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Review of the Biostratigraphy of the Hasa Group (Palaeogene) in Saudi Arabia, Kuwait and Adjacent Regions

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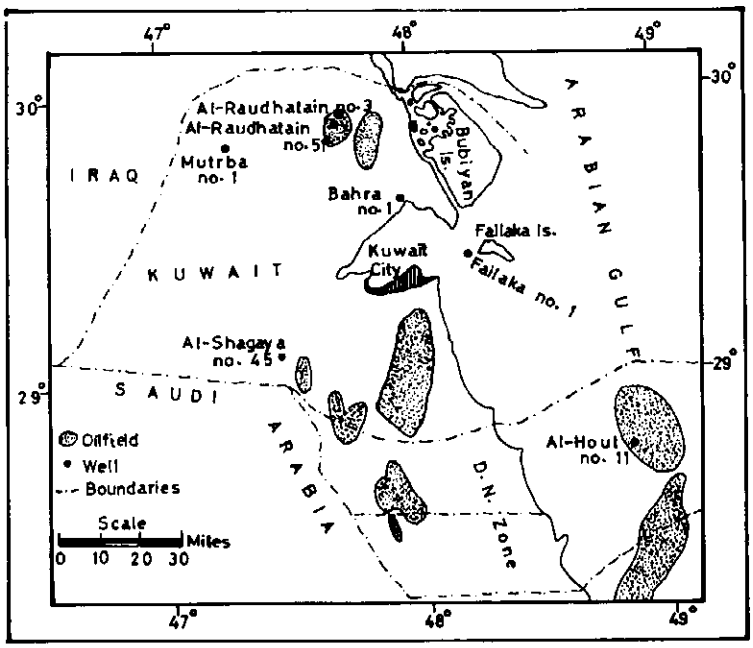
Abstract. The biostratigraphy of the Hasa Group (Palaeogene) in Saudi Arabia, Kuwait and adjacent regions is discussed. The Hasa succession consists of limestones and dolomites with marl, shale and anhydrite interbeds. This group is exposed in central, northern, southern and eastern Arabia. Also, it is found at the subsurface especially in the Arabian Gulf and the Rub' al Khali regions. The Hasa Group includes three formations which are, in ascending order, the Umm er Radhuma, Rus and Dammam Formations.

Introduction

In Arabia, the Lower Palaeogene consists of limestones and dolomites with marl, shale and anhydrite interbeds which were included within the Hasa Group. The present work aims to study the biostratigraphy of the Hasa Group typified by the succession of Kuwait, and to compile the available biostratigraphical information on this group with special emphasis on its occurrence in Saudi Arabia where the type sections of the constituent formations are found.

The present study is based on the biostratigraphical analysis of 330 rock cutting samples collected from the Palaeogene succession penetrated by the three oil wells Failaka no. 1, Al-Raudhatain no. 51 and Al-Hout no. 11, in Kuwait (Text - Fig. 1). In addition to these, eleven core samples from Al-Raudhatain no. 3, Bahra no. 1, Mutriba no. 1 and Al-Shagaya no. 45 wells (Text - Fig. 1), have been studied in this section for microfacies analysis. These samples have yielded no planktonic Foraminifera, but this important group of microfessils was recorded by previous workers [1-6], in equivalent rocks in Saudi Arabia and western Iraq. However, as the analysed succession of the Hasa Group of Kuwait is barren of planktonic Foraminifera, there has been no attempt in the present study to subdivide it into biostratigraphical zones.



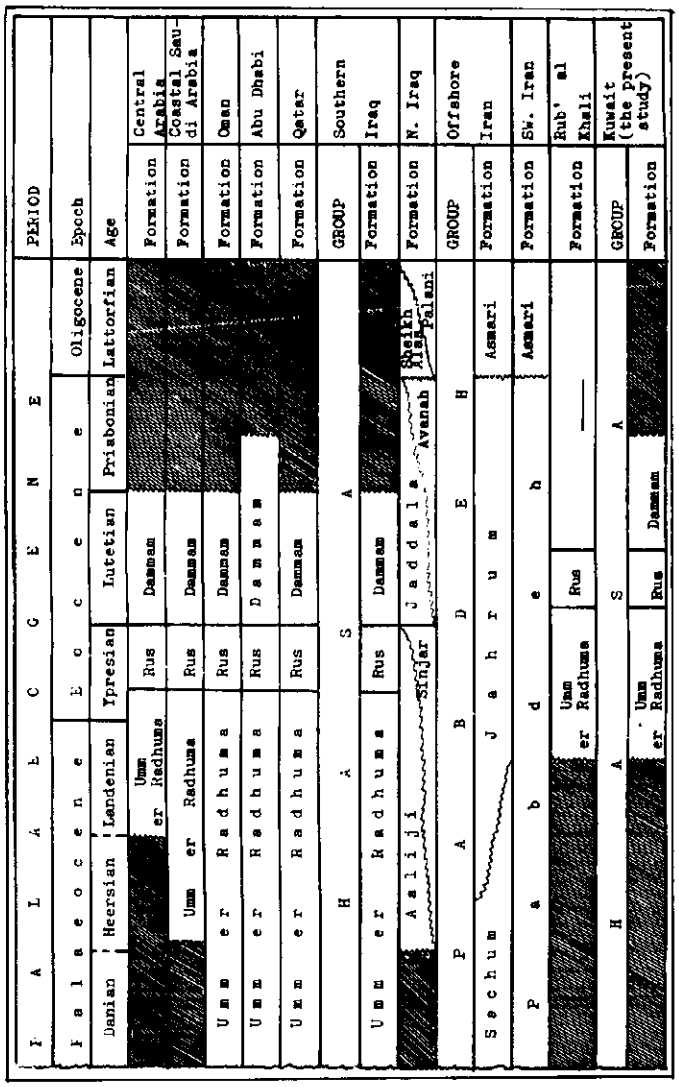
Text-Fig. 1. State of Kuwait, location map of the studied wells [7]

The Hassa Group succession of Saudi Arabia and Kuwait is correlated with the equivalent rock units in Arabia and adjacent regions (Text - Fig. 2).

Biostratigraphy of the Hassa Group in Arabia and Adjacent Regions

Definition

The Hasa Group was introduced by N.J. Sander in an unpublished report prepared in 1951 to include the Umm er Radhuma, Rus and Dammam Formations which range in age from Palaeocene to Eocene [8-9]. This rock unit was adopted by several authors [2,8-11].



Text-Fig. 2. Correlation of the Hasa Group succession in Saudi Arabia and Kuwait with equivalent rock units in Arabia and adjacent regions; after El-Nakhal [7], with modifications; the Rub' al Khali succession after Hasson [6].

However, [8] mentioned that "The original term (Bahrein Series), introduced by Pilgrim in 1908 in Bahrein, is rejected by Sander, because the Hassa area of eastern Saudi Arabia shows a better succession of the formations involved than the Bahrein Island".

A discussion of each of the three formations included within the Hasa Group is given below from base to top.

