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Basin Analysis of the Late Cretaceous Sediments in United Arab Emirates

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Abstract: The Late Cretaceous Simsima Formation has been proved to be one of the most prolific reservoirs in the Arabian Basin, but still needs more investigations to be ultimately exploited.This promising formation has been subjected to a comprehensive study by various geologic disciplines to build up an adequate basin model for such formation. The study revealed that the Late Cretaceous Simsima Formation could be classified into two facies. These are Planktonic Foraminiferal Biomicrite (open marine source rock facies outcropped at Jabal Qarn El-Barr); and Rudistids Algal Foraminiferal Biomicrite (shallow marine reservoir rock facies exposed at Jabal Buhays and Jabal Malaqet) facies. This facies distribution indicates that the Late Cretaceous sea deepened towards the NNW of UAE (Jabal Qarn El-Barr section). X-Ray diffraction analysis ensured the occurrence of open marine minerals (kaolinite and montmorillonite) within the Late Cretaceous Simsima Formation that outcropped at Jabal Qarn El-Barr. So, the Late Cretaceous Simsima Formation could act as an effective source rock (newly approved) in the northern part of UAE and a prolific reservoir rock in the other parts of UAE. The geochemical analyses also supported the occurrence of source rock facies (high TOC varies from 0.4 to 1.3 wt% and low Pr/Ph ratio) within the Late Cretaceous Simsima Formation. The petrophysical and petrographical investigations proved intercrystalline, vuggy and fracture porosity (varies from 0 to 31%) and permeability ranges from 0 to 850 md for the reservoir facies of Late Cretaceous Simsima Formation. Moreover, the occurrence of anticlinal and thrusted structures (almost acting as sealing faults) within the fractured limestones of the Late Cretaceous Simsima Formation would enhance the probability for hydrocarbon entrapment within these rocks.

Key words:

INTRODUCTION

The Late Cretaceous is one of the most significant periods in the geological history of the Arabian Peninsula, in view of the major structural and tectonic events of this age which have affected the region Glennie *et al*. (1974); Lippard *et al*. (1986); Searle and Cox (1999). As a result of this tectonic activity, the stratigraphic sequence records a greater complexity of facies changes than those pertaining to Early and mid-Cretaceous times Alsharhan and Nairn (1990). The outcrops of the Upper Cretaceous Simsima Formation in the United Arab Emirates are restricted in its eastern part, mainly in two localities (Fig. location map). The first is the eastern side of Al-Ain area, particularly in Gebel Malaqet and Gebel Mundassah. The second in Al-Sharjah Emirates, within El-Faiyah fold belt and the northwestern hills of Qarn El Barr. These structurally high mountains represent the western foot-hills of the northern Oman Mountains which were originated on the eastern part of the Arabian Plate at the end of the Cretaceous (Glennie *et al*., 1973 & 1974). These rocks are the oldest units lying unconformably upon the Semail Ophiolite and folded, thrusted Hawasina and Sumeini groups of Permian-Late Cretaceous age Glennie *et al*. (1974); and Wilson (2000). The stratigraphy, facies and faunal content of the Upper Cretaceous Neoautochthonous sequence of the Northern Oman Mountains have been discussed in numerous papers, including Glennie *et al*. (1974); Hamdan (1990); Alsharhan and Kendall (1991); Anan (1993); Noweir and Eloutefi (1997); Noweir *et al*. (1998); Sayed and Mersal (1998); Boukhary *et al*., (1999); Alsharhan *et al*. (2000); Noweir and Abdeen (2000); Abd-Allah (2001) ; Abdelghany (2003, 2006) and Baghdady *et al*. (2003, 2008).

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Aim of the Work:

This study is ultimately aimed at finding new hydrocarbon prospective horizons and /or areas to be added to the petroleum map of United Arab Emirates. This could be carried out via an integration process for all the collected multi-specialization data.

MATERIALS AND METHODS

Five well-exposed stratigraphic sections of the Campanian- Maastrichtian strata of the Simsima Formation were measured and sampled in the United Arab Emirates (Fig .1). These are Jabal Qarn El Barr, Jabal Buhays (Al Faiyah Range Mountains), Jabal El Rawdah, Jabal Malaqet and Jabal Mundassah. Forty rock samples were collected from four of the studied stratigraphic sections (Fig. 2) to study foraminifera, microfacies and petrographical analyses. Some of the samples were dyed with blue epoxy to investigate the porosity and permeability. Five samples were collected to study the palynomorphs of the Simsima Formation.

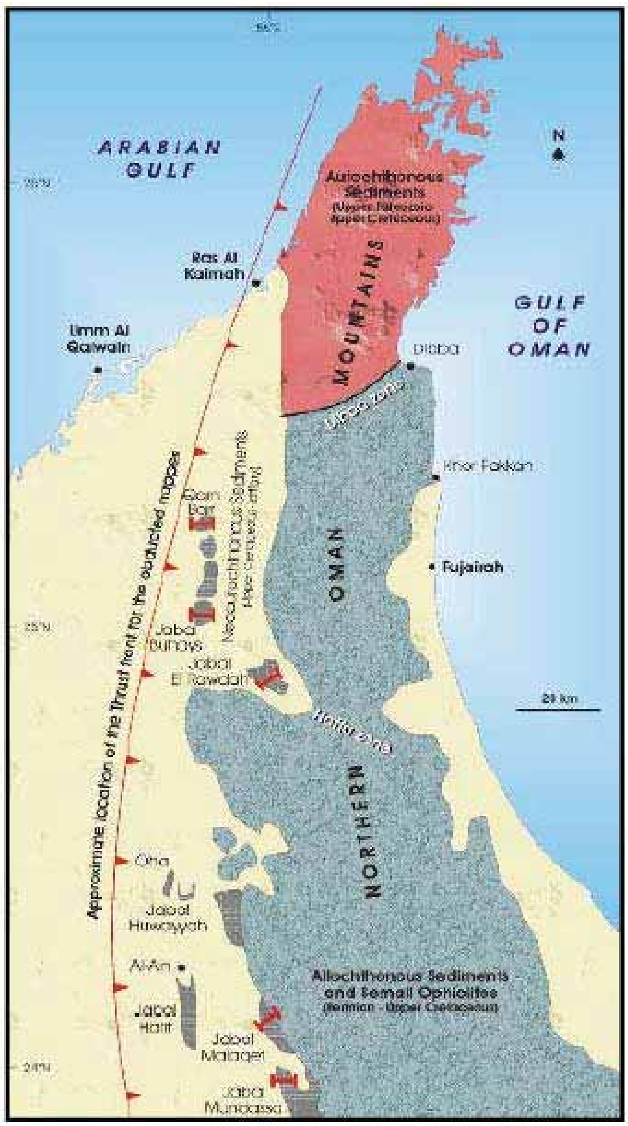

Fig. 1: Regional map for the Northern Oman

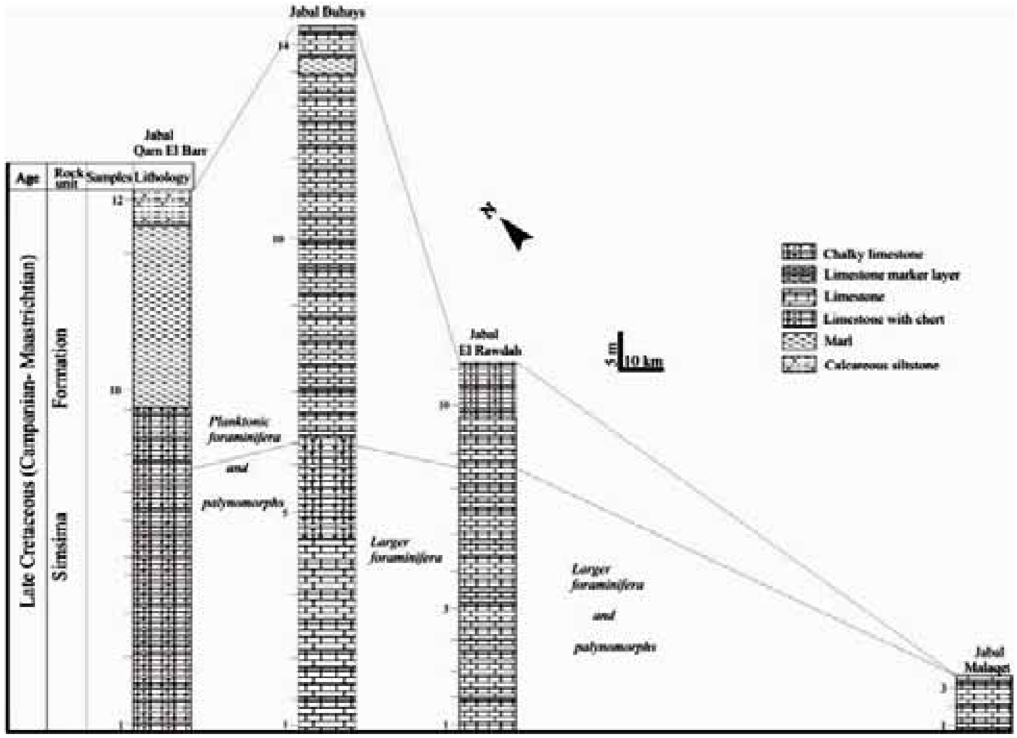

Fig. 2: Correlation between the studied setions based on the distribution of thestratigraphy important microfossils of the simsima Formation

