwest with thrust faults striking parallel to the fold axis. The anticlinal hinge was later displaced by a dextral strike-slip fault, named here as the Faiyah Fault, into two segments. The northeastern segment includes Jebels Rumaylah, Faiyah and Mulayhah, and the southwestern segment includes Jebels Buhays and Aqabah. The anticline is interpreted to result from northeast-southwest compression during the Tertiary.

In the Faiyah Range the neoautochthonous sedimentary rocks are the Maastrichtian Qahlah and Simsima formations, and the Eocene Dammam Formation. Stratigraphic evidence shows that the lower part of the Qahlah was deposited in a non-marine environment while the upper part was deposited during a marine transgression. The Simsima was deposited in a shallow-marine environment. These units unconformably overlap the allochthonous Semail Ophiolite. The microfaunal content of the so-called Muthaymimah Formation (?Tertiary), of earlier authors, indicates that it is of Maastrichtian age in the Faiyah Range. This sequence is also conformable to the Simsima and therefore it is considered to be the upper member of the Simsima in this area.

Ahmed, E.A., ALSHARHAN, A.S., Soliman, M.A. and Tamer, S. (1998). Mineralogical characteristics of the Quaternary sand dunes in the eastern province of Abu Dhabi, United Arab Emirates: *In:* Alsharhan, A.S., Glennie, K.W., Whittle, G.L. and Kendall, C.G.St.C., (eds), Quaternary Deserts and Climatic Change, Balkema, Rotterdam, The Netherlands, p. 85-90.

The light and heavy minerals of one hundred and seven samples of (he dune sands along Al Ain-Abu Dhabi road lor a distance of about 130 km were .studied using polarizing microscope, scanning electron microscope and X-ray diffraction techniques. The present study has revealed (hat these dune sands arc composed of varieties of minerals such as quartz, dolomite, calcitc feldspar, opaques, pyroxenes (mostly orthopyroxencs), zircon, amphibolcs (hornblende and actinolitc-trcmolite) rutile, staurolitc, garnet, biotitc, monazile and sphenc.

The relative abundance of the quartz, dolomite and calcitc minerals varies according lo the location and grain size of the dune sands. Calcitc and dolomite predominate in the dunes near the coast pointing to the effect of local contribution. Moreover, the fine fraction (<4$) shows relatively high amount of calcite and dolomite, probably reflecting the role of selective sorting. Dissolution features of the quartz grains and heavy minerals are common phenomena.

The mineralogical composition suggests a source within a mixed sedimentary, basic-ultrabasic, plutonic and metamorphic provenance, most probably the Tertiary folded belt of Zagros and Oman Mountains, with some minor local contributions.

Whittle, G.L., ALSHARHAN, A.S. and Kendall, C.G.St.C. (1998) Petrography of Holocene beachrock and hardgrounds, Abu Dhabi, United Arab Emirates: In: Alsharhan, A.S., Glennie, K.W., Whittle, G.L. and Kendall, C.G.St.C., (eds), Quaternary Deserts and Climatic Change, Balkema, Rotterdam, The Netherlands, p. 57-70.

Beachrock and hardgrounds occur in the southern Arabian Gulf along the Emirates of Abu Dhabi coast at Al Qanatir, Ras al Aish, and Jebel Dhanna. Component grains, cement fabrics, and early diagenetic effects were studied. All three locations contain cemented samples which are highly bioclastic, however, those from Jebel Dhanna are encrusted by a travertine-like aragonitic coating not present at Al Qanatir or Ras al Aish. This coating may possibly be inorganic, and the cement fabrics which bind the rock are at least somewhat dependent on microbial activity. Micritic aragonite is the predominant cement at Jebel Dhanna and Al Qanatir, while Ras al Aish samples contain acicular cements atop thick micrite envelopes. In all localities it was found that where micrite envelopes are thick, acicular aragonite cements develop; where the envelopes are thin or absent, micritic aragonite predominates.

Grain type estimation showed cerithid gastropods to be the most common grain type; subordinate grain types include red algae, pellets, ooids, and quartz grains. The ooids are superficial in structure with concentric layers of tangentially-oriented aragonite surroundiiig the nucleus, very similar in appearance to pisolites. Quartz and lime mud were found to be more abundant in Al Qanatir samples than at Jebel Dhanna or Ras Al Aish. Lithoclasts of quartz silt in a muddy matrix occur in samples from Al Qanatir and Ras al Aish and may represent storm-deposited rip-up clasts that have been incorporated into the beachrock.

Kendall, C.G.St.C., ALSHARHAN, A.S., and Whittle, G.L. (1998). The flood re-charge sabkha model supported by recent inversions of anhydrite to gypsum in the UAE Sabkhas: In: Alsharhan, A.S., Glennie, K.W., Whittle, G.L. and Kendall, C.G.St.C., (eds), Quaternary Deserts and Climatic Change, Balkema, Rotterdam, The Netherlands, p. 29-42.

The coastal areas of Abu Dhabi in the UAE are protected by wide tidal flats which can be divided into five distinctive Holocene facies belts from seaward to landward. These are: 1) an upper intertidal cyanobacterial mat facies ranging from 10 to 55 cm (4 to 20 inches) in thickness, which is composed of laminated cyanobacterial mats intercalated with aragonite mud, gypsum crystals and protodolomites; 2) a lower supratidal gypsum mush facies forming a layer, locally up to 30 cm (12 inches) thick, capped by a crinkled cyanobacterial mat surface; 3) a mid-supratidal salt flat facies, which is up to 60 cm (23 inches) thick and is characterized by a thin crumpled polygonal surface of halite (2-5 cm thick) capping polygonal anhydrite layers (which replace and displace gypsum), carbonate washover sands, and some pockets of gypsum crystals. Aragonite muds trapped below this layer may be partially replaced by protodolomite; 4) an upper supratidal salt-flat facies, which ranges in thickness from 2 to 65 cm (1 to 25 inches) and contains near-surface nodular anhydrite in a matrix of carbonate sand. Beneath this is a layer of chicken-wire anhydrite that has completely replaced the gypsum mush. The cyanobacterial peat below contains abundant large lenticular gypsum crystals. Protodolomite replaces intertidal carbonates, while anhydrite fills molds of gastropod shells also occurs; 5) landward of stranded cerithid beach ridges is an upper supratidal recycled eolianite facies, and storm washover sediment which includes gypsum crystals which were eroded from the upper cyanobacterial flats. These crystals now form the nucleus to the "cumulus cloud-like" nodules and layers of anhydrite which are commonly found just within and beneath the sabkha surface. These often overlie shallow lagoonal sediments which may be dominated by carbonate mud. Large gypsum rosettes are found in this mud.

On the most landward side of the sabkha, particularly within the sabkhas closer to the city of Abu Dhabi, the anhydrite layers and nodules are replaced by gypsum. This replacement is a response to the influx of the fresher continental waters from the Arabian interior entering the coastal system, and local flash flooding. The lateral facies belts, with the exception of the replacement of anhydrite by gypsum, have been explained as the product of storm washover of marine flood waters and/or the evaporative pumping of the marine ground waters. Recent road building parallel to the coast near Qanatir, just landward of the cyanobacterial flat has coincided with the fall in the marine water table landward of the road and is directly related to anhydrite conversion to gypsum. The evaporative pumping model predicts that the marine ground waters would percolate beneath the road, but clearly this is not so. Thus, the marine water table was recharged by flooding, but now is flooded only by fresh water, so the water table has dropped and the anhydrite has become gypsum.

ALSHARHAN, A.S. and Salah, M.G. (1998). Sedimentological aspects and hydrocarbon potential of the Quaternary in the Gulf of Suez rifted basin, Egypt: *In:* Alsharhan, A.S., Glennie, K.W., Whittle, G.L. and Kendall, C.G.St.C., (eds), Quaternary Deserts and Climatic Change, Balkema, Rotterdam, The Netherlands, p. 531-539.

The Quaternary sediments in the Gulf of Suez rift basin rest on almost five thousand meters of sediment ranging in age from Cambrian to Miocene. In this basin, the Quaternary section consists, in ascending order, of the Warden and Zaafarana formations. The Warden Formation consists of sandstone and shale with some anhydrite and thin carbonate interbeds. The Zaafarana Formation consists mainly of interbedded carbonates and shales with thin sandstone streaks. The distribution of the different Quaternary facies is controlled by the influence of structural topography and eustatic sea-level variations. During the Quaternary deposition, the Gulf of Suez was an area for alluvial sedimentation, and included the alluvial fans which were built out from the bounding rift scarps. The Quaternary sediments were deposited in continental to shallow marine settings with localized restricted lagoonal environments. They lie unconformably over the late Miocene Evaporites (Zeit and South Gharib formations). This unconformity was produced by the renewed uplift of the rifted basins. The latter caused the Red Sea to connect the Indian Ocean with the onset of marine conditions. The Quaternary section of the North African rifted basins the Gulf of Suez, Gulf of Aqaba, Red Sea and Gulf of Aden attracted the attention of oil explorators in the last ten years. This has tested hydrocarbons at different locations in these basins. The Wardan sandstones, as well as, the Zeit Sandstones produced and/or tested hydrocarbons in the Abu Durba Oil Field (Egypt), Suakin Discovery (Sudan) and Abbas Discovery (Yemen). The hydrocarbon trapping mechanisms for the Quaternary reservoirs are structural and stratigraphic.

M.G. Salah and A.S. ALSHARHAN (1998). The Precambrian basement: A major reservoir in the rifted basin, Gulf of Suez. Journal of Petroleum Science and Engineering V. 19, P. 201-222

The expected instruction from an exploration manager, to stop drilling and abandon a well where the bit hits the Precambrian basement, no longer applies. The fractured and altered Precambrian basement rocks are the most prolific reservoirs in the southern Gulf of Suez and the northern Red Sea rifts where hydrocarbons are produced from 8 fields, with porosity and permeability values up to 15% and 300 millidarcy, respectively. The surface and subsurface Precambrian basement rocks are related to the final stages of the tectonic-magmatic cycle of the Arabo-Nubian Shield and are composed of quartz-diorite, granodiorite, syenogranite, alkali granites and andesite porphyry, dissected by means of dykes, fractures and joints. Three main directions of fractures, northwest-southeast, northeast-southwest and east northeast-west southwest have been detected in the study area. The porosity and production rates of this reservoir, as well as the oil-water contact movement, depend mainly on the age, intensity and direction of the fractures, diagenetic processes and the dip and direction of the dykes and brecciated zones. The alteration processes reach their maximum intensity in the topmost section, known as the basement cover, where the solution and leaching has led to the enlargement of the fractures and vertical communications. The underlying fracture zone has been affected by differential alteration processes, creating zones of high and low vertical porosity and permeability. Thus, the reservoir potential of the Precambrian basement has been greatly underestimated.

M. Boukhary and A.S. ALSHARHAN (1998). A stratigraphic lacuna within the Eocene of Qatar: an example of the interior platform of the Arabian Peninsula: Revue Paleobiology., v. 17 (1), Geneve, Switzerland, p. 49-68.

An unconformity between the Rus and Dammam formations represents a gap in the stratigraphic succession of the Eocene of Qatar. The chronostratigraphic equivalent of this missing interval in the western part of Qatar Peninsula spans P10 and P12, while in the eastern part of Qatar it spans the whole Lutetian (P10-P12). This means that the magnitude of this gap in time widens eastward in the direction of the Arabian Gulf in response of epeirogenic uplift of the Qatar Peninsula from the close of the Ypresian until the beginning of the Middle Lutetian. Following the deposition of the Middle Lutetian Midra and Saila sediments of the peninsula emerged and most of the Midra (and Saila) shale was differentially eroded. This interval is represented by a degradation vacuity in the stratigraphic record. During the Late Lutetian, the sea level fell ending sedimentation. A new incursion of the sea occurred during the Bartonian and sediments were deposited all over the whole area of the Qatar Peninsula; after which the sea regressed.

Rizk, Z.S., ALSHARHAN, A.S. and Shindo, S., (1997). Evaluation of groundwater resources of United Arab Emirates. Proceedings of the 3rd Gulf Water Conference, Muscat, Sultanate of Oman, v. 1, p. 95-122.

During early 1996, over 200 groundwater samples were collected from private wells tapping different aquifers in the U.A.E. Reid measurement of groundwater levels and ground-truth information were gathered for remote-sensing studies. The water samples were analyzed for major, minor and trace dissolved constituents, in addition to stable and radioisotopes.

Preliminary results indicate the presence of local, intermediate and regional groundwater flow systems, which affect salinity, quality and type of groundwater. Excessive groundwater pumping has created cones-of-depression ranging from 50 to 100 km in diameter at Al Dhaid, Hatta, Al Ain and Liwa areas. These cones have caused decline of groundwater levels, dryness of several shallow wells and salt-water intrusion problems. Measured depths to groundwater are < 5 m in the Liwa, Diba, Khor Fakkan, Kalba, Shaam and Khatt areas; 10-25 m in Al Shuayb, Madinat Zayed and Al Madam areas; 25-50 m in Al Wagan, Al Hayer, Jabal Hafit, Al Faiyah, Al Jaww plain, Hatta and Masafi areas; 50-100 m in Wadi Al Bih and Al Ain areas; and >100 m in Al Dhaid area.