The Umm er Radhuma Formation

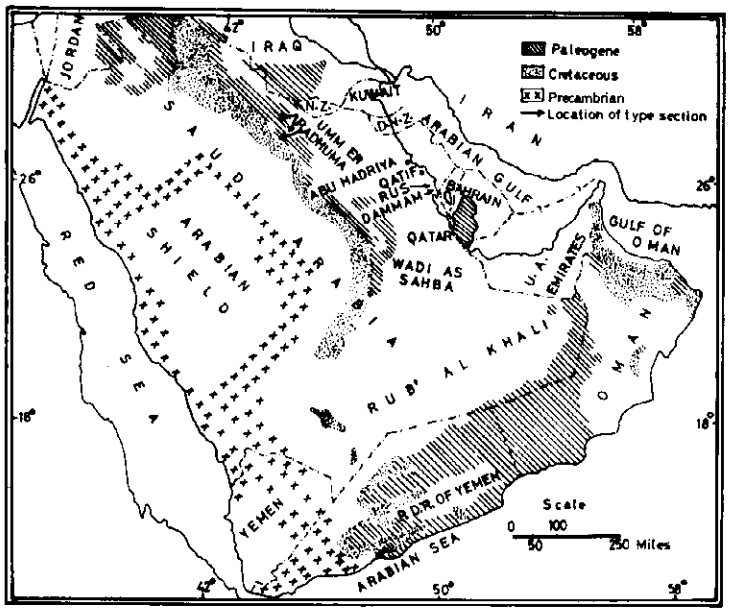
Definition

This formation was named by S.B.Henry and A.B.Brown in 1935 in an unpublished report, for the Umm Radhmah wells (Text -Fig. 3), in Saudi Arabia (Lat. 28° 41′ N., Long. 44° 41′ E.). But, because of difficulties in working out a full section in that area, M. Steineke and J.W.Hoover in 1936, designated a reference section in Wadi al Batin which was remeasured by W.H.Reiss and R.D. Mac Dougall in 1953. The reference section was pieced together from many intervals measured in a continuous 43 miles traverse from the top of the Linah escarpment (Lat. 27° 38′ 0.3″ N., Long. 44° 53′ 24″ E.) northeast along Wadi al Batin (Lat. 27° 59′ 00″ N., Long. 45° 27′ 48″ E.), with a total thickness of about 797 feet (243 meters). The lower contact with the Aruma "Formation" represents a paraconformity whereas the upper contact with the Rus Formation is conformable [6,9,12]. This formation crops out in a wide belt extending from just south of Wadi Jabaliyah (Lat. 22° 25′ N.) to the Saudi Arabia – Iraqi border, a distance of about 750 miles. In addition to this main outcrop, rocks at least partially equivalent to the Umm er Radhuma Formation (and the overlying Rus and Dammam Formations), are exposed over much of the area north of Lat. 29° 30′ N., and west to the 40th meridian. To the northwest, these rocks were informally termed the "Hibr Formation". El-Khayal [4] following Powers *et al.* [12] and Powers [9] described the "Hibr Formation" as representing a Mediterranean facies deposited in a seaway not directly connected with the Arabian Gulf basin. El-Khayal [4] equated the Hibr strata with the Umm er Radhuma, Rus and Dammam Formations. However, Buday [13] questioned the relationship between the Hibr and Umm er Radhuma Formations as they are lithologically different.

The Umm er Radhuma Formation is also widespread in the subsurface, being recognized in well sections throughout the Rub' al Khali, eastern Arabia and Arabian Gulf areas [6,9,12].

Lithology and fossil content

The type section of the Umm er Radhuma Formation consists of grey, cream, light coloured occasionally soft chalky limestone, dolomitic limestone and dolomite with fossil fragments and poorly preserved Foraminifera at several levels. Silicification takes place at several horizons. In the type locality, this formation is poorly fos-



Text-Fig. 3. Generalized geological map of the Arabian Peninsula showing locations of type sections of the studied rock units (after El-Nakhal [7], with modifications).

siliferous, but in eastern Nejd and the Hasa area it is richly fossiliferous. Its lower part includes: *Lockhartia haimei* (Davies), *L. diversa* Smout, *L. conditi* (Nuttall) and *Daviesina khatiyahi* Smout, whereas its middle part bears: *Kathina delseota* Smout, *Lockhartia haimei* (Davies), *Sakesaria cotteri* Davies, *Miscellanea miscella* (d'Archiac and Haime), *Saudia discoidea* Henson. Similarly, the upper part is rich with: *Nummulites lahirii* Davies, *N. globula* Leymerie, *Lockhartia tipperi* (Davies), *Rotalia trochidiformis* (Lamarck), *Alveolina* sp. cf. *A. subpyrenaica* Leymerie, *Flosculina globosa* (Leymerie), [14]

In the subsurface, the present formation is divisible into lower and upper units which are unconformably superimposed. The lower unit consists of light grey, aphanitic limestone with persistant beds of grey to brown shale or shaly limestone,

while the upper unit has a highly variable lithology, being commonly characterized by more limestone and shale than dolomite, with chert occurring in its upper half [9,12].

On palaeontological data, Powers *et al.* [12] and Powers [9] subdivided the Umm er Radhuma Formation into three principal subdivisions. The lower unit contains *Asterigerina dukhani* Smout, *Daviesina danieli* Smout, *D. khatiyahi* Smout, *Kathina delseota* Smout, *Lacazinella* sp., *Lockhartia altispira* Smout, *L. conica* Smout, *L. prehaimei* Smout, *Rotalia dukhani* Smout and *R. hensoni* Smout. In the middle subdivision the following fossils are mentioned: *Daviesina langhami* Smout, *Dictyokathina simplex* Smout, *Kathina major* Smout, *K. selveri* Smout, *Lokhartia conditi* (Nuttall), *L. diversa* Smout, *L. haimei* (Davies), *Miscellanea meandrina* (Carter), *M. miscella* (d'Archiac and Haime), *M. miscella* var. *dukhani* Smout, *Operculina* sp. aff. *O. patalensis* Davies, *O.* sp. cf. *O. ammonea* Leymerie, *Sakesaria dukhani* Smout, *S. dukhani* var. *cordata* Smout, and *S. ornata* Smout. The upper faunal subdivision contains the following fauna: *Sakesaria cotteri* Davies, *Lockhartia tipperi* (Davies), *L. hunti* var. *pustulata* Smout, *Heterostegina ruida* Schwager, *Nummulites fraasi* de la Harpe, *N. lahirii* Davies var. A, *N. lahirii* Davies var. B, *Operculina* spp., and *Rotalia trochidiformis* (Lamarck), [9,12].

El-Khayal [15] described the lithology of the Umm er Radhuma Formation of eastern Saudi Arabia as being similar to the reference section (at Wadi al Batin), and he subdivided it into three units: an upper unit and two lower units. In this formation, he recorded a rich assemblage of larger and planktonic Foraminifera which includes: *Rotalia* sp. cf. *R. trochidiformis* (Lamarck), *R. jacobi* Sander, *R. hensoni* Smout, *Asterigerina dukhani* Smout, *Lockhartia prehaimei* Smout, *L. haimei* (Davies), *L. diversa* Smout, *L. conditi* (Nuttall), *L. altispira* Smout, *L. smouti* El-Khayal; *Daviesina danieli* Smout, *D. khatiyahi* Smout, *D. langhami* Smout, *Sakesaria dukhani* Smout, *S. dukhani cordata* Smout, *S. ornata* Smout, *S. cylindrica* Ruggieri, *S. cylindrica costulata* Ruggieri, *Miscellanea miscella* (d'Archiac and Haime), *Operculina* sp. cf. *O. ammonea* Leymerie, *O. qatarensis* El-Khayal; *Discocyclina redmondi* El-Khayal; *Kathina selveri* Smout, *K. major* Smout, *K. delseota* Smout, *Nummulites fraasi* de la Harpe; *Acarinina esnaensis* (Nakkady), *A.* sp. cf. *A. esnaensis* (Nakkady), *A. mckannai* (White), *A.* sp. cf. *A. mackanni* (White), *A. strabocella* (Loeblich and Tappan); *Globorotalia acuta* Toulmin, *G. aequa* Cushman and Renz, *G. acutispira* Bolli and Cita, *G. angulata* (White), *G. convexa* Subbotina, *G. conicotruncana* Subbotina, *G. occulosa* Loeblich and Tappan, *G. pusilla laevigata* Bolli, *G. pusilla pusilla* Bolli, *G. pusedobulloides variantas* (Subbotina), *G. uncinata* Bolli, *G. velacoensis* (Cushman); *Subbotina triloculinoides* (Plummer), *S. triangularis* (White), and *S. linaperta* (Finlay).

These fossils were used [15] for establishing nine biostratigraphical zones. Also, he chose the El-Alat well as a subsurface reference section for the biostratigraphic zonation for the Palaeocene of eastern Saudi Arabia, as the reference section of the Umm er Radhuma Formation in Wadi al Batin is poorly fossiliferous.