Two samples from Jabal Mundassah, two Mountains showing the location of the studied samples from Jabal Malaqet and one sections; modified after Warrak (1996). Smple from Jabal Qarn El Barr. Standard separation of the palynomorphs (spores, pollen and dinoflagellates). Two slides from each sample were prepared using glycerin jelly. The representatives forms are photographed palynological techniques are applied for except the badly preserved ones. Samples collected from the Simsima carbonates were examined microscopically before and after staining with Alizarin Red-S. The rocks were classified according to Dunham (1962) and Folk (1959, 1962). X-Ray diffraction analysis was done for the bulk samples and clay fractions selected from this rock unit in Jabal Qarn El Barr. To identify these clay minerals, the carbonates constituents were removed by using dilute HCl (5%). The sand and silt sized fractions of the insoluble residue were separated from the clay fraction by wet sieving and pipette methods. Three mounts (air dried, glycolated and heated) of clay fractions were analyzed with X-ray diffraction to identify their clay mineral species. X-ray diffraction analysis was conducted on the samples using a Philips diffractometer (model PW/1 840) with Ni filter, Cu –Kα Å). Instrument settings were 40 Kv and 30 mA potential, scanning speed of 0.02° /second and the 2 ranged between 2° and 60°. Mineral identification was achieved by comparing the obtained data with those published by the American Society of Testing and Materials (ASTM). The relative proportions of the various mineral species were semi-quantitatively determined based on the intensities of their strongest diffraction peaks. The field mapping of the study area was carried out in 2 field seasons. The vertical aerial photographs (scale 1:25,000) and space images (scale 1:50,000) were preliminarily studied and followed by reconnaissance field trips to recognize the different mappable rock units and observe some of the main structural elements. This was followed by detailed field and stereoscopic studies. The field work focused on marking the rock unit' contacts and the traces of the structural elements and the measurement of the bedding data. The aerial photographs, space images and topographic maps (scale 1:50,000) were used as base maps in the detailed field work. The collected data were compiled on the topographic map to constitute the geologic map of the study area. Geologic cross-sections were constructed orthogonal to the main structural elements to show their style and subsurface extensions. Total organic carbon values are obtained by treating 10g of crushed rock sample with hot HCL 10% Concentration to remove carbonates. The washed residue is filtered on to a glass fiber, pad and ignited in a Leco carbon analyzer CS-200 for measuring TOC wt % and Sulfur %. Blanks and standards re run as routine and where values from duplicated samples do not concur within strict accuracy limits, they are rerun. A maximum of 50g of crushed sample is extracted for a minimum of 12 hours in a Soxhlet apparatus using laboratory redistilled Chloroform CHCL3. The solvent and the more volatile components (approximately up to n-$C1_5$) are lost by evaporation in an air flow and the resulting total extract is weighed, dissolved in hexane and separated into alkane (saturate) hydrocarbon, aromatic hydrocarbon, resins and asphaltene (polar) fractions by silica adsorption chromatography. Fractions of the extract, separated by column chromatography are retained for further analysis by gas chromatography or for stable carbon isotope determination. A portion of the Soxhlet extract is eluted with hexane through a short silica column to yield the saturate hydrocarbon fraction. This fraction is evaporated in a stream of dry nitrogen at room temperature. A small portion of the fraction is then taken up in hexane and introduced into a 25 meter, Vail-coated, open tubular glass capillary column coated with oven, or equivalent, mounted in a 3800 Varian gas chromatograph which is temperature programmed from 50ºC to 3 25ºC at 5oC per minute. Chromatograms are inspected for the distributions of n-alkanes, and the presence and abundance of isoprenoids (particularly pristane and phycane), the ratios pristine: phytane and pristine n - C17, and Carbon Preference Index (CPI) values are calculated. Kerogen concentrates for microscopic examination are prepared using standard palynological procedures but omitting oxidation or acetolysis. Acid maceration involves the use of hot hydrochloric acid to remove carbonates hot 60% hydrofluoric acid to remove or break down silicates. Mineral residues are separated from the kerogen by a combination of ultrasonic vibration and zinc bromide flotation. All the exposed potential reservoir rocks have been evaluated via comprehensive petrophysical and petrographical an alyses. This may include: estimation of reservoir porosity and permeability (through liquid permeameter, gas permeameter, gas porosimeter, capillary pressure …etc), and determination of reservoir diagenesis through microscopic examination. Materials required include surface plug samples and subsurface core samples if available

RESULTS AND DISCUSSION

3.1 Stratigraphy:

The Simsima Formation was first described by Glennie *et al*. (1974). Due to the inaccessibility of the type section, Nolan *et al*. (1990) designated Jabal Al Faiyah section, on the western side of the Northern Oman Mountains (19km northwest of Jabal El Rawdah) as an alternative surface type -section for this formation. The Simsima Formation unconformably overlies the Qahlah Formation of Early Maastrichtian age, which has a variable thickness of conglomerates; therefore, this may be as effect of the formation paleotopography of the Semail Ophiolite during the deposition of this Abdelghany (2006). The Simsima Formation unconformably underlies the Muthaymimah

Formation, which appears to be of Paleocene to (Middle?) Eocene age. Alsharhan *et al*. (2000) subdivided the Simsima Formation in the eastern side of the UAE into a Lower Member and an Upper Member. The Lower Member in the Qarn El Barr section (Fig. 2) consists of chalky limestone with chert bands and nodules of 50m thick. This chalky limestone is rich in planktonic and benthonic foraminifera. This member is 94m thick. at Jabal Buhays, 38m thick at Jabal El Rawdah and 7m thick at Jabal Malaqet. It consists of yellowish white, algal, orbitoidal limestone rich in macrofossils (e.g. rudists, corals and echinoids) as in (Fig.3). The Upper Member in the Jabal Qarn El Barr section is 28m thick and consists of marl rich in planktonic and benthonic foraminifera and topped by calcareous siltstone. In the Jabal Buhays and Jabal El Rawdah sections, this member is composed of nodular, bioturbated orbitoidal dolomitic limestone, and attains a thickness of 46m at Jabal Buhays, 8m at the Jabal El Rawdah, but is missing from the Jabal Malaqet section, (Fig. 2). At Jabal Mundassah the Simsima Formation consists mainly of limestone and marl with some conglomerates interbeds and attains about 100m thick. In the Jabal Qarn El Barr section, the late Campanian to Maastrichtian age assignment of the Simsima Formation is based on planktonic foraminifera and some characteristic palynomorphs. In the other sections (Buhays, El Rawdah Malaqet and Mundassah), the age determination of the Simsima Formation is based on the occurrence of the larger foraminifera and some diagnostic Late Cretaceous palynomorphs.

Biostratigraphy:

The biostratigraphic study carried out resulted in recognizing three planktonic foraminifera biozones, seven species belonging to two distinct orbitoidal horizons of larger foraminifera, twenty four species of spores and pollen and eight species of dinoflagellates cysts in addition to black to brown wood remains, cuticles, plant tissues, fungal spores and undetermined palynomorphs.

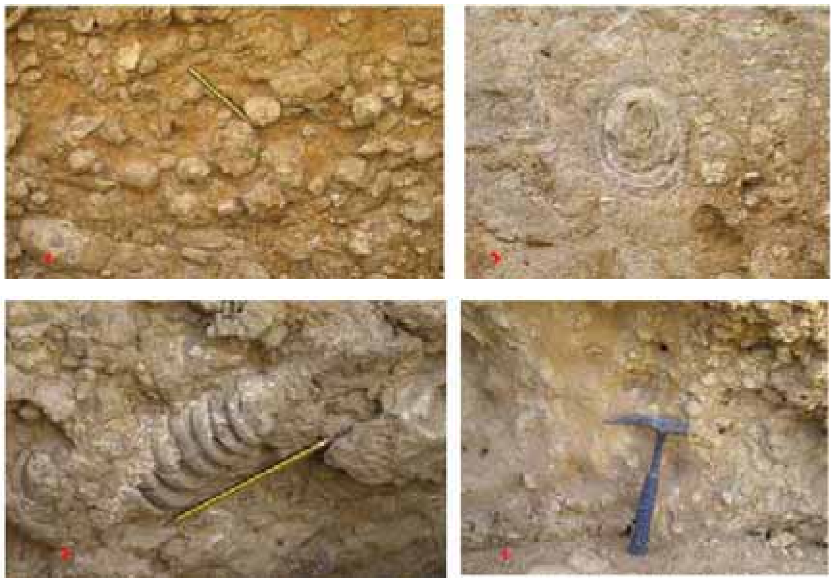

Fig. 3: Field photographs showing the characteristic fossils of the Simsima Formation in the sections studied. 1-4 Showing the characteristic fossils (*Orbitoides*, calcareous red algae and mollusc shell fragments).

Planktonic Zones Are Described in Plate I as Follows:

The Simsima Formation of the Jabal Qarn El Barr section yielded numerous planktonic foraminiferal species, especially those belonging to genera *Heterohelix* and *Globotruncana.* Three planktonic foraminifera biozones are described in Plate I as follows:

Zone # I:

Globotruncana aegyptiaca Interval Zone (Late Campanian), this zone includes only the basal part (18m thick) of the Simsima Formation in the Qarn El Barr section, while its upper boundary is indicated by the first appearance of *Gansserina gansseri.* The associated species in this zone include *Globotruncana rosetta.* The data presented herein supports the proposed late Campanian age for the basal part of the Simsima Formation at Qarn El Barr section.