Low groundwater salinity, 230-1000 milligrams per liter (mg/1), is present in Al Jaww plain, Masafi and Al Shuayb areas. Groundwater salinities of 1000-3500 mg/1 are measured in Al Ain, Diba, Hatta, Khatt and Al Fujairah areas, whereas salinities of 3500-6500 mg/l are recorded in Ras Al Khaimah, Madinat Zayed, Liwa and Dubai areas. Groundwater with >10,000 mg/1 of dissolved salts are observed in Al Dhaid, west and south of Al Ain and Kalba areas.

High-temperature groundwater (40-50°C) occurs in all U.A.E. permanent springs and the Jabal Hafit new wells, indicating the deep circulation of such water or the possibility of the presence of radioactive sources. Centers of high-temperature groundwater lie along NNE-SSW striking thrust faults which represent the western boundary of the Oman Mountains.

The cation dominance in groundwater of U.A.E. has the order: Mg^{2+}> Ca^{2+}> Na^{+}> K^{+} in the eastern part, Ca^{2+} > Mg^{2+}> Na^{+}> K^{+} in the central part and Na^{+}> Ca^{2+}> Mg^{2-}> K^{+} in the western part. The anion dominance has the order: HCO_{3-} > Cl^{-}> SO_4^{2} >CO_3^{2} in the eastern part, SO_4^{2}> Cl^{-}> HCO_3^{-}> CO_3^{2-} in the central part and Cl^{-}> SO_4^{2+} > HCO_3^{-}> CO_3^{2} in the western part. The groundwater-dissolved salts are Ca(HCO3)2 and Mg (HCO3)2 in the northern and eastern parts, $Na_2(SO_4)$, $CaSO_4$ and $MgSO_4$ in the central part and $MgCl_2$ and NaCI in the western and southwestern parts. The dominant groundwater types are bicarbonates (HCO_3^{-}) in the northern and eastern parts, sulphates (SO_4^{2}) in the central part and chlorides ($C1^{-}$) in the western and southwestern parts. The CV (CO^{3+} HCO_3) and Na/Cl ratios indicate the presence of salt-water intrusions problems in Ras Al Khaimah, Al Dhaid, Diba, Kalba, Dubai-Jabal Al Dhanah, Madinat Zayed, Liwa and Al Ain.

Groundwater in the eastern mountains and the flanking gravels is mainly fresh (<1500 mg/1 total dissolved solids) and can be used for all purposes. Groundwater is hard to very hard in the northeastern part, Al Dhaid, Kalba, Al Khaznah and along the western coast. The calculated Sodium Adsorption Ratios (S. A. R.) show that the groundwater in the northern and eastern parts has little harmful effect on plants and soils (S. A. R. <10), whereas the groundwater along the western coast, West of Al Ain and east of Liwa has high S. A. R. values and can be very harmful to plants and soils when used for irrigation (S. A. R. >26).

A.S. ALSHARHAN and M. G. Salah (1997). Common Source Rock for Egyptian and Saudi Hydrocarbons in the Red Sea. AAPG Bulletin, V. 81, No. 10, P. 1640-1659.

The northern Red Sea area hosts a classic triple junction of the Red Sea, Gulf of Aqaba, and Gulf of Suez rifted basins. The sedimentary succession here can be divided into prerift (pre-Miocene) and synrift (Miocene and post-Miocene) megase-quences. The prerift section has been penetrated in only a few wells drilled on the western (Egyptian) side of the Red Sea, whereas the synrift section is known on both the Egyptian and the Saudi sides of the Red Sea. Although the synrift units on both sides of the water are similar in facies, thicknesses, and depositional environments, they have different stratigraphic nomenclatures.

The northern Red Sea consists of elongated troughs separated by elongated structural highs, both of which trend northwest-southeast (Gulf of Suez trend). These highs are dissected by cross elements trending northeast-southwest (Gulf of Aqaba trend) and east-northeast-west-southwest, and are looked upon as strike-slip faults dislocating these highs.

Identified rich source rocks are present in the upper Senonian carbonates, the Sudr and Duwi formations on the western side of the sea, the early Miocene Rudeis Formation (Burqan Group), and the middle Miocene Kareem and Belayim formations (Maqna Group). The pre-Miocene and the early Miocene source rocks host oil-prone kerogen, whereas the middle and late Miocene source rocks contain oil- and gas-prone kerogen. All of these source rocks are sufficiently mature in most of the deep hydrocarbon kitchens to generate hydrocarbons.

Using both bulk and specific parameters, the correlation of liquid hydrocarbons and source rock extracts from the northern Red Sea suggests three scenarios. (1) The Egyptian and Saudi Red Sea oils form one genetic family that is different from the typical Gulf of Suez oils. The Gulf of Suez oil is sourced from the upper Senonian carbonates, but the northern Red Sea oil (Egyptian and Saudi) is sourced from the lower Miocene Rudeis Formation and the middle Miocene Kareem and Belayim formations (Burqan and Maqna groups, respectively). (2) The northern Red Sea oil group is characterized by a relatively higher wax content, low sulfur content, a pris-tane/phytane ratio of more than 1.0, a dominance of C_{29} steranes, and an abundance of the biomark-er gammacerane; the interpretation of these parameters suggests the possibility of two sources for these oils: a siliciclastic marine source and a relatively restricted, nonmarine source. (3) Both the Gulf of Suez oil group and the Red Sea oil group may mix in one field.

ALSHARHAN, A.S. and Salah, M.G. (1997). Lithostratigraphy, sedimentology and hydrocarbon habitat of the Pre-Cenomanian Nubian Sandstone in the Gulf of Suez oil province, Egypt: GeoArabia, Bahrain, v. 2, n. 4, p. 385-400.

The Paleozoic-Lower Cretaceous Nubian Sandstone is a thick sequence of up to 1,200 meters of clastic and thin carbonate sediments. In ascending order it is classified into the following groups and formations: Qebliat Group, Umm Bogma Formation, Ataqa Group and El-Tih Group. This sequence is composed mainly of sandstones with shale and minor carbonate interbeds and was deposited in continental and fluviomarine to marine settings. Petrographically, two main fades of Nubian Sandstone can be recognized in the Gulf of Suez: quartzarenite and quartzwackes. Both contain subfacies that are different in then-secondary components, cement and matrix types, reflecting their different depositional environments and diagenetic histories. The pre-Cenomanian Nubian Sandstone is one of the most prolific reservoirs in the Gulf of Suez oil province. These sandstones have intervals with good reservoir quality throughout the basin, with net pay thickness of up to 450 meters, and net sand ratios ranging from 60% to 90%. Porosity varies from 10% to 29%, and permeability from 70-850 millidarcies. The quality of the reservoir depends on its shaliness, diagenetic history and the depth of burial (compaction). The Nubian Sandstone still has a high potential as a reservoir, particularly in the northern sector of the Gulf of Suez where few wells have specifically targeted this interval.

ALSHARHAN, A.S. and Salah, M.G. (1997). The Miocene Kareem Formation in the Southern Gulf of Suez, Egypt: A review of Stratigraphy and Petroleum Geology: Journal of Petroleum Geology, The Netherlands, v. 20, n. 3, pp. 327-346.

The middle Miocene Kareem Formation in the Gulf of Suez is up to 500-m thick, and is composed of interbedded sandstones, shales and carbonates; minor anhydrites are present in the lower part of the formation. The siliciclastics were deposited in alluvial and submarine fans building out from the rift shoulders, while the carbonates and anhydrites were precipitated in local lagoons as a result of sea-level fluctuations. The formation is divided into the Rahmi and overlying Shagar Members, and is Langhian to Serravallian in age.

Three main sandstone lithologies have been identified (quartz arenites, arkoses and quartz wackes) each of which differ in their content of secondary minerals, cements and matrix types, reflecting their differing depositional settings and diagenetic histories.

The sandstones of the Kareem Formation form one of the most prolific reservoir lithologies in the Gulf of Suez oil province, and produce oil and/or gas in almost 30fields. These sandstones have a good reservoir quality throughout the basin, with gross- and net-pay thicknesses of up to 235 m and 195 m, respectively. The sandstones' porosity varies from 9% to 33%, and permeabilities range from 20 md to 730 md. Reservoir quality depends on the sandstones 'shaliness, diagenetic history and degree of compaction.

The sandstones still have high exploration potential particularly in the southernmost portion of the Gulf of Suez where they are extensive and thick but where there has been little drilling. Organic-rich shales within the Kareem Formation constitute potential source rocks for oil and gas, especially in the southernmost part of the Gulf of Suez where the geothermal gradient is high and where, according to previous studies, these sediments are located within the oil-generation "window ".

ALSHARHAN, A.S. and Salah, M.G. (1997). Tectonic implications of diapirism in hydrocarbon accumulation in United Arab Emirates: Bulletin of Canadian Petroleum Geology, Canada, v. 45, n. 3, p. 279-296.

The offshore of the United Arab Emirates (U.A.E.) contains eight diapiric islands; Dalma, Zirkouh, Qarnain, Das, Sir Bani Yas, Arzana, Sir Abu Nuwair and Abu Musa. These islands and Jebel Dhanna Peninsula owe their relief to the diapiric movement of salt which has pierced and deformed the overlaying strata.

These diapiric islands have similar shapes, stratigraphic sequences, areal distribution of the identified stratigraphic units and general tectonic framework. With the exception of Das Island, the stratigraphic sequence on the surface of all the diapiric islands consists, in ascending order, of: 1) Infracambrian to Cambrian (Hormuz Group) composed of igneous and metamorphic rocks, salt, anhydrite, carbonate and clastic interbeds; 2) Miocene composed of sandstone, siltstone, shale, carbonate and evaporite interbeds; and, 3) Pliocene to Recent sediments composed of mixed facies of elastics, carbonates and evaporites.

The structural configuration and the tectonic development of the Arabian Gulf Basin played an important role in the salt movement, which enhanced the formation and distribution of the islands, the timing of hydrocarbon generation, migration, and entrapment in the surrounding fields. The U.A.E., one of the world's richest in oil reserves, has almost 200 billion barrels (Bbbl) of oil and 275 trillion cubic feet (TCF) of gas that is sourced mainly from the Upper Jurassic and Lower to Middle Cretaceous formations and accumulated in carbonate reservoirs that range in age from upper Paleozoic to Oligo-Miocene. The geophysical and the geological data revealed three trap geneses in the U.A.E.: 1) Salt-related; 2) basement-related; and, 3) fold belt (collision) traps. Salt-related oil fields of the U.A.E. offshore area are characterized by: (a) dome-shaped structures; (b) independent closures; (c) radial faults within the structures; and, (d) multi-step structural growth histories. Subtle turtle structures exist between the diapiric islands of the U.A.E.. These structures form fields at Hair Dalma and Dalma, near Dalma Island, Mandous field, near Sir Abu Nuwair Island, and Mubarek field near the Abu Musa Island. The quality of the carbonate reservoir in the salt related oil fields is attributed to the effects of the diapiric salt movement.

ALSHARHAN, A.S. and Salah, M.G. (1996). Geologic Setting and Hydrocarbon potential of North Sinai, Egypt: Bulletin of Canadian Petroleum Geology, Canada, v.44, no. 4, P. 615-631.

The Sinai Peninsula is bounded by the Suez Canal and Gulf of Suez rift to the west, the transform Dead Sea-Aqaba rift to the east and the Mediterranean passive margin to the north. The stratigraphic section in North Sinai ranges in age from Precambrian to Recent and varies in thickness between 2000 m of mostly continental facies in the south to almost 8000 m of marine facies in the north. Four main tectonic trends reflect the influence of regional tectonic movements on the study area: 1) ENE-WSW-trending normal faults at the Triassic, Jurassic and Early Cretaceous levels; 2) NE-SW-trending anticlines at the Late Cretaceous and Early Tertiary levels; 3) NNW-SSE-trending normal faults at the Oligocene and Early Miocene levels; and 4) NNW-SSE-trending transform faults during the Late Miocene. Several oil and gas fields have been discovered in North Sinai since 1955. The Oligo-Miocene shales, the Early Cretaceous carbonates and the Jurassic fine elastics are rich source rocks yielding oil and gas in deep source kitchens. The sandstones of the Miocene, Oligocene, Cretaceous and Jurassic ages, the Jurassic carbonates and the Cretaceous carbonates form the reservoirs in north Sinai. The intraformational Mesozoic and Cenozoic shales and dense carbonates and the middle Miocene anhydrite form the seals. Structural, stratigraphic and combination traps are encountered in the study area. The north Sinai district has a good oil exploration potential. Only a few plays have been tested.

Salah, M.G. and ALSHARHAN, A.S. (1996). Structural influence on Hydrocarbon Entrapment in the Northwestern Red Sea, Egypt: American Association of Petroleum Geologists Bulletin, U.S.A, v. 80, no. 1, pp. 101-118.

The northwestern part of the Egyptian Red Sea has attracted the attention of many geologists because it lies at the triple junction of the main rifts between the Red Sea, the Gulf of Aqaba, and Gulf of Suez. The geometry of the fault system in this area of the basin clearly indicates an extensional setting. The area has a southwestward regional dip, and it has experienced more extension than the rest of the Gulf of Suez.

Six tectonic stages, different in their stress history, sedimentary fill, and depositional setting, are recognized for the northwestern Red Sea: (1) Cambrian to early Cretaceous stage; (2) late Cretaceous to Oligocene stage; (3) early Miocene stage; (4) early to middle Miocene stage; (5) middle to late Miocene stage; and (6) post-Miocene stage.