Recently, Hasson [6] described the subsurface succession of Umm er Radhuma Formation in the Rub'al Khali basin as consisting of different types of limestones which vary from fine-grained calcilutites and calcarenites to crystalline dolomitic limestones and more rarely, tightly cemented siliceous limestone with marl, shale and dolomite interbeds, and with a rich assemblage of Foraminifera. In addition to the forms mentioned by Powers *et al.* [12] and Powers [9], Hasson [6] recorded the following planktonic and benthic Foraminifera: *Chiloguembelina wilcoxensis* (Cushman and Ponton), *Globorotalia formosa formosa* Bolli, *G. broedemanni* Cushman and Bermudez, *G. wilcoxensis* Cushman and Ponton, *G.* sp. cf. *G. pentacamerata* Subbotina, *G. caucasica* Glaessner, *G. formosa gracillis* Bolli, *G. aragonensis* Nuttall, *G. quetra* Bolli, *G.* sp. cf. *G. subbotinae* Morozova, *G. lensiformis* Subbotina; *Globigerina linaperta* Finlay, *G. soldadoensis soldadoensis* Brönnimann, *G. soldadoensis angulosa* Bolli; *Alabamina dubifera* (Haque); *Anomalina bandyi* Haque; *Asterigerina texana* (Stadnichenka); *Cibicorbis* sp. cf. *C. nammalensis* (Haque); *Cincoriola arabica* Hasson; *Dictyoconus indicus* Davies; *Discocyclina redmondi* El-Khayal; *Epistomaria saudica* Hasson; *Fabularia ovata* (de Roissy); *Fasciolites subpyrenaica* (Leymerie); *Operculina canalifera* d'Archiac and Haime, *O. qatarensis* El-Khayal; *Redmondina henningtoni* Hasson; *Reedella radhumaensis* Hasson; *Saudella rugosa* Hasson, *S. inflata* Hasson, *S. ornata* Hasson; *Soriella corrugata* Hasson; *Stomatorbina ranikotensis* Haque; *Valvulina triangularis* d'Orbigny, *Clavulina parisiensis* d'Orbigny, *Elphidiella multiscissurata* Smout, *Pararotalia mexicana* (Nuttall), *Glyphostomelloides* sp.

Age and correlation: (See Text – Fig. 2)

On the basis of the fossil content of the subsurface sections, Powers *et al.* [12] and Powers [9] assigned the Umm er Radhuma Formation in Saudi Arabia to the Palaeocene – Early Eocene. These authors equated the two lower faunal subdivisions of this formation, at least in part, with the Ranikot beds, and its upper faunal subdivision with the Laki beds of Pakistan.

Similarly, on palaeontological data El-Khayal [15] assigned the present formation in eastern Saudi Arabia, to the Palaeocene – Early Eocene. He equated Umm er Radhuma Formation with the *Cardita beamonti* Beds, Ranikot Formation and the lower part of Laki Formation of Pakistan. El-Khayal [15] subdivided the Palaeocene part of this formation into nine biostratigraphical zones which are, from base to top, as follows: the *Rotalia jacobi* Zone, *Lockhartia haimei vermiculata* Zone, *Lockhartia*

prehaimei Zone, *Lockhartia haimei suturadicata* Zone, *Lockhartia smouti* Zone, *Lockhartia haimei* Zone, *Discocyclina redmondi* Zone, *Operculina qaterensis* Zone, and *Miscellanea miscella* Zone. The first five of these zones were considered to be of Early Palaeocene age, whereas the 6th and the 7th zones were assigned to the Middle Palaeocene, and the 8th and the 9th were assigned to the Late Palaeocene. The Palaeocene / Eocene boundary was taken at the top of the *Miscellanea miscella* Zone. The *Discocyclina redmondi* Zone contains both larger and planktonic Foraminifera. On the basis of the occurrence of the planktonic faunal assemblage, El-Khayal [15] correlated that zone with *Globorotalia pusilla pusilla* Zone and the lower part of *Globorotalia pseudomenardii* Zone of Bolli [16] which have a Middle Palaeocene age.

In Kuwait – Basrah area, this formation (which consists mostly of dolomitic and marly limestones) was assigned to the same age on the basis of the recorded fossils from which the following are mentioned: *Alveolina ovoidea* d'Orbigny, *A. oblonga* d'Orbigny, *A. delioliformis* Schwager [8,10,17]. The last two references mentioned that for field mapping purposes the Umm er Radhuma Formation was subdivided into two informal units, namely, the Ghurra Beds and the overlying Basita Beds. The lower unit contains non-diagnostic fossils whereas the upper one includes: *Alveolina primaeva* Reichel, *Dictyoconus* sp. cf. *D. walnutensis* Carsey, *Operculina libyca* Schwager, and *Saudia* sp. cf. *S. discoidea* Henson.

In Abu Dhabi, the Umm er Radhuma Formation is represented by limestones (locally dolomitic or argillaceous), dolomites and occasional thin marls [11]. This formation was assigned to the Palaeocene – Early Eocene on the basis of the recorded fossils which include: *Lockhartia hunti* Ovey, *L. haimei* (Davies), *L. prehaimei* Smout, *L. pustulosa* Smout, *Sakesaria dukhani* var. *cordata* Smout, *S. cotteri* Davies.

This information was also recognized in the People's Democratic Republic of Yemen and on palaeontological basis it was assigned to the Palaeoene. However, in some parts of Yemen, the separation of the Umm er Radhuma Formation from the overlying Jeza' Formation is no longer possible because of continuous deposition. As a result of this the two formations merge and the age then becomes Palaeocene – Early Eocene based on the occurrence of the following fossils: *Lockhartia conditi* (Nuttal), *L. tipperi* (Davies), *Sakesaria* sp. cf. *S. cotteri* (Davies), *Nonionella* sp. cf. *N. jacksonensis* Cushman, *Globorotalia velascoensis* Cushman, *Rotalia trochidiformis* (Lamarck), *Operculina sindensis* Davies, O. salsa Davies, *Assilina dandotica* Davies, *A. ranikoti* Nuttal, *Nummulites wadiai* Davies, *N. thalicus* Davies, *N. gobulus* Leymerie var. indicus Davies, Operculina patalensis Davies, *Furcoporella diplopora* Pia, *Taberina daviesi* Henson, *Kathina selveri* Smout, *Valvulina triangularis* d'Orbigny, *Dictyoconus* sp., *Lockhartia haimei* Davies, *L. diversa* Smout, *Daviesina khatiyahi* Smout [18-20].

Budy [13], following Van Bellen *et al.* [8], assigned the Umm er Radhuma Formation of Iraq to the Paleocene – Early Eocene. Also, he correlated this rock unit with the Kolosh Formation of Northern Iraq, the lower Pabdeh of Iran, and the Kermav Formation of Turkey.

However, as mentioned above, Hasson [6] recorded a planktonic foraminiferal assemblage in the lower part of the subsurface Umm er Radhuma Formation in the Rub' al Khali basin which includes: *Globorotalia formosa formosa* Bolli, *G. broedermanni* Cushman and Bermudez, *G. wilcoxensis* Cushman and Ponton, *G.* sp. cf. *G. pentacamerata* Subbotina, *G. caucasica Glaessner, G. formosa gracilis* Bolli, *G. aragonensis* Nuttall, *G. quetra* Bolli, *G.* sp. cf. *G. subbotina* Morozova, *G. lensiformis* Subbotina; *Globigerina linaperta* Finaly, *G. soldadoensis soldadoensis* Brönnimann, G. soldadoensis angulosa Bolli, *Chiloguembelina wilcoxensis* (Cushman and Ponton). The study of this assemblage by Hasson indicated that it falls within the Early Eocene *Globorotalia* Zone of Bolli [16], with the probability that it includes the lower part of *G. aragonensis* Zone (Early Eocene). The Early Eocene age assignment was also confirmed by the occurrence of small Foraminifera such as *Uvigerina, Trifarina* and *Amphimorphina* which do not appear before the Eocene. Accordingly, the Ummer er Radhuma Formation belongs to the Early Eocene, but it may contain relatively little pre-Eocene sediment [6]. On the light of the new information, Hasson [6] questioned the correlation of the present formation with the Ranikot and Laki Formations of Pakistan which may now need to be revised.