Zone # II:

Gansserina gansseri Interval Zone (Late Campanian to Middle Maastrichtian), this zone occupies the middle part of the Simsima Formation and is 1 7m thick in the Qarn El Barr section. The lower boundary of the zone is indicated by the first appearance of *Gansserina gansseri,* while its upper boundary is indicated by the first appearance of *Abathomphalus mayaroensis.* The associated species in this zone, *Contusotruncana fornicata, Globotruncana orientalis, G.* cf. *insignis, Globotruncanita conica, G. stuarti, Globotruncanella minuta* and *Globotruncanella petaloidea.*

Zone # III:

Abathomphalus mayaroensis Partial Zone (Late Maastrichtian), this zone occupies the uppermost 34m of the Simsima Formation in the Qarn El Barr section. The lower boundary of this zone is determined by the first appearance of *Abathomphalus mayaroensis,* while the upper boundary is placed at the last occurrence of globotruncanids for example, *G. aegyptiaca* and *G. havanensis.* The associated species in this zone include *Rugoglobigerina macrocephala.*

Larger Benthonicforaminifera Biozones:

The present study reveals several species of larger foraminifera in the shallow carbonate facies of the Simsima Formation. These species include *Loftusia morgani; Orbitoides apiculata; Omphalocyclus macropora; Sulcoperculina dickersoni, Siderolites calcitrapoides; Orbitoides media* and *Lepidorbitoides minor.* This fauna allows the subdivision of the Simsima Formation into two distinct orbitoidal horizons. The lower

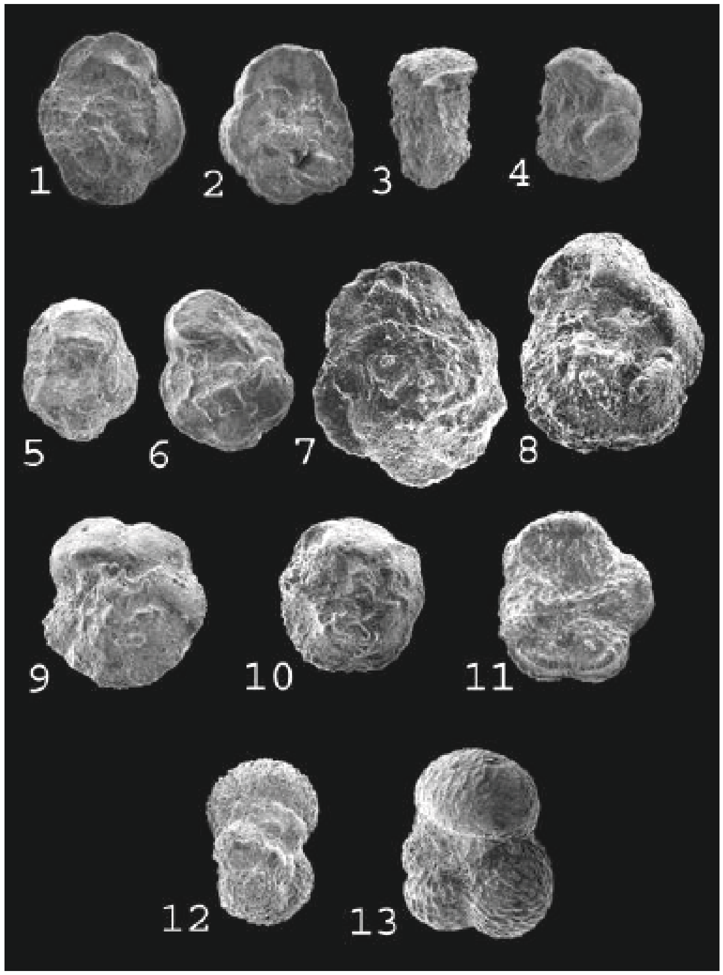

Plate I: Scale bar represents 100µm. All the specimens were recovered from the Simsima Formation, Jabal Qarn El Barr section. 1- *Contusotruncana fornicata* (Plummer), spiral side. 2-4-*Gansserina gansseri* (Bolli), 2- spiral side, 3- side view, 4- umbilical side. 5- *Globotruncana aegyptiaca* Nakkady, umbilical side. 6- *Globotruncana orientalis* El Naggar, umbilical side. 7, 8-*Globotruncana rosetta* Carsey, 7- spiral side, 8- umbilical side. 9- *Globotruncana* cf. *insignis - Globtruncanita conica* Gandolfi, umbilical side. 10(White), spiral side. 11- *Abathomphalus mayaroensis* (Bolli), umbilical side. 12, 13- *Rugoglobigerina macrocephala* Brönnimann, 12- side view, 13- umbilical view. Horizon yields *(Orbitoides media-Lepidorbitoides minor)* and the upper horizon yields *(Orbitoides apiculata–Siderolites calcitrapoides).* The lower horizon can be correlated with the *Globotruncana aegyptiaca interval z* one and the lower part of the *Gansserina gansseri* Interval Zone (Figure 2), whereas the upper horizon can be correlated with the upper part of the *Gansserina gansseri* Interval Zone and the *Abathomphalus mayaroensis* Zone (Fig .2).

Two larger foraminifera biozones are described in Plate II as follows:

Zone #I:

Lepidorbitoides minor, figures 9-11; *Orbitoides media,* figures 4-6, and *Omphalocyclus macroporous,,* figures 7-8.

Zone # II:

Orbitoides apiculata, figure 3; and *Siderolites calcitrapoides,* figures 13-14. This facies is well developed in Jabal El Rawdah, Jabal Buhays, Al Faiyah Range Mountains and Jabal Malaqet.

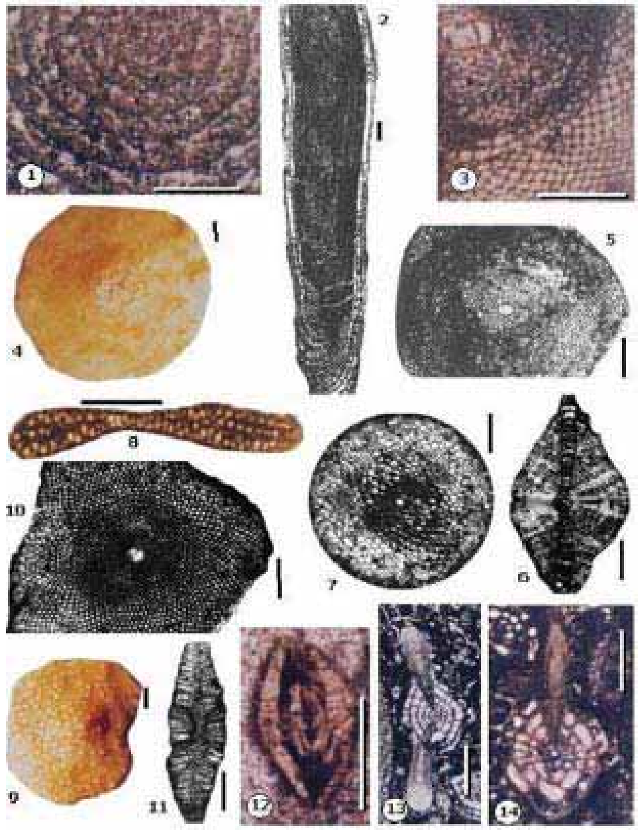

Plate II: Scale bars represent 1.0mm. All the specimens were recovered from the Simsima Formation. 1, 2- *Loftusia morgani* Douvillé, 1- equatorial section, 2- axial section. 3- *Orbitoides apiculata* Schlumberger, equatorial section. 4- 6- *Orbitoides media* (d' Archiac), 4- external view, 5- equatorial section, 6- axial section. 7, 8- *Omphalocyclus macropora* (Lamarck), 7- equatorial section, 8- axial section. 9-11 - *Lepidorbitoides minor* (Schlumberger), 9- external view, 10- equatorial section, 11- axial section. 12-*Sulcoperculina dickersoni* (Palmer), axial section, 13,14 - *Siderolites calcitrapoides* Lamarck, equatorial section.

Palynomorphs of the Simsima Formation:

The detailed study of the palynological investigation of the five samples resulted in recognizing twenty four species of spores and pollen and eight species of dinoflagellates cysts in addition to black to brown wood remains, cuticles, plant tissues, fungal spores and undetermined palynomorphs.

Taxonomic List:

The taxa listed below have been encountered in the present study. The nomenclature follows that of Jansonius and Hills (1976) for miospores and Lentin and Williams (1993) for dinocysts. Unfortunately most of the recovered species are badly preserved.

Sporites species include *Appendicisporites tricornitatus, Cicatricosisporites sinuous, Cingulatisporites* sp., *Cythidites australis, Cyatidites minor, Murospora florida* and *Lygodioisporites perverrucatus.*

Pollens species include *Araucariacites australis, Araucariacites* sp., *Cretacaeioporites densimurus,* cf. *Punctamonocolpites scaphormis, Classopollis obidosensis, Classopollis* sp., *torsosus, Cry belosporites pannecus, Cry belosporites Dichastopollenites* cf. sp *dunverganensis, Ephedripites ., Inaperturopollenites* cf. *atlanticus, Inaperturopollenites* sp., *Spheripollenites scabratus, Spheripollenites subgranulatus, Spheripollenites* sp. and *Scabratriporites simpliformis.*

Dinocysts species include *Aptea* sp., *Cannosphaeropsis utinensis, Cribroperidium* sp., sp., *Florentinia florida, Mudrongia* sp., *Pseudoceratium securigerum* and *Afropollis* sp.