Magnetic, gravity, seismic, surface, and subsurface data from the northwestern Red Sea delineate several elongate structural highs separated by elongate troughs. Both highs and troughs have the same northwest-southeast direction as the clysmic trend. Some of the highs are dissected by cross elements that trend northeast-southwest and east-north-east-west-southwest and laterally offset these highs.

The tectonic framework of the northwestern sector of the Red Sea had a significant influence on hydrocarbon generation, migration, and accumulation. The evidence for this influence includes the following: (1) the troughs form the main source kitchens where the Precambrian basement rocks are present at depths exceeding 4877 m (e.g., Gemsa Trough); (2) the magnitude of throw on the clysmic fault is critical in the entrapment mechanisms; (3) the cross elements play a major role in the hydrocarbon migration and accumulation because they truncate the extension of most of the oil fields and form their bounding faults; and (4) all the discovered oil fields in the study area are structural and/or combination traps and show good matches to the magnetic anomalies.

Whittle, G.L. and ALSHARHAN, A.S. (1996). Diagenetic history and source rock potential of the Upper Jurassic Diyab Formation, offshore Abu Dhabi, United Arab Emirates: Carbonates and Evaporites, U.S.A., v.11, no. 2, p. 145-154.

The Upper Jurassic Diyab Formation is a highly argillaceous dolomitic limestone unit underlying one of the most prolific hydrocarbon reservoirs in the world: the Arab Formation. The Diyab is thought to be the primary source for the Arab in the United Arab Emirates. Thin sections from cores in offshore Abu Dhabi show the Diyab to contain dolomitized grains tones at the base with associated glauconitization and chertification grading upward to olive-green, argillaceous, organically-rich, dolomitic limestones in the upper third of the Diyab, creating a marly texture which persists through to the top of the section. Late diagenetic calcite (and subordinate anhydrite) cement, which include coarse spar as well as blocky and poikilotopic fabrics, occlude much of the secondary porosity and are interpreted to have occurred during burial diagenesis. Dolomite is in the form of euhedral rhombohedra which primarily replace the matrix of the limestones. Allochemical grains, which include peloids, intraclasts and bioclasts, have recrystallized to low Mg-calcite and are partially glauconitized in the lower part of the section. Pressure solution has caused fracturing and stylolitization, fractures being filled by sparry calcite and stylolites by a bituminous residue.

The source rock potential of the Diyab is fair-moderate, with TOC between 0.72 and 1.8%. In western Abu Dhabi the Diyab was a major source rock (TOC of 0.3 to 55%) for the Upper Jurassic Arab and Lower Cretaceous Thamama formations.

Whittle, G.L., ALSHARHAN, A.S., and El Deeb, W.M.Z. (1996). Facies analysis and early diagenesis of the Middle-Late Eocene Dammam Formation, Abu Dhabi, United Arab Emirates: Carbonates and Evaporites, U.S.A., v.11, no.1, p. 32-41.

Within onshore Abu Dhabi, United Arab Emirates, the Middle-Late Eocene Dammam Formation can be separated into three distinct units on the basis of lithological analysis. Petrographic analysis shows these units to consist of interbedded yellow-brown marl and shale with gray bioclastic packstone/grainstones and mudstone/wackestones. Dolomite and gypsum occur locally in the upper half of the section. A lithostratigraphy and fades analysis of the Dammam suggests cycling between the grain-supported and mud-supported limestones, and with pulses of terrigenous material producing the marly and shaley interbeds.

The diagenetic history of the Dammam is dominantly a reduction of porosity primarily due to secondary cementation by two generations of calcite and the recrystallization of unstable grains and cement, as opposed to dissolution. In addition, dolomitization, which often has the effect of creating good secondary porosity, which is only local in extent.

The Dammam of the onshore Abu Dhabi is interpreted in the area to represent a transitional period between the more restricted limestones of the underlying Lower Eocene Rus Formation and the more complex sub-environments of the overlying Oligocene Asmari Formation.

ALSHARHAN, A.S. and Nasir, S.J.Y. (1996). Sedimentological and geochemical interpretation of a transgressive sequence: the Late Cretaceous Qahlah Formation in the western Oman Mountains, UAE: Sedimentary Geology, The Netherlands, 101, pp. 227-242.

The stratigraphic and palaeogeomorphologic conditions of the Qahlah Formation deposition in the United Arab Emirates are related to the geotectonic evolution of the western Oman Mountains during the Late Cretaceous. The Qahlah Formation ranges from a few metres to more than 70 m in thickness. It is the first sedimentary deposit to onlap the obducted Semail ophiolite, which was subjected to extensive weathering in a tropical environment during the Maastrichtian. Erosion accompanied the transgression of the Maastrichtian sea across the region. The sedimentary sequence can be divided into four facies: ophiolitic breccia, ophiolitic conglomerate, lateritic ferruginous siltstone and lithic sandstone. These sediments were probably formed in a shallow-marine to beach setting adjacent to a retreating cliff line of the ophiolite. A comparative analysis of the principal chemical and mineralogical components of the different facies indicates a genetic relationship between them. The nickel content (0.85-1-1.16 wt%) in the laterite facies is of economic interest as a low-grade ore provided that larger reserves can be identified.

ALSHARHAN, A.S., Ahmed, E. and Tamer, S. (1995). Textural characteristics of Quaternary sand dunes in the eastern province of Abu Dhabi, U.A.E. IGCP-349 international conference on Quaternary Deserts and Climatic Change, Al Ain, U.A.E.

The sand dunes that extend between Al Ain and Abu Dhabi in belt some 120 km long and 20 km wide were studied from geomorphological and sedimentological point of view. One hundred and thirty samples were collected and analyzed using conventional sieving methods, scanning electron microscopy, and X-ray diffraction. These sediments are classified as fine sand moderately well sorted, near symmetrical, and mesokurtic. Sands from the crests of the dunes are generally coarser and less well sorted than those from the remaining portions of the dunes. The leeward slopes are finer and better sorted than the stossward slopes. The grains are subrounded and poorly sorted. The relatively high degree of roundness may be attributed to the sands being recycled aeolian sand grains. An increase in grain roundness is associated with increase in grain size of the sands, while increasing sorting was associated with a decrease in grain size and roundness of the sands. Mechanical and chemical (dissolution) features affect the surface features of the quartz grains. The mechanical features include upturned plates, meandering ridges irregular depressions and pits, conchoidal fractures, and polygonal cracks. Chemical features are intensively imprinted on the sand grains, particularly where both dissolution and precipitation have occurred. These features include irregular solution pits, gulling, silica globules, quartz overgrowths, and smoothed surfaces. The huge sand dunes in the UAE are part of a great belt that extends from southern Iraq to northeast Saudi Arabia, formed oy the prevailing winds of the last glacial period.

ALSHARHAN, A.S. and Salah, M.G. (1995). Geology and hydrocarbon habitat in rift setting: northern and central Gulf of Suez, Egypt: Bulletin of Canadian Petroleum Geology, Canada, v. 43, no. 2, pp. 156-176.

The area of concern is part of the prolific Gulf of Suez oil basin which contains an excess of 40 oil fields with reserves ranging from 1350 MMbl to less than 1 MMbl in reservoirs from Early Paleozoic to post-Miocene in age. The lithostratigraphic units in the northern and central Gulf of Suez can be subdivided into three megasequences, a prerift succession (pre-Miocene), a synrift succession (Miocene) and a postrift succession (post-Miocene). These units vary in lithology, thickness, areal distribution and oppositional environment.

The interpretation of both geological and geophysical data shows that the northern and central Gulf of Suez consists of northwest-trending elongated troughs. These contain several high trends which are dislocated by northeast- and east-northeast-trending cross faults.

Major prerift and synrift rich source rocks could yield oil and/or gas and are mature enough in the deep kitchens to generate hydrocarbons. Geochemical parameters, sterane distribution and biomarker correlations show a single major group of oils, generated from marine source rocks. It is believed that oils in the north and central Gulf of Suez were sourced from the prerift beds.

The pre-Cenomanian sediments. Late Cretaceous Nezzazat sandstones and the fractured Eocene Thebes limestone form prerift reservoirs, while the Miocene sandstones and carbonates of the Nukhul, Rudeis, Kareem and Belayim formations and the sandstones of South Gharib, Zeit and post-Zeit are synrift reservoirs, which are more important in the northern Gulf of Suez. The Upper Miocene Evaporites (South Gharib and Zeit formations) are the ultimate seal in the central Gulf of Suez, whereas the shale and dense limestones of the prerift and the synrift stratigraphic units are the primary seal in the northern Gulf of Suez. Structural, stratigraphic and combination traps are encountered in the study area. The northern Gulf of Suez has an excellent oil exploration potential as few plays have been tested and the central Gulf of Suez still has untested plays.

ALSHARHAN, A.S. and Whittle, G.L. (1995). Carbonate-Evaporite Sequences of the Late Jurassic, Southern and Southwestern Arabian Gulf: American Association of Petroleum Geologists Bulletin, U.S.A., v. 79, no. 11, pp. 1608- 1630.

The carbonate-evaporite sequences of the Upper Jurassic Arab and overlying Hith formations in the southern and southwestern Arabian Gulf form many supergiant and giant fields that produce from the Arab Formation and are excellent examples of a classic reservoir/seal relationship. The present-day sabkha depositional setting that extends along most of the southern and southwestern coasts of the Arabian Gulf provides an analog to these Upper Jurassic sedimentary rocks. In fact, sabkha-related diagenesis of original grain-supported sediments in the Arab and Hith formations has resulted in five distinct lithofacies that characterize the reservoir/ seal relationship: (1) oolitic/peloidal grainstone, (2) dolomitic grainstone, (3) dolomitic mudstone, (4) dolomitized grainstone, and (5) massive anhydrite. Interparticle porosity in grainstones and dolomitic grainstones and intercrystalline porosity in dolomitized rocks provide the highest porosity in the study area. These sediments accumulated in four types of depositional settings: (1) supratidal sabkhas, (2) intertidal mud flats and stromatolitic flats, (3) shallow subtidal lagoons, and (4) shallow open-marine shelves.
The diagenetic history of the Arab and Hith formations in the southern and

southwestern Arabian Gulf suggests that the anhydrite and much of the dolomitization are a result of penecontemporane-ous sabkha diagenesis. The character and timing of the paragenetic events are responsible for the excellent porosity of the Arab Formation and the lack of porosity in the massive anhydrites of the Hith, which together result in the prolific hydrocarbon sequences of these formations.

ALSHARHAN, A.S. (1995). Facies variation, diagenesis and exploration potential of the Cretaceous rudist-bearing carbonates of the Arabian Gulf: American Association of Petroleum Geologists Bulletin, U.S.A., v.79, no. 4, pp. 531-550.

The Cretaceous rudist-bearing carbonates of the Arabian Gulf region are proven exploration targets for hydrocarbons and form the reservoirs of a number of giant fields, including Bu Hasa, Fateh, Fahud, Idd El Shargi, Rumaila, Shaybah, and Shah. Rudist buildups occur in three principal formations: (1) Aptian Shuaiba, (2) Cenomanian Mishrif, and (3) Maastrichtian Simsima. A regional subaerial unconformity marks the upper boundary of each of these formations.

Associated with the rudists that dominate the Shuaiba Formation are calcareous algal crusts, fora-minifera, and echinoid plates, which accumulated in mudstone, packstone, and carbonate sands. These rudists are mainly caprinids, with a lesser number of caprotinids, monopleurids, and requienids, deposited in a normal-marine shallow-shelf setting.

The Mishrif Formation contains mollusk fragments, bioclastic packstones to grainstones, milio-lid and nonrudist bivalves in muddy limestones, and rudist (mainly radiolitids and caprinids) conglomeratic floatstones, with fragmented rudists mixed with wackestone lithoclasts. The Mishrif sediments accumulated as a progradational, low-energy leeward margin formed in marginal slope, shoal-backshoal, and lagoonal settings.

The Simsima Formation consists of bioclastic grainstone to packstone, and dolomitic lime mud-stones to wackestone. These are rich in bioclastic grains (Loftusia, rudist and rudist debris, coral, and foraminifera) deposited on a restricted to semire-stricted shallow-marine shelf that was exposed to moderate energy conditions.

The excellent reservoir porosity and permeability of the rudist deposits and their associated sediments are the products of primary and secondary diagenesis. Freshwater leaching during post-Aptian, post-Cenomanian, and post-Maastrichtian erosion enhanced the secondary moldic porosity. Fracturing locally improved porosity and permeability. Other porosity types that occur include interparti-cle, intraparticle, vuggy, growth framework, shelter, intercrystalline, and karstic.

Because of their favorable depositional and post-depositional conditions, the Cretaceous succession of rudists in this region contains many giant oil fields.

ALSHARHAN, A.S. and Magara K. (1995). Nature and distribution of porosity and permeability in Jurassic carbonate reservoirs of the Arabian Gulf Basin: Facies, Germany, v.32, no. 32, pp. 37-254.