The occurrence of planktonic Foraminifera in the Umm er Radhuma Formation in eastern Saudi Arabia was previously reported by earlier authors [1-4]. Those authors however, correlated the recorded planktonic fauna with the *Globorotalia pusilla* and *Globorotalia pseudomenardii* Zones of Bolli [16] which have a Palaeocene age. In his recent work, Hasson [6] revised the results of the above mentioned authors, and he pointed that:

a– This fauna is not well preserved, which may account for its assignment to the Palaeocene *Globorotalia pusilla* and *G. pseudomenardii* Zones [1,3].

b– No specimens of *G. pseudomenardii* Bolli were reported by either of these authors.

c– The form which was identified as *Globorotalia velascoensis* (Cushman) is instead *Globorotalia caucasica* Glaessner, its Early Eocene homeomorph.

d– This is confirmed by the absence of species normally accompanying *Globorotalia velscoensis*, and by the present of forms intermediate between *Globorotalia caucasica* Glaessner and *G. aragonensis* Nuttall, as well as other Early Eocene species including: *Globorotalia aragonensis* Nuttall, *G. wilcoxensis* Cushman and Ponton, *G. formosa formosa* Bolli, *G. formosa gracilis* Bolli, *G. broedermanni* Cushman and Bermudez, *G. lensiformis* Subbotina, *G. pentacamerata*

Subbotina, *G. quetra* Bolli, *G. subbotinae* Morozova, *Globigerina soldadoensis* Brönnimann, *G. soldadoensis angulosa* Bolli, and *G. linaperta* Finlay.

e- Re-examination of El-Alat well, which was an important source of information for the above mentioned authors, shows that the planktonic species which Page and El-Khayal placed in the Palaeocene *Globorotalia pseudomendardi* Zone, are in fact belong to the Early Eocene *G. formosa* Zone.

f- The Palaeocene / Eocene boundary cannot be taken at the extinction level of *Miscellanea*, as those authors suggest. The extinction level lies above the zone of the Eocene planktonic Foraminifera. The Palaeocene / Eocene boundary must occur somewhere below the planktonic zone if, it is to be found in this area at all.

g- It is presently impossible to say how much, if any, of the Palaeocene is present in eastern Saudi Arabia. There is no criteria to date the sparce fauna of benthic Foraminifera that lie below the planktonic zone and the *Miscellanea* assemblage in El-Elat well.

h- Because of the new age interpretation for the planktonic horizon of the Umm er Radhuma Formation, the Palaeogene stratigraphic section for eastern Saudi Arabia as described [1-2,4,15] must be revised.

i Similarly, the assignment of an Early Eocene age to the Umm er Radhuma planktonic interval, makes necessary a reassessment of the age of the *Miscellanea* assemblage that overlies the planktonic Foraminifera. The genus *Miscellanea* had been widely accepted as an indicator for the Palaeocene [6].

The Rus Formation

Definition

The Rus Formation was first introduced by R.A.Bramkamp in unpublished report prepared in 1946 to replace the old term "Chalky Zone" which had been used by S.B.Henry and J.W.Hoover in 1934. The formation was named after the Umm ar Ruus Hill, in Saudi Arabia (Lat. 26° 19′ 04″ N., Long. 50° 07′ 51″ E.), (Text Fig.3). The exposures of this formation in Saudi Arabia are limited to a narrow band extending some 100 miles northward from Wadi as Sahba, and a circular area about 6 miles diameter in the core of the Dammam Dome. However, this rock unit is widespread in the subsurface blanketing the Rub' al Khali, eastern Arabia and the Arabian Gulf area. The thickness of the Rus Formation ranges from about 96 feet (30 meters) in the Ghawar Oil Field to 492 feet (150 meters) at Abu Hadryia and up to 836 feet (255 meters) in the central Rub' al Khali. The contacts of the present rock unit with the underlying Umm er Radhuma and the overlying Dammam Formations are conformable [9-12].

Lithology and fossil content

Steineke *et al.* [14], Powers *et al.* [12] and Powers [9] described the Rus Formation in Saudi Arabia as being almost barren of microfossils and they divided it in the outcrop, into three units which are as follows:

a– A basal unit of about 69 feet (21 meters) of grey to buff, compact, commonly dolomitic limestone with minor beds of soft limestone, and some quartz geods in its upper part.

b– A middle unit of about 104 feet (32 meters) of marls and limestones with irregular masses of crystalline gypsum and occasional geodal quartz, and

c– An upper unit of about 12 feet (3.7 meters) of white, soft, chalky limestone with several thin beds of calcarinite at its top.

Age and correlation: (See Text-Fig. 2)

On the basis of its stratigraphic position, the Rus Formation in Saudi Arabia, was assigned to the Early Eocene [9,12,14]. This unit was recognized in Kuwait – Basrah area, being a prominent subsurface unit consisting of massive anhydrites and unfossiliferous limestones with a few blue shales and marl beds. Owen and Nasr [10] assigned it to the Middle Eocene, whereas Van Bellen *et al.* [8], and Al-Naqib [17] referred it to a probable Early Eocene age.

In Bahrain, the Rus Formation, which represents the oldest outcropping rock unit, consists of about 220 feet (67 meters) of chalk– and chert–bearing dolomitic limestones with numerous quartz geodes and some anhydrite interbeds. It has been assigned to the Early Eocene [21].

In Abu Dhabi, Fox and Brown [11] described this formation as being represented by unfossiliferous anhydrites with thin dolomite and dolomitic limestone interbeds. It was regarded as transitional between the Early and Middle Eocene.

In Qatar, the exposed part of the Rus Formation consists of white, soft, chalky, irregularly dolomitized, porous limestone with thin clay interbeds. At the top there is a thin fossiliferous, granular calcarinite limestone bed. This formation is represented by two main facies one of which is calcareous whereas the other is gypsiferous. In Qatar, the Rus Formation was divided into two informal memebers which were designated as A and B. This formation has yielded the following fossils: *Nummulites* sp. aff. *atacicus* Leymerie, *N. globulus* Leymerie, *Lituonella douvillei* Davies, *Ammobaculites* sp., *Verneuilina* sp. *Gaudryina* sp., *Clavulina* sp., *Eggerella* sp., Miliolidae; Mollusca such as: *Velates schmiedeli* (Chemnitz), *Hydrobia* sp., *Cardium* sp., *Corbula* sp., *Terebellum* sp., Cerithidae; ostracoda, echinoid fragments, and shark's teeth. In this country, the present rock unit was assigned to the Early Eocene [22-23].

In the People's Democratic Republic of Yemen, the Rus Formation is represented by bedded gypsum with occasional bands of chert, marl, gypseous chalk and dolomitic limestone. The limestone bands carry a sparse fauna of non-diagnostic fossils. However, on stratigraphical grounds, the Rus Formation has been assigned to the Early Eocene [18-20].

Buday [13] considered the present formation to be of Early Eocene age and equated it with the upper part of the Aaliji Formation of northern Iraq, and the Afaq Flint of Syria.

However, on the basis of the occurrence of Early Eocene planktonic Foraminifera in the lower part of the Umm er Radhuma Formation at Rub' al Khali, and the estimation of sedimentation rates for the area, [6] assigned the Rus Formation to the Middle Eocene (Early Lutetian).

The Dammam Formation

Definition

This formation was introduced by Bramkamp in an unpublished report prepared in 1941 [9,12]. It was named after the Dammam Dome, in Saudi Arabia, where the entire sequence crops out. The type locality lies along Dhahran al Alah road at Lat. 26° 19′ 16″ N., Long. 50° 04′ 50″ E. (Text–Fig. 3). The outcrops of this rock unit are limited to a number of small but widely scattered patches north of Wadi as Sahba, near the coast and in southeastern Rub' al Khali. The Dammam Formation ranges in thickness from about 107 feet (33 meters) at the type locality to 394 feet (120 meters) nearby Qatif Field, and up to 630 feet (192 meters) on the flanks of Abu Hadriya Field. The lower contact of this rock unit with the Rus Formation is conformable, whereas its contact with the overlying Hadrukh Formation is unconformable [9,12].