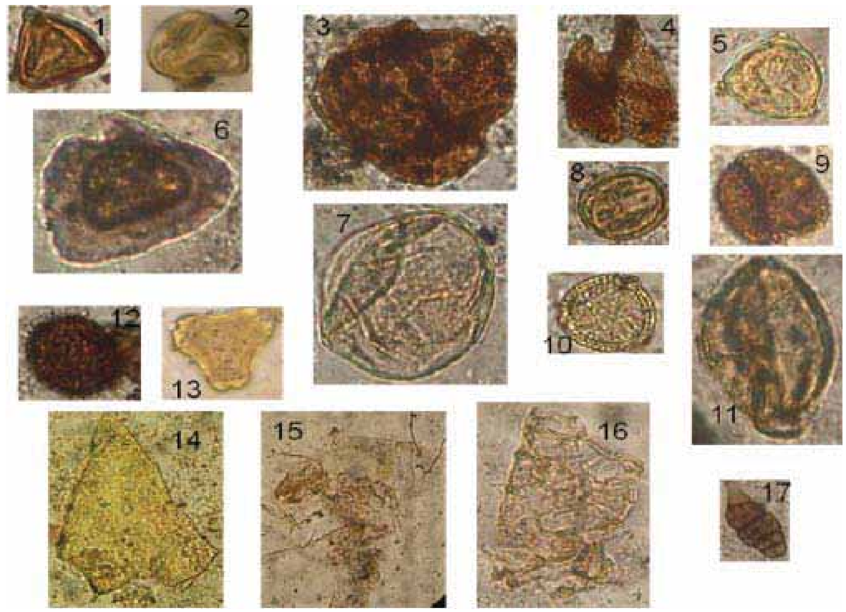

Plate III: Palynomorphs of the Late Cretaceous of the Simsima Formation: 1-*Appendicisporites tricornitatus;* Mundassah Sample 2;2- *Cyatidites minor;* Mundassah Sample 2;3- *Lygodioisporites perverrucatus;* Qarn El Barr Sample 8; 4-*Cicatricosisporites sinuous;* Qarn El Barr Sample 8; 5- *Murospora florida;* Mundassah Sample 2; 6- *Cingulatisporites* sp.; Mundassah Sample 2; 7- *Araucariacites australis;* Qarn El Barr Sample 8; 8-*Classopollis torsosus;* Mundassah Sample 2; 9-*Cretacaeioporites densimurus;* Mundassah Sample 2 ; 10- *Dichastopollenites* cf. *dunverganensis;* Mundassah Sample 2 ; 11- Cf. *Punctamonocolpites scaphormis;* Mundassah Sample 2; 12- *Crybelosporites pannecus;* Mundassah Sample 2; 13-*Scabratriporites simpliformis;* Mundassah Sample 2; 14- *Pseudoceratium securigerum.;* Mundassah Sample 2; 15- *Cannosphaeropsis utinensis;* Mundassah Sample 2; 16- *Afropollis* sp.; Mundassah Sample 2;17- Fungal spore; Mundassah Sample 2

Chronostratigraphy:

The palaeontological investigation of the studied sections reveals that the Qarn El Barr section is a source of numerous planktonic foraminiferal species, especially those belonging to genera *Heterohelix* and *Globotruncana* and smaller benthonic foraminiferal species, these species have enabled us to date this section into Late Campanian to Maastrichtian age, in addition to the presence of some characteristic terrestrial palynomorphs such as pollen grains and spores. The remaining four sections (Jabal Buhays, Jabal El Rawdah, Jabal Malaqet and Mundassah) yielded several larger foraminiferal species. The discovered species are *Loftusia morgani, Orbitoides apiculata, O. media, Omphalocyclus macropora, Lepidorbitoides minor, Sulcoperculina dickersoni, and Siderolites calcitrapoides,* that also supported the suggested late Campanian to Maastrichtian age for the sections studied. Also the age dating based upon the occurrence of some undoubtly and diagnostic Late Cretaceous palynomorphs. The identified species are *Appendicisporites tricornitatus, Cicatricosisporites sinuous, Cingulatisporites sp., Cretacaeioporites densimurus,* cf. *Punctamonocolpites scaphormis, Cry belosporites pannecus, Dichastopollenites* cf. *dunverganensis,* Cannosphaeropsis *utinensi*s, *Afropollis* sp. and *Mudrongia* sp.

Depositional Environment:

The occurrence of planktonic foraminifera species at Qarn El Barr section indicate open marine environment prevailed during the deposition of the Simsima Formation. The palynofacies of the upper part of this formation at this locality shows that there is rare organic microflora characterized by terrestrial palynomorphs. These species indicate that deposition near shore line and shallowing conditions during the deposition of the most upper part of the Simsima Formation. This is supported also by the reduction or absence of organic marine matter (dinoflagellates) and deposition of calcareous siltstone. On the other sections the occurrence of larger foraminifera species and enrichment of the terrestrial palynomorphs such as pollen grains and spores in addition to black - brown wood remains, cuticles, plant tissues and fungal spores which are more frequent than dinoflagellates especially at the upper part of the Simsima Formation at Jabal Mundassah. This indicates that deposition of the Simsima Formation took place under shallow-water environment at Jabal Buhays, Jabal El Rawdah, Jabal Malaqet and Jabal Mundassah. Generally, the litho and biofacies distribution of the recovered taxa of the Simsima Formation indicates that the Late Cretaceous Sea deepened towards the NNW i.e. towards the Qarn El Barr section (Fig.2).

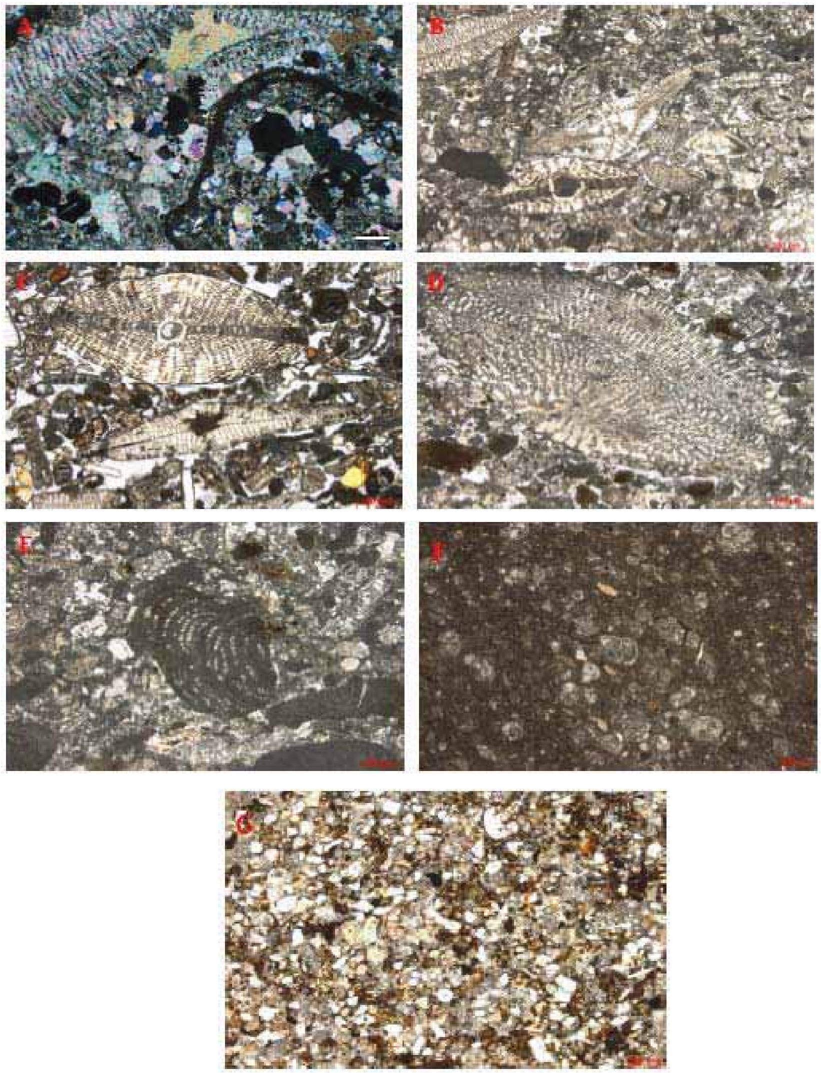

Fig. 4: Photomicrographs showing the different facies of the Simsima Formation.E

3.2 Facies Analysis:

The microscopic analysis revealed that the Simsima carbonates can be texturally classified as wackestone, packstone and grainstone. These facies dominated with skeletal allochems such as foraminifera (mainly lager forams with some planktonics), algae, echinoids, shell debris, bryozoa, ostracods, corals and sponge spicules. The less dominant non-skeletal are terrigenous grains (intraclasts, quartz, chert and ophiolitic fragments) and peloids.