The Middle-Upper Jurassic section in the Arabian Gulf basin forms one of the most prolific sequences in the world, in which an excellent combination of source, reservoir and seal rocks was developed within a major sedimentary cycle. The sequence consists of a) relatively quiet deep-water mudstone, wackestone and shale (source fades), b) shallow-water high energy grains tone and packstone (reservoir facies), and c) very shallow supratidal anhydrite (seal facies). The principal factors, which controlled the sedimentation of this sequence, are considered to have been eustatic sea-level change and epeirogenic movement of carbonate shelves.

The Jurassic reservoirs of the major oil fields in this region show exceptionally high porosity up to 30% for their relatively old geologic age (some ISO million years old) and depths of burial in the range between 1,200 and more than 2,700 m. Porosity occurs most commonly as intergranular/remnant primary pore spaces, but its distribution is quite uneven and very complicated. To account for the existence of such high porosity (and permeability) in the Jurassic reservoirs, probable geological, physical and chemical factors for preserving and enhancing porosity (and permeability), such as acidic formation fluids, reduced fluid mobility, tectonic forces, ductility of intercalated beds (e.g. anhydrite), and dolomitization were examined.

It has been observed in various fields in the region that oil-saturated portions of the Jurassic reservoirs tend to retain higher porosity than the surrounding water-saturated zones. Porosity preservation by hydrocarbons is possible primarily because of excess hydrocarbon pressure and of reduced mobility of water in such oil-saturated zones. To continue sediment diagenesis, a steady supply of minerals by formation water and the mobility of the water may have been essential. Because the entrapment of oil in the Jurassic reservoirs in the region is considered to have been as late as early Tertiary, some other (pre-migration) mechanisms which may have worked in the earlier geologic stages for preserving and creating porosity (and permeability) seem to be necessary.

ALSHARHAN, A.S. and Whittle, G.L. (1995). Sedimentary-diagenetic interpretation and reservoir characteristics of the Middle Jurassic (Araej Formation) in the southern Arabian Gulf: Marine and Petroleum Geology, U.K., v. 12, no. 6, pp. 615-628.

Oil and gas condensates discovered so far in the Middle Jurassic Araej Formation occur in several structures in western and central offshore Abu Dhabi and Qatar. The source for the oil is thought to have migrated updip primarily from the Hanifa/Diyab

Formation (Upper Jurassic), whereas the source of the gas condensate is believed to be from Middle Triassic-Lower Jurassic formations. The Araej Formation is described from well data and thin sections from wells drilled in the south and south-west Arabian Gulf. It is a carbonate sequence that has a thickness ranging from 180 to 300 m (590 to 980 ft) and is divided into three members: Lower Araej, Uwainat and Upper Araej. The Lower Araej Member is made up of slightly argillaceous lime mudstones and wackestones with subordinate interbeds of peloidal/bioclastic packstones and grainstones. The Uwainat Member consists of peloidal bioclastic packstones and grainstones with subordinate wackestones and lime mudstones. The Upper Araej Member consists predominantly of variably cemented grainstones and packstones with minor wackestones. The sediments of the Araej Formation were deposited as a shallowing upwards sequence in quiet shelf waters grading to a shallow to very shallow marine shelf. Lithological variation within each member suggests higher order shallowing upwards sequences produced by sea-level fluctuations. Petrographic analysis of the Araej suggests a diagenetic path which includes neomorphism and recrystallization of allochems and marine cements to low Mg-calcite, dissolution and partial dolomitization of muddy lithologies. Pressure solution seams and stylolitization improved the permeability and these compactional features are often filled by bitumen. Some seams are filled by coarse mosaic calcite crystals or coarse rhombic dolomite, which is believed to be a late diagenetic cement. Porosity is highly variable, but never exceeds 16%. Intercrystalline, interparticle, mouldic and vuggy porosities are the dominant pore types.

ALSHARHAN, A.S. and Nairn, A.E.M. (1995). Stratigraphy and Sedimentology of the Permian in the Arabian Basin and Adjacent Areas: A Critical Review. In: P. Scholle, T.M. Peryt and D.S. Ulmer-Scholle (eds.). The Permian of Northern Pangea, v.2, pp. 187-214. Springer Verlag, Germany.

The area covered in this review extends as far east as the Zagros Crush zone of Iran, while its extent westwards is limited by the Arabian Shield. To the southeast, in Oman, it is bounded by the Arabian Sea, and to the north by the Taurus Mountains which continue the line of the Zagros Crush zone. The greater part of the Permian strati-graphic sequence lies in the subsurface and consequently is known only through drilling. However, more subsurface data are becoming available because of the discovery of enormous quantities of non associated gas contained within reservoirs in the Khuff Limestone and its equivalent

The principal outcrops of Permian sedimentary rocks are located in the Al Qasim district near the eastern edge of the Arabian Shield in Saudi Arabia, and the formational names, Unayzah and Khuf£ are taken from the names of the two principal settlements in the area. The second region of importance from the point of view of outcrop data lies in the Zagros basin of Iran.

As in many parts of the world, the Permian rocks of the Middle East can be divided into a lower, primarily clastic sequence, which may extend back into the Late Carboniferous, followed by a limestone/dolomite succession. The beds rest unconformably upon older Paleozoic rocks, above an unconformity sometimes called "the Great Hercynian Unconformity". The carbonates are more extensive than the elastics and are observed to overlie a variety of Lower Paleozoic sedimentary strata or to rest directly upon Precambrian basement rocks. The carbonates and elastics interfinger, and in the Widyan Basin of north-northeastern Arabia) there appears to be stratigraphic continuity between the beds of the older, clastic phase and the younger carbonate beds, with the oldest of the carbonates interbedded near the top of the predominantly clastic sequence in the Unayzah section. A distinctive feature of both sequences is their rhythmic/cyclic, fining-upwards character. Permian rocks crop out in Oman both as displaced blocks within the Oman exotics and in the autochthon. Elsewhere in the Arabian Gulf region, the Permian rocks are deeply buried and seldom penetrated by chilling. However, in the coastal provinces of Iran, Permian rocks rise to the surface.

The Mid-Carboniferous was a time of erosion during which considerable thicknesses of earlier Paleozoic sediments, measurable in many hundreds of meters, were removed. Thus, in some places in Saudi Arabia, the limestones rest on the Precambrian, as mentioned above, but in other places, as in Iran, Permian beds may rest upon Devonian, Silurian, or Cafnbro-Ordovician rocks. The "Hercynian" upwarping was associated with extensional faulting which formed basins trending in an east-west and northeast to southwesterly direction. The products resulting from the erosion of the uplifted terrain accumulated in these basins. The changed depositional pattern reflects changes in the regional stress field from that existing throughout the Early Paleozoic. This Hercynian event presumably was related to the development of stresses in this marginal area of Gondwana which ojlminated later during the Triassic in the separation and translation of the Cimmerian fragment or fragments of the Gondwana margin.

ALSHARHAN, A.S. and Nairn, A.E.M. (1995). Tertiary of the Arabian Gulf: sedimentology and hydrocarbon potential. Palaeogeography, Palaeoclimatology, Palaeoecology, The Netherlands, v. 114, pp. 369-38

The Paleogene-Neogene paleogeography of the Arabian Basin shows a change from the basic continuation of the Mesozoic pattern during the Paleogene to a new pattern of sedimentation established during the Neogene and resulting from movements in the Zagros. The Paleogene shallow-water carbonate-dominated lithologies in Eastern Arabia were replaced by deep-water Neogene carbonates near the Zagros and mixed carbonate and elastics in the northern Arabian Gulf.

The hydrocarbon potential of these rocks, except locally, is low and the decreasing amplitude and frequency of faulted and folded structures away from the Zagros front suggests that the discovery of fields in structures such as those in Iraq-Iran is low. This poverty may however suggest that the untapped potential of the Mesozoic rocks may still be high.

Whittle, G.L., ALSHARHAN, A.S., and El Deeb, W.M.Z. (1995). Bio-lithofacies and diagenesis in the Early-Middle Oligocene of Abu Dhabi, United Arab Emirates. Carbonates and Evaporites, U.S.A., v. 10, no. 1, pp. 54-64.

The Early to Middle Oligocene is missing throughout much of the Arabian Peninsula. Only in the Oman Mountains and related linear NW-SE trending mountains are these sediments found. In the United Arab Emirates shallow water carbonates of the Asmari Formation (Early to Middle Oligocene) range from 435-481 m (1427-1578 ft), cropping out at the Jabal Hafit area near Al Ain. Detailed measured sections, sampling and thin section analysis show these carbonates comprise seven distinct fades: 1) Nummulitic Packstone, 2) Foraminiferal Wackestone/Packstone (non-Nummulitic forams), 3) Echinoderm/Red Algal Packstone, 4) Coral Framestone, 5) Peloidal Packstone, 6) Mudstone/Wackestone, and 7) Dolomite.
Diagenetic events which have affected the Oligocene section include early cementation, formation of micrite envelopes, inversion of original aragonite and high Mg-calcite fabrics (i.e., biogenic tests and early marine cements) to low Mg-calcite, leaching of tests, dolomitization, stylolitization and fracturing, late diagenetic coarse calcite spar cementation, emplacement of bitumen within stylolitic seams and finally, hematite and pyrite staining.

A depositional model has been proposed based on the fossil and lithofacies assemblages which suggests that a deep, outer shelf, quiet water lagoon supplies peloids to the back-reef, reef and fore-reef fades as well as the shallow open marine fades of the inner shelf. A short-lived sea level low is believed to have occurred, where continental waters manifested their presence in rare cherufication and partial to complete dolomitization of some samples.

ALSHARHAN, A.S. and Kendall, C.G.St.C. (1995). Facies variation, depositional setting and hydrocarbon potential of the Upper Cretaceous rocks in the UAE: Cretaceous Research, U.K., 16, pp. 435-449.

The Upper Cretaceous (Aruma Group) of the United Arab Emirates (UAE) was deposited over nearly 23 Ma. This was after a period of major erosional emergence in the Turonian. The variable thicknesses and lithofacies of the sediments of this group were controlled by regional subsidence induced by plate collision and partial subduction, eustatic sea-level fluctuations and differential sedimentation rates. The Upper Cretaceous in the southern UAE (Abu Dhabi region) consists of two major transgressive-regressive cycles involving the sediments of four formations, the Laffan, Halul, Fiqa and Simsima. In the central UAE (Dubai region) the group consists of the Laffan, Ham, and Fiqa Formations, while in the northern UAE it consists of the Muti, Juweiza, Qahlah and Simsima Formations.

The earliest Late Cretaceous sedimentation accompanied a marine transgression that probably began in the late Turonian, with the sea spreading to cover most of the UAE by Coniacian times. This marine event was marked by the deposition of basinal muds (not shales) and neritic marls. Later, during the Santonian, neritic shelf carbonates were deposited. Subsequent subsidence in the early Campanian resulted in the accumulation of deep-water marls, argillaceous limestones and muds (shales). During the Maastrichtian, a widespread regression occurred, and neritic shelf bioclastic limestones and dolomites containing rudists and orbitoids were deposited on the shelf margin. Toward the centre of the basin, in the northern UAE, thicker basinal, slope and shelf edge sediments were deposited resulting in a succession that consists mostly of marls, argillaceous limestones, cherts, conglomerates, sandstones and shales.

Commercial hydrocarbons in the Upper Cretaceous are confined to the Simsima and Ham Formations, which are the best potential exploration targets, particularly in the offshore of the northeastern Emirates in a belt parallel to the Oman Mountains. The basal part of the Upper Cretaceous is a major seal over middle Cretaceous reservoirs of the UAE.

Whittle, G.L. and ALSHARHAN, A.S. (1995). Observations on the diagenesis of the Lower Triassic Sudair Formation, Abu Dhabi, UAE: Facies, Germany, v.32, pp. 85-194.

The Lower Triassic Sudair Formation in the United Arab Emirates (U. A.E.) ranges in thickness from 178-297 m and comprises three units consisting of interbedded limestone, argillaceous limestone, dolomite and anhydrite. The Lower Unit contains variable energy shallow marine, slightly argillaceous mudstones and subordinate oolitic-peloidal packstones and grainstones with minor dolomite and anhydrite. The Middle Unit consists of argillaceous and ferroan dolomite deposited in a lagoonal to supratidal setting. The Upper Unitcomprises argillaceous mudstones and dolomites at the base grading upward into argillaceous anhydrite deposited in a restricted shallow marine to sabkha setting. These units represent the transition from a carbonate/evaporite shelf with significant terrestrial input to an evaporitic platform defined by an overall shallowing-upward sequence.

Diagenesis in the Sudair includes extensive leaching of grain-supported carbonates, partial to complete dolomiti-zation, evaporite formation, clay nucleation, fracturing/ pressure solution, late cementation by coarse calcite spar and saddle dolomite, and hematite formation. These processes have had the cumulative effect of reducing the secondary porosity. Dolomitization occurred in two stages: an earlier progression of rhombic - sucrosic - aphanocrys-talline dolomite, and a later coarse crystalline and saddle dolomite fracture fill.

ALSHARHAN, A.S. (1995). Sedimentology and depositional setting of the Late Cretaceous Fiqa Formation in the United Arab Emirates: Cretaceous Research, U.K., v.16, pp. 39-51.