Lithology and fossil content

Steineke *et al.* [14] described the type Dammam Formation as consisting of 28 meters of light coloured, chalky, porous dolomitic, locally silicified, marly limestone with dolomite and marl interbeds, and with *Orbitolina complanata* Lamarck, *Nummulites staminea* Nuttall, *N. discorbina* Schlotheim var. *major* Rozlozsnik, *N. somaliensis* Nuttall and Brighton, *N. globula* Leymerie, *N. beaumonti* d'Archiac and Haime, *N.* sp. aff. *N. lucasana* (Defrance in d'Archiac), *Alveolina subpyrenaica* Leymerie, *Dictyoconus egyptiensis* (Chapman), *D. indicus* Davies, *Dictyoconoides kohaticus* (Davies), *Linderina buranensis* Nuttall and Brighton, *Euphenax jamaicensis* (Trechmann), *Coskinolina balsillei* Davies, and *Ostrea turkestanensis* Romanovski.

In complete sections, the Dammam Formation is divisible into five members which can be described from base to top as follows [9,12].

a– The Midra Shale Member: about 10 feet (3 meters) of yellow–brown, fissile, very thinly laminated shale with *Nummulites* sp. aff. *N. lucasana* (Defrance), and *N. globulus* Leymerie in the subsurface.

b– The Saila Shale Member: about 14 feet (4.27 meters) thick of dark-brown, yellow subfissile shale, clayey shale and grey-buff limestone with *Alveolina* sp. cf. *A. decipiens* Silvestri and *Nummulites globulus* Leymerie.

c– The *Alveolina* Limestone Member: about 3 feet (0.91 meters) of light-tan partially recrystallized limestone rich in *Alveolina elliptica* var. *flosculina* Silvestri, *Dictyoconoides*, sp., and *Linderina* sp. cf. *L. patonai* Osimo. This member appears to be so closely related to the Saila Shale Member that they can be combined in one rock unit.

d– The Khobar Limestone Member: about 30 feet (9 meters) of brownish, partially recrystallized, marly, nummulitic limestones with *Asterigerina* sp., *Coskinolina balsilliei* Davies, *Dictyoconoides cooki* (Carter), *Halkyardia chapmani* (Halkyard), *Linderina brugesi* Schlumberger, *L. buranensis* Nuttall and Brighton, *Nummulites somaliensis* Nuttall and Brighton forms A and B, and *Rotalia* sp.

e– The Alat Limestone Member: about 49 feet (15 meters) of cream tan coloured chalky, porous, commonly dolomitic marl with abundant molds of molluscus and other indeterminate organic debris, local silicification and occasional specimens of very large *Dictyoconus* sp.

Age and correlation: (See Text–Fig. 2)

On palaeontological evidence, Steineke *et al.* [14], Powers *et al.* [12], and Powers [9] assigned the Dammam Formation in Saudi Arabia to the Early– Middle Eocene.

In the Kuwait – Basrah area, the Dammam Formation is represented by whitish grey, porous dolomitized, nummulitic, soft, chalky limestone with a persistant, grey green, waxy shale bed occurring near the base which occasionally contains dolomite rhombs, pyrite grains, nodules of calcium phosphate and shark's teeth [10]. Within the boundaries of Kuwait, this formation has been known to crop out in only one locality, namely, the Ahmadi Quarry southeastern Kuwait. Owen and Nasr [10] mentioned that the Dammam Formation is lithologically divisible into four members which are from base to top as follows:

1– Chalky and marly limestones with *Operculina libyca* Schwager.

2– Chalky limestone member.

3– Nummulitic limestones with *Alveolina elliptica* (Sowerby), *Nummulites gizehensis* (Forskal), *N. discorbinus* (Schlotheim).

4– Bryozoan-peneroplid limestones and shelly limestones.

The nummulitic member in the subsurface includes *Lockhartia hunti* var. *pustulosa* Smout, *Dictyoconoides kohaticus* Davies, on the basis of which the Dammam Formation was assigned a Middle Eocene (Lutetian) age.

In southern Iraq, Van Bellen *et al.* [8], Al-Naqib [17] and Buday [13] assigned the Dammam Formation to the Middle Eocene and mentioned that it outcrops in the southeast of the country and occurs in all deep wells drilled in the south. They added that this formation had been subdivided into ten informal field units by H. Huber and R.M. Ramsden (in unpublished reports prepared in 1944–1945). In ascending order these are: the Wagsa, Sharaf, Shabicha, Huweimi, Shawiya, Chabd, Rudhuma, Barhak, Ghanimi and Tuqaiyid Beds which later, in 1953, were combined by R.M. Ramsden and C.A. Andre' [8,13,17] so that the following four informal rock units remain:

1 – The Wagsa unit: chalky limestone with *Operculina libyca* Schwager.

2 – The "Sharaf, Shabicha, Huweimi (chalk) unit": chalk with a fresh water appearance alternating with chalky limestones containing badly preserved bivalves.

3 – The "Huweimi (nummulitic), Shawiya, Chabd unit": nummulitic lime-stone with *Alveolina elliptica* (Sowerby), *Dictyoconus kohaticus* Davies, *Halkyardia minima* (Liebus); *Nummulites discorbinus* (Schlotheim); *N. gizehensis* (Forskal), Orbitolites complanatus Lamarck, *Peneroplis dusenburyi* Henson, *Rhapidionina urensis* Henson, *R. urensis* var. *minima* Henson, and *Somalia danieli* Henson.

4 – The "Rudhuma, Barbak, Ghanimi, Tuqaiyid unit": Bryozoan-peneroplid and shelf limestone containing *Coskinolina balsillei* Davies, *Dictyoconus kohaticus* Davies, *Opertorbitolites douvillei* Nuttal, *Orbitilites complanatus* Lamarck, *Peneroplis damesini* Henson, *P. dusenburyi* Henson, *Praerhapidionina huberi* Henson, *Rhapydionina urernsis* Henson, *R. urensis* var. *minima* Henson, *R. williamsoni* Henson, *Somalia danieli* Henson, and *Spirolina cylindracea* Lamarck.

Buday [13] following Van Bellen *et al.* [8] considered the Dammam Formation in the supplementary subsurface type section in Iraq to be of Middle Eocene age. Also, he mentioned that in the surface sections the lower units might be of Late Early Eocene age, but the Late Eocene has not been proved. Buday [13] correlated the present formation with both the Avanah Limestone of northern Iraq, and the Jaddala Formation of central and western Iraq.

In western Iraq, the Dammam Formation consists of nummulitic limestone which locally becomes coarsely recrystalized, detrital, marly or chalky, with a thin phosphorite interbed. At this part of Iraq, the Dammam Formation has yielded a rich foraminiferal assemblage among which the following forms are mentioned: *Assilina* sp. cf. *A. laminosa* Gill, *Discocyclina nudimargo* Schwager, *Nummulites*