Jabal Malaqet:

The Simsima Formation of Jabal Malaqet is represented only by the grainstone (intrabiosparite) facies. *Grainstone (intrabiosparite)facies* (Fig. 4A)

This facies consists of skeletal grains and intraclasts. The skeletal grains are dominated by large forams *(Siderolites* sp., *Orbitoides sp.),* red algae and echinoids. Foraminiferal tests are commonly filled with micrite, sparite or dolomite.

Jabal El Rawdah:

The Simsima Formation of Jabal Rawdah is dominated by algal foraminiferal packstone (algal foraminiferal biomicrite) facies. On the other hand, the foraminiferal grainstone (foraminiferal biosparite) facies is rarely observed in the lower part of the rock unit.

Algal foraminiferal packstone (algal foraminiferal biomicrite) facies (Fig. 4B)

It is characterized by abundant skeletal grains with rare terrigenous grains and peloids. The skeletal grains are dominated by algal fragments and foraminifera tests. Moldic and fracture porosity were reduced by the effect of calcite filling.

Foraminiferal grainstone (foraminiferal biosparite)facies (Fig. 4C)

This facies consists of abundant skeletal grains and rare ophiolitic fragments. The larger benthonic foraminifera are the dominant skeletal grains. Sparitic calcite is the main constituent of the rock groundmass. Silica and iron oxides are rare. This facies is characterized by poor porosity which is mainly moldic ones.

The two facies of the Simsima Formation in Jabal Rawdah is showing several diagenetic processes. Micritic envelops are observed on some skeletal grains. Micritization of algal fragments was responsible for the formation of coarse peloids. The compaction is manifested by the presence of stylolites and grain sutured contacts. Syntaxial calcite overgrowths are common on some echinoid fragments. The rarity of silica in the rock groundmass and skeletal allochems is related to the minor role played by the freshwater diagenesis. Meanwhile, other diagenetic processes revealed that most of the Simsima Formation in Jabal Rawdah highly affected by the marine phreatic and burial diagenesis.

Jabal Buhays:

The Simsima Formation of Jabal Buhays includes two facies. These are the foraminiferal wacke stone and algal foraminiferal wackestone facies.

Foraminiferal wackestone (foraminiferal biomicrite)facies (Fig. 4D)

The foraminiferal wackestone facies is the most dominant facies in the Simsima Formation of Jabal Buhays. It is composed of abundant skeletal grains and rare terrigenous grains. The skeletal grains slightly decrease upwards and dominated by foraminifera with rare algae, ostracods and shell debris. The rock cement is dominated by intergranular calcite with rare dolomite and iron oxides. Some of the skeletal grains completely filled with coarse calcite. Intergranular, intercrystalline and moldic porosity are frequently observed in this facies.

Algal foraminiferal wackestone (algal foraminiferal biomicrite)facies (Fig. 4E)

This facies is restricted to the basal and uppermost parts of the Simsima Formation in Jabal Buhays. The algal foraminiferal wackestone facies grades upward to wackestone/ lime mudstone facies and consists of abundant skeletal allochems with rare terrigenous grains. They embedded in partially recrystallized micritic groundmass. Porosity ranges from poor to good. It includes intergranular, intercrystalline and moldic porosity. Aggrading neomorphism and leaching are the most common diagenesis processes in the Simsima of Jabal Buhays. Meanwhile, dolomitization and silicification are rarely observed.

Jabal Qarn El Barr:

The Simsima Formation of Jabal Qarn El Barr is classified into two facies. These are foraminiferal wackestone/packstone (foraminiferal biomicrite) and dolomitized ferruginous siltstone facies.

Foraminiferal wackestone/packstone (foraminiferal biomicrite)facies (Fig.4F)

It composed mainly of skeletal grains with very fine, subrounded to subangular quartz grains and traces of amorphous silica and glauconite. The skeletal grains are abundant planktonic foraminifera *(globotruncanella minuta, rugoglobigerina macrocephala, globigerinelloides, globotruncana rosetta),* ostracods and sponge spicules. Algae, shell debris and benthonic forams increase toward the upper part of the facies. This facies is highly argillaceous toward its upper part as evidenced by X-ray diffraction analysis which revealed the presence of montmorillionite and illite. The upper part of this facies has proven a poor porosity as a result of calcite filling the intergranular pore space and moldic porosity. Meanwhile in its lower part, most of foraminiferal tests are leached out promoting a good porosity. Spotty to patchy iron oxides are recognized. Diagenesis processes comprise neomorphism, silicification and leaching.

Dolomitizedferruginous siltstonefacies (Fig.4G)

It forms the upper part of the Simsima formation in Qarn El Barr area. It is composed of abundant silt size quartz grains. They are sub-angular to sub-rounded, occasionally angular and poorly sorted. The microcrystalline calcite cement occasionally recrystallized to coarse calcite. Locally traces of dolomite crystals are recorded.

X-ray diffractograms (Fig.5) revealed the abundance of calcite with subordinate amounts of quartz which in turn increases upward in the rock unit. On the other hand, the dolomite appears only in the uppermost part of the Simsima Formation. Clay minerals (montmorillionite and illite) with low percentages are observed in the Simsima Formation of Jabal Qarn El Barr (Fig.6).

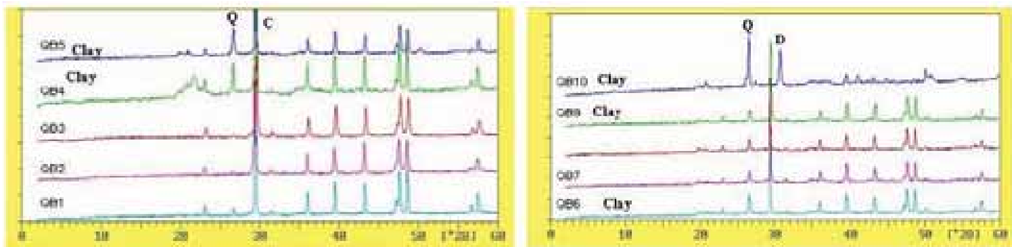

Fig. 5: X-ray diffractograms of representative bulk samples in Jabal Qarn El Barr. C= Calcite, Clay= Clay minerals, D= Dolomite, Q= Quartz

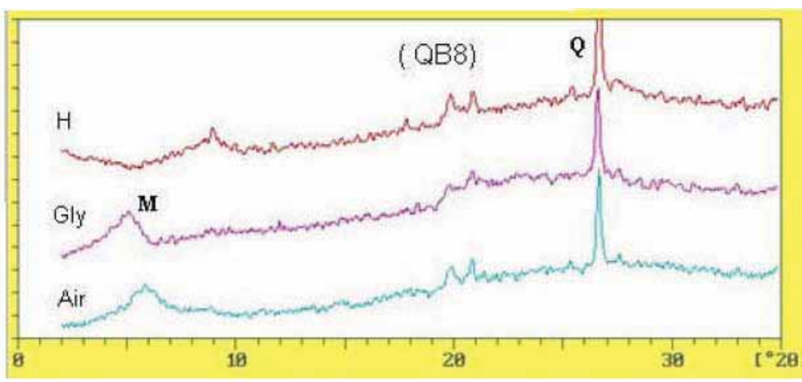

Fig. 6: X-ray diffractograms of clay size fractions in the Simsima Formation of Jabal Qarn El Barr. M= Montmorillionite, I = Illite, Q= Quartz, Air= Air dried, Gly= Glycolated, H = Heated

Depositional Environment:

In Jabals Malaqet, El Rawdah and Buhays; the Simsima carbonates were laid down within the photic zone of high energy shallow marine environment (carbonates platform). This explains: (1) the marked richness of the sediments with high diverse skeletal grains which dominated by larger foraminifera and algae; (2) the presence of terrigenous allochems which derived from the pre-Simsima allochthonous unit; and (3) the textural nature of the limestones being composed almost of grainstones and packstones. Some parts of the Simsima Formation in Jabal El Rawdah were accumulated in more restricted areas as evidenced by the presence of miliolids and peloids.

On the other side, the Simsima argillaceous carbonates in Jabal Qarn El Barr were deposited in more deep marine environment (slope margin). This evidenced by the dominance of planktonic foraminifera and wackestone facies. The presence of algal fragments, shell debris, quartz and glauconite with some packstones and rock types are related to the reworking of these components from other more shallow locations due to the dipping nature of the slope margin. So, the Late Cretaceous sea in UAE was deepening towards the northern parts (Fig.7)