In the United Arab Emirates, the Fiqa Formation (Coniacian-middle Maastrichtian) ranges from about 60 to 1220 m (200-4000 ft) in thickness and consists of argillaceous limestones, dark grey to grey-brown shales, marls and marly shale with abundant benthonic and planktonic foraminifera. These sediments were laid down in a shallow to deep open-marine shelf setting. Clay content in the rock ranges up to 60%, and is generally higher in the Lower Fiqa (Shargi Member) than in the Upper Fiqa (Arada Member); kaolinite dominates the clay fraction, suggesting redeposition of latenticweathering deposits formed under alternating arid and humid climates. The non-clay fraction is dominated by calcite, quartz and feldspar with traces of dolomite, pyrite, siderite, glauconite and phosphate. The petroleum source-rock potential of the Fiqa Formation is generally low, primarily because of a lack of organic maturation owing to relatively shallow burial in most areas.

ALSHARHAN, A.S. and Salah, M.G. (1995). Geology and hydrocarbon habitat in rift setting: northern and central Gulf of Suez, Egypt: Bulletin of Canadian Petroleum Geology, Canada, v. 43, no. 2, pp. 156-176.

The southern Gulf of Suez in Egypt is located at the junction of the African and Arabian plates, and has excellent hydrocarbon potential. The stratigraphic units in the area are grouped into two main megasequences, the pre-rift (Pre-Oligocene) and the syn-rift (Oligocene-Recent) lithostratigraphic units. Gravity, magnetic, seismic and well data were used to delineate outlines of several narrowly elongated northwest-trending depositional troughs, separated by structural ridges. Several pre-rift and syn-rift rich source units occur and are mature enough in the deep troughs to generate hydrocarbons. A geochemical study of source rocks and oil samples showed two groups of oil: 1. Gulf of Suez oils from pre-rift sediments; and 2. southern Gulf of Suez oils from Middle Miocene carbonates. The reservoirs are also classified into: 1. pre- rift reservoirs, such as fractured and weathered Precambrian basement, Nubia sandstone, Cretaceous sandstone and fractured Eocene limestone; and 2. syn-rift reservoirs such as Lower and Middle Miocene carbonates and

sandstones. Most oil fields in the region have multiple, producing reservoirs. The Miocene Evaporite Group forms the primary seal for most of the reservoirs, and the shales and dense carbonates of both the pre-rift and syn-rift sections form secondary seals. Trap types include structural, stratigraphic and combination traps. The southern Gulf of Suez, which shares more than one-third of the whole Gulf of Suez reserves, remains high in hydrocarbon potential with many untested plays.

Kendall, C.G.St.C., Sadd, J.L. and ALSHARHAN, A.S. (1994). Holocene marine cement coatings on beachrocks of the Abu Dhabi coastline (U.A.E.), an analog for cement fabrics in ancient limestone: Carbonates and Evaporites, U.S.A., v.9, n.2, pp. 119-131.

ABSTRACT: Marine carbonate cements, which are superficially like travertines from meteoric caves, are coating and binding some intertidal sedimentary rock surfaces occurring in coastal Abu Dhabi, the United Arab Emirates, (UAE). Near Jebel Dhana these surficial cements can be up to 3 cm thick and envelope beach rock surfaces and fossils. They are also present both as thin coats and a fracture-fill cement in the intertidal hard grounds associated with the Khor Al Bazam algal flats.

The thickness, microscopic characteristics, and morphology of the marine cement coatings from Jebel Dhana indicates incremental deposition of aragonite in conjunction with traces of sulfate minerals. Most of these cement coatings are micritic, but the layers which encrust the hard grounds from the algal flat of the Khor al Bazam have a more radial and fibrous micro-structure and are composed solely of aragonite.

The stable isotopic composition of coatings from Jebel Dhana (818O = +0.35, 8I3C = +4.00) falls within the compositional range for modern marine non skeletal aragonite and suggests that the marine travertine-like cements precipitate from the agitated, slightly hypersaline Arabian Gulf sea water during repeated cycles of exposure, evaporation and immersion.

Similar cement coatings and microfabrics are present in the tepee structured and brecciated sediments of the Guadalupe Mountains (Permian) and the Italian Abs (Triassic), in Hobcene algal head cements from the Great Salt Lake, and in similar Tertiary algal heads in the Green River Formation of the western US. The petrographic similarity of these ancient "flow stone" like cements with Recent hypersaline marine cement coatings suggests that high rates of carbonate cementation and hypersaline conditions contribute to tepee formation and cavity fill.

ALSHARHAN, A.S. (1994). Albian clastics in the western Arabian Gulf region: A sedimentological and petroleum-geological interpretation: Journal of Petroleum Geology, U.K., v.17, no. 3, pp. 279-300.

Clastic sediments of Albian age are widely distributed throughout the Arabian Gulf, varying in thickness from less than 78 m to more than 390 m. The transition from sandstones in the northern part of the western Arabian Gulf (South Iraq, Kuwait and eastern Saudi Arabia) to shales in the SW and southern part (Qatar, United Arab Emirates and Oman) shows vertical and lateral variations. A complex nomenclature has been applied to different fades across the region, and the sediments may have several formation and member names (such as Nahr Umr andBurgan Formations, or Khafji and Safaniya Members).

Clastic sediments of Albian age provide hydrocarbon source rocks, reservoirs and seals. Major reservoirs occur in sandstones to the north, and have a limited reservoir potential in offshore Qatar. Distal shales are a major seal in offshore Qatar, the United Arab Emirates and Oman. Local source-rock potential exists in the northern part of the Arabian Gulf and in the extreme SE of Saudi Arabia (in the Rub Al Khali Basin).

ALSHARHAN, A.S. and Kendall, C.G.St.C. (1994). Depositional setting of the Upper Jurassic Hith Anhydrite of the Arabian Gulf an analogue to Holocene Evaporite of the United Arab Emirates and Lake Macleod of western Australia: American Association of Petroleum Geologists Bulletin, U.S.A., v. 78, n.7, pp. 1075-1096.

The Upper Jurassic Hith Anhydrite is a major hydrocarbon seal in the Arabian Gulf region. Outcrops, core samples from the subsurface, and the literature indicate that the Hith Formation is composed mainly of anhydrite. In most locations where a section of the Hith Formation has been measured, this unit contains less than 20% carbonate, much of which is in the form of thin laminations. This lack of carbonate, locally thick layers of salt, and the predominance of anhydrite favor a playa for the setting in which this sediment was accumulated. In fact, much of the Hith has the sedimentary characteristics of the Holocene Lake MacLeod playa of Western Australia, which is dominated by layers of gypsum and halite (what little carbonate that occurs is found in layers at the base of the section).

Locally the Hith appears to have accumulated in a sabkha setting, particularly toward central Abu Dhabi where it pinches out into shallow-water, and periti-dal carbonate. This sabkha setting is indicated by the interbedded relationship of the Hith anhydrites with these carbonates and the local predominance of horizontally flattened nodules and enterolithic layers of anhydrite. These latter features match some of the characteristic fabrics found in the Holocene coastal sabkhas of the United Arab Emirates. As with the local occurrences in the Hith, the Holocene sabkhas are dominated by carbonates and are divisible into a series of lateral fades belts. These are also expressed as equivalent vertical layers. Traced from seaward to landward, or from the base of the vertical sequence upward, these facies are characterized by (1) algal mat, (2) a layer of a gypsum crystal mush (3) active anhydrite replacement of gypsum (4) anhydrite with no gypsum mush, and (5) recycled eolianite and storm-washover sediments.

ALSHARHAN, A.S. and Nairn, A.E.M. (1994). Geology and hydrocarbon habitat in the Arabian Basin: the Mesozoic of the State of Qatar: Geologie en Mijnbouw, Dordrecht, The Netherlands, v. 72, pp. 265-294.

The State of Qatar is situated in the southwestern Arabian Gulf and covers an area of about 12 000 sq km. The land portion is formed by a large, broad arch, which is part of the regional, NE-SW trending Qatar-South Fars Arch, separating two Infracambrian salt basins. The Dukhan Field on the west coast of the Qatar Peninsula, with its reservoirs in Upper Jurassic limestones, was the first oil field discovered. Since this discovery in 1940, a series of other discoveries have been made, and Qatar became a member of the Organization of Petroleum Exporting Countries (OPEC) in 1973.

Hydrocarbon accumulations are widely dispersed throughout the stratigraphic column with production from Middle Jurassic to Middle Cretaceous strata. The most prolific reservoirs are in shelf carbonate sequences and minor accumulations occur in Albian clastic sediments.

Seals, mainly anhydrite and shale, occur as formations of regional extent as well as intraformationally with smaller areal distributions. There are several stratigraphic intervals which contain source rocks or potential source rocks. Upper Oxfordian-middle Kimmeridgian source rocks were formed in an extensive, starved basin during a period of sea-level rise. They contain organic matter of sapropelic, liptodetrinitic and algal origin and have a total organic carbon content of 1 to 6%.

Both depositional environment and tectonic evolution through geologic time have influenced sedimentary facies and stratigraphic features, which controlled reservoir, source and seal characteristics and subsequent hydrocarbon generation, migration and entrapment.

ALSHARHAN, A.S. (1994). Geology and hydrocarbon occurrences of the clastic Permo-Carboniferous in the central and eastern Arabian Basin: Geologie en Mijnbouw, Dordrecht, The Netherlands, v.73, pp. 63-78.

The siliciclastic lower part of the Permo-Carboniferous in the Arabian Basin represents a cyclic transgressive and regressive unit, consisting of sandstones, shales and thin beds of argillaceous limestone. This unit crops out in small exposures in central and northwest Saudi Arabia, but is widespread in the subsurface of central and eastern Arabia. It is known as the Unayzah Formation in Saudi Arabia and in the western and southern Arabian Gulf region, and as the Haushi Group in Oman.

The Permo-Carboniferous elastics in the Arabian Basin proved to be prospective for hydrocarbons. Oil and gas were encountered in Saudi Arabia, Qatar, the United Arab Emirates (U.A.E.) and Oman:

The Unayzah Formation in the subsurface of the U.A.E. ranges in thickness from 140 to 206 m. The relatively thin upper section consists of pyritic siltstone and terrigenous mudstone with minor sandstone, whereas the lower section is dominated by a thick sequence of very fine to coarse-grained, subangular to subrounded, moderately to poorly sorted quartzitic sandstones with minor interbeds of siltstone. Minor quantities of clay minerals, plagioclase, dolomite and pyrite occur in the sandstones. The formation is interpreted to be of fluvial origin.

Six lithostratigraphic units were identified in the U.A.E. Three units have moderate to good reservoir potential, while others act as seals over these reservoirs. Porosity in the reservoir units ranges from less than 1 to 27%, and permeability from less than 1 to 75 md.

The sediments in the U.A.E. are highly affected by diagenesis. The main diagenetic events include silica cementation (which occurs as quartz overgrowths), precipitation of illite and minor kaolinite, carbonate cementation (calcite and dolomite) filling pores around the quartz grains, and locally a partial dissolution and leaching of feldspar grains.

Shebl, H.T. and ALSHARHAN, A.S. (1994). Sedimentary facies and hydrocarbon potential of Berriasian-Hauterivian carbonates in Central Arabia: In: Micropalaeontology and hydrocarbon exploration in the Middle East, Simmons, M.D. (ed.), chapter 8, pp.159-174, U.K.

The Berriasian-Hauterivian carbonates of the Sulaiy, Yamama and Buwaib Formations are described from outcrops in central Saudi Arabia. Based on microfacies analysis, the sediments are classified into standard microfacies types. The sediments were deposited under open platform, shelf-lagoon conditions. Such deposition was slightly interrupted by the pre-Buwaib disconformity. The overall depositional setting is interpreted in terms of a carbonate ramp. Regressions influenced deposition in the Early Hauterivian and in the Barremian. In the subsurface of northeastern Saudi Arabia, the Sulaiy and Yamama Formations contain good source and reservoir rocks respectively.

ALSHARHAN, A.S. and Magara, K. (1994). The Jurassic of the Arabian Gulf Basin: facies, depositional setting and hydrocarbon habitat: In Pangea: global environments and resources, Embry, A.F. (ed.), Canadian Society of Petroleum Geologists, Memoir 17, pp. 397-412, Canada.

The Jurassic succession of the Arabian Gulf region represents the progressive flooding of a stable craton by a shallow sea during a major sedimentary cycle. This cycle ended in the Late Jurassic with the stagnation of sea water and the formation of an extensive evaporitic platform over much of the region. Variation in the sedimentary facies throughout the Jurassic can be explained by eustatic sea level rise or fall, as well as by epeirogenic movements and faulting in various parts of the basin.

The Lower Jurassic was dominated by a carbonate-evaporite platform with substantial clastic influx from paleo-highs in western and southern Arabia. During the Middle Jurassic a vast marine platform became the setting for a well developed carbonate ramp in which clastic sediments rimmed the western and southern parts of the shallow sea. The sediments grade into impure carbonates and finally into pure carbonate shelf deposits. During the Late Jurassic the carbonate shelf environment became dominant and was differentiated into broad shelves and local intrashelf basins. Shelf carbonate consists of broad sheets of peloidal-oolitic grainstones and packstones, commonly dolomitic and anhydritic. Intrashelf basins contain interbedded, kerogen-rich marine lime mudstones and marls. In the latest Jurassic the shelf al sea became a sabkha rimmed by an evaporitic platform.