deserti de la Harpe, *N. akashensis* Al-Hashimi, *N. fraasi* de la Harpe, *N. praemurchisoni* Nemkov and Barkhatova, *N. atacicus* Leymerie, *N. globulus* Leymerie, *N. lucasanus* (d'Archiac), *N. murchisoni* (Rutimeyer), *N. nitidus* de la Harpe, *N. planulatus* (Lamarck), *N. aturicus* Joly and Leymerie, *N. discorbinus* (Schlotheim), *N. gizehensis* (Froskal), *N.* sp. cf. *N. somaliensis* Nuttall and Brighton, *N. incrassatus* (de la Harpe), *N. praefabiani* Verentsov and Menner, *N. striatus* (Bruguiere), *N. bouillei* de la Harpe, *Operculina libyca* Schwager, *O. discoidea* Schwager, *Chiloguembelina cubensis* Palmer, *Globanomalina micra* (Cole), *Globorotalia bolivariana* (Petters), *G. centralis* Cushman and Bermudez, *G. lehneri* Cushman and Jervis, *G. spinulosa* Cushman, *G. cerroazulensis* (Cole), *Globigerina linaperta* Finlay, *G. yeguaensis* Weinzierl and Applin, *G. officinalis* Subbotina, *G. ampliapertura* Bolli, *G. venezuelana* Hedberg, *Truncorotaloides rohri* Brönnimann, *T. topilensis* (Cushman), *Catapsydrax echinatus* Bolli, *C. dissimilis* (Cushman and Bermudez), *Nodosaria latejugata* Gumbel, *Dentalina communis* (d'Orbigny), *Lenticulina chambersi* (Garrett), *L. degloyeri* (Plummer), *L. midwayensis* var. *carinata* (Plummer), *Lagena laevis* var. *stavensis* Bandy, *Palmula woodi* var. *undulata* Nakkady, *Siphonodosaria frizzeli* Rau, *Bolivina alata* (Seguenza), *Bulimina jacksonensis* Cushman, *B. truncana* Gumbel, *B. bradburyi* Martin, *Quinqueloculina ludwigi* Reuss, *Q. seminulum* (Linne), and *Q. vulgaris* d'Orbigny. On the basis of the occurrence of this assemlage, the Dammam Formation of western Iraq was assigned to the Early – Late Eocene (Early Ypresian – Late Priabonian), [5].

Willis [21] assigned the Dammam Limestone in Bahrain to the Early and Middle Eocene and divided it into four informal units which are from base to top: the Shark Tooth Shale, Brown Crystalline Limestone, Orange Marl, and White Limestone Members.

In Abu Dhabi, the Dammam Formation at Zakum Oilfield is divisible into two lithologic units: a lower, brown, very finely crystalline limestone, and an upper light brown, microcrystalline dolomite. The lower unit carries *Dictyoconus aegyptiensis* (Chapman), *Lituonella douveillei* Davies, *Coskinolina balsillei* Davies, *Palaeonummulites* sp., and *Lockhartia* sp., while the upper unit contains *Nummulites fabiani* (Perver), *N. incrassatus* (de la Harpe). On the basis of these fossils, the formation was assigned a Middle – Late Eocene age [11].

In Qatar, the present formation consists of different types of fossiliferous limestones and claystones. It is divisible into three members which are (in ascending order): the Midra Shale, Dukhan, and Umm Bab Members. In this country, the Dammam Formation contains the following fossils: *Alveolina elliptica elliptica* (Sowerby), *A. elliptica flosculina* Silvestri, *Assilina cuvillieri* (Sander), *Dictyoconoides cooki* (Carter), *Dictyoconus aegyptiensis* (Chapman), *D. daviesi* Silvestri, *Halkyardia minima* (Liebus), *Linderina brugesi* Schlumberger, *L. buranensis* Nuttall and

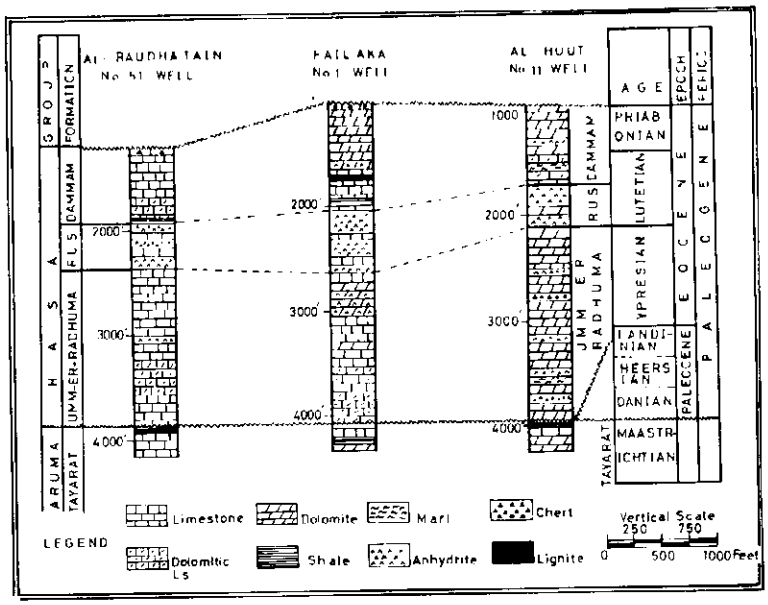
Brighton, *Lituonella douvillei* Davies, *Lockhartia alveolata* Silvestri, *L. conditi* (Nuttall), *L. hunti* Ovey, *L. hunti pustulosa Smout, Nummulites beaumonti* d'Archiac and Haime, *N. discorbinus* (Schlotheim), *N. migiurtinus* Azzaroli, *N. praediscorbinus* Schaub, *Rotalia trochidiformis* (Lamarck); Mollusca such as *Velates* sp. cf. *V. schmiedeli* (Chemnitz), *Terebellum* sp; echinoid fragments, and shark's teeth. On the basis of the occurrence of these fossils, the Dammam Formation of Qatar was assigned to the Early - Middle Eocene [22-23].

The Hassa Group in the Studied Wells in Kuwait

The Hasa Group with its constituent formations (Umm er Radhuma, Rus and Dammam) has been recognized in the studied wells. A brief description for each of these formation is given below (in ascending order):

The Umm er Radhuma Formation: (See Pl. 1, Figs. 1 – 9)

This formation is represented by the following drilled depths in the studied wells (Text-Fig. 4):



Text-Fig. 4. Correlation of the Hasa Group succession in the studied wells in Kuwait, datum plane base of Umm er Radhuma Formation [7].

In Failaka no. 1 well: 2565 - 4130 feet (782 - 1259 meters).
In Al-Raudhatain no. 51 well: 2384 - 3870 feet (727 - 1180 meters).
In Al-Hout no. 11 well: 2100 - 3890 feet (640 - 1186 meters).

In Failaka no. 1 well, the formation consists of light grey, whitish, microcrystalline dolomite with anhydrite, limestone and dolomitic limestone interbeds as well as partings of black fissile calcareous shale. In Al-Raudhatain no. 51, it is represented by light grey, fine granular, soft, chalky limestone and light tan, fine grained, dolomitic limestone with whitish anhydrite interbeds. In Al-Hout no. 11, the formation is composed of dolomite with anhydrite interbeds. The dolomites are grey, cream, fine grained to cryptocrystalline, hard and compact.

Analysed rock samples from the Umm er Radhuma Formation in the present study contain no planktonic foraminiferids, but on the basis of its strati-graphic position, and the occurrence of Early Eocene planktonic Foraminifer in the lower part of this formation in Rub' al Khali basin [6], it is accepted to be of Latest Palaeocene - Early Eocene age.

The Rus Formation: (See Pl. 2, Figs. 1 – 3)

Rocks correlatable with this formation lie between the following drilled depths in the studied wells (Text-Fig. 4):

In Failaka no. 1 well: 1917 - 2565 feet (584 - 782 meters).
In Al-Raudhatain no 51 well: 1916 - 2384 feet (584 - 727 meters).
In Al-Hout no 11 well: 1700 - 2100 feet (518 - 640 meters).

In both Failaka no. 1 and Al-Raudhatain no. 51 wells, the Rus Formation consists of white to grey, dense, anhydrite interbedded with white, grey, soft, chalky, locally microcrystalline limestone. In Al-Hout no. 11, this formation is composed of anhydrites with dolomite interbeds and traces of shale and marly partings. The anhydrites are white, grey soft to somewhat hard; the dolomites are grey, fine grained to microcrystalline. In the present study, the Rus Formation has not yielded any planktonic foraminiferids and on the basis of its stratigraphic position it is accepted to be of Early Lutetian age [6].

The Dammam Formation: (See Pl. 2, Figs. 4-9; Pl. 3, Figs. 1 – 8)

In the studied wells, the following drilled depths are considered to be correlatable with the Dammam Formation (Text-Fig. 4):

In Failaka no. 1 well: 1018 - 1917 feet (310 - 584 meters).
In Al-Raudhatain no. 51 well: 1200 - 1916 feet (366 - 584 meters).
In Al-Hout no. 11 well: 960 - 1700 feet (293 - 518 meters).