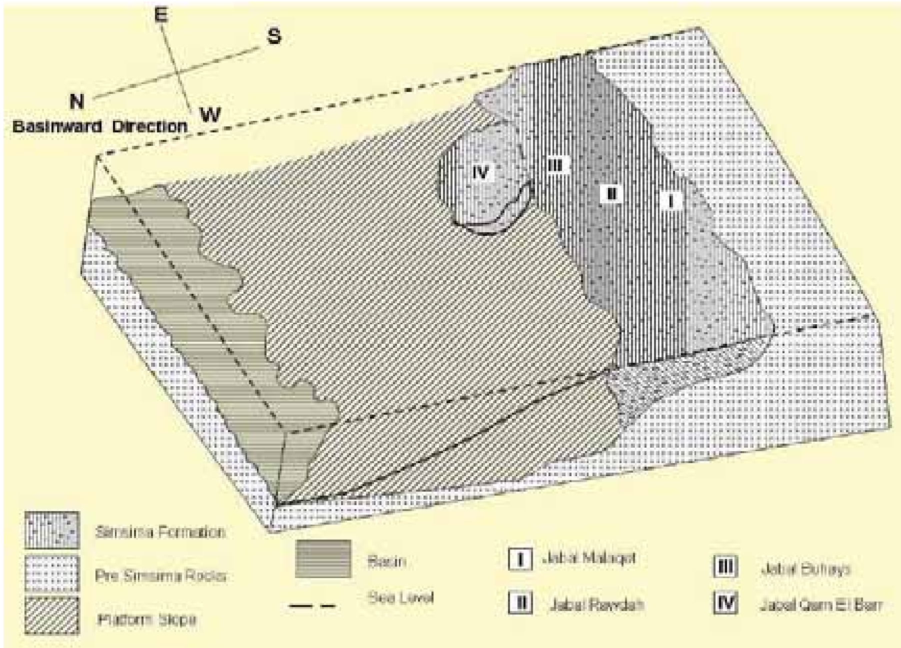

Fig. 7: Depositional model of the Simsima Formation throughout the study area

To prove occurrence of clay minerals within the late Cretaceous Simsima formation at Jabal Qarn El-Barr, the carbonates constituents were removed by using dilute HCl (5%). The sand and silt sized fractions of the insoluble residue were separated from the clay fraction by wet sieving and pipette methods. The re-concentrated clay fractions were analyzed with X-ray diffraction to identify their mineral species. Figure 3 is showing well developed peaks of two different clay minerals (montmorillionite and illite) in addition to clay sized quartz. The presence of these clay minerals is very useful for characterization of Simsima Formation in Jabal Qarn El Barr as source rocks for hydrocarbons.So, based on the obtained results, the Simsima Formation could be classified into two facies. These are foraminiferal wackestone/packstone (planktonic foraminiferal biomicrite) facies; and Algal Foraminiferal larger benthonic, Rudistids Wackestone (Algal Foraminiferal Biomicrite) facies.

3.3 Structural Geology:

Al-A in Locality:

The outcrops of the Upper Cretaceous Simsima Formation at Al-Ain area are restricted to Gabal Malaqet and Gabal Mundassa which are located to the east of Al-Ain (2003). The two mountains form together a large doubly plunging asymmetric NNW-SSE-oriented anticlinal fold. This fold plunges gently towards NNW through Gabal Malaqet and towards SSE through Gabal Mundassa (1990). The outcrops on the northeastern limb of the fold are well developed and relatively dip gently towards the northeast while those on the southeastern fold limb are relatively very thin and disconnected and dip steeply towards the southwest. The Simsima Formation crops out only in the internal part of the northeastern limb, whereas its outcrops on the other southwestern limb are thrusted under the northeastern limb through a large extended thrust running parallel to the hinge line of the fold.

At Gabal Malaqet, the Simsima Formation occupies a long, but very narrow strip (maximum 40 m width) that lies very close to the fold core. Along this strip the Simsima Formation has a maximum thickness 8 m and is made up of a greenish yellow dolomitic, siliceous and fossiliferous limestone. It is conformably overlies the breccia of the Qahla Formation while unconformably underlies the marl of the Paleocene Muthaymimah Formation through a discontinued thin conglomerate bed at the contact of the two formations.

At Gabal Mundassa, the outcrops of the Simsima Formation are completely different. The formation is represented by a very thick sequence of carbonates (60 m) which are composed of marls, cherty limestone and thick conglomerates at its lower part and thin-bedded green and orange marl at its upper part and topped by a thin conglomeratic bed. These outcrops occupy a wide area that reaches 600 m width at the central part of the mountain. At this part, the formation is unconformably overlies the rocks of the Semile ophiolites through a large thrust and underlies the marls of the Paleocene Muthaymimah Formation through a thin conglomerate bed.

The great difference in the litho- and bio-stratigraphic facies of the Simsima Formation between the two mountains can be attributed to the difference in the paleotopography of the ancient basin in these two areas. It worth mentioning that, the southern part of the basin (Gabal Mundassa) was deeper and active during the Cretaceous period and it received thick carbonates interbedded with chert bands and very coarse conglomerates in a cyclic sedimentation. The northern part of the basin (Gabal Malaqet) was topographically high except for the uppermost part of the Late Cretaceous period during which a thin bed of limestone had been deposited (Fig. 1).

The Simsima Formation at this part is affected by frequent fractures that can be classified into three sets orienting NE-SW, NNW - SSE and E-W. The NE-SW-oriented fractures are cross-fractures that developed orthogonal to the hinge line of the main fold. The SSE-

NNW-oriented fractures are longitudinal release fractures that developed parallel to the fold hinge line after the release of the affecting force. The E-W-oriented fractures were developed obliquely to the fold hinge. Some of these fractures were filled later either by calcite veins or clastic materials while the others are still unfilled. The studied mountains, including the rocks of the Simsima Formation, passed through different periods of deformation that occurred during the deposition (i.e. syndepositional deformations). The first one was strong and occurred during the Late Campanian/Early Maastrichtian time (during the deposition of the Simsima Formation) and led to the deposition of thick conglomerates composed of granules to boulder-size rock fragments acquired from the older limestones and serpentinite of the Semile Ophiolites. The second was mild and occurred at the end of the Late Maastrichtian that mostly affected the northern part of the basin (Gabal Malaqet) and formed the thin conglomerate beds between the Simsima and Muthaymimah Formations. Other phases of deformations affected the area at the end of the Paleocene and continued intermittently till after the Miocene.

Al-Sharjah Locality:

This locality includes El-Faiyah fold belt that is formed of two separated right-stepped en-echelon arranged, NNE-SSW oriented, doubly plunging and highly asymmetric anticlines. In addition to the northwestern located few small hills of Qarn El Barr. Gebel Buhays forms the southern and also the smaller anticline, while the northern and longer one consists of Gebel Al-Faiyah and Gebel Milaha.

Gebel Buhays forms a doubly plunging, highly asymmetric, westerly verging, NNE-SSW oriented anticline (Fig. 8b). The southern fold nose clearly plunges towards SSW while the northern one, which is strongly eroded, plunges to the NNE. The outcrops of the Cretaceous Simsima Formation are widely extending along the discontinuous southeastern limb of the fold. The have gentle dip angles that change from 15º to 40º towards the east and southeast. On the other hand, the outcrops of the same rock unit form a relatively tight strip on most of the central part of the continuous northwestern fold limb. Whereas the Simsima Formation is thrusted over the younger rocks of the Paleocene and Lower Eocene Muthaymimah Formation (Fig. 8a). In this later limb the dip of the Simsima carbonate rocks is more steeper and range between 22º and 85º towards the west and southwest (Fig. 8a). This dip increases occasionally to be vertical and overturned in the middle part of this limb. But along the hinge area the dip of these rocks changes from the horizontal attitude at the central part to 15º at the fold noses (Fig. 8b). The rocks of the Simsima Formation in Gebel Buhays anticlinal fold is dissected by several fault sets that change in types in the different parts of the fold. The plunging noses of this fold are dominated by different N-S oriented high angle normal faults (Fig. 10) that dips either in the same direction (forming step-like blocks) or in opposite directions (forming Graben blocks). But the central part of the steep northwestern limb is affected by a long N-S oriented thrust fault, in addition to two sets of parallel NE and NW oriented strike slip faults (Fig.8).

Accordingly, there is a similarity in the structural setting of the studied localities. But there are also some differences in the litho- and bio-stratigraphic facies of the Simsima Formation between the studied areas, even in the same locality. This can be attributed to the difference in the paleotopography and the local tectonic regimes of the ancient basins of deposition formed in these areas. It can be concluded that in Al-Ain locality the basin which occupied the southern part (Gebel Mundassah) was much deeper and tectonically unstable during the Cretaceous whereas it received a large thickness of fine carbonate beds with parallel chert bands and conglomerates with large boulder-size rock fragments, both types are interbedded in cyclic sedimentation. While the northern part of the same basin (Gebel Malaqet) was topographically (or tectonically) much higher except for a short period of time which permitted the deposition of the thin sequence of limestone of the Simsima formation in the latest Late Cretaceous.