Middle-Upper Jurassic strata are widely known for their prolific oil production in the western and southwestern Arabian Gulf region. The limits of Jurassic production coincide closely with the limits of mature Late Jurassic source rocks present in the intrashelf basins. The Tithonian Hith anhydrite effectively provides regional seals for the porous, grain-rich Middle and Late Jurassic reservoirs in the oilfields of Saudi Arabia, Bahrain, Qatar and offshore Abu Dhabi. These reservoirs were charged with hydrocarbons from underlying Late Jurassic kerogen-rich basinal sediments. It is this source-reservoir-seal combination which constitutes the world's richest single oil deposit (e.g. Ghawar Field, Saudi Arabia).

Whittle, G.L. and ALSHARHAN, A.S. (1994). Dolomitization and chertification of the early Eocene Rus Formation in Abu Dhabi, UAE: Sedimentary Geology, Elsevier, The Netherlands, v.92, pp. 273-285.

The Early Eocene carbonates of the Rus Formation in the Jabal Hafit area near Al Ain, United Arab Emirates, were sampled to study their diagenetic history. These carbonates were cyclically deposited in a shallow water environment, alternating with marls or marly limestones, and are characterized by extensive dolomitization and chertification (with associated glauconitization). The cyclic nature of sedimentation suggests that deposition was eustatically driven. The diagenetic history of the limestones proceeded through the following path: (1) marine cementation of allochems concomitant with formation of micrite envelopes; (2) micritization of peloids, ooids and skeletal grains; (3) neomorphism of formerly high Mg-calcite and aragonite grains to low Mg-calcite; (4) partial to complete dolomitization; (5) partial chertification of both calcite and dolomite; (6) glauconitization of chert; (7) fracturing during shallow burial; and (8) precipitation of late coarse calcite spar or mosaic and saddle (baroque) dolomite spar filling voids and fractures. Porosity is virtually nil in these rocks except for infrequent unfilled fractures, vugs and oomolds, due primarily to cementation and chertification.

Biogenic grains are abundant in the limestones with Nummulites sp., Alveolinid and miliolid foraminifera and crinoid ossicles and other echinoderm fragments being most common. The tests of Nummulites sp. are commonly replaced by length-fast chalcedony fibers which are occasionally later replaced by glauconite. Spherulitic and zebraic chalcedony and, more rarely, megaquartz, occur as void-filling cements and fringing chalcedonic fibers frequently rim the tests of skeletal grains. All except the fringing chalcedonic fibers were subject to glauconitization.

Prior to the chertification process is an extensive dolomitization period. Rhombic and sucrosic dolomite partially to completely replaced calcite at a relatively early diagenetic stage. Silicification caused the replacement of calcite by chert at a much more rapid rate than that of dolomite which was found "floating" within a chertified matrix. Fractures occurred both early and late in the Rus and are usually filled by a late coarse mosaic calcite spar (or coarse mosaic and saddle dolomite spar in completely dolomitized samples).

ALSHARHAN, A.S. and Nairn, A.E.M. (1993). Carbonate Platform Models of Arabian Cretaceous Reservoir: In Cretaceous Carbonate Platforms, Simo, J.A.T., Scott, R.W., and Mase, J.P. (eds.), American Association of Petroleum Geologists Memoir 56, Chapter 15. pp. 173-184, U.S.A.

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 intracra-tonic basins, their location presumably related to the ecology of the bivalves. A brief outline of the stratigraphy based on the reviews of Munis (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.

ALSHARHAN, A.S., Nairn, A.E.M. and Mohammed, A. (1993). Late Palaeozoic glacial sediments of the southern Arabian Peninsula: their lithofacies and hydrocarbon potential: Marine and Petroleum Geology, U.K., v.10, pp. 71-78.

Evidence of Late Palaeozoic glaciation is known in the southern Arabian Peninsula, in Yemen, Saudi Arabia and Oman. Palynological assemblages date these beds as Late Carboniferous to Early Permian (Sakmarian). The lithofacies consist of diamictites, varvites with dropstones, sandstones, siltstones and shales, suggesting depositional environments ranging from grounded tillites to glacio-lacustrine to marine. Oman oil is reported to be trapped primarily in the sands (in Haushi Group elastics), which are sealed by the Cretaceous Nahr Umr shales. The source is presumed to lie in the Late Precambrian marine algal limestones.

ALSHARHAN, A.S. (1993). Asab Field - United Arab Emirates Rub al Khali Basin, Abu Dhabi: In Structural taps VIII, Treatise of Petroleum Geology, Atlas of Oil and Gas Fields, Foster, N.H. and Beaumont, E.A.(eds.), American Association of Petroleum Geologists, pp. 69-97, U.S.A

Abu Dhabi is the largest emirate in the United Arab Emirates (U.A.E.), with a total area of about 25,500 mi^2 (66,000 km^2), and contains the largest oilfields in the U.A.E., such as Bab, Bu Hasa, Zakum, Umm Shaif, and Asab. Asab field is approximately 95 mi (150 km) southwest of Abu Dhabi Island, 55 mi (85 km) southeast of Bab field and 60 mi (100 km) east-southeast of Bu Hasa field. The field lies within the limits of the concession granted in 1939 to Petroleum Development Limited (now Abu Dhabi Petroleum Company or ADCO). The terrain is mostly sand dunes separated by flat sand corridors and occasional very small, inland sabkha flats.

Asab is one of the giant onshore fields producing from Lower Cretaceous carbonates, with estimated reserves of 10.5 billion barrels of oil. It is located on the north side of the Rub Al Khali basin, on the eastern shelf of the Arabian platform. In this setting, thick sedimentary deposits—primarily carbonates-accumulated, and intermittent tectonic movement resulted in relatively gentle folding, faulting, and salt movements.

ALSHARHAN, A.S. (1993). Bu Hasa Field-United Arab Emirates, Rub Al Khali Basin, Abu Dhabi: In Structural traps VIII, Treatise of Petroleum Geology, Atlas of Oil and Gas Fields, Foster, N.H. and Beaumont, E.A. (eds.), American Association of Petroleum Geologists, pp. 99-127, U.S.A.

Bu Hasa field is located in Abu Dhabi, United Arab Emirates, approximately 30 mi (50 km) southwest of the Bab field. The field is an ovate anticline with a north-south major axis about 22 mi (35 km) long. The field lies within the limits of the concession granted in 1939 to Petroleum Development Limited, now known as Abu Dhabi Company for Onshore Oil Operations (ADCO). The terrain is mostly sand dunes separated by flat sand corridors and occasional very small, inland sabkha flats.

Bu Hasa is a giant onshore field producing from Lower Cretaceous rudist buildups, with estimated reserves of 20 billion bbl of oil. It is located on the northern side of the Rub al Khali basin, on the eastern shelf of the Arabian platform. In this setting, thick sedimentary deposits, primarily carbonates, accumulated and were deformed by intermittent tectonic movements that resulted in relatively gentle folding, faulting, and salt movements.

ALSHARHAN, A.S. (1993). Facies and sedimentary environment of the Permian carbonates (Khuff Formation) in the United Arab Emirates: Sedimentary Geology, The Netherlands, v. 84, pp. 89-99.

The Late Permian to Early Triassic Khuff Formation of the United Arab Emirates is a 625-970 m thick sequence of shallow water carbonates (dolomites, limestones and dolomitic limestones with subordinate anhydrite). It can be subdivided into ten facies units distinguished on the basis of their depositional textures, that represent an overall regressive carbonate-evaporite sequence. Based on the paleoecology, sedimentary structures and lithology, four distinct depositional settings can be recognized: supratidal (sabkha), lagoon, shoal and shallow shelf. The Khuff Formation has both primary (interparticle) and secondary (dissolution vugs and intercrystalline) porosities.

ALSHARHAN, A.S. (1993). Sedimentary facies analysis of the subsurface Triassic and hydrocarbon potential in the United Arab Emirates: Facies, Germany, v. 28, pp. 97-108.

The Triassic sediments in the subsurface of the United Arab Emirates has been divided into three formations (from bottom to top): Sudair, Jilh (Gulailah) and Minjur. The Sudair Formation consists of four lithofacies units composed mainly of limestones and minor dolomites interbedded with terrigenous shaley mudstones and anhydritic dolomitic limestones were deposited in shallow marine supratidal to subtidal settings. The Jilh (Gulailah) Formation has five lithofacies units dominated by anhydritic dolomitic limestone, fine terrigenoclastic sediments and bioclastic and intraclastic limestones. The formation was laid down under lagoonal to supratidal sabkha conditions with little normal marine influence. The Minjur Formation is composed of three lithofacies units characterized by argillaceousquartzitic sandstones, shales, mudstones, dolomitic and ferruginous limestones with thin coal seams. n e w facies represent deposition in prograding delta lobes, reflecting humid continental to marginal-marine conditions.

Diagenesis plays a major role in the reservoir development in the Triassic sediments, the pores are occluded by dolomite and anhydrite. The grains are compacted, leached or cemented by marine cements. Porosity generally ranges from fair to poor with values from 6% to 9% in the carbonates and from 6% to 15% in the classics. Interparticle and vuggy porosities are the main pore types. The porosity was controlled by diagenesis, depth of burial and lithology.

No oil has been discovered so far in the Triassic sediments of the United Arab Emirates but pronounced gas shows have been reported from offshore fields. Western offshore United Arab Emirates is a promising area for potential hydrocarbon accumulations. The Triassic sediments have low to moderate source rock potential; the organic matter is mainly sapropelic kerogen, and the degree of thermal alteration ranges between mature to highly mature stages.

Kendall, C.G.St.C., Bowen, B., ALSHARHAN, A.S., Cheong, D., Stoudt, D. (1991). Eustatic controls on carbonate facies in reservoir and seals associated with Mesozoic hydrocarbon fields of the Arabian Gulf and Gulf of Mexico: Marine Geology, The Netherlands, v. 102, pp. 215-238.

Abundant subsurface data for Mesozoic and Cenozoic sections of the US Gulf Coast and the Middle East make it possible to track the relationship of shelf carbonates and evaporites (associated with minor amounts of elastics) to eustasy. Our contention is that because the sedimentary deposition for both regions was in part controlled by gentle tectonic subsidence punctuated by eustatic variations, the major hydrocarbon fields which occur here can be related to sea-level behavior at the time of deposition of the reservoir sections and their early diagenesis. With the exception of chalks, most of these carbonate hydrocarbon fields can be related to highstand system tracts and include the following:

- Keep-up reservoirs with sheet-like geometry formed when carbonate accumulation matched sea-level rise, aggrading to form shoaling-upward cycles during sea-level highstands.
- Give-up and catch-up reservoirs with lense-like carbonate geometry formed on drowned shelves during and following rapid sea-level rises, often

downslope from carbonate margins. Give-up reservoirs occur when carbonate accumulation was unable to match sea-level rise and catch-up reservoirs form where carbonate accumulation was initially unable to keep pace with the sea-level rise but then aggraded to sea-level.

- Reservoirs with the prograded discontinuous clinoform geometry of the platform margin, formed during stillstands by carbonate accumulation that not only kept up with the sea-level rise, but also advanced in a seaward direction.

Source rocks for these carbonate reservoirs are often formed during rapid sea-level rises, while the reservoir seals are usually transgressive shales, dense transgressive limestones and/or highstand evaporites.

ALSHARHAN, A.S., Nairn, A.E.M. and Shegawi, O. (1991). The Palaeozoic Sandstones of the Rub Al Khali Basin, Arabia: A Review: Palaeogeography, Palaeoclimatology, Palaeoecology, The Netherlands, v. 85, pp. 161-168.

In Southern Arabia, the Paleozoic is represented by sheets of virtually unfossiliferous siliciclastic deposits laid down in depositional environments which grade from braided stream in the south to shallow littoral in the north. Different formation names and ages have been assigned by different authors. The confusion resulting from the recovery of Late Carboniferous-Early Permian palynomorphs and the presence in some locations of Tigillites in what was believed to be the same unit is resolved here by proposing the existence in outcrop of two formations, the Cambro-Ordovician Wajid and the Permo-Carboniferous Bani Khatmah formations.
The Cambro-Ordovician Wajid Formation represents the continuation south of the Central Arabian Arch of the sand sheets found in northern Saudi Arabia and Jordan.
The Bani Khatmah Formation is proposed as the fluvial and shallow-marine deposits derived from the melting Permo-Carboniferous ice sheets.

ALSHARHAN, A.S. and Kendall, C.G.St.C. (1991). Cretaceous chronostratigraphy, unconformities and Eustatic Sea-level changes in the sediments of Abu Dhabi, UAE: Cretaceous Research, U.K., v. 12, pp. 379-401.

The Cretaceous of the United Arab Emirates is divided into three major lithostratigraphic units separated by three regional unconformities: Lower Cretaceous Thamama Group (Berriasian-mid-Aptian); Mid-Cretaceous Wasia Group (Albian-Cenomanian, possibly Early Turanian) and Upper Cretaceous Aruma Group (Coniacian-Maastrichtian). In the United Arab Emirates, because of the abundance of subsurface data, it has been possible to relate the character of the Mesozoic shelf carbonates and their associated minor elastics and evaporites to eustatic sea-level changes. The patterns of sedimentation were driven by gentle tectonic subsidence punctuated by eustatic sea-level variations. Most of the carbonates are sheets formed in response to deposition during sea-level highstands while some of the upper Lower, Middle, and Upper Cretaceous carbonates contain build-ups that caught up with the sea-level highstands following rapid marine transgressions that initially stressed deposition. Shale-rich units deposited during sea-level lowstands and transgressive phases are common in the Cretaceous sequences. They occur in the Lower Cretaceous Lekhwair Formation and Bab Member. The Middle Cretaceous includes the lowstand Nahr Umr Formation and the basinal Shilaif, while the Upper Cretaceous contains the transgressive Laffan shales.