In Failaka no. 1, this formation consists of a basal unit of white to grey, soft, chalky, dolomitic limestone with greenish grey, calcareous, nummulitic shale interbeds. This is followed upwards by cream, dense, nummulitic limestone with few lignite interbeds, followed by cream, brown, finely crystalline dolomite with anhydrite intercalations. Near the top of the formation the dolomite includes pale grey, irregular cherty bands.

In Al-Raudhatain no. 51, the Dammam is composed of greenish grey, soft, fissile, marly, slightly pyritic shale, followed upwards by light tan, dolomitic, finely crystalline, nummulitic limestone. This is followed in turn by white, chalky, soft, fine grained, crystalline, locally dense limestone with black and cherty limestone interbeds.

In Al-Hout no. 11, this formation is represented by dolomites and anhydrits with limestone, marl and shale interbeds. The dolomites are whitish, cream fine grained, microcrystalline, locally friable and occasionally intercalated with chert and gypsum bands. The limestones are whitish, grey, cream, brownish, chalky, dolomitic and microcrystalline. The marls are grey, plastic and soft, while the shales are somewhat carbonaceous.

In the present study, the Dammam Formation has yielded only benthic foraminiferids such as *Alveolina* and *Nummulites* spp. (Pl. 2, Figs. 5-9; Pl. 3, Figs. 1-8). Accordingly, its age assignment will depend mainly on its stratigraphic position in Kuwait and nearby regions. Most of the previous workers have assigned the present rock unit to the Early - Middle Eocene [9,12-14,21-23], or to the Middle Eocene [8,10,17], and this was mainly based on the occurrence of benthic foraminiferids. However, as mentioned above, Hasson [6] recorded a fauna of Early Eocene planktonic Foraminifera in the lower part of the Umm er Radhuma Formation in the Rub' al Khali wells. On the basis of these planktonic species the Umm er Radhuma Formation is assigned to the Latest Palaeocene - Early Eocene. By applying the new planktonic foraminiferal chronostratigraphy and estimates of sedimentation rates for the area, Hasson [6] assigned the Rus Formation to the Early Lutetian. As the Rus and Dammam Formations are conformably superimposed, the lower stratigraphic range of the Dammam can be delineated as Late Lutetian.

On the other hand, available geological information shows that the maximum recorded thickness for the Dammam Formation is 899 feet (273 meters) in Failaka no. 1 well, Kuwait (Text-Figs. 1, 4). If we accept the average sedimentation rate of shallow water carbonates as 100 m / m. y. [6],we can estimate the geological time required for the deposition of the Dammam sequence which is about 2.73 m. y. This will put the upper boundary of the Dammam Formation within the Early Priabonian. Accordingly, the age of the Dammam Formation is Middle - Late Eocene (Late

Lutetian - Early Priabonian). This result is confirmed by Al-Hashimi [5] who referred to the presence of the Upper Eocene in the Dammam Formation in the Western Desert of Iraq on the basis of the occurrence of *Nummulties striatus* (Bruguiere), *N. praefabianii* Verenstov and Menner, *N. incrassatus* (de la Harpe), *N. bouillei* de la Harpe, *Operculina discoidea* Schwager, *Catapsydrax echinatus* Bolli, *C. dissimlis* (Cushman and Bermudez), *Globorotalia cerroazulensis* (Cole), *Globigerina officinalis* Subbotina, *G. ampliapertura Bolli, G. venezuelana* Hedberg [24].

Summary and Conclusions

The revision of the biostratigraphy of the Hasa Group in Saudi Arabia, Kuwait and adjacent regions has led to the following conclusions:

a. The Hasa is a group includes three formations which are, in ascending order, the Umm er Radhuma, Rus and Dammam.

b. In both the outcrop and the subsurface, the Hasa succession consists of carbonate rocks with subordinate bands of shale and anhydrite, of Early Palaeogene age.

c. Recent record of Early Eocene planktonic Foraminifera in the lower parts of the Umm er Radhuma Formation makes it necessary to revise the Palaeogene stratigraphy of Arabia.

d. The new age interpretation for the planktonic horizon of the Umm er Radhuma Formation indicates that the age of this formation is Latest Palaeocene – Early Eocene.

e. Similarly, the geologic age of the Rus Formation is Middle Eocene (Early Lutetian), and that of the Dammam Formation is Middle – Late Eocene (Late Lutetian – Early Priabonian).

f. The correlation of the Umm er Radhuma Formation with the Ranikot and Laki Formations of Pakistan, should be discontinued.

g. The Umm er Radhuma, Rus and Dammam Formations are divisible into variable numbers of informal members of local importance.

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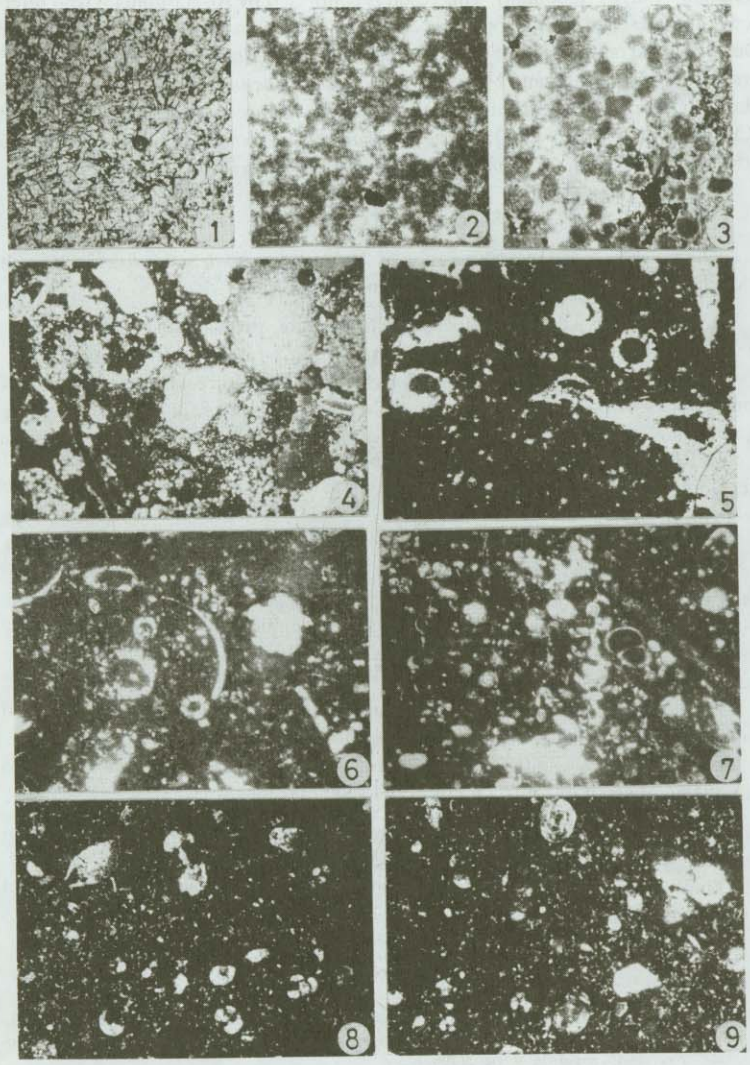
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Plate 1
(All figures from core samples)

Figs. 1–9. Umm er Radhuma Formation.

1: Recrystallized limestone with rare shell debres, from Mutriba no. 1 well, 3414–3424 feet (1041–1044 meters), plane-polarized light, × 53.

2: Dolomitic limestone, from al-Raudhatain no. 3 well, 2850–2860 feet (869–872 meters), plane-polarized light, × 53.

3: Pelletal limestone, from Bahra no. 1 well, 2544–2562 feet (775–781 meters), crossed nicols, × 53.

4: Irregularly-shaped quartz grains, clay pellets and calcite frugments stained with hydrocarbon, in a recrystallized, clayey limestone groundmass, from Al-Raudhatain no. 3 well, 2600–2610 feet (792–796 meters), × 53.

5 – 9: Calcareous clay with leached out fossils.