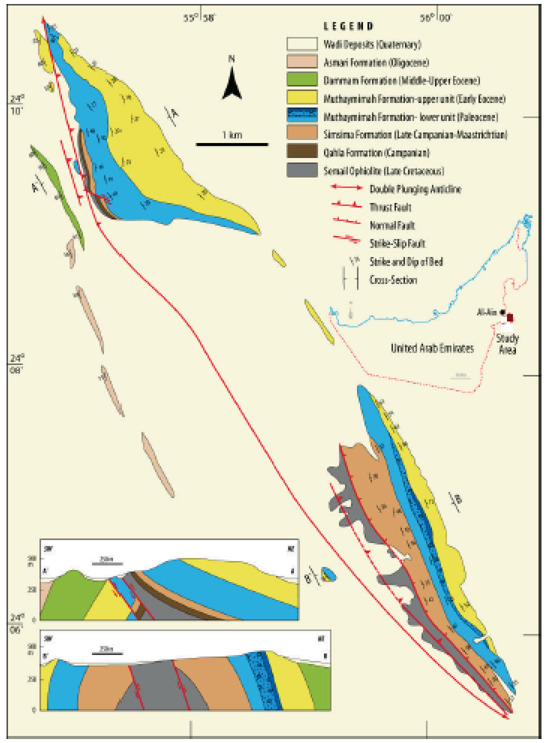

Fig. 8a: Geologic map of Gebel Malaqet and Gebel

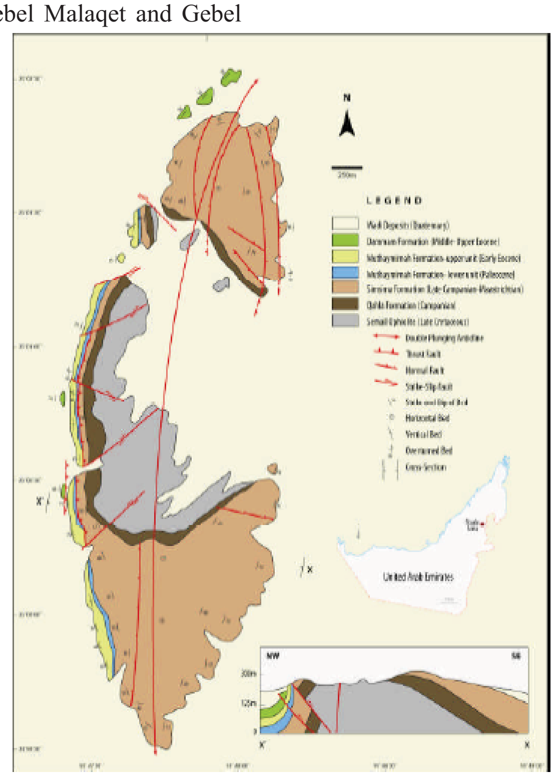

Fig. 8b: Geologic map of Gebel Buhays

But in Al-Sharjah locality, there was two different separated basins, the southern one that occupied the area of El-Faiyah fold range and was similar, to some extent, to that of Gebel Mundassah whereas they contains similar carbonate deposits with large thickness. Whereas, the second basin was formed to the northwest in Qarn El Barr area that was tectonically deeper and received deep pelagic sediments. This fact directed Abd-Allah (2001) to propose a thrust fault between the Gebel Milaha (the northern end of El-Faiyah fold range) and Qarn El Barr area. Such fault may resulted in the subsidence of the Qarn El Barr basin relative to that in the fold range area which consequently account for the sudden changes in the facies distribution between these areas.

The fractures obtained in Gebel Malaqet-Mundassah fold can be classified, according to their trends; into three sets are NE-SW, E-W and NNW-SSE (Fig. 9). The studied fractures in Al-Sharjah locality are grouped into 4 main groups are oriented in E-W, NE-SW, N-S and SE-NW (Fig. 10). Although the sets of fractures studied in both localities show different trends, but they form the same relation with their folds. Whereas most of them are orthogonal to the fold hinge line while some are oriented in the expected oblique trend and few followed the trend of the fold hinge line. Thus most of the obtained fractures are certainly systematic fractures that developed in relation to the geometry of their hosting fold.

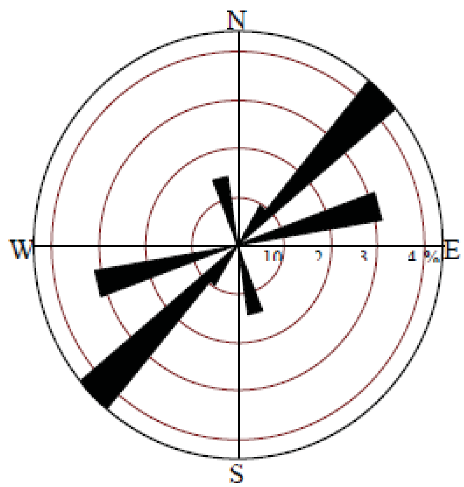

Fig. 9: Rose diagram shows the orientation of the joint sets affecting the rocks of the Simsima Formation in Malaqet-Mundassah fold.

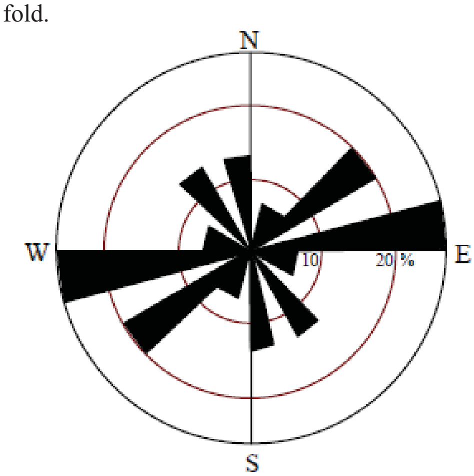

Fig. 10: Rose diagram shows the orientation of the joint sets affecting the rocks of the Simsima Formation in Buhays fold.

Implication of Structures on the Hydrocarbon Potentiality:

The occurrence of such (Malaqet-Mundassa) anticlinal and thrusting structures greatly enhances the opportunities for hydrocarbon entrapment. The formation of highly fractured Simsima Limestones capped by marly rocks (Paleocene Muthaymimah Formation) as well as the uplifting of the eastern anticlinal limb also favors the reservoir characteristics of such rocks. The underthrusted Simsima Formation on the downthrown western limb can form a good location for hydrocarbon accommodation In this western limb the steeply dipping rocks of the Simsima Formation is laterally facing the sealing predotite rocks which were uplifted on the upthrown side, and vertically covered by the marly rocks of the Paleocene age. Hence, hydrocarbons could be easily trapped within this steeply dipping Simsima Formation, particularly if the thrusting was acting as sealed fault zone.

This assumption could be greatly supported by the absence of any surface oil seepages. More geochemical analysis is needed to determine the age of the oil generation and migration and relate it to the main age of folding and thrusting (which is expected to be after the Eocene age).

3.5 Source Rock Potentiality:

Ten samples were selected from Gebel Qarn El Bar represent the Cretaceous sediments with TOC values ranges from 0 to 1.3 wt % (average 0.36) that reflects poor to fair source richness (table 1).Another four samples were selected from Gebel Mundassah and Gebel Malaqet with TOC values ranges from 0.11 to 0.6 wt % (average 0.26) indicate poor source richness(table 2).Upon extraction , all of the samples yield low values for total extract 3.4 ppm (table 3).The chromatogram of the samples is characterized by the absence of pristine and phytane with dominant C26 hydrocarbons that indicate the presence of paraffinic and waxy source related hydrocarbons.

Table 1: Late Cretaceous source rock data at Gebel Qarn El Barr

Sample No.	TOC%	Sulfur%	IR
QB1	0.30	0.18	36.09
QB2	0.96	0.21	52.48
QB3	1.30	0.17	43.24
QB4	0.00	0.11	64.63
QB5	0.15	0.21	58.69
QB6	0.14	0.21	58.65
QB7	0.08	10.70	51.10
QB8	0.14	11.80	57.56
QB9	0.21	14.50	44.09
QB10	0.09	0.17	73.44

Table 2: Late Cretaceous source rock data at Gebels Malaqet and Mundassah

Sample No.	TOC%	Sulfur%	IR
Mal1	0.17	0.16	59.99
Mal 2	0.14	31.20	60.18
Mun1	0.60	0.23	24.79
Mun2	0.11	0.66	35.45

Table 3: Late Cretaceous Extract data of Gebel Qarn El Barr

Sample No.	Extract%	Extract ppm
QB1	0.003	3.366

3.6 Reservoir Characterization:

Six samples were selected from Gebel Qarn El Bar represent the Cretaceous sediments with porosity varies from 0 to 48.02 % (average 20 .09 %) with intercrystalline type and zero permeability. Two samples were selected from Gebel Mondasa and Gebel Malqat with Zero porosity and permeability. Twelve samples were selected from Gebel El Rawdah that reflects porosity values varies from 0 to 30.08 % (average 3.9 %) with intercrystalline, vuggy and fracture type and permeability values ranges 0 to 851.6 md (average 77.7 md).Twelve samples were selected from Jabal Buhays that shows porosity values varies from 0 to 44.9 % (average 11.1%) with intercrystalline ,vuggy ,and fracture type and permeability values from 0 11.2 md (average 1.6 md).