The timing of the older unconformity at the end of the Lower Cretaceous deposition coincides with a pronounced eustatic lowering of sea-level during the middle Aptian. From the Valanginian through the middle Aptian the stratigraphy of the United Arab Emirates was a time of relative crustal stability, and reflects a steady rising of sea-level with minor fluctuations. The sea-level was relatively higher during the Middle Cretaceous. Tectonism in the form of the collision of the Omani plate with the Arabian plate, played an even greater role in controlling deposition during the Late Cretaceous but the unconformity at the end of the Late Cretaceous correlates well with a major sea-level low.

Hamdan, A.R.A. and ALSHARHAN, A.S. (1991). Palaeoenvironments and Palaeoecology of the Rudist in the Shuaiba Formation (Aptian), UAE: Journal of African Earth Sciences, Pergamon Press, The Netherlands, v.11(4), pp.569-581.

The rudists of the Shuaiba Formation (Aptian) of the United Arab Emirates are associated with five principal palaeoenvironmental zones: the shelf lagoon, the back barrier slope, the rudist barrier, the barrier foreslope and the open marine. Six principal lithofacies and five distinguishing biofacies are significant to the recognition and delineation of these palaeoenvironments. The rudist development and colonization were preceeded by the development of algal platform. The thickest and most elevated parts of this platform provided a suitable substrate for die attachment and stabilization of individual rudists. The palaeoecology and the distribution of the Shuaiba rudists are comparable to many Cretaceous rudists reported in North America, Europe and die Middle East. Different Types of rudists lived in different palaeoenvironmental zones. In general, the *Monopleuridae, Requienidae,* and *Caprotinidag* are less abundant than the *Caprinidae.* The *Monopluridae* and *Requinidae* predominate in the shelf lagoon and display a patchy distribution vertically and laterally. The main rudists framework-builders are the *Caprinidae.* They grow in the rudist barrier zone and may be found tr ansported by gravitational collapse into the back barrier slope and the barrier foreslope zones. The Shuaiba rudists are characterized by low diversity and could survive intermittent exposure and withstand fluctuations in temperature and salinity. However, the influx of argillaceous mud and the deposition of the Nahr Umr shales in Late Aptian killed off the Shuaiba rudists of the region.

ALSHARHAN, A.S. (1991). Sedimentological Interpretation of the Albian Nahr Umr Formation in the United Arab Emirates: Sedimentary Geology, The Netherlands, v.80, pp. 317-327.

In the United Arab Emirates, the Nahr Umr Formation (Albian) comprises a series of varicoloured shales, siltstones and mudstones, with increasing carbonate content toward the northern United Arab Emirates. The percentage of clay minerals in the shale ranges from *62%* to *73%,* while the non-clay fraction is dominated by calcite, quartz and traces of dolomite, feldspar pyrite, glauconite and phosphate. The formation ranges in thickness from *63* to *220* m *(200-700* ft) and forms an excellent cap rock to the major Aptian reservoirs. Geochemical studies indicate that the shales have no oil or gas generating potential; the total organic carbon content ranges from a low of *0.20%* to a high of 0.50%. These sediments were deposited in a shallow marine to distal offshore shelf setting.

ALSHARHAN, A.S., and NAIRN, A.E.M. (1990). Geology and Hydrocarbon Potential in the State of Qatar, Arabian Gulf. American Association Petroleum Geological Bulletin, vol. 74, no. 5, p. 598.

The State of Qatar is situated in the southern Arabian Gulf and covers an area of 12,000 km^2. It is formed by a large, broad anticline, which is part of the regional south-southwest-north-northeast trending Qatar-south Fars arch. The arch separates the two Infracambrian salt basins. The Dukhan field was the first discovery, made in 1993, in the Upper Jurassic limestones. Since then, a series of discoveries have been made so that Qatar has become one of the leading OPEC oil state.

Hydrocarbon accumulations are widely dispersed throughout the stratigraphic column from upper Paleozoic to Cretaceous producing strata. The most prolific reservoirs are the Permian and Mesozoic shelf carbonate sequences. Minor clastic reservoirs occur in the Albian and Paleozoic sequences.

Seals mainly anhydrite and shale, occur both infraformationally and regionally. Several stratigraphic intervals contain source rocks or potential source rocks. The Silurian shales are the most likely source of the hydrocarbon stored in the upper Paleozoic clastics and carbonates. The upper Oxfordian-middle Kimmeridgian rocks formed in the extensive starved basin during the Mesozoic period of sea-level rise. Total organic carbon ranges between 1 and 6%, with the sulfur content approximately 9%. The source material consists of sapropelic liptodetrinite and algae.

The geological background of the sedimentary facies through geologic time, stratigaphy, and structural evolution, which control source, and the subsequent timing and migration of large-scale hydrocarbon generation, are presented in detail.

ALSHARHAN, A.S., and NAIRN, A.E.M. (1990). Geology and Hydrocarbon Habitat in the Arabian Basin: the Mesozoic of the State of Qatar. Geologie en Mijnbouw, vol. 72, p. 265-294.

The State of Qatar is situated in the southwestern Arabian Gulf and covers an area about 12,000 sq km. The land portion is formed by a large, broad arch, which is part of the regional, NE-SW trending Qatar-south Fars Arch, separating two infracambrian salt basins. The Dukhan Field on the west coast of the Qatar Peninsula, with its reservoirs in Upper Jurassic limestones, was the first oil field discovered. Since this discovery in 1940, a series of other discoveries have been made, and Qatar became a member of the organization of petroleum Exporting countries (OPEC) in 1973.

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Both depositional environment and tectonic evolution through geologic time have influenced sedimentary facies and stratigraphic features, which controlled reservoir, source and seal characteristics and subsequent hydrocarbon generation, migration and entrapment.

ALSHARHAN, A.S. and NAIRN, A.E.M. (1990). A review of the Cretaceous formations in the Arabian Peninsula and Gulf; Part III, Upper Cretaceous (Aruma Group) stratigraphy and paleogeography: Journal of Petroleum Geology, v. 13(3), p. 247-265.

A historical review of the development of the stratigraphy of the Upper Cretaceous rocks in the Arabian Peninsula and Gulf provides a practical explanation for many of the different formational names. A type section is presented for the United Arab Emirates, and lithofacies variations within the region are related to this.

In Oman, the basal Laffan Formation (Coniacian, marls and shales) rests unconformably on Middle Cretaceous Mishrif Formation Carbonates, and is overlain by Ilam Formation (late Coniacian to Santonian); there is disconformable contact with marls of the Upper Campanian Fiqa Formation which grades up into shaley maris near the top and passes (?) disconformably into limestones of the Simsima Formation (Maastrichtian).

In addition to the simple model of migration of predominantly shallow-water facies belts across a shelf, the Upper Cretaceous also contains deep-water facies due to the onset of plate-margin tectonic activity which resulted in the emplacement of the Hawasina complex and the Semail ophiolites of Oman. Two carbonate/clastic transgressive cycles can be recognised in the southeastern part of the region, with general south-or southeast-shallowing facies belts.

ALSHARHAN, A.S. (1990). Geology and reservoir characteristics of Lower Cretaceous Kharaib Formation in Zakum Field, Abu Dhabi, United Arab Emirates: *In* Classic Petroleum Provinces, Brooks, J. (ed)., Geological Society Special Publication no. 50, U.K., pp. 299-316.

The Zakum oil field is an eastwest plunging anticline, located in offshore Abu Dhabi, UAE. The field was discovered in 1963 by seismic survey, and came on production in 1967 at an initial rate of 50000 bopd from the Lower Cretaceous carbonate sediments. The Zakum structure is a broad asymmetric anticlinal feature characterized by gentle dips throughout; the steepest dips occur in the north and northeast where the average dip is about 2.5°. The structure is about 45 km long and 28 km wide, and has a vertical closure in excess of 1200 ft.

At Zakum field the Lower Cretaceous Thamama Group is a thick shallow-marine carbonate sequence with an average thickness of about 2300 ft, and is divided into four formations: Shuaiba, Kharaib, Lekhwair and Habshan (in descending order). An informal reservoir-oriented classification was set up for this group. It was subdivided into six zones given a numerical notation from top to bottom (Zones I to VI).

The Kharaib Formation represent shallowing upward cycles formed in very shallow epicontinental seas. The energy level grades from low-energy subtidal to high-energy setting at or above wave base. It is characterized by dense-argillaceous pyritic bioclastic lime mudstones/wackestones, peloidal-ooidal packstones/ grainstones, dolomitic limestones and thin black shale laminae.

The reservoir quality of the formation is controlled by vertical and lateral distribution of porosity, permeability and stylolites. The porosities ranges from 5 to 28%, and permeabilities from less than 1 to 100 Md. The influence of initial environment of deposition, diagenesis and petrophysical properties on the reservoir characteristics is evaluated.

ALSHARHAN, A.S. and NAIRN, A.E.M. (1988). A review of the Cretaceous formations in the Arabian Peninsula and Gulf; Part II, Mid-Cretaceous (Wasia Group) stratigraphy and paleogeography: Journal of Petroleum Geology, v. 11(1), p. 89-112.

The stratigraphic sequence of the "Middle" Cretaceous Wasia Group in the Arabian Gulf, and the terminology used, are revised. Type sections and synonomy are established for the succession in the United Arab Emirates, and an historical introduction provides a key to the understanding of the varied formational and member names in current use.

Lithologies found in Oman include lower Nahr Umr Formation shaley strata and overlying "Wasia" limestones in the Jebel Akhdar and Wasia Limestone or Natih Formation in the oil fields. The term "Natih Formation" is commonly used for shallow shelf carbonates in central, eastern and southern Oman, but the carbonate sequence in the Fahud and Natih area cannot be recognised elsewhere in northwestern Oman where shaley and marly partings are absent - here Mauddud and Mishrif lithologies, equivalent respectively to the Natih E-G and A-D Members, are recognised, along with intraplatform basin Khatiyah (or Rumaila) limestones. The (Albian) Nahr Umr Formation lies unconformably on the Shuaiba Formation; the top of the carbonates is marked by an Early Turonian unconformity below Aruma Group shales.

Most of interior Oman was covered by Early to Mid Albian shallow marine clastics of the Nahr Umr, with minor carbonate development in the northeast; during Late Albian-Early Cenonian south-thinning shallow shelf carbonates were extensive, with localised basin-margin and basinal carbonates in the central west and northwest; extensive shelf carbonates record Cennomanian conditions south and west of the Oman mountains.

Aldabal, M.A. and ALSHARHAN, A.S. (1989). Geological Model and reservoir evaluation of the Lower Cretaceous Bab Member in the Zakum Field, Abu Dhabi, UAE: *In*: 6th Middle East Oil Show, Society of Petroleum Engineers SPE, Bahrain.

In the Zakum Field, the Shuaiba Formation (Aptian) is the upper most rock unit of the Lower Cretaceous Thamama Group, in ascending order it is divided into three zones, Thamama IA, IB and IC. The last two have been termed the Bab Member, has an average thickness of about 230 ft. and shows a diverse litho-logy. Minor changes in eustatic sea level at the time of deposition produced a major change in the lithofacies distribution across the field. These range from deep water basinal to shallow shelf sediments.

The lower part of the Bab Member (Thamama IB) is divided into three: A progradational carbonate cycle of deep water argillaceous globigirinal limestone at the base (Tar Unit), which could represent a good source rock. Above it are drowned shelf sediments of bioclastic wackestone with a moderately developed reservoir facles (IX unit). These end with a highly dolomitized unit of poorly developed reservoir facies, which forms a comparatively good seal.

The upper part of the Bab Member (Thamama IC) consists of calcareous shale interbedded with limestone of good reservoir quality. The limestone is separated into two reservoir facies units (IT & IW) and is well developed in the East, representing a shallow shelf to high energy shoal deposits (oolitic grainstone, calcareous algae, orbitolinid and skeletal debris). These sediments were transported westward and deposited over the slope of the deeper water environment and limiting the reservoir facies to the crest and eastern flank of the field.

In order to evaluate the economic potential of the sequence, all of the possible reservoir units were defined using wireline logs and petrographic description.

Facies units (IT, IW Se IX) were mapped over the field. Units IT Se IW represent a stratigraphic trap, with some later influence of structural uplift due to deep seated salt piercement. The oil accumulation in the reservoir units is restricted to the shelf and shelf edge facies. The tilted oil/water contact (OWC) is a pronounced feature of the field.

The prolific cyclic carbonate sand facies (IT & IW) as part of abroad carbonate shelf platform extend further East of Zakum Field. Subsequently, development of reservoir quality connot a potential future prospect.

ALSHARHAN, A.S. (1989). Petroleum Geology of the United Arab Emirates. Journal of Petroleum Geology, v. 12(3), pp. 253-288, U.K.

The Permian to Holocene sediments of the United Arab Emirates consist mainly of epeiric shelf carbonates, associated with minor elastics and evaporites, reflecting major cycles of transgression and regression. These were deposited on the eastern margin of the Arabian Shield, which lay along the southern margin of the Tethys Ocean during the Mesozoic-Cenozoic eras. Sedimentation patterns were controlled by prominent regional structural features, epeirogenic movements and/or sea-level fluctuations.