5, 6: From Bahra no. 1 well, 2884–2896 feet (879–883 meters), plane-polarized light, × 66.

7: From Bahra no. 1 well, 2313–2331 feet (705–710 meters), plane-polarized light, × 53.

8,9: From Mutriba no. 1 well, 3414–3424 feet (1041–1044 meters), crossed nicols, × 66.

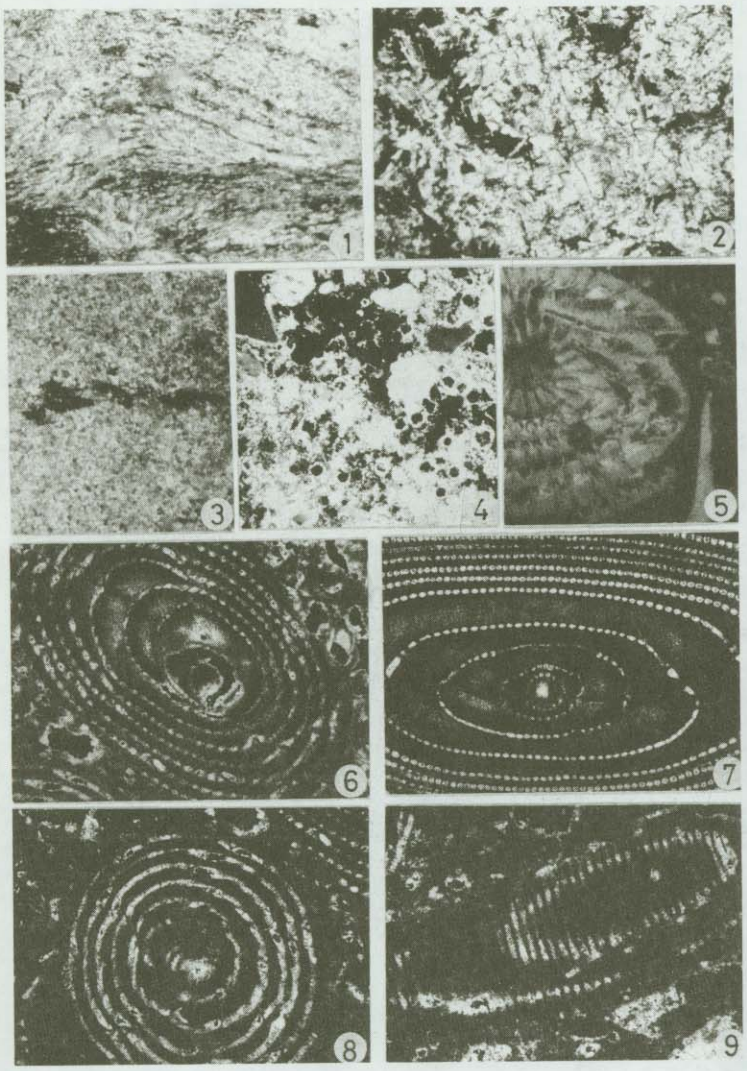
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Plate 2
(All figures from core samples)

Figs. 1 – 3: Rus Formation.

1: Showing contorted thinly banded anhydrite, from Bahra no. 1 well, 1593–1596 feet (485.5 – 486.5 meters), crossed nicols, × 53.

2: Showing hydrocarbon-stained anhydrite spicules in a calcareous groundmass, from Al-Raudhatain no. 3 well, 2290–2300 feet (698–701 meters), crossed nicols, × 53.

3: Showing hydrocarbon-stained micritic limestone with leached out fossils, from Bahra no. 1 well, 1920–1938 feet (585–591 meters), crossed nicols, × 53.

Figs. 4–9. Dammam Formation.

4: Fine grained, recrystallized limestone with scattered quartz grains, from Bahra no. 1 well, 1250–1263 feet (381–385 meters), crossed nicols, × 53.

5–9: From Al-Shagaya no. 45 well, crossed nicols, × 66.

5: Showing a part of an oblique axial section in *Nummulites* sp. embedded in a biomicritic limestone groundmass.

6–9: Showing random sections in *Alveolina elliptica* var. *flosculina* Silvestri, embedded in a bioclastic limestone groundmass.

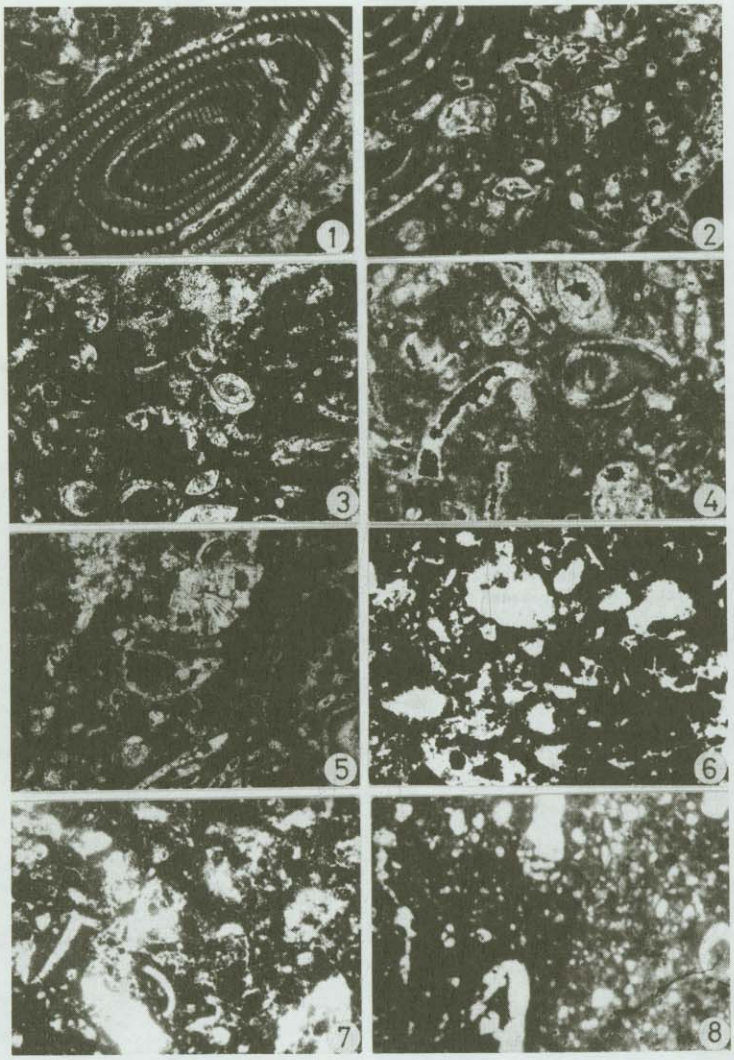
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Plate 3

Figs. 1–8. Dammam Formation, from a core sample from Al-Shagaya no. 45 well, crossed nicols, × 66.

1: Showing oblique section in *Alveolina elliptica* var. *flosculina* Silvestri, embedded in a bioclastic limestone groundmass.

2–5: Showing bioclastic limestone with alveolinid, rotaliid and algal remains.

6–8: Showing high leaching in bioclastic, chalky, nummulitic and alveolinid limestone.

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مراجعة الطبقية الحيوية لمجموعة الاحساء (باليوجين) في المملكة العربية السعودية والكويت والمناطق المجاورة

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ملخص البحث. تم في الدراسة الحالية مراجعة الطبقية الحيوية لمجموعة الاحساء في المملكة العربية السعودية والكويت والمناطق المجاورة. وتتبع هذه المجموعة عصر الباليوجين، وتتكون من صخور جيرية ودولومايتية تتخللها طبقات من المارل والطين الصفحي والأنهيدرايت. وتظهر صخور مجموعة الاحساء على السطح في أواسط الجزيرة العربية وشمالها وجنوبها وشرقها، كما تتواجد تحت السطح وخصوصًا في منطقتي الخليج العربي والربع الخالي. وتضم هذه المجموعة ثلاثة متكونات وهي (مرتبة تصاعديًا): أم رضمة والرس والدمام.