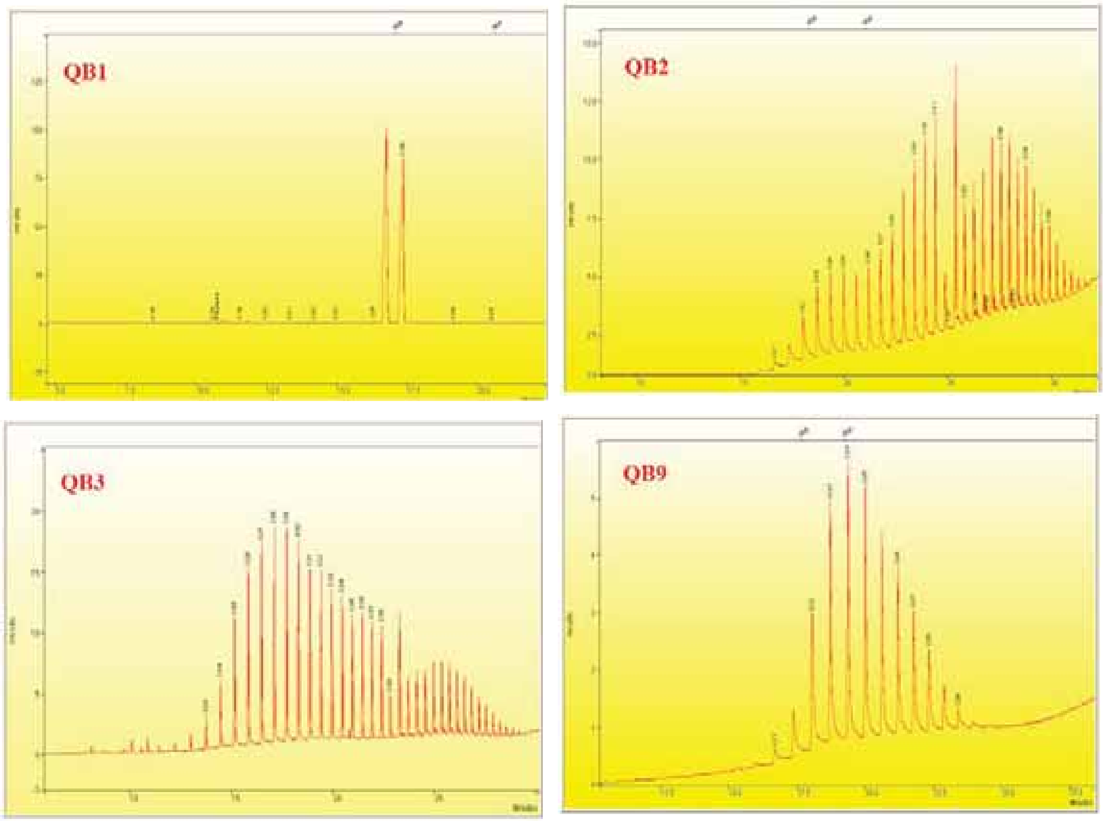

Fig. 11: Gas chromatograms of the Simsima source extracts at Gebel Qarn El-Barr

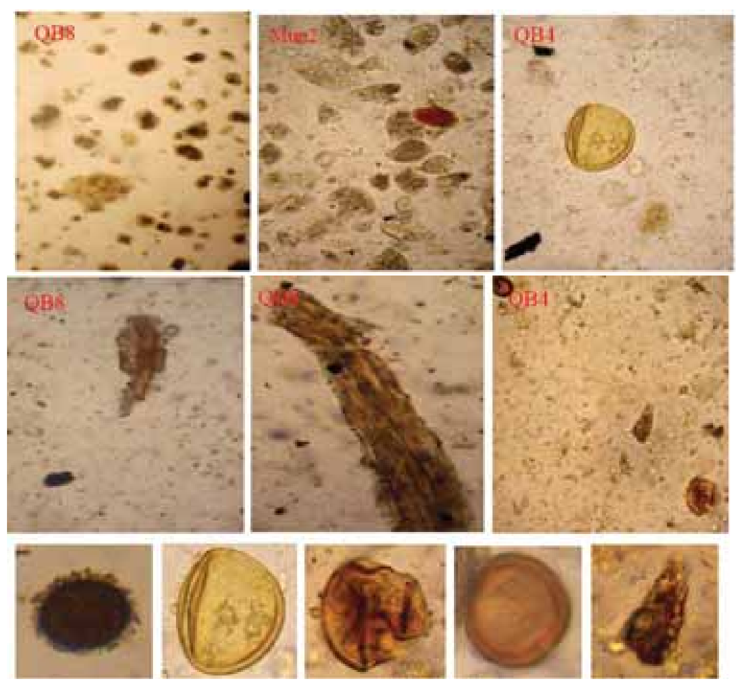

Fig. 12: Photomicrograph showing spores, pollen, dinoflagellates cysts, black to brown wood remains, plant tissues, fungal spores, and undetermined palynomorphs

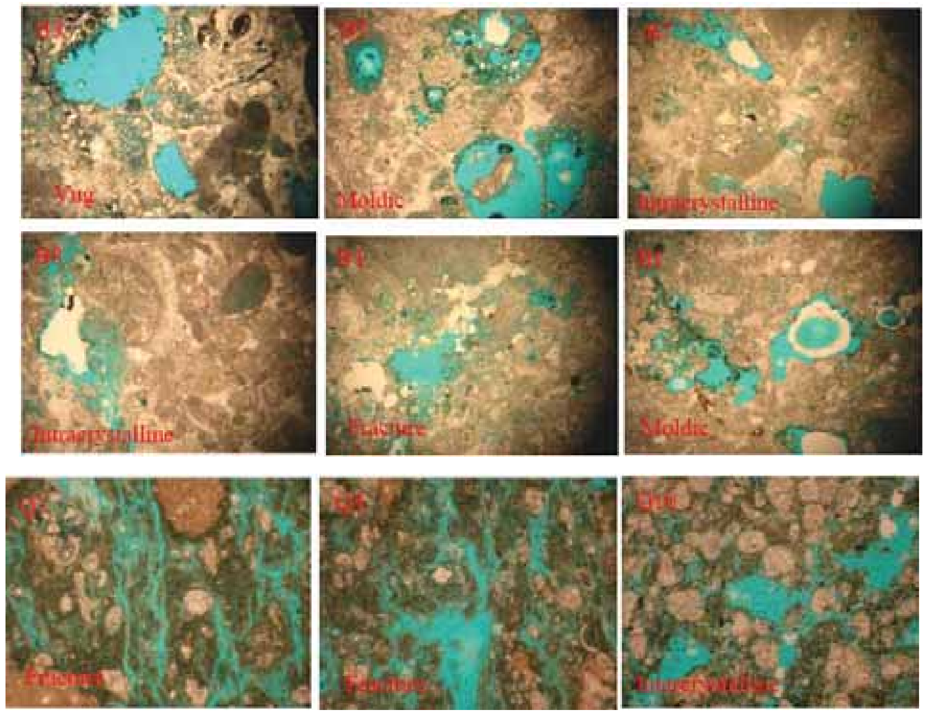

Fig. 13: Different porosity types within the studied reservoir rocks.

Table 4: Late Cretaceous reservoir data at Gebel Qarn Al Barr

Sample No.	Porosity%	Permeability md
Q1	0	0
Q3	48.02	0
Q4	4.1	0
Q6	*	0
Q9	*	0
Q10	31.53	0

Table 5: Late Cretaceous reservoir data at Gebels Malaqet and Mundassah.

Sample No.	Porosity%	Permeability md
M1	0	0
M2	0	0

Table 6: Late Cretaceous reservoir data at Gebel El Rawdah

Sample No.	Porosity%	Permeability md
RW1	0	851.58
RW2	12.65	0
RW3	0	1.9
RW4	0	0
RW5	0	1.1
RW6	0	0
RW7	*	*
RW8	0	0
RW9	30.81	0
RW10	0	0
RW12	0	0
RW11	0	0

Table 7: Late Cretaceous reservoir Data at Gebel Buhays

Sample No.	Porosity%	Permeability md
B1	31.04	0
B2	6.55	11.21
B3	33.93	0
B5	15.95	0
B6	0	0
B7	0.42	0
B8	44.98	0
B9	0	7.72
B10	0	0
B11	0	0
B12	0	0
B14	0	0

Conclusions:

1- Up till now more than 15 field trips were performed and about 300 rock samples were collected that subjected to multidiscipline comprehensive studies. About 300 photographs were also picked up.

2- The present study accomplished preliminary (screening) investigations for all the exposed source and reservoir rocks. More emphasis was made on the Late Cretaceous Simsima Formation as it represents one of the main reservoir horizons in the Arabian Basin. This formation still needs comprehensive investigations to be ultimately exploited.

3- The study revealed that the Late Cretaceous Simsima Formation could be classified into two facies. These are Planktonic Foraminiferal Biomicrite (open marine source rock facies outcropped at Jabal Qarn El (shallow marine reservoir rock facies exposed at Jabal Buhays and Jabal Malaqet) facies. This facies distribution indicates that the Late Cretaceous sea deepened toward the NNW of UAE (Jabal Qarn El

4- X-Ray diffraction analysis ensured the occurrence of open marine minerals (illite and montmorillonite) within the Late Cretaceous Simsima Formation that outcropped at Jabal Qarn El-Barr. So, the Late Cretaceous Simsima Formation could act as an effective source rock (newly proved) in the northern part of UAE and a prolific reservoir rock in the other parts of UAE which has not yet been discussed through any previous literatures. This open marine facies of Simsima Formation has been already proved as an effective hydrocarbon source rock in the neighbor Zagrous Basin.

5- The geochemical analyses also supported the occurrence of source rock facies (high TOC varies from 0.4 to 1.3 wt% and low Pr/Ph ratio) within the Late Cretaceous Simsima Formation.

6- The petrophysical and petrographical investigations proved intercrystalline, vuggy and fracture porosity (varies from 0 to 31%) and permeability ranges from 0 to 850 md for the reservoir facies of Late Cretaceous Simsima Formation. Moreover, the occurrence of anticlinal and thrusted structures (almost acting as sealing faults) within the fractured limestones of the Late Cretaceous Simsima Formation would enhance the probability for hydrocarbon entrapment within these rocks.

7- However, the study proved that many unexplored areas and/or horizons should be added to the petroleum map of UAE.

Recommendation:

Proving of high thermal maturity for many of the studied source rocks implies that more exploration activities should be given to the Tertiary (Recent) petroleum system which has been already approved as petroliferous system in the neighbor Zagrous Basin.

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