The tectonic history of the UAE in the Mesozoic-Cenozoic is connected with the opening (Triassic) and closure (Upper Cretaceous-Paleogene) of the southern Neo-Tethys Ocean.

The distinctive structural style, together with the tripartite development of source-reservoir-seal, has produced in the UAE one of the world's richest Jurassic — Cretaceous oil habitats. Significant oil discoveries have also been made in the Permian; Middle and Upper Jurassic; Lower- Middle-Upper Cretaceous and Oligo-Miocene carbonates.

Two main source rocks have been identified. One is the Upper Jurassic Diyab/Dukhan Formation, which supplies the most prolific reservoirs in the Upper Jurassic (Arab Formation) and Lower Cretaceous (Thamama Group). The other is the Middle Cretaceous Shilaif/Khatiyah Formation, which feeds both Mishrif and Simsima reservoirs. Other minor potential source rocks have also been identified in the study area.

There are two principal sealing formations — the Hith Anhydrite and the Nahr Umr shale; these are the main seals for the oil and gas accumulations in the underlying Arab Formation and Thamama Group, respectively. Secondary seals and barriers also exist in the stratigraphic sequence.

ALSHARHAN, A.S. and Williams, D.F. (1988). Petrography and stable isotope of baroque dolomite from the Shuaiba Formation, Abu Dhabi, UAE: Journal of African Earth Sciences, Pergamon Press, The Netherlands, v. 6(6), pp. 881-890.

Integration of petrographic and stable isotopic analyses of dolomite from the reefal f acies of the Lower Cretaceous Shuaiba Formation of Abu Dhabi, indicates two types of dolomites: host (very fine to medium crystalline dolomite formed in a meteoric-marine mixing zone) and baroque (white, coarsely crystalline dolomite). The baroque dolomite is characterized by coarsely crystalline mosaics of anhedral to subhedral crystals with undulose extinction, curved crystal faces and cleavage planes, and abundant inclusions. Baroque dolomite from this formation was precipitated in veins and narrow solution channels and is commonly composed of coarse bladed crystals, sometimes fan-shaped toward the center, precipitated as void filling cements that partially occlude porosity. Analysis of the formation of water chemistry and stable isotope for the dolomite of the Shuaiba Formation reveals that it probably formed by mixing seawater or meteoric water in the subsurface, with interstitial brines derived from halite-bearing evaporites. Also, oxygen isotope analyses (<5^{ls}O PDB values range from -4.8 to -9.6%o and <5^{13}C PDB values range from 2.4 to 4.9%o) suggest that baroque dolomite formed at temperatures ranging from 67 to 112°C.

ALSHARHAN, A.S. (1987). Geology and Reservoir Characteristics of Carbonate Buildup in Giant Bu Hasa Oil Field, Abu Dhabi, United Arab Emirates. Geology and reservoir characteristics of the carbonate buildup in Giant Bu Hasa oilfield, Abu Dhabi, U.A.E. The American Association of Petroleum Geologists Bulletin, V. 71, No. 10, p. 1304-1318.

Bu Hasa field in Abu Dhabi was the first giant oil field in the Arabian Gulf to produce from the Lower Cretaceous Shuaiba Formation (Aptian). The field has a productive area of about 155,673 ac (63,047 ha.) and 12.6 billion bbl of oil reserves. The formation is composed mainly of rudistid and algal sediments, rudistid mounds having overlain and built up the topography of an algal platform. The position and elevation of the platform edge, combined with rising eustatic sea level, created a tendency toward both vertical and lateral growth, and regulated the form and distribution of the rudist accumulation.

The Shuaiba Formation has good reservoir quality ranging in porosity from 18-25% and with average permeability exceeding 100 md. Nine reservoir units (A-I), classified by their porosity, permeability, and lithology, can be clearly defined from the logs.

Eleven main lithofacies have been defined in the Shuaiba from detailed core descriptions. These lithofacies were deposited in three main phases. The earliest phase consisted of chalky mud-supported sediment with some algal colonies, followed by a middle phase characterized by a thick algal platform. During this stage of deposition, a shallow-water carbonate platform developed over the south and central part of the field, grading into deeper, open-marine sedimentation toward the north. The late phase was characterized by rudistid buildups (mainly caprinids and caprotinids). The growth of the thick algal platform in the south and central areas controlled the initial distribution of the main rudistid buildup; toward the north, small rudistid reefs are sparsely developed and present only in the latest stage on high-energy shoals.

The Bu Hasa field is an elongated domal anticline structure, located in onshore Abu Dhabi, United Arab Emirates, approximately 37 mi (60 km) south of the Arabian Gulf (Figure 1), and is operated by the Abu Dhabi Company for onshore operation (ADCO), The field was discovered in 1962 using seismic data and is currently producing from some 200 wells from a reservoir in the Aptian Shuaiba Formation. This formation was originally defined by P. M. Rabanit (1951) in an unpublished report for the Iraq Petroleum Company (cited in Van Bel-len et al, 19S9) for a succession of Aptian sediments and the name is now widely used in the Arabian Gulf countries.

The Shuaiba Formation (Figure 2) is the principal oil-bearing horizon in the Bu Hasa field, with a maximum thickness of 487 ft (148 m), and a pay thickness ranging from 230 to 320 ft (70 to 98 m). The formation is the uppermost unit of the Lower Cretaceous Thamama Group and is characterized by algal and rudistid, carbonate, platform-margin limestones.

The contact between the Shuaiba Formation and the overlying Nahr Umr Formation is an unconformity (Murris, 1981; Alsharhan, 1985a, b) where the irregular and bored surface of the Shuaiba is overlain by pyritized and glauconitic shales of the lowermost Nahr Umr Formation, as observed in cores and clearly demonstrated by Alsharhan (1985a).

The contact between the Shuaiba Formation and the underlying dense limestone of the Kharaib Formation is marked by **Orbitolina** wackestones and packstones, with abundant glauconites occurring in wavy layers in the uppermost part of the limestone.

ALSHARHAN, A.S. and KENDALL, C.G. St. C. (1986). Precambrian to Jurassic rocks of the Arabian Gulf and adjacent areas: their facies, depositional setting and hydrocarbon habitat: American Association of Petroleum Geologists Bulletin, v. 70(8), p. 977-1002.

The first sediments to onlap the metamorphosed Precambrian Arabian shield were Infracambrian (Proterozoic) to Middle Cambrian carbonates, clastics, and evaporates. The oldest Arabian reservoir rocks occur in the Precambrian to lower Paleozoic Ara salt of the Huqf Group, which forms the Birba field of Oman. The Middle Cambrian sequence was followed by Late Cambrian through Early Permian marine sandstones and continental to littoral siltstones and variegated shales. The first commercial oil discovered in the Arabian Gulf region occurs in fluvial sands of the Ordovician to Permian Haima and Haushi Groups of the Marmul field in south Oman. These strata are also productive in other fields and are sealed by unconformable contact with the Al Khlata Formation or beneath shale of the Albian Nahr Umr Formation. The deeply buried kerogen sediments of the Huqf Group to the southeast are believed to be the source rocks for these fields of south Oman.

The Late Permian to Triassic deposits of the Arabian Peninsula are mainly widespread carbonates and evaporates that were deposited during a period of relative tectonic stability. Their deposition on an epeiric shelf was punctuated by a series of transgressions and regressions. Significant gas reserves have been proven in deep wells in the Arabian Gulf. These wells penetrate large deep structures in the Permian Khuff shelf carbonates. These carbonates have developed secondary porosity and lie beneath interbedded shale and dolomites of the Sudair or Suwei Formation. The source of gas in the Khuff is unknown but could be in more deeply buried Silurain formations. The large deep structures of the Khuff are considered to be among the most attractive for gas potential in the region today.

The stable-shelf depositional environment established during the Permian and Triassic continued through the Mesozoic. Jurassic rock units of the Arabian Gulf formed a sedimentary megacycle of epeiric shelf carbonates. These include relatively deep-water mudstones and wackestones to shallow-water grainstones and packstones with the greatest facies variations occurring in the post-Dhruma to Arab "D" rocks. Some of the best and most extensive reservoirs of the area occur in the primary and secondary porosity of the Upper Jurassic Arab Formation, and in the Middle Jurassic Araej and Dhruma Formations of Saudi Arabia, Qatar, and Abu Dhabi.

In the Dhofar, the late Permian Khuff Group is the youngest unit preserved; in the western interior and in the Musandam the Khuff or its equivalent units (Bih, Hagil) of the Rus Al Jibal Group are the oldest - the succession is complete in the Musandam but in the interior there is a gap throughout the Upper Cretaceous between the Jihl and Marrat Formation.

The sources for hydrocarbons in these Jurassic sediments are thought to be in the Dhruma and lower Hanifa Formation (Diyab equivalent) of the gulf area in general. The Jubailah is a source in Qatar and some of the offshore gulf. The most common seals are the argillaceous carbonate at the top of the Dhruma and the Hith anhydrite, the latter also marking the termination of Jurassic deposition across the Arabian platform. The Upper Jurassic "cycles" of marine limestones and anhydrites of the Arab and Hith Formations accumulated in response to changes of sea level caused either by regional epeirogenic movements or by eustasy.

ALSHARHAN, A.S. and NAIRN, A.E.M. (1986). A review of the Cretaceous formations in the Arabian Peninsula and Gulf; Part 1, Lower Cretaceous (Thamama Group) stratigraphy and paleogeography: Journal of Petroleum Geology, v. 9(4), p. 365-391.

This paper is a review of the standard stratigraphic column accepted by many workers for the Lower Cretaceous (Barremian-Aptian) of the Arabian Gulf. Type sections, synonymy and summary palaeontological details are included. A historic introduction provides an explanation of the profusion of formational and member names. The observed facies variation in the region, both vertical and laterally, can best be understood in terms of the migration of pre-dominantly shallow-water carbonate facies-belts across a shell Two, predominantly carbonate, cycles can be recognised, with the maximum development of the marginal clastic facies occurring within the upper cycle. A series of palinspastic maps traces changes throughout the Lower Cretaceous.

The major lithostratigraphic units recognised in Oman are classified into the Kahmah Group: Upper Jurassic (Tithonian) Rayda, passing up unconforrnably to Salil and its transgressing lateral equivalent Habshan (Valanginian-basal Hautervian) grading up into Lekhwair (Hautervian-mid-Barreminian) which in turn passes (?) paraconfonnably into Kharib (midBarremenian-top Aptian). Albian Nahr Umr Shale of the Wasia Group unconformably overlies the Kahmah Group.

ALSHARHAN, A.S. (1985). Depositional environments reservoir units evolution and hydrocarbon habitat of Shuaiba Formation (Lower Cretaceous) of Abu Dhabi, UAE: American Association of Petroleum Geologists Bulletin, U.S.A., v. 69, pp. 899-912.

The Shuaiba Formation (Aptian) is a thick, porous shelf carbonate, present in the subsurface over much of the Arabian Gulf. It is the uppermost formation of the Thamama Group (Lower Cretaceous), and is overlain by the Nahr Umr Formation (Albian) and overlies the Kharaib Formation (Barremian). The formation is divided into nine reservoir units, A to I (from the base upward). Reservoir units A, B, and C represent calcareous algal platform sediments showing some open-marine influence. They are dominated by chalky lime mudstones to wackestones with abundant Codiacian green algae *(Bacinella irregularis* and *Lithoco-dium aggregatum)* and stylolite seams. Reservoir units D and F are deeper open-marine shelf facies dominated by dense, argillaceous, lime mudstones to wackestones which are burrowed and bioturbated. Reservoir units G and I represent lagoonal facies dominated by dense, argillaceous, wackestones to packstones, which are sparsely fossiliferous and commonly stylolitic. Reservoir unit H represents a shallow-water, coarser grained shelf limestone containing abundant rudists, algae, orbitolinids, and other foraminifers. Reservoir unit H_0 represents a shoal facies characterized by wackestone to packstone sediment with abundant *Orbito-lina* and scattered rudist debris and other foraminifers. In northeast and southeast Abu Dhabi, the basinal Shuaiba equivalent (Bab Member) was deposited under slightly deeper, quieter marine conditions, and is dominated in parts of the section by dense, argillaceous lime mudstones and shaly wackestone, and calcareous shale intervals.

The major reefal Shuaiba buildup in Abu Dhabi trends northwest-southeast. It is in this trend that the major oil fields (Shah, Bu Hasa, and Zurarah-Shaybah) were discovered and from which some wells produce in western Abu Dhabi (e.g., Ruwais-2). Hydrocarbons also occur outside of by an unusual pre-reefal growth of orbitolinids, rudists, and algae. An isolated buildup (patch reef) consisting of coralgal boundstones, encountered in Jam Yaphour and Zabbara fields, may represent organic growth over either a rising salt structure or an uplifted zone formed by deep-seated faults.

Geochemical studies reveal that the main source for the Thamama oils are the Upper Jurassic Dukhan Formation (onshore Abu Dhabi) or Diyab Formation (offshore Abu Dhabi), however, some Shuaiba source rocks may have existed in intrashelf basinal areas in the upper Thamama zone. The Nahr Umr Shale acts as a seal for the Shuaiba reservoir in this area.